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**QUEENSLAND DEVELOPMENT 1997 CONFERENCE**

**PROCEEDINGS OF SELECTED PAPERS**

*Tom Waring*

ABARE

# Key issues for Australian minerals and energy
## A Queensland perspective

The forecast expansion of the Australian minerals and energy sector and the associated forecast growth in export earnings in large part reflects the expanding materials requirements of the Asian region.

Prices of most mineral and energy commodities have remained relatively flat or have eased in 1997, mainly as a result of supply increases in many of these commodities. In 1998, prices for most commodities are forecast to rise moderately as significant growth in world economic activity results in further increases in global demand.

The outlook for the Queensland minerals and energy sector is particularly positive, with significant industry expansion forecast, based on a number of major projects planned and recently commissioned. The range of projects at advanced stages of planning are being supported by increasing expenditure on exploration and infrastructure. Such investment is expected to continue to support minerals and energy development projects throughout the state over the medium and longer term.

## INTRODUCTION

The mineral resources sector is of considerable and growing economic significance to Australia. In the five years from 1991–92 to 1996–97, the aggregate value of minerals and energy exports grew by 13 per cent in real terms to reach $36.5 billion, an average annual rate of growth of 2.4 per cent. The sector now accounts for around 45 per cent of Australia's merchandise exports and 36 per cent of total exports. The minerals sector is also a significant contributor to employment and regional development, both directly and indirectly, through its consumption of goods and services, including exploration, construction and transport, and through its economywide effects on incomes.

The mineral resources sector has for many years been similarly important to Queensland's economic growth and prosperity. With export earnings of around $6.4 billion in 1996–97, it accounts for around 50 per cent of Queensland's export income and contributes approximately 20 per cent of Australia's minerals and energy sector exports. The sector spends around $300 million a year on exploration in Queensland alone, directly employs some 15 000 people and indirectly supports the employment of around 40 000 other Queenslanders. The mineral resources industry in Queensland provides the base for associated minerals processing, smelting and refining, as well as for transport and a wide range of input and service industries. In 1996–97, the mine level value of mineral production alone in Queensland was in excess of $6 billion, accounting for around 20 per cent of Australia's total value of mine production.

Growth in demand for mineral resource exports and continuing prospects for strong and broadly based world economic growth over the next five years have been encouraging for the sector. But Australia is not alone in responding to sound demand prospects. Rapidly growing investment in new mine and processing capacity in Australia is being matched in a range of other resource rich countries, as good prospectivity and reform of key elements of mining policies have encouraged international investment in these regions.

Of concern to most of Australia's expanding export oriented minerals and energy industries over the medium term will be the timing and

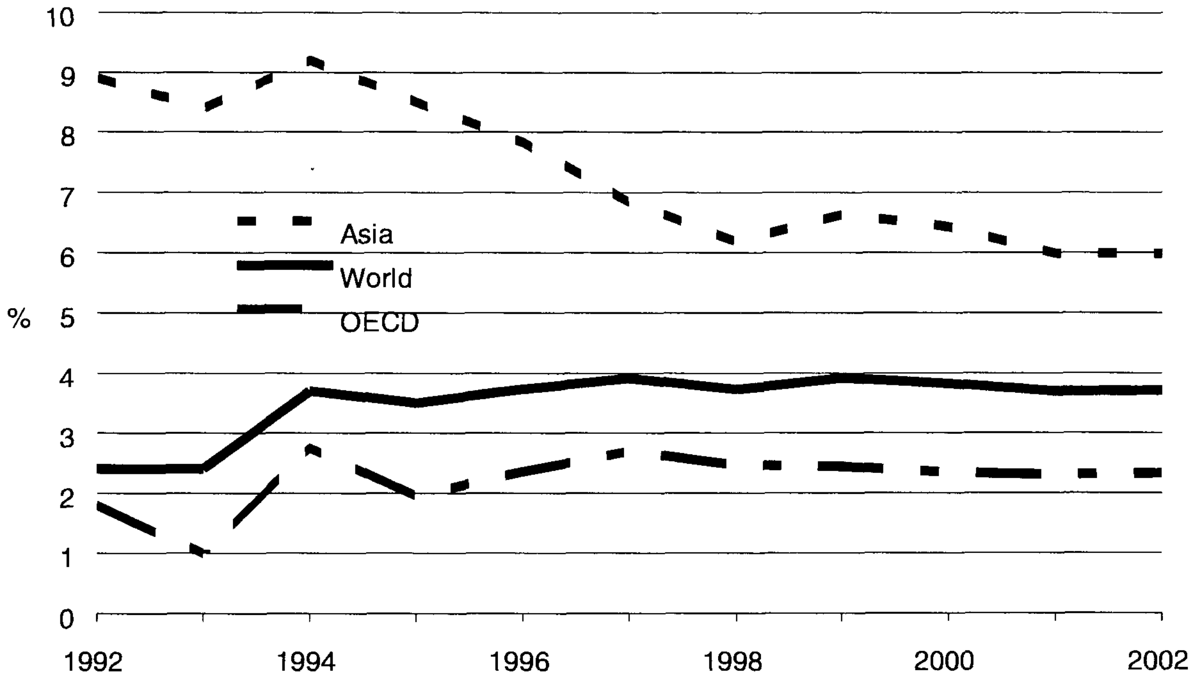


*Figure 1. Economic growth.*

effects of expected substantial growth in world supply on the prices those industries will face in world markets. While the medium term demand outlook remains positive, expected strong supply responses, particularly beyond 1997–98, are forecast to place downward pressure on prices for many industries over the medium term.

Overall, the medium term outlook for Australia's minerals and energy sector is for growth in export earnings. Not only is the level of export earnings from the sector expected to reach record levels in 1997–98 but capital investment in mining in real terms is also forecast to reach an all time high this year.

The Queensland industry in particular is set for new developments. New industrial infrastructure is being developed and integrated mining and processing projects are being advanced. For example, the extensions that are underway to Queensland's gas distribution network are laying the foundation for significant future expansions to the mineral resources sector. In the north west region of the state, several mineral projects having been recently commissioned and others are at advanced stages of planning and development.

The forecast expansion of the Australian minerals and energy sector and the associated forecast growth in export earnings, in large part reflect the expanding materials requirements of the Asian region. Despite the recent financial turmoil in some Asian countries, strong economic growth in the medium term from an increasingly large economic base is expected to continue to underpin regional demand for industrial raw materials. However, ABARE's forecast slowing in Australian export earnings in the latter years of the outlook period reflects expectations that prices will tend to ease as projected sustained growth in global demand is readily met by very responsive and efficient global minerals supply industries operating from a geographically broader production base.

## MACROECONOMIC SETTING

ABARE assumes that demand for Australia's minerals and energy exports will be underpinned by sustained world economic growth over the medium term. From an estimated 4 per cent growth in 1997, world GDP is assumed to increase by 3.7 per cent in 1998 and to average around 3.8 per cent a year to 2002 (Figure 1).

Economic growth in western Europe is assumed to strengthen from 2.3 per cent to 2.8 per cent in 1998, as the effects of loose monetary policy more than offset fiscal spending, which continues to be restrained as countries work toward the Maastricht

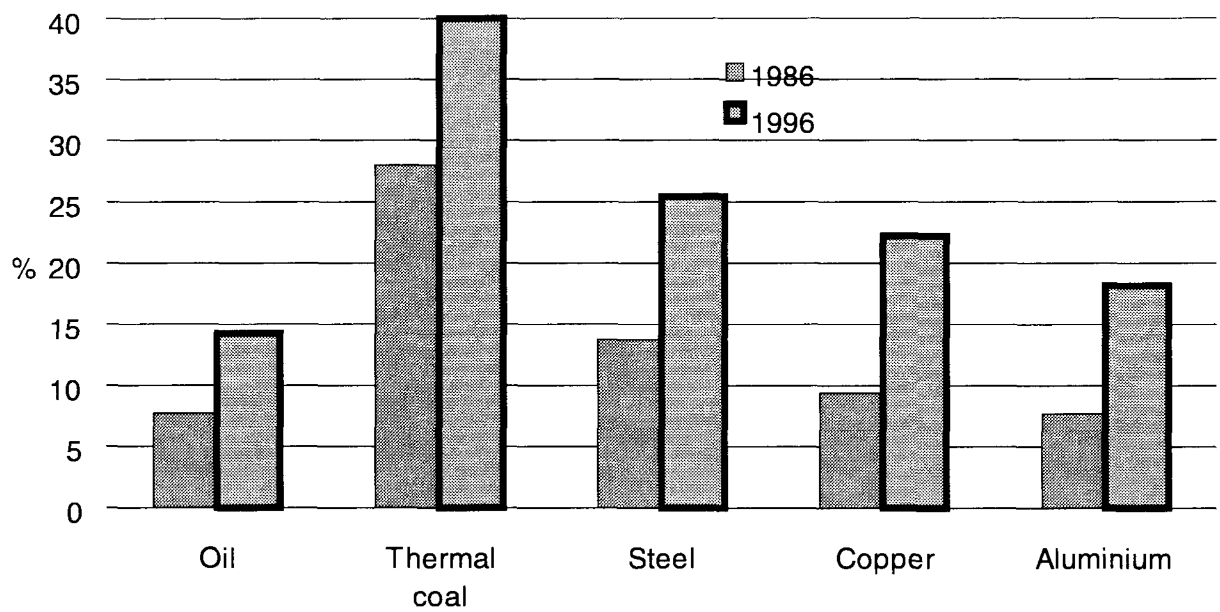


*Figure 2. East Asia's share of world consumption.*

convergence criteria. Economic growth over the medium term is assumed to average around 2.5 per cent. Such rates of economic growth are considered to be achievable without creating significant inflationary pressures in part because of relatively high levels of unemployment in the region.

Eastern European economic recovery is now well established as these countries continue to benefit from increasing exposure to foreign investment and trade. The situation in Russia, however, is less certain. A modest turnaround in economic activity is assumed for Russia, on the basis that political and economic reform proceeds.

In the short term, growth in the United States, especially in domestic demand, is expected to moderate as the economy approaches its productive capacity. The Federal Reserve is expected to gradually increase interest rates over the next year in order to avoid any significant increase in inflationary pressure. Growth is assumed to average 3.6 per cent in 1997, before easing to 2.5 per cent in 1998 and to 2 per cent over the medium term.

While having important influences on aggregate global demand and hence on world prices, these regions are not the key to Australia's resources trade. Asia remains the focus of Australia's minerals and energy exports as Asia represents Australia's region of transport cost advantage and it has experienced the highest regional rates of economic growth over the past decade — at more than three times the average rate in OECD countries. Current economic uncertainty in the South East Asian region is expected to be a short term phenomenon. The recent sharp depreciation of some Asian currencies has resulted in a number of Asian governments reassessing their economic policies in order to reduce current account imbalances and inflationary pressure. The main impact to date appears to have been a decline in business and consumer confidence, and hence some reduction in commodities demand. In the medium term, economic growth of around 6 per cent from a progressively larger economic base, with associate growth in industrial activity and rising incomes, is expected to sustain the growth in demand for industrial raw materials in the region.

## ASIAN MINERAL RESOURCE CONSUMPTION

Relatively stable demand growth for mineral resources in the Asian region continues to underpin world markets and dampen volatility in world demand growth (Heap, 1996). Rising incomes, industrialisation and expansion of industrial and social infrastructure in the region imply minerals and energy intensive growth. Many countries are approaching or have reached levels of industrialisation that are characterised by high levels of metals and energy consumption per person (Von Arentschildt, 1995).

Over the past decade, East Asia (excluding Japan) has doubled its share of world consumption of a range of metals and fuels (Figure 2), and its share is projected to increase further in the next five years. For example, the demand for fuel for electricity generation in the region will see the region accounting for increasing shares of thermal coal, LNG and uranium trade and consumption in future. Similarly, the increasing concentration of global steel production in the region will result in the region's share of the consumption of traded steelmaking raw materials (not only iron ore, metallurgical coal and scrap but also direct reduced iron, nickel, zinc and manganese) increasing significantly. The region's share of global steel production is projected to increase from 24 per cent in 1997 to 25 per cent in 2002, accounting for over 40 per cent of the projected increase in world steel production over the period.

### Minerals markets in Asia

While Japan was the dominant influence on Australian minerals and energy development to the end of the 1980s, during the 1990s, the other East Asian economies of South Korea, China and Taiwan have become more important. South Korea and Taiwan, together with the smaller economies of Hong Kong and Singapore, have modest domestic reserves of minerals. As a result, there is strong complementarity between the development of minerals and metals using industries in those countries and the minerals and metals producing industries in Australia. The value of Australian mineral exports to these countries has risen by over 90 per cent in the past 8 years in real terms and are projected to rise further over the next several years.

Other Asian countries such as Indonesia and China have larger resource endowments. China, in particular, has large domestic resources of metalliferous minerals. However, many of these are relatively underdeveloped, of poor quality and/or in remote areas with poor infrastructure support. In order to meet the rapidly expanding needs of Chinese industry, much of which is located in the coastal regions and the south of the country, imports of some minerals have risen significantly. Through this growth in the domestic economy, China is exerting an increasing influence on world mineral and metal markets.

### Energy markets in Asia

As an energy exporting nation, Australia has an interest in building on its traditional trading focus on Japan, South Korea, Taiwan and Hong Kong. These countries are projected to account for the world's fastest and largest regional growth in electricity demand and generation capacity in the period to 2010.

While much of the discussion of prospects for Australian energy exports to Asia tend to be focused on coal, Australian exports of other fuels (liquid natural gas, oil and nuclear) are also important, particularly as importing countries seek to diversify sources of supply. Australia's role as a supplier of LNG to Asia (especially Japan) is expected to grow as local producers invest in capacity to meet the increasing demands from regional electricity generators.

The speed with which new power plants are constructed will be an important determinant of the rate of growth in demand for fuels in Asia. A major consideration will be the ability of governments and private sector developers to structure development proposals in ways which attract the necessary capital. To supply the expected growth in energy demand in Asia, Daniel (1995) estimated that investment in power generation capacity will need to be around US$55–65 billion a year between 1996 and 2002.

## TRADE ISSUES

The issues of access to markets and how best to maintain and extend the benefits arising from pursuing more liberal trading arrangements remains of overriding importance to a commodity exporter such as Australia. Ongoing efforts within the context of APEC and the World Trade Organisation (WTO), as well as on a bilateral basis, to achieve a less restrictive international trading environment have the potential to bring long term economic benefits to both importing and exporting countries.

## APEC

The Asia Pacific Economic Cooperation forum has developed from a relatively informal information sharing group into an important regional vehicle for promoting open trade and investment policies.

Australia's primary industries appear likely to gain significantly from APEC trade liberalisation as added Asian emphasis on manufacturing would increase regional demand for raw materials. Australia is in a position to exercise its comparative advantage as a supplier and basic processor of minerals and energy resources and agricultural products in responding to such demand.

Increased Asian demand for resource commodities may also create further opportunities for Australian value adding in this sector. Examples of industries in which these sorts of responses are evident include BHP's decision to construct a direct reduced iron plant in Western Australia and Korea Zinc's decision to build a smelter and refinery in Queensland. Both projects are oriented toward supplying strong Asian demand for their respective products and both represent recognition of the increasing attraction of processing close to the resource.

### Climate change

Concerns about the potential risks of global warming motivated more than 150 countries to become parties to the United Nations Framework Convention on Climate Change which came into force in March 1994. The third Conference of the Parties to the Convention is to be held at Kyoto in December 1997.

At international climate change negotiations held in December 1996 a number of countries tabled proposals aimed at defining the structure and broad content of an international protocol for the limitation of greenhouse gas emissions in developed countries. The nature of any possible agreement on these issues remains unclear as the various proposals from parties on details of possible limitation strategies for greenhouse gas emissions in OECD countries are in the early stages of development. However, it is clear that achieving any substantial reduction in global greenhouse gas emissions will impose substantial economic costs on OECD countries.

## WORLD MINERALS AND ENERGY SUPPLY

An important issue for Asian government and industry leaders is where their large additional requirements of raw materials will come from and whether those requirements will be reliably supplied when needed and at competitive prices.

Despite periodic concerns about the prospect of declining global resource availability, strongly growing world consumption of minerals and energy continues to be readily satisfied at declining real prices. An underlying cause of declining world mineral prices is increasing efficiency in production. Costs of production continue to be reduced as exploration, mining and processing technologies improve and production processes become better managed.

### Exploration

Another important reason why increasing global consumption may continue to be met without real prices rising is that productive areas around the world are being opened up to exploration and lower cost mine development. In addition to reflecting the high prospectivity of some regions, this trend reflects increasing stability in the mining policies of a number of countries. It also reflects the 'demonstration effects' on international mining companies of a number of notable mining success stories in new regions. Decisions are being taken by experienced mining companies in traditional mining countries to broaden their areas of operation in order to diversify overall risk, and to find and develop new large scale projects. In doing so some may also be responding to increasing restrictions and delays associated with policy uncertainty, as social preferences in advanced industrialised economies change in favour of higher levels of environmental protection and other values that place constraints on access to mineral resources.

As new regions are opened up, a substantial and increasing role in the discovery of minerals and energy resources and the processing and supply of minerals and energy to the world is being played by multinational mining companies. The commercial requirements of such investors are, in turn, increasing the pressure for policy reform in target countries (Clark, 1995).

For example, the expected strong expansion in the role of independent power producers in the projected rapid growth in electricity generation in Asia is placing pressure on governments in the region to liberalise policy, not just in the electricity sector, but also in relation to the reform of energy price formation processes, private involvement in the extraction and transport of domestic

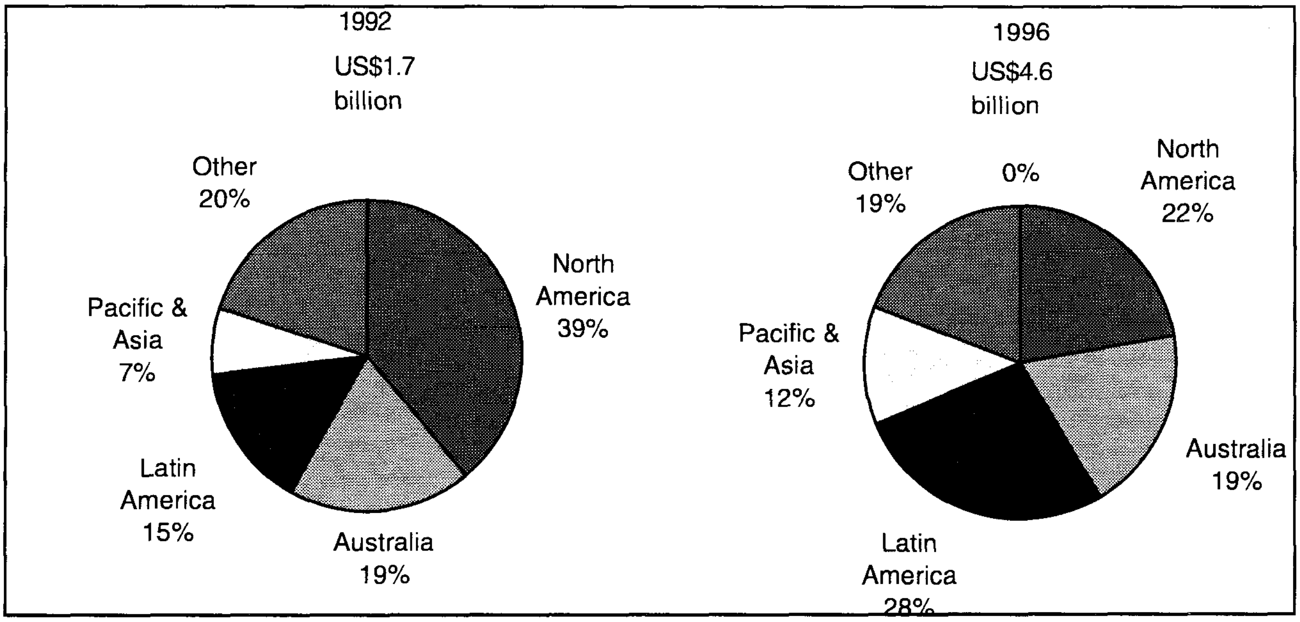


*Figure 3. World exploration expenditure.*

energy, and international trade in fuels (Blake, Dawson, Waldron & ABARE, 1995).

The geographic distribution of exploration expenditure by the companies is changing and the amounts being spent are increasing. Global expenditure on nonferrous mineral exploration is estimated to have increased by approximately 30 per cent to US$4.6 billion in 1996, up from US$3.5 billion in 1995. For the third successive year, Latin America attracted the most exploration effort, with expenditure growing by more that 27 per cent to US$963 million in 1996. Australia has remained in second place in terms of expenditure and three of the top five exploring companies in the world are substantially Australian owned (Metals Economics Group, 1996).

World exploration expenditure increased by 170 per cent between 1992 and 1996 (Figure 3). Over this period the proportion of exploration expenditure going to Latin American, Pacific and Asian countries almost doubled, while the proportion of expenditure in North America almost halved (from 39 per cent to 22 per cent). The proportion of exploration in Australia remained at 19 per cent.

## Process technologies

An increasingly important dimension of world minerals and energy supply is supply from secondary sources (minerals recycling). Metals have been recycled for as long as they have been produced and secondary metal now meets a substantial proportion of the global consumption of most metals. For example, in recent years virtually all of the increase in world supply of lead has come from increased recycling. With new technologies in the steel industry increasing the range of products coming from electric arc furnaces — furnaces that recycle steel — the demand for good quality scrap steel has risen to a point at which 'scrap substitutes', such as direct reduced iron, are becoming important additions to the steel industry.

In summary, the outlook for the global supply of minerals and energy demand is positive. However, a robust global supply response is expected. For most commodities ABARE expects supply to exceed demand at some stage in the next five years, raising stocks and placing downward pressure on real world prices. Furthermore, Australian producers are expected to continue to play a significant role in the supply of mineral resources to the world market.

# AUSTRALIAN MINERALS AND ENERGY SUPPLY

Although total mineral resource exploration expenditure in Australia trended downward in real terms over the 1980s, it has been rising since 1991–92, increasing by an average of 10 per cent a year over the past five years (Figure 4). However, within this recovery, there have been shifts in the focus of expenditure. Annual expenditure on petroleum in the past five years has increased by 61 per cent in real terms, while real exploration expenditure on base metals has risen by

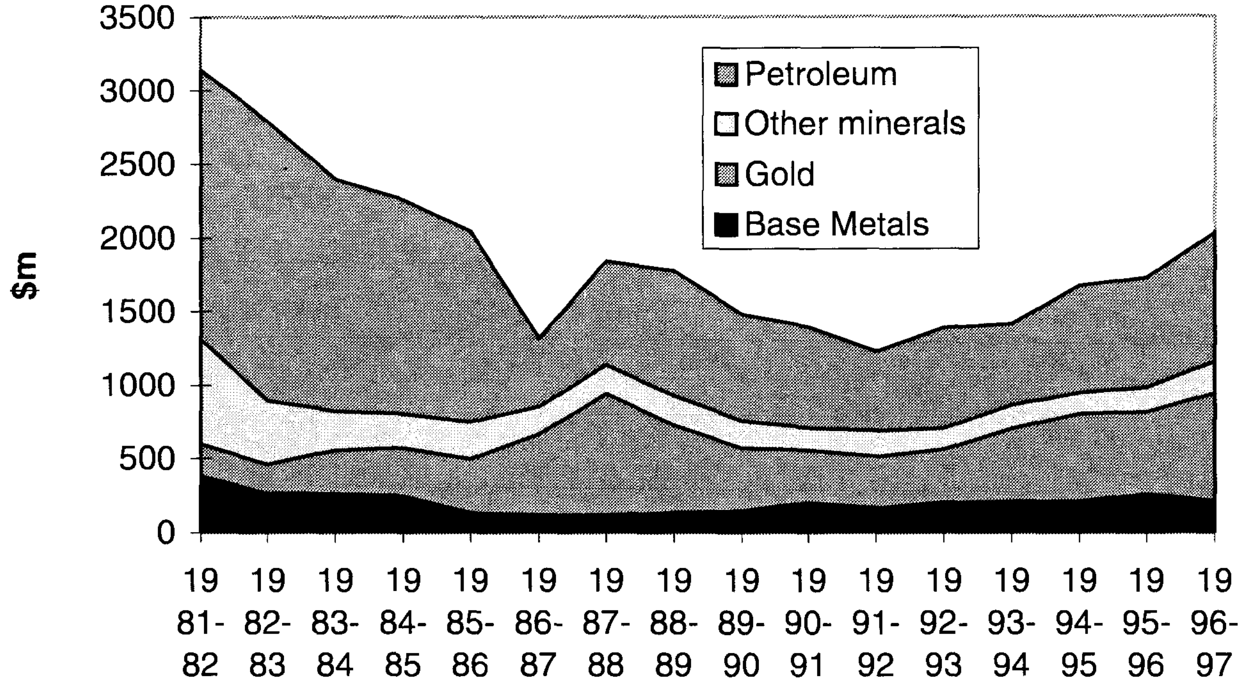


*Figure 4. Real exploration expenditure, 1996–97 dollars.*

around 31 per cent and gold by nearly 110 per cent. It is also worth noting that, the rising costs associated with increasingly complex exploration challenges (including that of finding resources under deep cover) have been offset to some extent by the benefits of technological advances.

Exploration expenditure on gold has accounted for the largest and most volatile component of metallic minerals exploration expenditure since the mid-1980s. The recent exploration expenditure on base metals was boosted initially by rising metal prices and sustained by exploration success, with a number of major discoveries of lead–silver–zinc (Cannington), zinc (Century) and copper (Earnest Henry) in the Mount Isa/ Carpentaria Minerals Province, and nickel (Silver Swan) in the Yilgarn Province in Western Australia.

Petroleum exploration expenditure, the dominant component of energy sector exploration in Australia, peaked in the early 1980s and then declined, broadly mirroring the trend in world oil prices over this period. Expenditure has increased since 1991–92, boosted by encouraging results, some technological advances in exploration and production and good prospectivity in the Carnarvon Basin (offshore Western Australia) and in the Bonaparte Basin in the Timor Sea.

An indication of the extent to which Australian mining companies are focusing their attention on other countries is provided by the annual survey undertaken by Coopers & Lybrand on behalf of the Minerals Council of Australia which shows that the proportion of minerals exploration expenditure by the large Australian mining companies that was directed overseas increased sharply from 26 per cent in 1990–91 to 40.5 per cent in 1995–96 (Minerals Council of Australia 1996). Significantly, however, minerals exploration expenditure in Australia by these companies increased by 40 per cent over the period — from $335 million to $469 million.

## Mining and minerals processing projects in Queensland

New capital expenditure in the Australian mining industry has increased at an average of nearly 13 per cent in real terms in each of the past five years (Figure 5). Such expenditure is estimated to have increased by 14 per cent in 1996–97, to around $8.8 billion. If achieved, this level will be an annual capital investment record for the industry in real terms.

There a number of facilities that have recently commenced operation in Queensland which will provide significant contributions to state mineral and metal production, including:

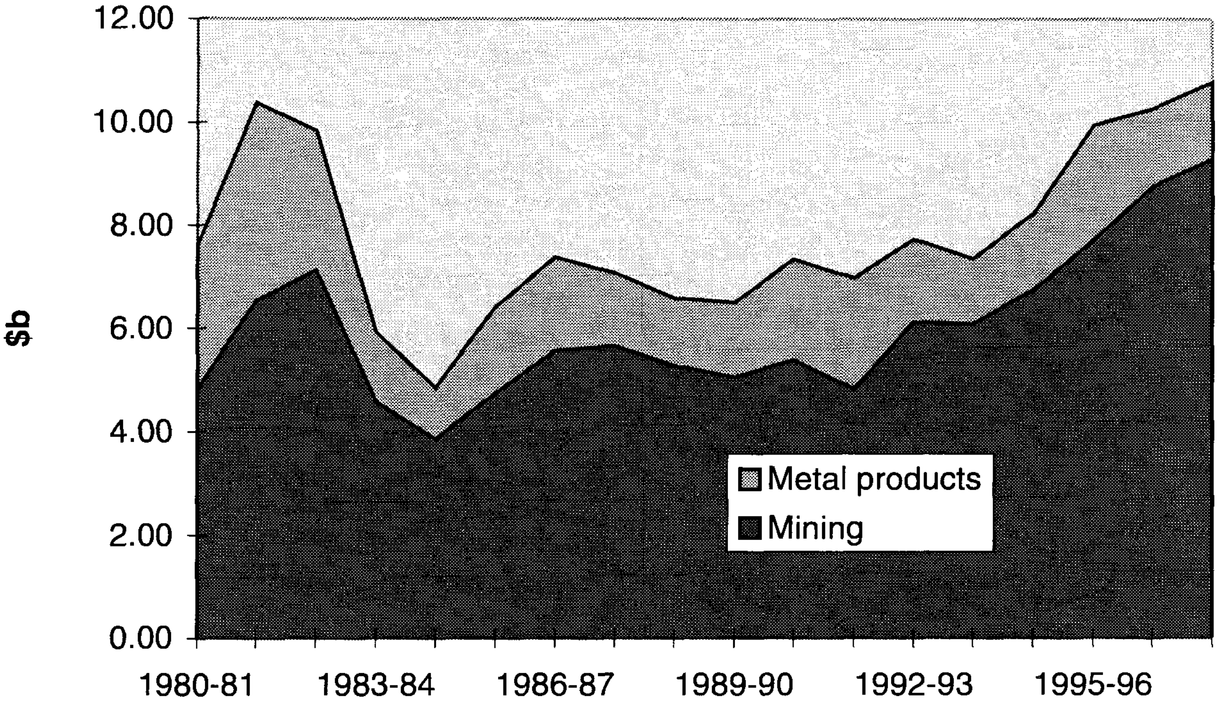


*Figure 5. New capital expenditure, 1996–97 dollars.*

- BHP's $450 million lead–silver–zinc Cannington project in the Mount Isa region;
- MIM and Savage Resource's Ernest Henry $350 million copper–gold mine, also in the Mount Isa region; and
- the $1 billion capacity expansion to the Boyne Island aluminium smelter.

A substantial proportion of the projected growth in minerals and energy production over the outlook period will also come from projects that are currently in advanced stages of the planning and development process (Table 1). A significant number of these projects have been committed to by the mining companies concerned.

The Queensland government's budget that was delivered in May 1997 contained a $4.2 billion capital works program that, along with private sector infrastructure investment, is expected to assist mineral resource developments. In particular, the extensions that are underway to Queensland's gas distribution network are playing a significant role in the expansion of infrastructure that will in turn facilitate the continued expansion of the minerals sector.

Of significance is the gas pipeline that AGL is currently constructing between Bellera in the southwest to Mount Isa. The pipeline, which is due to be commissioned in April 1998, will link the gas fields in the south to the developing minerals region in the north west of the state.

The north west region is becoming host to a number of new projects in addition to the Cannington and Ernest Henry operations. For example, MIM is involved in a number of projects that are currently under construction in the region, including the Enterprise copper mine and the expansion to the Mount Isa copper smelter that will process output from the new Ernest Henry mine. Other committed projects in this region include WMC's Phosphate Hill fertiliser and phosphate rock project and Pasminco's Century lead and zinc project. These projects alone represent nearly $2.5 billion in capital expenditure over the outlook period.

In the coal industry, mine developments that are under construction include Shell Australia's new Moranbah North longwall mine, Idemitsu Kosan's expansion to the Ensham opencut mine near Emerald and MIM's Oaky North project inland from Rockhampton. These coal developments are all expected to be in production by 1998 and represent nearly $1 billion in capital expenditure. A further $375 million has been committed by BHP to expansions to the Peak

## Table 1: Major Queensland minerals resources developments.

| Commodity | Company | Project | Capital expenditure $ | Expected startup |
|---|---|---|---|---|
| *Mining projects* | | | | |
| **Coal** | | | | |
| Under construction | Idemitsu Kosan | Ensham/Yongala | 268m | 1998 |
| | Shell | Moranbah North | 500m | 1998 |
| | MIM Ltd | Oaky North | 100m | 1998 |
| Committed | Central Queensland Coal | Saraji and Peak Downs | 375m | 2001 |
| | Portman Mining | Burton | 60m | 1998 |
| Feasibility study completed | MIM Ltd | Newlands | 150m | 1998 |
| | Normandy Energy | Commodore | 150m | 2001 |
| Feasibility study underway | Allied Qld Coalfields | Kogan Creek | 65m | 1998 |
| | Togarah North JV | Togarah North | 325m | 1998 |
| | Hail Creek JV | Hail Creek | 400m | 2000 |
| | Pacific Coal | Meandu | na | 2002 |
| **Petroleum** | | | | |
| Under contruction | AGL | Gas Pipeline | 180m | 1998 |
| Feasibility study underway | PGT Australia | Gas Pipeline | 125m | na |
| | Chevron | Gas Pipeline | 1.95b | 1998 |
| Under consideration | Stuart Energy | Oil shale R&D plant | 250m | 1998 |
| **Zinc/lead** | | | | |
| Committed | Pasminco | Century | 1.1b | 2000 |
| Feasibility study completed | Lachlan Resources | Balcooma | 60m | na |
| Feasibility study underway | MIM | George Fisher | 500m | 1999 |
| | Buka Minerals | Lady Loretta | 330m | 2001 |
| **Copper** | | | | |
| Under construction | MIM | Enterprise mine | 293m | 1999 |
| Feasibility study completed | Aberfoyle | Gunpowder mine | 125m | 1998 |
| **Bauxite** Committed | Alcan South Pacific | Ely | 130m | 1999 |
| **Kaolin** | | | | |
| Under construction | Australian Kaolin | Skardon River | 74m | 1998 |
| **Gold** | | | | |
| Feasibility study underway | MIM | Sarsfield Project | 45m | 1998 |
| *Minerals processing facilities* | | | | |
| **Alumina** | | | | |
| Location study underway | Comalco Aluminium | Alumina refinery | 1b | After 2000 |
| **Zinc/lead** | | | | |
| Under construction | Korea Zinc | Zinc smelter | 530m | 1999 |
| **Copper** | | | | |
| Under construction | MIM | Mount Isa smelter | 285m | 1998 |
| | MIM | | 50m | 1999 |
| **Nickel** | | | | |
| Feasibility study underway | Calliope Metals | Townsville refinery | 316m | 1999 |
| **Magnesium** | | | | |
| Committed | QMC JV | Pilot plant | 63m | 1998 |
| Feasibility study underway | AMC | Magnesium smelter | 700m | 2002 |
| **Phosphate and fertilisers** | | | | |
| Committed | WMC | Phosphate Hill | 650m | 1999 |

Projects listed here are confined to those with expected capital expenditure of $40 million or more.

**Table 2: Key World minerals and energy projections.**

| | Unit | 1997 | 1998 | % change | Annual average growth rate 2002 | 1997 to 2002 % |
|---|---|---|---|---|---|---|
| **Prices** | | | | | | |
| Aluminium | | | | | | |
| -nominal | US$/t | 1 651 | 1 795 | 8.7 | 1 656 | 0.1 |
| -real[a] | US$/t | 1 651 | 1 762 | 6.7 | 1 447 | -2.6 |
| Copper | | | | | | |
| -nominal | US$/t | 2 385 | 2 100 | -11.9 | 2 020 | -3.3 |
| -real[a] | US$/t | 2 385 | 2 061 | -13.6 | 1 765 | -5.8 |
| Lead | | | | | | |
| -nominal | US$/t | 650 | 600 | -7.7 | 600 | -1.6 |
| -real[a] | US$/t | 650 | 589 | -9.4 | 524 | -4.2 |
| Zinc | | | | | | |
| -nominal | US$/t | 1 380 | 1 450 | 5.1 | 1 100 | -4.4 |
| -real[a] | US$/t | 1 380 | 1 423 | 3.1 | 961 | -7.0 |
| Nickel | | | | | | |
| -nominal | US$/t | 7 229 | 8 000 | 10.7 | 6 538 | -2.0 |
| -real[a] | US$/t | 7 229 | 7 853 | 8.6 | 5 713 | -4.6 |
| Gold | | | | | | |
| -nominal | US$/oz | 336 | 345 | 2.7 | 409 | 4.0 |
| -real[a] | US$/oz | 336 | 339 | 0.8 | 357 | 1.2 |
| Crude oil | | | | | | |
| -nominal | US$/bbl | 18.30 | 18.75 | 2.5 | 22.00 | 3.8 |
| -real[a] | US$/bbl | 18.30 | 18.40 | 0.6 | 19.22 | 1.0 |
| **Consumption** | | | | | | |
| Aluminium | kt | 21 350 | 22 150 | 3.7 | 23 700 | 2.1 |
| Copper | kt | 12 700 | 13 110 | 3.2 | 14 400 | 2.5 |
| Lead | kt | 5 840 | 5 940 | 1.7 | 6 350 | 1.7 |
| Zinc | kt | 7 725 | 7 900 | 2.3 | 8 440 | 1.8 |
| Nickel | kt | 970 | 1 006 | 3.7 | 1 120 | 2.9 |
| Gold | t | 3 520 | 3 701 | 5.1 | 4 028 | 2.7 |
| Crude oil | mbd | 73.8 | 75.6 | 2.4 | 82.0 | 2.1 |
| **Production** | | | | | | |
| Aluminium | kt | 21 425 | 22 100 | 3.2 | 24 500 | 2.7 |
| Copper | kt | 13 100 | 13 700 | 4.6 | 14 730 | 2.4 |
| Lead | kt | 5 780 | 6 040 | 4.5 | 6 350 | 1.9 |
| Zinc | kt | 7 520 | 7 820 | 4.0 | 8 460 | 2.4 |
| Nickel | kt | 971 | 1 001 | 3.1 | 1 163 | 3.7 |
| Gold | t | 2 411 | 2 502 | 3.8 | 2 737 | 2.6 |
| Crude oil | mbd | 74.3 | 76.6 | 3.1 | 82.1 | 2.0 |

a In 1997 dollars.

## Table 3: Key Australian mineral and energy projections.

| | Unit | 1997 | 1998 | % change | Annual average growth rate 2002 | 1997 to 2002 % |
|---|---|---|---|---|---|---|
| **Mine production** | | | | | | |
| Bauxite | Mt | 43 | 44.1 | 2.6 | 53 | 4.3 |
| Copper | kt | 560 | 630 | 12.5 | 750 | 6.0 |
| Lead | kt | 520 | 595 | 14.4 | 775 | 8.3 |
| Zinc | kt | 1 060 | 1 100 | 3.8 | 1 590 | 8.4 |
| Nickel | kt | 115 | 130 | 13.0 | 213 | 13.1 |
| Coal | Mt | 206.5 | 214.3 | 3.8 | 249 | 3.8 |
| Gold | t | 298.8 | 314.4 | 5.2 | 336 | 2.4 |
| Crude oil | ML | 31 049 | 32 600 | 5.0 | 31 500 | 0.3 |
| Natural gas | $GM^3$ | 32 | 33.4 | 4.4 | 48.8 | 8.8 |
| LPG | ML | 3 789 | 4 475 | 18.1 | 5 260 | 6.8 |
| **Refined production** | | | | | | |
| Alumina | kt | 13 252 | 13 570 | 2.4 | 16 150 | 4.0 |
| Aluminium | kt | 1 388 | 1 564 | 12.7 | 1 645 | 3.5 |
| Copper | kt | 305 | 360 | 18.0 | 550 | 12.5 |
| Lead | kt | 202 | 220 | 8.9 | 250 | 4.4 |
| Zinc | kt | 319 | 335 | 5.0 | 500 | 9.4 |
| Nickel | kt | 73 | 86 | 17.8 | 147 | 15.0 |
| Refined petroleum | ML | 43 000 | 43 700 | 1.6 | 46 300 | 1.5 |
| **Export values**[a] | | | | | | |
| Alumina | $m | 2 602 | 2 840 | 9.1 | 2 845 | 1.8 |
| Aluminium | $m | 1 059 | 1 234 | 16.5 | 2 673 | 20.3 |
| Copper | $m | 1 007 | 1 243 | 23.4 | 1 435 | 7.3 |
| Lead | $m | 467 | 438 | -6.3 | 460 | -0.3 |
| Zinc | $m | 842 | 1 165 | 38.3 | 1 240 | 8.1 |
| Nickel | $m | 1 095 | 1 253 | 14.4 | 1 576 | 7.6 |
| Metallurgical coal | $m | 4 815 | 4 998 | 3.8 | 5 287 | 1.9 |
| Thermal coal | $m | 3 119 | 3 352 | 7.5 | 4 338 | 6.8 |
| Gold | $m | 4 706 | 4 865 | 3.4 | 6 310 | 6.0 |
| Crude oil | $m | 2 097 | 2 037 | -2.8 | 2 641 | 4.7 |
| Natural gas | $m | 1 537 | 1 446 | -5.9 | 2 263 | 8.0 |
| LPG | $m | 356 | 297 | -16.5 | 380 | 1.3 |

a In 1996–97 dollars.

Downs and Saraji opencut operations with $125 million also to be spent to expand the shipping capacity of the Hay Point facility. Portman Mining has also committed $60 million to double the capacity of the recently opened Burton coal mine.

Other projects of note that are under construction in Queensland include Korea Zinc's new $530 million zinc smelter, Australian Kaolin's $74 million Skardon River Kaolin project and MIM's $50 million expansion of the Townsville copper refinery. In addition to these projects, Alcan South Pacific has committed $130 million to the development of the Ely bauxite deposit north of Weipa, while QMC, Ford, Normandy Mining and the CSIRO have committed $63 million to the construction of a magnesium pilot plant in Gladstone.

## Potential mining and minerals processing projects

Other large projects are under active consideration and some of these may commence production within the next five years. Such projects include those for which a full feasibility study has yet to be completed, and those for which no definite decision has been made on development either for technical, financial or market reasons. Some of these may be expected to contribute substantially to production and export income growth beyond the outlook period.

However, some may not proceed in the foreseeable future because they confront changed economic or competitive conditions, or they may be aimed at market opportunities for which there is strong competition between suppliers, including other Australian projects. Such circumstances may occur, for example, for some proposed Australian coal mine developments.

One of the largest single projects under consideration is Chevron's proposed $2 billion pipeline to deliver gas from fields in Papua New Guinea to consumers in north Queensland. At this relatively early stage, the uncertain resource policy environment in Papua New Guinea is a source of concern for the developers. Chevron, however, appears confident that they can complete the initial construction phase and commence gas supply by 2001. PGT Australia is currently investigating the feasibility of a $125 million project to extend the current gas distribution network from Injune to Brisbane. Aside from distribution proposals, Stuart Energy are considering a $250 million project to construct an oil shale research plant in Gladstone. Oil shale processing technology has developed to a stage where, under favourable circumstances, it may provide an economic alternative to more traditional energy sources. Coal seam methane extraction is another potential contributor to Queensland's growing energy requirements, with small quantities already being supplied to the gas market.

There are a number of base metals that are under consideration in the north west region. MIM, Buka Minerals and Aberfoyle are investigating projects that represent a combined potential capital expenditure of close to $1 billion. In other parts of the state, there are six coal mine developments under consideration involving a notional combined capital expenditure of over $1 billion. Other significant potential projects include Comalco's proposed $1 billion alumina refinery, Australian Magnesium Corporation's proposed $700 million magnesium smelter and Calliope's proposed $316 million facility to refine nickel from ore imported from New Caledonia. Australian Magnesium Corporation and Calliope plan to construct their projects in Gladstone, while Comalco is in the process of evaluating sites in Gladstone and in Malaysia.

The developments mentioned above represent only the most significant of those currently at relatively advanced stages of planning. If a substantial proportion of projects under these earlier stages of consideration proceed, the recent growth in new capital investment will be sustained and the size of Queensland's minerals and energy sector will increase significantly.

## Australian production

Reflecting increased market opportunities, increased expenditure on exploration and increased capital investment, Australian minerals and energy production is expected to grow particularly strongly in the medium term, with the total volume of Australian mine production projected to rise by more than 20 per cent overall in the five years to 2001–02. In that period all major industries are expected to contribute significantly. ABARE's projections for key world and Australian mineral and energy variables are presented in Tables 2 and 3.

Australian production of lead and zinc is projected to increase significantly between 1996–97 and 2001–02. New Queensland projects feature significantly in the world outlook for lead and zinc. The Cannington and Century projects are each expected to account for around 6 per cent of world lead and zinc mine production respectively. However, over the medium term, world lead and zinc smelting capacity is expected to increase sufficiently to place downward pressure on world prices in real terms.

The expansion expected in some individual industries is dramatic. Australian copper mine production is projected to increase by 34 per cent in the five years to 2001–02 while refined copper output is projected to increase by over 80 per cent. The rise in mine and refined production will be largely underpinned by new output from MIM's Mount Isa operations and the Olympic Dam project in South Australia. The development of these projects in Australia and others in Chile and South America is expected to lead to a steady buildup in stocks and a consequent decrease in prices over the outlook period.

Australian production of alumina and aluminium is projected to increase by 22 and 19 per cent respectively between 1996–97 and 2001–02. Growth in domestic alumina production is largely a result of Reynold's expansion to the Worsley refinery in Western Australia while the projected rise in aluminium output is underpinned by the recent expansion at the Boyne Island smelter. Over the medium term, increases in world production from new capacity in Asia and expansions in Western world output are expected to result in sustained increases in aluminium production, and prices are expected to decline gradually in real terms.

Nickel mine production is projected to increase by 85 per cent over the outlook period as a number of new projects commence operations in Western Australia. Prospective producers are attempting to establish their operations well before the massive Voisey's Bay operation in Canada comes on stream early next decade. Over the medium term there is expected to be downward pressure on nickel prices as output from these new, low cost operations begin to affect the market balance.

Production of gold is projected to rise by 12 per cent between 1996–97 and 2001–02. While gold production is expected to increase sharply in the first half of the outlook period, limited growth is expected in the latter years, reflecting modest recent exploration success and expected pressure on industry profitability.

Australian black coal production is projected to increase by around 21 per cent in the five years to 2001–02. However, the future success of Australian coal industry development plans depends not only on the existence of resources and development plans, but also on world prices, industry cost trends and the availability of infrastructure to support exports. Australian coal export facilities have expanded rapidly over the past five years and are expected to continue to expand in line with production growth.

Other Australian energy production is also expected to grow, with natural gas production projected to increase by around 38 per cent and LPG production by close to 40 per cent by 2001–02. Based on Bureau of Resource Sciences projections, however, crude oil production is projected to peak in 1999–2000 before declining. The rate of decline in production from the mature fields of the Gippsland Basin, some of which have been in operation for twenty-five years, is expected to be moderated by infill programs due to come on stream over the next five years. Production from existing fields in the Bonaparte Basin is projected to decline, but new discoveries are likely to substantially increase production in that area of the Timor Sea before the end of the decade. The Carnarvon Basin is projected to double production rates within the next five years, reflecting mainly new crude oil production expected from the Cossack/ Wanaea project.

## Export earnings

Following a rise in Australia's total minerals and energy export earnings in 1996–97 of 5.4 per cent to $36.5 billion, export earnings are forecast to increase at a similar rate in 1997–98, to reach $38.6 billion. With the generally very positive outlook for export volumes across the board, most of Australia's major minerals and energy commodities are expected to contribute to the forecast 1997–98 rise in earnings.

Export earnings from metals and other minerals are forecast to increase by 6.6 per cent to $24.1 billion 1997–98, while energy export earnings are forecast to rise by a more modest 4.2 per cent to $14.5 billion.

Over the medium term, metals and other minerals export earnings are projected to reach almost $29 billion in real (1996–97 dollar) terms in 2001–02. Commodities that are forecast to contribute significantly to increased metals and other minerals export earnings over the medium term include aluminium (up 152 per cent), zinc (up 47 per cent), nickel (up 44 per cent), copper (up 43 per cent) and gold (up 34 per cent).

A strong medium term export performance is also projected for the energy sector. Total earnings from energy exports are forecast to rise by almost 25 per cent to around $18 billion in the five years to 2001–02. Export earnings are projected to rise by 47 per cent for natural gas, by 39 per cent for thermal coal and by 23 per cent for crude oil.

## REFERENCES

BLAKE, DAWSON, WALDRON & ABARE, 1995: *Regional Cooperation for Power Infrastructure*, A report to the APEC Energy Working Group, Melbourne.

CLARK, A. 1995: Structural changes in global minerals supply – Australia's changing role. In *Outlook 96*, Proceedings of the National Agricultural and Resources Outlook Conference, Canberra, 6–8 February, vol. 3, *Minerals and Energy*, ABARE, Canberra, 24–31.

DANIEL, M., 1995: *Asian Coal Prospects to 2020*, IEAPER/18, International Energy Agency Coal Research, London.

HEAP, A., 1996: Base metals – the economic outlook, Paper presented at the Second Australian Metals Conference, Melbourne, November.

METALS ECONOMICS GROUP, 1996: *Corporate Exploration Strategies: A Worldwide Analysis*, Halifax, Canada.

MINERALS COUNCIL OF AUSTRALIA, 1996: *Minerals Industry '96 Survey Report*, Survey conducted by Coopers & Lybrand, Canberra.

SACHS, J.D. & WARNER, A.M., 1995: *Natural Resource Abundance and Economic Growth*, A report for International Development, Harvard University, October.

VON ARENTSCHILDT, C., 1995: The emerging trends in Asia's minerals and metals markets – an opportunity and a challenge. In *Outlook 95*, Proceedings of the National Agricultural and Resources Outlook Conference, Canberra, 7–9 February, vol. 3, *Minerals and Energy*, ABARE, Canberra, 14–29.

**Reference for this paper:**
**MAURER, A., 1997: Key issues for Australian minerals and energy - a Queensland Perspective. *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 1-14.**

*Michael Hood*

Cooperative Research Centre for Mining Technology and Equipment

# Recent advances in mining technology

## PREAMBLE

Although mining companies have rarely, if ever, seen developing new technology as part of their core business activities — and this is particularly the situation today — the mining industry is an avid technology consumer. In the main this industry relies on its suppliers, on universities, and on other organisations to conduct the research to develop this technology. Often mining companies will support this research either with direct funding or with in-kind support, such as the provision of mine sites for field trials.

This paper reports on work in progress at the Cooperative Research Centre for Mining Technology and Equipment (CMTE) which is aimed at developing technology to improve safety and productivity for the Australian mining industry.

## INTRODUCTION

CMTE is one of 65 Cooperative Research Centres (CRC) which have been established by the Commonwealth Government over the past six years. These Centres all aim to foster a culture of innovation throughout the country by strengthening the linkages between Australian industry and Australian researchers. The Centres are all joint ventures between industry and universities and, generally, other research organisations — CSIRO participates actively in the majority of the CRCs.

CMTE has three core research partners (the universities of Queensland and Sydney, and the CSIRO). It also has nine industry companies as members (Aberfoyle, AMT, BHP Coal, Hamersley Iron, MTA, Pasminco, Rio Tinto R&TD, Shell Coal, and WMC Resources). The Centre is headquartered in Brisbane but operates throughout Australia.

The Centre's research program is focused in four areas:

(i) new mining and drilling systems,

(ii) sensors and control methodologies for automating existing mining systems,

(iii) geological sensing, and

(iv) new condition monitoring systems for equipment reliability.

## RESEARCH OUTPUTS

### New Mining and Drilling Systems

The work in this area seeks to develop improved methods of rock excavation for both bulk rock breakage and drilling. Our work in bulk breakage has concentrated on developing new cutting methods, to replace — in some mining situations — the ubiquitous drill-and-blast methods. The work in drilling has concentrated on improving methods for drilling in coal seams.

#### *New Mining Systems*

Figure 1a shows the Mobile Miner MM130 operating at the Broken Hill mine. This machine drives a beautiful tunnel, with a flat back and a flat floor (Figure 1b). The excavation can be graded, to provide drainage for water; it requires a minimum amount of roof and rib support; and it offers minimum resistance to ventilation airflows. The weak link in this exciting new mining system has been the cutting tool. The tools used by this machine are steel discs, similar to those employed by full-face tunnel boring machines (TBM). The difference is that while a TBM might have 20-30 cutters loading the face, the MM130, with a similar amount of power transmitted to the cutterhead, has only 2-3 cutters in contact with the rock at any one time. The consequence of this high unit power

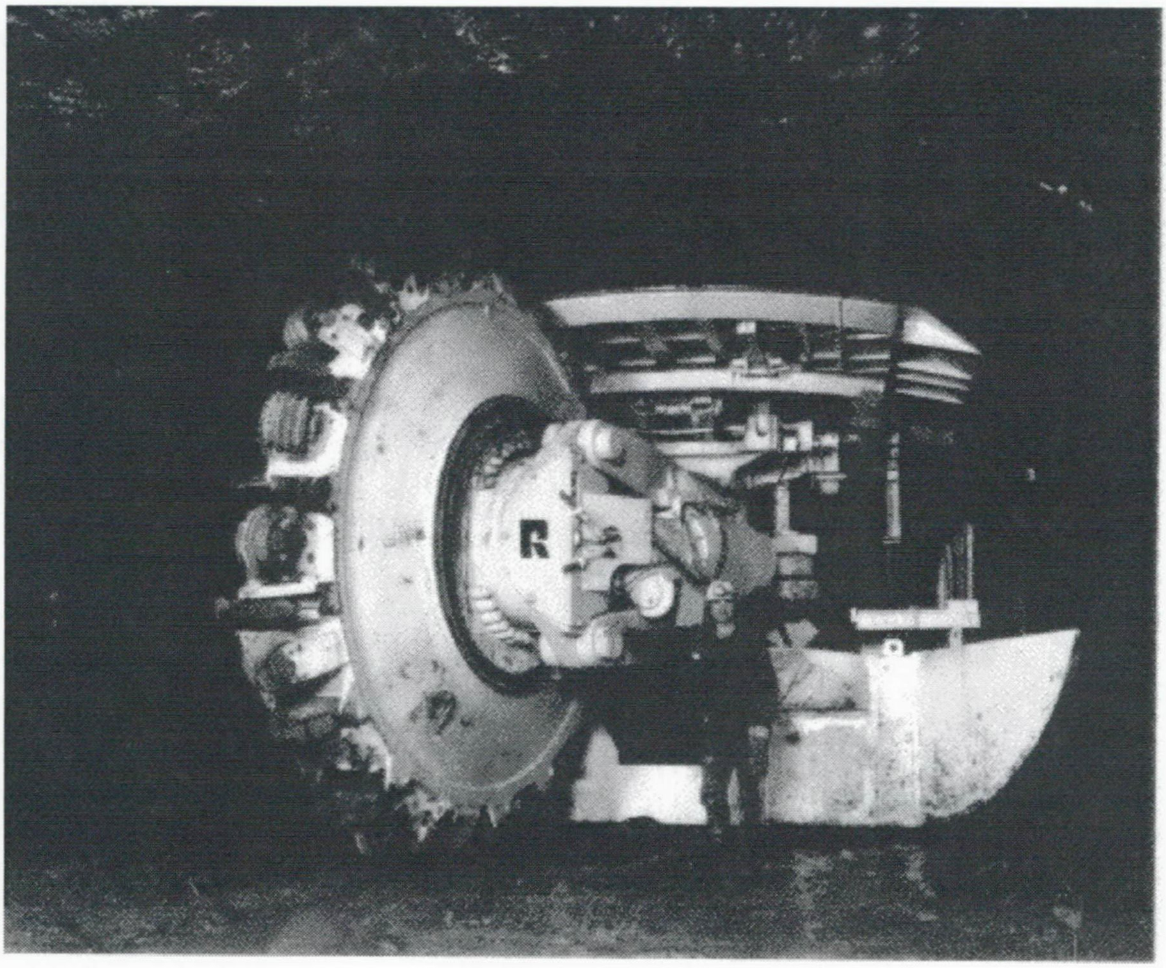

*Figure 1a. Mobile Miner MM130 operating at the Broken Hill mine (photo courtesy of Pasminco Ltd).*

*Figure 1b. Tunnel decline drive by MM130 at the Broken Hill mine.*

per cutter is that these Mobile Miner tools experience a high rate of wear.

The wear rate of a cutting tool can be improved by increasing the hardness of the tool material. Unfortunately the brittleness of a material also increases with its hardness and the more brittle the material the more susceptible it is to catastrophic failure. For this reason previous attempts by others to manufacture disc cutters from materials harder than hardened steel, specifically from cemented tungsten carbide, have failed because these cutters experienced brittle fracture. Despite this cautionary experience the Centre and Pasminco embarked on a project to develop cemented tungsten carbide (WC) rings for the Mobile Miner disc cutters. The encouragement and enthusiasm to undertake this work came from Rick Willoughby at Pasminco. The innovative design which allowed this idea to be translated into a workable product by minimising the tensile stresses induced in the brittle WC ring, was conducted by a CMTE graduate student, Zhiqiang Guan, and his supervisor, Dr Hal Gurgenci.

A single WC cutter of their design was manufactured by Sandvik and tested on the MM130. The first important thing to note is that the WC cutter did not break when it first came into contact with the rock, despite the very high loading which it experienced on this machine. This cutter was mounted on the cutting wheel with eight conventional steel cutters. The radial wear of the WC cutter was less than 1mm, while the steel cutters wore some 17mm. Currently we are in the process of testing a set of six WC cutters on the MM130. If these perform as well as the single cutter in the first trial then we expect that a substantial market will exist for these new wear-resistant cutters on TBMs and other types of boring machines.

The Centre is also engaged in developing a radically new system for the rapid excavation of hard rock. This system, termed the oscillating disc cutter (ODC), was first conceived and tested by David Sugden. It employs a disc cutter which attacks the rock in an undercutting mode (Figure 2). This method of attacking the rock promotes tensile rock failure. Since, like other brittle materials, rock is about an order of magnitude weaker when it is loaded in tension than when it is loaded in compression, this undercutting method of loading greatly reduces the forces and hence the energy needed to promote rock failure. Because the propensity for cutter wear and cutter failure both increase with force and energy this method of attacking the rock enhances cutter life. This undercutting method with disc cutters is not new; it is employed on the HDRK-Wirth continuous mining machine (Figure 3).

The goal is to develop a mining system which excavates hard rock rapidly with a lightweight machine. In mining operations a low machine mass is desirable because it gives the system the flexibility to speedily change the direction of the excavation and/or to move the equipment rapidly from one section of the mine to another. Conventional excavation machines employing disc cutters require a high machine mass to transmit the needed high forces to the cutters. Undercutting partially addresses this problem but the ODC system incorporates two innovative ideas which further reduce the reaction forces on the machine. One is to provide the cutters with an internal drive, rather than employ conventional passive cutters which require that the force be provided by the machine. The other is to recognise that the cutter forces vary over time. Typically a large machine is required to resist some multiple of the peak cutter force. However, if this oscillatory force signal was damped, then only the mean force would need to be resisted by the machine and this might be only one third the magnitude of the peak force. The ODC damps this peak cutter force by placing an inertial mass between the cutter and the machine (Figure 2).

CMTE has conducted laboratory testing of this ODC over the past year. The results obtained to date show the promise of developing new mining systems — for both underground and surface mines — with the capability to excavate weak and strong rock in a surgically precise manner.

*New Drilling Systems*

Our work in coal drilling is motivated by the need to drill in coal seams to provide paths for drainage of gases contained in these seams. These gases are both a hazard — unless they are drained from the coal there is the risk of explosions or outbursts — and an opportunity — because the principal gas is methane; a clean and plentiful energy source.

At present this drilling is performed in underground coal mines using either rotary drills or downhole motor (DHM) drills. Although both of these drilling methods can be effective they both suffer disadvantages. Rotary drilling is relatively inexpensive, but it

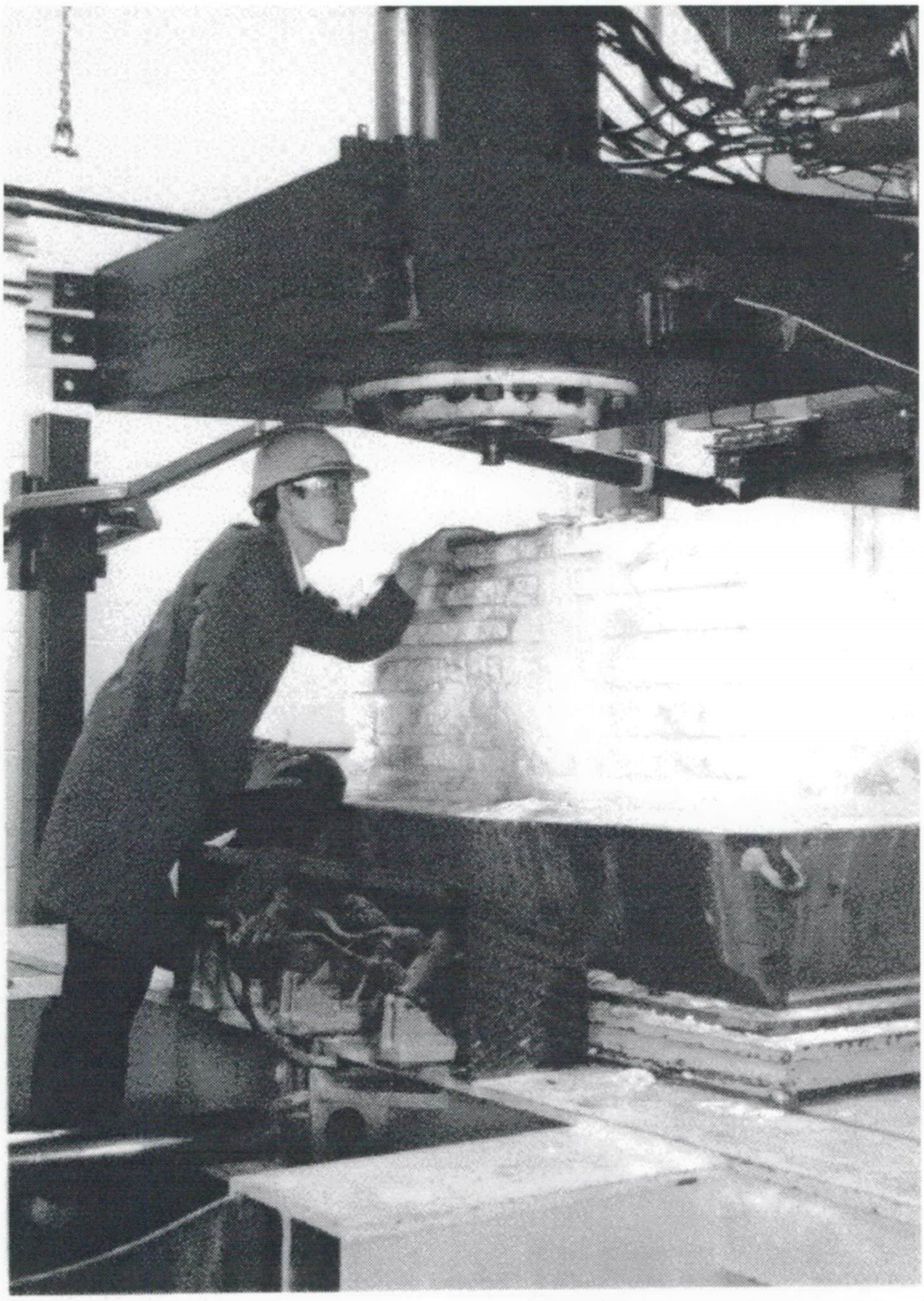

*Figure 2. Oscillating disc cutter laboratory apparatus.*

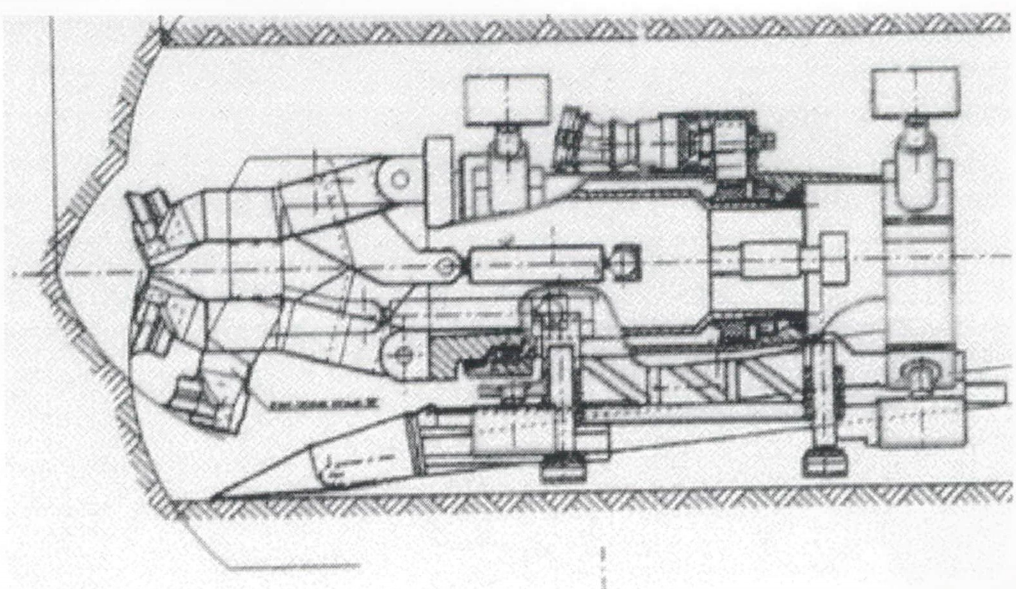

*Figure 3. Wirth/HDRK continuous mining machine.*

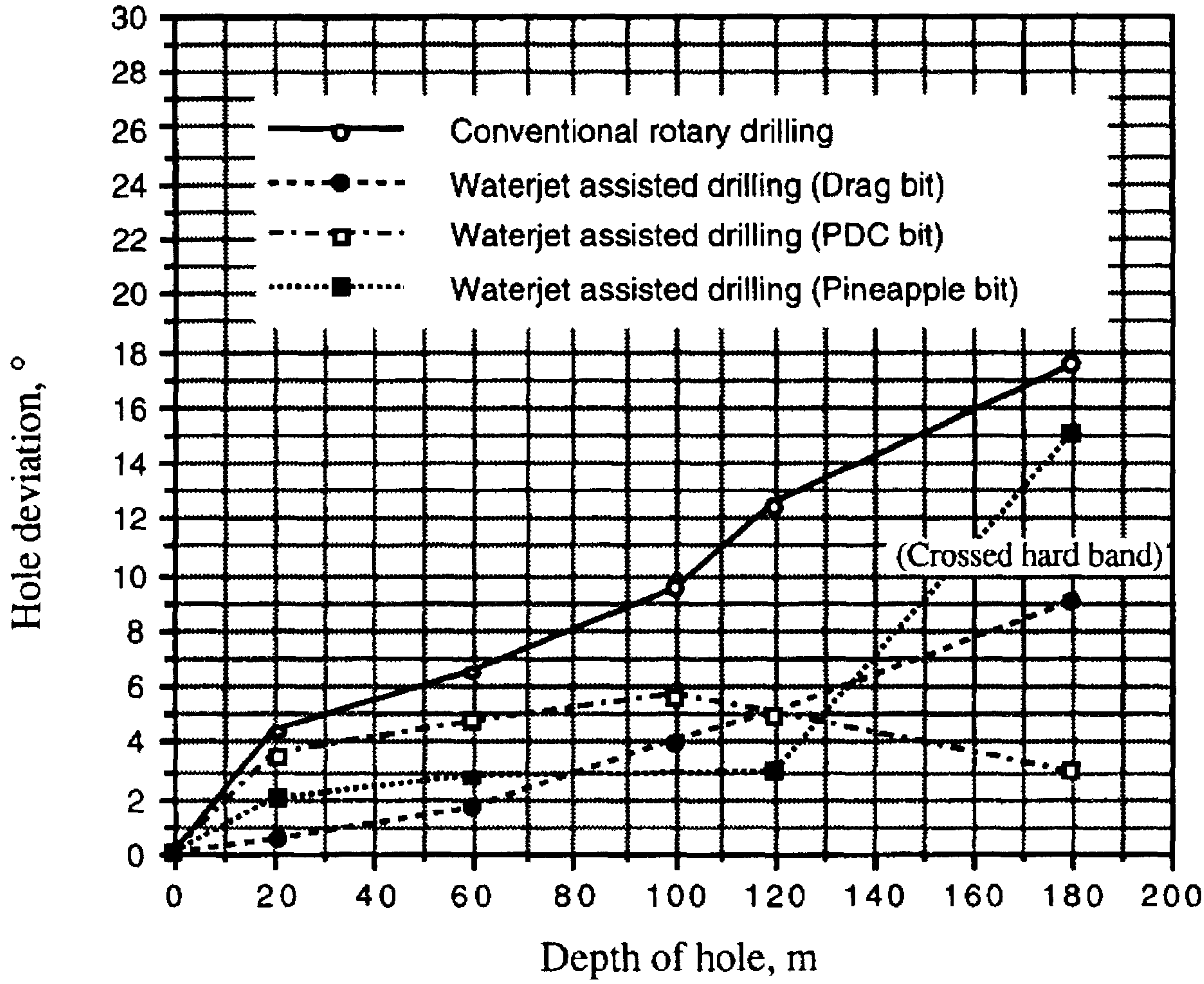


*Figure 4. Improved straightness of holes drilled using water jets.*

is inaccurate — the holes often do not follow the desired trajectories. The consequence is that often much more drilling is conducted than would have been needed with holes that were accurately located. DHM drilling allows the drills to be steered, and hence the accuracy problem is solved. However, the cost of these drilling systems is high and the rate of drilling is low.

Our work has been aimed at developing a rapid, steerable, low-cost rotary drill. This work has two components. One is the development of a water jet assisted drill. In this drilling system high pressure water jets are used to assist the cutting action of the drill bit. These jets greatly reduce the forces acting on the bit. Since the tendency of a drill to deviate from its intended trajectory is caused by high bit forces, the water jet assisted drill has a natural tendency to remain on the desired trajectory. The other component of this work is the development of geophysical sensors. These sensors are mounted behind the drill bit, to monitor the position of the drill with respect to the roof and floor of the seam. This information allows the driller to maintain the drill in the seam even when the seam undulates.

The water jet assisted drills have been field tested at Appin and Dartbrook collieries. These trials have shown the potential to drill straighter holes than is possible with conventional drills and, furthermore, the jet assisted holes are drilled more rapidly than is possible with conventional drills (Figure 4).

Field work also has been conducted to test three types of geophysical sensor: radiometric,

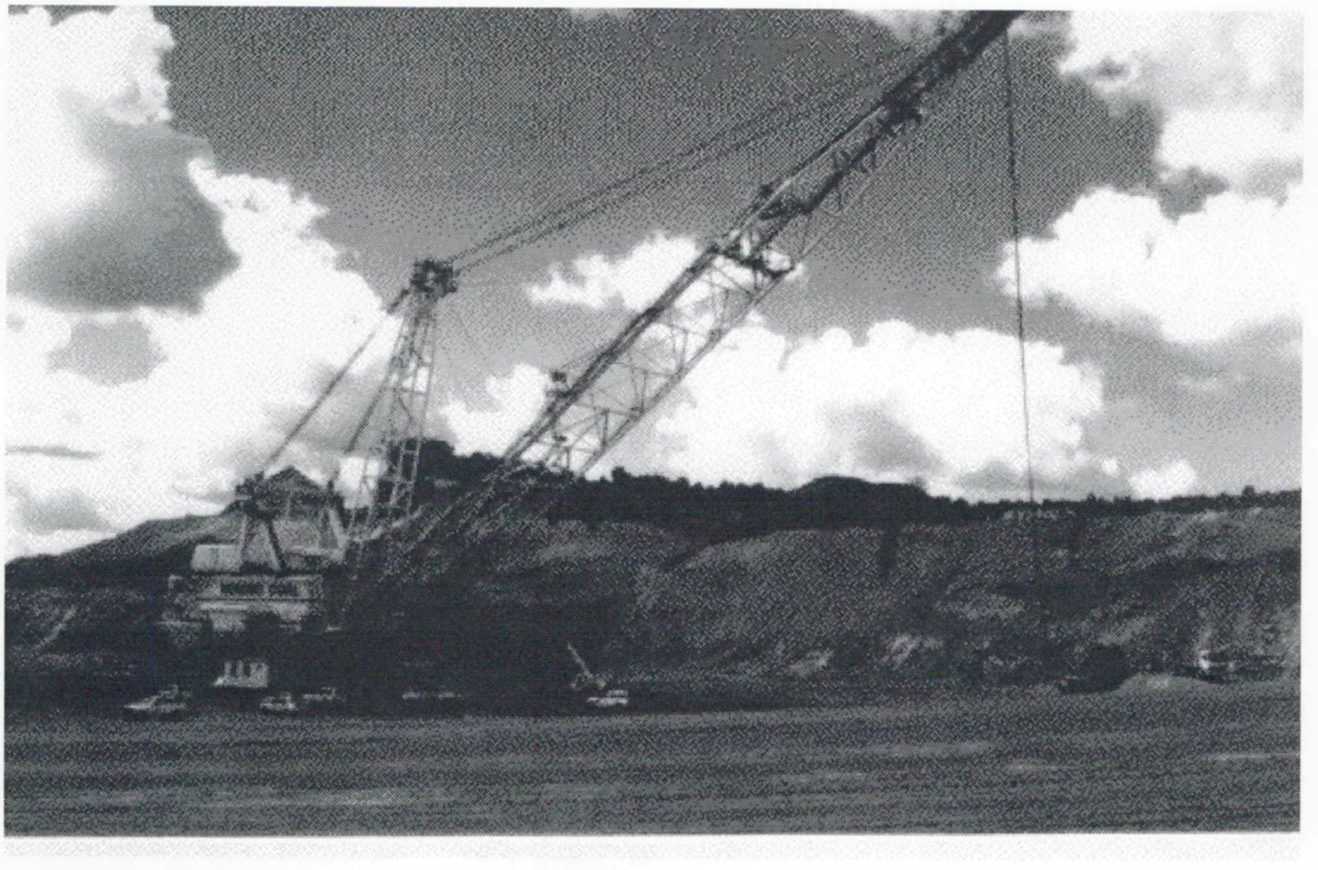

*Figure 5. Dragline at Pacific Coal's Meandu mine.*

radar, and dielectric. All three show promise and further work is now being conducted to identify the most suitable tools for different drilling applications.

## Automation of mining equipment

The mining industry is unusual in that while it is highly mechanised it is almost completely un-automated. Automation in other industries, such as manufacturing, has occurred mainly during the past two decades and has produced significant improvements in productivity. In mining, a main target area would be the automation of tasks in the most dangerous areas of the mine. This would result in improvements in both productivity and safety.

However, the automation of mining systems poses a number of significant technical problems, which is the reason it has not yet been achieved[1]. These problems relate both to the mine environment and to the nature of mining machines.

The mining environment is both hostile and unstructured. The former means that the sensors and computer hardware needed for automation need to be rugged (equivalent to military specification). The latter poses a problem for the machine to "know" where it is in the ever-changing mine environment.

Although most mining machines can be thought of as robots, they are, in robotic terms, "bad robots" because generally they are large compliant structures. "Good robots" by contrast are small with rigid linkages. High compliance again causes a problem for the machine or robot to "know" where it is.

Despite these difficulties it is possible today to develop and employ advanced sensing techniques and control strategies to automate compliant robots and even mobile equipment in unfriendly environments.

Two CMTE automation projects which have reached an advanced stage of development are: (i) automation of the dragline swing, and

1 Automation of mining equipment is difficult for two reasons. One, this equipment operates in a hostile and unstructured environment. Two, although most mining machines can be considered as robots they are, in robotic terms "bad robots" because generally they are large compliant structures. "Good robots" by contrast are small with rigid linkages. Despite these difficulties it is possible today to develop and employ advanced sensing techniques and control strategies to automate compliant robots and even mobile equipment in unfriendly environments.

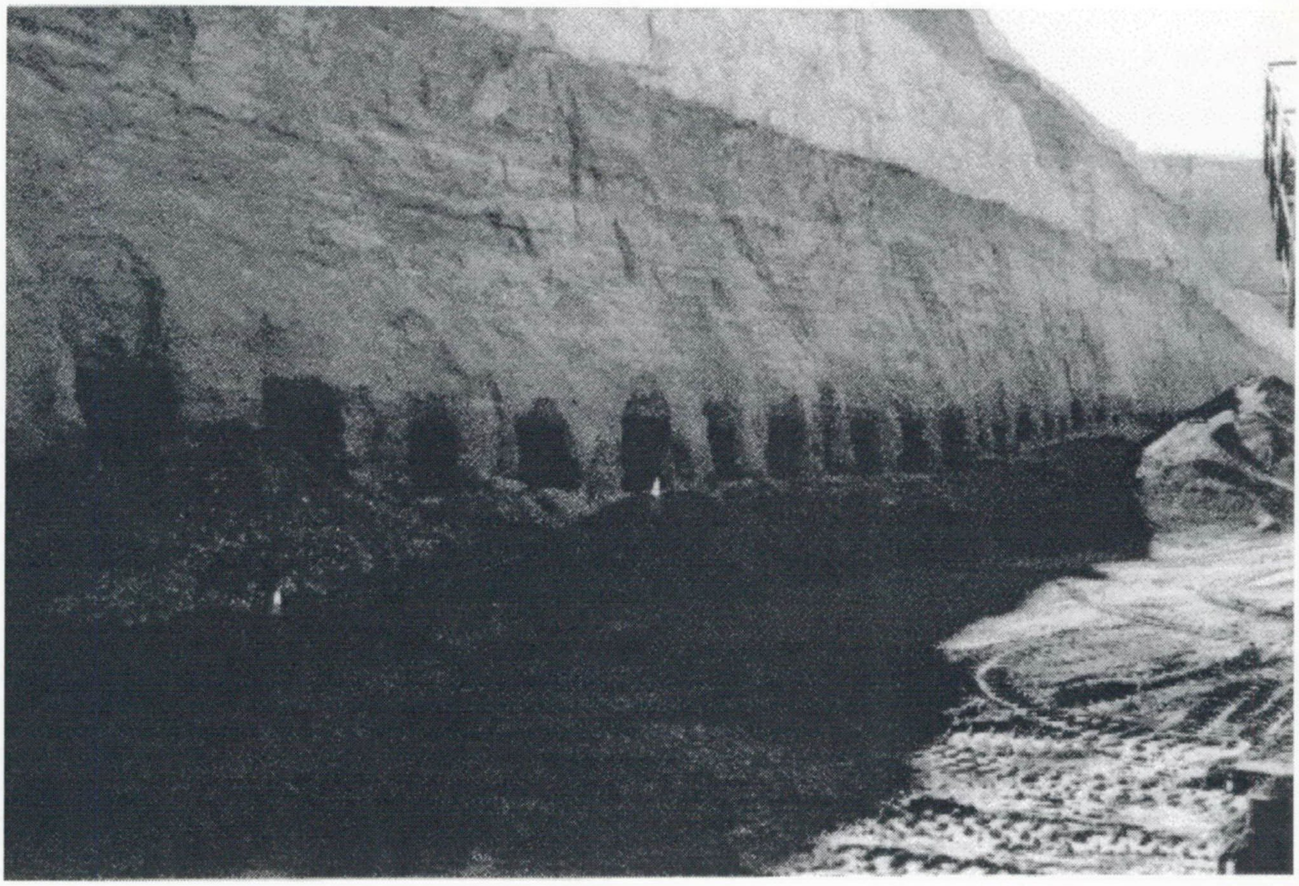

*Figure 6. Highwall mining operations at BHP Coal's Moura mine.*

(ii) inertial guidance for highwall mining systems.

### *Dragline Swing*

The project leaders of the dragline swing project (formerly Dr David Hainsworth and now Dr Graeme Winstanley) term the dragline "the world's largest robot". There are two motivations for wanting to automate the swing part of the dragline operating cycle. One is to improve productivity. Our goal is to perform this swing operation consistently and in a minimal time. Typically this swing action occupies 70–80 percent of the total cycle time for the machine.

The other motivation is to reduce the dynamic loading of the boom. These booms are designed to take loads in a vertical plane but not in a horizontal plane. When an operator inadvertently induces an oscillating swing motion with a loaded bucket this can cause excessive stressing of the boom. The automated swing action would eliminate this swinging motion and thus reduce boom loading.

A key to the automation system is a sensor (scanning laser rangefinder) which allows the position of the bucket to be monitored remotely. This sensor is mounted at the top of the boom and measures the vertical angle of the hoist ropes. This angle, together with information on the lengths of the hoist and drag ropes allows the bucket position to be computed. The bucket position information then is used as input to a computer model of the dragline which, in turn, is used to control the dragline swing.

We have implemented our automation system using servo-operated joystick controls on the dragline operator's seat. The system works in a manner similar to that of cruise control in a car. The operator loads the bucket manually and then engages the automated swing action by pressing a button. The automation system then takes over and the foot pedals and joysticks move as they would if the operator was driving the machine. If at any time the operator feels uncomfortable with the automated machine behaviour (s)he can take back control immediately by exerting pressure on the joysticks — similar to a car driver switching out of cruise control by touching the brake pedal.

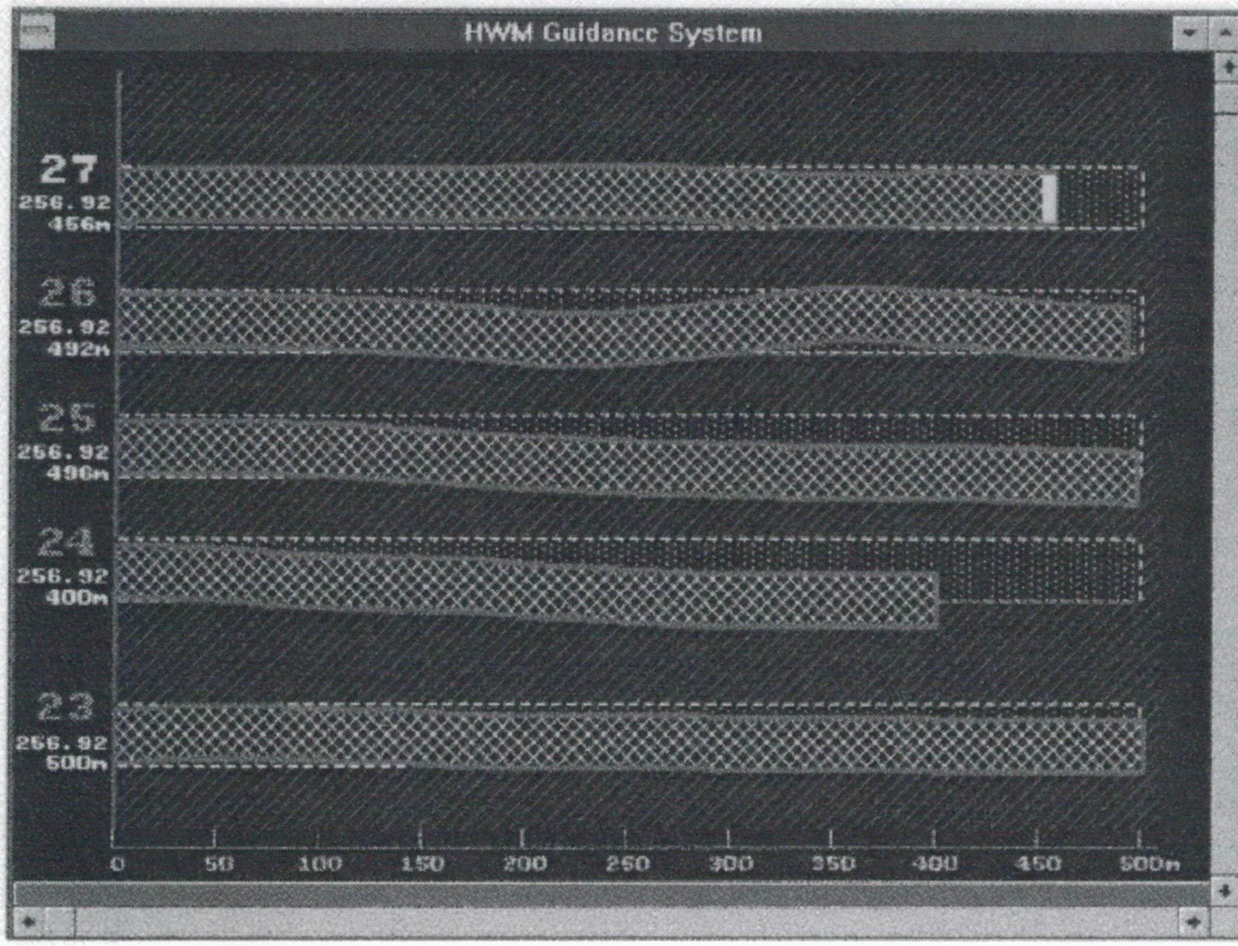


*Figure 7. Computer display showing position of highwall drives.*

This automation system has been demonstrated on a 1/10 th scale model dragline and is now being tested on a full scale machine at Pacific Coal's Meandu mine (Figure 5).

### *Highwall mining guidance*

Highwall mining is a relatively new method of coal extraction. This mining system uses an excavation machine (usually an auger or a continuous miner) to drive a series of parallel holes in the coal seam at the base of a final highwall (Figure 6). No people enter these drives. The excavation is performed remotely by the mining crew working in the floor of the pit. When a continuous miner is employed the operator uses video cameras and other sensors mounted on the machine to control the excavation system from a cab in the "launch vehicle". The length of the drives excavated using this system continues to increase; typically today it is of the order 300-400m. Although this mining method was first developed in the United States much of the pioneering work to advance this system has been performed in Queensland over the past five years.

The stability of the excavations relies on maintaining a pillar of coal between the drives. If this pillar is mined through by two adjacent drives intersecting then there is a high probability of roof collapse and loss of the mining equipment. Hence, it is essential that the miner operator drives these excavations exactly parallel to each other.

The Centre (Drs David Hainsworth and David Reid), working closely with its partners BHP Coal and MTA Ltd, has developed an inertial guidance system to provide the miner operator with visual information on the position of the current drive with respect to the adjacent drives (Figure 7).

This system employs a Honeywell HORTA ring laser gyroscope (similar to that used on military aircraft) as the sensor unit. The Centre, working with Honeywell, has worked to modify the software associated with this

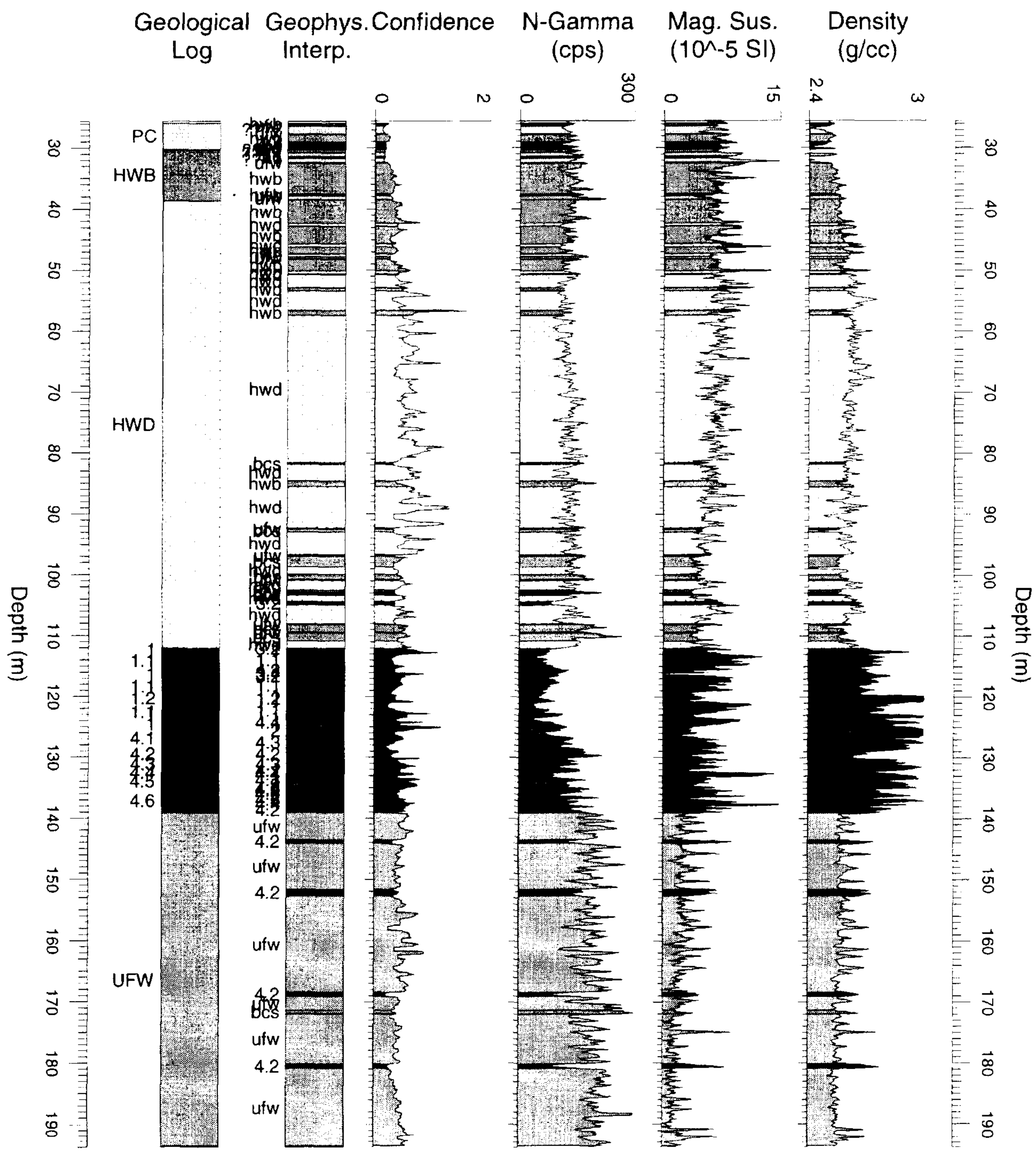

*Figure 8. Geological log vs automated geophysical interpretation.*

sensor to make it suitable for mining operations. In addition the Centre has developed its own software and a communications system to give the miner operator the information that (s)he needs to control the machine position. This guidance system is now being used routinely by MTA and BHP Coal.

## Geological Sensing

The effective extraction of the orebody or the coal seam with existing mining systems is made difficult because the miner (the person operating the mining equipment) has represented in the mining face only a two dimensional view of the valuable mineral and the structure of the rock mass. Changes in the third dimension (orthogonal to the mining face) in mineral grade, in mineral deposit thickness, in deposit continuity, and in rock mass quality, is information not available to the miner. This *blind mining* leads to three difficulties. One is that valuable mineral is not extracted because the miner is unaware it is there — by definition it is difficult, or

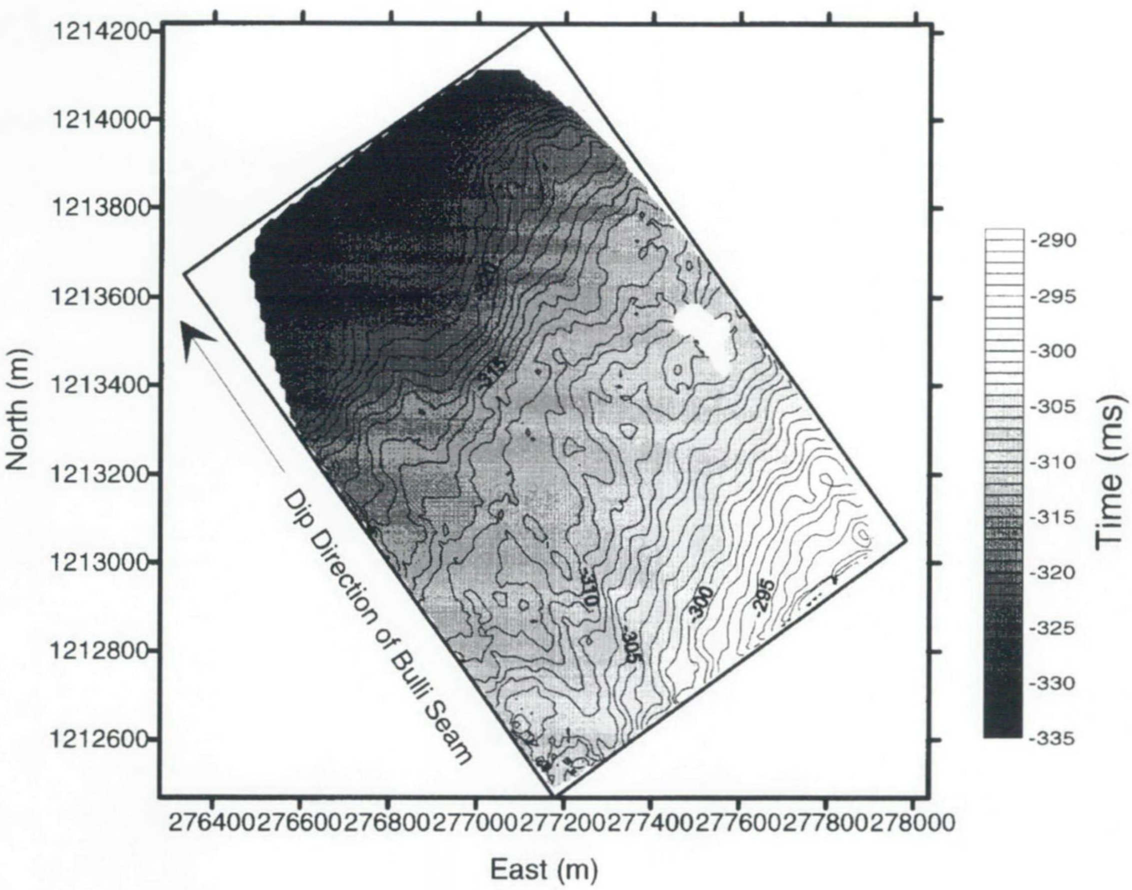


*Figure 9. Two-way reflection time contours of Bulli coal seam from Appin Colliery 3-D seismic survey.*

impossible, to quantify the value of this *lost* mineral. Two is dilution of the valuable mineral with waste rock because the lack of *geological vision* makes it impossible for the miner to guide the mining system in an optimal manner. Three is the inadequate knowledge of structures — such as faults, dykes, and shear zones — within the rock mass. This leads to both operational (=productivity) and safety problems.

These problems are more severe in underground than in surface operations because the miner in a surface mine has a quasi-three dimensional view of the deposit. However, almost all surface mines would benefit greatly from an ability to *see* through the rock during the mining operation. It follows that underground mines would profit tremendously from this ability.

*Geophysics in metalliferous mining*

Through a project developed with AMIRA we have undertaken trial geophysical surveys at seven metalliferous mines throughout Australia. These trials were focussed on establishing the geophysical responses of the various rock types and to then undertake surveys capitalising on these responses to provide information on ore boundaries, grade and rock mass characteristics. We had a specific focus on demonstrating geophysical logging procedures which can determine geological parameters within boreholes without the need to embark on expensive diamond coring (Figure 8).

The project team led by Dr Peter Fullagar (and formerly Dr Peter Hatherly) worked closely with mine site staff. Geophysical contractors were engaged to make most of the measurements with the detailed analyses undertaken by Centre staff.

As a result of this work, a number of the sponsoring companies have boosted their efforts in geophysics. The Centre is also using the results as a springboard for further developments in this field.

*Seismic surveying in coal mining*

Working closely with BHP Coal, Drs Peter Hatherly and Binzhong Zhou have developed new seismic surveying and interpretation procedures. This work has resulted in the first production three-dimensional (3D) seismic

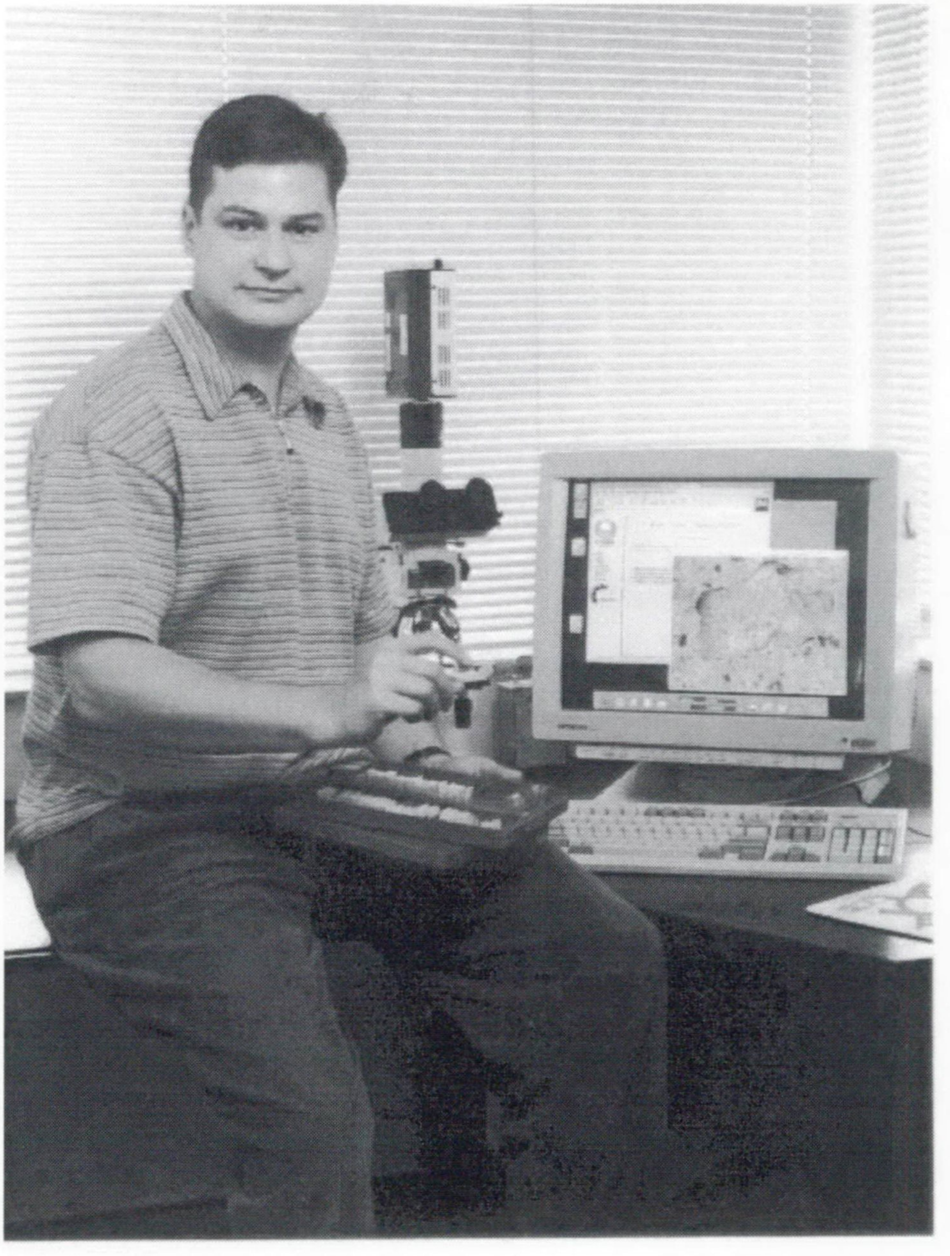

*Figure 10. Elliot Duff with computer display of wear particles.*

survey for an Australian coal mine (Figure 9). Unlike conventional 2D seismic surveying which delivers information along profile lines, 3D seismic surveys provide continuous information on the subsurface in all directions. This information is therefore much more precise and allows underground longwall panels to be planned with much greater certainty. Our interpretation procedures are computer based and facilitate rapid analysis and transfer of information.

### Equipment Reliability

The utilisation of the existing, expensive capital fleets in mines is typically very low. There are two reasons for this. One, the harsh operating environment in a mine results in high rates of equipment wear and high incidences of machine breakdown. This translates to low equipment availability. Two, particularly in underground mining, the numerous unit operations involved in drilling-and-blasting complicate the task of scheduling all of the different pieces of equipment which comprise the mining system. This makes it difficult to utilise the available equipment efficiently. This problem is exacerbated by management's lack of knowledge of the locations of the mobile equipment during a shift.

The Centre's approach to the machine availability problem is to develop and implement improved systems for equipment maintenance. A part of this solution is to develop better methods for the real-time monitoring of the health of equipment components. (As noted above in connection with draglines, automation of the equipment will also help with this problem, since automatic control will not allow the machine to operate in an overload condition. Further, automation can provide continuous information to management on the location of mobile equipment.)

One of the most effective methods available for determining the health of engines and transmissions is the analysis of the oil used in these mechanical items. Microscopic analysis of wear particles filtered from this used oil can provide timely information on the state of wear of the components that make up these units. At present this analysis is performed manually (and thus slowly and expensively) by experts.

Dr Elliot Duff has now completed a project, funded partially by the coal industry[2], which allows the analysis of these wear particles to be automated. Dr Duff has written software to segment filtergram images and extract relevant particle information — shape, size, colour, *etc* — (Figure 10).

The Centre expects to identify a suitable instrument manufacturer to commercialise this new automated analytical method in the near future.

## CONCLUSIONS

CMTE works with its members to develop and help to implement technologies which have a measurable positive impact on mining safety and/or mining productivity. The project examples cited in this paper illustrate that considerable field work at mine sites is usually an essential step in developing this technology.

The Centre is proud to have as its members most of the major mining companies operating in Queensland. We have conducted several projects (some described above) which have had an influence on mining productivity in the coal mines of the Bowen Basin and we continue to have an active research portfolio in coal. We have conducted geophysical work (AMIRA project P436) at the new Century mine and we are pleased to have Pasminco as one of our members.

Although Mt Isa Mines is not yet a member of CMTE we have conducted a successful preliminary project on the automation of underground vehicles at Mt Isa. This has led to the development of a proposal, through AMIRA, for a major industry-funded project in this area. The Centre's influence, however, extends beyond the state borders. We have been described by a prestigious international review panel[3] as:

> ...the focus for mining R&D in Australia and a centre of excellence for the world.

The fact that we are Queensland based adds value to this state's economy because most of the 50 plus full-time equivalent (FTE) staff and 25 postgraduate students are located either at the University of Queensland or CSIRO's laboratory at QCAT[4]. More than half of these professional and technical staff have been hired specifically by the Centre.

However, the real benefit to the state will come if the Queensland Government joins with the Centre, and other similar research organisations, in helping to commercialise the research outputs. Transforming research prototypes into commercial products is a crucial step in gaining long-term benefit from R&D, and it is the step where most R&D fails. It requires seed funding and state encouragement for start-up ventures. The leverage on this funding can be tremendous.

The goal is to spawn a raft of Queensland-based high technology companies and, with them, the new professional jobs that will help Queensland to become, for Australia, the technology-based success that California is for the United States.

**Reference for this paper:**
**HOOD, M., 1997: Recent advances in mining technology. *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 15-26.**

2 by the Australian Coal Association Research Program (ACARP)

3 Stage 1 Panel for Commonwealth Government's 5th Year review of the Centre. Panel members: Professor Miklos Salamon, Colorado School of Mines (chair); Professor Frank Aplan, Penn State University; Professor emeritus Klaus Schoerert, University of Clausthal, Germany; Dr George Giralt, Director CNRS, France; Dr Ken McCracken, AO, Australia; Dr Max Richards, Chmn Aberfoyle, Australia.

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*Gerhard Hofmann*

Queensland Department of Mines and Energy

# Information infrastructure and mineral prospectivity — the impact of the GEOMAP 2005 Program

## SUMMARY

An infrastructure of geoscientific and mineral resource information has underpinned mineral development in Queensland for more than a hundred years. Initially in the form of maps and inspection reports by government geologists, the information base was built up since the 1950s by systematic mapping programs. Since 1993, the Geological Survey of Queensland (GSQ) has undertaken a 12-year program, GEOMAP 2005, to update selected geological maps, build a data base of mineral occurrences, and assess petroleum reservoir potential.

Three projects have been completed (Anakie Province, North Queensland, Bowen-Surat Basins). Five projects are current (Southeast Queensland, Yarrol Province, South Connors Province, Mount Isa Minerals, Cooper-Eromanga Basins) and six are planned to start (Georgina, Coastal Block, North Connors, Drummond, Texas, Adavale Basin). The GSQ also manages a geophysical data acquisition project (AIRDATA) and participates in the North Australian Basins Resource Evaluation Project.

An information infrastructure which enhances mineral prospectivity has a positive impact on exploration activity, as demonstrated by exploration initiatives in other Australian States. The availability of updated and accurate information on the geological potential of a State is a key factor in evaluations for potential resource investors. Examples for Queensland include the reassessment of geological provinces in north Queensland, following the release of third-pass (second generation) geological map data, which led to the discovery of eighteen deposits with economic reserves.

The impact of the GEOMAP 2005 Program can be measured for each project area by the number of Exploration Permits for Minerals (EPM) subblocks under grant at any time. The release of high resolution airborne geophysical data for the New England Fold Belt (AIRDATA Project area) increased the number of EPMs granted in 1996 by 191%. A high turnover of EPMs before and after the geophysical data release was observed.

## INTRODUCTION

The use of geological expertise by the Queensland Government to promote discovery and utilisation of mineral resources, is not new. Since the beginnings of the colony in 1859, successive governments were persuaded to engage geologists to lead the gold rushes or provide advice on new mineral discoveries, so that mineral fields could be declared and miners attracted to the State. The benefits of this initial infrastructure of geoscientific and mineral resource information to the colony, and later to the State, economy were well understood after the discovery of gold at Gympie had saved the fledgling colony.

Today, the value of Queensland's mineral production exceeds $6 billion a year. Most of this comes from coal which represents about 40% of the State's export earnings ($4.5 billion in 1996–7). Revenue from the mineral industry contributes considerably to the State's finances. Royalties and rail freights, for instance, provide about 25% of the State budget's current outlays. This contribution from the minerals sector will continue for some time despite attempts to broaden Queensland's industrial base.

The work of the Geological Survey ensures that exploration for mineral and energy resources in Queensland will continue. The current GEOMAP 2005 Program, like its predecessors, the joint BMR-GSQ mapping program of the 1950s to 1970s and the Queensland Regional Geological Mapping Program (RGMP) of the 1980s, provides the geoscientific information infrastructure for private sector investment. All these programs have been described in detail by Day (1995).

The perception of mineral prospectivity is based on information: information on mineral occurrences and the geological structures and rock units with which mineralisation is associated, previous results from exploration activities, and more detailed geophysical surveys. The availability of this information saves explorers the expense of generating it themselves and reduces exploration time and expenditure. Because of the high financial risk of mineral exploration, explorers are strongly influenced by two factors in site selection: the perceived prospectivity of the location and the amount of background data available, all other factors being equal. To attract exploration investment, all governments are now aware of the need to provide an infrastructure of essential information along with other incentives if they wish to retain a viable minerals industry.

## GEOMAP 2005 PROGRAM

The GEOMAP 2005 Program was launched in 1993 with a 12-year plan. Its aims are:

- to complete the updating of geological mapping for the potentially mineralised provinces of Queensland,
- to evaluate their mineral resource potential, and
- to complete the regional assessment of major petroleum-prospective basins.

Mineralised provinces cover almost half (60 of the 119 standard 1:250 000 sheet areas) of Queensland: the outcropping Precambrian Inliers of the Carpentaria-Mount Isa Mineral Province, Georgetown Province and Far North Queensland, and the Palaeozoic Thomson and New England Fold Belts. Major petroleum basins comprise the Surat-Bowen, Cooper-Eromanga and Adavale Basins. The location of current projects is shown in Figure 1.

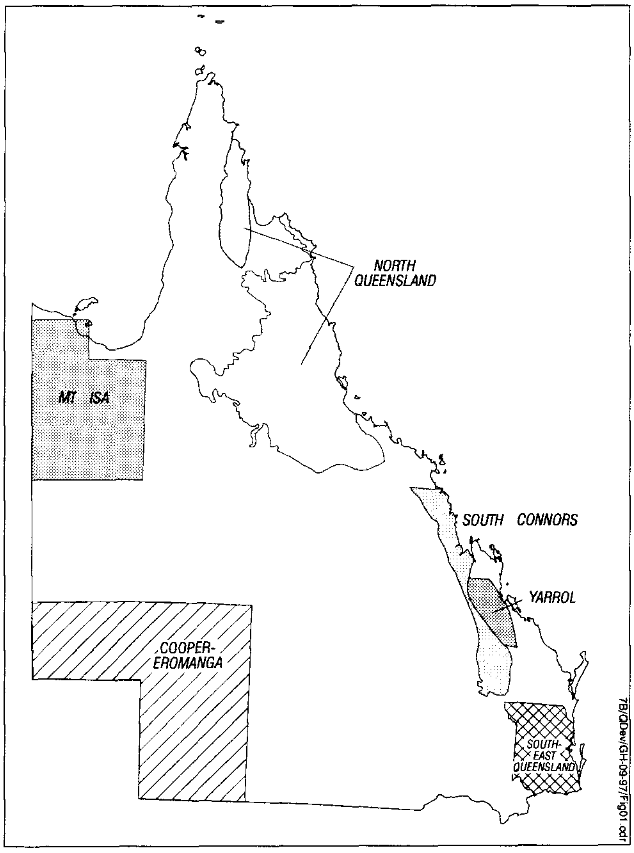


*Figure 1. Location of current GEOMAP 2005 Project*

Three projects have been completed since the start of the GEOMAP 2005 Program (Anakie Province, North Queensland, Bowen-Surat Basins). Five projects are current (Southeast Queensland, Yarrol Province, South Connors Province, Mount Isa Minerals, Cooper-Eromanga Basins) and six are planned to start (Georgina, Coastal Block, North Connors, Drummond, Texas, Adavale Basin). The GSQ also manages an airborne geophysical data acquisition project (AIRDATA) and participates in the North Australian Basins Resource Evaluation Project.

The North Queensland Project was completed in June 1997 after thirteen years of mapping effort during which a total of 15 map sheets at 1:250 000 scale were updated (Figure 2).

The Southeast Queensland Project started in 1989 as a small project to encourage new exploration interests in the Gympie goldfield and it now also includes the Yarraman-Esk and Beenleigh regions. Updating of geological maps and field checking of mineral occurrences is continuing. This project, and the Yarrol and South Connors Projects, is collaborating with the Cooperative Research Centre for Landscape Evolution and Mineral

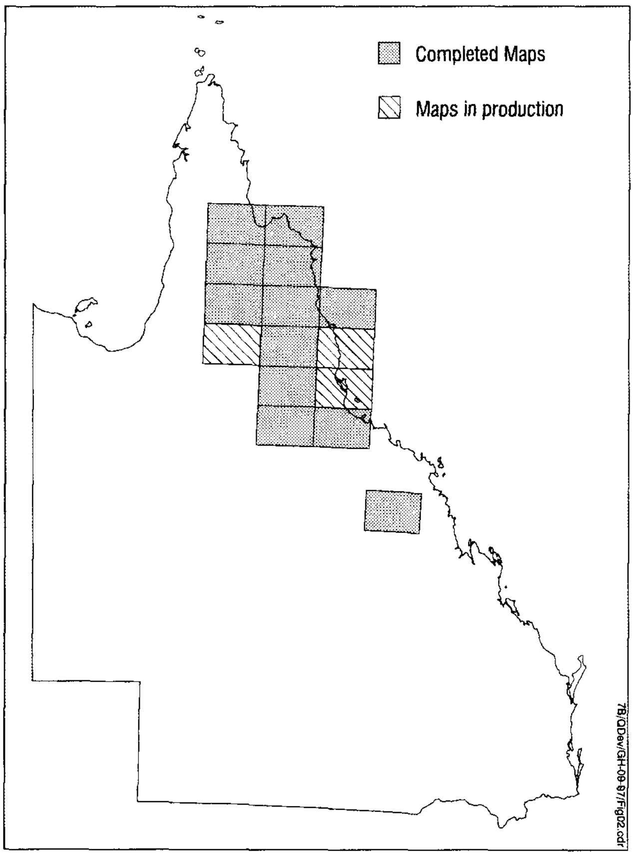


*Figure 2. New geological maps for north Queensland.*

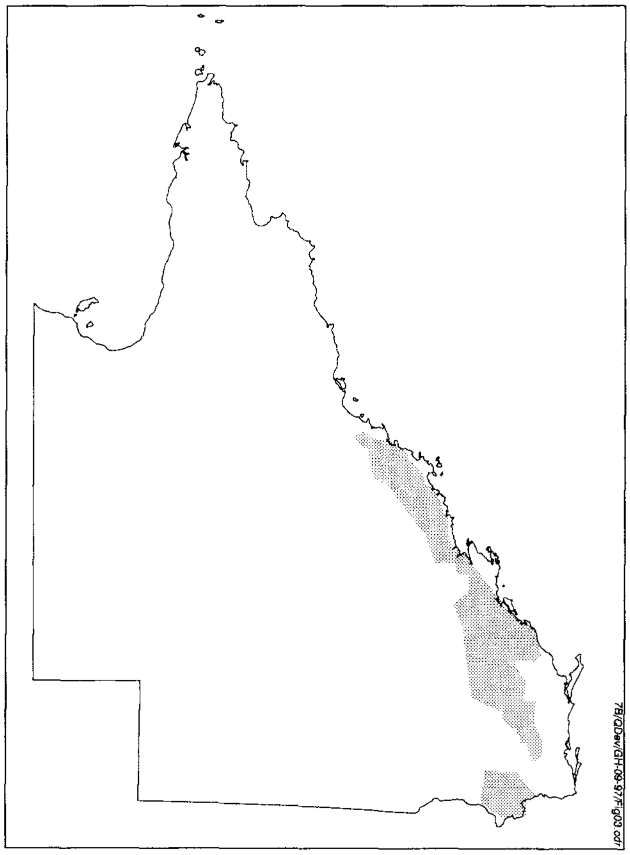

*Figure 3. AIRDATA Project area.*

Exploration (CRC LEME) in the investigation of regolith transects through the New England Fold Belt.

The Yarrol Project commenced in August 1993 and will be completed at the end of 1998. Results were presented at a seminar in March 1997, in a paper published in May 1997 (Yarrol Project Team, 1997), and at a field conference in June 1997. Gravity surveys added 5400 new stations at 2km intervals in the Yarrol and South Connors Project areas and another 448 stations were recovered from a previous oil-shale project.

The South Connors Project includes the South Connors-Auburn-Gogango Provinces between Mackay and Mundubbera. It started in January 1996. Field work in 1997 is being carried out in the southern part on the Mundubbera and Monto 1:250 000 sheets.

The Cooper-Eromanga Basins Project started in April 1996 as a joint National Geoscience Mapping Accord (NGMA) study with South Australia, the Northern Territory, New South Wales and the Commonwealth. This project will assess the hydrocarbon potential of those basins which have gained economic significance as the next major source of gas for industrial and domestic markets in southeast Queensland, following the commissioning of the gas pipeline from Ballera to Wallumbilla. Exploration opportunities in the Cooper and Eromanga Basins have been summarised by Gray & Suchocki (1996).

The Mount Isa Minerals Project is building a comprehensive database of mineral occurrences for the Mount Isa Province. During 1997–98, mineral occurrences are being compiled for the Westmoreland, Lawn Hill and Camooweal 1:250 000 sheet areas.

The AIRDATA Project manages the geophysical data acquisition funded by special budget allocations. An allocation of $3.6 million over 1994–95 and 1995–96 enabled the acquisition of 320,587 line km of magnetic and radiometric data for an area of 112,773km$^2$ over the New England Fold Belt between Ayr near Townsville and the New South Wales Border at Texas (Figure 3).

The airborne surveys took place between December 1994 and August 1996. The data sets were released in two stages in October 1995 (Area 1) and June 1996 (Area 2). Advanced sales for Area 1 were offered from June 1995.

The acquisition of more airborne geophysical data has been made possible with a second

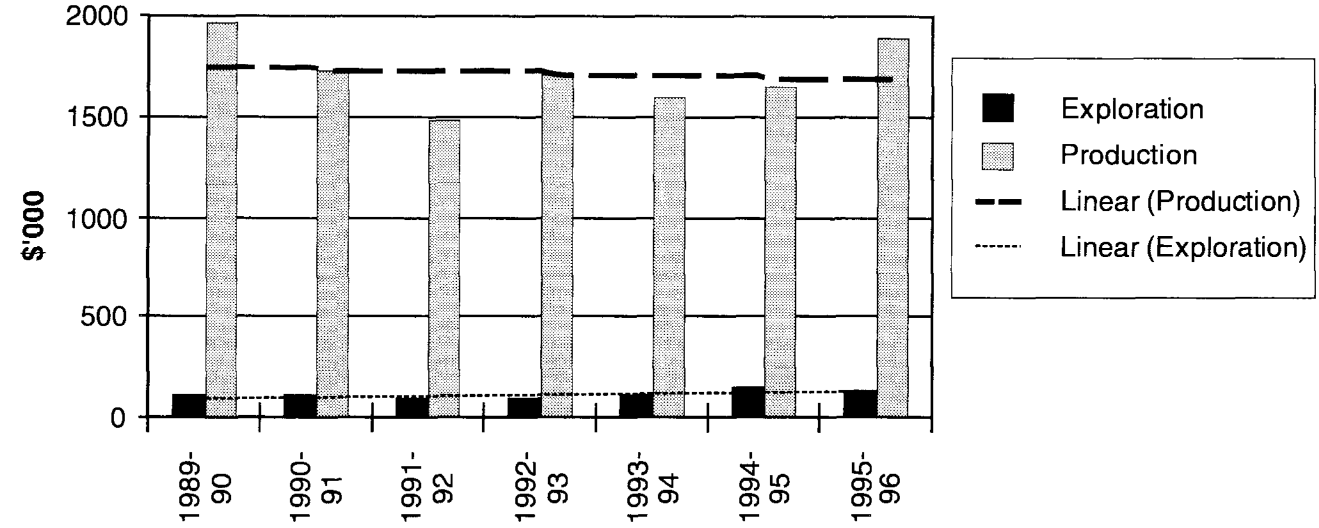


*Figure 4. Metallic mineral production values and exploration expenditures for Queensland.*

special allocation of $4.5 million over three years from 1996-97 to 1998-99. Surveys were flown over the Drummond Province and overlying Galilee Basin between April and August 1997. The data are being processed and will be released in November 1997. Tenders were called in October 1997 for a third survey over the Adavale Basin.

## IMPACT ON EXPLORATION

### General

The fact that Government investment in geoscience data and information attracts private sector investment in mineral and petroleum exploration is today undisputed. A spectacular turn-around in exploration activities in South Australia and Victoria following the South Australian Exploration Initiative (SAEI) of 1992, and the Victorian Initiative for Minerals and Petroleum (VIMP) of 1994, has been well publicised. Factors other than new government geoscience data undoubtedly contributed to those turn-arounds, for instance amended mining and planning legislation. Market factors will always have primary influence on company decision making, but where all other factors are equal, accessibility to quality modern geoscience data will make a decisive difference. This significant factor was acknowledged back in 1990 by Johnson (1990) when he reported that the availability of updated and accurate information on the geological potential of a country is a key factor in the calculations of potential resource investors.

It has been estimated that an amount equal to at least 5% of a country's mineral production value must be spent annually on mineral exploration in order to replenish mined resources and thus maintain a future royalty stream once producing mines are exhausted. Figure 4 shows the relationship between those two values, and their trends, for Queensland from 1989–90 to 1995–96. Exploration expenditure for metallic minerals (excluding coal and construction materials) as a percentage of metallic mineral production rose from 5.3% in 1989–90 to 8.6% in 1994–95, and dropped to 7.1% in 1995–96.

There is still a limited literature on the relationship between exploration activity and accessibility to geoscience information. Australian figures have been presented from the various State initiatives, for instance, the release of new airborne geophysical data at 200m line spacing in the Victorian Eastern Highlands raised mineral exploration expenditure in VIMP areas from $3 million in the June quarter of 1993 to $11 million in the June quarter of 1995 (Willocks, 1997). In the western Gawler Craton of South Australia, the release of new SAEI data caused the number of Exploration Licences to rise from 2 in 1992–93 to 55 in 1995–96, by which time 18 new companies had taken up tenures and the Challenger gold prospect was discovered (R Horn, personal communication, 1996). Examples of mineral discoveries in the circum-Pacific region based on government geoscience data, are given by Sillitoe (1995).

In Queensland, exploration activity has followed geological mapping activity from the Mount Isa Inlier (1971–75) to the Georgetown Inlier (1976–80), from north Queensland (Charters Towers and Atherton-Mossman) and the Coen Inlier (1981–86) to the Anakie Inlier and Gympie (1986–91) as shown by Day (1995).

**Table 1: Exploration decisions based on new geoscience data**

| Explorer | Decision | Reason |
|---|---|---|
| MIM Exploration P/L | Apply for 9 Exploration Permits (Minerals) in Coen Inlier in 1991 with expenditure commitments of $926,100 | Announcement of airborne geophysical surveys by Australian Geological Survey Organisation and Department of Mines and Energy |
| MIM Exploration P/L | Drill gravity anomaly in Mt Isa region in 1993 | New detailed gravity data released by Geological Survey of Queensland |
| Sons of Gwalia NL | Drill magnetic anomaly in Red River/ Georgetown area in 1994 | New airborne geophysical data released by Geological Survey of Queensland |
| Strike Mining NL | Acquire 4 Exploration Permits (Minerals), fly infill helicopter magnetics, and drill in Yarrol and Monto areas in 1996 | New airborne geophysical data released by Geological Survey of Queensland |
| Marlborough Gold Mines NL | Apply for Exploration Permits (Minerals) in the northern Connors Arch in 1997 | New airborne geophysical data released by Geological Survey of Queensland |

Day (1995) concluded that exploration activity increased whenever second-pass mapping began and remained high over time in these areas, especially in areas considered as prospective. Although increased exploration is not the final objective, a high level of exploration improves the chance of discovery (Williams & Huleatt, 1996).

North Queensland experienced a high level of mineral exploration during the Regional Geological Mapping Program from 1984 to 1992. In anticipation of the availability of new mapping data, explorers took up ground resulting in:

- an increased number of Exploration Permits for Minerals (EPM) applications in the State from just under 500 per year in 1984–85 to almost 1200 in 1987–88, and 1700 in 1995–96,
- a hydrothermal gold exploration boom in volcanic units between Mount Coolon and Ravenswood in 1987–88,
- the discovery of 2 million ounces of gold in the Lolworth-Ravenswood Province and Drummond Basin between 1984 and 1993,
- a reassessment of the prospectivity of the Broken River Province with subsequent discovery of the Amanda Bel goldfield and start of the Camel Creek gold mine, and
- the discovery of extensions to the Red Dome gold-copper deposit which extended mine life by seven years.

The commencement of NGMA mapping activities in the Cape York Pensinsula in 1991 led to an almost immediate upsurge of exploration in the Coen Inlier.

Table 1 lists some reported cases where new data releases, or their expectation, influenced exploration decisions.

The impact of new geoscience data in the North Queensland Project area is somewhat difficult to measure in retrospect, mainly because of the large area involved and the fact that data releases have been spread over more than ten years. Exploration activity which followed geological mapping in north Queensland had some success in the discovery of a number of economic mineral deposits. Since the beginning of the Regional Geological Mapping Program in 1984, which replaced the joint mapping with the Bureau of Mineral Resources, the following economic resources were discovered in north Queensland (Table 2).

## GEOMAP 2005

The examples given support the notion that access to new geoscience information leads to renewed exploration interest, especially if the new data enhance the perception of mineral prospectivity. Access to new airborne geophysical data that permit higher resolution target definition, has raised exploration activity in several areas.

The development of the Department's Mineral and Energy Resources Location and Information Network (MERLIN) has provided the tools for evaluating the impact of new data releases on exploration activity in individual

**Table 2: Deposits of economic mineral resources discovered in north Queensland since 1984**

| Mineral Deposit | Commodity | Year discovered |
|---|---|---|
| Balcooma | Base metals | 1983 to 1985 |
| Yandan | Gold | 1985 and 1987 |
| Mount Leyshon | Gold | 1986 |
| Red Dome | Gold-copper | 1986 |
| Wirralie | Gold | 1986 |
| Highway/Reward | Copper-gold | 1986 and 1988 |
| Twin Hills | Gold | 1987 |
| Camel Creek | Gold | 1987 |
| Big Rush | Gold | 1990 |
| Far Fanning | Gold | 1990 |
| Mount Wright | Gold | 1992 and 1996 |
| Nolans | Gold | 1993 |
| Mungana | Base metals-gold-silver | 1993 |
| Eldridge/Kidston | Gold | 1993 |
| Charters Towers | Gold | 1995 |
| Vera-Nancy | Gold | 1995 |
| Girofla | Copper-gold | 1996 |
| Great Britain | Gold | 1997 |

project areas. Using spatial data bases and geographic information systems (GIS), searches can now be made of the number of subblocks under EPM in each GEOMAP 2005 project area.

The number of EPMs granted each year since 1990 in the AIRDATA Project area is shown in Figure 5. It shows a sharp decline for 1995, from a high in 1993, which occurred against a general downward trend in Exploration Permits (Minerals) granted in the whole of the State. A possible explanation could be a decline in interest following the suspension of further exploration on the Develin Creek prospect discovered in 1992 by Queensland Metals Corporation. However, exploration activity increased dramatically in 1996, following the October 1995 geophysical data release, against a slight increase for the whole of the State. The number of EPMs granted in the AIRDATA area increased by 191% in 1996 (12.5% increase for Queensland).

In the Yarrol Project area, exploration activity increased after the start of the project in August 1993 and peaked late in 1994. The fall-off in subblocks held since early 1997 is attributed to the High Court Wik decision of December 1996. Following the release of information at the Yarrol seminar in March 1997 and the field conference in June, applications were received from a number of companies including Resolute Ltd and North Ltd.

In the adjacent South Connors Project area, exploration activity fluctuated similarly (Figure 7). The project started in January 1996 and began its first field season in July 1997. Exploration activity is expected to increase following the completion of field work in October 1997 and subsequent data releases.

Finally, Figure 8 shows the level of exploration activity in the Southeast Queensland Project area. There was a sharp increase in the number of subblocks held under EPM during the second half of 1996 which may be related to the expansion of the Gympie Project into the Southeast Queensland Project in July 1996.

In addition to measuring the area under exploration over time in a project area, as shown in Figures 5 to 8, Figures 9 to 11 depict the change in location of exploration tenures in the AIRDATA Project area. The light shaded areas in Figures 9 to 11 are EPMs granted in 1990 to mid-1995 (before the first release of data) and the darker areas show the status of EPMs granted from July 1995 to 1997. The figures show that the new data sets clearly changed the perception of prospective localities in the AIRDATA Project area.

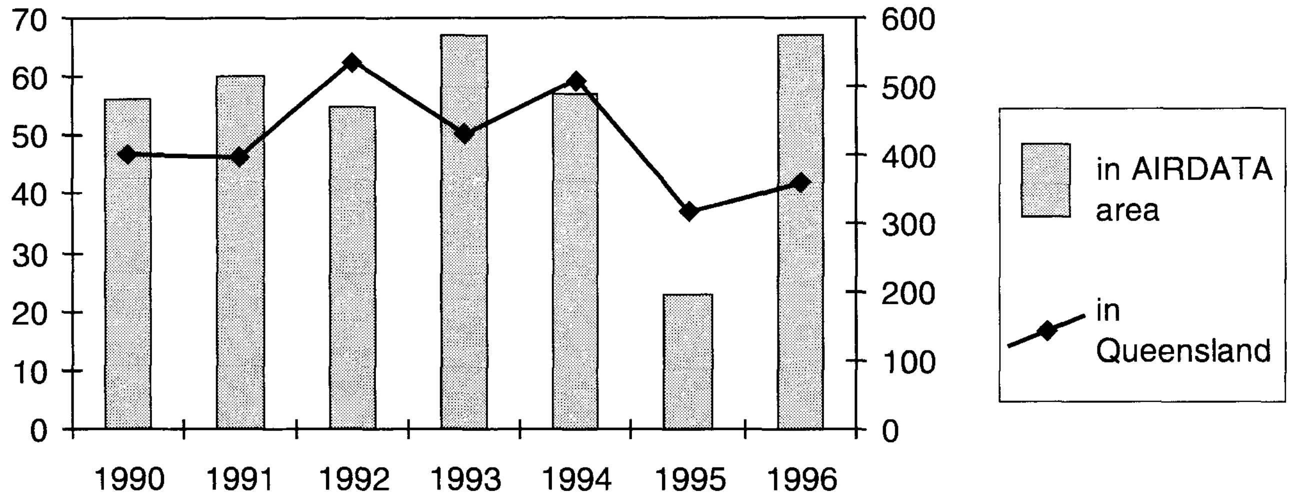


*Figure 5. Number of Exploration Permits (Minerals) granted in Queensland and in AIRDATA Project area from 1990 to 1996.*

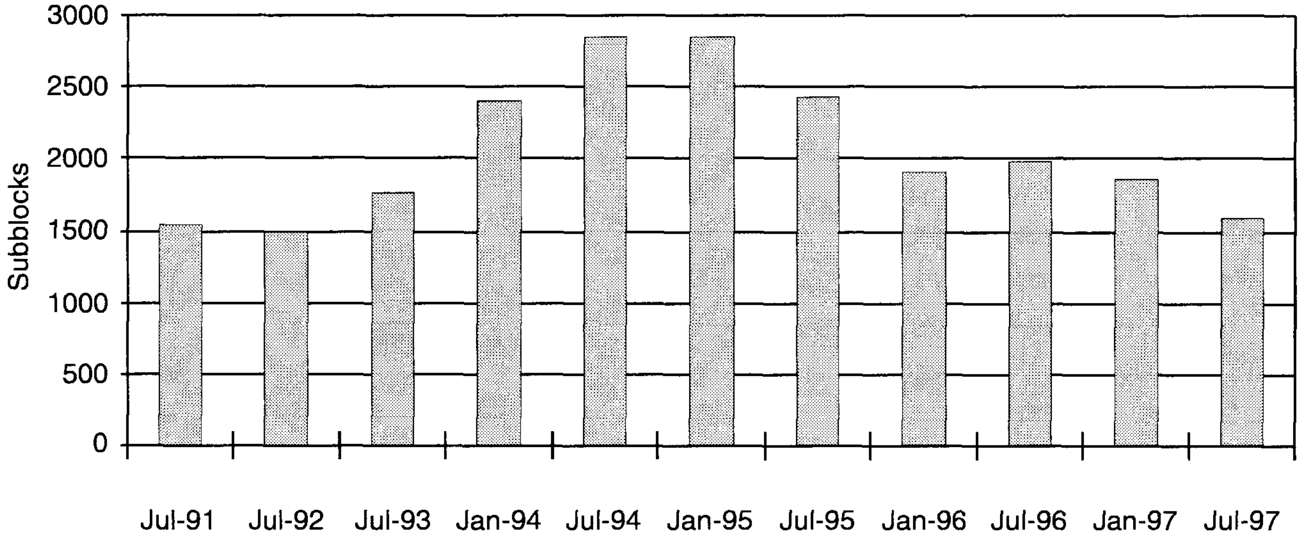


*Figure 6. Number of Exploration Permit (Minerals) subblocks held at start of month in the Yarrol Project area.*

Of exploration interest in the Mackay region (Figure 9) are the Carboniferous intrusives and Permian volcanics in the Connors Arch, and also the Devonian-Carboniferous Connors Volcanics. EPM applications have been received over the eastern, structural boundary of the Connors Arch.

Significant changes in the Rockhampton-Mundubbera region (Figure 10) are the renewed exploration interest in Permian volcanics east of the Bowen Basin and in the Permo-Triassic intrusives between the southern Gogango Overfolded Zone and the Auburn Arch.

In the Kingaroy and Texas regions, there is renewed exploration interest in the Yarraman Block and at the western and eastern edge of the Texas Block following the release of the airborne geophysical data.

## CONCLUSION

The Geological Survey of Queensland is committed to the successful completion of the GEOMAP 2005 Program. This entails:

1. Updating the accuracy of map data for potentially mineralised regions
2. Assessing the hydrocarbon generation potential of major basins
3. Maintaining geological maps up to date under the control of province custodians
4. Evaluating mineral resources of potentially mineralised regions.

Although the exploration industry traditionally maintained that governments should generate new data sets for the private sector to interpret, Geological Surveys have begun to realise that it is insufficient to only remap and release new data. With the globalisation of the mineral industry, governments now also need

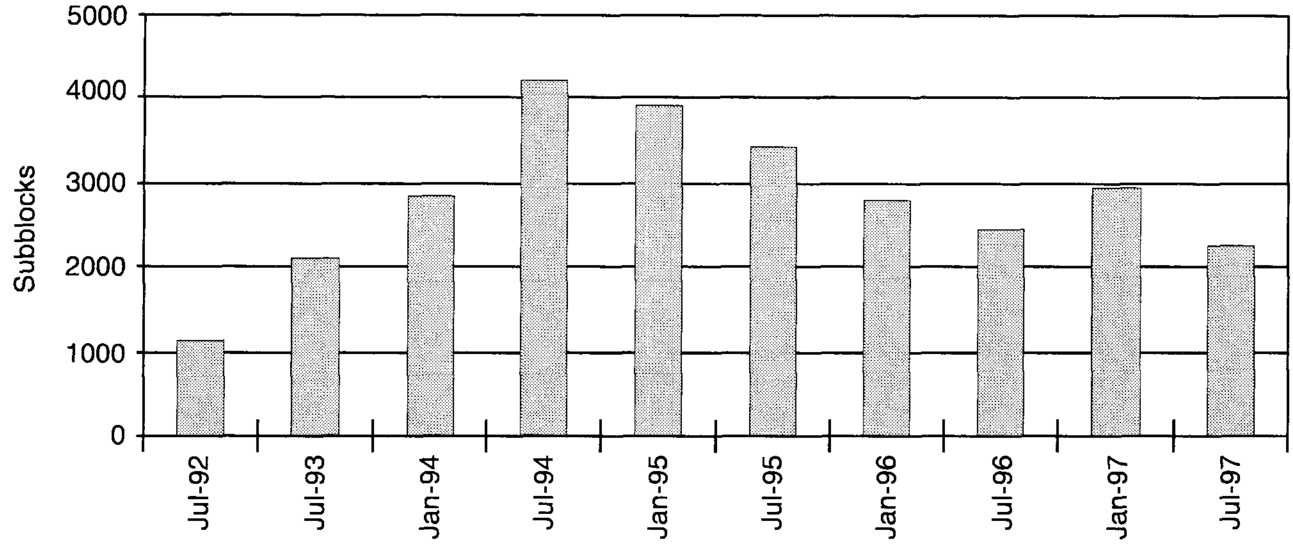


*Figure 7. Number of Exploration Permit (Minerals) subblocks held at start of month in the South Connors Project area.*

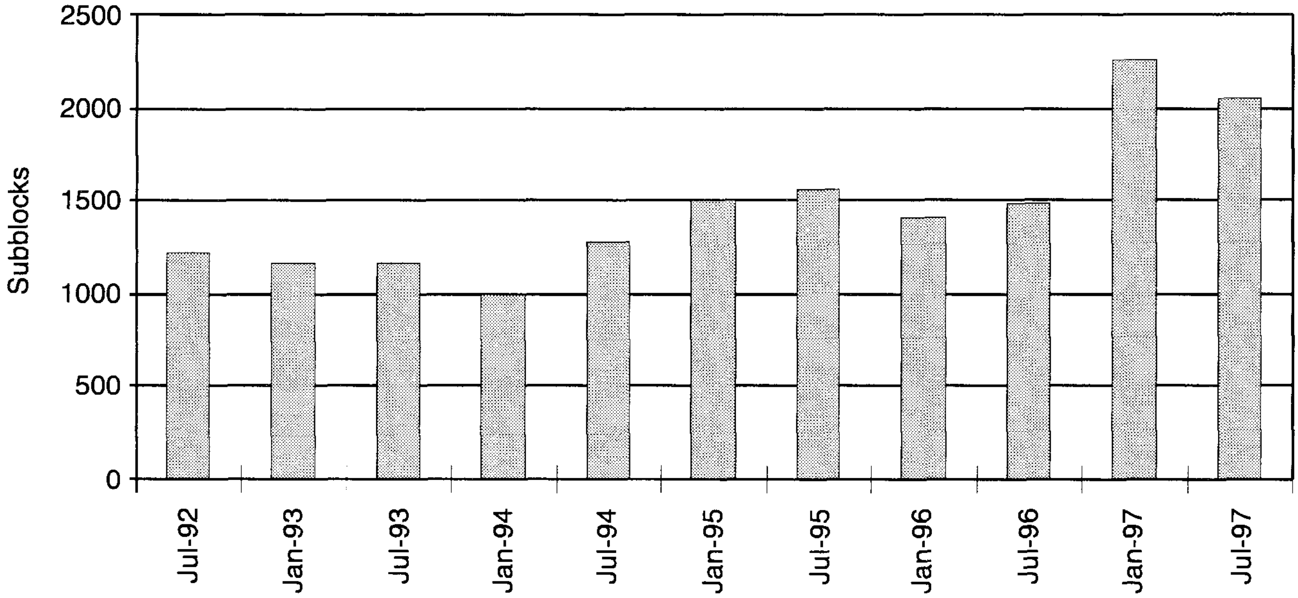


*Figure 8. Number of Exploration Permit (Minerals) subblocks held at start of month in the Southeast Queensland Project area.*

to promote the prospectivity of their territories. Promotion of one's mineral potential, first needs an audit of one's resources. In order to evaluate mineral resource potential, Geological Surveys require to develop concepts and ore genesis models. These activities will gain more importance in the future and will diversify activities in addition to data gathering and regional mapping.

Queensland is strategically located in close proximity to consumers in Asia, with high resource potential in a wide range of geological setttings, supportive governments relying on the minerals sector for economic growth, modern mining legislation, available energy resources, and mining infrastructure. All of these advantages offer opportunities for government policies and strategies to assist the private sector to generate sustainable employment and wealth for Queenslanders. The GEOMAP 2005 Program is a vehicle which fits neatly into this framework to identify the State's undiscovered resources which will sustain continuing economic development.

In conclusion, it is today undisputed that accessibility to quality geoscience data sets influences exploration decisions. Recent examples from other Australian States have demonstrated that the prospectivity of greenfield areas can be enhanced with new data sets. The performance for Queensland was less spectacular, partly because most, if not all, pre-Mesozoic non-basinal geological provinces have been prospected and explored at some time in the past. This performance is also partly the result of relatively smaller budget allocations in special initiatives which

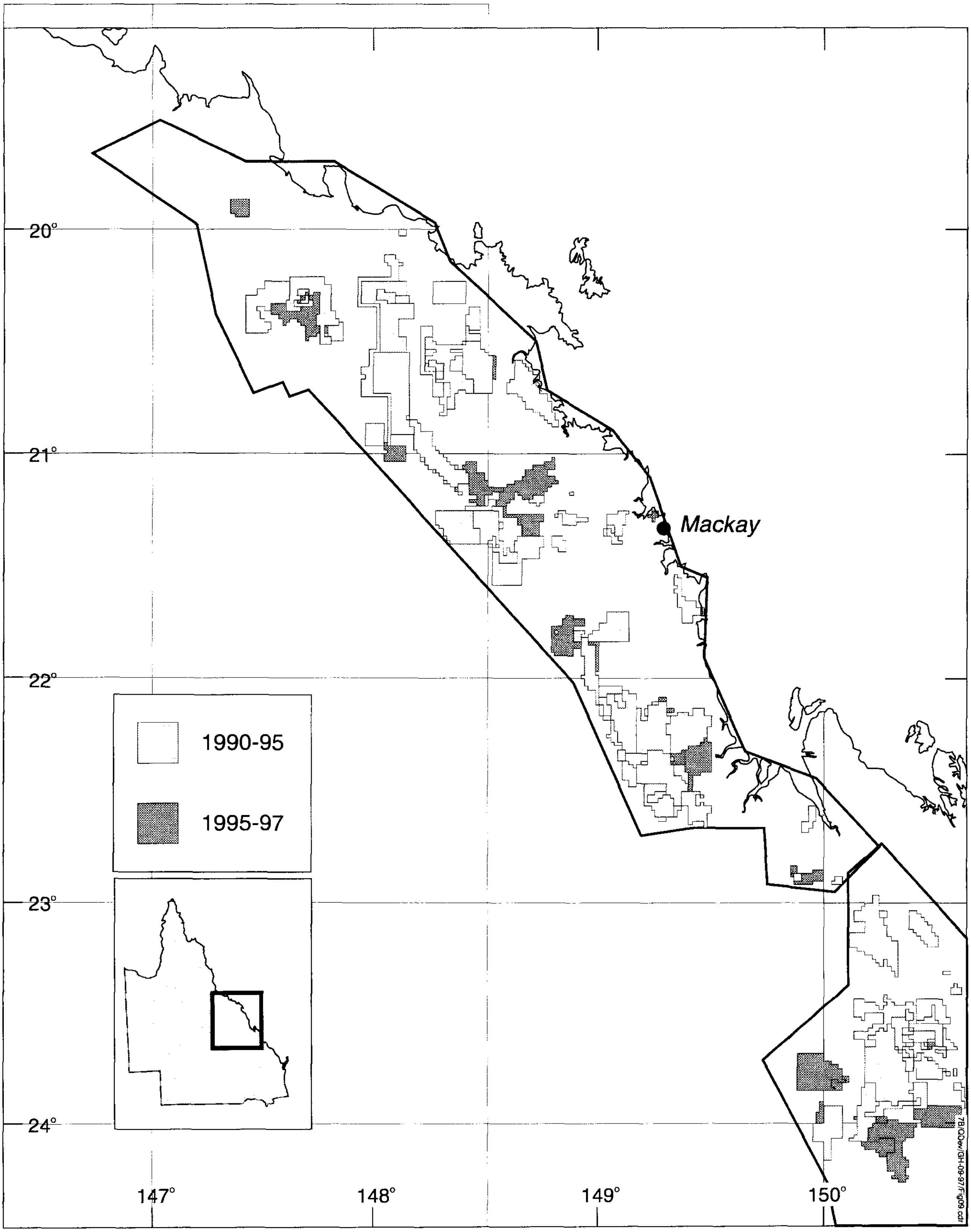


*Figure 9. Status of EPMs in the Mackay region of the AIRDATA Project area (Area 2, data released June 1996) from 1990-95 (light grey) to 1995-97 (dark grey).*

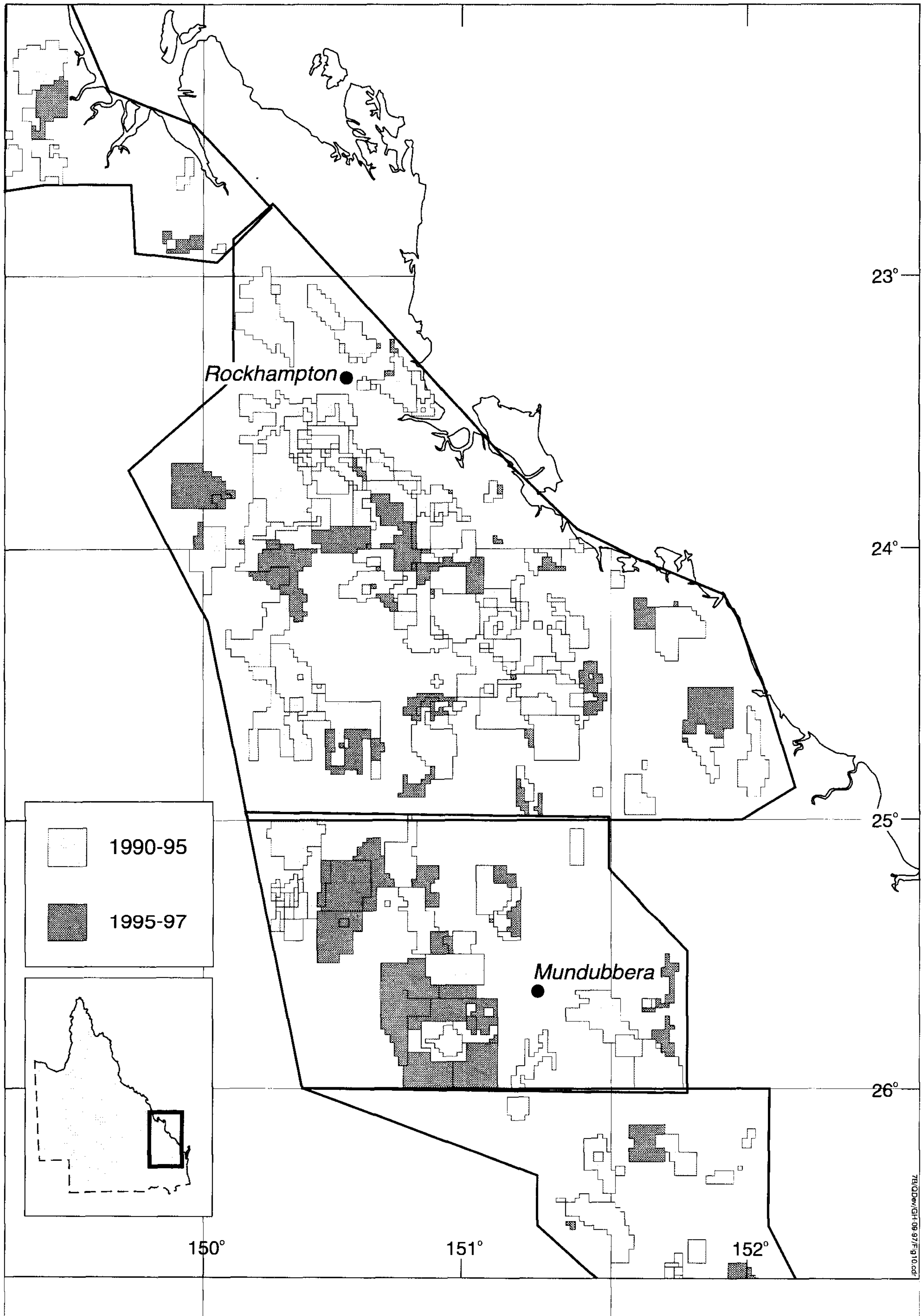


*Figure 10. Status of EPMs in the Rockhampton-Mundubbera region of the AIRDATA Project area (Area 1, data released October 1995) from 1990-95 (light grey) to 1995-97 (dark grey).*

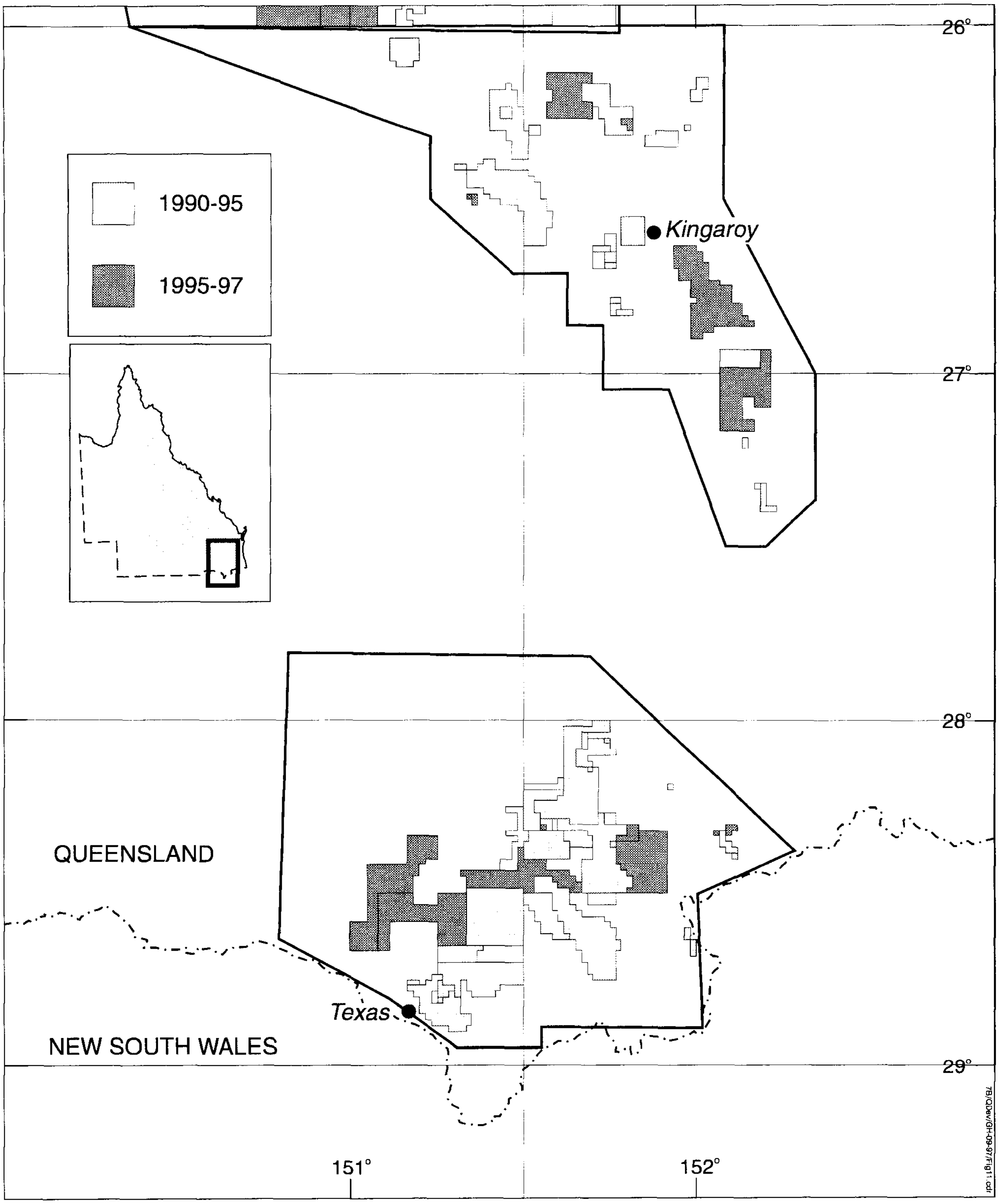


*Figure 11: Status of EPMs in the Kingaroy and Texas regions of the AIRDATA Project area (Area 2, data released June 1996) from 1990-95 (light grey) to 1995-97 (dark grey).*

have moderated the amount of new data releases and consequent jumps in exploration activity. Nevertheless, the GEOMAP 2005 Program has had a demonstrable impact on mineral exploration activity in Queensland. This impact is most obvious in the AIRDATA Project area where the number of EPMs granted per year has almost tripled after the first release of high-resolution geophysical data.

## ACKNOWLEDGEMENTS

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## REFERENCES

DAY, R.W., 1995: GEOMAP 2005 program, the key to unlocking Queensland's mineral wealth. *Queensland Government Mining Journal*, **96**, 1126, 20–31.

GRAY, A.R.G & SUCHOCKI, V., 1996: Department of Mines and Energy southeast Queensland petroleum land release 1996. *Queensland Oil & Gas*, April 1996, 11–18.

JOHNSON, C.J., 1990: Ranking countries for exploration. *Mining Review*, July 1990.

SILLITOE, R.H., 1995: Exploration and discovery of base- and precious-metal deposits in the circum-pacific region during the last 25 years. *Resource Geology Special Issue*, 19.

WILLIAMS, N. & HULEATT, M., 1996: The importance of regional geological mapping in minerals exploration. *In*: ABARE 1996, *OUTLOOK 1996: Proceedings of the National Agricultural and Resources Outlook Conference*, **3**.

WILLOCKS, A.J., 1997: Regional surveys in Victoria, experiences and lessons. *Exploration Geophysics*, **28**, 307–312.

YARROL PROJECT TEAM, 1997: New insights into the geology of the northern New England Orogen in the Rockhampton-Monto region, central coastal Queensland: Progress report on the Yarrol Project. *Queensland Government Mining Journal*, **98**, 1146, 11–26.

**Reference for this paper:**
**HOFMANN, G.W., 1997: Information infrastructure and mineral prospectivity — the impact of the GEOMAP 2005 Program. *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 27-38.**

*Cec Murray and the Yarrol Project Team**

Queensland Department of Mines and Energy

# The Yarrol Project — increasing the prospectivity of the New England Orogen in the Rockhampton-Monto Region, central coastal Queensland

## SUMMARY

The Yarrol Project Team re-mapped the region between Rockhampton and Monto in the northern New England Orogen with the aim of attracting mineral exploration by increasing prospectivity and reducing risk. Mapping was greatly assisted by airborne radiometric and magnetic data acquired as part of the Department's AIRDATA Project, which clearly outlined the boundaries of many geological units and enabled specific targeting of problem areas. The main phase of fieldwork was carried out from September 1995 to June 1997.

Major changes have been made to the 1st edition 1:250 000 scale geological maps dating from the 1960s. The existing stratigraphic nomenclature was derived largely from detailed studies in restricted areas, and was difficult to apply on a regional scale. Several new stratigraphic units which can be recognised over the entire project area have been erected to rationalise nomenclature. Refinement of upper Silurian to Lower Carboniferous biostratigraphy by conodont micropalaeontology has been crucial in establishing precise age control for correlation. Significant results from the mapping program include: the recovery of Ordovician conodonts from rocks previously included in the Devonian Calliope beds; recognition that large areas of rocks previously regarded as Middle Devonian and older are of Late Devonian and possibly even Early Carboniferous age; recognition of equivalents of the host rocks of the Mount Morgan gold-copper mine in the Dee Range and in previously undivided Silurian-Devonian strata of the Craigilee beds; division of the former Kroombit beds into separate Middle Devonian and Upper Devonian sequences; refinement of boundaries between mid-Carboniferous–Lower Permian strata and older sequences based on contrasting radiometric responses; subdivision of the Permian Berserker beds, which host the Mount Chalmers Kuroko-style gold-copper deposit, and confirmation of a Late Permian age for sediments in the upper part of this unit; sub-division of Permo-Triassic intrusives into discrete plutons of differing composition and geophysical response, and discovery of a possible breccia pipe in one intrusion; identification of a possible caldera structure associated with rhyolite domes and flows of Triassic volcanics in the northwestern area of the Kroombit Tops; more precise distinction between Triassic and Cretaceous volcanics in the Stanwell to Westwood area; and correlation of a linear belt of gold mineralisation in the Raglan area with a fault system identified from geophysical data. Field

* RM Barker, PR Blake, PE Burrows, SBS Crouch, BG Fordham, MA Hayward, MD Livingstone, DA Morwood, SM Parfrey, ADC Robertson & GA Simpson

checking has determined the style and precise locations of about 700 mineral occurrences, and more than 5000 new gravity readings were taken in and adjacent to the Yarrol Project area to upgrade the existing 11km grid database.

The revised and updated geoscientific data will enable better definition of potential host rocks for different mineral deposit types and in some cases has provided specific targets for mineral exploration programs, thereby reducing the risk involved.

## INTRODUCTION

The Yarrol Project is part of the Department of Mines and Energy's GEOMAP 2005 program which is upgrading the geoscientific knowledge base of prospective basement terranes and basins in Queensland. The project extends from near Marlborough north-west of Rockhampton almost to Monto, and is centred on Mount Morgan (Figure 1). It was an obvious area to commence re-mapping of the northern New England Orogen, because it contains one world class ore deposit (Mount Morgan), one medium sized deposit (Mount Chalmers), and one significant recent discovery (Develin Creek).

The aim of the Yarrol Project is to attract mineral exploration by increasing the region's prospectivity and reducing risk. Re-mapping has been greatly assisted by the use of airborne magnetic and radiometric data acquired under the DME's AIRDATA Project.

The Yarrol Project began in 1993 with a review of available information, data requirements, and mapping priorities (Murray, 1994). Following preliminary literature research, mainly on the results of company exploration (Blake & others, 1995, 1996; Hayward & others, 1995; Osborne & others, 1997), the main phase of fieldwork was carried out from September 1995 to June 1997. In addition to geological mapping, almost 700 mineral occurrences have been accurately located, and basic data gathered on mineralisation styles and structural controls. A program of gravity mapping has taken more than 5000 new readings to upgrade the existing 11km grid database. Reports detailing progress of the Yarrol Project have been published by Withnall & others (1995) and the Yarrol Project Team (1997). In addition, information on project results has been provided to clients by means of a half day seminar in March 1997, and a 6 day safari style field excursion in June 1997. The project is scheduled for completion in 1998.

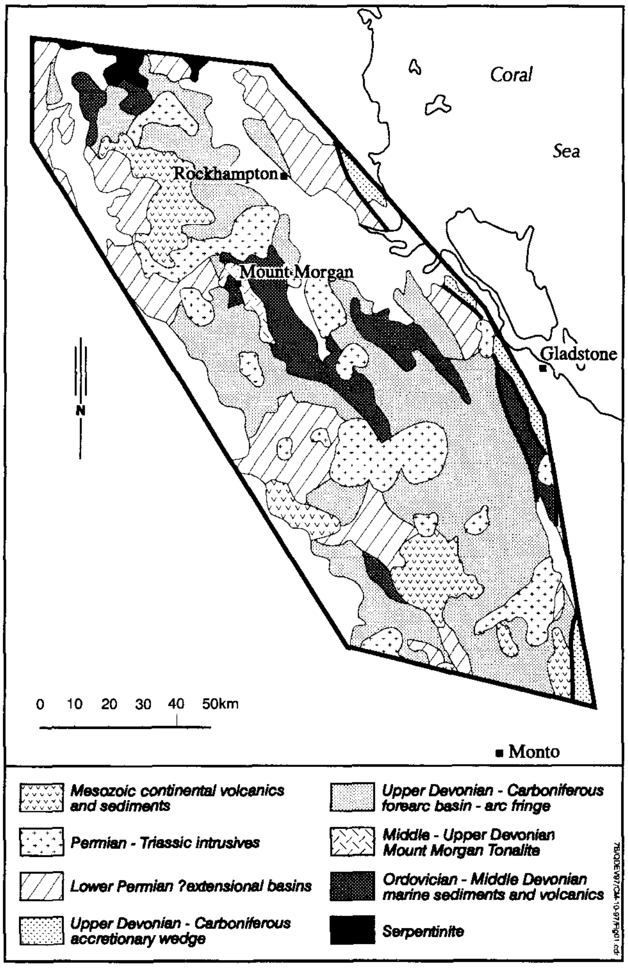


*Figure 1. Simplified pre-Cenozoic geology of the Yarrol Project area.*

## GEOLOGY

### Introduction

The oldest rocks in the project area occur as several separate outcrop areas which have been grouped as the Calliope Volcanic Arc (Day & others, 1978) or the Calliope Volcanic Assemblage (Morand, 1993a). They consist of marine volcaniclastic sediments, coralline limestones, and some primary volcanics. These rocks were considered to range in age from late Silurian to Middle Devonian, but are now known to include strata as old as Early Ordovician. Marsden (1972) interpreted them as an oceanic island arc sequence, consistent with an origin as an exotic terrane or terranes, whereas Henderson (1980) favoured a convergent continental margin setting. They include the rocks which host the Mount Morgan gold-copper deposit, so an understanding of their stratigraphy and tectonic setting is crucial for exploration.

A tectonic framework of the region has been established for Late Devonian-Carboniferous time, when it appears to have been the site of a convergent continental margin above a west-dipping subduction zone (Murray, 1975; Day & others, 1978). Three parallel north-north-west trending belts of contrasting stratigraphic and structural style have been recognised, comprising an accretionary wedge in the east, a forearc basin in the centre, and a volcanic arc in the west (Murray & others, 1987). The forearc basin occupies most of the Yarrol Project area (Figure 1), and is separated from the accretionary wedge by a major fault, the Yarrol Fault System, marked by serpentinite lenses. The forearc basin sequence consists of volcaniclastic sediments deposited on a marine shelf which shallowed to the west and with time, some primary volcanics increasing in proportion towards the western arc, and persistent oolitic limestone beds. These rocks overlie the Middle Devonian and older rocks unconformably (Kirkegaard & others, 1970; Leitch & others, 1992). They are only sparsely mineralised except in the vicinity of later intrusives.

Overlying the forearc basin strata are scattered outcrops of mafic to felsic volcanics and associated clastic sediments of Early Permian age. These include both marine and continental deposits, and have recently been interpreted as the fill of a series of extensional basins which developed at the same time as the Bowen Basin to the west (Fielding & others, in press). This interpretation is consistent with the fact that many of the Permian outcrops overlie or are in faulted contact with rocks of Early Carboniferous or older age, implying removal or non-deposition of a substantial part of the stratigraphic section.

However, subsidence rates calculated for Lower Permian deposits are much too low to have been generated by significant amounts of crustal extension, and continuous Carboniferous to Lower Permian marine sequences occur locally in the eastern part of the forearc basin. Therefore, an extensional basin environment is considered to be unlikely for all Lower Permian rocks in the Yarrol Project area. Some Lower Permian rocks are prospective for volcanic hosted massive sulphide (VHMS) style mineralisation. Mount Chalmers in the Berserker beds is a classic Kuroko-type deposit, and the Develin Creek discovery has demonstrated that the Rookwood Volcanics are also a target for VHMS mineralisation.

Mid-Carboniferous to Lower Permian sediments give a high radiometric response compared with sequences of Early Carboniferous and older ages, reflecting a much greater content of granitic and felsic volcanic detritus. This difference may have been related at least in part to a significant unroofing event, rather than simply to a change in igneous rock composition.

The rocks of the New England Orogen were deformed by the Late Permian Hunter-Bowen Orogeny. Recent studies have generated two significant hypotheses. The first is that the Hunter-Bowen Orogeny was the only cleavage-forming folding event in the Yarrol Project area; a previous suggestion that cleavage in Middle Devonian and older sequences was produced by Middle to Late Devonian deformation has been disputed by Morand (1993b). The second is that the Hunter-Bowen Orogeny was characterised by thin-skinned west-north-west thrusting exemplified by the Gogango Overfolded Zone along the western edge of the Yarrol Project area (Fergusson, 1991; Fielding & others, 1994; Holcombe & others, in press).

If this thrust model applies throughout the Yarrol Project area, the thrust sheets must be considerably thicker than in the Gogango Overfolded Zone, because of the existence of relatively wide stratigraphically continuous successions in many places. Another recent suggestion is that the thrust belt associated with the Hunter-Bowen Orogeny moved progressively westward from Late Permian to Middle Triassic time, controlling sedimentation in the eastern part of the Bowen Basin (Fergusson, 1991; Holcombe & others, in press).

However, suggestions that major thrusting events continued into the Middle Triassic in the Yarrol Project area are difficult to reconcile with the fact that Upper Permian to Lower Triassic granitic plutons show no evidence of deformation or displacement, as indicated by their coincidence with gravity lows (Murray & others, 1989). In addition, it would have been easier to emplace these plutons into an extensional rather than a contractional environment.

Post-tectonic Upper Permian and Triassic intrusives form relatively small, discrete plutons and range from layered gabbro to granite. Granodiorite is probably the most common composition. Gust & others (1993) proposed that active subduction produced the voluminous Late Permian and Early Triassic plutonism in the northern New England Orogen, and was replaced by an extensional phase marked by bimodal and alkalic magmatism in the Late Triassic. Most of the ore deposits in the Project area are related spatially and genetically to these intrusives.

Mesozoic volcanics form relatively undeformed, flat-lying sequences which unconformably overlie the older rocks. The largest outcrops of Triassic volcanics are in the Kroombit Tops area, where they are overlain by Jurassic Precipice Sandstone, and west of Many Peaks. All these volcanics have been grouped in a single unit, the Muncon Volcanics. However, compositions range from basalt to rhyolite, and it is possible that the unit includes both Middle Triassic and Upper Triassic sequences. The Native Cat Andesite west of Rockhampton is considered to be of Triassic age, and volcanics also occur at the base of the Upper Triassic Callide Coal Measures. The tectonic setting of the Triassic volcanics must be similar to that of the Triassic plutonic rocks, some of which may be comagmatic. Upper Cretaceous basalts and rhyolites crop out over a large area in the Mount Salmon-Westwood region, and represent a typical within-plate volcanic suite.

Extension related to opening of the Coral Sea formed a series of deep, narrow half grabens in central coastal Queensland in the early Cenozoic. These basins contain enormous oil shale resources. The Casuarina and Yaamba Basins lie within the Yarrol Project area, and the Biloela Basin, Nagoorin Graben and The Narrows Graben are marginal to it. Mid-Cenozoic basalt plugs and small outcrops of basalt flows are widespread over the southern part of the Project area. The main area of alluvium is along the Fitzroy River and its tributaries.

## Lower Ordovician–Middle Devonian stratigraphy

Because rocks of this age are hosts to the Mount Morgan orebody, and therefore a prime target for volcanic hosted massive sulphide (VHMS) deposits, considerable effort was devoted to resolution of their stratigraphy and tectonic setting. Although Middle Devonian and older strata have previously been grouped as a single tectonic unit (Calliope Volcanic Arc of Day & others, 1978, or Calliope Volcanic Assemblage of Morand, 1993a), detailed re-mapping and conodont sampling by the Yarrol Project has demonstrated significant differences between sequences in individual outcrop areas. In most cases, firm lithological and age correlations cannot be established to indicate a shared stratigraphy and tectonic setting for these rocks. The sedimentary rocks are interpreted as submarine deposits. Episodic but widespread submarine volcanism is inferred from the close association of volcanic and marine sedimentary rocks and the presence of flow breccias and peperites.

The largest area of Middle Devonian rocks forms a belt trending south-east from Mount Morgan (Figure 1). These rocks have been defined as the **Capella Creek Group** (Yarrol Project Team, 1997). Most of the current knowledge of this unit comes from detailed company mapping over the last 25 years. The Yarrol Project team, with additional control from biostratigraphy, has generalised the detailed company investigations to define regionally mappable rock units.

Three constituent formations can now be defined, consisting of: a lower unit of siltstone and minor sandstone; a middle unit dominated by sandstone sourced from rhyolitic to dacitic volcanics, accompanied by silicified rhyolite, chert, jasper, peperite, and minor andesitic breccia and limestone; and an upper unit of sandstone, conglomerate, breccia, and minor limestone. In this upper unit, the clastic rocks are mainly sourced from andesitic and basaltic volcanics, with an increasing felsic component towards the top. The middle, more siliceous unit includes the host rocks of the Mount Morgan orebody, and can be traced along the Dee Range, where small stratabound base metal sulphide deposits occur. The Capella Creek Group was folded and intruded by the Mount Morgan Tonalite before deposition of the overlying Upper Devonian strata.

The Silurian to Devonian **Craigilee beds** about 50km west-north-west of Rockhampton (Figure 1) occur in two discrete outcrop areas, the Morinish area in the east and the Mount Cassidy area in the west. The Craigilee beds consist of volcanic rocks ranging from andesite to dacite, volcaniclastic breccia, sandstone, siltstone, mudstone, minor limestone and polymictic conglomerate. They have been subdivided into a lower felsic series of sandstones, siltstones, granular conglomerates, limestone, and minor volcanic rocks; a middle part dominated by porphyritic andesite to dacite flows and local flow breccias; and an upper part comprising sandstone, breccia, siltstone and mudstone, and minor conglomerate and limestone. Sandstone and breccia in the upper part were derived mainly from intermediate volcanics, with a dominantly felsic source towards the top. Although the sequence extends lower than the known Capella Creek Group, the base of which is not preserved, the upper parts of the

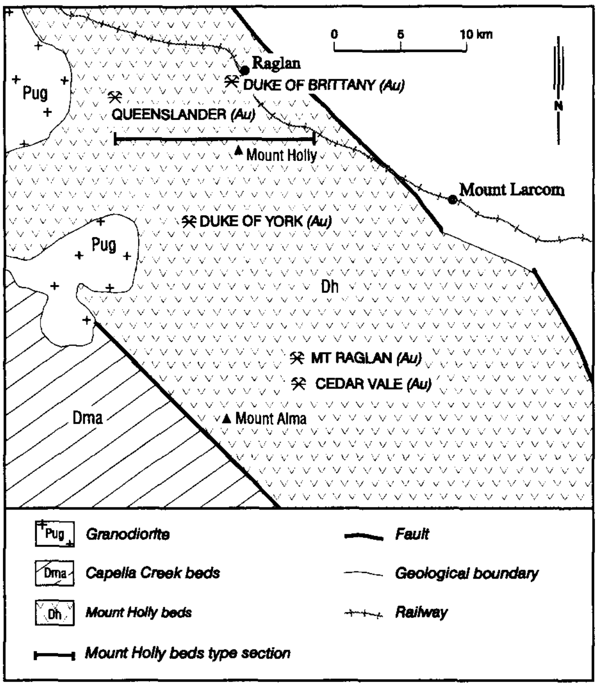


*Figure 2. Geology of the Raglan area as shown on the 1st edition Rockhampton 1:250 000 geological map.*

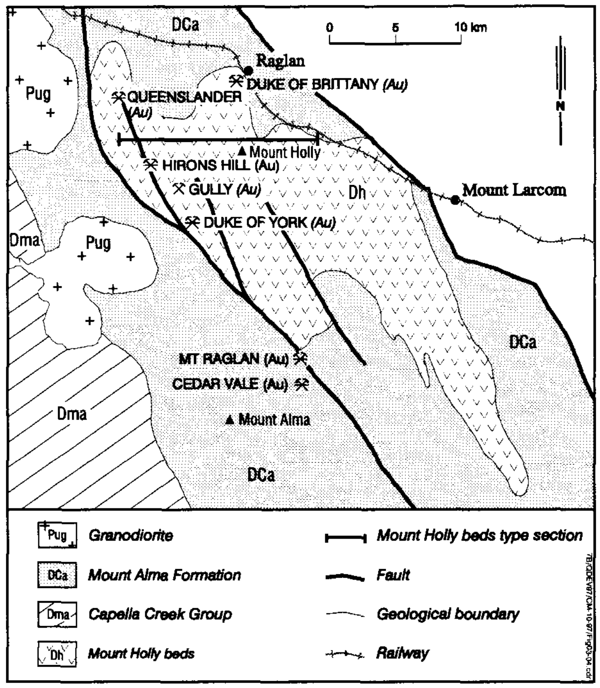


*Figure 3. Revised geology of the Raglan area, showing the restricted outcrop area of the Mount Holly beds.*

Craigilee beds can be correlated by age and rock types with the Capella Creek Group, and therefore may contain equivalents of the host rocks of the Mount Morgan gold-copper deposit.

The **Marble Waterhole beds**, which together with the Lochenbar beds were previously included in the Kroombit beds (Yarrol Project Team, 1997), may also be correlatives of the upper, felsic part of the upper unit of the Capella Creek Group. The Marble Waterhole beds, 75km south-west of Gladstone, contain large areas of fossiliferous limestone, but also include quartz-bearing feldspatholithic sandstone, granule to pebble dacitic breccia/conglomerate, and dacitic to rhyodacitic tuff/ignimbrite. The limestones contain abundant corals which, combined with conodont work, have returned a very precise age in the early to middle Givetian (late Middle Devonian). The Allen Creek or Mount Kroombit copper mine is hosted by the Marble Waterhole beds.

The **Mount Holly beds**, located midway between Mount Morgan and Gladstone (Figure 1), represent a stratigraphic assemblage without any clear relationship to the Capella Creek Group, Craigilee beds or Marble Waterhole beds. They were mapped by Kirkegaard & others (1970) as a fault bounded belt of rocks extending south-south-east from Bajool to the southern boundary of the Rockhampton 1:250 000 Sheet area (Figure 2). Mapping by the Yarrol Project has greatly reduced the distribution of this unit, based largely on airborne radiometric data. The re-defined Mount Holly beds, which include the nominated type section (Figure 3) have a comparatively high content of radiogenic elements, particularly potassium. The surrounding rocks, which give a much weaker radiometric response, are now mapped as a separate and younger Upper Devonian sequence, the Mount Alma Formation. Numerous limestone lenses are aligned along the contact of the Mount Holly beds and Mount Alma Formation, just within the latter unit. The revised Mount Holly beds consist mainly of coarse grained sandstones and conglomerates sourced from rhyolitic volcanics, accompanied by minor limestone and rare rhyolitic and dacitic lavas. Some of the sedimentary rocks have a tuffaceous appearance, but regional metamorphism has destroyed the microscopic features necessary to prove whether they were pyroclastic volcanics. The potassic nature of the volcanics and volcaniclastic sediments indicated by the airborne radiometric survey contrasts markedly with the chemistry of volcanics in the Capella Creek Group to the west, which are notably potash poor. Bedding is usually poorly developed, and the rocks commonly display a well developed cleavage which dips steeply to sub-vertically to the east-north-east. McKellar & others (1971) identified both upper Silurian–Lower Devonian and upper Lower–lower Middle Devonian corals from the Mount Holly beds, and Druce (1971) recovered Gedinnian (lower Lower Devonian) conodonts from all but one site. Recent conodont sampling has confirmed levels about the Silurian–Devonian and Lower–Middle Devonian boundaries. The western contact between the Mount Holly beds and Mount Alma Formation is in part a north-west trending fault or shear zone with more northerly trending splays. Several old workings and one current gold mining operation are located along these structures (Figure 3).

The **Calliope beds**, which form a north-north-west trending belt south of Gladstone (Figure 1), constitute a stratigraphic assemblage which does not appear to be related to any other pre-Upper Devonian sequence. They comprise breccia, conglomerate and sandstone sourced dominantly from andesitic volcanics, together with locally extensive limestone and rare siltstone and andesitic lava. Areally restricted sediments derived from dacitic to rhyolitic volcanics are probably part of a younger Upper Devonian unit. The Calliope beds form a geophysically distinctive north-north-west trending belt with very low radiometric and strong magnetic responses. This belt, however, also includes part of the younger Upper Devonian unit, and appears to represent a zone of mafic intrusives. Some of the finer units within the Calliope beds display a cleavage which dips steeply to subvertically towards the east-north-east, sub-parallel to the cleavage in the Mount Holly beds and the Mount Alma Formation. Although they have even recently (Morand, 1993a) been considered higher than the Mount Holly beds, most dates are, as yet, confined to the early Early Devonian.

A significant finding of the Yarrol Project is the discovery of Ordovician conodonts from limestones in the Santa Glen area 35km south of Gladstone. Mid-Ordovician conodonts have been recovered from a limestone bed in a thin sequence roughly conformable with the surrounding Devonian sediments. In addition, a conglomerate within the Devonian sequence contains limestone clasts of both Late Ordovician and Devonian age. The location of the Ordovician rocks, near the Yarrol Fault System, is similar to that of Cambrian and Ordovician strata in the Tamworth area of the southern New England Orogen.

## Upper Devonian–Carboniferous forearc basin stratigraphy

Upper Devonian to Carboniferous rocks are broadly similar throughout the column: they are dominantly marine volcaniclastic sediments with a relatively small proportion of primary volcanics. As a result, their stratigraphic subdivision relied heavily on biostratigraphy. The first-pass regional mapping program (Malone & others, 1969; Kirkegaard & others, 1970; Dear & others, 1971) adopted stratigraphic schemes based on detailed mapping and fossil collecting over relatively small university thesis study areas, and extended these over the whole region. These schemes were first established in the Mount Morgan area (Maxwell, 1953, 1954), the Neerkol area (Fleming, 1960, 1967), the Yarrol-Cannindah area (Maxwell, 1964; McKellar, 1967), and the Cania area (Dear, 1968). One problem with this approach is that while these subdivisions may be perfectly valid for the small areas where they were originally defined, they cannot be recognised everywhere outside those areas. Another problem is that similar stratigraphic units have been given different names depending on their proximity to particular thesis areas. As a result, it has been necessary to revise much of the Palaeozoic stratigraphic nomenclature in the Yarrol Project area so that units can be recognised on a regional scale.

The Upper Devonian–Carboniferous forearc basin sequence appears to be separated from all older stratigraphic assemblages by a regional hiatus. The unconformity between the Capella Creek Group and the former Dee Volcanics in the Mount Morgan area (Kirkegaard & others, 1970; Leitch & others, 1992) is now known to be confined to a very short interval in the upper Givetian (very upper Middle Devonian). This is consistent with age evidence from other areas, where, however, definite stratigraphic contacts are somewhat problematic or are not exposed.

The Upper Devonian–Carboniferous forearc basin sequence forms a more or less continuous belt extending throughout the project area and beyond to the north and south (Figure 1). In marked contrast to previous work, the present project has found the mappable units in this stratigraphic assemblage to consist of largely lateral equivalents in the Upper Devonian (Lochenbar beds, Mount Hoopbound Formation, Balaclava Formation, Mount Alma Formation, Three Moon Conglomerate) overlain by a single Lower Carboniferous unit, the Rockhampton Group. Any one section through this stratigraphic assemblage will typically consist of a sequence of only two or three of these units. Another new finding is that the base of the prominent oolite interval which characterises the Rockhampton Group appears to occur at a similar level throughout the project area and near the base, not the top, of the Tournaisian (lower Lower Carboniferous).

The Capella Creek Group may have formed a topographic high from the Late Devonian to the earliest Carboniferous, as formations of the same age on either side of it are distinctly different. Upper Devonian formations to the west of the Capella Creek Group (Mount Hoopbound and Balaclava Formations) are usually coarse grained and have sedimentary structures suggesting a shallow marine environment, whereas the Upper Devonian Mount Alma Formation to the east is dominated by fine grained sediments and possesses sedimentary features which suggest a more distal and deeper marine environment. This distinction is emphasised by structural differences between the western more proximal units, including the Lochenbar beds and Three Moon Conglomerate, which are only gently dipping and lack cleavage, and the distal Mount Alma Formation which is cleaved over much of its outcrop area.

The **Mount Hoopbound Formation** south of Mount Morgan, and the **Lochenbar beds** 60km north-west of Monto, are dominated by granule to cobble sized andesitic epiclastic rocks, with lesser fine grained sediments, some andesitic lava, and a few limestone occurrences. The dominance of mafic volcanic material imparts a very low to low radiometric response to these units. A basal polymict conglomerate in the Mount Hoopbound Formation at its contact with the Mount Morgan Tonalite contains cobbles and boulders of the tonalite. The abundance of these clasts diminishes rapidly within 100m of the contact. Both the Mount Hoopbound Formation and the Lochenbar beds are of Late Devonian (Frasnian and Famennian) age.

The **Balaclava Formation** is partly a time equivalent of, and partly overlies, the Mount Hoopbound Formation in the area south and south-east of Mount Morgan. Typical lithologies in the Balaclava Formation include siltstone, feldspatholithic to lithofeldspathic arenite, rhyolitic ignimbrite and accretionary lapilli tuff, and granule to pebble volcaniclastic conglomerate and breccia derived from dominantly rhyolitic to dacitic volcanic rocks. A less common lithology is an epiclastic andesitic breccia/conglomerate which appears similar to rocks of the Mount Hoopbound Formation. However, the andesitic breccias/conglomerates assigned to the Balaclava Formation differ in containing at least minor amounts of free quartz (extremely rare in the Mount Hoopbound Formation), and containing few if any hematised lithic fragments which are characteristic of the Mount Hoopbound Formation. Rocks of the Balaclava Formation are typically quite feldspathic, contain abundant volcanic quartz, and return a moderately high radiometric response in all three channels. This contrasts with the very low response of dominantly andesitic volcaniclastic units such as the Mount Hoopbound Formation and the upper part of the Capella Creek Group.

The **Three Moon Conglomerate** contains fine to coarse purplish sandstone, poorly sorted conglomerate, siltstone, and minor andesite. Conglomerates in the unit contain rip-up clasts but are usually dominated by subangular to rounded purple hematised andesitic to dacitic volcanic fragments and lithic sandstone blocks. Sharp erosive contacts have been observed at the base of these conglomerates. Sediments within the unit contain a minor though consistent proportion of quartz, but the unit is less felsic than the Balaclava Formation and possesses a correspondingly diminished radiometric signal, with a low response in all channels. It contains more abundant coarse grained facies than the Mount Alma Formation and is distinguished by the presence of purple hematised clasts in the sandstones and conglomerates. The consistent presence of minor quartz and the presence of finer grained graded facies and rip-up clast conglomerates can be used to distinguish the unit from the Lochenbar beds. The unit is a partial time equivalent of the Mount Alma and Balaclava Formations and is currently considered to overlie the Lochenbar beds and underlie the Rockhampton Group in the Cania area 40km north-north-west of Monto.

The **Mount Alma Formation** is a very extensive unit in the eastern part of the forearc basin sequence. It is comprised dominantly of interbedded siltstone and fine grained sandstone, with minor conglomerate. The fine grained sandstone and siltstone are usually thinly bedded, rhythmically interbedded in places, and commonly possess a weak cleavage which is parallel to that in the Mount Holly beds. Ripple laminations and other current formed sedimentary structures are rare, but soft sediment deformation features are very common. Conglomerates and very coarse grained sandstones are a minor component, but are distinctive because they almost always contain rip up clasts. Limestones at the base of the sequence in the Mount Holly region have yielded upper Lower Devonian to lower Middle Devonian conodonts and corals.

However, sandstone units within the sequence contain Upper Devonian brachiopods, and thin limestone beds sampled from within the Mount Alma Formation in the Craigilee area have returned Upper Devonian conodonts. Therefore the limestones at the base of the sequence in the Mount Holly region are believed to be allochthonous and sourced from the Mount Holly beds, and the contact between the Mount Holly beds and the Mount Alma Formation, where not faulted (Figure 3), is interpreted to be an unconformity which is equivalent to the intra-Devonian unconformity between the Capella Creek Group and the Mount Hoopbound Formation in the Mount Morgan area.

Although the Lower Carboniferous succession of the forearc basin is dominated by fine sandstone and siltstone, it is characterised by the cyclic development of oolitic limestone and ooid-bearing sandstone. The name **Rockhampton Group** has been applied to this sequence throughout the Yarrol Project area (Yarrol Project Team, 1997). This unit consists of a suite of rocks ranging in age from Tournaisian to Visean (Early Carboniferous) which includes oolitic limestone, calcareous ooid-rich and fossiliferous sandstone, siltstone, mudstone, polymictic conglomerate (locally containing intraformational rip-up clasts), and minor rhyolitic ignimbrite. The dominant rock types are siliceous mudstone and siltstone, which differ from the fissile, rhythmically interbedded siltstone and mudstone of the Mount Alma Formation.

The sediments of the Rockhampton Group are generally richer in quartz and acid volcanic clasts than underlying units, and give a higher radiometric response (with the exception of parts of the more localised Balaclava Formation). The increased content of radiogenic elements in the Rockhampton Group indicates a regional change in the composition of volcaniclastic sediments, and hence of the source volcanics, which became progressively more felsic with time. This trend is continued later in the Carboniferous, with another marked regional increase in radiometric response of all mid-Carboniferous to Lower Permian sedimentary units. Although there is a progressive change to more felsic compositions with time, radiometric images indicate that this change occurs in distinct stages, with abrupt increases in radiogenic element content in Late Devonian to earliest Carboniferous time, and in the mid-Carboniferous. These abrupt increases in radiometric signature locally correspond with significant disconformities.

The upper age limit of the forearc basin fill, and of the Late Devonian–Carboniferous convergent margin tectonism, is unclear. Dates from arc volcanics and granitoids west of the Yarrol Project area suggest that westward subduction beneath the continental margin continued through much if not all of the Late Carboniferous. This is consistent with the existence of an essentially continuous marine Carboniferous sequence in the Yarrol Syncline at the south-eastern limit of the project area, and also in areas west and north-west of Rockhampton. The mid-Carboniferous to Lower Permian marine succession in these areas, previously mapped as the Boiling Creek Group, Burnett Formation and Neerkol Formation, is grouped as a single unit, the **Lorray Formation**. Rock types include quartzose feldspatholithic sandstone, siltstone, mudstone, polymictic conglomerate and minor limestone. Bryozoan mudstone is dominant locally.

The **Youlambie Conglomerate** is a dominantly continental unit which is partly equivalent to at least the upper section of the Lorray Formation. In the south of the project area, the two units are separated, the marine Lorray Formation occurring to the east of the non-marine Youlambie Conglomerate, which disconformably overlies strata of Early Carboniferous and even Late Devonian age. However, in the area west and north-west of Rockhampton, the Youlambie Conglomerate has been mapped in sequence with and overlying the Lorray Formation (formerly Neerkol Formation). The Youlambie Conglomerate consists of boulder to pebble conglomerate, conglomeratic mudstone, quartzose feldspatholithic and lithic sandstone, siltstone, and acid volcanics. Conglomerate is polymictic, with clasts of acid and intermediate volcanics, granite, aplite, quartz porphyry, and indurated siltstone. The unit contains sparse Lower Permian fossils, but its base could extend into the Carboniferous.

The marked regional increase in radiometric response of the Lorray Formation, Youlambie Conglomerate and other sedimentary units of Early Permian age compared to older strata seems to be due to a distinct episode of unroofing of granite plutons with a high content of radiogenic elements: the increase in radiometric signature can be directly correlated with an abrupt increase in the amount of granitic detritus (and accompanying felsic volcanic clasts) within the sediments. It is possible that this unroofing was the result of dissection of the plutonic core of the volcanic arc to the west.

## Permian stratigraphy

Lower Permian strata in and adjacent to the Yarrol Project area have recently been interpreted as the fill of a series of extensional basins which developed at the same time as the Bowen Basin to the west (Fielding & others, in press). This interpretation is consistent with the fact that many of the Permian outcrops, especially the **Youlambie Conglomerate,** overlie or are in faulted contact with Lower Carboniferous or older rocks, implying removal or non-deposition of a substantial part of the stratigraphic section. In fact, an entirely regional hiatus may be present about the Carboniferous–Permian boundary. But opposed to this concept of extensional basin formation at the beginning of the Permian is: firstly, the existence of continuous and uniform Carboniferous–Permian marine sequences such as that in the Yarrol Syncline, located only about 20km east of the type section of the Youlambie Conglomerate where it disconformably overlies Lower Carboniferous sediments; and secondly, the calculation of tectonic subsidence rates for the Lower Permian sequences, which provide little if any evidence for significant crustal thinning caused by pull-apart or rift histories (Yarrol Project Team, 1997).

The Lower Permian **Rookwood Volcanics**, which host the Cu-Zn VHMS deposit at Develin Creek, occur towards the north-west margin of the project area as a number of discrete blocks. The unit consists dominantly of basalt and high-level mafic intrusives, with minor rhyodacite lava, volcanilithic breccia and sandstone, and mudstone. The basalt ranges from porphyritic to aphyric. Pillows, autobreccias, and peperites are relatively common in the northern blocks whereas the southern exposures are dominantly massive. Geochemical analyses indicate that the basalt has MORB-like affinities (O'Connell, 1995). Volcaniclastic sediments are more common in the north. Thin to laminated carbonaceous mudstones which contain trace fossils indicative of shelfal depths, appear to be hemipelagic and low concentration turbidite deposits. The overall depositional environment is inferred to be shelfal, below storm wave base. The disconnected outcrop pattern of the Rookwood Volcanics can be attributed to a tectonic mode of emplacement of the unit to its present position.

Holcombe & others (in press) proposed a thrust model whereby sequences including parts of the Rookwood Volcanics were thrust from the east into their present position, locally overlying stratigraphically higher Bowen Basin sediments. The Rookwood Volcanics are similar in many respects to the Permian Berserker beds, and at their closest point the two units are separated by only about 30km. However, they differ significantly in the composition of the volcanic rocks, the Berserker beds being dominantly felsic.

The **Berserker beds** comprise broadly folded sediments and acid to intermediate volcanics which form a north-north-west trending belt along the eastern margin of the Yarrol Project area, both north and south of the Fitzroy River. Project mapping has been concentrated on the better known northern section between the Rockhampton-Yeppoon road and Thompson Point on the Fitzroy River, in an attempt to map and define subdivisions which can be recognised in other areas. Airborne geophysics, both magnetics and radiometrics, have proved to be of little assistance in determining the distribution of rock types within the Berserker beds. Laminated siltstones and fine grained sandstones occur around Lakes Creek, and coarser volcaniclastic sediments and siltstone form a belt just west of the Tungamull Fault, with fossiliferous calcareous sandstone 3km north-north-west of Thompson Point. Mixed sedimentary and volcanic sequences, comprising sandstones, siltstones and felsic to intermediate pyroclastics, occupy the central part of the area, and are host to the Mount Chalmers VHMS deposit.

Much of the high country from Mount Archer north-east to Mount Nicholson consists of intrusive to extrusive domes of rhyolitic and dacitic composition. Similar rhyolite and dacite occur along the Flat Top Range and in the Mount Kilner-Broadmount area. Marine fossils correlative with faunas in the Lower Permian Buffel Formation of the Bowen Basin have been collected from several localities, and a younger fauna equivalent to that in the Ingelara and Barfield Formations of the Bowen Basin has been re-collected from conglomerate 800m north of Mount Chalmers. Gabbro intrusives occur from Mount Dick north to Mount Etna, predominantly along the western side, and also form sills in the Mount Larcom area south of the Fitzroy River. The Berserker beds are bounded by the Tungamull Fault in the east and the Parkhurst Fault in the west. Both faults are clearly evident on aeromagnetic images.

The Upper Permian **Moah Creek beds** and **Dinner Creek Conglomerate** unconformably overlie the Lorray Formation and Rookwood Volcanics in the Candlelight Syncline 35km west of Rockhampton. They also appear to share stratigraphic contacts with Bowen Basin units to the west. The Moah Creek beds are a nearshore marine unit dominated by conglomeratic mudstone, whereas the fluviatile Dinner Creek Conglomerate consists mainly of monomict cobble conglomerate and minor interbeds of sandstone and mudstone. The cobbles are almost exclusively fine to medium grained lithic sandstone, and therefore the conglomerate is markedly different in composition from those in Lower Permian strata.

## Triassic volcanics

The largest exposure of Triassic volcanics, assigned to the **Muncon Volcanics**, is located in the Kroombit Tops area 60km north of Monto. Mapping by the Yarrol Project team has shown that the dominantly basic lavas of the Muncon Volcanics as described from the type area near Cania are not typical of much of the unit elsewhere. The widespread distribution and variation of rock types suggests a number of eruption points, at least one of which is a newly identified caldera structure covering part of the Kroombit Tops. The ages of these individual sequences are yet to be determined.

The Kroombit Tops caldera produced mainly rhyolite, rhyolitic ignimbrite, agglomerate and breccia with only minor amounts of basic lavas. An outline of the caldera structure can be defined from airborne magnetics and the location of a cluster of rhyolite domes can be determined from airborne radiometrics. Geological mapping suggests that within the caldera, the eruption sequence moved from west to east with the later rhyolite flows partly obscuring the earlier eruption sequences. Both diagenetic (white mica, chlorite, epidote) and hydrothermal (clays, zeolites, micas, silicification, ferruginisation, carbonates, sulphides) alteration of the acid derivatives is widespread with introduced sulphides and carbonates being commonplace. The caldera rocks are considered to offer a target for epithermal gold, especially in the lower rhyolitic flows and vent breccias adjacent to domes. Traces of gold have been noted in panned concentrates towards the headwaters of Dry, Palm Tree, Kroombit and Three Moon Creeks. During the Jurassic, this whole volcanic sequence was buried beneath the **Precipice Sandstone**.

The **Native Cat Andesite** is a Triassic andesitic volcanic succession extending in an east-west direction about 35km west-south-west of Rockhampton. The andesite is moderately well defined by its aeromagnetic signature and the airborne radiometrics indicate that there is a difference between the eastern and western portions of the volcanic unit. The eastern portion approximately as far as Mount Candlelight exhibits a greater potassium response than the western part that includes Black Mountain. The eastern portion contains a sequence of volcanics that include basic agglomerate and breccia and some breccias that also contain acid volcanic material. The andesite ranges from fine grained varieties to andesitic material with feldspar phenocrysts to 5cm or more in length. Rhyolitic lavas have been mapped parallelling the general layering of the andesitic unit, but it is not known if this acid material is part of the Native Cat Andesite or belongs to the Cretaceous acid volcanics extending from Wycarbah in the south to Mount Salmon in the north.

The western part of the Native Cat Andesite contains fine grained andesitic lavas and pyroclastic derivatives and is accompanied by acid volcanic float in the Kalapa North area. This western portion has been intruded by a north- west trending plutonic body (not previously mapped) that ranges from granite at its southeastern margin to gabbro (exhibiting mineral layering) along its north-western boundary. The andesite has been hornfelsed for some distance from the margin of the plutonic body. Gold has been recovered in the vicinity of the intrusive body. The Native Cat mine is sited in the hornfelsed Native Cat Andesite while extensive alluvial deposits were worked in the vicinity of Golden Spur Gully and in the gullies flowing westward from Black Mountain.

## Cretaceous volcanics

To the north-east of Rockhampton, the **Hedlow Trachyte** occurs as a series of remnant plugs extending to the coast in the vicinity of Yeppoon. Dating indicates that the plugs are mainly of Late Cretaceous age (80–73±3Ma), with one plug possibly of early Cenozoic age (50.5±4.4Ma) (Sutherland & others, 1996). The accompanying basalt has been dated as Late Cretaceous and the association of acid and basic lavas suggests a central volcanic province as defined by Wellman & McDougall (1974).

About 30km west of Rockhampton, and extending from Wycarbah in the south to Mount Salmon in the north, an extensive sequence of basic and acid volcanics has been erupted. In the Wycarbah area, a number of rhyolite domes are exposed: Mount Hay and an unnamed dome to the east, White Rock, and Norman Head or Mount Sugarloaf. These are believed to be remnants of a large, complex caldera. Rhyolitic lavas and pyroclastic ejecta from this caldera overtopped the Native Cat Andesite in the Native Cat Range and flowed northward towards Mount Salmon. The quantity of acid volcanics north of the Native Cat Range which were produced from eruption points in the Wycarbah area is not known. There is a strong possibility that at least some of the Cretaceous volcanics in the Mount Salmon area were sourced from an extrusion point north of the Native Cat Range. Basalt lavas associated with this eruptive phase extend from Westwood east almost as far as Mount Morgan, and north to the Fitzroy River. Radiometric data show that the acid volcanics north of the Native Cat Range do not form a continuous belt northward to Mount Salmon as mapped on the 1st edition Rockhampton 1:250 000 geological map, but are divided into two unequal parts by Cretaceous basalt and the Permian Dinner Creek Conglomerate.

Some of the basic volcanics contain lherzolite xenoliths and ?xenocrysts of hornblende and pyroxene. Similar material has been mapped at Eulogie Park south of Mount Morgan, and gave a Late Cretaceous age (68.6±0.5Ma; Sutherland & others, 1996). In the Pheasant Creek area north-west of Wowan, suspected Cretaceous lavas of nephelinitic composition contain not only weathered lherzolite xenoliths and hornblende and pyroxene ?xenocrysts but also xenocrysts of garnet and rare anorthoclase. This material is very similar to that in the Brigooda diatreme near Proston from which diamond was recovered (Robertson & Robertson, 1994).

## Cenozoic volcanics

Basalts crop out over a large area between Biloela and Monto, with the greatest volume being erupted in the mid-Cenozoic. The main period of eruption from small shield volcanoes around the Oligocene–Miocene boundary (27–22Ma) produced widespread plateau forming flows composed mainly of alkali basalt and hawaiite. These flows are now extensively weathered and in places lateritised (Sutherland & others, 1989). Volcanic activity between 20 and 18Ma produced a series of plugs and dykes that intruded the older volcanic sequence. This younger sequence comprises olivine melilitite, nephelinite, basanite, hawaiite and alkali basalt, most of which contain upper mantle xenolith and megacryst suites. The emplacement of these younger basalts is controlled by deep seated fault structures.

Basalyic plugs carrying deep seated inclusions should be prospected for their diamond potential, especially in the Cania area north-west of Monto. During gold dredging operations on Three Moon Creek (1900 to approximately 1906), unconfirmed reports of small, bright, shiny and extremely tough stones occasionally observed in the gold concentrate suggest that diamonds may have been recovered.

## Intrusions

Re-mapping of intrusions in the Yarrol Project area has been greatly assisted by interpretation of airborne geophysical data acquired by the AIRDATA Project, which have been particularly useful in delineating the distribution of different rock types within, and the internal structure of, most of these plutons. Intrusions which have been subdivided by the present mapping program include the Mount Gerard Complex, Galloway Plains Tonalite, Glassford Complex, Kyle Mohr Granodiorite, Bouldercombe Complex, Ridgelands Granodiorite, and the unnamed granite/ granodiorite/diorite pluton at Mount Seaview. Two new intrusive units, the Kariboe Gabbro and the Lookerbie Igneous Complex, have been described from the south-west part of the Project area. Preliminary results for some intrusions were presented by the Yarrol Project Team (1997). About 130 samples have been submitted for analysis to provide geochemical data to determine the relationships and possible tectonic setting of the intrusive rocks, and several isotopic age determinations are being carried out.

Revisions to the geology of the **Mount Gerard Complex** are summarised as a representative example of the results from the re-mapping program, and their effect on prospectivity. The Mount Gerard Complex, about 50km south of Mount Morgan, was described by Dear & others (1971) as diorite and gabbro (Figure 4). It coincides with a positive gravity anomaly, gives a strong magnetic response, and appears to be part of a north-west trending belt of layered gabbros extending from Westwood in the north-west, through Eulogie Park and Kariboe, to Goondicum in the south-east. The complex has been explored unsuccessfully for platinum group metals.

Interpretation of airborne magnetics and radiometrics covering the Mount Gerard Complex showed that: (1) the mapped

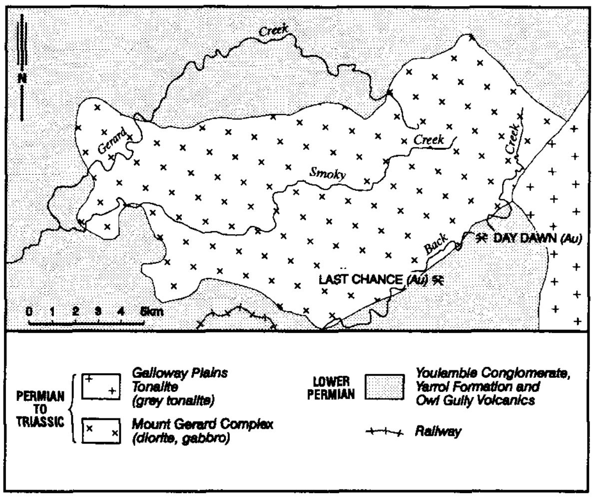


*Figure 4. Geology of the Mount Gerard Complex as shown on the 1st edition Monto 1:250 000 geological map.*

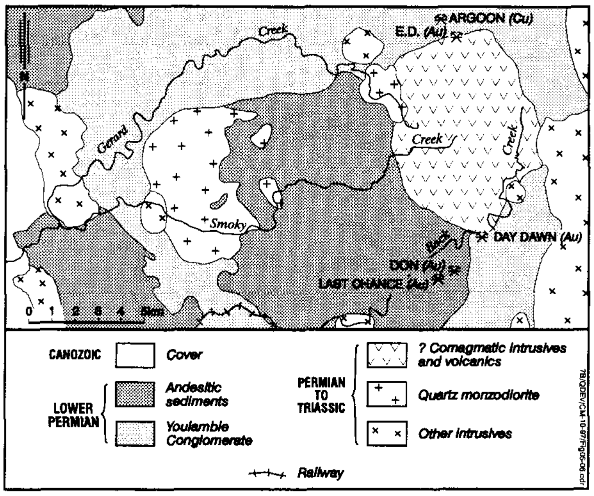


*Figure 5. Revised geology of the Mount Gerard Complex, showing the restricted outcrop area of plutonic rocks.*

boundary as shown on the Monto 1:250 000 geological map is inaccurate; (2) there are obvious subdivisions within the complex; and (3) the complex gives too great a radiometric response, particularly for potassium, to be entirely or even partly of gabbroic composition.

The present mapping program has confirmed these interpretations, and the results are shown in Figure 5. Plutonic rocks in fact make up only a relatively small proportion of the Mount Gerard Complex as originally mapped, and are quartz monzodiorite rather than diorite or gabbro. The only rock of mafic composition is a small plug of foliated gabbro or diorite which straddles Smoky Creek at the western contact of the main monzodiorite body (Figure 5). Most of the central part of the complex is a volcaniclastic unit consisting dominantly of andesitic conglomerate, breccia and sandstone. This sequence appears to be relatively flat lying, and is considered to be a Lower Permian unit conformably overlying the Youlambie Conglomerate, which surrounds the complex. Dear & others (1971) mapped andesitic volcanics in this area as the Lower Permian Owl Gully Volcanics. The volcaniclastic sequence forms a thin cover which is intruded by the main mass of quartz monzodiorite in the west. Aeromagnetic data suggest that it becomes thicker, and the intrusion more deeply buried, towards the east. It gives a much weaker radiometric response, particularly for potassium, than the monzodiorite.

The north-eastern part of the Mount Gerard Complex gives a similar radiometric response to the main quartz monzodiorite intrusion, but is much more weakly magnetic, and stands out as a distinct feature on images generated from the aeromagnetic data. This section consists of a mixture of volcanic and high level plutonic rocks which may be comagmatic. Volcanics are dominant in the south and intrusive rocks in the north. The volcanics are dark grey, and locally exhibit fragmental textures and contain small plagioclase phenocrysts. Compositionally they are close to rhyodacite. The intrusive rocks are similar in composition to samples from the main area of quartz monzodiorite, but are more siliceous. They have significantly lower magnetic susceptibilities.

The mapping results clearly indicate that the name Mount Gerard Complex will have to be abandoned and new units defined for each of the subdivisions.

There are several small gold deposits around the eastern end of the Mount Gerard Complex (Figure 5). In addition, some stream sediment samples have given anomalous gold values. In view of this, and the fact that the intrusion is a quartz monzodiorite, it is suggested that the area warrants exploration for gold.

## STYLES OF MINERALISATION

Historically, the Yarrol Project area has been a gold-copper province, with production dominated by Mount Morgan and to a lesser extent by Mount Chalmers. The area contains examples of several styles of mineralisation. The distribution of the most important deposits, and their geological settings, are depicted on Figure 6.

The best known and by far the largest example of **volcanic hosted massive sulphide (VHMS) deposits** is Mount Morgan (Taube, 1986; Large, 1992), which occurs in the Middle Devonian Capella Creek Group near the contact of the

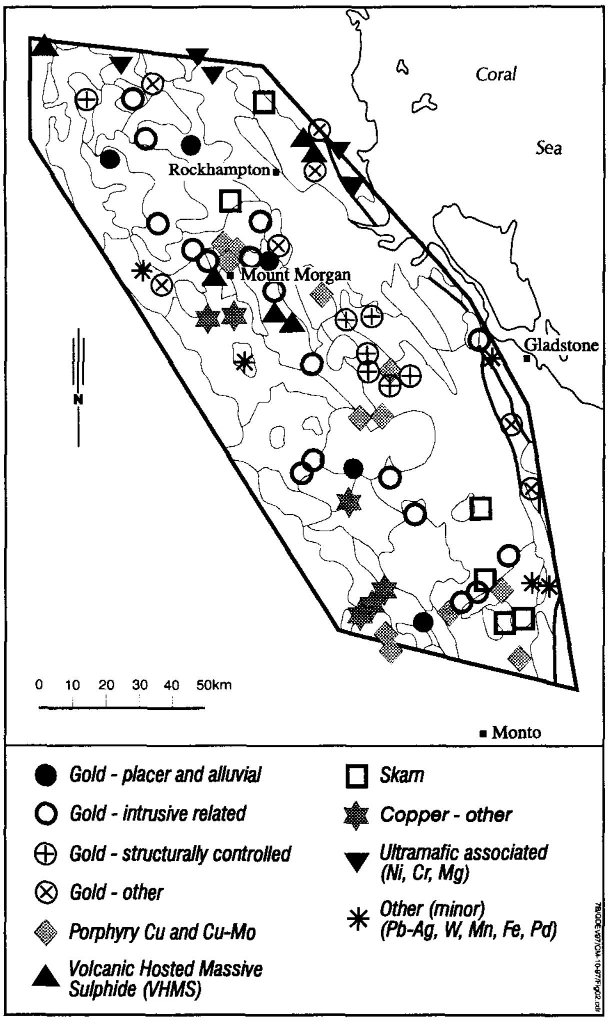


*Figure 6. Main mines and mineral occurrences of the Yarrol Project area, superimposed on geological boundaries from Figure 1.*

Mount Morgan Tonalite. This world class deposit, which produced 250t gold and 360 000t copper, was first interpreted as of volcanogenic origin (although not a typical example) in the late 1960s. Arnold & Sillitoe (1989) reverted to an earlier interpretation as a replacement deposit related to the Mount Morgan Tonalite. However, the orebody appears to have been metamorphosed by the tonalite, and must therefore be older, making a volcanogenic origin almost certain (see recent review by Golding & others, 1993). Smaller, more typical VHMS deposits which occur south-east of Mount Morgan in rocks believed to be equivalent to the host Mine Corridor sequence at Mount Morgan are the Ajax copper mine (Taube & Messenger, 1994) and the Upper Nine Mile Creek prospect (Taube & McLeod, 1987).

Classic Kuroko-type VHMS deposits occur in the Lower Permian Berserker beds at Mount Chalmers and nearby localities north-east of Rockhampton (Large & Both, 1980; Taube & van der Helder, 1983; Hunns, 1994). The recent Develin Creek discovery about 80km north-west of Rockhampton (Horton & others, 1994) is also a VHMS deposit within the Lower Permian Rookwood Volcanics.

**Porphyry type copper and molybdenum deposits** have been documented by Horton (1978, 1982). From north to south, identified porphyry style deposits in the project area include Moonmera, Moongan, Struck Oil, Bajool (Limonite Hill), Mount Bennett, Briggs (Riverhead), Mannersley, Ridler Creek (Burns Spur), Munholme Creek, and Mount Cannindah (Figure 6). Many of these deposits are associated with small satellite stocks not shown on currently published 1:250 000 scale geological maps.

The largest of the porphyry type deposits is Moonmera (Dummett, 1978), but all are presently uneconomic because of low grades. Some copper was produced from the supergene enriched zone at Mount Cannindah (Bedford, 1975). In recent years many of the porphyry systems have been explored for their gold potential, with limited success. Gold at Mount Cannindah appears to be related to a separate and later mineralising event (Creenaune & Harvey, 1996).

**Intrusive related gold-bearing quartz/calcite veins** are the most numerous deposits in the project area. The hydrothermal veins are concentrated at intrusive contacts, and occur within both country rocks and granitoids, commonly associated with dykes. Individual reefs are small, but collective production was substantial. An important centre was Bouldercombe at the margin of the Bouldercombe Complex (particularly the Mount Usher mine, from which recorded production was 930kg gold). In composite plutons, the gold mineralisation is preferentially located in the older, more basic phases. However, gold-bearing veins are also associated with silicic granitoids.

Individual deposits have sometimes been grouped together and called other styles. An example is the Walter Hall group, located north of Mount Morgan, which comprises numerous small zones of gold workings put down principally on quartz veins, but also on dykes, shear zones and combinations of all of these. Another example is the Monal goldfield 40km north of Monto, where numerous closely spaced individual workings were relatively small producers, but where there is widespread development of sulphide mineralisation and copper carbonates over the entire area.

**Structurally controlled gold deposits** occur in the Langmorn goldfield about 50km south-east of Mount Morgan (Figure 6). Several old workings and one operating mine are located along a fault zone, and splays from it, at the western edge of the Mount Holly beds (Figure 3). Gold occurs not only in quartz or quartz/calcite veins, but also has formed as thin sheets along cleavage planes and fractures in the host rocks.

**Gold-bearing quartz/calcite veins** occur in serpentinite in the Cawarral goldfield north-east of Rockhampton, comprising the Helena/Annie group, Constitution Hill and Mount Wheeler group. The genesis of this mineralisation is uncertain. It could be related to the emplacement of Late Cretaceous trachyte plugs.

**Palaeo-placer gold deposits** have been found in the Mount Rainbow goldfield 60km south-west of Gladstone where they occur in a cemented wash 0.15 to 1.8m thick at the base of 3 to 5m of sediments overlying granodiorite. At Cameron's Lookout, the wash was overlain by basalt. Another area of wash underlying Cretaceous basalt which had significant production was at Hunters Gully at Ridgelands west-north-west of Rockhampton. Reported production figures suggest that grades were about 30g/t.

In the Mount Victoria workings just west of Mount Morgan, gold occurs in conglomerate comprised of pebbles of quartz, greywacke, and slate, cemented with red iron oxide. This conglomerate was overlain by Jurassic Razorback beds equivalent to the Precipice Sandstone.

**Alluvial gold deposits** along present day drainage systems were the initial discoveries in many goldfields in the project area. Some were very rich, but reserves were small and rapidly exhausted. The Rosewood goldfield west of Rockhampton and the upper Dee River near Mount Morgan were two of the more notable sites for this style of deposit. Some areas have been worked repeatedly, such as Gavial Creek at Bouldercombe, where dredging took place. One of the dredges from here was removed to Three Moon Creek in the Cania goldfield 40km north-north-west of Monto where it met with less success, primarily due to the size of the boulders, which were too large for the dredge to work. Remaining resources of alluvial deposits appear limited.

**Skarn deposits** are developed where granitoids intrude calcareous sediments. Glassford Creek 30km north of Monto was the major copper deposit of this type, and a zinc-bearing skarn occurs at Mount Sperber just to the south. Minor production also came from the Ajax deposit at Diglum 45km south-south-west of Gladstone. Skarns worked exclusively for magnetite include Mount Etna and Kabra, north and west of Rockhampton respectively (Geological Survey of Queensland, 1978).

**Other types of copper deposits** include the Mount Rainbow mine 70km south-west of Gladstone, which appears to be a stratabound deposit upgraded by later skarn formation, and the Dee copper mine south-west of Mount Morgan, which is a replacement or vein type deposit at an intrusive contact. Disseminated copper mineralisation is present in andesite flows of the Upper Devonian Mount Hoopbound Formation south of Mount Morgan. Native copper occurs in vesicles and in the groundmass of non-vesicular rocks, and chalcocite is present in quartz and calcite veins (Wilson, 1980). The mineralisation is erratic and low grade.

**Chromite, magnesite** and **nickel** mineralisation is associated with the ultramafics in the northern part of the Yarrol Project area (Figure 6). Chromite occurs as podiform deposits, disseminations, segregations and small vein deposits in serpentinite (Krosch, 1990). Most production has come from Elgalla and Balnagowan, east of Rockhampton, but has totalled less than 10 000t grading 28–36% chromic oxide. The largest known resource at Princhester is estimated to contain 86 000t grading 28% chromic oxide. All past production has been of refractory grade ore, but the silica content of many remaining deposits is higher than the minimum currently specified for refractory purposes (Krosch, 1990). Very large deposits of high grade nodular magnesite have recently been discovered at Yaamba and Kunwarara, the latter locality being just north of the Yarrol Project area. The low-iron magnesite nodules appear to have been deposited from circulating groundwater (Milburn & Wilcock, 1994), and form surficial deposits related to the present topography and drainage. Lateritic nickel-cobalt deposits were formed by deep weathering of ultramafic rocks in the Canoona-Princhester district (Parianos, 1994). The southernmost of these deposits extend into the Yarrol Project area.

Other minor occurrences include **silver-lead, tungsten, manganese,** and **iron and platinum group elements** related to layered gabbros. Small amounts of silver-lead have been produced from lodes of fractured country rock with quartz veins at Bompa 45km north-north-east of Monto. At the nearby Littlemore tungsten deposit, scheelite occurs with tourmaline and magnetite in greisenised granite intruded by porphyry dykes. Secondary manganese deposits occur in ribbon cherts in the western part of the accretionary wedge assemblage. Disseminated manganese mineralisation was mobilised by weathering processes to form replacement deposits. Orebodies are typically lensoidal, concordant with the enclosing sediments, restricted to shallow depths, and small. Mount Miller, located 10km west of Gladstone, was by far the largest producer. Permian-Triassic plutons include a number of layered gabbros, which contain titaniferous magnetite layers (notably the Eulogie Park Gabbro 25km south of Mount Morgan) and anomalous platinum group elements (particularly the Bucknalla Complex 25km west of Mount Morgan; Carrigg & others, 1989; Hoatson & Glaser, 1989).

## CONCLUSIONS

The Yarrol Project has made significant advances in the understanding of the regional geology, tectonics, and metallogenesis of the New England Orogen in central coastal Queensland. The revised and updated geoscientific data provide better definition of potential host rocks for different styles of mineralisation and mineral deposit types, and in some cases identify specific targets for mineral exploration programs. Examples include the structurally controlled gold deposits of the Raglan area, which appear to be related to north-north-west trending faults, and the Mount Gerard Complex, previously mapped incorrectly as gabbro and diorite and explored unsuccessfully for platinoids, but now considered to be prospective for gold.

Progress results from the project have been made available to clients by means of published reports, a seminar, and a field excursion. As a consequence, some companies have applied for exploration permits over prospective ground within the Yarrol Project area.

## REFERENCES


ARNOLD, G.O. & SILLITOE, R.H., 1989: Mount Morgan gold-copper deposit, Queensland, Australia: Evidence for an intrusion-related replacement origin. *Economic Geology*, **84**, 1805–1816.

BEDFORD, I.V., 1975: Mount Cannindah copper deposit. *In* Knight, C.L. (Editor): *Economic Geology of Australia and Papua New Guinea. 1. Metals*. The Australasian Institute of Mining and Metallurgy, Melbourne, 787–789.

BLAKE, P.R., CROUCH, S.B.S., DOMAGALA, J. & HAYWARD, M.A., 1995: Review of mineral exploration within the Mount Morgan (8950) and Bajool (9050) 1:100 000 Sheet areas, central Queensland. *Queensland Geological Record* **1995/1.**

BLAKE, P.R., HAYWARD, M.A., SIMPSON, G.A., OSBORNE, J.H. & MURRAY, C.G., 1996: Review of mineral exploration within the Biloela (9049), Calliope (9149), Monto (9148) and Scoria (9048) 1:100 000 Sheet areas, central Queensland. *Queensland Geological Record* **1996/12.**

CARRIGG, J.A., REEVES, S.J. & McIVER, R.G., 1989: A preview of the geology and geochemistry of the Bucknalla Complex, Westwood, central Queensland. *In* Whitaker, W.G. (Editor): *1989 Field Conference Rockhampton Region*. Geological Society of Australia, Queensland Division, Brisbane, 28–38.

CREENAUNE, P. & HARVEY, K., 1996: The geology and mineralisation of the Mount Cannindah porphyry copper and gold system. *In*: Mesozoic Geology of the Eastern Australia Plate Conference. *Geological Society of Australia Abstracts*, **43**, 157–161.

DAY, R.W., MURRAY, C.G. & WHITAKER, W.G., 1978: The eastern part of the Tasman Orogenic Zone. *Tectonophysics*, **48**, 327–364.

DEAR, J.F., 1968: The geology of the Cania district. *Geological Survey of Queensland Publication* **330.**

DEAR, J.F., McKELLAR, R.G. & TUCKER, R.M., 1971: Geology of the Monto 1:250 000 Sheet area. *Geological Survey of Queensland Report* **46.**

DRUCE, E.C., 1971: Lower Devonian conodonts from the northern Yarrol Basin, Queensland. *Bureau of Mineral Resources, Geology and Geophysics Australia Bulletin* **108**, 43–73.

DUMMETT, H.T., 1978: Geology of the Moonmera porphyry deposit, Queensland, Australia. *Economic Geology*, **73**, 922–944.

FERGUSSON, C.L., 1991: Thin-skinned thrusting in the northern New England Orogen, central Queensland, Australia. *Tectonics*, **10**, 797–806.

FIELDING, C.R., HOLCOMBE, R.J. & STEPHENS, C.J., 1994: A critical evaluation of the Grantleigh Trough, east-central Queensland. *In* Holcombe, R.J., Stephens, C.J. & Fielding, C.R. (Editors): *1994 Field Conference Capricorn Region Central*

*Coastal Queensland*. Geological Society of Australia, Queensland Division, Brisbane, 17–30.

FIELDING, C.R., STEPHENS, C.J. & HOLCOMBE, R.J., in press. Permian stratigraphy and palaeogeography of the northern New England Fold Belt in coastal central Queensland. *Geological Society of Australia Special Publication*.

FLEMING, P.J.G., 1960: Stratigraphical and faunal studies in the upper Palaeozoic at Neerkol, central Queensland. B.Sc. (Honours) Thesis, University of Queensland.

FLEMING, P.J., 1967: Names for Carboniferous and Permian formations of the Yarrol Basin in the Stanwell area, central Queensland. *Queensland Government Mining Journal*, **68**, 113–116.

GEOLOGICAL SURVEY OF QUEENSLAND, 1978: Mineral resources of the Bowen region. *Queensland Government Mining Journal*, **79**, 187–208.

GOLDING, S.D., HUSTON, D.L., DEAN, J.A., MESSENGER, P.R., JONES, I.W.O., TAUBE, A. & WHITE, A.H., 1993: Mount Morgan gold - copper deposit: The 1992 perspective. *In: The AusIMM Centenary Conference*. The Australasian Institute of Mining and Metallurgy, Melbourne, 95–111.

GUST, D.A., STEPHENS, C.J. & GRENFELL, A.T., 1993: Granitoids of the northern NEO: their distribution in time and space and their tectonic implications. *In* Flood, P.G. & Aitchison, J.C. (Editors): *New England Orogen, eastern Australia*. Department of Geology and Geophysics, University of New England, Armidale, 565–571.

HAYWARD, M.A., DOMAGALA, J., BLAKE, P.R., SIMPSON, G.S. & CROUCH, S.B.S., 1995: Review of mineral exploration within the Rookwood (8851) and Ridgelands (8951) 1:100 000 Sheet areas. *Queensland Geological Record* **1995/2**.

HENDERSON, R.A., 1980: Structural outline and summary geological history for northeastern Australia. *In* Henderson, R.A. & Stephenson, P.J. (Editors): *The Geology and Geophysics of Northeastern Australia*. Geological Society of Australia, Queensland Division, Brisbane, 1–26.

HOATSON, D.M. & GLASER, L.M., 1989: Geology and economics of platinum-group metals in Australia. *Bureau of Mineral Resources, Geology and Geophysics Australia, Resource Report* **5**.

HOLCOMBE, R.J., STEPHENS, C.J., FIELDING, C.R., GUST, D., LITTLE, T.A., SLIWA, R., KASSAN, J., McPHIE, J. & EWART, A., in press: Tectonic evolution of the northern New England Fold Belt: The Permian-Triassic Hunter-Bowen event. *Geological Society of Australia Special Publication*.

HORTON, D.J., 1978: Porphyry-type copper - molybdenum mineralization belts in eastern Queensland, Australia. *Economic Geology*, **73**, 904–921 (also *Queensland Government Mining Journal*, **79**, 474– 489).

HORTON, D.J., 1982: Porphyry-type copper and molybdenum mineralisation in eastern Queensland. *Geological Survey of Queensland, Publication* **378**.

HORTON, D., MILBURN, D., PATTERSON, J., VENABLES, J. & WILLIAMS, L., 1994: The Develin Creek copper-zinc deposits, central Queensland. *In* Holcombe, R.J., Stephens, C.J. & Fielding, C.R. (Editors): *1994 Field Conference Capricorn Region Central Coastal Queensland*. Geological Society of Australia, Queensland Division, Brisbane, 93–98.

HUNNS, S.R., 1994: Geology of the Mount Chalmers volcanic-hosted massive sulfide, and implications for its formation. *In* Holcombe, R.J., Stephens, C.J. & Fielding, C.R. (Editors): *1994 Field Conference Capricorn Coast Region Central Coastal Queensland*. Geological Society of Australia, Queensland Division, Brisbane, 80–92.

KIRKEGAARD, A.G., SHAW, R.D. & MURRAY, C.G., 1970. Geology of the Rockhampton and Port Clinton 1:250 000 Sheet areas. *Geological Survey of Queensland, Report* **38**, 1–137.

LARGE, R.R., 1992: Australian volcanic-hosted massive sulfide deposits: features, styles and genetic models. *Economic Geology*, **87**, 471–510.

LARGE, R.R. & BOTH, R.A., 1980: The volcanogenic sulfide ores at Mount Chalmers, eastern Queensland. *Economic Geology*, **75**, 992–1009.

LEITCH, E.C., FERGUSSON, C.L. & HENDERSON, R.A., 1992: Geological note: The intra-Devonian unconformity at Mt Gelobera, south of Rockhampton, central Queensland. *Australian Journal of Earth Sciences*, **39**, 121–122.

MALONE, E.J., OLGERS, F. & KIRKEGAARD, A.G., 1969: The geology of the Duaringa and Saint Lawrence 1:250 000 Sheet areas, Queensland. *Bureau of Mineral resources, Geology and Geophysics Australia Report* **121**.

MARSDEN, M.A.H., 1972: The Devonian history of northeastern Australia. *Journal of the Geological Society of Australia*, **19**, 125–162.

MAXWELL, W.G.H., 1953: Upper Palaeozoic formations in the Mount Morgan district - Stratigraphy and structure. *Department of Geology, University of Queensland Papers* **4**(4).

MAXWELL, W.G.H., 1954: Upper Palaeozoic formations in the Mount Morgan district - Faunas. *Department of Geology, University of Queensland Papers* **4**(5).

MAXWELL, W.G.H., 1964: The geology of the Yarrol region. Part 1. Biostratigraphy. *Department of Geology, University of Queensland Papers* **5**(9).

McKELLAR, R.G., 1967: The geology of the Cannindah Creek area, Monto district, Queensland. *Geological Survey of Queensland Publication* **331**.

McKELLAR, R.G., DEAR, J.F. & FLEMING, P.J.G., 1971: Devonian, Carboniferous and Permian fossils from the Rockhampton 1:250,000 Sheet area. *Geological Survey of Queensland Report* **38**, 138–155.

MORAND, V.J., 1993a: Stratigraphy and tectonic setting of the Calliope Volcanic Assemblage, Rockhampton area, Queensland. *Australian Journal of Earth Sciences*, **40**, 15–30.

MORAND, V.J., 1993b: Structure and metamorphism of the Calliope Volcanic Assemblage: Implications for Middle to Late Devonian orogeny in the northern New England Fold Belt. *Australian Journal of Earth Sciences*, **40**, 257–270.

MURRAY, C.G., 1975. A plate tectonic interpretation of mineralization in the New England Geosyncline in Queensland. *Geological Survey of Queensland, Record* **1975/13**.

MURRAY, C.G. 1994: Yarrol Project 1993-2000 - A review of available information, data requirements, and mapping priorities. *Queensland Geological Record* **1994/18**.

MURRAY, C.G., FERGUSSON, C.L., FLOOD, P.G., WHITAKER, W.G. & KORSCH, R.J., 1987: Plate tectonic model for the Carboniferous evolution of the New England Fold Belt. *Australian Journal of Earth Sciences*, **34**, 213–236.

MURRAY, C.G., SCHEIBNER, E. & WALKER, R.N., 1989: Regional geological interpretation of a digital coloured residual Bouguer gravity image of eastern Australia with a wavelength cut-off of 250km. *Australian Journal of Earth Sciences*, **36**, 423–449.

O'CONNELL, S.A., 1995: Geology and structure of the Aeroview area, Rockhampton region, central Queensland: Implications for mineralisation of the Lower Permian Rookwood Volcanics. B.Sc. (Honours) Thesis, University of Queensland.

OSBORNE, J.H., SIMPSON, G.A., BLAKE, P.R., HAYWARD, M.A., CROUCH, S.B.S. & DOMAGALA, J., 1997: Review of mineral exploration within the Rockhampton (9051), Cape Capricorn (9151) and Gladstone (9150) 1: 100 000 Sheet areas, central Queensland. *Queensland Geological Record* **1997/3**.

ROBERTSON, A.D. & ROBERTSON, C.M., 1994: The Brigooda diamond enigma. *Queensland Government Mining Journal*, **95**(1115), 32–33.

SUTHERLAND, F.L., ROBERTSON, A.D. & HOLLIS, J.L., 1989: Monto. *In* Johnson, R.W. (Editor): *Intraplate Volcanism in eastern Australia and New Zealand*. Cambridge University Press, Cambridge and Australian Academy of Science, Canberra, 106–107.

SUTHERLAND, F.L., ROBERTSON, A.D., BARRON, B.J. & POGSON, R.E., 1996: The Rockhampton plume and its late Mesozoic trace. *In* Mesozoic Geology of the Eastern Australia Plate Conference. *Geological Society of Australia Abstracts*, **43**, 519–527.

TAUBE, A., 1986: The Mount Morgan gold - copper mine and environment, Queensland: a volcanogenic massive sulfide deposit associated with penecontemporaneous faulting. *Economic Geology*, **81**, 1322–1340.

TAUBE, A. & McLEOD, R.L., 1987: Mt Morgan mine, Mt Chalmers mine, and UNMC prospect - penecontemporaneous faulting and volcanogenic massive sulphide deposits in central Queensland. *In: Proceedings Pacific Rim Congress 87*. The Australasian Institute of Mining and Metallurgy, Melbourne, 423–425.

TAUBE, A. & MESSENGER, P., 1994: Volcanic stratigraphy of the Dee Range: a new perspective on Mt Morgan. *In* Henderson, R.A. & Davis, B.K. (Editors): Extended Conference Abstracts — New developments in geology and metallogeny: Northern Tasman Orogenic Zone. *Contributions of the Economic Geology Research Unit, Key Centre in Economic Geology and Geology Department, James Cook University of North Queensland*, **50**, 85–87.

TAUBE, A. & VAN DER HELDER, P., 1983: The Mount Chalmers mine and environment — a Kuroko-style volcanogenic sulphide environment. *In: Permian Geology of Queensland*. Geological Society of Australia, Queensland Division, Brisbane, 387–399.

WELLMAN, P. & McDOUGALL, I., 1974: Cainozoic igneous activity in eastern Australia. *Tectonophysics*, **23**, 49–65.

WILSON, M.M., 1980: Origin and deposition of native copper in altered andesites of the Devonian and Permo-Carboniferous volcanic sequences in the Yarrol Shelf and Bowen Basin. *In* Hofmann, G.W. (Editor): *1980 Field Conference Mount Morgan- Rundle Range-Yeppoon Area*. Geological Society of Australia, Queensland Division, Brisbane, 25–39.

WITHNALL, I.W., FORDHAM, B.G., DONCHAK, P.J., DOMAGALA, J. & CROUCH, S.B.S., 1995: Progress report on geological investigations in south Queensland. *Queensland Government Mining Journal*, 96(1123), 16–22.

YARROL PROJECT TEAM, 1997: New insights into the geology of the northern New England Orogen in the Rockhampton-Monto region, central coastal Queensland: Progress report on the Yarrol Project. *Queensland Government Mining Journal*, 98(1146), 11–26.

**Reference for this paper:**
**MURRAY, C.G. & THE YARROL PROJECT TEAM, 1997: The Yarrol Project — increasing the prospectivity of the New England Orogen in the Rockhampton-Monto Region, central coastal Queensland. *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 39–56.**

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Queensland Department of Mines and Energy

# South Connors-Auburn-Gogango Project

The South Connors-Auburn-Gogango Project, extending from Mackay to Mundubbera, is part of the Department's GEOMAP 2005 program. The five-year project, started in 1996, is designed to draw mineral exploration to this underexplored region by updating the geological information base and providing a reassessment of the mineral potential of the area. The project is integrating newly acquired Departmental airborne radiometric and magnetic data, gravity data, satellite imagery, geochemical data, petrological data, previous exploration and research data, with data from Departmental remapping in selected areas. Data from the investigation are being compiled in the Department's geographic information system and results will be made available to explorationists as soon as possible throughout the investigation.

Field work completed to date comprises a four-week reconnaissance trip in 1996 over the whole project area, and a full field season in 1997 that covered the southern half of the project area, in the Gogango Overfolded Zone, Auburn Arch and Rawbelle Batholith. Preliminary U-Pb isotopic studies on samples collected in 1996 has shown that the bulk of the magmatism in the area was Late Carboniferous to Early Permian, although there was at least some in the Early Carboniferous. Mapping has resulted in further subdivision of the granitic rocks and clarification of the relationships between the volcanic units. The rocks in the Gogango Overfolded Zone, which is more correctly a stack of imbricate thrusts, can be correlated with less deformed rocks in the Bowen Basin and Connors and Auburn Arches.

*Keywords. Exploration potential; mineral exploration; mineral occurrence; geological mapping; Connors Arch; Gogango Overfolded Zone, Auburn Arch, Strathmuir Synclinorium; SF55-7; SF55-8; SF55-12; SF55-16; SF56-13; SG56-1; SG56-5; SG56-9; Queensland.*

## INTRODUCTION

The South Connors-Auburn-Gogango (SCAG) Project covers approximately 27 500km$^2$ of central eastern Queensland from Mackay to Mundubbera (Figure 1). The five-year project, started in 1996, forms part of the Department of Mines and Energy's (DME) GEOMAP 2005 program, which focuses on second-pass mapping to help establish the mineral resource potential of regions within the State (Day, 1995). The area of investigation was selected in consultation with the exploration industry, academia and government, as one of the priority areas for government geoscience mapping in Queensland (Hofmann, 1989). The project is designed to draw mineral exploration to this underexplored region by updating and adding value to the geoscientific knowledge base, and providing a reassessment of the mineral potential of the area. In addition to reducing the risk to explorers, the updated interpretations will improve land use decision making by ensuring that it takes account of mineral resource potential.

## METHODOLOGY AND OUTPUT

The investigation is aimed primarily at developing mineral prospectivity models for the project area by linking geological characteristics with the potential for mineralisation. Within a tectonic setting of all geological elements, a consistent and comprehensive stratigraphic framework is being developed, which is linked with those of adjacent provinces. The potential for mineralisation is based on metallogenic studies involving the application of generic models plus data from known mineral occurrences in the area, including distribution, style and type of deposits.

Because the traditional field mapping process is slow and expensive, the Department is

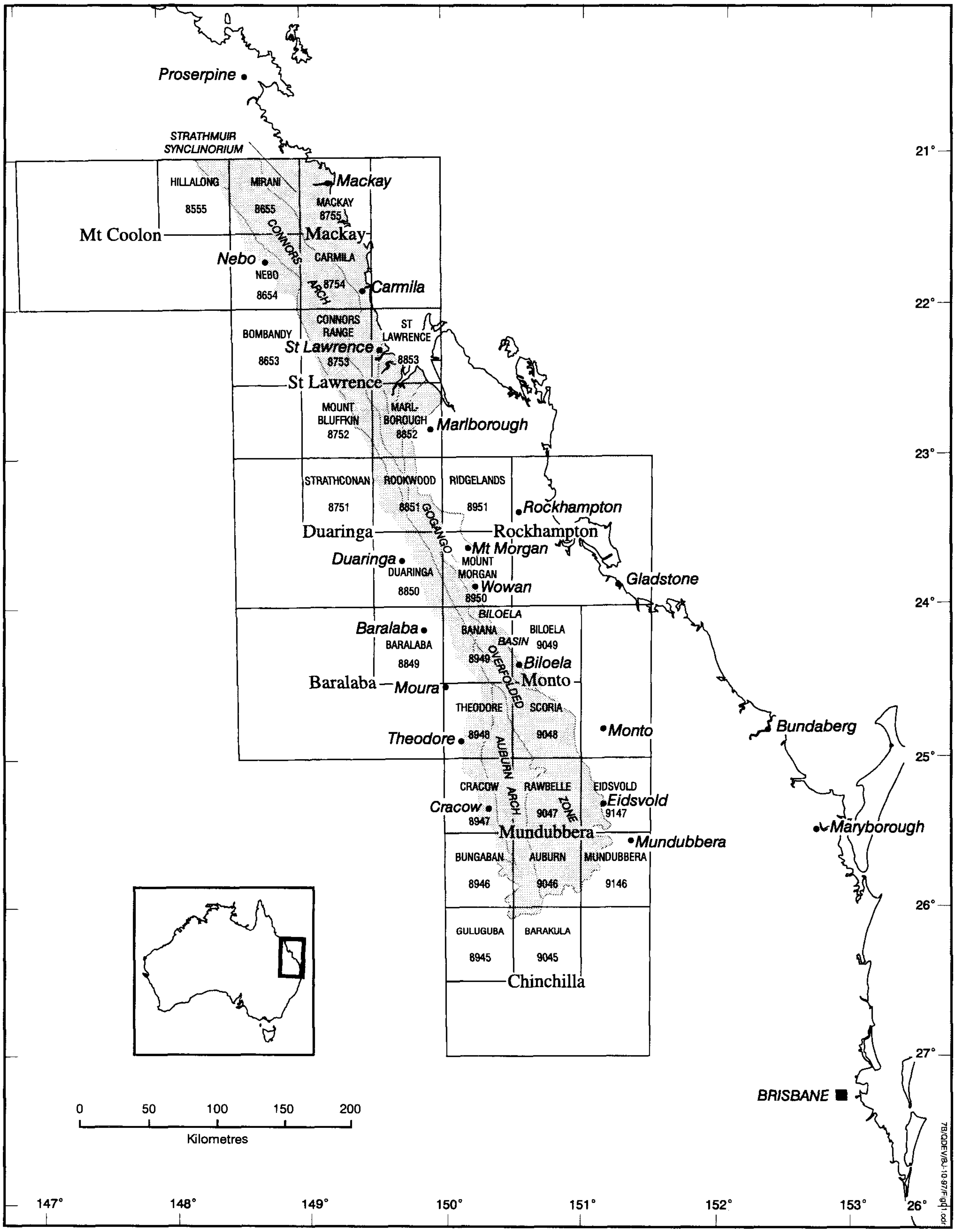


*Figure 1. South Connors-Auburn-Gogango Project area.*

making increasing use of new technologies involving remote sensing and data management (Day, 1995). For the South Connors Project, geological re-interpretations are based on newly acquired airborne radiometric and magnetic data gained from the Department's AIRDATA Project, which covers the entire project area. This is integrated with gravity data, satellite imagery, geochemical data, petrological data, previous exploration and research data, and data from Departmental remapping in selected areas. Preliminary interpretations, and field validation and data capture have just been completed for the southern half of the project area. The northern half is scheduled for completion in 1998/99.

Project results will be made available progressively throughout the term of the project. Outputs will comprise geological and mineral occurrence maps, reports and reviews, and digital data sets. Queensland Geological Records presenting preliminary data from the first field season are scheduled for release early in the new year. Data from the investigation are being captured into the Department's MERLIN corporate information system, and manipulated within a project GIS environment. In addition to supporting data storage and manipulation, MERLIN also facilitates the efficient production of digital and hard copy maps and reports. Preformatted hard copy maps for the South Connors area will be produced at a variety of scales and extents, depending on the geological complexity, and the known and potential mineral occurrences. The flexibility provided by MERLIN however, will also enable the provision of print-on-demand maps as well as ad hoc digital graphical and attribute data as specified by clients. At the completion of the project a synthesis report will be produced, together with a GIS of the project area.

## GEOLOGICAL SETTING

The SCAG Project area forms part of the northern New England Fold belt. The major structural provinces within the study area are the Connors and Auburn Arches and the Gogango Overfolded Zone. They are flanked to the east by the Yarrol Province and to the west by the Bowen Basin (Figures 1 and 2).

In the north-eastern part of the study area, a succession of Late Devonian to Early Carboniferous volcanic rocks of the Campwyn Block is the northern continuation of the ***Yarrol Province***.

The ***Connors Arch*** in the north and ***Auburn Arch*** in the south both consist of late Palaeozoic granites and silicic volcanic rocks that have been regarded as representing a Late Devonian to Early Carboniferous Andean volcanic arc west of the Yarrol Province. The latter has been interpreted as a forearc basin with a complimentary accretionary complex in the Coastal Block (Day & others, 1978; Murray, 1986). This volcanic arc was referred to as the Connors-Auburn Volcanic Arc by Day & others (1978), the main volcanic units being the Connors Volcanics in the north and the Torsdale beds in the south. The age and existence of the volcanic arc was poorly constrained, being based on the fact that the volcanic rocks are intruded by Late Carboniferous granites (Webb & McDougall, 1968) (and hence must be older) and a single K-Ar age of 343Ma (Whitaker & others, 1974) for an outlier of volcanic rocks correlated with the Torsdale beds in the Auburn Arch. Volcanism was interpreted to have ceased during the Late Carboniferous when voluminous granites were intruded. In the Early Permian, a second arc, the Camboon Volcanic Arc was inferred to have developed on the site of the older arc, but no corresponding forearc or accretionary complex were identified. The main units recognised were the Camboon Volcanics and the Nogo and Narayen beds.

In the southern part of the Connors Arch, Dear (1994) described three sequences or cycles of largely felsic volcanic rocks within the Connors Volcanics. Cycle 1 was postulated to be Middle Devonian and Cycle 2 was correlated with the Torsdale beds and thought to be Early Carboniferous. Cycle 3 was correlated with the Camboon Volcanics.

Recent work from both the Auburn and Connors Arches (Allen & others, submitted; Holcombe & others, submitted) has suggested that, although internal unconformities can be recognised, both volcanic episodes are broadly Late Carboniferous to Early Permian. Holcombe & others (submitted) postulate a magmatic episode spanning about 40my from about 320Ma, peaking at about 305Ma. They question the existence of any arc-type rocks that can be related to the interpreted fore-arc sequences in the Yarrol Province.

The Connors and Auburn Arches are separated by the ***Gogango Overfolded Zone*** (GOZ). It is largely a belt of monotonous, strongly cleaved sandstone and mudstone with belts of deformed intermediate to felsic volcanic rocks up to 10km long. Day & others (1978) proposed that the Connors Arch formed the eastern margin of the Bowen Basin during the Early Permian and that sedimentary rocks in the GOZ to the east formed in a separate deep-water basin, the Grantleigh Trough. Stratigraphic, sedimentological and structural studies in recent years (Fielding & others, 1994 and submitted; Fergusson, 1991; Fergusson & others, 1994) have led to the conclusion that the GOZ is simply a part of the Bowen Basin

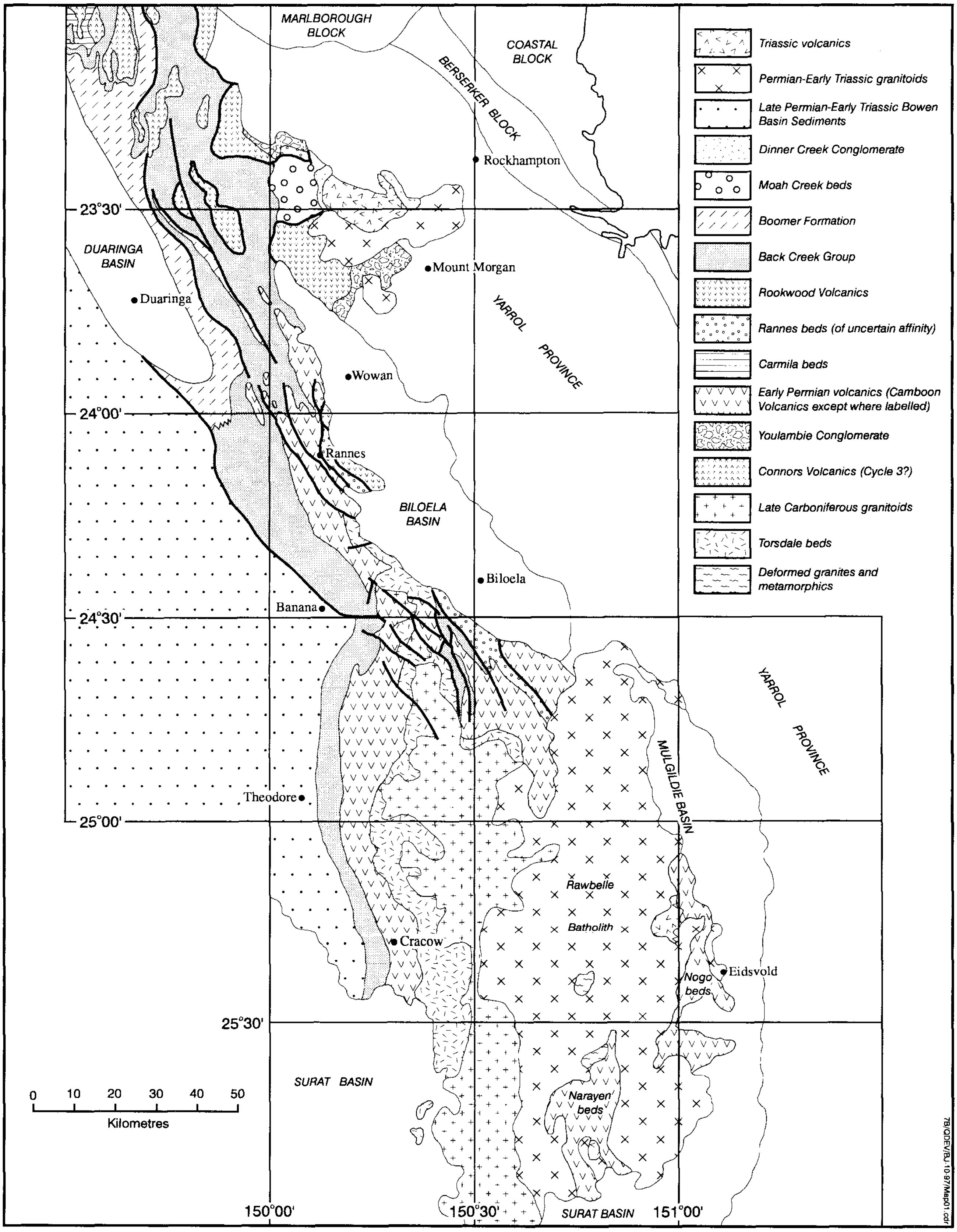


*Figure 2. Simplified geological map of the southern part of the South Connors-Auburn-Gogango project area.*

that was more intensely deformed by thrusting during the Late Permian to Early Triassic Hunter-Bowen Orogeny. Fergusson (1991) interpreted that the Connors Arch, as now exposed, is a later structural feature, possibly the upper part of a passive-roof duplex or antiformal stack of fault bound slivers, that plunges southwards under the GOZ. The volcanic rocks are slivers of the underlying basement.

The basal part of the ***Bowen Basin*** that flanks the Connors and Auburn Arches, both to the east and west generally consists of shallow marine sandstone, mudstone and subordinate carbonates deposited in a shallow marine environment. However, in many places, these rocks are separated from the volcanic rocks of the Auburn and Connors Arches by local successions of fluvial and lacustrine sedimentary rocks and bimodal volcanic rocks that have been interpreted as the early extensional or rift phase in the formation of the Bowen Basin. These include the Carmila beds and possibly the Youlambie Conglomerate. In the GOZ, a sequence of submarine volcanic rocks, the Rookwood Volcanics, was possibly emplaced as part of this extensional phase. The overlying marine sediments were deposited during the thermal sag phase of basin development (Fielding & others, 1994 and submitted).

Intruding the Auburn Arch and southern part of the GOZ is the ***Rawbelle Batholith*** that consists of granitoids that have mostly given Late Permian to Triassic ages.

## MINERALISATION

Based on previous interpretations of the area the project will focus mainly on specific ore genesis models, including volcanic-hosted massive sulphide (VHMS), gold-rich porphyry systems and epithermal quartz veins. Small to moderate-sized base metal/gold VHMS, including the Develin Creek prospect, are indicated in the Permian Rookwood Volcanics and their equivalents in the GOZ; small to moderate-sized gold-rich porphyry deposits are associated with high-level Carboniferous-Permian igneous complexes in the (*eg* Mount Mackenzie); small to moderate-sized epithermal gold deposits have been identified in the Carboniferous and Permian volcanic rocks of the northern Yarrol Province, Connors and-Auburn Arches and basal Bowen Basin succession (*eg* Cracow and possibly Grasstree mines). In addition, disseminated copper mineralisation (sulphides, oxides and native copper) is widespread in basal andesitic volcanic rocks of the Bowen Basin.

## 1996 RECONNAISSANCE TRIP

A four-week reconnaissance trip was carried out in October-November, 1996, to examine the entire area from Mackay to Mundubbera to collect data for logistical planning and to develop a feel for the geology. A wide range of samples of granites, and some volcanic rocks were collected for geochemistry (approximately 130) and six of these were submitted for U-Pb zircon dating by the SHRIMP method at the Australian National University. The results of the dating is presented later in this paper (Table 1).

## 1997 GEOLOGICAL MAPPING

Field work in 1997 was focussed on the southern part of the project area that falls within the Duaringa, Rockhampton, Monto and Mundubbera 1:250 000 Sheet areas (Figure 2). The field work was conducted from June to October with a total of 70 man weeks spent on geological mapping and about 12 man weeks on mineral occurrence mapping. Geological mapping has largely been completed in this area, although some further work will probably be needed in the Auburn Arch area. Mineral occurrence mapping was completed.

With field work having been completed so recently, the results discussed below are preliminary only. Queensland Geological Records containing more detailed data and further analysis will be released early in 1998.

### Volcanic rocks in the Connors and Auburn Arches

#### *Connors Volcanics*

Rocks assigned to this unit on existing maps have been mapped in the Rookwood Sheet area at the southern end of the Connors Arch and as large lenticular bodies up to 25km long within the GOZ. The latter are partly fault-bounded anticlinal fold closures. At the southern end of the Connors Arch, dacitic ignimbrite is overlain by andesitic lavas and clastic rocks (possibly some basalt and dacite). The dacitic ignimbrite may be part of Cycle 3A of Dear (1994), whereas the andesites may be the upper part of his Cycle 3A or Cycle 3B, which he correlated with the Camboon Volcanics. This pattern of felsic rocks overlain by andesitic rocks appears to be repeated consistently throughout the large lenticular bodies in the GOZ, although some of the contacts are probably tectonic. In addition to ignimbrite, however, dacitic lavas and thick sequences of fluvial sandstone and conglomerate of dacitic provenance are also present in the lower part of the sequence. In the GOZ, the volcanic rocks are commonly deformed in narrow zones and have developed anastomosing foliations with flattened and stretched clasts. Alteration, particularly of the mafic rocks is widespread, with extensive epidotisation accompanied by actinolite and chlorite.

Fine-grained sedimentary rocks are locally present in the andesitic sequences, and are particularly widespread in the lenticular body in the central part of the Rookwood Sheet area. The sediments have the same radiometric response as the andesitic rocks, and are thought to represent lacustrine sequences, deposited in local rifts formed in response to the early extensional phase of the Bowen Basin. They are probably equivalent in age to the Carmila beds (Figure 3).

*Torsdale beds*

During the 1997 field season, the Torsdale beds in the Theodore area were distinguished as those volcanic rocks and associated sedimentary rocks which pre-date the intrusion of the Late Carboniferous granites in the Auburn Arch. In many places adjacent to plutons, they have been at least slightly hornfelsed, and some form large septa or screens between plutons. The Torsdale beds as mapped include predominantly rhyolitic to dacitic ignimbrite, lava, and related epiclastic sediments. In the Cracow area and in the Banana Range west of Biloela, they are almost exclusively massive ignimbrite (much less altered than ignimbrites in the Camboon Volcanics), but in the Theodore area, more mafic rocks such as andesitic lava, breccia and conglomerate are also present. Some areas of granite have a radiometric signatures similar to nearby rhyolitic ignimbrite. The similarity of the signatures suggests similar chemistry and the possibility that the rocks are co-magmatic.

*Camboon Volcanics*

The Camboon Volcanics are interpreted to overlie granites and the Torsdale beds. In some parts of the area, the base of the Camboon Volcanics is marked by conglomerate which differs from conglomerates in the Torsdale beds in that it contains granite clasts. However, in practice, it is difficult to distinguish between the two units, as similar rocks occur in both units, although in different proportions. Conglomerate appears to be more common in the Camboon Volcanics on the eastern side of the Auburn Arch. Overlying the basal conglomerate is a sequence of and dacitic to andesitic tuff, lava, volcaniclastic rocks and minor ignimbrite. West of the Auburn Arch, the Camboon Volcanics comprise mainly dacitic to andesitic lava, ignimbrite, and volcaniclastic rocks. Some rocks contain K-feldspar as the main phenocryst phase and may be trachytic. Outcrop in the Theodore area is poor with only isolated outcrops surrounded by thick soils. Dips are shallow but some fold hinges can be interpreted. The thickness of the sequence is unknown.

Near the top of the Camboon Volcanics north-east of Theodore, a thick trachytic ignimbrite forms a continuous ridge. This unit has been mapped out from east of Theodore to the Barfield area south of Banana. A prominent altered trachytic plug, Mount Tam, may be a vent for the eruption of this ignimbrite. Between the ignimbrite and the basal marine sequence of the Bowen Basin. a belt of andesite to basalt represents a more mafic part of the Camboon Volcanics. They are represented by darker colours on the RGB (red-green-blue K-Th-U) composite radiometric image.

In the Cracow area, densely welded ignimbrites are common in the Camboon Volcanics. They are usually strongly altered.

In the area north of Banana, the Camboon Volcanics are mostly andesitic lavas (possibly including basalt and dacite) and volcaniclastic rocks, including epiclastic sandstone and conglomerates as well as probable pyroclastics. Local zones of alteration, brecciation and epithermal-style quartz veining in this area contain low-grade gold mineralisation that has been investigated by Placer and Queensland Metals Corporation. Potassic anomalies in the airborne radiometrics in this area are partly due to alteration, but also appear to include small rhyolite intrusions. Strain increases eastwards towards the GOZ, where the rocks are strongly foliated and lineated, particularly the clastic rocks.

Discontinuous areas of felsic rocks occur in a belt within the GOZ from west of Wowan to about 10km south-east of Rannes. They are strongly deformed and have well developed foliations and stretching lineations. The original character is often difficult to determine, but the rocks are mainly volcaniclastic and may have included some ignimbrite. It is uncertain whether they are part of the Camboon Volcanics or a continuation of the Torsdale beds.

A belt of sedimentary rocks, previously mapped as Rannes beds occurs in the Camboon Volcanics in a belt extending south-east for 20km from north-west of Rannes. The rocks have the same radiometric signature as the andesites of the Camboon

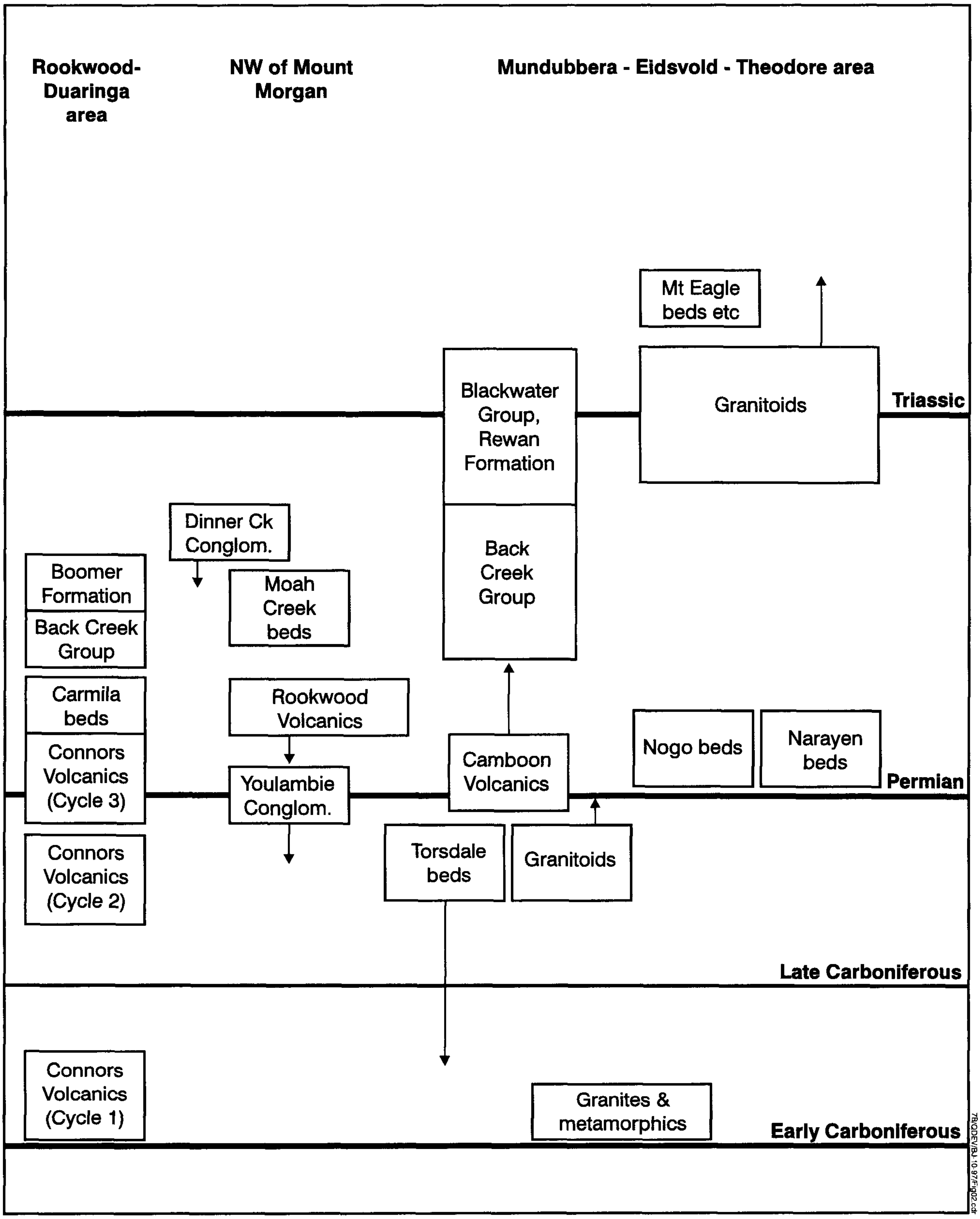


*Figure 3. Time-space diagram showing relationships between units in the southern part of the South Connors-Auburn-Gogango project area.*

Volcanics (relatively low in all channels giving purple hues on the composite RGB radiometric image), but consist of khaki-weathering cleaved siltstone and fine-grained sandstone. They are overlain by the Back Creek Group and appear to mainly overlie the volcanic rocks, although there appear to be some intercalated lavas in the south. The sequence was probably deposited in as a lacustrine environment, possibly occupying a rift formed by the early extensional phase of the Bowen Basin. Thus they may correlate with the

Carmila beds and similar sediments in the "Connors Volcanics" in the Melaleuca Creek area.

### *Narayen beds*

The Narayen beds occur in the southern part of the project area, south-west of Mundubbera. The exposure in this unit is dominated by andesite and andesitic breccia and conglomerate, although the poorly exposed lithic siltstone and sandstone may actually be more voluminous. Minor felsic rocks occur mainly in the south-west. An interesting feature of the volcaniclastic rudites is that the clasts are mostly well rounded, suggesting fluvial depositional processes. Structurally, some open folds with reversals on a 30m scale have been identified. Near Giarka homestead, a zone of intense deformation has produced slates and has stretched and flattened pebbles in the rudites. This may be related to thrusting suggesting that the GOZ extended at least this far south. The Narayen beds have previously been dated as Early Permian. Fossils recovered from coquinite at a new locality in the Narayen Beds may help define the age more accurately.

### *Nogo beds*

The Nogo beds crop out to the east of the Rawbelle Batholith from near Eidsvold to west of Mundubbera. They are very poorly exposed and over much of the area have been hornfelsed by the Eidsvold Complex and Rawbelle Batholith. Volcanic arenites and rudites, mostly derived from andesite appear to be the most common rock types, but andesite lavas and more felsic rocks such as flow-banded rhyolite and dacitic to rhyolitic ignimbrite have been identified. Fine-grained sediments, including cleaved siltstone, carbonaceous mudstone and minor sandstone crop out in places, and could be much more extensive than the sparse outcrops suggest.

## Gogango Overfolded Zone (including adjacent parts of the Bowen basin)

### *Carmila beds*

This unit is more extensive in the northern half of the project area, but in the 1997 field season, rocks that have previously been assigned to the unit were mapped in the north-western part of the Rookwood Sheet area. There, they consist mainly of siltstone, and some fine-grained sandstone and rare strongly altered mafic lavas. They overlie the andesite of the "Connors Volcanics" (Camboon Volcanics equivalents). They are interpreted as a lacustrine sequence deposited in a rifted basin during the early extensional phase of the Bowen Basin. The unit terminates abruptly north of Leura homestead, and the andesitic rocks are directly overlain by mudstones of the Back Creek Group. The Carmila beds are characterised on the composite RGB radiometric image by a green hue that contrasts with the purple hues of the other lacustrine successions associated with the Camboon Volcanics and mafic part of the "Connors Volcanics". This suggests a local provenance in which felsic rocks were more abundant.

### *Undivided Back Creek Group*

In the western part of the Rookwood Sheet area, the andesitic rocks of the "Connors Volcanics", and where present, the Carmila beds, are overlain by a sequence consisting dominantly of cleaved, massive mudstone. Minor lithic sandstone occurs locally, but is clearly subordinate. The rocks are unfossiliferous, but calcareous and/or phosphatic concretions are common in the mudstone, and trace fossils are locally present (*Cruziana* ichnofacies). In places, particularly in the headwaters of Leura Creek and farther north, a sequence of calcareous sandstone and limestone occurs at the base. This basal sequence is locally fossiliferous, and has a fauna assigned to Fauna II by Malone & others (1969). It may therefore correlate with the Buffel Formation in the south-eastern Bowen Basin. Farther south near Thuriba homestead, a thin limestone-bearing sequence overlying the Camboon Volcanics containing a Fauna IV assemblage was assigned to the Oxtrack Formation by Malone & others (1969). Both these areas were re-examined and faunas collected.

The undivided Back Creek Group is characterised by a "hot" radiometric signature, appearing as white on composite RGB radiometric images. In the eastern half of the Rookwood and Duaringa Sheet areas, extensive areas having the same "hot" signature contain a significant proportion of grey lithic sandstone, although mudstone is probably still dominant overall. The "hot" signature of this sandier facies contrasts with the otherwise lithologically similar Boomer Formation (see below). Previously, these rocks were mapped partly as Rannes beds and partly as Boomer Formation.

The sandy facies has been mapped as forming a significant part of the Back Creek Group within the Gogango Overfolded Zone southward to the southern edge of the Duaringa Sheet area. Its relationship to the mudstone dominated facies is uncertain. Mapped contacts with the mudstone dominated facies may be tectonic (thrusts). The radiometric similarity suggests a similar provenance, and the sandy facies may simply be more proximal. In the south, it locally contains intervals rich in flinty siliceous siltstone that may be tuffaceous in origin.

West of Wowan, lenses of strongly deformed crinoidal limestone are common within part of the undivided Back Creek Group that was previously mapped as Rannes beds. No identifiable fauna is preserved, and it is uncertain whether the rocks can be correlated with the Buffel and/or Oxtrack Formations.

The radiometrically "hot" package can be traced south to about Banana, where it was mapped as undivided Back Creek Group rather than Rannes beds. Over most of this area, it is dominated by mudstones, although some sandstone is present locally. The undivided Back Creek Group passes into Barfield Formation near Banana, although only the Station Creek Mudstone Member at the top of the formation has the "hot" signature. Farther south towards Theodore and Cracow, none of the Back Creek Group is "hot".

*Boomer Formation*

The Boomer Formation consists of lithic sandstone and cleaved mudstone, superficially similar to the sandy facies of the Back Creek Group as described above. However, it is radiometrically much cooler (pink or brown on RGB composite images). In the western part of Rookwood Sheet area, it conformably overlies the massive mudstone of the Back Creek Group. The different radiometric signature suggests a different provenance, and where fresh, the sandstones appear to be bluish grey, and possibly more feldspathic than the "hot" sandstones in the undivided Back Creek Group. Suites of samples from both units have been collected for petrographic and geochemical studies to examine provenance differences. Trace fossils are common within the unit, but no body fossils have been found. Plant debris is present locally. A peculiar facies that occurs in several places mainly within rocks mapped as Boomer Formation contains very poorly sorted pebble to cobble conglomerates that commonly have a silty or silty sandstone matrix. This facies is similar to rocks described recently by Fielding (1997) in the Moah Creek beds farther east (Figures 2 and 3), and interpreted by him as due to submarine mass wasting, reflecting the onset of foreland thrust loading.

*Rannes beds*

As previously mapped the Rannes beds is a "bag" unit for any strongly deformed, mostly sedimentary rocks within the GOZ. One of the aims of the work in 1997 was to split the unit into its components and, if possible, reassign them to the other units in the area. Most of the rocks are part of the undivided Back Creek Group, but the unit also included deformed volcanic and volcaniclastic rocks that are now mapped as Camboon Volcanics. These include the lacustrine sequence south from Rannes. One group of rocks of uncertain affinities occurs along the Leichhardt highway between Wowan and Rannes and east of Rannes. They are in contact with the Rookwood Volcanics and locally appear to be interleaved within them. However, the rocks are strongly deformed (locally mylonitic) and the contacts could be tectonic. The rocks include chert, phyllitic mudstone and volcaniclastic sandstone and have a "hot" radiometric signature. They could be sediments within the Rookwood Volcanics, or may be part of the sandy facies of the Back Creek Group. Similar rocks also occur south of Biloela.

*Rookwood Volcanics*

The main outcrop areas of the Rookwood Volcanics have been examined as part of the Yarrol Project (see Murray & others, this volume). However, their southern continuation falls with this project area and was examined south of Wowan and east of Rannes. They are identical with those farther north, and consist mainly of altered aphyric basalt. Local spectacular pillows confirm their submarine emplacement.

## STRUCTURE

The GOZ is characterised throughout by the development of strong slaty cleavage in mudstone and siltstone, although sandstone and volcanic rocks also commonly have a well-developed foliation. This is generally expressed as an anastomosing fracture cleavage, but in more intense zones, particularly in the east between Rannes and the Capricorn Highway, clasts are strongly flattened and commonly stretched. Stretching lineations generally plunge steeply east, and shear-sense indicators are consistent with an east-over-west transport.

Field mapping in the GOZ, aided by interpretation of the radiometric data, has outlined belts of volcanic rocks, undivided Back Creek Group and Boomer Formation. In the eastern part of the GOZ, these generally show a consistent eastward younging and have been interpreted as an imbricate stack of thrust sheets. Thrusts have been interpreted where younging is inconsistent with known stratigraphic relationships (eg, Back Creek Group overlying Boomer Formation, or volcanic rocks overlying Back Creek Group). Some fold closures have been seen at outcrop scale, although they are relatively uncommon. Although some limbs are overturned, many folds are upright, and the description "overfolded" zone is somewhat of a misnomer. Gogango Thrust Zone may be more appropriate.

In the north-western part of the Rookwood Sheet area, on the western side of the Connors Arch, the sequence dips shallowly westwards towards the centre of the Bowen Basin. Although dips are relatively gentle, and folds are upright and open, the mudstones and some sandstones still have a pronounced cleavage. Several low-angle thrusts have been recognised.

## Granitoids in the Auburn Arch

The northern Auburn Arch is extensively intruded by plutons ranging from gabbro to felsic fractionated granite. While detailed relationships between the plutons are uncertain, there appears to be a succession from earlier intermediate and quartz poor varieties (granodiorite, diorite, monzonite and possibly syenite) to later pink to red fractionated granites, although the gabbro appears to be one of the latest bodies. Some of the fractionated granites are high-level and may be co-magmatic with the Torsdale beds.. The granitoids were originally all assigned to a single unit, the Glandore Granodiorite, but at least 18 different units have been recognised and given provisional names.

In the Cracow area, the presumed Late Carboniferous granitic rocks show variable high temperature alteration manifest by reddening due to K-feldspar along joints. The presence of hydraulic breccias and alteration, including quartz-sericite, phyllic and tourmalinisation is a feature of the area, such as at Mount Koangle. The alteration also extends into the Torsdale beds. The granites are inferred to intrude the Torsdale beds, although contact relationships and hornfelsing are rarely seen. The radiometric data has not proved very useful in distinguishing the granites from the Torsdale beds, due to similar responses.

The Kilbeggan Monzogranite in the southern part of the Auburn Arch is clearly a composite unit, with extensive granodiorite and tonalite as well as monzogranite and scattered gabbro. However, poor outcrop and lack of distinctive geophysical signatures may preclude subdivision.

## Metamorphic rocks in the southern part of the Auburn Arch

Extensive deformed zones or "metamorphics" were previously included in the Rocky Springs part of Delubra Quartz Gabbro, requiring expansion of the area previously mapped as unnamed Palaeozoic metamorphics near Yerilla. The metamorphics strike north to north-north-east. They do not contain rock types which would preclude them from being deformed and/or metamorphosed Narayen beds tectonically combined with deformed granitoids. However, they are more likely to be an older sequence, because no obvious transition from pristine Narayen beds has been observed. Metamorphosed equivalents of andesitic rudites appear to be lacking from the metamorphics. There also does not appear to be a transition from undeformed granite into orthogneiss.

U-Pb SHRIMP dating of a deformed granite collected from near the Eidsvold-Cracow road during the 1996 reconnaissance trip has given an Early Carboniferous age (see Table 1), confirming that some older rocks exist in the area, although when the metamorphism and deformation took place is still unknown.

The metamorphic rocks east of Yerilla include some L-tectonites suggesting that some simple shear took place locally. Other metamorphic areas include an amphibolite-grade calc-silicate gneiss of unknown extent presently mapped within the Hawkwood Gabbro, but these probably represent country rock rafts derived from Narayen Beds, which are known to contain limestone elsewhere.

Another metamorphic block may occur in the upper portion of Well Station Creek, in the extreme south-east of Narayen Beds as previously mapped. Rocks include amphibolite, meta-arenite, slate and carbonaceous-schist, and could be high grade Narayen beds. However, there seems to be a sudden transition from fairly low grade to higher grade if this is the case, and considerable dip-slip faulting/thrusting would be required. They have a tectonic foliation dipping moderately to steeply north-west.

## Permian to Triassic granitoids

### *Rawbelle Batholith*

Granitoids in the Rawbelle Batholith are mostly inferred to be Late Permian or Triassic in age, based on Rb-Sr and K-Ar dating by Webb & McDougall (1968) and Whitaker & others (1974). Samples were collected for geochemistry and possibly U-Pb zircon dating in the 1997 season. They range from gabbro to granite. They contrast with the Late Carboniferous granitoids by being fresher in outcrop, and containing sphene, at least in the less fractionated phases.

Some subdivision of the batholith was attempted by Whitaker & others (1974) and most of these subdivisions appear valid, although the shape and extent of many of the plutons will change as a result of the more detailed mapping and interpretation of the geophysical data. Where the same unit name was previously extended to separate, widely distributed plutons (*eg* the Delubra Quartz Gabbro), additional names may be introduced. The largest unit is the Wingfield Adamellite (Monzogranite) in the north. Field work indicates that it is a composite unit, but the poor outcrop and similar geophysical responses of many of the phases precludes subdivision. The most widespread rock type is porphyritic hornblende-biotite monzogranite, but equigranular granitic rocks and some diorite and gabbro were observed locally.

In the southern part of the Rawbelle Batholith, the Delubra Quartz Gabbro has been shown to contain layering, although it is not as conspicuous as in the Hawkwood Gabbro. The eastern margins of Delubra Quartz Gabbro are commonly net veined. It probably intruded synchronously with an underlying body of felsic mainly hornblende-free granodiorite; which can be seen as small scattered plugs and extensive areas of net veining with no obvious mixing. The division between the Delubra Quartz Gabbro and Hawkwood Gabbro appears to be arbitrary, as both have quartz-free and quartz-bearing parts as now mapped. One possible difference though is that the Hawkwood Gabbro contains anorthosite.

### *Eidsvold Complex*

The Eidsvold Complex is a small area of granitic rocks intruding the Nogo beds and overlain by the Jurassic sedimentary rocks of the Mulgildie Basin. Three main rock types are present, leucocratic biotite granite, hornblende-biotite granodiorite and fine to medium-grained diorite. The diorite and granodiorite form an extensive net-vein complex, with the diorite as xenoliths having finer-grained, crenulate margins in the granodiorite. The relationship of the granite to the other two units is uncertain. The Eidsvold Complex is host to the gold mineralisation of the old Eidsvold Goldfield. The mineralisation occurs in quartz veins in altered and sheared granites and in quartz stockworks and granite-quartz breccias.

## Cainozoic deposits

Re-mapping of the Cainozoic deposits, except by photo-interpretation, is largely outside the scope of the project, but some observations have been made. Extensive areas of deep weathering occur through the southern part of the area and also over Tertiary sediments of the Biloela Basin. Very little true ferricrete is developed. Most mesas and cappings are mottled and pallid parts of the weathering zone. This material breaks down to a soil containing ferruginous pebbles which can be mistaken for ferricrete. Small, previously unmapped outliers of basalt have been observed between Biloela and Rannes, and the mapped extent of basalt in the area between Monto and Theodore has been modified.

# MINERAL OCCURRENCE MAPPING

Mineral occurrence mapping has been completed for the Mundubbera 1:250 000 Sheet area. At the time of writing (late September) work had commenced in the Banana, Scoria and Theodore 1:100 000 Sheet areas in the Monto 1:250 000 Sheet area, and was expected to be completed by late October. In the Mundubbera 1:250 000 Sheet area, more than 130 deposits were examined. Mineralisation inspected includes gold, antimony, arsenic, copper, tungsten, manganese and kaolin deposits hosted in Devonian to Early Permian sedimentary rocks and Nogo Beds, in Permian to Triassic intrusive rocks and in recent alluvium.

Lode gold was mined in the Eidsvold Goldfield where the Mount Rose, Mount Jones and Mount Brady deposits are hosted in the Eidsvold Complex. Under the direction of the

Inspector of Mines from Rockhampton a program of mine-shaft rehabilitation was recently carried out by the lease holder. Most of the old workings on Mount Rose south of the airstrip have been filled apart from a few deep shafts which have been fenced off. The positions of most of the mines were recorded before or while the rehabilitation was being undertaken. Eluvial gold occurs below the Jurassic sandstone at its boundary with the weathered Permo-Triassic intrusive rocks.

Gold was mined extensively from alluvial deposits along St John Creek and from fissure lodes associated with intrusive rocks and sedimentary rocks. Most of the lode deposits consist of quartz veins closely associated with a fine-grained felsic dykes emplaced in shear/fault zones in the Permian to Triassic granitoids of the Rawbelle Batholith. The gold occurs with multiple arsenopyrite-pyrite veins in the quartz. Most of the lodes strike 120° and dip steeply to the south-west. The lodes rarely exceed 1 m in width and past mining by shafts and stopes reached a maximum depth of 30m. The individual lodes are small and outcrops do not exceed more than 100m in strike length.

The Yarrol deposit in the Eidsvold area is similar in type and style of mineralisation to the Mount Jones/Mount Rose deposits but may be distinguished by the development of skarn as host rock and the lack of evidence of aplite or pegmatite dyke intrusions.

Minor occurrences of epithermal quartz vein deposits are in the Middle Triassic Mount Eagle Beds.

Lode gold mineralisation in the Cracow area is mainly quartz-calcite vein with minor sulphides. Most of the deposits are structurally controlled and closely associated with shear/fault zones in the Camboon Volcanics. The lode consists of multiple quartz-calcite-arsenopyrite-pyrite-gold veins in stockwork as well as a network of veins in andesitic breccia and lava. West of the Golden Plateau, the Rose's Pride, Klondyke and Royal Standard lodes are calcite-rich lodes and have been emplaced along a north to north-north-westerly ?fault/breccia zone in the andesitic volcanic rocks near the boundary of the Back Creek Group. The calcite content of the gold-bearing veins decreases from the Golden Plateau in the central area of Cracow to the Golden Ridge, Revival, Dawn and Big Gun in the east, being replaced largely by chalcedonic quartz. No marble or calc-silicate rich minerals were identified in any of the gangue material.

A gold deposit associated with a ring dyke in a caldera system is being developed for mining in the Mount Saul area by Cardia Mining NL. A reserve of more than 700 000t at 1.5g/t gold has been outlined. Further drilling is in progress to delineate the ore zone extension to the south.

Antimony was mined in the Hungry Hill area. The lodes are auriferous and occur as fissure lodes in granitoids of the Rawbelle Batholith. Recent company exploration in the Hungry Hill area was mainly for low grade gold mineralisation associated with the antimony lodes.

Minor copper was mined from the Hidden Treasure on Hooper Creek and May Queen at Brovinia homestead. Mineralisation is associated with Permian-Triassic intrusive rocks intruded Carboniferous Beds. The Kildare tungsten deposit consists of fissure quartz lodes. They are narrow and shallowly dipping.

Manganese occurs as supergene enrichment generally filling fractures and joints in strongly weathered Permian-Triassic igneous rock.

## U-Pb (SHRIMP) DATING RESULTS

Six samples from the 1996 reconnaissance trip were selected for U-Pb zircon dating by the SHRIMP method at the Research School of Earth Sciences at the Australian National University. The results (Mark Fanning, written communication) are in Table 1.

The dating confirms that the Torsdale beds do contain Late Carboniferous rocks as suggested by Holcombe & others (submitted). Webb & McDougall (1968) obtained Late Carboniferous ages for the Glandore Granite and other plutons in the Auburn Arch, and therefore, it is possible that some of them are co-magmatic with the volcanic rocks. The significance of the Early Carboniferous K-Ar hornblende age of 343Ma obtained by Whitaker & others (1974) for the Torsdale beds is now uncertain. The site needs to be re-examined and possibly re-sampled for SHRIMP dating to confirm whether parts of an Early Carboniferous arc are preserved in the Auburn Arch. The Early Carboniferous age for the deformed granite west of Eidsvold does at least confirm the presence of some magmatic rocks of this age. They may have been the basement for the Torsdale beds. The age of the deformation is uncertain. The K-Ar biotite age obtained by Webb & McDougall (1968) for the granite is

**Table 1: U-Pb (SHRIMP) dating results**

| Sample | Geological Unit | Locality | Rock type | Age (Ma) |
|---|---|---|---|---|
| RSC011 | Lizzie Creek Volcanics | N of Eungella Dam (636475 7667820) | crystal-rich dacitic ignimbrite | 291±6 (Early Permian) |
| RSC074A | Connors Volcanics Cycle 2 | Big Codling Creek near Croydon-Killarney road (type area of unit) (732290 7520075) | crystal-rich, lithic-poor rhyolitic ignimbrite | 303±5 (Late Carboniferous) |
| RSC093 | Connors Volcanics Cycle 1 | Old Bruce Hwy near Mt Mackenzie (749770 7470770) | crystal-rich, lithic-poor rhyolitic ignimbrite | 350±7 (Early Carboniferous0 |
| RSC157 | Torsdale beds | Eidsvold Cracow road (234121 7198220) | rhyolitic ignimbrite | 313±6 (Late Carboniferous) |
| RSC218A | Torsdale beds | Cockatoo Creek, near Taroom-Auburn road | rhyolitic ignimbrite | 316±6 (Late Carboniferous) |
| RSC164A | Rawbelle Batholith | Eidsvold Cracow road near St Johns Creek crossing (276831 7188285) | Deformed (gneissic) granite | 349±6 (Early Carboniferous) |

Early Triassic (233Ma) and may be reset, because it is identical to ages obtained for the adjacent Rawbelle Batholith. The deformed granite lies along strike from the GOZ, and the deformation may be related.

Dating of the Connors Volcanics confirms that at least some Early Carboniferous volcanic rocks are preserved there as Cycle 1, even if limited in extent. Dear (1994) suggested that Cycle 1 was Middle Devonian and that Cycle 2 was Early Carboniferous. The results above show that Cycle 2, the most extensive unit in the Connors Volcanics, is probably Late Carboniferous. This is in accord with the work of Holcombe & others (submitted) and Allen & others (submitted) that show that the peak of magmatic activity in the Connors Arch was at about 305Ma. The age of the Lizzie Creek Volcanics is confirmed as being Early Permian, and is similar to an age reported for ignimbrite in the Carmila beds by Allen & others (submitted).

## CONCLUSIONS

Although analysis of the field data is at an early stage, some conclusions can be made. The SHRIMP dating has indicated that Early Carboniferous magmatic rocks are present in the Connors and Auburn Arches, but they are likely to be restricted in extent. It is likely that the bulk of the rocks preserved in the belt are Late Carboniferous to Early Permian. The significance of the break between the Torsdale beds and Camboon Volcanics is uncertain at present. The probable lacustrine rocks that occur towards the top of the Camboon, Connors and Lizzie Volcanics and in the Carmila beds were probably deposited in small rift basins that formed during the early extensional phase of the Bowen Basin. Determining whether the Camboon Volcanics and other Early Permian volcanic successions are also related to this extensional event or precede it, and are part of a broad, relatively continuous Late Carboniferous to Early Permian magmatic episode, must wait for further studies, in particular geochemistry and isotopic dating.

Metamorphic rocks are more widespread than previously mapped in the Auburn Arch. An Early Carboniferous U-Pb age obtained on gneissic granite suggests that these rocks probably formed basement to the Torsdale beds, but whether the deformation is also of this age or younger and related to the Hunter-Bowen Orogeny and the deformation manifest by the Gogango Overfolded Zone is not known.

The Gogango Overfolded Zone is a stack of imbricate thrusts that incorporates elements of the Bowen basin and Connors and Auburn Arches. In particular, the Rannes beds are regarded as obsolete having been shown to consist largely of sedimentary rocks that can be equated with the Early Permian Back Creek Group, as well as some deformed felsic volcanic and sedimentary rocks that are related to the Camboon and Connors Volcanics.

Field data capture and validation have been greatly enhanced through the adoption of new technologies. In addition to traditional pre-field photogeological interpretations, the interpretations of Departmentally generated airborne radiometric and magnetic data have made field work quicker and more efficient, enabling geologists to focus on key areas. Further subdivision of the granitoids of the Auburn Arch and Rawbelle Batholith has been possible, utilising the airborne geophysical data. The radiometric data also proved useful in mapping sedimentary units within the Gogango Overfolded Zone, and distinguishing felsic and mafic units in the volcanic sequences. However, some difficulty was experienced distinguishing granites and volcanics in the Torsdale beds. The capture of pre-field data into the project GIS enabled the production of preliminary compilation sheets displaying the above interpretations, together with previous geological boundaries and observation sites, cultural features and drainage. The system also facilitated the compilation and display of historical tenure and mineral occurrence data in support of metallogenic mapping.

## REFERENCES


ALLEN, C.M., WILLIAMS, I.S. & STEPHENS, C.J. (submitted): Ages of plutonic rocks in the northernmost New England Orogen. *Australian Journal of Earth Sciences.*

DAY, R.W., 1995: GEOMAP 2005 Program: the key to unlocking Queensland's mineral wealth. *Queensland Government Mining Journal*, **96**(1126), 463–468.

DAY, R.W., MURRAY, C.G. & WHITAKER, W.G., 1978: The eastern part of the Tasman Orogenic Zone. *Tectonophysics*, **48**, 327–364.

DEAR, J.F., 1994: Major cycles of volcanism in the southern Connors Arch. In Holcombe, R.J., Stephens, C.J. & Fielding, C.R. (Editors): 1994 Field Conference, Capricorn region, central coastal Queensland. *Geological Society of Australia Inc. (Queensland Division)*, 31–45.

FERGUSSON, C.L., 1991: Thin-skinned thrusting in the northern New England Orogen, central Queensland, Australia. *Tectonics*, **10**, 797–806.

FERGUSSON. C.L., HENDERSON, R.A. & LEITCH, E.C., 1994: Tectonics of the New England Fold Belt in the Rockhampton Gladstone region, central Queensland. In Holcombe, R.J., Stephens, C.J. & Fielding, C.R. (Editors): 1994 Field Conference, Capricorn region, central coastal Queensland. *Geological Society of Australia Inc. (Queensland Division)*, 1–16.

FIELDING, C.R., 1997: Submarine mass-wasting deposits as an indicator of the onset of foreland thrust loading — Late Permian Bowen Basin, Queensland. *Terra Nova (The European Journal of Geosciences)*, **9**, 14–18.

FIELDING, C.R., HOLCOMBE, R.J. & STEPHENS, C.J., 1994: A critical evaluation of the Grantleigh Trough, east-central Queensland. In Holcombe, R.J., Stephens, C.J. & Fielding, C.R. (Editors): 1994 Field Conference, Capricorn region, central coastal Queensland. *Geological Society of Australia Inc. (Queensland Division)*, 17–30.

FIELDING, C.R., STEPHENS, C.J. & HOLCOMBE, R.J. (submitted): Permian stratigraphy and palaeogeography of the northern New England Fold Belt in coastal central Queensland. *Australian Journal of Earth Sciences.*

HOFMANN, G.W., 1990: Queensland's questionnaire on geoscience mapping. *Queensland Government Mining Journal*, **90**, 463–468.

HOLCOMBE, R.J., STEPHENS, C.J., FIELDING, C.R., GUST, D., LITTLE, T.A., SLIWA, R., MCPHIE, J. & EWART, A, (submitted): Tectonic evolution of the northern New England Fold Belt: Carboniferous to Early Permian transition from active accretion to extension. *Australian Journal of Earth Sciences.*

MALONE, E.J., OLGERS, F. & KIRKEGAARD, A.G., 1969: Geology of the Duaringa and St Lawrence 1:250 000 Sheet areas, Queensland. *Bureau of Mineral Resources, Australia, Report* **121**.

MURRAY, C.G., 1986: Metallogeny and tectonic development of the Tasman Fold Belt System in Queensland. *Ore Geology Reviews*, **1**, 315–400.

WEBB, A.W. & McDOUGALL, I., 1968: The geochronology of the igneous rocks of eastern Queensland. *Journal of the Geological Society of Australia*, **15**, 313–346.

WHITAKER, W.G., MURPHY, P.R. & ROLLASON, R.G., 1974: Geology of the Mundubbera 1:250 000 Sheet area. *Geological Survey of Queensland, Report* **84**.



**Reference for this paper:**
**I.W. WITHNALL, I.W. JOHN, B.H. HUTTON, L.J. LAM, J.S. BULTITUDE, R.J. VON GNIELINSKI, F.E. RIENKS I.P. & GARRAD, P.D., 1997: South Connors-Auburn- Gogango Project. *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 57–70.**

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# What is coalseam methane?

## INTRODUCTION

### Understanding coalseam methane

An appreciation of the potential value of coalseam methane gas as a fuel and feedstock source in eastern Queensland depends upon a good understanding of its nature, its origin, and its availability to the market.

### Nature of coalseam methane

Coalseam methane gas is methane gas derived from coalseams. It is primarily composed of methane gas, with the formula $CH_4$, the key constituent of "natural gas".

## ORIGIN OF COALSEAM GAS

### Origin of coalseam methane

All methane gas is methane gas whether derived directly from a coal seam or produced from a secondary sandstone reservoir into which it has migrated after initial generation in the coal seam. No methane gas is generated or "created" in any reservoir except coal or other highly carbonaceous rock.

Methane gas produced from sandstones or limestones originated in a coal, was expelled from the coal at great pressure by the generation of additional methane within the coal, migrated upward into an overlying sandstone reservoir, and was then produced as "natural gas" from the sandstone reservoir. Coals produce many times their holding capacity for gas, and the excess volumes of gas migrate upward through microfractures in the overlying rock to the surface, or to intervening reservoir rocks.

### Purity of coalseam methane

Natural gas produced directly from coal is usually more pure than gas from other reservoirs which may contain greater amounts of carbon dioxide, nitrogen, and hydrogen sulfide and require treatment before entering a pipeline.

Methane generation in coalseams. Methane gas is generated under two conditions, biogenic and thermogenic. Biogenic gas is created by the decay of organic material in swamps, refuse dumps, or similar situations at ambient surface temperatures.

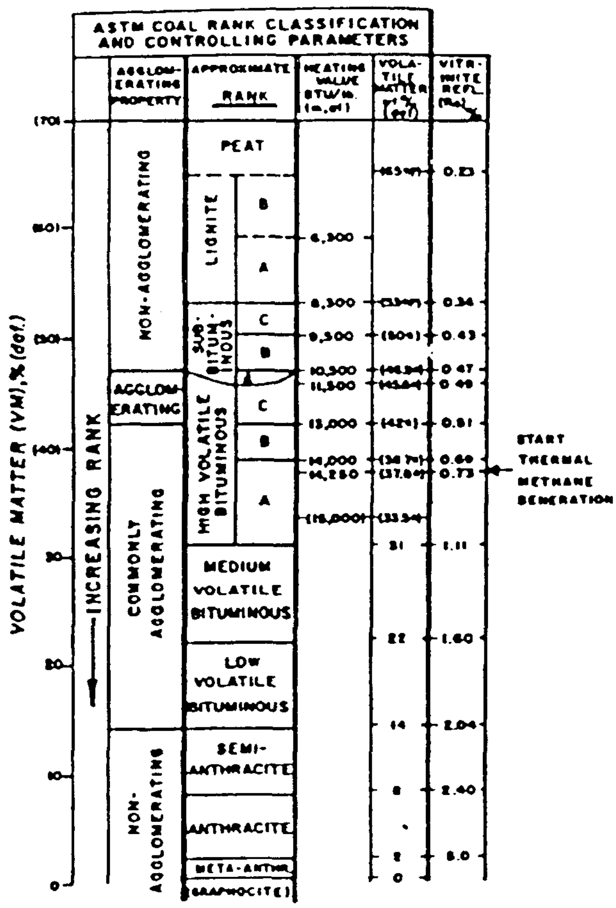


*Figure 1. Coal rank and physical characteristics (Meissner, 1984).*

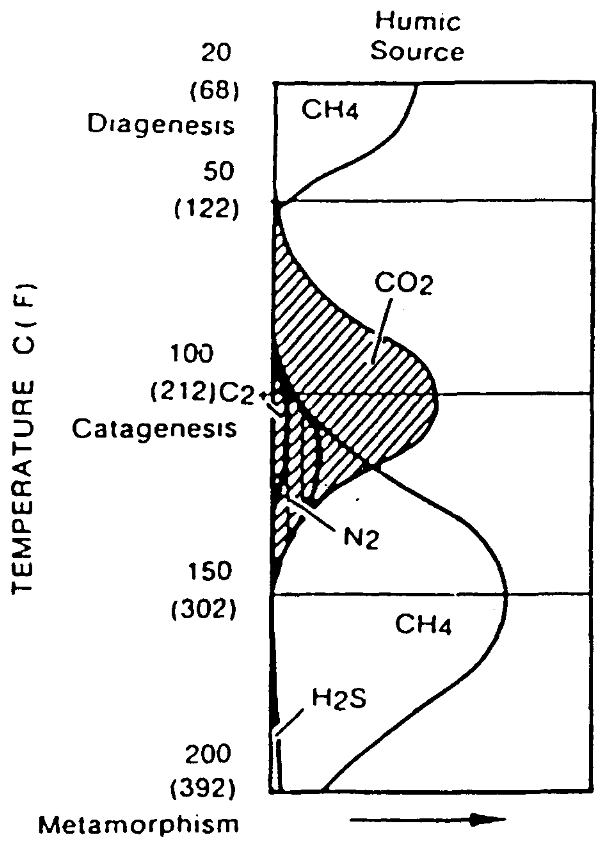


*Figure 2. Sequence of gas generation as a function of temperature (Hunt, 1979).*

## Thermal generation of methane

Thermogenic methane forms in coals during the thermal maturation of coal as it metamorphoses through the sequence: peat-lignite-bituminous-anthracite. As peat is buried, heat and pressure transform the peat into lignite; with increasing depth of burial, lignite is transformed into bituminous, then finally anthracite. Time duration and sporadic thermal events are secondary factors affecting gas content.

Vitrinite reflectance is the standard measure of the degree of thermal maturation. Reflectance varies from zero in peat, 0.71% in bituminous coal, to 3.0% in anthracite coal.

The start of thermogenic creation of natural gas in coal is at a reflectance value of about 0.73% in high-volatile "A" bituminous coal (Figure 1).

## Generation of various gases

The graph shown here as Figure 2 shows the sequence of various gases generated during the burial history/temperature regime of the coal and accounts for the presence of $CO_2$, $N_2$, and $H_2S$ as well as $CH_4$ (methane).

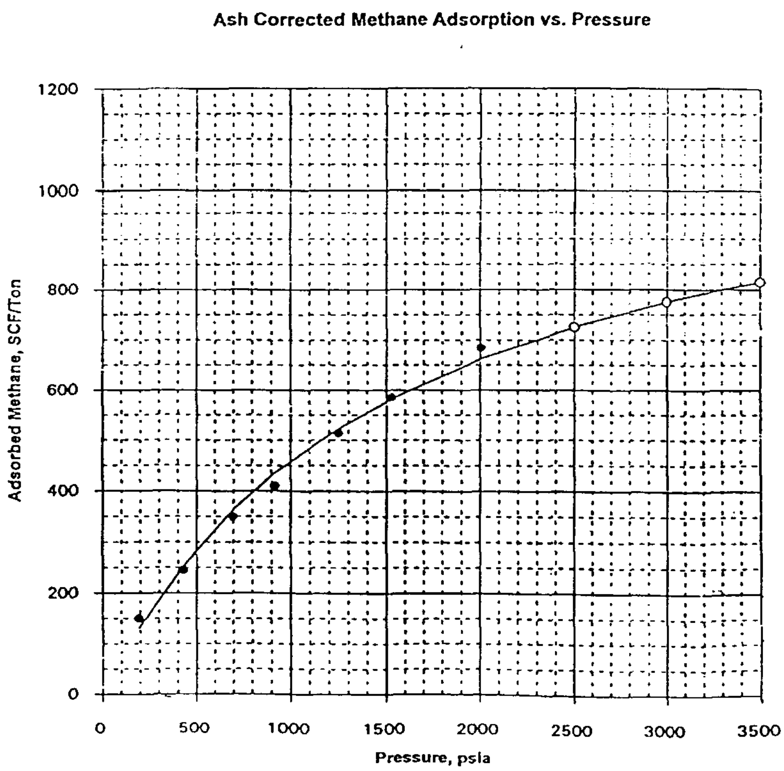


*Figure 3. Coal methane adsorption isotherm.*

*COMPANY: Tri-star Petroleum*
*WELL: Fairview#1*
*Seam Temperature, F: 120.0*
*Moisture Content %: 5.20*
*Ash Content (dry basis) %: 9.01*

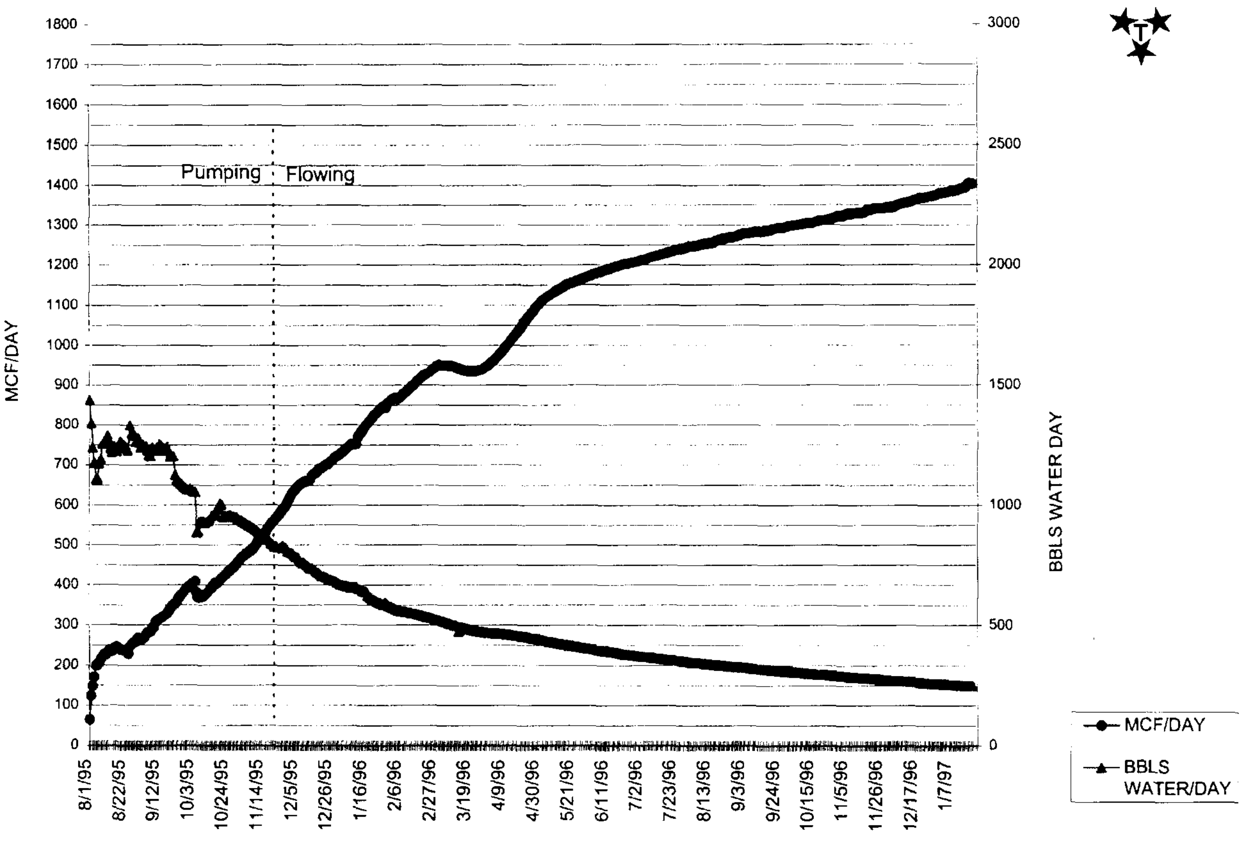


*Figure 4. FAIRVIEW #13 - Daily gas and water production rate installation of gas-water sererator.*

## EXPLORATION

### Exploration for coalseams

Methane exploration is quite simple, a matter of identifying an area where the coals are at a proper depth, with sufficient thickness, permeability, and gas content to produce profitably into the nearby pipeline.

## ESTIMATION OF RESERVES

### Reserve estimation

The quantity of producible gas contained in any specific coal be easily determined by grinding the coal to a powder, evacuating the contained gases, and then re-injecting gas into the sample at increasing pressure stages. A graphical representation of pumping gas back into the coal at staged pressures is called a "sorption isotherm" (Figure 3). "Isotherm" means that the injection of the gas was carried out at a constant temperature. "Sorption" refers to adsorption. The resulting curve is a representation of the producible gas contained in the coal at any particular pressure. The rate of production is controlled by the permeability of the coal, and the quantity of ultimately producible gas is reflected by the curve.

## PRODUCTION

In conventional reservoirs, the initial pressure of the reservoir is the driving force that enables the petroleum to be pushed to the borehole. As the pressure declines, so does the rate of production. However, in coalseam reservoirs, decreases in reservoir pressure result in increased gas productivity. In coalgas production, the goal is to reduce the reservoir pressure so that the gas will migrate from the matrix of the coal into the cleats and then to the borehole. Buried coals usually contain the water that was in the bog or swamp where the original plant material accumulated and was deposited. This water is pumped out of the coalseam, lowering the reservoir pressure, and allowing gas to migrate to the borehole. As the water is depleted, the gas production increases as shown in Figure 4. This figure shows the production history of the Tri-Star #13 Fairview well for 18 months and is typical of a commercial coalseam gas well in the Bowen Basin.

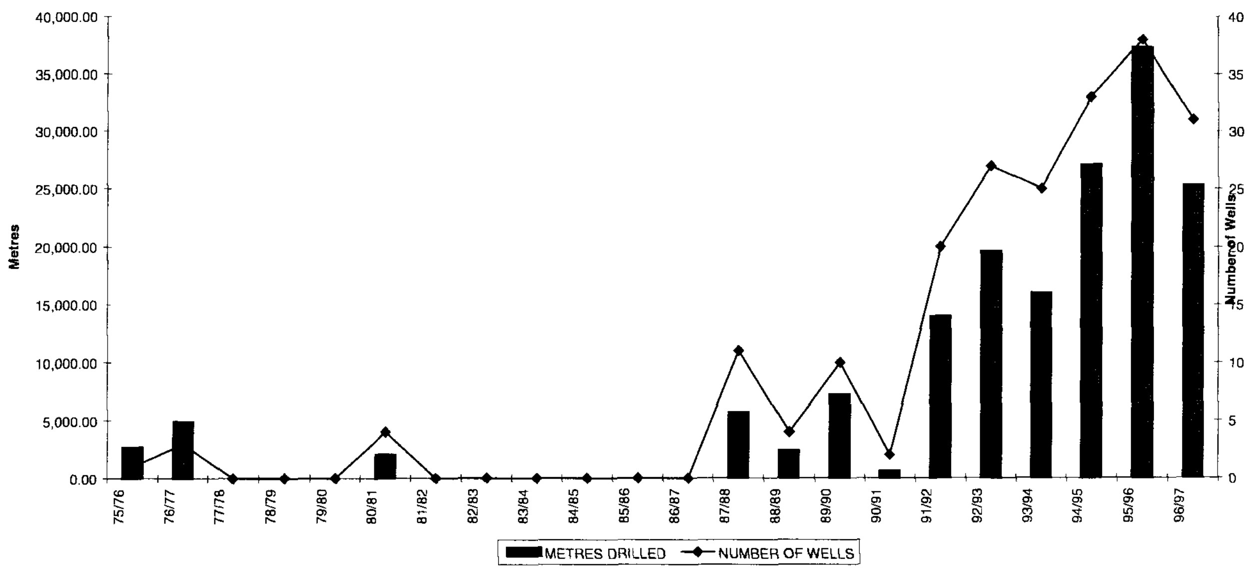


*Figure 5. Fluctuations in drilling activity.*

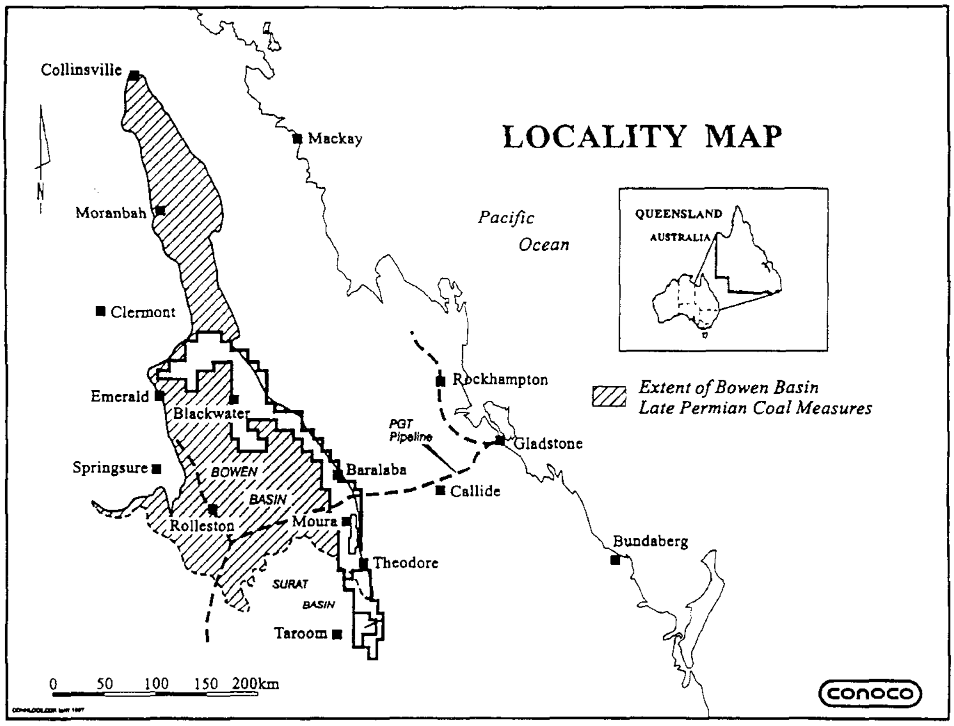


*Figure 6. Locality Map.*

## DRILLING ACTIVITY

A graph of coalseam gas drilling activity covering the past 20 years was provided by the Department of Mines and Energy and is shown here as Figure 5. Subject to the resolution of Native Title questions, we expect drilling rates will increase greatly as the coalseam resources of the Bowen Basin are developed.

## COMMERCIAL FEASIBILITY

The coalgas resources of Queensland are located close to the industrial eastern seaboard (Figure 6) and will be the low-cost gas-of-choice, given that drilling costs and pipeline tariffs can be maintained at reasonable levels. Production costs are expected to be lowered by "economies-of-scale" associated with large-scale development.

**Reference for this paper:**

**BUTLER, J., 1997: What is coalseam methane? *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 71–74.**

*Peter Green*

Queensland Department of Mines and Energy

# Petroleum exploration in Queensland — new opportunities in the pipeline

## SUMMARY

Over the last 5 years, a massive expansion in pipeline infrastructure has occurred in Queensland. This expansion mirrors the need to tap new gas reserves to augment the traditional supply of gas from the Bowen and Surat Basins in south-east Queensland and to provide energy to the growing industrial markets on the east coast. Completion of the proposed pipelines will see an even greater expansion of the pipeline infrastructure in Queensland. These pipelines are providing the ideal situation to capitalise on any gas discoveries in the remote areas in the State. Previously, discoveries had to be either near infrastructure or sufficiently large to justify the capital expenditure needed to connect with major cities in eastern and southern Australia. Reduced infrastructure cost is renewing interest in many of Queensland's prospective sedimentary basins.

## INTRODUCTION

### Exploration history

Following the brief harnessing of gas for town lighting from a water bore at Roma in 1906, the first commercial discoveries of gas and oil in Australia were at Timbury Hills and Pickanjinnie, and Moonie in 1960 and 1961 respectively. This success resulted in a major upturn in exploration in Queensland during the 1960s and the subsequent discovery of numerous gas fields along the western margin of the Surat and Bowen Basins (Figure 1). The gas from these basins was to dominate supply to the south-east Queensland market for the next 30 years.

The discoveries in the Surat and Bowen Basins provided a stimulus for exploration in other parts of Queensland. Success soon followed with the discovery of the Gilmore Gas Field in the Adavale Basin in 1964. The isolation of this field in central Queensland and its small reserves resulted in the development of these reserves being deferred until 1995. Unfortunately, over the years, interest in the Adavale Basin waned owing to the relatively deep targets and the abundant gas reserves in the Bowen and Surat Basins to the east.

In 1963, a gas flow from Gidgealpa 2 in the South Australian portion of the Cooper Basin confirmed the potential of this basin to contain significant quantities of gas. However, it was not until 1969 that gas was discovered in the Queensland portion of the Cooper Basin in TEA Roseneath 1. Although the Permian-Triassic Cooper Basin was recognised as a major hydrocarbon province, the overlying Jurassic-Cretaceous Eromanga Basin in Queensland was considered to have minimal hydrocarbon potential. This perception changed in 1980 with the discovery of the Jackson oilfield, the largest onshore oilfield in Australia. The Cooper and Eromanga Basins have become Australia's most important onshore petroleum basin supplying gas to Adelaide, Sydney, Canberra and Brisbane, and liquids to Brisbane and Point Bonython.

Exploration of other basins in Queensland has been encouraging without commercial success. AOD Ethabuka 1 in the Cambrian-Ordovician Georgina Basin in western Queensland flowed gas at 7150m$^3$/d. This test should be considered to be indicative only, as the well had to be abandoned owing to drilling difficulties.

In the north-eastern Galilee Basin, gas was recovered from the Late Carboniferous–Early

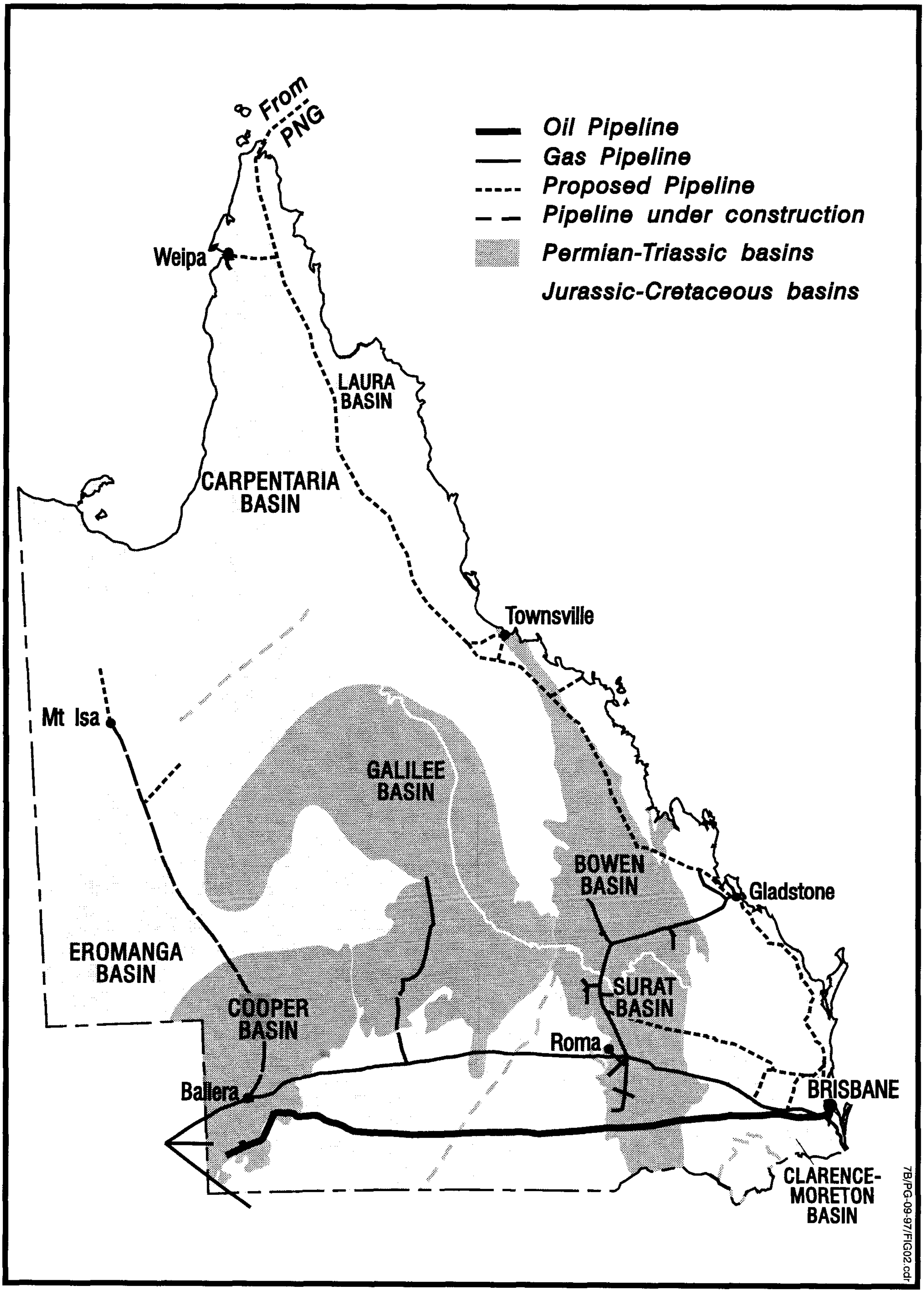


*Figure 1. Queensland petroleum basins and pipeline infrastructure.*

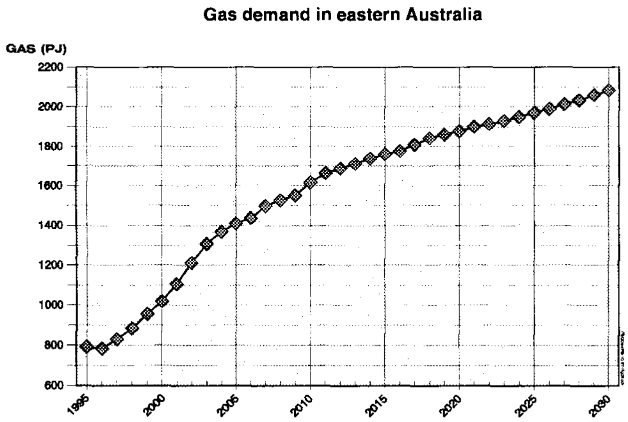


*Figure 2. Gas demand in eastern Australia.*

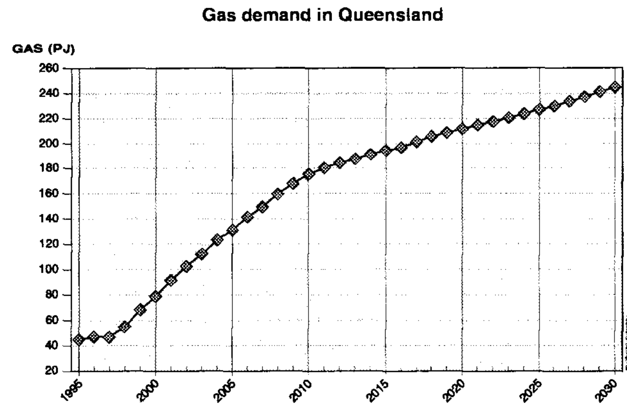


*Figure 3. Gas demand in Queensland.*

Permian Lake Galilee Sandstone in FPN Koburra 1 and oil was recovered for the same units in ENL Lake Galilee 1.

The Bamaga Basin in the Gulf of Carpentaria is yet to be drilled.

## Pipeline development

The development of the Bowen and Surat Basins' oil and gas reserves required the construction of the Moonie–Brisbane and Wallumbilla–Brisbane oil and gas pipelines which were commissioned in 1964 and 1969 respectively.

Infrastructure development in south-west Queensland began in 1983 with the construction of the pipeline from the Jackson field to connect with the Moonie–Brisbane oil pipeline.

Pipeline developments continued through the 1980s with the construction of the State Gas Pipeline which connected the Roma gas fields with those in the Denison Trough for the supply of gas to the alumina plant in Gladstone. The availability of gas in this region has been accompanied by increased industrial development in Gladstone including an explosives plant. An extension of the pipeline supplies gas to the magnesia plant in Rockhampton.

Gas infrastructure in south-west Queensland began in 1992 with the connection of the Stokes Gas Field on the Queensland-South Australian border to the gas centre at Moomba in South Australia. Also, construction of the Ballera gas centre and a pipeline to Moomba were undertaken to meet the Pipeline Authority of South Australia (PASA) gas contract.

Gas reserves in the Bowen and Surat Basins were considered insufficient to meet peak-demand in south-east Queensland by 1997. To overcome shortfalls, a pipeline was constructed from the Ballera Gas Centre to Wallumbilla with gas being supplied late in 1996.

The Ballera-Mount Isa pipeline is currently under construction. This pipeline will provide gas to the Carpentaria Minerals Province and underpin the development of Mount Isa as a major mineral processing centre. This pipeline is scheduled to be operational by April 1998.

The development plans for additional pipelines in Queensland are well advanced. A pipeline is proposed from Papua New Guinea near the east coast to connect with the current pipeline network at Gladstone. Additional distribution pipelines are planned to connect all the major population centres in south-east Queensland. Other major infrastructure planned including the connection of the Ballera-Wallumbilla line to the Gilmore Gas Field and an additional pipeline linking central Queensland with the coast. A pipeline connecting Denison Trough fields with Brisbane is also under consideration.

## Gas demand and supply

The demand for gas in eastern Australia (Figure 2) is increasing with the expectation that supplies from Bass Strait, Cooper Basin, and the Bowen and Surat Basins will be unable to meet this demand (Australian Gas Association, 1997). Thus, additional gas reserves are required. This demand will see increased exploration in old areas and will also require the introduction of gas from new sources.

The demand of gas in Queensland (Figure 3) is likely to markedly increase during the next few

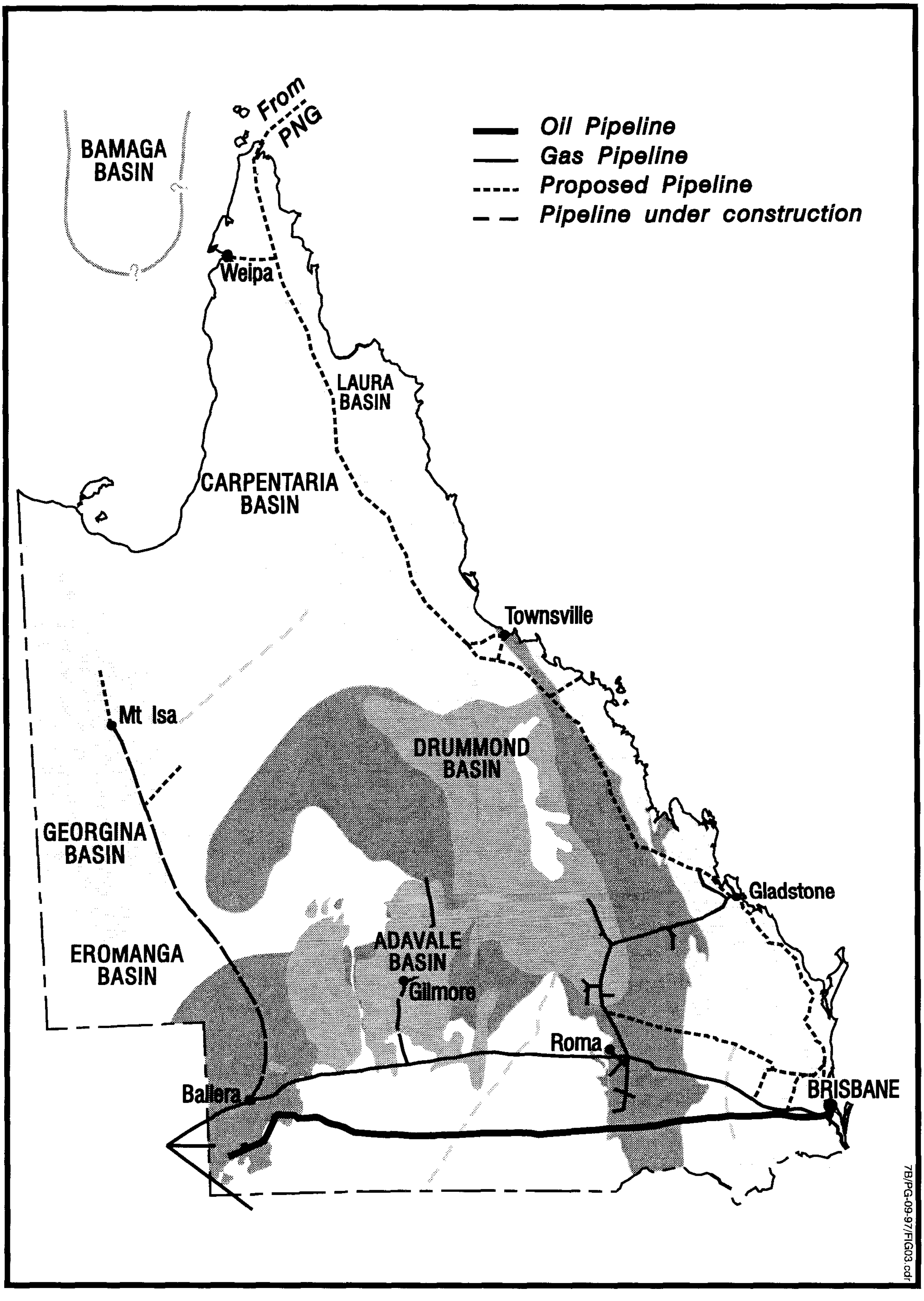


*Figure 4. Queensland prospective basins.*

years to meet the requirements for new industrial development and power generation. These developments are likely to see the demand for gas in Queensland rise to $4.6 \times 10^9 m^3$/year (175PJ) by 2010 and may be as much as $7.7 \times 10^9 m^3$/year (292PJ) by 2030. The current reserves of gas in Queensland are estimated at $56 \times 10^9 m^3$ (2128PJ) with present production being $4.6 \times 10^9 m^3$/year (Scott & others, 1997).

The major source of gas for Queensland will be the Cooper and Eromanga Basins. Exploration activity in the Cooper and Eromanga Basins increased during 1996/97 with 29 wells being drilled for 12 discoveries compared with 23 wells for 8 discoveries in 1995/96.

Additional reserves are needed to ensure long term gas supplies. Additional small reserves are likely in the Bowen and Surat Basins where 12 exploration wells were drilled during 1996/97 for 4 discoveries.

Interest in coal seam gas exploration is continuing with the current test sites entering commercial production. Although there are potentially large reserves associated with coal seam methane, concerns still exist regarding the production of gas from this source. The unavailability of reliable estimates of coal-seam methane deliverability makes planning difficult.

These factors highlight the need for the discovery and development of additional gas reserves to meet the expanding Queensland market. The economics of supplying gas from other source in Queensland have been substantially improved by the extensive pipeline development currently being undertaken or planned in the State. The major likely sources of gas are discussed in the following section according to the geological age of basins rather than in their ranked potential to supply gas (Figure 4).

## EXPLORATION OPPORTUNITIES

### Georgina Basin

The Cambrian-Ordovician Georgina Basin has long been viewed as a potential hydrocarbon-producing basin. The location of the basin near the Carpentaria Minerals Province makes this basin a logical source of gas for this region. However, initial exploration was disappointing and the potential of the basin was downgraded.

The geological setting of the Georgina Basin in Queensland can be subdivided into three structural elements, the Toko Syncline, Undulla Sub-basin and the Burke River Structural Belt. However, only the Toko Syncline appears to have any potential as shown by the gas show in AOD Ethabuka 1.

Sedimentation in the Toko Syncline began in the Neoproterozoic with the deposition of a tillite. A period of non-deposition separates the next phase of sedimentation associated with a Middle Cambrian transgression. This transgression was relatively rapid and resulted in the deposition of shelf carbonates and phosphorities in the Undulla Sub-basin and Burke River Structural Belt while a condensed sequence was deposited in the Toko Syncline.

The carbonate-shelf deposition occurred throughout the Middle to Late Cambrian. During the Early Ordovician, restricted marine conditions developed resulting in extensive dolomitisation. The next phase of sedimentation was marine clastic before fluvial red-bed sedimentation completed the sedimentation history.

The development of deep-water marine sedimentation in the southern part of the Toko Syncline resulted in the accumulation of organic rich rocks suitable for the generation of hydrocarbons. Structural traps are likely along the Toomba Fault which forms the western margin of the Toko Syncline.

Stratigraphic traps in the Toko Syncline may also be possible as the deep-water carbonates pass northwards into a carbonate shelf succession. Porosity development may be associated with these shallow water carbonates and their lateral position relative to the good source units would provide excellent trapping opportunities.

The construction of the Ballera-Mount Isa pipeline has significantly changed the economics of developing a gas resource in the Georgina Basin. Previously, any hydrocarbons found would have to have been large to justify the cost of its development in this remote location. A 700km pipeline would have to be constructed to connect the resource to Mount Isa, the nearest market. However, this distance has been substantially reduced with the development of the Ballera-Mount Isa pipeline. The connection distance from any field to this pipeline is approximately 150km, thus significantly reducing project development costs.

## Adavale Basin

Exploration in the Adavale Basin has been in three phases. The initial phase was in the 1960s when an extensive analogue-seismic program supported by drilling was undertaken. The quality of this seismic data was relatively poor resulting in many wells being incorrectly placed and thus were not necessarily valid tests of the structures targeted. The second phase was during the late 1970s–early 1980s when a regional digital seismic coverage was acquired over most of the basin. A few unsuccessful petroleum wells were drilled during this period. The final phase of exploration has recently been undertaken with the specific aim of increasing gas reserves in the basin. This program has been restricted mainly in the area around the Gilmore Gas Field.

The Devonian Adavale Basin remains one of the enigmas of the petroleum exploration scene in Queensland. The potential of this basin to contain hydrocarbons was demonstrated in the 1964 with the discovery of the Gilmore Gas Field. However, later exploration failed to yield any additional discoveries.

Devonian rocks are present in the Warrabin Trough to the west of the Canaway Fault and in the Adavale Basin in the east. Owing to the similarities in depositional history the structural units will be considered to be part of a single depositional identity and will not be considered separately.

The basin developed through two distinct phases. The initial phase consisted of rifting, accompanied by the formation of half grabens throughout most of the area. Marine sedimentation dominated most of the early phase with extensive delta development occurring in the northern part of the Adavale Basin. The basin subsequently became barred and extensive evaporites formed along the eastern margin. A later sag phase resulted in the deposition of a basin-wide carbonate interval followed by marine clastics and finally red-bed sedimentation.

The basin underwent an extensive period of deformation in the Late Carboniferous resulting in the erosion of up to 3000m of section. A break in the vitrinite reflectance profiles in many wells suggests that this was the major period of hydrocarbon generation.

Further understanding of the geological history of this basin is to be assessed as part of the GEOMAP 2005 program. The availability of improved seismic data and modern geophysical, geological and geochemical techniques should enable a better assessment of the hydrocarbon potential of this basin to be made. Current indications suggest that the basin has potential for additional petroleum discoveries.

## Galilee Basin

The Galilee Basin remains one of the disappointments of the Queensland petroleum scene. The basin contains rocks of similar age and depositional setting to the Cooper Basin in the south-west and the Bowen Basin to the east — both of these basins contain significant quantities of hydrocarbons.

Sedimentation began in the Late Carboniferous with the deposition of fluvial sandstones. Then followed fluvial and lacustrine deposition with periods of glaciation. Volcanic activity in the east then produced numerous tuff horizons. Coal measure deposition began in the late Early Permian and continued during the Late Permian. Fluvial Early and Middle Triassic sedimentation completed the depositional succession in this basin.

Hydrocarbons have been recorded from this basin, with the most promising occurrence being in the lowermost part of the succession (Lake Galilee Sandstone) in the east. These occurrences were particularly intriguing owing to the absence of any major source interval near these occurrences.

The geophysical data coverage of this area is relatively sparse with most data being acquired during the 1960s with a later less extensive coverage being acquired in the late 1970s and early 1980s. The need to upgrade the regional geophysical data set over the Galilee Basin has long been recognised. During 1997, the Department undertook an aerial geophysical survey over the Drummond Basin and along the eastern margin of the Galilee Basin. This survey had a dual purpose in completing the geophysical coverage over the Drummond Basin and providing new coverage over the eastern Galilee Basin. The new geophysical data will assist in understanding the geological setting of the Galilee Basin, especially its structural setting. The processing and interpretation of this data are continuing.

## Northern Cooper Basin

The Cooper Basin is Australia's most productive onshore hydrocarbon-producing basin and has supplied the gas requirements for Adelaide, Sydney, Canberra and provincial towns for over 20 years. Most of this gas has been supplied from the south-western (South Australian) portion of the Cooper Basin.

The northern Cooper Basin consists of a Permian coal measure succession followed by deposition of Triassic fluvial clastics units. The Jurassic-Cretaceous Eromanga Basin occurs throughout the region and consists of interbedded fluvial and fluvial-lacustrine units of Jurassic age followed by Cretaceous fill consisting mainly of marine mudstones with a final sedimentation being fluvial sandstones and mudstones.

The recoverable reserves in the Cooper Basin are presently estimated to be 2948PJ with another 1397PJ of reserves (Bureau of Resource Sciences, 1997) that are not currently commercially viable. The estimates of the quantity of undiscovered gas in the Cooper Basin vary from 645 to 1260PJ with a 50 per cent probability of an additional 915PJ being discovered in the basin.

Production of gas from the Queensland portion of the basin began in 1993. Most of this production comes from the southern part of the Cooper Basin. The northern part of the Cooper Basin has been considered to be less prospective than the south owing to its shallower depth and thin (coal) source potential. However, recent gas discoveries in the basin and discovery of the Inland Oil Field in the Eromanga Basin to the north of the Cooper Basin margin suggest that this area has excellent potential for future hydrocarbon discoveries. The Ballera–Mount Isa pipeline has enhanced the development economics of any discovery in this region.

### Bamaga Basin

The Bamaga Basin remains one of the great unknowns in Queensland petroleum exploration. The Gulf of Carpentaria was initially explored for the seaward extension of the Carpentaria Basin with the hope that the Basin would be deeper and the sedimentary section thicker with better petroleum prospects. The area was recently explored with the aim of finding an energy source for the bauxite mine at Weipa.

Seismic surveys of this region have delineated an older basin beneath the Carpentaria Basin. The age of this basin can only be inferred mainly from the geology of older basins known onshore. The fill of the basin has been subjected to speculation ranging from Early Palaeozoic carbonates to Late Palaeozoic and Triassic clastics.

Maturation levels in this basin are likely to be sufficient for the generation of oil and possibly gas. An Early Palaeozoic fill would suggest an oil and gas prone basin whereas a Late Palaeozoic-Triassic terrestrial succession would more likely to be gas prone. This maturation trend is based on the known maturity values of nearshore wells which suggests the area should have generated hydrocarbons.

The interest in this basin has been highlighted by the potential development of the pipeline from Papua New Guinea. This pipeline is being planned to bring gas adjacent to the east coast of Queensland to fuel the possible expansion of the alumina refinery at Gladstone.

Regional investigations have identified several potential targets and the potential of this basin is now waiting to be tested.

## DEPARTMENTAL ACTIVITIES

The Department of Mines and Energy, Queensland (QDME) recognises the importance of providing up-to-date geological information as a means of attracting exploration to the State. Updating programs have been undertaken through co-operative projects with Commonwealth and other State government agencies and as specific Departmental initiatives.

The revision of the geology of the Bowen and Surat Basins was the major focus of the National Geoscience Mapping Accord (NGMA) 'Sedimentary Basins of Eastern Australia' (SBEA) Project. This was a joint project between the Department, the Australian Geological Survey Organisation (AGSO) and the New South Wales Department of Mineral Resources. The QDME's contribution to this project has been completed and a report on these results has recently been published (Green, 1997).

The Cooper and Eromanga Basins are currently the focus of a joint project between Queensland and agencies of the Commonwealth, South Australian, Northern Territory and New South Wales governments. Phase 1 of the project has been completed resulting in the standardisation of lithostratigraphic and chronostratigraphy across the Queensland-South Australian border. Phase 2 of the project to develop a hydrocarbon generation model is scheduled for completion by the end of February 1998. The other major aspect of this phase of the project is the development of regional data sets. A draft regional 'C'-horizon (top of the Cadna-owie Formation) has been completed and a final version of the map will be released in June 1998. A standardised data set for all wells in the project area is scheduled for release by the end of June 1998. The project is planned for completion by early 1999.

The Department also recognises the need to update the regional geophysical coverage in Queensland and has been acquiring aerial geophysical data over eastern parts of Queensland since 1993. The oldest magnetic coverage is in western Queensland over the petroleum prospective basins. The need to update this coverage resulted in a change in emphasis of the aerial geophysical program from eastern Queensland. The 1997 survey focused on the Drummond Basin and overlying Galilee Basin. This survey was designed to improve the understanding of the geology of the Drummond Basin and the controls on the mineralisation associated with the volcanic units at the base of this succession.

The Adavale Basin will be the prime target for the Department's 1998 aerial geophysical program. This basin was selected owing to the recent interest, plus the generally poor quality of the aerial geophysical data coverage. The timing of the acquisition program has been scheduled to enable the data and preliminary interpretation to be completed in time for the commencement of the Department's Adavale Basin project in the middle of 1999. The need to update the geology of the Adavale Basin has been included in the Department's GEOMAP 2005 program.

## CONCLUSIONS

The gas supplies for Queensland have traditionally come from the Bowen and Surat Basins and are now being augmented by those from the Cooper Basin in south-west Queensland. The need to develop gas resources in conjunction with the requirement for the construction of major pipelines has created additional opportunities in previously prospective basins. Originally, the geographic location to these basins meant that the size of the field had to be large enough to justify its development. Now, the new pipeline infrastructure means that even modest reserves can be connected by way of relatively short pipelines to just about any market in Queensland. Thus the extension of the pipeline network throughout Queensland will assist the economics of developing any discoveries in the Georgina, Adavale, eastern Galilee, northern Cooper and Bamaga Basins.

## REFERENCES


AUSTRALIAN GAS ASSOCIATION, 1997: *Gas supply and demand study 1997. A fourth report to the participants on the findings of a study into Australia's natural gas supply and demand to the year 2030.* Participants report. The Australian Gas Association. Canberra. ACT.

BUREAU OF RESOURCE SCIENCES, 1997: *Oil and Gas Resources of Australia 1996*. Bureau of Resource Sciences, Canberra. 14.

GREEN, P.M., (Editor), 1997: The Surat and Bowen Basins, south-east Queensland. *Queensland Minerals and Energy Review Series,* Queensland Department of Mines and Energy.

SCOTT, S.G., SUCHOCKI, V. & KOZAK, A., 1997: Petroleum operations, production and reserves - Annual report 1995/96. *Queensland Geological Record* **1997/4**.



**Reference for this paper:**
**GREEN, P.M., 1997: Petroleum exploration in Queensland — new opportunities in the pipeline. *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 75–82.**

*Philip Dash and Stephen Matheson*

Queensland Department of Mines and Energy

# An overview of coal exploration and development activity in Queensland during 1996–97

## SUMMARY

Queensland produced an all-time record of 99.43 million tonnes (Mt)of saleable coal during the financial year 1996/97, an increase of 6.05% over the previous financial year. Two mines, Burton (1 147 182t) and South Walker Creek (705 790t), commenced operations during the year, while construction continued at Moranbah North and a number of mine expansions were progressed during the year.

Coal exploration again reached record levels during 1996–97, surpassing the high levels achieved over the previous three years. The record levels of exploration were achieved even though the Wik decision of December 1996 necessitated a freeze until June 1997 on the grant and renewal of exploration permits and mineral development licences over land which was not freehold. After that time the Department adopted work procedures for assessing the likelihood of Native Title and has been progressing limited numbers of tenure actions.

A number of companies are continuing to undertake intensive exploration programs over known deposits, with a view to progressing development to the mining stage in the near future. The majority of applications has been from smaller explorers, who continue to investigate less well-known areas, typically targeting small resource areas suitable for open-cut mining and close to existing infrastructure. Much of this exploration has been in the north and central Bowen Basin and has resulted in delineation of several small thermal/Pulverised Coal Injection (PCI) coal deposits and a major deposit of coal at Coppabella, near Nebo.

## EXPLORATION ACTIVITY LEVELS

After the relatively constant levels of exploration in the late 1980s and early 1990s, a rapid increase has occurred from 1993. This high level of exploration was maintained and surpassed during 1996–97. The number of Exploration Permits for Coal (EPCs) current at 1 July 1997 was 71 (with 27 applications outstanding) compared with 76 (and nine applications outstanding) on 1 July 1996 (Figure 1).

The total number of EPCs was expected to decrease in 1996–97 due to the progressive replacement of EPCs by Mineral Development Licences (MDLs). However delays in the granting of MDLs has meant that numerous deposits will be covered by both EPs and MDLs until the MDLs are granted. In addition, the anticipated long term increase in thermal coal demand has prompted an upsurge in exploration activity to record levels. Table 1 lists the 38 EPC applications received in 1996–97 detailing the applicant, locality, purpose/target and status. Interestingly 29 of the 38 had thermal coal (including PCI) as the main target.

The number of EPC applications received (38) was the highest ever and significantly more than the 25 in 1995–96 (Figure 2). However the actual number of EPCs granted in 1996–97 (15) dropped from 1995–96 (21) due to the impacts of the Wik decision (Figure 3).

As expected, the number of MDL applications continued to fall in 1996–97 after the dramatic rise in 1994–95 caused by EPCs (current at the time that the Mineral Resources Act was introduced in 1990) reaching the end of their fifth year during 1994–95 and 1995–96. In

**NUMBER OF EPCs CURRENT**
**1 JULY 1988 - 1997**

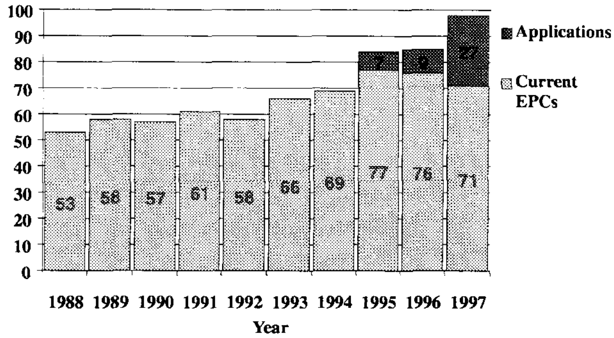


*Figure 1.*

**NUMBER OF EPC applications received**
**Fiscal Years 1988/89 to 1996/97**

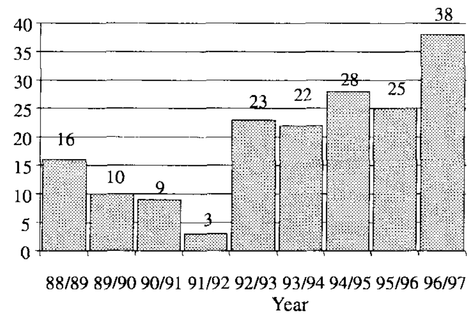


*Figure 2.*

1996–97, 8 applications were received, compared with 21 in 1995–96 (Figure 4).

The high levels of coal exploration expenditure between 1994–95 and 1995–96 were again surpassed during 1996–97, amounting to $47.3 million (Figure 5, Australian Bureau of Statistics figures).

Exploration levels are still high because of two main factors:

## 1. Outlook for thermal and PCI coal demand

During 1996–97, most analysts were predicting that major increases in power demand from Asian countries could be expected over the next 10 years as these countries' annual growth rates exceed 5%. This was anticipated to create additional markets and at least maintain the price of for thermal coal. Australia is well positioned to take advantage of such an increased need for energy and it was expected that Australian thermal coal exports will increase from the present (1994–95) 62.6 million tonnes per annum (Mtpa) to 110Mtpa, by the year 2000.

Current predictions however are that these estimates will not be realised. Supplies of thermal coal have been more than adequate to meet the short term rise in demand and this has resulted in a drop in thermal coal prices late in the financial year. Analysts are still predicting demand increases from perhaps 2001 and beyond but that the market for coal will be highly competitive as many countries gear up to meet the anticipated demand. Countries such as Colombia and Indonesia are and will continue to increase production significantly. Projects such as the new gas resource at Tanngguh offshore from Iran Jaya will also put pressure on coal as a fuel source in Asia.

In addition lower growth rates may now occur in East Asia following currency and equity market collapses in south-east Asia, which could also reduce thermal coal demand rates. A number of greenfield projects previously identified for short term development may now be delayed.

Queensland has traditionally been considered as a coking coal exporter but actually one third of its current coal exports are thermal coals, and with vast resources of identified thermal coal that can be easily extracted in the future, the State is well placed to meet any demand increase. In the Bowen Basin there are more than 1.7 billion tonnes of identified thermal coal resources. In the Moreton and Surat Basins there are approximately 5 billion tonnes of high-volatile coal resources amenable to open-cut mining methods.

Steel makers around the world have been adopting pulverised coal injection (PCI) as a technique to lower their consumption of coking coal and improve throughput in their furnaces. The ideal PCI coal has a high carbon content, low volatile content and high calorific value. About 25 percent of the identified thermal coal resources of the Bowen Basin is of a low-volatile nature, potentially saleable on the PCI market. Explorers have recognised that many of the undeveloped coal resources in the northern and central Bowen Basin have these qualities. This has sparked renewed exploration for hitherto unmarketable coal which has already been noted in many places during past exploration for higher value coking coal.

It is note worthy that of the 38 applications for EPCs in 1996/97, 29 indicated thermal coal (including PCI) as the main exploration target.

## NUMBER OF EPCs GRANTED
### Fiscal Years 1988/89 to 1996/97

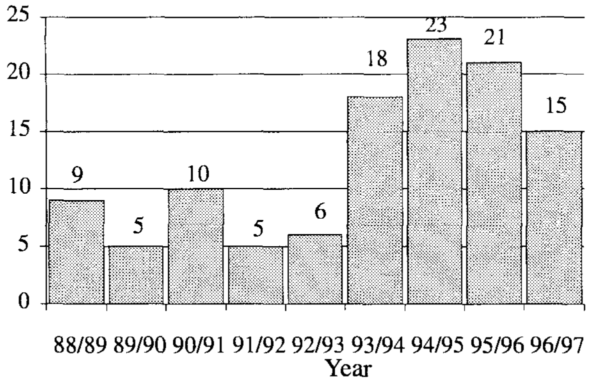


*Figure 3.*

### 2. Central Queensland Coal Exploration Land Release

The Queensland Government's removal of restrictions on exploration in the area known as Restricted Area 55 (RA55), which covered the entire Bowen Basin, made available land where access was previously restricted or only released on an occasional basis. This release took place in three stages over 18 months from 1 March 1993 to August 1994. While this release was some three to four years ago, the effect in terms of easier land access and exploration activity is still being seen.

In all, a total of 43 EPCs were taken up during the period of the release from 1 March 1993 to September 1994 (Department of Minerals and Energy, 1994) and almost 90 in the period since (up to 1 July 1997).

There are only two remaining restricted areas in the Bowen Basin, RA279 (Cullin-la-ringo) and RA290 (Taroborah).

The **Cullin-la-ringo** area is 30km south-west of Emerald in the south-west Bowen Basin. The deposit contains significant resources of low-ash, high-volatile thermal coal which could be accessed by underground mining.

The restricted area over this deposit (RA279) remains in place after two separate releases promoted little interest.

The other remaining restricted area at **Taroborah** (RA290) has been used for a joint Department of Mines and Energy/NEDO (Japanese New Energy and Industrial Development Organisation) research program which was completed in February 1997.

## Number of MDL Applications Received
### Fiscal Years 1989/90 - 1996/97

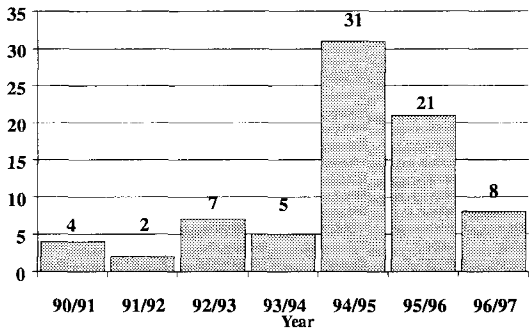


*Figure 4.*

## COAL EXPLORATION EXPENDITURE
### Fiscal Years 1988/89 to 1996/97

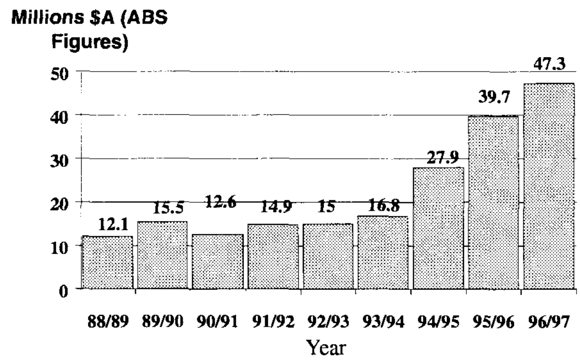


*Figure 5.*

## NATIVE TITLE

Processing times for new applications and renewal applications have been substantially increased during 1996–97 because of the freeze imposed on all tenure dealings between 2 January 1997 and 10 June 1997, due to the High Court handing down its decision on the Wik Native Title claim.

In June 1997, the Department of Mines and Energy, in conjunction with the Department of Premier and Cabinet Legal Unit, finalised Work Procedures for assessing the likelihood of Native Title, based on the Native Title Act and the Wik decision. However, even after those Procedures have been applied only limited processing of tenure dealings has been possible within the scope of the Procedures.

By September 1997, the majority of the Bowen Basin was subject to Native Title claims, which has further slowed the progress of tenure grants and renewals.

## *QTHERM*

The *QTHERM* program (Queensland Thermal Coal Development Program) was set up by the Queensland Government to promote further exploration and development of Queensland's thermal coal resources. The program's aims are to increase the knowledge base of these resources and help to disseminate that information to potential users, investors and developers. Activities have concentrated in the areas of infrastructure, coal quality and utilisation and the effects of changing technology.

The program has developed a user-friendly database of Queensland's operating mines, major undeveloped deposits, coal products and coal explorers and producers. The system provides search, retrieval and reporting on all of the above data categories, including coal resource figures. With this system, users can also find which coal brands match their required quality specifications and then obtain information on companies and mines associated with those brands. The system uses Access software and is available as a run-time product for both Windows 3.1 and Windows 95.

Specialist reports have recently been prepared on behalf of *QTHERM* relating to Queensland's PCI coals, low-medium volatile coals and performance of a variety of Queensland coals in local power stations. These reports are aimed at globally promoting Queensland coals and demonstrating the value of those coals.

The Queensland Government, through *QTHERM*, has contributed $600 000 to the Black Coal Cooperative Research Centre towards establishment of a pressurised entrained flow reactor at CSIRO's Pinjarra Hills site. The reactor will be used for high temperature gasification and combustion experiments to determine the suitability of Australian coals in new and emerging clean coal-fired power generation technologies.

*QTHERM* has also sponsored a proposal by HRL Technology Pty Ltd to test and report on the performance of a Walloon coal in their pilot scale pressurised air-blown fluidised bed gasifier in Victoria. The results from that study are the subject of another paper in these proceedings.

The Department of Mines and Energy is currently conducting a re-examination of the study of coal resources updating its information on measured and indicated coal resources. A graphical coal resources layer for the Departmental MERLIN system, which will display all known measured and indicated coal resources in Queensland is being developed as part of this work. Potential hard copy and digital products from this layer are also being appraised.

## MINE DEVELOPMENTS AND MINE EXPANSIONS

Readers are referred to the 46th Coal Industry Review which is to be published in December 1997 for a detailed account of mine developments and expansions, but a summary of the key developments is outlined below and their locations are shown in Figures 6 and 7.

### *Burton (ML 70109)*

Mining Lease ML 70109 was granted over the Burton deposit, 40km north-east of Moranbah, to a Portman Mining Ltd subsidiary, Pelsoil N.L., in late 1995. Construction began in early 1996 and open-cut truck and shovel mining operations commenced in October 1996 on the thick Burton seam which dips at an average 20 to 22 degrees to the east. Coking and thermal coal products are produced. The "box cut along-strike" mining method is currently producing at a rate of 1.9Mtpa. During the part financial year of operation, Burton produced 1 147 182t of coal. Thiess Contractors have a 5% share in the project and are the operators of the $80 million mine at which approximately 130 people are employed. Burton has recently committed to doubling production to approximately 4Mpta by increasing the highwall depth to 100m. Capital cost on this expansion is expected to be approximately $60 million.

### *South Walker Creek (ML 4750/ML 70131)*

After successful overseas trials of a 100 000t bulk sample from the South Walker portion of its Kemmis Walker lease (ML 4750), south-west of Nebo BHP Mitsui Coal (BHPMC) commenced a two year open-cut trial mining phase at 1Mtpa, contracted out to Thiess. For the operational period of 1996–97, the mine produced 705 970t of coal from a 12m seam in the Rangal Coal Measures. The low-volatile coal is marketed for PCI and thermal use, and also as a blend component in coking coal. BHP anticipate that markets will be secured for additional coal and if so may double production in the future.

*Moranbah North (ML 70108)*

ML 70108, adjoining the southern end of the Goonyella Mining Lease (ML), 15km north of Moranbah, was granted to Moranbah North Coal Pty Ltd, a subsidiary of Shell Coal Pty Ltd, in December 1995. Construction began early in 1996 on the underground longwall coking coal mine, expected to produce upwards of 3.5Mtpa, all of which will be exported. Development coal is currently being stockpiled as the gateways and roadways for the longwall panels are driven in the Goonyella Middle seam of the Moranbah Coal Measures. The mine is a $500 million capital investment, involving the construction of a rail spur and a new housing estate at Moranbah township. The operating mine will employ 180 people and longwall production coal is expected in 1998. Proven resources at Moranbah North total 350 (Mt).

*Ensham*

Initial production at Yongala pit of the Ensham mine was 900 000tpa but production levels have increased to 1.7Mtpa, with expansion of operations in the main mining leases which cover the majority of the open-cut resources. Construction to further increase production to 3.6Mtpa should be completed by 1999. The expansion includes a new railway loop and loading facility at the Ensham leases.

*Suttor Creek/Newlands Underground*

In early 1996, Itochu Corporation bought out the NCA (Newlands-Collinsville-Abbott Point) Project debt and purchased Agipcoal Australia's 25 percent interest in the project. MIM was retained as operator of the project.

MIM has announced its commitment to production from the new underground longwall mine at Newlands. The development has been undertaken by Thiess Contractors and will be in production in early 1999.

MIM is at present carrying out a feasibility study to develop the Suttor Creek deposit, to supplement production from Newlands. *In situ* resources of thermal coal to 60m depth are estimated at 38Mt, with a further 90Mt of underground measured resources, predominantly in the 4m thick Leichhardt Seam (Upper Newlands equivalent). Mining techniques could involve both dragline and truck and shovel. Coal quality is variable but a 14 percent ash product, similar to that produced at Newlands, could be produced. Both road and conveyor haulage are options being considered to transport the Suttor Creek coal to the Newlands washplant.

These two new operations to the NCA Project have the potential to expand the total production from 4Mtpa to 7Mtpa.

*Crinum and Kenmare*

After completing gate road developments, longwall equipment has now been commissioned in the Kenmare (November 1996) and Crinum (June 1997) mines.

*Oaky Creek*

A second underground operation, Oaky Creek North, is being developed as a trial mine by contractors at Oaky Creek using two continuous miners and will convert to longwall operation subject to confirmation of the structural and mining conditions encountered in the trial mine. In addition, a contract longwall retreat mining operation from the highwall at Oaky Creek, known as the Alliance Colliery, has commenced within a sub-lease in the mine. Anticipated production from this operation is 1.5Mtpa.

*Peak Downs/Saraji*

BHP Coal have announced plans to substantially expand production at Peak Downs and Saraji mines. This will involve a capital cost of $470m. Production at Peak Downs is planned to increase to 10Mtpa (up from 7Mtpa) by the year 2001, while at Saraji production will increase to 7Mtpa (up from 5Mtpa) by 2000.

## Highwall mining

Highwall mining technology and performance is continually being improved in the Bowen Basin. This cheaper and more flexible option utilising remotely controlled continuous miners or augering is being used at an increasing number of open-cut mines in lieu of conventional underground mining. Highwall mining techniques have been used at Oaky Creek, German Creek, South Blackwater, Collinsville and Moura.

BHP has successfully trialed highwall mining at **Moura** after several years research into the hybrid mining technology to access the more steeply dipping seams found at Moura. Contractor, Mining Technologies Australia, has been running a flat-dip highwall mining system between 1995 and 1997, with average production of some 83 000t per month and

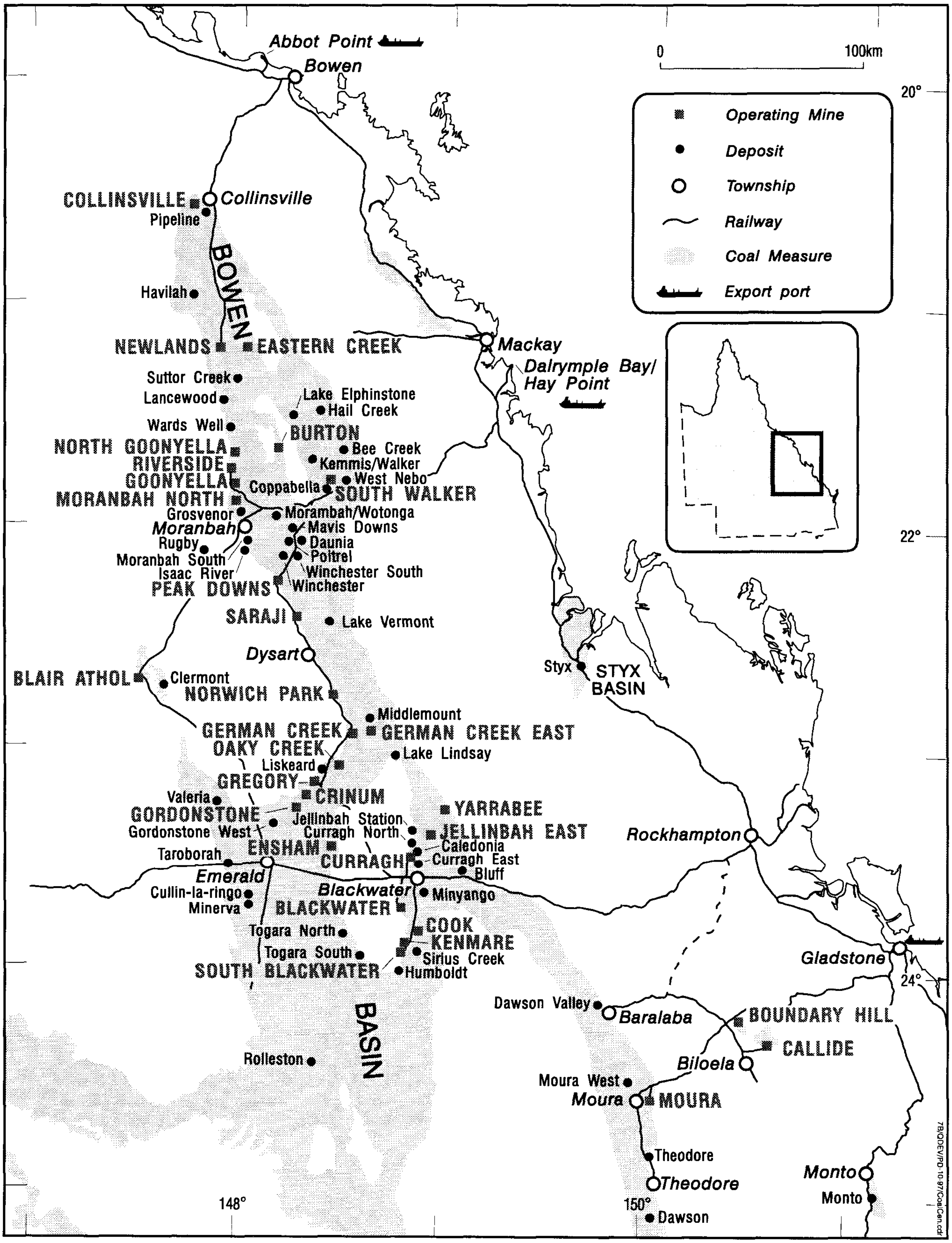


*Figure 6. Central Queensland coal mines and deposits.*

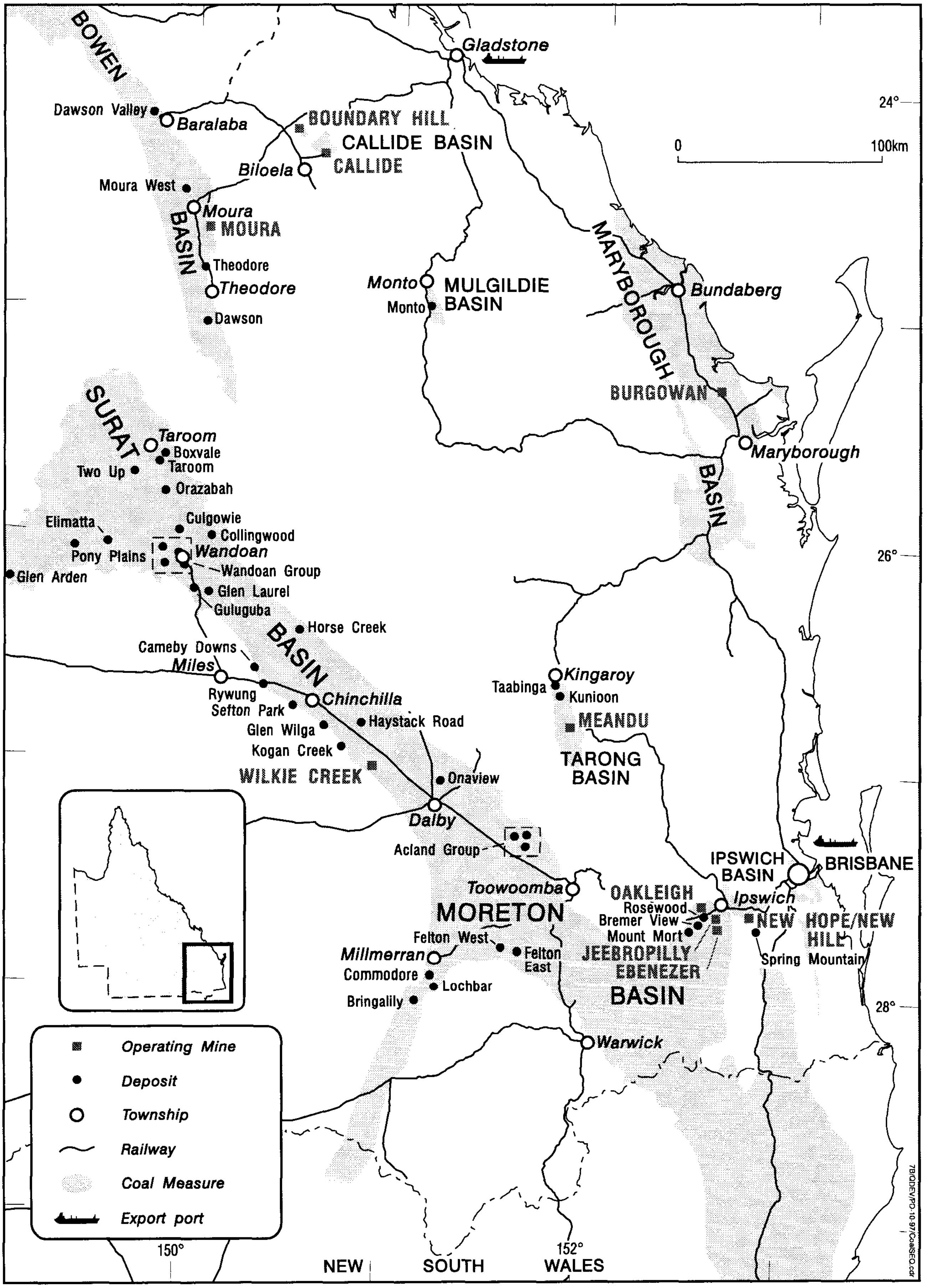


*Figure 7. South-east Queensland coal mines and deposits.*

productivity of up to 35 000t per man year which exceeds even the most efficient longwall. As a result of the trials, a specially constructed Joy highwall miner has recently been commissioned to mine the steeply-dipping seams.

## EXPLORATION ACTIVITY SUMMARY

There are a number of coal deposits being currently explored and new resources are being delineated in the north Bowen Basin. A list of the status of these projects is summarised in Table 2 with further details described below, in perceived order of potential development.

### Previously Known Deposits

*Hail Creek (ML 4738)*

The Hail Creek deposit, 35km north-west of Nebo, is the largest known remaining undeveloped coking coal deposit in Queensland. It contains 810Mt of coal in the Elphinstone and Hynds seams of Late Permian age, of which 175Mt is amenable to open-cut mining. Pacific Coal has held an interest in the Hail Creek deposit for many years and carried out several feasibility studies for a mine based on both a single hard coking coal product and multiple coal products. However, a recent pre-feasibility study involving multiple products has shown the deposit to be potentially viable and the company is undertaking a full feasibility study for a 5Mtpa opencut mine. A decision is expected on this project by mid-December 1997. The area is now subject to a Native Title claim and negotiations with the claimants are believed to be in progress.

*Nebo West (MDLA 235)*

BHP Mitsui Coal Pty Ltd (BHPMC) has been exploring this structurally-complex area over the past few years, and has outlined Indicated resources of anthracite in all seams totalling 177Mt, of which 100Mt is at less than 60m depth. However, not all the seams will be economically viable to mine. A major geological report has been prepared which will be used as the basis for a pre-feasibility study. BHPMC has applied for a mineral development licence (MDL) over the deposit and also intends to extract a 10,000t bulk sample from an area of the deposit already covered by ML 70131 "Tootoolah", currently utilised to facilitate mining and transport of coal from the adjacent South Walker deposit.

Following the testing of this coal in the market place, BHP Coal Pty Ltd may also progress development of the Poitrel and Daunia deposits to the south-west, for which it is the operating company.

*Coppabella (EPC 531, EPC 646, MLA 70161)*

The Coppabella deposit is a new discovery located immediately to the south-west of South Walker Creek. The deposit comprises a 12m thick seam of the Rangal Coal Measures, thought to be a combined Leichhardt/Vermont seam, in a small basinal structure not previously detected by regional exploration drilling in the area. Over 300 holes have been drilled in the project area to date, with 42Mt of Measured resources delineated in the proposed initial open pit area and potential for some hundreds of millions of tonnes more in the remainder of the exploration tenements. The proponents, Macarthur Coal Pty Ltd, Queensland Coal Resources Pty Ltd and CITIC Australia Pty Ltd applied for a mining lease over the deposit in September 1997 with a view to rapid development to satisfy an identified PCI market niche for the low-ash high-carbon thermal coal.

*Theodore (ML 5657)*

This deposit was previously called "Theodore North". Exploration of this southern Bowen Basin export thermal coal deposit, immediately north of Theodore township, was mainly carried out in the 1970s and 1980s but, with the increased demand for thermal coal, Shell is now assessing the feasibility of developing an open-cut mine of up to 3Mtpa capacity. Indicated and measured resources totalling 584Mt occur in the Baralaba Coal Measures of Late Permian age, dipping to the west at 13 to 19 degrees.

Development depends upon successful negotiations with Queensland Rail for an upgrade of the current low-capacity line between Theodore and Moura and for economically viable freight rates to Gladstone. Construction of the mine could begin in early 1998. A revised EMOS and Plan of Operations has been submitted for the proposed operation and is currently being assessed.

*Minerva (MDL 232; ML 70145)*

Following a successful bid in the Stage II RA55 release, New Hope Corporation and Nissho Iwai have been exploring the low-ash high-volatile thermal coal of the Reids Dome beds in the Minerva/Gindie area. A potential open-cut resource of about 30Mt of coal (free of basalt cover and intrusions) has now been defined in the Lexington Dome area. The coal will not need to be washed. The company has been granted MDL 232 and a mining lease application was lodged in September 1996. The Warden has recommended grant and compensation has been determined but is subject to appeal.The area is also now subject to a Native Title claim and negotiations with the claimants are believed to be in progress.

*Togara North (EPC 550; MDL 238; MLA 70149)*

The Togara North area, south of Comet, was awarded in the RA 55 land release. Geological investigations are well advanced on this export quality underground thermal coal deposit in the Rangal Coal Measures, currently being undertaken by consultants for the Savage, Mitsui Mining and Korean joint venturers. Exploration has been concentrated in the southern portion of the EPC where a 6m thick seam is present (Comet Downs deposit).

A mining lease application was lodged in September 1996 over this area and the Mining Warden has recommended grant and has made a determination on compensation. The Joint Venturers propose the development of underground longwall mining of the deposit, initially producing a raw coal product. A small open-cut operation is also proposed. The truck and shovel operation would mine at the rate of 1Mtpa for about three years. The proponents are currently negotiating options with Government to resolve rail and road options.

*Red Hill/Goonyella Underground*

BHP Coal is investigating seams from the Moranbah Coal Measures down dip from the Goonyella Mine. About 60 holes have been drilled to test the quality and thickness of seams as well as the general sequence stratigraphy. Possible pockets of shallow coal in the Rangal Coal Measures are a secondary target in the east of the EPC.

BHP were also re-evaluating the potential for longwall mining within the current Goonyella mining lease at Ramp Zero, down dip of the present open-cut operations. However, exploration is now being focused on the Eureka underground area to the north of Ramp Zero in the middle of the mining lease. Infill drilling is in progress. Potential for an opencut in the Goonyella Lower seam to the south of the preparation plant is also being investigated.

*Wards Well — EPC 555 (over ML 1790)*

BHP Mitsui Coal (BHPMC) is investigating the Goonyella Upper, Middle and Lower seams from the Moranbah Coal Measures in this area to evaluate resources capable of being mined by underground longwall methods to replace declining supplies of coal from the Riverside Mine.

BHPMC are seriously appraising innovative ways of low-cost entry via a box/slot cut into the Upper seam, with test development of longwall roadways using a continuous miner, to fully appraise the geotechnical aspects of the deposit.

*Togara South (EPC 551)*

After being awarded this area in the RA55 land release, Ingwe Australia Pty Ltd, a subsidiary of Ingwe Corporation of South Africa, has been intensively exploring Togara South and has targeted the Pollux seam of the Rangal Coal Measures as a potential longwall mining operations. Drilling and high resolution reflection surface seismic surveys have been carried out to assess the structure and quality of the Pollux seam in one portion of the deposit. A pre-feasibility study was completed in early 1997 and a decision was made to progress to a feasibility study of the remainder of the area. Ingwe has also taken out EPC 596 "Comet Ridge", to further investigate coal measures in areas adjacent to Togara South.

*Dawson (MDL 216)*

This deposit was previously called "Theodore South". Shell has held tenure over this export-quality thermal coal resource for ten years and has progressed the knowledge of the deposit to a point where an Initial Advice Statement has been lodged in preparation for a mining lease application. About 84Mt of coal amenable to open-cut mining and 653Mt of underground coal has been outlined. Development of this deposit is dependent upon upgrade and extension of the Moura to Theodore rail line, as the current low-capacity rail head is 25km to the north of the deposit.

## New areas

Exploration is also being conducted in areas of the Bowen Basin which have previously been poorly explored or not explored at all. These include Clermont, Coppabella (as mentioned above) and a number of EPCs in the Collinsville-Glenden-Hail Creek area of the north Bowen Basin which is generally structurally complex with a likelihood of intrusions. Companies are also exploring the more structurally complex areas along the eastern side of the basin around Middlemount.

Most of the sub-crop of the Rangal Coal Measures in the Bowen Basin is now under tenure.

In the Mount Hillalong area (EPC 600 and 601) adjacent to the Hail Creek deposit, Queensland Coal Exploration Pty Ltd is exploring interpreted sub-crops of coal seams of the Rangal and Moranbah Coal Measures in EPC 601 to supplement 11Mt of coal resources identified in EPC 600.

In the same region, to the east of the Hail Creek deposit, Mt Robert Coal Pty Ltd (previously Goldamere Pty Ltd) has drilled over 170 holes at Mt Robert (EPC 607) and defined some 17Mt of Indicated Resources small tonnage resources of low-volatile thermal/PCI coal in steeply dipping multiple seams of the Moranbah Coal Measures.

Rio Tinto Exploration Pty Ltd is continuing to investigate the Clermont district using a combination of geophysical (gravity) surveys and drilling, with the aim of discovering additional coal bearing sub-basins along the western side of the Basin in the vicinity of the Blair Athol and Clermont deposits.

This exploration has resulted in the discovery of coal seams in extensions of the Moorlands Basin near Clermont. The company is also exploring for possible equivalents of the Collinsville Coal Measures in the Wolfang East and Mount McLaren areas between Clermont and Rugby. Rio Tinto has also taken up ground previously surrendered by its subsidiary Pacific Coal Pty Ltd with a view to further drilling of anomalous areas.

Arco is exploring areas adjacent to the Curragh coal mining leases. EPC 525 and EPC 571 are to the west and north-west of the mining leases and the company is investigating seams from the Burngrove Formation. EPC 603 is a larger area west of EPC 525 which also continues northwards to adjoin the Lake Lindsay deposit. In this EPC the potential for shallow occurrences of coal seams in the Fair Hill and Burngrove Formations is being explored.

In the northern Bowen Basin region, areas previously regionally mapped as Fort Cooper Coal Measures are being explored for isolated areas of Rangal or Moranbah Coal Measures not detected during the regional mapping.

### Recently used exploration techniques

**High resolution seismic reflection** profiling is being successfully utilised to assist in the appraisal of some potential underground longwall projects. Results from this technique aid in the delineation of faults and the more effective placement of drillholes to delineate seam structure.

Back-pack mounted **ground-penetrating radar equipment** is being used at the Blair Athol Mine to delineate hidden historic underground workings which present a danger to staff and equipment working on the exposed coal surface.

## FUTURE DIRECTIONS

The pressure for continual increases in mining productivity to retain current markets in the competitive global coal industry is expected to result in:

- the continued decline in conventional underground mining and commensurate increases in longwall and highwall mining,
- continued improvements in longwall and highwall mining equipment and techniques,
- automation of dragline movements (swing),
- development of even larger trucks,
- increased extraction of coal seam methane prior to mining, and
- workplace reform.

Future exploration levels in terms of expenditure and activity are mainly dependent upon:

- the perceived long term future market potential and pricing of thermal and PCI coal, and
- the outcome of the Federal legislative amendments to the Native Title Act.

### PCI coal

The market potential for PCI coal is expected to remain high as steel makers continue to replace coking coal consumption with PCI coal. Thus it is anticipated that exploration of areas in the Bowen Basin containing low-volatile high-carbon coals and close to existing infrastructure will be maintained.

## Target Resource Size

The increased use of contract mining companies, triggered by the need to lower the capital investment in new mining projects, has resulted in smaller operations of the order of 1Mtpa, compared to the more traditional (for Queensland) large tonnage, large capital and infrastructure intensive projects. This has meant that explorers are now targeting a smaller resource size for a given mine life. This change in strategy has opened up a number of exploration opportunities and increased the number of potential targets, some of which comprise resources which were defined in the 1970s but dropped because they were insufficient for the large project scenarios of the time. Areas previously discarded because igneous intrusions, structural complexity and steep dips precluded large resources, are now being re-appraised with smaller tonnages in mind. This is particularly evident in the north Bowen Basin and along the eastern margin of the Bowen Basin.

Exploration is expected to continue for small areas either Rangal or Moranbah Coal Measures within structurally complex regions in the northern Bowen Basin previously regionally mapped as Fort Cooper Coal Measures.

## Target Coal-Bearing Formations

Other new targets being appraised in recent times are the lower-quality, high-ash, coal-bearing formations such as the Burngrove Formation and Fort Cooper Coal Measures, which have up to now been ignored as uneconomic. These areas are now being examined for selective mining of clean coal plies and for washing to an acceptable quality at nearby already-operating washplants. Preliminary testing indicates that this concept may yield an acceptable thermal coal product and a viable operation in some cases. If this proves successful in these areas, it may initiate further exploration in other parts of the coal fields.

New techniques currently being tested at Collinsville by Transfield Pty Ltd involving dry ash separation during coal milling may provide additional impetus for the exploration and development of these high ash coals for mine-mouth power stations.

## Electricity market

Changes in the electricity industry over the next five years will provide opportunities for private investment in electricity production in Queensland. These changes have already started a search for energy sources in a variety of localities throughout Queensland, particularly in north Queensland where exploration in the north Galilee Basin, north Bowen Basin and Laura Basins has been undertaken for this purpose. Development of a base load power station in southern Queensland is also a likely option in an expanded electricity market and investigations and evaluations continue at sites such as Wandoan, Acland and Millmerran. CS Energy has recently announced the recommissioning of the Callide A power station.

The announced new electricity study corridor proposed for the New South Wales to Queensland electricity link is located in the Surat Basin and will provide further impetus for development of a "mine-mouth" power station in that region.

## Surat Basin Infrastructure

In October 1996, the Queensland Government called for expressions of interest for private infrastructure development options in relation to largely untapped coal resources of the Surat Basin/Dawson Valley. It is hoped that this initiative could provide added impetus to the exploration and development of the Surat Basin, as infrastructure is the key to development of this region.

On 29 October 1997 the Government announced a short list of private enterprise proponents, and proposals, for the development of a new dam, new rail systems and new power stations. The Government believes that the short listed proposals have the potential to be developed into commercially viable infrastructure projects worth an estimated $3 billion and capable of creating at least 3000 direct new permanent jobs in the region.

## Other Infrastructure

The recent Queensland Cabinet decision to acquire land for a Northern Bowen Basin Rail Line extending from near the South Walker mine to service the region to the north-west of Nebo, will provide much needed impetus to this region. The first coal along this line will probably be from the Hail Creek project. In

## TABLE 1: EPC APPLICATIONS RECEIVED 1996/1997 FISCAL YEAR

| Tenure | Applicant | Project |
|---|---|---|
| EPC 615 | Rio Tinto Exploration Pty Limited | Mount McLaren Project |
| EPC 616 | Goldamere Pty Ltd | Wilpeena Project |
| EPC 617 | Coal Operations Australia Limited | Roper Creek |
| EPC 618 | Roxbell Pty Ltd | Hornet Bank |
| EPC 619 | Needin Pty Ltd | - |
| EPC 620 | Needin Pty Ltd | - |
| EPC 621 | Yarrabee Coal Company Pty Ltd | Yarrabee North |
| EPC 622 | Ingwe Australia Pty Ltd | Yamala Project |
| EPC 623 | Jeebropilly Collieries Pty Ltd | Jeebropilly Project |
| EPC 624 | The Shell Company of Aust Ltd | Boxvale |
| EPC 625 | Ross Pastoral Co Pty Ltd | Kemmis Creek Project |
| EPC 626 | Yarrabee Coal Company Pty Ltd | - |
| EPC 627 | Rio Tinto Exploration Pty Limited | Theresa Creek Project |
| EPC 628 | Needin Pty Ltd | Northern Bowen Basin Joint Venture |
| EPC 629 | Mt Leyshon Gold Mines Limited | Beaufort |
| EPC 630 | Macarthur Coal Pty Ltd | - |
| EPC 631 | QCOAL Pty Ltd | Cattle Creek Project |
| EPC 632 | Goldamere Pty Ltd | Coomooboolaroo |
| EPC 633 | Arco Coal Australia Inc | Carnangarra Project |
| EPC 634 | Linc Energy NL | Moreton U.C.G. Project |
| EPC 635 | Linc Energy NL | Chinchilla U.C.G. Project |
| EPC 636 | BHP Coal Pty Ltd (& Others - CQCA) | Norwich Park Mine Project |
| EPC 637 | BHP Coal Pty Ltd & Caburah Mining Co | Haystack Road Extended Project |
| EPC 638 | Surat Coal NL | Culgowie Project |
| EPC 639 | QCOAL Pty Ltd | Pelican Creek Project |
| EPC 640 | Ellrock Pty Ltd | Collingwood Project |
| EPC 641 | Burnett Coal Pty Ltd | Calliope Project |
| EPC 642 | SCM Brisbane Pty Ltd | Oakleigh Extended Project |
| EPC 643 | Ross Pastoral Co Pty Ltd | Kemmis Creek Exploration Project |
| EPC 644 | Rio Tinto Exploration Pty Limited | Hill View Project |
| EPC 645 | Rio Tinto Exploration Pty Limited | Mabbin Creek Project |
| EPC 646 | Macarthur Coal Pty Ltd | Coppabella extended |
| EPC 647 | Pelsoil NL | Kerlong Project |
| EPC 648 | Yarrabee Coal Company Pty Ltd | Yarrabee North Project |
| EPC 649 | Macarthur Coal Pty Ltd | Deverill Project |
| EPC 650 | Acapulco Mining NL | Elimatta Project |
| EPC 651 | South Blackwater Coal Limited | Shotover Project |
| EPC 652 | Linc Energy NL | Swanbank U.C.G. Project |

| Locality | Purpose/Target | Status |
|---|---|---|
| NE Clermont | Thermal / Blair Athol style basins | Granted |
| 27km N Blackwater | Coking & Thermal / Rangal C.M. | Granted |
| W Middlemount | Coking & Thermal / Rangal C.M. | Granted |
| NW Wandoan | Thermal / Walloon C.M. | Abandoned |
| S Collinsville | Thermal / Rangal C.M. & Moranbah C.M. | Granted |
| ENE Glendon | Thermal / Rangal C.M. & Moranbah C.M. | Granted |
| N Blackwater | Thermal / Moranbah C.M. | Granted |
| Comet, Central Qld | Thermal / Rangal C.M. | Granted |
| N Rosewood | Thermal / Walloon C.M. | Abandoned |
| SE Taroom | Thermal / Walloon C.M. | Granted |
| 37km W Nebo | Coking & Thermal / Elphinstone C.M. | Proposal accepted |
| Bluff | Thermal / Rangal C.M. | Application |
| S Clermont | Thermal / Blair Athol style basins | Application |
| S Collinsville | Thermal / Rangal C.M. & Moranbah C.M. | Application |
| Centred approx 40km SW of Charters Towers | Thermal / Betts Creek Beds | Application |
| NE Blackwater | Thermal / Rangal C.M. | Application |
| SSE Theodore | Thermal / Walloon C.M. | Application |
| 15km SW Duaringa | Thermal / Baralaba C.M. | Granted |
| North & West of Blackwater | Thermal / Rangal C.M. | Application |
| E Ipswich | Gas / Ipswich C.M. | Rejected |
| S Chinchilla | Gas / Walloon C.M. | Application |
| NE Dysart | Coking / German Creek Fm | Application |
| W Toowoomba | Thermal / Walloon C.M. | Application |
| N Wandoan | Thermal / Walloon C.M. | Application |
| S Collinsville | Coking & Thermal / Moranbah & Collinsville C.M. | Application |
| Wandoan | Thermal / Walloon C.M. | Application |
| 40km E Biloela | Thermal / Callide C.M. | Application |
| Rosewood | Thermal / Walloon C.M. | Granted |
| 37km W Nebo | Coking & Thermal / Elphinstone C.M. | Proposal accepted |
| 25km West Emerald | Thermal / Permian Coals | Proposed |
| 20km South Newlands | Thermal / Collinsville Coal equivalents Western Bowen Basin | Application |
| SE Coppabella | Thermal / Rangal C.M. | Granted |
| NNE Moranbah | Coking & Thermal / Rangal C.M. | Application |
| N Blackwater | Thermal / Rangal C.M. | Application |
| SE Moranbah | Thermal / Rangal C.M. | Application |
| SW Taroom | Thermal / Walloon C.M. | Application |
| 10km SSW of South Blackwater | Thermal / Rangal C.M. | Application |
| SW Ipswich | Gas / Ipswich C.M. | Application |

## TABLE 2: CURRENT STATUS OF COAL MINING PROJECTS

| PROJECT | OPERATOR | TYPE |
|---|---|---|
| **COMPLETED DURING 1996/1997** | | |
| South Walker Creek | BHP Coal Pty Ltd | Opencut thermal/PCI |
| Burton | Portman Mining Pty Ltd | Opencut coking/thermal |
| Crinum | BHP Coal Pty Ltd | Underground coking |
| Kenmare | South Blackwater Coal Ltd | Underground coking |
| **UNDER CONSTRUCTION** | | |
| Alliance Colliery (Oaky Creek) | Thiess/Namoi Joint Venture | Longwall retreat - highwall underground coking. |
| Moranbah North | Shell Coal Australia | Underground longwall coking |
| Newlands U/G | NCA Joint Venture/MIM | Underground thermal |
| Oaky North (3km N of Oaky No.1) | MIM Ltd | Underground longwall coking |
| Ensham expansion | Ensham Resources Pty Ltd | Opencut thermal |
| **COMMITTED** | | |
| Peak Downs expansion | BHP | Opencut coking |
| Saraji expansion | BHP | Opencut coking |
| **PROPOSED** | | |
| Hail Creek | Pacific Coal | Opencut coking, some thermal coal |
| Nebo West | BHP Mitsui Coal | Opencut PCI / thermal |
| Theodore (previously called Theodore North) | Shell | Opencut and underground thermal |
| Coppabella | Macarthur Coal Pty Ltd; Queensland Coal Resources Pty Ltd; CITIC Australia Resources Pty Ltd | Opencut PCI / thermal |
| Minerva | New Hope | Opencut thermal |
| Togara North | Savage, Mitsui, Mining, Korean JV | Underground thermal |
| Eastern Creek Nth<br>Suttor Creek | NCA Joint Venture/MIM | Opencut thermal<br>Opencut thermal |
| Red Hill | BHP Coal | Underground (Moranbah C.M.)<br>Opencut (Rangal C.M.) |
| Goonyella underground | BHP for CQCA | Underground coking |
| Wards Well | BHP for BHP Mitsui | Underground coking |
| Togara South | Ingwe Australia Pty Ltd | Underground longwall thermal |
| Daunia/Poitrel | BHP for CQCA | Opencut thermal |
| Grasstrees | German Creek | Underground coking coal |
| Lake Lindsay | ARCO for Curragh Joint Venture | Opencut coking /thermal |
| Clermont | Pacific Coal Pty | Opencut thermal |
| Dawson (Theodore South) | Shell Coal Pty Ltd | Opencut & underground thermal |
| Valeria | Pacific Coal Pty | Opencut thermal |

| PRODUCTION | STATUS |
| --- | --- |
| 1Mtpa | Operating as a trial mine. If successful, will increase production to 3Mtpa. |
| 1.9Mtpa | Announced in May 1997 that the mine would be expanding to double production to 4Mtpa with a further $160m capital investment. |
| 3Mtpa | Longwall equipment commissioned June 1997. |
| 3Mtpa | Longwall equipment commissioned November 1996. |
| 1.5Mtpa | Sub-leased to Thiess/Namoi JV. Committed 1997. Highwall equipment procured. 2 panels directly off highwall. German Creek seam 2 m thick. |
| 3.5Mtpa | Driftage coal being stockpiled. Longwall production expected mid-1999. |
| 3.0Mtpa increase over existing operations, including Suttor Ck and Eastern Ck Nth | Longwall production due to commence in early 1999. |
| 300 000tpa | Under construction. Three entries off highwall. |
| 3Mtpa | Under construction. |
| from 7 to 10Mtpa | To be complete by 2001/02. Total proposed capital increase in Peak Downs and Saraji: $470m. |
| From 5 to 7Mtpa | To be complete by 2000. Total proposed capital increase in Peak Downs and Saraji: $470m. |
| 5Mtpa | Extensive feasibility being undertaken. Commitment to be decided in late 1997. Production is tentatively targeted for 2000. |
| - | 10,000t bulk sample proposed to be taken from ML 70131. MDL 235 over remaining major portion is being assessed. |
| 3.5Mtpa | No commitment yet. Small opencut production could be followed by underground mining. Feasibility study in progress. |
| - | ML application lodged September 1997. Proponents have identified PCI markets. |
| 800 000tpa | ML application made September 1996. Bulk sample to be taken late 1996 completed March 1997. Possible production by 1998. |
| 3.0–7.0Mtpa | ML application made September 1996. Construction could commence late 1997 with production from 1998. |
| An increase of 3.0Mtpa over existing operations | Itochu has bought AGIP's and the banks' interests in NCA. MIM recently purchased AGIP's 25% share and now owns 100% of Suttor Creek. Commencement could be in conjunction with the Newlands underground project. |
| - | Exploration drilling in progress. |
| Up to 4.0Mtpa | Commencement date unknown. Focus has moved from Ramp Zero to the Eureka proposed U/G area to the north. |
| Up to 4.0Mtpa | Would replace Riverside coal production after 2000, feasibility undertaken but no commitment Currently appraising low-cost entry into upper seam via box / slot cut and development of roadways to test geotechnical conditions. |
| 4.0–8.0Mtpa | Pre-feasibility study completed. Full feasibility in progress. Production not likely until 2005. |
| | Bulk sample now delayed. Commencement date unknown. |
| 3.0Mtpa? | Plans for further development (deeper) at Central have put this project on hold. Would replace dwindling production from O/C and U/G mines. |
| 1.0Mtpa | No commitment yet. |
| Up to 13Mtpa | Will phase in as Blair Athol production decreases. Mine construction could commence from 2000, with coal production from 2004? |
| Up to 3.5Mtpa | Development depends on extension of Moura rail line. |
| 5.0Ma? | No commitment Coal production not likely until 2000–2005? |

addition to Hail Creek, numerous resources in the area, such as Bee Creek, Mt Robert, Hillalong and Kemmis Walker, will have ready access to rail transport when this line is completed.

## BIBLIOGRAPHY

COXHEAD, B. A., 1996: *Queensland Coals — Physical and Chemical Properties, Colliery and Company Information, 11th Edition,* Queensland Government.

DEPARTMENT OF MINERALS AND ENERGY, 1991: Departmental coal exploration — open file results in record series. *Queensland Government Mining Journal,* **92**, 468–474.

DEPARTMENT OF MINERALS AND ENERGY, 1994: Land Release sparks exploration rush. *Queensland Government Mining Journal,* **95**, (Queensland Coal, September/October), 30–38.

DEPARTMENT OF MINERALS AND ENERGY, 1996: *Queensland Minerals and Energy Review* Queensland Government, 77–86.

MATHESON, S. G., 1994: An overview of coal exploration developments in Queensland. *In* Department of Minerals and Energy, *Abstracts of Queensland Exploration Potential Symposium.*

MATHESON, S. G., 1995: An overview of recent coal exploration in the Bowen Basin. *In* Follington, I.L., Beeston, J.W. & Hamilton, L.H., (Editors): *Proceedings of the Bowen Basin Symposium 1995,* 1–6.

MATHESON, S. G., BALFE P. & COFFEY, D., 1993: Coal exploration and development opportunities in Queensland — Central Queensland Coal Exploration Land release. *In* Beeston, J.W., (Editor): *New Developments in Coal Geology - A Symposium,* 3–11.

MATHESON, S. G. & DASH, P.H., 1996: An Overview Of Coal Exploration And Development Activity In Queensland During 1995-96. *Queensland Government Mining Journal,* **97**, September, 37–44.

MENGEL, D. C., BALFE, P. E. & COFFEY, D., 1990: A history of coal exploration and mining in Queensland. *In* Glasson, K. R. & Rattigan, J. H.,: Geological aspects of the discovery of some important mineral deposits in Australia. *AusIMM Monograph* **17**, 317–345.

QUEENSLAND COAL BOARD 1996: 45th *Queensland Coal Industry Review 1995/96.*

QUEENSLAND COAL BOARD, in preparation: 46th *Queensland Coal Industry Review 1996/97.*

**Reference for this paper:**
**DASH, P.H. & MATHESON, S.G., 1997: An overview of coal exploration and development activity in Queensland during 1996-97. *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 83–98.**

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# Behaviour of Walloon coal in HRL's IGCC Process

## SUMMARY

A sample of coal from the Walloon Coal Measures in south east Queensland was successfully trialed in a 200kg/h pilot-scale pressurised air-blown gasification unit at HRL. The fuel gas produced burnt easily in a pilot-scale pressurised combustion turbine simulator.

The reactivity of the Walloon coal under gasification conditions was initially determined by means of tests in a pressurised thermobalance. The results of this work were encouraging and gave a preliminary indication of the process conditions required.

A pilot-scale gasification trial was carried out and a fuel gas was produced with an acceptable heating value. There were no problems in the handling of the Walloon coal in the plant systems. The fuel gas was easily fired in a pressurised combustion turbine simulator and produced a stable flame with low levels of NOx and $SO_2$ emissions.

The performance of Walloon coal in these tests indicates strong potential for the application of Integrated Gasification Combined Cycle (IGCC) technology for power generation in Queensland and in associated export markets.

HRL has been working with a pressurised air-blown fluidised bed gasification process since the late 1980s and has developed a high efficiency IGCC process for power generation from coal. This process gasifies the coal in a pressurised air-blown fluidised bed. The gas is then partly cooled and filtered before combustion in a gas turbine. In addition to the power generated by the gas turbine, additional power is generated by a steam turbine connected to a waste heat boiler that cools the gas turbine exhaust.

HRL's IGCC process has an efficiency about 20% higher than that of a conventional coal-fired power station (with correspondingly lower $CO_2$ emissions). Additional benefits of the IGCC technology include low NOx emissions and less cooling water consumption.

## INTRODUCTION

The Jurassic Walloon Coal Measures of the Moreton Basin and its equivalents of the Surat Basin in south east Queensland contain extensive deposits of high volatile bituminous thermal coal. The Queensland Department of Mines and Energy reported (Queensland Government Mining Journal, June 1997) that some 5.2 billion tonnes of resources (raw coal *in situ*), potentially amenable to open cut mining, have already been proven to indicated status. Of this some 2,708 million tonnes are located in the Surat Basin which lies to the west of the Kumbarilla Ridge (approximately to the west of Dalby township). The locations of these deposits are shown on the Department of Mines and Energy map of south east Queensland coal areas (Figure 1).

The coal is of high volatile bituminous rank with vitrinite reflectance (Rv, max of band telocollinite) ranging from 0.42 percent in the west at Wandoan to 0.59 percent in the east at the Jeebropilly Mine area (Smith, 1986). Carbon content is generally in the range 77 to 80 percent (daf basis) with specific energy in the range 32 to 34.6MJ/kg (daf basis).

The coal is perhydrous being rich in vitrinite and liptinite macerals and generally contains a low to moderate ash content and low levels of sulphur and nitrogen. Volatile matter content generally ranges between 48 and 51 percent (daf basis). Analyses data are taken from "Queensland Coals", (the Queensland Coal Board, 1995).

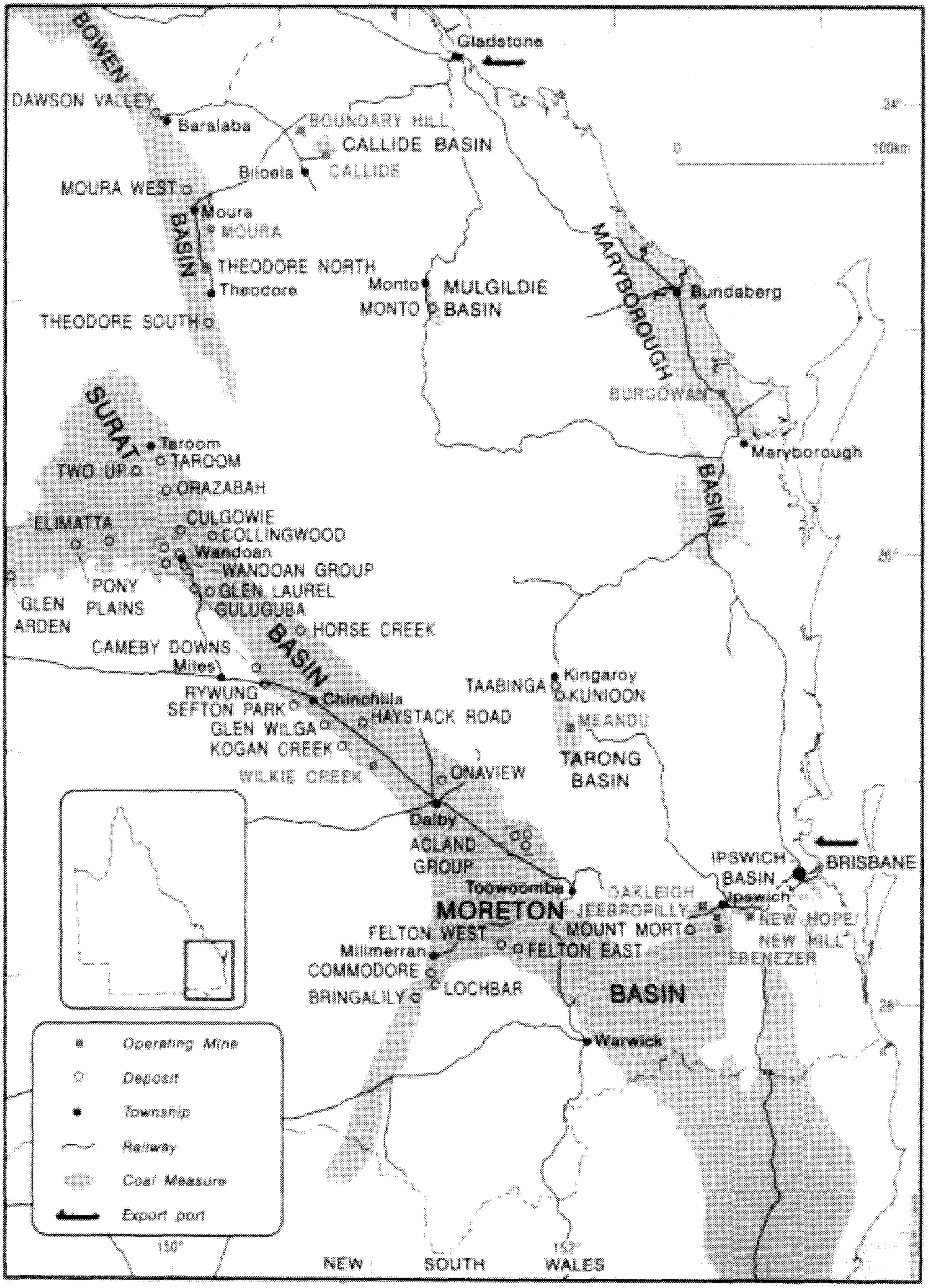


*Figure 1. Map of south-east Queensland coal areas.*

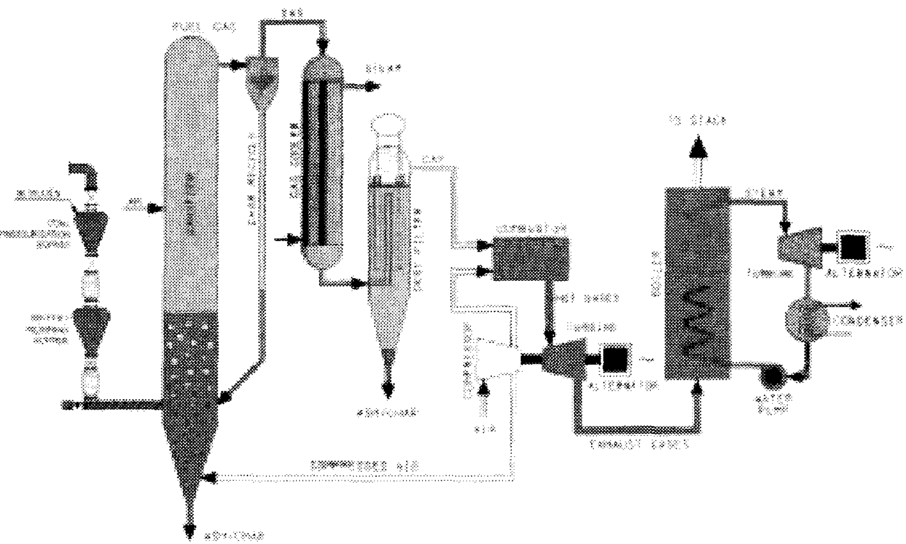

*Figure 2. Schematic of HRL's IGCC Process.*

Cook (1975) reported the following as distinctive features of coals from the Walloon Coal Measures based on the examination of some 55 samples:

- most coals are rich in vitrinite >80 percent (mmf),
- liptinite is abundant, ranging up to 20 percent,
- vitrinite generally contains an abundance of suberinite,
- inertinite content is very low — sometimes trace amounts only, and
- the seams contain numerous dirt bands and a high proportion of disseminated mineral matter.

The coal is very reactive on combustion and gives very high burnout in power station use. The fusion temperature of the ash is generally above 1300°C, due to the low concentrations of fluxing elements such as iron and sodium in the ash.

The high reactivity of the coal, together with a moderate ash fusion temperature makes the coal attractive for gasification in an air-blow fluidised-bed environment.

Having recognised this potential, Q*THERM* and HRL Limited agreed to conduct a test program at both laboratory and pilot scale to assess this potential.

The reactivity of a sample of Walloon coal char under gasification conditions was initially determined using a pressurised thermobalance. The Walloon coal char showed similar reactivity characteristics to that of a Morwell coal char, which was known to perform well in HRL's gasification process.

A sample of Walloon coal was then tested in HRL's pilot-scale Coal Gasification Development Unit (CGDU) at Mulgrave. The product gas was successfully fired in a Combustion Turbine Simulator (CTS) with good combustion stability and low emission levels.

An overall electrical power generation efficiency of around 42% is calculated for Walloon coal in HRL's Integrated Gasification Combined Cycle (IGCC) process (see Figure 2). This efficiency is around 20% higher than a conventional pulverised fuel-fired boiler/steam turbine plant, with corresponding reductions in coal consumption and $CO_2$ emissions for the same power output. Additional benefits of the IGCC technology include a 50% reduction in cooling water consumption and low NOx emissions.

## GASIFICATION PROCESS

Gasification is a complex chemical process of conversion of carbon in a carbonaceous material to fuel gas by subjecting the material to a hot air or oxygen environment. The product gas comprises mainly CO, $H_2$ and $CH_4$ as combustible gases, the remainder being mostly $N_2$ and $CO_2$.

Some principal reactions taking place during the gasification process are:

Boudouard Reaction:

$$C + CO_2 = 2CO \quad (1)$$

Heterogeneous Water Gas Reaction:

$$C + H_2O = CO + H_2 \quad (2)$$

Homogeneous Water Gas Reaction:

$$CO + H_2O = CO_2 + H_2 \quad (3)$$

Heterogeneous Methane Reaction:

$$C + 2H_2 = CH_4 \quad (4)$$

Homogeneous Methane Reaction:

$$CO + 3H_2 = CH_4 + H_2O \quad (5)$$

All the above reactions are exothermic except Reactions (1) and (2) which are endothermic, requiring heat input to complete the reactions.

When the gasification process occurs at a sufficiently high pressure, the product gas, after filtration to remove particulates, can be directly fired in a gas turbine to produce power, and by adopting a combined heat and power cycle, the overall thermal efficiency of the plant can be further improved. This technology is generally known as Integrated Gasification Combined Cycle (IGCC).

Variations among the advanced gasification processes can be classified into three main types:

- fixed bed (Lurgi, BGL),
- fluidised bed (HTW, KRW and U-gas, British Gas, HRL), and
- entrained flow (Shell, Texaco, Prenflo, Dow).

Fixed-bed and entrained-flow processes generally require oxygen as the gasifying agent to generate high calorific value gas and produce liquid slag for convenience of ash removal. Fluidised-bed processes use either air or oxygen to generate low to medium heating value gas and produce dry ash.

## COAL CHARACTERISATION

### Analysis

QTHERM provided a six tonne coal sample from the Walloon Coal Measures which was mixed and analysed prior to testing. Tables 1 and 2 detail the analysis of the coal.

**TABLE 1: Chemical analysis of Walloon coal**

| | | |
|---|---|---|
| *Proximate Analysis* | | |
| Moisture | 10.5 | %ar |
| Ash | 13.4 | %db |
| Volatile Matter | 42.5 | %db |
| Fixed Carbon | 44.1 | %db |
| *Ultimate Analysis* | | |
| Carbon | 67.6 | %db = 78.1 %daf |
| Hydrogen | 5.3 | %db = . 6.1 %daf |
| Nitrogen | 0.92 | %db = 1.06 %daf |
| Sulphur | 0.4 | %db = 0.46 %daf |
| *Specific Energy* | | |
| Gross Dry | 27.98MJ/kg | =6682 kcal/kg |
| Gross Wet (as received) | 25.0MJ/kg | =5970kcal/kg |
| Net Wet (as received) | 23.8MJ/kg | =5683kcal/kg |
| *Ash Analysis* | *(% wt expressed as oxide)* | |
| Silicon (as $\%SiO_2$) | 66.5 | |
| Aluminium(as $\%Al_2O_3$) | 26.5 | |
| Iron (as $\%Fe_2O_3$) | 1.6 | |
| Titanium (as $\%TiO_2$) | 1.5 | |
| Potassium(as $\%K_2O$) | 0.29 | |
| Magnesium(as %MgO) | 0.9 | |
| Sodium (as $\%Na_2O$) | 1.3 | |
| Calcium (as %CaO) | 1.8 | |
| Sulphur (as $\%SO_3$) | 1.0 | |

**TABLE 2: Physical properties of Walloon coal**

| | |
|---|---|
| Apparent Density ($g/cm^3$) | 1.243 |
| True Density($g/cm^3$) | 1.433 |
| Porosity(% volume) | 20.6 |
| Surface Area($m^2/g$) | 230 |
| Hardgrove Index | 29 |

Particular features of interest are:

- the relatively high volatile matter content (42.5% dry basis), indicative of high reactivity,
- the relatively low sulphur content (0.4%db), avoiding requirements for additional measures to control SOx emissions from the process, and
- the Hardgrove Index is also particularly low (29), indicative of potential difficulties when producing a pulverised fuel. This is not expected to be a significant factor in HRL's IGCC process that only requires the feed to be crushed.

### Gasification Reactivity Assessment

$CO_2$ gasification reactivity tests were performed using a high-pressure

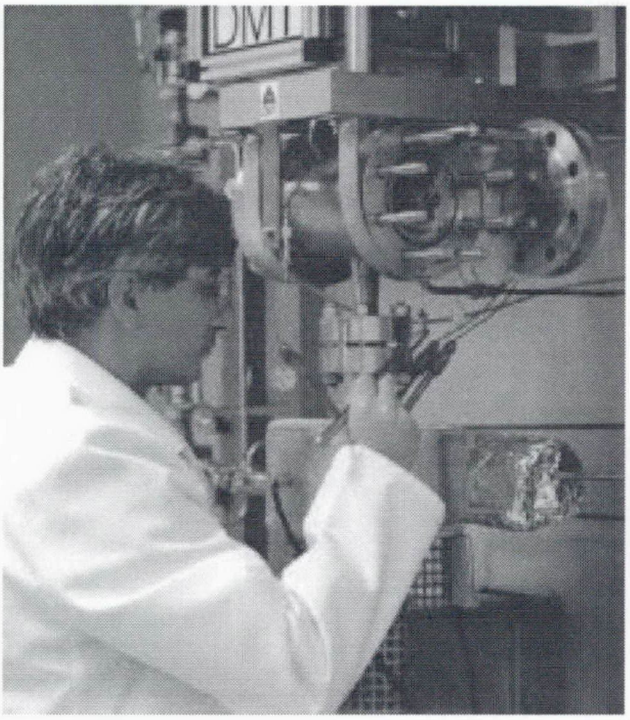

*Figure 3. Determination of Char Reactivity in a High Pressure Thermobalance.*

thermobalance (see Figure 3). This instrument is capable of operation at pressures up to 100 bar and temperatures up to 1100°C. The balance has a sample capacity of 5 grams and a resolution of 1$\mu$g.

The reactivity of the Walloon coal char to $CO_2$ at 10 bar was determined by monitoring the weight loss of char:

- under variable temperature conditions, enabling calculation of the activation energy, and
- at constant temperature, to confirm the gasification rate under specific conditions.

These results were used to indicate a suitable operating temperature for the gasifier.

## PILOT-SCALE TESTING

### Gasifier Test Rig Description

The CGDU (Figure 4) is a fluidised bed gasifier, based on the HTW concept with air as the gasification agent. It was designed as a process development unit capable of gasifying 300kg/h (7t/d) of brown coal at a maximum pressure of 1100kPaA.

The gasifier consists of a refractory lined vertical cylinder (5.5m high) with a conical bottom. Coal is conveyed into the gasifier via a system of lock-hoppers, valves and a screw

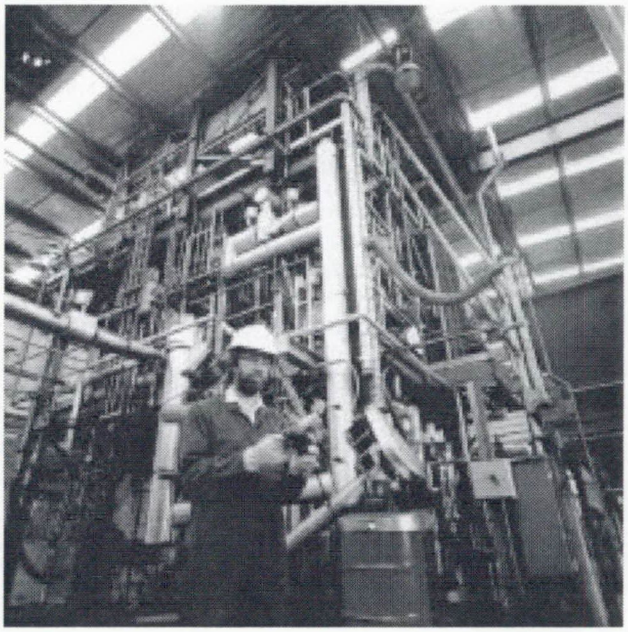

*Figure 4. Pilot-scale Coal Gasification Development Unit (CGDU).*

conveyor. The coal is then gasified in the fluidised bed by hot air (with or without added steam).

Hot air is injected into the gasifier via a system of control valves and air rings located at five levels along the gasifier height. Steam is available for both controlling the gasifier temperature and for gasification. Carbon dioxide is also used to fluidise material at the base of the gasifier, in assisting the dust recirculation back into the bed and for cooling the ash/char before removal from the gasifier.

The first three levels of air injection are located below the coal screw conveyor to provide the bulk of the gasification and fluidisation medium. The fourth and fifth levels of air injection are located in the freeboard region above the fluid-bed to provide assist conversion of char that is entrained out of the fluid-bed.

The highly dust-laden product gas at the top of the gasifier is partially cleaned via a cyclone. A recirculation pipe is provided to return all the solid material separated from the cyclone back to the fluidised-bed region of the gasifier vessel, increasing the residence time of material within the gasifier. Bed materials including ash and char can be withdrawn from the base of the fluidised bed, via a water-cooled screw conveyor and lockhopper system. This is periodically done to maintain the bed at a required height.

The product gas exiting the cyclone is cooled before being cleaned by a high-temperature

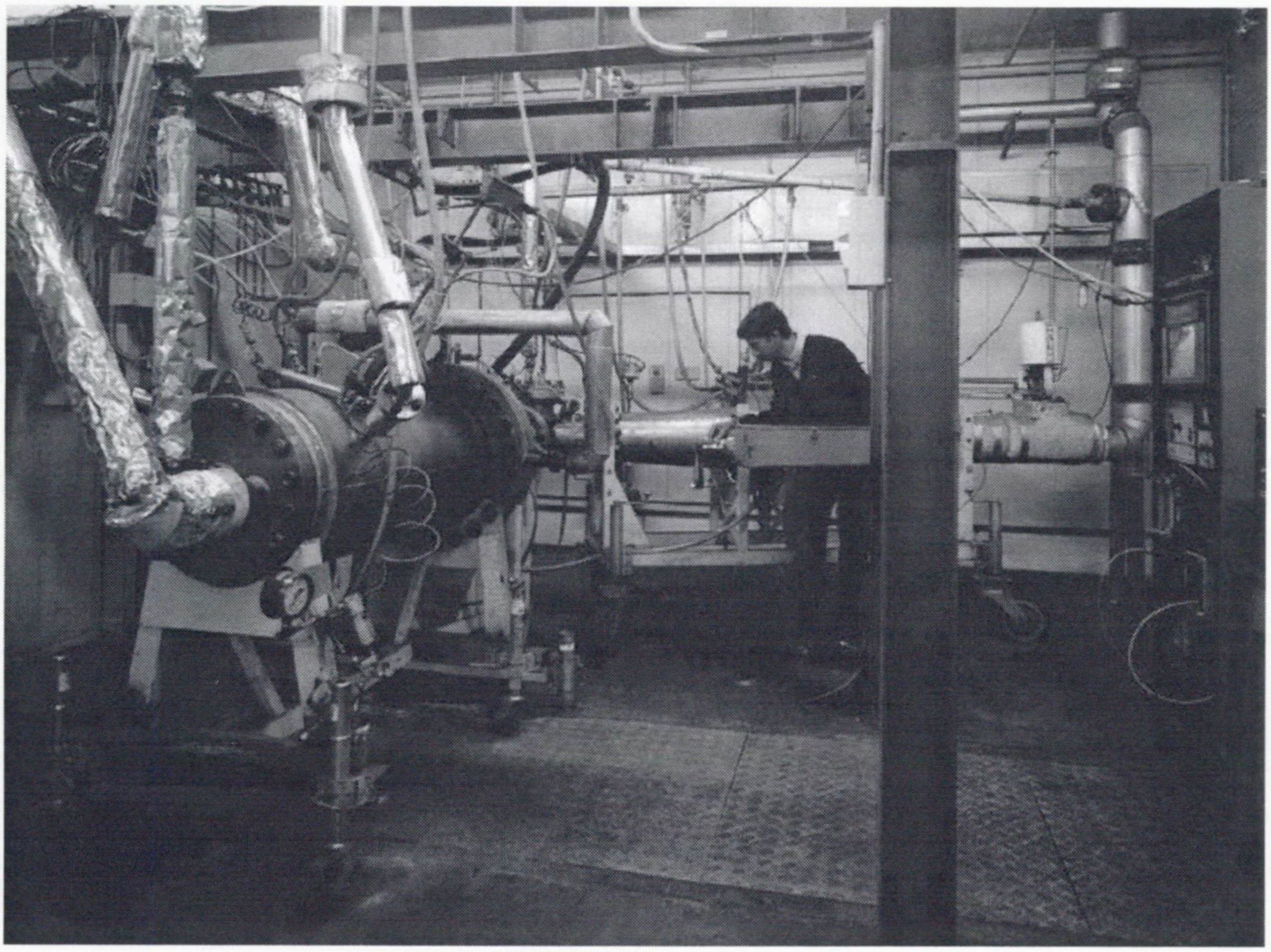

*Figure 5. Product Gas Combustion Trial in Combustion Turbine Simulator (CTS).*

high-pressure barrier filter. The filter consists of six elements made of porous silicon carbide (Si-C) sintered ceramic. It is designed to operate within the gas temperature range of 300–750°C and to collect more than 99.9% of the dust from the product gas stream, including sub-micron particles. The cleaned gas can be directed to either a pressurised Combustion Turbine Simulator (Figure 5) or to an atmospheric pressure incinerator. Sampling points are provided for collecting gas, condensate samples and solid residues at a number of locations before and after the filter.

## Test Procedure

The gasifier is first warmed with hot air and then purged with nitrogen to avoid possible risk of unwanted combustion or over-pressure excursions during initial feeding with char. The heated nitrogen is then switched over to air to start the gasification process.

Char is used as start-up fuel for raising temperature within the gasifier to about 600°C thus avoiding deposition of tar and heavy oils that might form if coal was used (as a result of release of volatile matter at low combustion temperatures). Once the temperature within the fluidised-bed region has reached approximately 750°C, dried coal is introduced. Within an hour from the start of char gasification, the fluidised-bed temperature is normally stabilised at around 750–820°C. The gasifier pressure is then gradually increased to the required operating pressure.

The bed level is estimated by measuring the pressure drops using four pressure differential transducers installed along the height of the gasifier. Removal of bed material from the bottom of the gasifier is carried out only when the fluidised-bed height exceeded a set value of the gasifier height.

Any dust carried over with the product gas and passing through the cyclone is cooled to a preset temperature, removed from the gas by the hot gas filter and collected in a hopper. The product gas is then further cooled in the gas cooler downstream of the filter.

Once steady-state operation is reached, process parameters including pressure, temperature

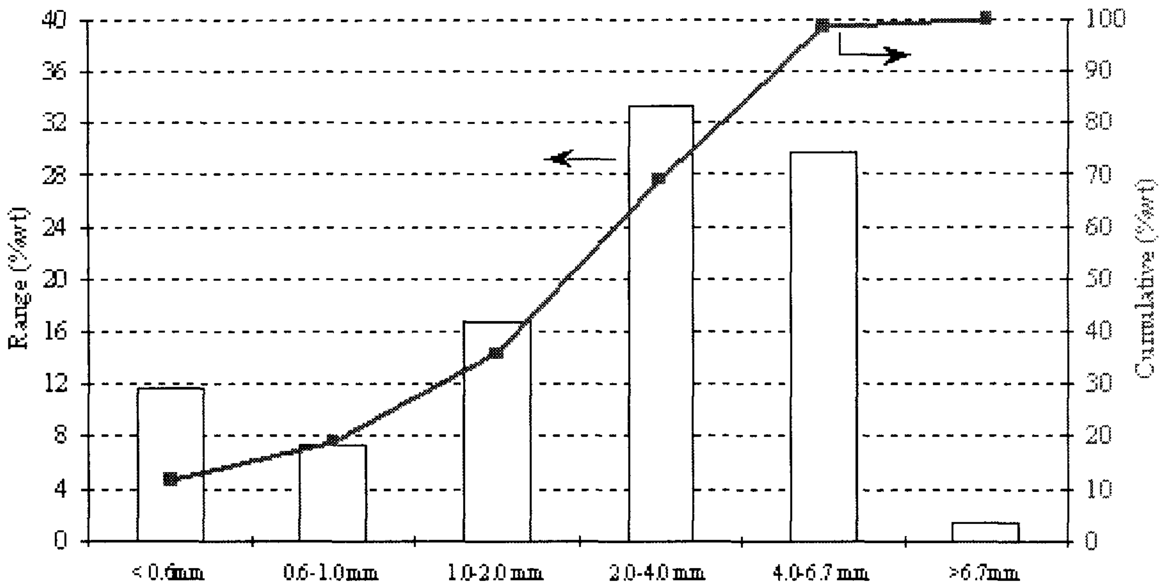


*Figure 6. Particle Size of the Walloon Coal used in the Pilot-Scale Gasification Test.*

**TABLE 3: Operating conditions during Walloon coal gasification test**

| | |
|---|---|
| Pressure | 900 kPaA |
| Coal Feed rate | 200 kg/h |
| Total Air to the gasifier | 470 kg/h |
| Total Steam to the gasifier | 46 kg/h |
| Total $N_2$ to the gasifier | 35 kg/h |
| Air/Coal Ratio | 2.38 kg/kg feed coal |

**TABLE 4: Gasification process performance of Walloon coal**

| *Fuel Gas Composition* | *(% dry vol, db)* |
|---|---|
| $H_2$ | 13.5 |
| CO | 15.6 |
| $CH_4$ | 2.1 |
| $N_2$ | 57 |
| $CO_2$ | 11.9 |
| *Efficiencies* | |
| Carbon conversion | 69.0% |
| Cold gas | 54.4% |
| Hot gas | 77.0% |
| Lower Heating Value | 3.56MJ/kg=4.16MJ/Nm$^3$ |

and gas analysis (for CO, $H_2$ and $O_2$) are monitored and recorded for process control and later evaluation. The product gas is also sampled at regular interval for detailed analysis using a gas chromatograph. Samples of bed material and filter dust are also taken at regular intervals for analysis.

### Test Conditions

The coal was crushed to a mean particle size of approximately 2.5mm diameter, with 30% wt above 4mm (Figure 6).

Process conditions during the gasification of Walloon coal are listed in Table 3. The test duration was over four hours, with approximately three hours of steady operation.

Variations in system pressure, coal and airflow rates during the test are shown in Figure 7.

## POWER STATION PERFORMANCE MODELLING

The performance of a full-scale power station based on HRL's IGCC process has also been modelled using the ASPEN PLUS and GTPRO systems. The IGCC process model is shown in Figure 1.

A typical calculation gave 221MW output from the gas turbine and 151MW from the steam turbine, with a net output of 363MW after accounting for used-in-station energy. The efficiency of the IGCC efficiency was calculated at around 42% for a power station sited in south east Queensland, compared to around 34% for a conventional pulverised fuel fired boiler/steam turbine.

An additional benefit of the IGCC process is the reduced cooling water consumption, less than 50% of that for a conventional pulverised fuel fired boiler/steam turbine.

## OBSERVATIONS AND DISCUSSION

Mass and energy balances for the gasifier were carried out using data from the period of

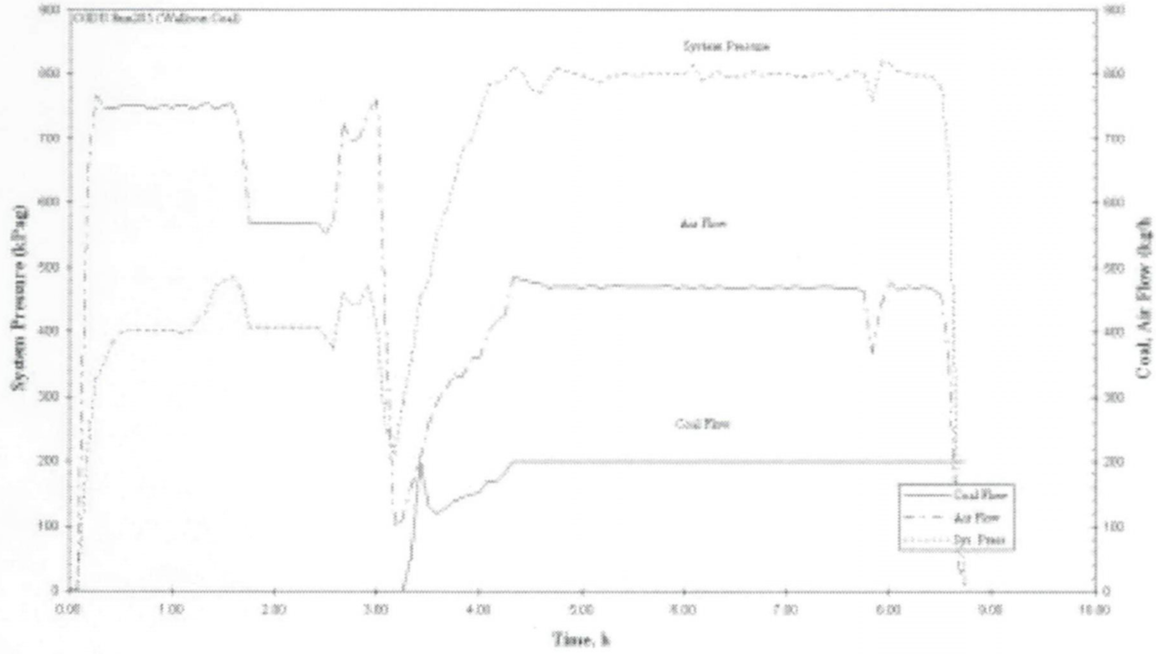


*Figure 7. Variations in system pressure, coal and air flow rates.*

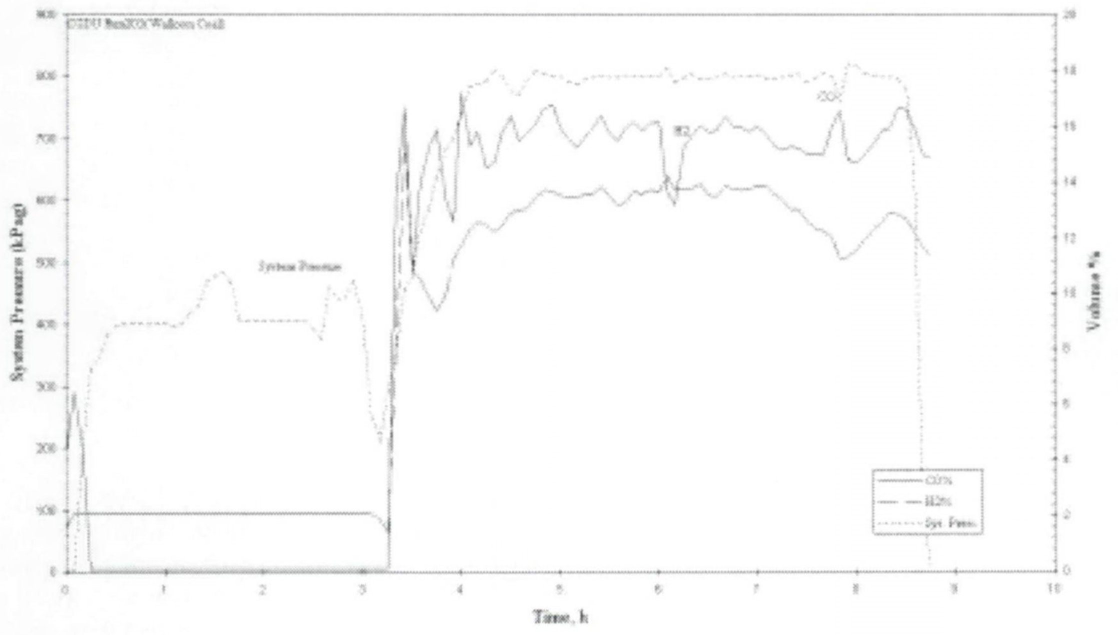


*Figure 8. Variations in product gas composition (%vol, db).*

steady operation of the gasifier. Inputs included:

- coal composition (C, H, O, N, ash and moisture contents),
- flow rates into the process (coal, air, $CO_2$, $N_2$ and steam), and
- composition of the dry product gas.

Values calculated include:

- flow rate and composition of the (wet) fuel gas,
- higher and lower heating values of the gas,
- mass flow rate of dust,
- the carbon conversion rate,
- cold and hot gas efficiencies (ratios of energy content of the gas to the feed coal), and
- heat losses within the system.

Significant process performance parameters are summarised in Table 4.

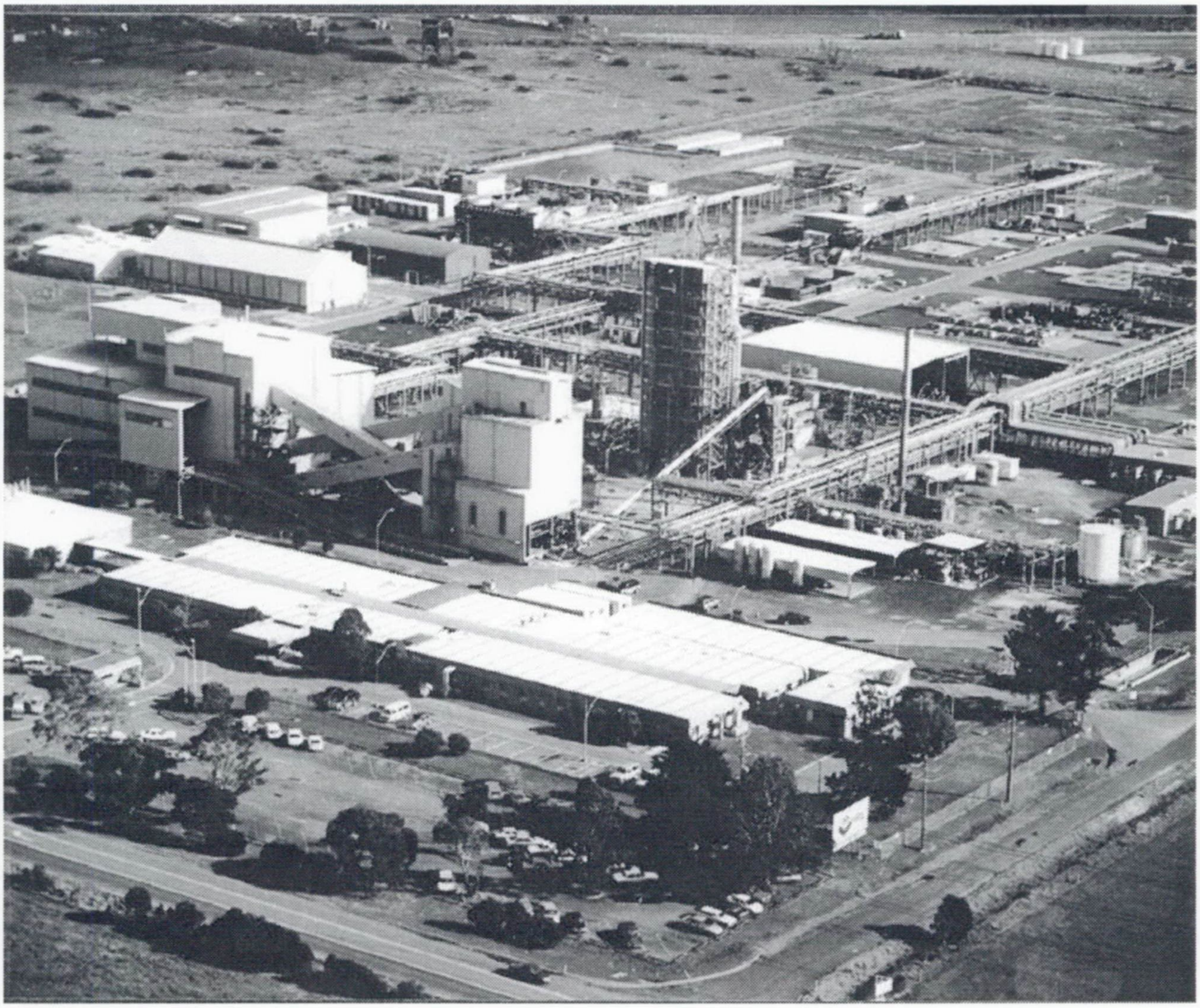

*Figure 9. 10 MW-scale Coal Gasification Development Facility at Morwell.*

Variations in product gas composition measured during the test are shown in Figure 8.

Overall the coal performed well within the gasification process, giving steady operation with sufficient heating value for combustion turbine operation.

At 69%, the carbon conversion was lower than expected, due to the portion of dust escaping the cyclone with the ash. Measurements on the filter dust indicated high reactivity, so a significantly higher carbon conversion is expected when improvements to the cyclone design are implemented and gasifier operation is optimised.

The fuel gas burnt without difficulty in the combustion turbine simulator, with a stable flame throughout the test period.

Emission levels in the combustion exhaust were also monitored during this test, with NOx of 80–225ppmv and $SO_2$ of 70–90ppmv, both corrected to 15% $O_2$, dry basis. These emissions are mainly formed due to the presence of $NH_3$ and $H_2S$ in the fuel gas. These NOx levels are relatively low considering the nitrogen content of the feed coal and are attributed to the process conditions within the gasifier and combustor.

HRL intends to further develop the IGCC process for Walloon coal, including optimisation of the gasification conditions, improvements to cyclone efficiency and testing at the 10MW-scale Coal Gasification Development Facility at Morwell (Figure 9).

## CONCLUSION

A preliminary test run carried out in HRL's pressurised pilot-scale gasification unit (CGDU) has demonstrated satisfactory performance for the high volatile content

Walloon coal from south east Queensland. The gasifier produced fuel gas of sufficient quality to achieve stable combustion in the Combustion Turbine Simulator with low NOx and $SO_2$ emissions. The carbon conversion rate observed in this preliminary test is expected to increase with optimisation of the gasifier conditions and improvements to the cyclone.

The combination of IGCC technology with the Walloon Coal Measures provides a new benchmark in coal-fired power generation efficiency. The development of such power stations would diversify the source of power generation within Queensland and enhance the prospects for export for Walloon coals.

## ACKNOWLEDGMENTS

This work was funded jointly by HRL Limited and *QTHERM*.

*QTHERM* is a Queensland government project to increase awareness of Queensland's 23 billion tonnes of high quality thermal coal and to provide strategic planning information for the efficient development of the State's thermal coal industry.

The authors also wish to acknowledge the efforts of the *QTHERM* and other HRL staff who contributed to the success of this project.

## REFERENCES

COOK, A.C., 1975: The spatial and temporal variation of the type and rank of Australian coals. *In* Cook, A.C., (Editor): *Australian Black Coal - its occurrence, mining, preparation and use.* Australasian Institute of Mining and Metallurgy, Illawarra Branch, Wollongong, 63–84.

THE QUEENSLAND COAL BOARD, 1995: *Queensland Coals - physical and chemical properties, colliery and company information* (10th edition). The Queensland Coal Board, Brisbane.

SMITH, R.J., 1986: Comparison of washed coals from the Walloon Coal Measures of the Moreton Basin with those from the Wandoan district in the Surat Basin. Geological Survey of Queensland Record 1986/34.

**Reference for this paper:**
**OTTREY, A.L., HUYNH, D. & SMITH, R.J., 1997: Behaviour of Walloon coal in HRL's IGCC Process. *In,* Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference,* 13-14 November, Brisbane, Department of Mines and Energy, 99–108.**

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# Paper one day, GIS the next...

## (Converting paper and digital records into the South-east Queensland Geological GIS)

## ABSTRACT

Geographic Information System (GIS) technology provides much greater scope to update geological map data. The Queensland Department of Mines and Energy's (DME) experience with this technology led to the proposal of a pilot project to generate a geological GIS over the Southeast Queensland Region, including the SEQ 2001 planning region. This paper sets out the project's progress and describes the process of translating multiple, disparate geological data sets into a corporate GIS asset.

The primary data set underpinning the Southeast Queensland project is a seamless digital geological map of the region. This current update of the geology of the area has been digitally compiled from:

- a combination of field mapping and investigation of mineral prospects,
- published 1:100 000, 1:250 000 and other geological paper map data from various sources,
- field notebook information from previous Geological Survey 1:250 000 and 1:100 000 mapping projects and resource studies,
- borehole information, and
- interpretations from geophysical (radiometric, magnetic and gravity) images and satellite imagery.

Significantly, the production of a seamless map has led to the resolution of ambiguous interpretation differences between geological units and boundaries, in different map sheet areas. In addition, digital geological map symbols have been generated from published maps and existing data stored in DME's corporate Minerals and Energy Resources Location and Information Network (MERLIN) Geoscience and Resource Data Base (GRDB).

The result is a unique map legend for the Southeast Queensland Region including the SEQ 2001 area, and the ability to produce:

- updated 1:100 000 geological maps in digital and hard copy format, and
- a seamless digital and hard copy geological map of the region.

Feature attribute data will be added to the seamless digital geology enabling derivative themes to be produced. This data enhancement will facilitate the development of the GIS for Southeast Queensland which may also include data themes on mineral occurrences, mineral deposits, mineral and energy prospectivity, industrial minerals and extractives resources. The GIS environment will also allow spatial modelling techniques to be applied to some data sets to create derivative themes eg mineral potential.

Further additions to the seamless map will occur as a result of field mapping and investigation of mineral prospects undertaken in 1997 to the west of SEQ 2001 (Murgon, Kingaroy, Esk, Oakey and Nanango 1:100 000 Sheet areas), and to be undertaken in 1998 over part of the Jandowae and Boondooma 1:100 000 Sheet areas.

## INTRODUCTION

Systematic geological mapping of the South-east Queensland region commenced in the early to mid 1970s as standard 1:250 000 Sheet areas using 1: 85 000 photography as a basis for compilation. This produced the Warwick, Tweed Heads, Ipswich, Brisbane, and Gympie 1:250 000 Sheets (Olgers, 1970; Cranfield & others, 1976; Murphy & others, 1976). Mapping of the Caboolture and Ipswich 1: 100 000 Sheet areas using 1: 25 000 aerial photographic bases dates from the mid to late 1970s with most adjoining map units matched across the sheet boundaries. Caboolture (1978), Ipswich (1980), and Brisbane (1986) are the only full colour remapped 1:100 000 Sheet areas completed (Murphy & others, 1974, 1979a,b, 1987; Cranfield & others, 1981, 1989, and Cranfield & others, 1986).

Other 1:100 000 sheet areas were produced in the late 1970s and 1980s as preliminary maps (Esk and Helidon ) or colour maps (Beenleigh, Murwillimbah and Mount Lindsay). These maps were generally based on the 1:250 000 mapping and information updates from auger drilling and point observations related to quarries. They were mainly focused on land use planning and development, in particular the provision of basic locations of known sources of industrial minerals, quarry rock, and sand and gravel resources.

To provide a regional geological overview, map sheet geological boundaries were rationalised at a scale of 1:500 000 resulting the production of MORETON GEOLOGY (Whitaker & Green, 1980). This map is available digitally and has been used for a range of land use purposes including regional modelling of forest types by other government agencies. A new mapping project was started in the Gympie and Laguna Bay 1: 100 000 Sheet areas in 1990 and completed in 1993 (Cranfield & Scott, 1993). This geological mapping was accompanied by mineral occurrence mapping (Barker & others, 1993).

In 1994 and 1995 geological mapping that focused on Palaeozoic metamorphic rocks and plutonic rocks of the North D'Aguilar Block was undertaken by Donchak & others, (1995) and Crouch & others, (1995, 1997). Mineral occurrence mapping in the same area was completed by Randall & others, (1996). These projects included large parts of the Goomeri, Nanango and Nambour 1:100 000 Sheet areas. Remapping of these areas include the integration of new mapping with the earlier 1:250 000 scale mapping over the Gympie 1:250 000 Sheet area.

## THE SOUTH-EAST QUEENSLAND PROJECT

The South-east Queensland Project commenced in July 1995 as a new Departmental initiative based around the SEQ 2001 planning area which is a designated major land use planning zone of the Queensland Government. The project area includes the Ipswich, Brisbane, Gympie and parts of the Tweed Heads, Warwick, Chinchilla and Mundubbera 1:250 000 Sheet areas.

The purpose of the project is to compile digital information that conveys mineral and energy resource potential to investors and provides inputs for strategic land use planning by Government. Historically significant mining in the Southeast Queensland region has been for gold around Gympie and its environs (including the Kilkivan area) and for coal in the Ipswich area. Important issues in this region include:

- highlighting areas of greater prospectivity for minerals and energy,
- sources of industrial minerals,
- land use decisions affecting alienation of mineral and energy resources,
- disposal of toxic waste, and
- rehabilitation following historic mining (eg Gympie and Ipswich areas).

Mapping of the Yarraman Sub Province (to the west of the SEQ 2001 area) is also incorporated in the South-east Queensland Project. Berkmann (1997) has shown this area to have some mineral and energy resources and potential, and it is underexplored having considerable thicknesses of residual weathering profiles. To assist in mapping the Yarraman Sub Province, airborne geophysics has been flown to:

- show different granite phases related to mineralisation,
- show areas of different rock units,
- highlight areas of residual weathering profiles, and
- identify magnetic bodies that may be associated with mineralisation.

### SEQ 2001 planning area

The SEQ 2001 area includes the Moreton Bay catchment region extending from the Queensland border to Noosa in the north and Toowoomba to the west. The lack of consistent geological map data for land use studies in the planning area led to the proposal of a pilot project to generate a seamless digital geological map and geological GIS. The seamless map will cover the South-east Queensland region and SEQ 2001 area, and contains several different structural units (Figure 1).

Geological provinces in the SEQ 2001 area include the Palaeozoic Wandilla Province (comprising the North and South D'Aguilar

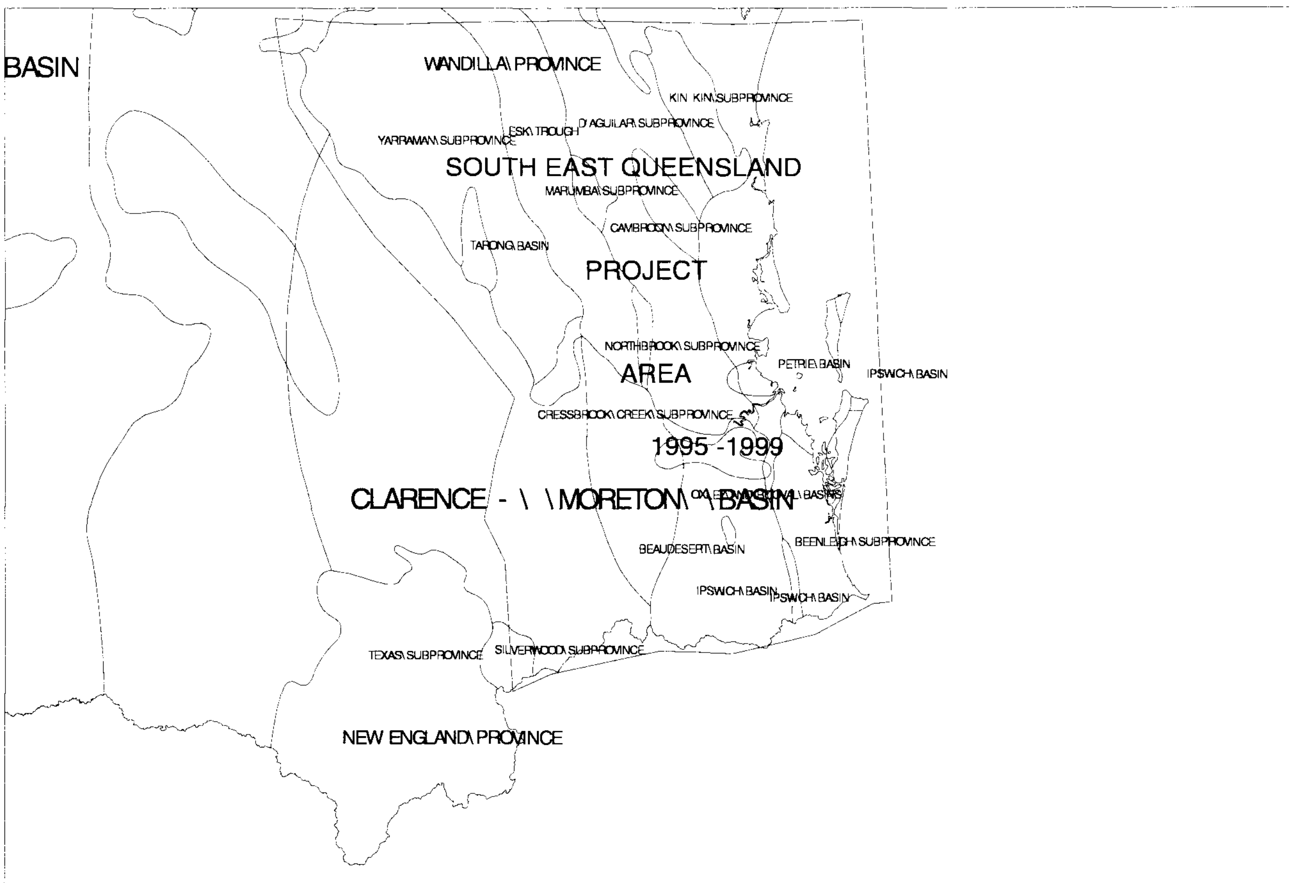


*Figure 1. Structural units of South-east Queensland.*

and Beenleigh Subprovinces), the Mesozoic Esk Trough, Ipswich, Nambour, and Clarence-Moreton Basins, and the Tertiary Beaudesert, Booval, Oxley, Petrie and Pomona Basins. The main depocentre for post -Tertiary Cainozoic rocks is Moreton Bay. Here the sediments include fluvial, marine shelf, fringing coral reefs and marine tidal delta deposits that are of Pleistocene and Holocene age.

## CURRENT AND PLANNED OUTPUT FOR THE SOUTHEAST QUEENSLAND PROJECT

Current and planned outputs from the South-east Queensland Project are in three stages:

### Stage 1

- A Seamless Digital Map with legend at best map scale over the area of SEQ 2001 (Nanango, Nambour, Caboolture, Ipswich, Beenleigh, Mount Lindesay, Warwick, Murwillumbah, Helidon, and Esk 1:100 000 map Sheet areas).
- A GIS project suitable for land use planning and development which includes themes for mineral resources, industrial mineral resources, quarry rock and sand and gravel resources.

### Stage 2

- Updates on the geology and mineralisation of the Yarraman Sub Province, the Gympie/Laguna Bay 1:100 000 map areas.
- an extension of the seamless geological map coverage to the western margin of the Gympie 1:250 000 map area as digital and hard copy products.

### Stage 3

- Comprehensive analysis of the mineral potential of the Yarraman Sub Province and the release of a Yarraman Sub Province GIS project.
- Update digital data over the whole of the South-east Queensland Project area.

This paper addresses stage 1 while the first product from stage 2 of the project will be an article on new data generated during mapping in 1997 (Cranfield & others, in preparation).

## COMPILING THE DIGITAL DATA THEMES

### Methodology

The production of a seamless digital geological map for South-east Queensland had to conform with DME's corporate MERLIN system which is based on ARC/INFO for graphical data combined with an ORACLE relational data base for attribute data. Digital map compilation is carried out by the DME's Graphical Services Unit officers who work with project geoscientists to build digital geological compilation maps up to the 1:100 000 presentation scale as well as providing extensive technical support through to final geological map production. Geological Survey Division geoscientists collect attribute data from library sources and geological and mineral occurrence mapping, for compilation in the Geoscience and Resource Database (GRDB).

The Graphical Services Unit applies their own spatial data capture standards and automated programs to streamline the digital geological map development cycle. Map compilation is an arc-driven process creating one master arc data set that is coded to enable polygon or other specific arc feature data sets to be created. Geological map units are assigned their unique id number as per the GRDB authority table, creating a link to a unit's associated attribute data stored in GRDB. Structural point data capture is also partially automated with special attention to generating structural symbology. A unique id number again creates a link to a point's associated attribute data in GRDB. Additional data themes such as mineral occurrence can be created from extracts of data from GRDB.

### Data sources

The production of a seamless geological map and GIS project for the South-east Queensland region required collecting and integrating a range of data from different sources including:

- Published 1:100 000, 1:250 000 and other geological map data from various sources (University theses and student projects, mining company exploration, research and other government agencies)
- Field notebook information from previous 1:250 000 and 1:100 000 mapping projects and resource studies.
- Borehole information from a range of diamond drill and auger holes and offshore drilling in Moreton Bay
- Comparing and updating of geological map data based on interpretation of signatures on geophysical (radiometric, magnetic and gravity) images and contour maps and satellite imagery.

Updates to the mineral occurrence information over the project area from 1993 to present have led to a relatively comprehensive data base of mineral occurrences over the whole of the SEQ 2001 area.

Data on mineral occurrence in the Esk 1:100 000 Sheet area was compiled in 1997 as part of geological mapping. Mineral occurrences in the Caboolture and Beenleigh 1:100 000 Sheet areas are being compiled from previously published data on mines and prospects in these areas. Mineral, energy and industrial minerals were compiled and updated from Berkmann (1997 and from Siemon & Holmes in preparation).

### Issues

Individual 1:100 000 geological maps in the South-east Queensland region have been compiled and published based on different levels of geological knowledge. As a result, inconsistencies of interpretation have occurred. Geological line work did not match up across most map sheet boundaries and the same geological unit was mapped differently across map sheet boundaries. To generate a seamless digital map and map database, it was necessary to:

- resolve these differences and recognise similarities between geological units in different areas, and
- generate a unique map legend that would be suitable for the whole region.

For the Palaeozoic and Mesozoic geology with named stratigraphic units this proved less difficult than for Cainozoic units that were morphostratigraphic in nature (i.e., related to landforms). To resolve Cainozoic unit inconsistencies in the region, the Brisbane 1: 100 000 Sheet area's Cainozoic nomenclature was used as a template. In addition, for the first time in Queensland, the Brisbane 1: 100 000 Sheet area also provided map information for unconsolidated Cainozoic offshore units in Moreton Bay.

### Resolution of issues - geological units and line work into a unified scheme

The primary data source for the seamless map was existing published 1:100 000 and 1:250 000 geological map sheets of South-east Queensland region. The compilation process involved:

- digitally capturing individual existing map sheet line work and geological unit nomenclature,
- updating geological line work using unpublished mapping from Geological Survey Division, company exploration and student theses,
- resolving all Cainozoic unit nomenclature using the Brisbane 1: 100 000 Sheet area as a template,
- resolving all other geological unit nomenclature to create continuity between map sheets,
- compiling a legend of geological units from updated maps resolving any further nomenclature issues, and rationalising duplications to create a unique seamless map legend; assigning colour scheme using DME's in-house shadeset library,
- edge matching and map joining all digital map sheets resolving geological line work mismatches and incorrectly assigned nomenclature at the joins; and dissolving map sheet boundaries,
- error checking and verification process for geological units via colour plots of the seamless map using unique map legend, and
- applying map corrections.

The end result is a seamless geological map of the South-east Queensland region at 1: 100 000 scale resolution.

## FUTURE WORK

The main objective is to create a geological GIS for the South-east Queensland region. The various primary data sets will be compiled into ARC/INFO and Arcview projects with a further proposal to make the project available as a CD ROM package in Arcview and MapInfo formats. To generate the GIS project, the seamless map will be compiled into themes with feature attributes coded in attached tables. Additional themes for historical tenure, mineral occurrence, extractive industry and resource assessment will be added allowing GIS modelling applications to be applied to the data.

The tasks required to complete the geological GIS data are:-

1. separating the seamless digital geology into relevant geological themes,

2. generating a geological symbols layer from data in the GRDB data base, and

3. compiling and updating current and predicted future resources as themes showing:
   - mineral occurrences and mineral deposits,
   - industrial minerals,
   - quarry rock resources,
   - sand and gravel resources, and
   - combined measures of prospectivity for mineral occurrences and mineral deposits, industrial minerals, quarry rock resources and sand and gravel resources.

4. digitally capturing geological point-related observations on rock type and structure, boreholes, and geochemistry,

5. rigorously testing the integrity of all data themes including data theme interrelationships; addressing metadata issues,

6. spatial modelling to update new layers relating to mineral potential and quarry rock potential.

Work has been completed on task 1 and task 2 is well advanced. The mineral occurrence layer (task 3) exists from recent investigations and digital capture of previous compilation of mineral occurrences (Berkmann, 1997; Siemon and Holmes (in preparation). These layers are being updated and verified for the region in selected areas. Data for task 4 will be compiled using data entry consultants and cooperative student research as applicable. Task 5 is an ongoing process which will be completed before each and every data release. Task 6 is in the initial planning phase and will be developed over time with a land use planning and exploration focus.

**TABLE 1: DEPOSIT STYLES - SEQ 2001 AREA**

| Deposit _class | Model | Probability | Size category(SEQ) |
|---|---|---|---|
| gold deposits | volcanogenic | H | 4 |
| | structure/vein controlled | H | 4 |
| | skarn-type? | L | 2 |
| Heavy Mineral deposits | ilmenite | H | 10 |
| | gold | H | 2 |
| Industrial mineral deposits | limestone | M | 3 |
| | magnetite | L | 1 |
| | glass, silica and foundry sand | H | 5 |
| | dolomite | H | 2 |
| | diatomite | H | 1 |
| | perlite | H | 1 |
| | kaolin | L-M | 3 |
| | bentonite | L-M | 2 |
| | graphite | L | 1 |
| Metalliferous deposits | Porphyry Cu-Mo | H | 5 |
| | Skarn<br>Cu Au Pb Zn<br>Cu Au magnetite<br>Zn Pb Au | L | 2 |
| | Volcanogenic hydrothermal deposits<br>Cu Pb Zn Au | L-M | 2 |
| | Vein deposits<br>Cu Au<br>Cu Pb Zn<br>Cu Au Ag | L-M | 2 |
| OilShale | Oil shale deposits | H | 2 |
| Coal | Walloon | H | 10 |
| | Ipswich | H | 5 |

## MINERAL RESOURCE POTENTIAL MAPS

To generate mineral resource potential maps (task 3) in a common form used in regional mineral prospectivity studies for Australia, a classification of the importance of deposits was undertaken. Potential deposits were classed on a 1 to 10 scale based on their significance on a global scale. The world class deposits of the region (value 10) were the beach sand heavy mineral deposits and the Walloon Coal Measures. The potential of finding a deposit was weighted on the permissive criteria for that style of deposit based on known occurrences and the amount of prospecting for the deposit.

Categories in this area were Berkman's (1997) 'Possible' and 'Likely' areas of mineral potential. The category 'Possible' was given a low to medium potential, the category 'Likely' a medium to high potential and locally a high potential. The Bureau of Resource Sciences methodology was then applied to these categories. A weighted composite map was generated by multiplying the importance of the deposit by its potential for discovery. Overlaying of these values and choosing the highest value for each polygon produced a weighted composite map. Table 1 shows the deposit styles, the importance of each style and the weighting for each style in the SEQ 2001 area.

## CONCLUSIONS

Stage 1 of SEQ Project is essentially complete. A GIS containing the SEQ 2001 map and resource information is being completed. Further updates to digital data will be delivered in Stages 2 and 3 of this project. To date, the project has demonstrated a new direction for geological GIS in Queensland.

## REFERENCES


BARKER, R.M., BURROWS, P.E., SCOTT, M., CRANFIELD, L.C., & GENN, D., 1993: Mineral occurrences – Gympie and Laguna Bay 1:100 000 Sheet areas. Queensland Geological Record ,1993/14.

CHAMBERLIN, R.M., 1997: Geological maps, structural data, assay data and petrographic descriptions for railroad cuttings in the Triassic North Arm Volcanics, Eumundi Deviation - North Coast Railway, Southeastern Queensland. *Queensland Geological Record 1997/7.*

CRANFIELD, L.C., 1994: Maryborough. *Queensland 1:250 000 Geological Series - Explanatory Notes.* Geological Survey of Queensland, Department of Minerals and Energy, Queensland.

CRANFIELD, L.C., 1996: Geology and Mineralisation of the Gympie Province. In Mesozoic Geology of the eastern Australian Plate. *Geological Society of Australia Incorporated. Abstracts* No. **43,** 156.

CRANFIELD, L.C., & PASCOE, G., 1996: A seamless digital geological GIS for the Moreton region. Program and abstracts of Moreton Bay and Catchment Conference, 43.

CRANFIELD, L.C., SCHWARZBOCK, H. & DAY, R.W., 1976: Geology of the Ipswich and Brisbane 1:250 000 Sheet areas. *Geological Survey of Queensland Report*, **95**.

CRANFIELD, L.C., SHORTEN, G., SCOTT, M., & BARKER, R., in press: Geology of the Gympie Province, Australian Journal of Earth Sciences.

CRANFIELD, L.C., 1997: Mining Project Help Wanted. *Queensland Government Mining Journal*, **98** (1142), 42–43.

CRANFIELD, L.C., & PASCOE, G., in press: A seamless digital geological GIS for the Moreton region. Proceedings of Moreton Bay and catchment conference.

CRANFIELD, L.C., & SCOTT, M., 1993: Geology of the Gympie 1:100 000 Special area (9445, 9545), southeast Queensland. *Queensland Geological Record*, *1993/20*.

CRANFIELD, L.C., GREEN, P.M., HUTTON, L.J., & GRIMES, K.G.,1986: *Brisbane, First Edition, Sheet 9543,* Queensland, *1:100 000 Geological Map Commentary*, Queensland Department of Mines.

CRANFIELD, L.C., HUTTON, L.J., & GREEN, P.M., 1981: *Ipswich, First Edition, Sheet 9543, Queensland, 1:100 000 Geological Map Commentary*, Queensland Department of Mines.

CRANFIELD, L.C., HUTTON, L.J., & GREEN, P.M., 1989: *Ipswich 1:100 000 Geological Map Commentary*. Queensland Department of Resource Industries.

CRANFIELD, L.C., DONCHAK, P.J.T, RANDALL, R.E., CROSBY, G.C., OSBORNE, J.H, in preparation: Results of geological investigations in the Yarraman Sub province in 1997. Queensland Government Mining Journal.

CROUCH, S.B.S., DONCHAK, P.J.T., TENISON WOODS, K., SCOTT, M., KWIECIEN, W. & GRAYSON, R., 1995: Plutonic rocks of the North D'Aguilar Block. *Queensland Geological Record, 1995/8.*

CROUCH, S.B.S., TANG, J. & KWIECIEN, W., 1997: Geochemistry of the plutonic rocks of the North D'Aguilar Block. *Queensland Government Mining Journal*, **98** (1144), 6–18.

DONCHAK, P.J.T., LITTLE, T.A., SLIWA, R., & HOLCOMBE, R.J., 1995: Geology of metamorphic units of the North D'aguilar Block -Goomeri, Nanango and Nambour 1:100 000 sheet areas. *Queensland Geological Record 1995/7.*

MURPHY, P.R., SCHWARZBÖCK, H., CRANFIELD, L.C., WITHNALL, I.W. & MURRAY, C.G., 1976: Geology of the Gympie 1:250 000 Sheet area. *Geological Survey of Queensland Report*, **96.**

MURPHY, P.R., TREZISE, D.L., HUTTON, L.J., & CRANFIELD, L.C., 1974: Caboolture, 1:100 000 Geological Map, Geological Survey of Queensland.

MURPHY, P.R., TREZISE, D.L., HUTTON, L.J., & CRANFIELD, L.C., 1979a: Kurwongbah beds, a new stratigraphic unit of the D'Aguilar Block. *Queensland Government Mining Journal*, **80**, 65–70.

MURPHY, P.R., TREZISE, D.L., HUTTON, L.J., & CRANFIELD, L.C., 1979b: Fahey Range Andesite and Karana Quartz Diorite, new stratigraphic units in the Caboolture 1:100 000 Sheet areas. *Queensland Government Mining Journal*, **80**, 586–571.

MURPHY, P.R., TREZISE, D.L., HUTTON, L.J., & CRANFIELD, L.C., 1987: Caboolture 1:100 000 Geological map Commentary. Geological Survey of Queensland.

OLGERS, F., 1974: Warwick. Queensland and New South Wales 1:250 000 Explanatory Notes. Department of Minerals and Energy Bureau of Mineral Resources, Geology and Geophysics; Department of Mines, State Of Queensland, Geological Survey of Queensland. Australian Government Publishing Service.

RANDALL, R.E., OSBORNE, J.H., DONCHAK, P.J.T., CROSBY, G.C. & SCOTT, M., 1996: A Review of Mineral Exploration and known Mineral Occurrences within the Goomeri (9345), Nambour (9444) and Nanango (9344) 1:100 000 Sheet Areas, South Queensland. *Queensland Geological Record, 1996/4.*

WHITAKER, W.G. & GREEN, P.M., 1980: Moreton Geology - Geological map of the Moreton Distirct and northern New South Wales at a scale of 1:500 000. Department of Mines, Queensland.

**Reference for this paper:**
**CRANFIELD, L.C., TUTTLE, J.S., PASCOE, G. & GREIG, J., 1997: Paper one day, GIS the next. Converting paper and digital records into the South-east Queensland Geological GIS. *In,* Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference,* 13-14 November, Brisbane, Department of Mines and Energy, 109–116.**

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# Mineral development trends in Queensland

## EXPLORATION

The effect of the uncertainties of the Native Title regime has begun to show in the statistics for Queensland mineral exploration. In an industry where rapid turnover of exploration areas is essential for continued investment, the inability of the State to grant any exploration tenures is being reflected in a drop in exploration expenditures.

There has been growth in the area covered by mineral exploration permits and applications to 56 620 sub blocks in June 1997 but 30% of this area has not been granted awaiting clarification of the status of exploration under the Native Title regime. At the same time, expenditure on mineral exploration decreased by 19% from $141 million in 1995-96 to $114 million in 1996-97. Average exploration expenditure per sub block increased by more than $300 to about $3 000 in 1996-97, indicating that companies are spending more on available ground while they are waiting for new permits. These statistics point out the need for a quick resolution to the native title procedures for exploration and development on other than freehold land.

Another contributing factor to the decline in exploration expenditure is the winding down of intensive diamond drilling campaigns around mines that have just been commissioned such as Ernest Henry and Cannington.

The major focus for exploration continued to be base metals although expenditures for these commodities decreased from $83 million in 1995-96 to $56 million in 1996-97. This represented 26% of the Australian expenditure on exploration for base metals. Exploration expenditure for gold decreased from $52 million to $46 million in 1996-97 and that figure could decline still further with present price trends.

Expenditure on exploration for other commodities such as tin, tungsten, uranium and industrial minerals increased by $5 million to $12 million and appears to be attracting significant interest.

Queensland has had a remarkable record in exploration successes for the past ten years. In each year, there has been the discovery of a major, if not a world class mineral deposit. It is important to reverse the trend of declining expenditure on exploration if we are to continue the supply of major mineral discoveries for subsequent mine developments.

## DEVELOPMENT

Partly as a result of the discoveries over the last 10 years, 1997 has been an impressive year for the commissioning of major mineral projects. Ernest Henry copper-gold and Cannington silver-lead-zinc mines commenced production in the second half of the year. The WMC Fertilisers Phosphate Hill project ($650 million of which $500 million is now committed in contracts) and Century zinc ($1 billion) have both commenced construction. At the Ely bauxite deposit north of Weipa Alcan South Pacific (Alspac) has commenced construction of a mine and port to move 2.5 million tonnes of bauxite per annum to Gladstone and Ireland by 1999.

MIM has committed to the development of the Enterprise deep copper underground mine and expects to make a decision on the development of the George Fisher silver-lead-zinc deposit north of Mt Isa by the end of the year. Aberfoyle Limited announced their intention to expand their Gunpowder Esperanza copper mine from 8 000 to 44 000 tonnes of copper per annum at a cost of $120 million.

Normandy Mining have announced an increased rate of production at the 1.4 million ounce Vera-Nancy gold deposit at the Pajingo mine site.

Australian Kaolin commenced operations at their kaolin mine at Skardon River and have stockpiled 50 000 tonnes of product for shipping.

## DOWNSTREAM PROCESSING

A number of mineral processing developments have been started recently including Sun Metals zinc refinery in Townsville, WMC Fertilisers Phosphate Hill plant, Calliope Metals nickel smelter in Gladstone and the Australian Magnesium Corporation magnesium metal plant in Gladstone. MIM has announced a $250 million upgrade of the copper smelter in Mt Isa to process ore from the Ernest Henry mine and the new Enterprise copper mine. In addition, there are plans being developed for at least one new copper smelter in the Cloncurry area to toll treat ore from surrounding producers.

These proposals are responding to the increased accessibility of different forms of energy throughout Queensland and in particular to the delivery of gas to North West Queensland through the Ballera-Mt Isa pipeline and to Northern Queensland from PNG through the Chevron pipeline. Reforms to the electricity industry in Queensland will allow major customers such as mines and processors to negotiate more efficient supply contracts with competing retailers within the next couple of years. This should reduce input costs and provide more flexibility in arranging the provision of energy to the mine site.

## CONCLUSION

The minerals industry in Queensland is the scene of much activity particularly in the development of mines and integrated projects. There is a concern for the future if the decline in exploration expenditure continues, and this trend will only be turned around by a resolution of the native title aspects of the access to land for exploration and development.

**Reference for this paper:**
**DICKIE, G., 1997: Mineral development trends in Queensland. *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 117–118.**

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# North Queensland mineral province - Past, Present, Future

## SUMMARY

Since the discovery of gold at Cape River in 1867, the mining industry has been a mainstay of the north Queensland economy. As well as sustaining its own indigenous mining industry (with over $700 million of production per annum), north Queensland has been the major outlet for northwest Queensland and a supply base for mineral and energy projects in Indonesia and Papua New Guinea. Historically, gold, tin, tungsten, and base metals were the most significant mineral products from north Queensland. Tin and tungsten are no longer mined (although significant resources remain), but bauxite, nickel, silica sand and limestone have become important commodities since the 1960s. Although nickel mining has ceased, the nickel refinery at Yubulu continues to operate on imported ore. In terms of a mining industry, the future for north Queensland is promising. Potential for further gold discoveries are good. A second bauxite mine is under development. Additional base metal production is likely. Silica sand demand shows no sign of weakening. Kaolin will become a major export. Tin and tungsten resources are available if there is significant price movements and increased demand for these minerals. Industrial mineral demand will increase with further development. With new mines being developed and a fertiliser industry in preparation in northwest Queensland, Townsville will grow significantly as a port. More importantly, the zinc refinery under development and postulated energy developments, including the supply of natural gas to the area, will open up opportunities for more value-added products from north and northwest Queensland and an enlarged manufacturing sector.

## INTRODUCTION

The area of 450 000km$^2$ covered by this paper (Figure 1) was selected for the National Geoscience Mapping Accord (NGMA) North Queensland Project which was initiated in 1990. The aim of the Project, which is part of the Department of Mines and Energy GEOMAP 2005 program, was to provide a comprehensive geoscientific knowledge base for north Queensland. Existing maps and datasets were to be expanded and updated, and made readily accessible via computerisation.

The results of the project would provide governments, industry and the community with essential information for sound decision making on development and conservation strategies in a region of strategic national importance. New information and ideas presented in useable formats provide impetus for new exploration and reduce exploration risk.

North Queensland is an area of complex geology with a complex geological history. It contains the easternmost Proterozoic rocks in Australia, indications of the late Proterozoic Grenville Orogeny, the northernmost deformation of the Early Cambrian Delamerian Orogeny, igneous and sedimentary rocks of equivalent age to those in the Lachlan Fold Belt, igneous activity over large areas during much of the mid to latest Palaeozoic associated with widespread gold and tin mineralisation, deformation attributed to the Permian to Triassic Hunter-Bowen Orogeny, sediments of the Great Artesian Basin, large Cainozoic basalt fields with flows as young as 10 000yrs BP, and widespread regolith including bauxite deposits.

This paper examines the historical significance of mining in north Queensland and the current mining and exploration situation. The mineral resources are placed in their geological context

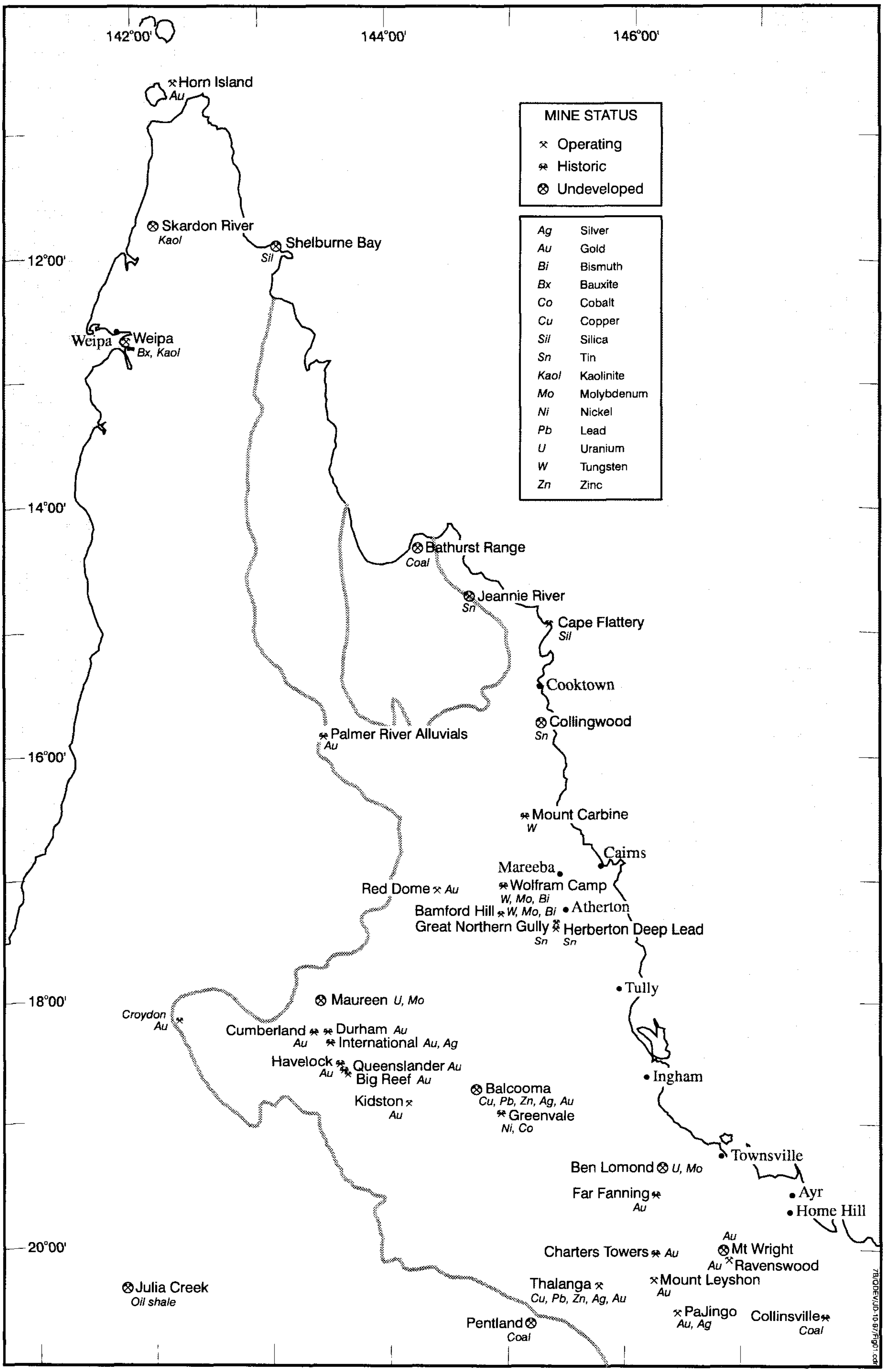



*Figure 1. Location map for north Queensland showing the principal mineral deposits (historic mines, current mines and undeveloped prospects).*

and the sources of geoscientific information outlined. Finally, a brief scenario for a promising future for north Queensland is presented.

I would like to acknowledge the contributions of the many staff of the Geological Survey of Queensland and the Australian Geological Survey Organisation who contributed to the geological understanding of north Queensland and on on whose work I have drawn to prepare this paper.

## THE PAST

### Historical Perspective

Following a favourable report on the upper Burdekin district by Dalrymple in 1856, pastoralists moved into north Queensland and by 1866 the southern parts of north Queensland were occupied. Ports were established at Bowen (Port Denison) in 1861 and Cardwell in 1864 to provide access to pastoral areas. Townsville was also established in 1864, but not gazetted as a port of entry until 1865. The port of Somerset was established at Port Albany on Cape York in 1864, but was abandoned by 1877 with Thursday Island becoming the main centre for the area. Normanton was established in 1868 to service the pastoral industry.

By 1866 the pastoral industry in north Queensland was struggling, but the discovery of gold in 1867 at Cape River began a new era in the north. The importance of this discovery is highlighted by Fitzgerald (1982):

*"Despite its short productive life, the notoriously brutal Cape field brought over 2,500 people to the struggling north: it created new ports, strengthened old ones, and provided a ready market for beef. Near-by pastoralists were kept in business, and a mining-oriented population was attracted to North Queensland, increasing the possibility of further finds".*

The Cape River discovery was followed by Ravenswood (1868), Etheridge (1870), Charters Towers (1871), Palmer River (1873), Hodgkinson (1876) and Croydon (1885). Towns sprang up to support the miners with Ravenswood, Charters Towers, Georgetown, Cooktown, Cairns and many smaller towns forming the framework around which north Queensland developed. Other minerals were discovered, and sugar cane was first planted in the early 1880s leading to a flourishing industry. North Queensland continued its development since then with mining, pastoralism, tourism and agriculture providing the economic backbone of the region.

The earliest geological observations of north Queensland were made by naturalists and others on board the various vessels that explored the coastline and the Great Barrier Reef. The first professional geologist to visit north Queensland was Joseph Jukes, who subsequently became Director of the Irish Geological Survey, aboard the HMS Fly in 1843-44 (Jukes, 1847).

Detailed geological investigations of north Queensland began with Richard Daintree–geologist, explorer, pastoralist and photographer. Daintree was the discoverer of the Cape River gold field in 1867 and was appointed Government Geologist for the northern region of Queensland in 1868. Daintree resigned from the position in 1871, and his map and report on the geology of Queensland was published in 1872 (Daintree, 1872).

North Queensland was without a government geologist till 1877 when Robert Logan Jack became the Geological Surveyor for north Queensland; he became Government Geologist for Queensland in 1879. A. Gibb Maitland was appointed in 1888 to assist Jack in north Queensland. The headquarters of the Geological Survey of Queensland remained in Townsville until 1892 when the Survey was consolidated in Brisbane. Jack was a very productive geologist and contributed enormously to the understanding of the geology of north Queensland. He produced two geological maps of Queensland (Jack, 1886; Jack & Etheridge, 1892), the first map and report of the Charters Towers goldfield (Jack, 1879), and collaborated with Robert Etheridge Jr to produce a monumental volume on the state's geology and palaeontology (Jack & Etheridge, 1892). He was also the first to recognise the Great Artesian Basin.

Other early contributors to geological studies in north Queensland were J. H. Reid, W.H. Rands, L.C. Ball, E.C. Saint-Smith, and B. Dunstan. In 1935, C. C. Morton was appointed Regional Geologist at Charters Towers, a new position. He was succeeded by A. K. Denmead in 1946, T. Connah in 1950, and K.R. Levingston in 1956. The position in Charters Towers was abolished in 1990.

Much of the early government work was in direct support of mining although some regional geological studies were carried out.

Since the Second World War, more systematic geological mapping has occurred although some systematic studies had been carried out between 1934 and 1940 by the Aerial, Geological and Geophysical Survey of Northern Australia (a joint Commonwealth/ State initiative). AGGSNA surveys included the Croydon and Herberton mineral fields. In 1950 the joint regional mapping program of GSQ and BMR began in north-west Queensland with the first maps in north Queensland commencing in 1956 (ATHERTON and CLARKE RIVER). Since 1956, 1:250 000 maps have been prepared for all of north Queensland and more recently second pass mapping has been carried out with a large number of maps prepared for selected areas at 1:100 000 scale, 1:250 000 scale and 1:500 000 scale. The results of geological mapping in north Queensland are outlined in Bain & Draper (in press, a,b).

Universities have contributed significantly to geological studies in north Queensland. The establishment of a university at Townsville, James Cook University of North Queensland (JCU), in the 1960s provided a focus for academic studies in north Queensland. Studies from that university covered many aspects of the geology of north Queensland including mineralisation, structure and tectonics, marine geology, and Cainozoic volcanism. R.A. Henderson and P.J. Stephenson from JCU are the editors of "The Geology and Geophysics of Northeastern Australia" which, since 1980, has been the major text on the geology of north Queensland (Henderson & Stephenson, 1980).

Since the 1950s, exploration and mining has been more controlled, with a statutory requirement to lodge reports on exploration. The Company Report system maintained by the Queensland Department of Mines and Energy is a valuable source of information on the geology of mineralised areas. Many exploration geologists have contributed to the understanding of north Queensland through company sponsored projects or through external funding bodies such as Australian Mineral Industry Research Association (AMIRA). "Mineral Deposits of Northeast Queensland: Geology and Geochemistry" (Beams, 1995), published by JCU, is an important volume presenting the results of company research in the area.

## Mining Overview

Since the discovery of gold at Cape River in 1867, mining has played an important role in north Queensland by providing income, opening up new areas and providing markets for pastoralists and retailers. Mining in north Queensland is valued at more than $700 million per annum.

The Charters Towers area is a world class gold province with 15 million ounces of gold discovered in that area alone to date. Over 24 million ounces of gold have been discovered in north Queensland. Important deposit types include epithermal, volcanogenic, porphyry, plutonic, slate belt, and placer. Important existing mines are Mount Leyshon, Kidston, Pajingo (Vera-Nancy), and Ravenswood (Nolans and Sarsfield). Historically important fields include Cape River, Charters Towers, Ravenswood, Palmer River, Etheridge, Croydon, Woolgar and Red Dome, which ceased operation in 1997.

Over 200 000 tonnes of alluvial and hard rock tin concentrate have been produced to date in north Queensland and more than 250 000t of low grade hard rock resource remains. Large alluvial resources are also present. Tungsten has been mined, with more than 31 000t produced (50 % from Mount Carbine). The undeveloped Watershed Grid deposit contains 39 000t tungsten as scheelite. Thirty-nine million tonnes of lateritic nickel ore at 1.5 % nickel and 0.1 % cobalt were mined at Greenvale between 1974 and 1992. The nickel refinery at Townsville continues to operate on imported ore. Volcanic-hosted massive sulphides are mined at Thalanga - other known deposits include Balcooma (at feasibility stage). Other important base metal deposits are Besshi-Kieslager type copper at Dianne and Mount Molloy, stratiform base metals at Einasleigh, copper at Red Dome; copper rich skarns in Chillagoe area and zinc rich skarn at Mount Garnet.

Bauxite is mined from a world class deposit at Weipa (reserves of 248Mt with a total resource of 3700Mt); 206Mt were produced between 1960 and 1993. Annual production of 8.5Mt is about 10 % of world supply. Over 700Mt bauxite resources occur elsewhere in western Cape York Peninsula. Production is expected to start shortly at the Ely deposit 25km north of Weipa. Kaolin is present with a possible resource at Weipa of 50Mt and a resource of 27Mt at Skardon River (feasibility stage). Kaolin was produced at Weipa between 1986 and 1996. Silica sand production at Cape Flattery is about 1.8Mt pa. Cape Flattery has reserves of 200Mt, the resource is much larger. Additional resources are present at Shelburne Bay (143Mt) and Colmer Point (192Mt).

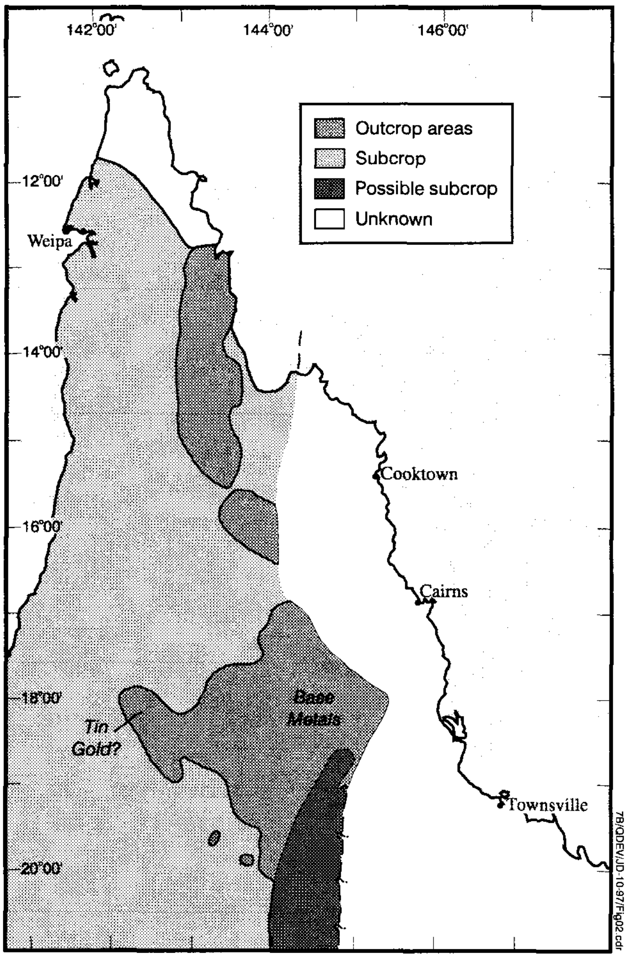



*Figure 2. Distribution of rocks deposited between 1990 and 1550 million years ago (Palaeo- to Mesoproterozoic). Areas within outcrop occurs and areas covered by younger rocks are shown separately. Major mineral commodity locations are shown.*

Other minerals produced or discovered in north Queensland include antimony, silver (by-product), uranium (Ben Lomond, Maureen), gemstones, limestone, dimension stone (including Chillagoe marble), dolomite, perlite, fluorite, coal (Bathurst Range, Pentland), molybdenum, heavy minerals, iron ore, manganese, diatomite and oil shale.

The north Queensland region has a major port in Townsville, which is the main export port for the Mount Isa area, and an international airport at Cairns. Townsville has copper and lateritic nickel refineries, and plans have been announced for the development of a zinc refinery. Townsville is well placed to service the expanding circum-Pacific region. Energy is available nearby from the coalfields and the large coal bed methane resources of the Bowen Basin, undeveloped coal deposits in the Laura and Galilee Basins, undeveloped oil shale near Julia Creek, undeveloped uranium resources, and the large natural gas fields of PNG (a feasibility study for a gas pipe line to Townsville is being undertaken).

### *Geology And Mineralisation*

Mineralisation is north Queensland is very diverse as shown by the wide range of commodities discovered or mined. This diversity is a result of the geological history of north Queensland. For details of the geology, mineralisation and mineral resources of north Queensland refer to Bain & Draper (1997a,b) and references therein. Resource assessments are available for Cape York Peninsula (Denaro & Ewers, 1995) and for the Georgetown Region (Denaro & others, 1997). To place the mineralisation within a geological context, seven broad geological periods are examined in this paper. Each of these periods has a distinctive geological history and a unique suite of mineralisation styles.

### *Palaeo- To Mesoproterozoic (1900-1550 my)*

The oldest rocks in north Queensland are of Palaeo- to Mesoproterozoic age (from about 1900 Ma to 1550 Ma). Rocks of this age crop out in the Georgetown, Yambo and Coen areas (Figure 2), are present in the subsurface to the west of the outcropping areas, but are not known to the east of the outcropping areas. The exposed rocks were originally deposited mainly as sediments with minor volcanics, but were subsequently deformed, metamorphosed and intruded by granites. At about the time the granites were being emplaced (1550 Ma), a large caldera was present in the Croydon area with volcanic rocks deposited within the caldera.

Although the Proterozoic rocks in north Queensland are similar in age and geological setting to those in the Mount Isa area, they do not contain significant mineralisation of Proterozoic age. In the Croydon area, tin mineralisation of this age occurs. The gold mineralisation at Croydon may be of this age, but may also be younger. Base metals occur near Einasleigh and in the Coen area, but do not form large deposits. Rocks of this age do form suitable hosts for younger mineralisation. Potential exists for the discovery of Mount Isa and Cannington style mineralisation in these rocks.

### *Mesoproterozoic To Cambrian (1550 - 500 my)*

Little is known about the geology of north Queensland from 1550Ma to about 900Ma although detrital material about 1100 Ma has been found in younger rocks. Sediments and

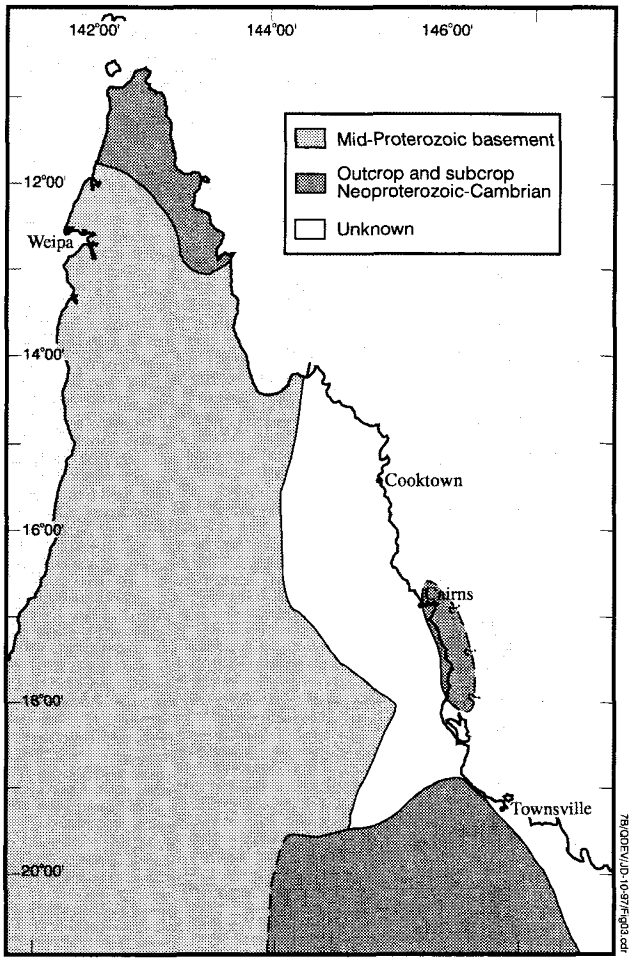



*Figure 3. Distribution of rocks deposited between 1550 and 500 million years ago (Mesoproterozoic to Cambrian). Only minor mineralisation is present.*

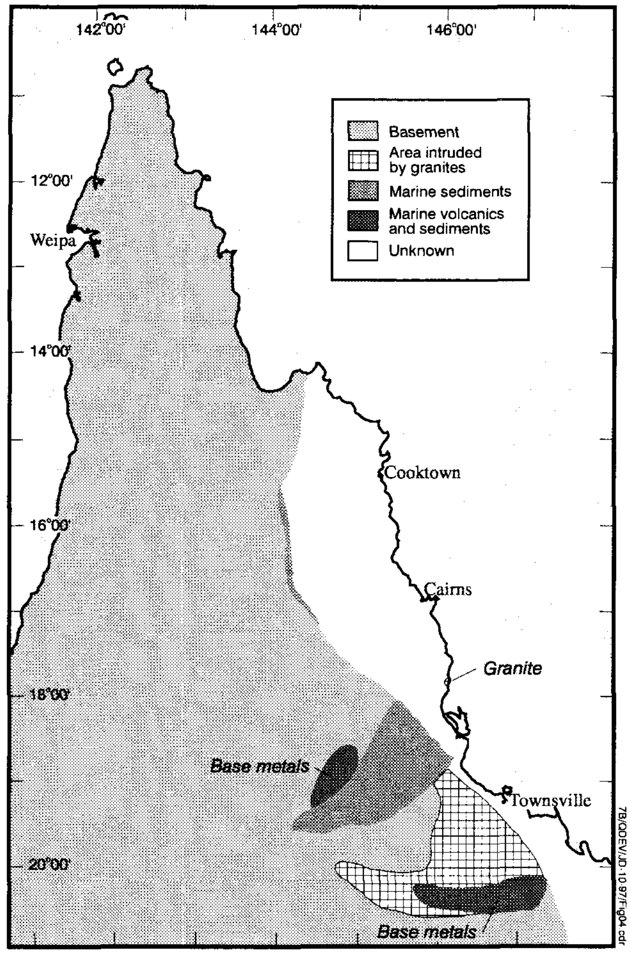



*Figure 4. Distribution of rocks deposited between 500 and 434 million years ago (Late Cambrian and Ordovician). Known mineralisation is restricted to the volcanic rocks.*

minor volcanics were deposited in the Charters Towers-Cape River area, Innisfail area and Iron Range area (Figure 3) between 900Ma and 510Ma. These sedimentary and volcanic rocks were metamorphosed and deformed at about 500Ma.

Little mineralisation is known from rocks of this age. Ironstone and manganese deposits are known, but are uneconomic. Minor gold is associated with the ironstones. Gold deposits hosted in rocks of this age in the Charters Towers-Cape River area are of a younger age. Potential for mineralisation in rocks of this age appears to be limited.

### *Late Cambrian And Ordovician (500 - 434 my)*

During this time period, volcanic rocks and associated sediments were deposited west of Townsville and granites were intruded in the same general area (Figure 4). There are also several small granite bodies of this age known on the coast. Marine sediments were deposited on the eastern side of the craton.

Base metal deposits such as those at Thalanga and Balcooma are associated with the volcanic rocks and potential exists for discovery of more deposits in these rocks. In the Charters Towers area, exploration for gold mineralisation similar to that at Cadia in NSW has had some success, but the age of the mineralisation found has yet to be determined and may be younger.

### *Silurian To Middle Devonian (434 - 369 my)*

A large mass of granite extending from the far north to the Charters Towers area was intruded during this period (Figure 5). Widespread marine deposition occurred to the east of the granites.

The large Charters Towers goldfield formed at this time as did many gold deposits in the Etheridge goldfield and in the Coen area. These deposits are associated with the granites and potential exists for further discovery of gold associated with these rocks. Significant limestone deposits are present and potential

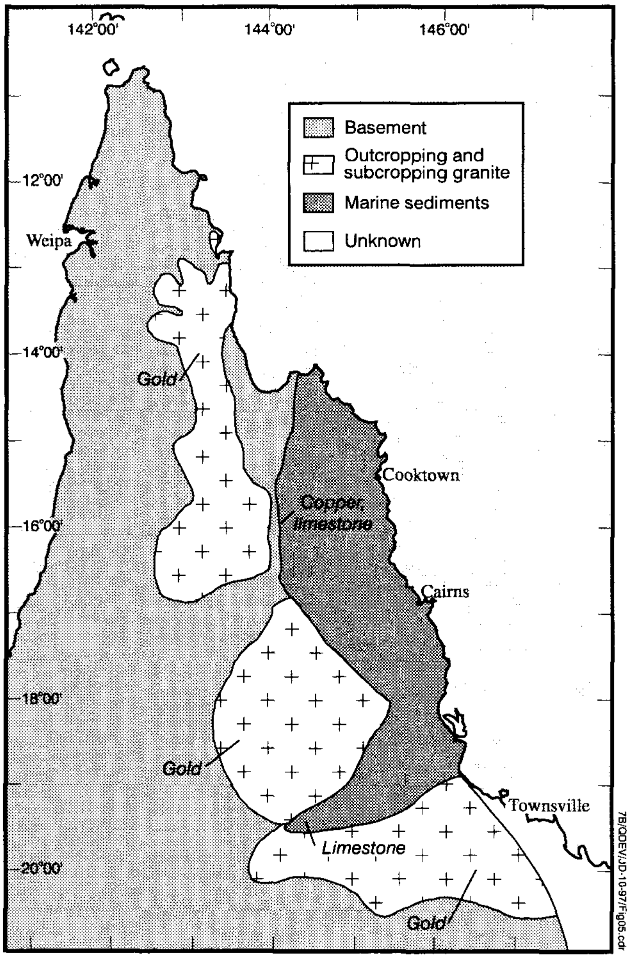



*Figure 5. Distribution of rocks deposited between 434 and 369 million years ago (Silurian to Middle Devonian). Significant gold mineralisation is associated with the granites.*

exists for copper mineralisation associated with marine volcanic rocks interbedded with the marine sedimentary rocks.

*Late Devonian To Middle Triassic (369 -230 my)*

Large areas of north Queensland were intruded by granites during this time period. Large areas of volcanic rocks were also extruded. Although many of these rocks crop out, large areas are obscured by younger rocks (Figure 6). A number of sedimentary basins also formed; some of these basins contain coal measures.

This period is the most mineralised period both in terms of distribution and of diversity of mineral deposits. Gold deposits at Kidston, Mount Leyshon, Ravenswood, Red Dome, Palmer River goldfields, Hodgkinson goldfield, Amanda Bel goldfield, parts of the Etheridge goldfield and many smaller goldfields were formed during this period. Tin deposits at Cooktown, in the Herberton area, in the Coane Range area and tinfields elsewhere in north Queensland also formed during this period. Tungsten, base metals, antimony, silver, perlite, fluorite and molybdenum were all deposited. Important limestone resources were deposited. Energy minerals formed during this time were uranium at Ben Lomond and Maureen, and coal in some of the basins (Collinsville and Pentland are mined and known resources respectively; coal was mined at Mount Mulligan).

Potential exists for further discoveries and there are large undeveloped resources such as gold at Mount Wright and tin at Collingwood and Jeannie River.

*Jurassic And Cretaceous (205 - 65 my)*

This period is marked by the development of widespread sedimentary basins across much of north Queensland (Figure 7). These sedimentary rocks covered a larger area than currently preserved because of subsequent uplift and erosion. Granites were intruded west and southeast of Townsville.

The sedimentary basins contain important groundwater resources and may have some potential for hydrocarbons offshore. Coal is present at Bathurst Range and oil shale (with vanadium) near Julia Creek. Palaeoplacers of gold and tin are known round the margins of the basins.

*Cainozoic (65 - 0 my)*

The Cainozoic in north Queensland is characterised by widespread fluvial sedimentation, intensive weathering and continental basalts (Figure 8). The Great Barrier Reef also developed during this period.

All metalliferous orebodies formed during the Cainozoic are either placers or the result of weathering. Furthermore, weathering in the Cainozoic was responsible for the development of the oxidised ore which has been an important component of many deposits that have been mined. Large bauxite deposits formed on the western side of Cape York Peninsula with the Weipa deposit currently being mined and Ely at project development stage. Lateritic nickel-cobalt deposits formed on ultramafic bodies at Greenvale in north Queensland.

Placers formed throughout the Cainozoic and are preserved now as shoreline deposits, deep leads, in modern streams and in elevated terraces. Recent and deep lead gold deposits

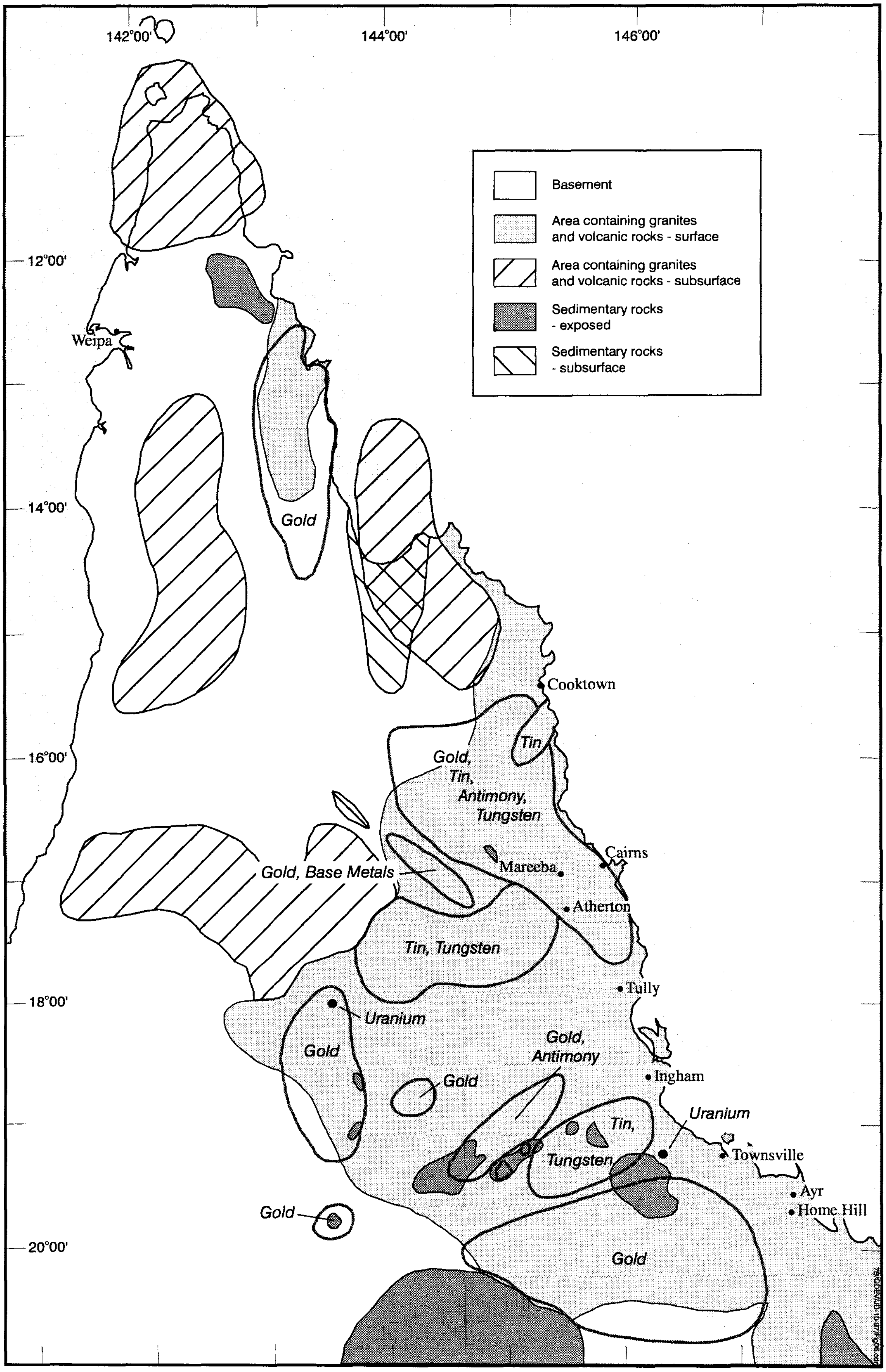



*Figure 6. Distribution of rocks deposited between 369 and 230 million years ago (Late Devonian to Middle Triassic). This is the most mineralised period of north Queensland geology as shown by the distribution and diversity of commodities.*

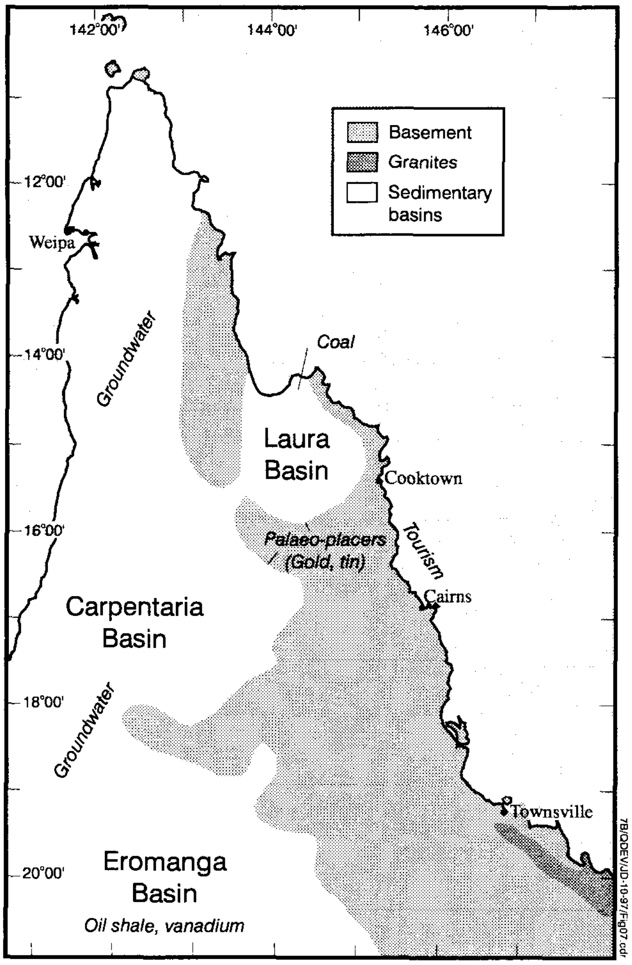



*Figure 7. Distribution of rocks deposited between 205 and 65 million years ago (Jurassic and Cretaceous). Groundwater is the only resource utilised at present.*

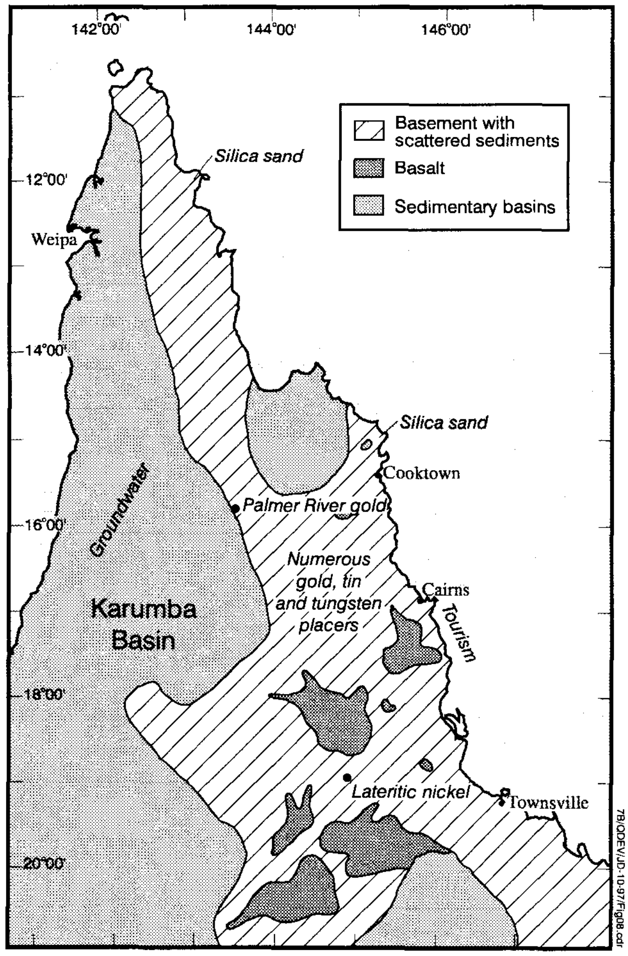



*Figure 8. Distribution of rocks deposited between 65 million years ago and today (Cainozoic). Sediments and weathering are distributed over most of the area and there are numerous basalt plugs outside the main basalt areas.*

correspond to different periods of upwarping, erosion and deposition, followed by stable periods dominated by planation and deep weathering. Shoreline deposits contain zircon, rutile and ilmenite. Coastal dunes form important silica sand deposits at Cape Flattery.

Alluvial deposits contain gold, cassiterite, wolframite, ilmenite and sapphires and are found over much of the mineralised areas of Queensland. In some mineral fields, the value of placer production exceeded the value of lode production. For example, the Palmer gold field produced 33 000kg of alluvial gold and 4300kg of lode gold and the Cooktown tinfield produced 12500t of alluvial cassiterite concentrate and 272t of lode cassiterite concentrate.

Large groundwater resources are present in the Karumba Basin. The Coral Sea Region has high hydrocarbon potential (very high risk). Cainozoic sediments, weathered rocks, volcanic landforms, Pleistocene reefs and coastal landforms are major tourist attractions.

# THE PRESENT

## Current Mining and Exploration

The mining industry in north Queensland is not without its problems at present. On the positive side, bauxite mining is expanding with the Alcan project at Ely in project development stage with a planned output of 2.5Mt per annum from a reserve of 75Mt giving a mine life of 25 years. Mining should commence in late 1999. Production at Weipa is approaching 10Mt per annum.

Gold production remains relatively stable in north Queensland which continues to be the main production area in Queensland. Recent falls in the price of gold have put pressure on the more marginal deposits. Within the Charters Towers area there are five operating mines: Mount Leyshon, Charters Towers, Vera-Nancy, Hadleigh Castle and Rishton. Nearby, the Ravenswood area continues its resurgence with development of the Nolan's deposit. Gold recovery continues from the Thalanga base metal mine. Further north the situation is less favourable with the recent closure of Red Dome and the Georgetown workings. At Kidston the opening of the Eldridge pit has extended the life of the mine. There are also a number of smaller mines operating.

Kaolin has had a somewhat chequered history recently. Kaolin was produced from Weipa from 1986 to 1996. Plans are still in place for the mining of kaolin from the Scardon River deposit.

Silica sand from Cape Flattery is produced at more than 2Mt per year for export to Asia.

Base metal production continues at Thalanga, but the closure this year of Red Dome has removed a source of copper and silver (5780t of copper and 17 850kg of silver were mined at Red Dome in 1994-95).

Nickel is no longer mined in north Queensland. However, the QNI refinery at Yubulu near Townsville continues to operate using imported lateritic ores.

Despite the unresolved tenure issues, exploration remains at a high level in north Queensland with gold the dominant target. The Charters Towers area with its high historic production and high potential is the main focus of exploration, but the eastern Georgetown area is also subject to intense exploration as is the Chillagoe area. The discovery of Vera-Nancy near Pajingo has refocussed interest in the Drummond Basin. Other areas of north Queensland are also being targeted. Exploration in existing mining leases for extensions to existing ore bodies or closely associated mineralisation continues with some success as shown by Kidston (Eldridge) and Ravenswood (Sarsfield).

### Information Base

The geoscientific information base for north Queensland is large and varied. Written descriptions of north Queensland geology started with Leichhardt and a large number of descriptive and interpretative works have been published since. Reports published by GSQ and AGSO include Explanatory Notes and Map Commentaries (for map sheets), Bulletins, Reports, and Records. Records contain a large amount of detailed information. Queensland Department of Mines and Energy (DME) maintains a collection of company reports (27 000) from exploration tenure. A major report on the geology of North Queensland (Bain & Draper, 1997a) is accompanied by a 1:1 000 000 scale map and a companion Atlas (Bain & Draper, 1997b).

Maps are available in a number of formats and a variety of scales. In hard copy form, maps are available as photoscale compilation sheets (generally 1:25 000 scale), 1:100 000 scale lithoprinted or 'print on demand' maps, 1:250 000 scale lithoprinted maps (standard coverage) and larger scale regional maps. Most of the maps in north Queensland are available in digital format.

A number of digital data bases are available. The Igneous Rock of north Queensland GIS covers many of the igneous rocks, but does not cover the whole area. DME maintains a corporate database MERLIN (Mineral and Energy Resources, Location and Information Network) which contains a land tenure component and a geoscience data component. MERLIN contains geological mapping data, petroleum exploration data, mineral occurrence data, geophysical survey indexes, geochemistry, digital geological maps, and current and historical tenure details. AGSO has a number of databases containing data from north Queensland including geological, geochemical, geochronological and isotopic data.

North Queensland is covered by a number of geophysical datasets. Airborne magnetic and radiometric surveys and gravity data are available; there is regional coverage plus a number of more detailed surveys including non-government multi-client surveys. Data from onshore and offshore seismic surveys are also available.

For further details on data availability contact AGSO in Canberra or Queensland Department of Mines and Energy in Brisbane. Administration of exploration onshore is the responsibility of the Queensland Department of Mines and Energy and, offshore, the Commonwealth Department of Primary Industries and Energy.

## THE FUTURE

Whilst it is difficult to predict the future, the indications are that north Queensland will continue to be a focus for mining and exploration and the main export point for products from the northwest. Potential exists, however, for north Queensland to develop into a major industrial area particularly in value adding to minerals based on projects in the pipeline and possible developments in the energy area. Other speakers at this conference will be discussing development and infrastructure issues in more detail, but I will look at from a mineral resource perspective and at north Queensland *per se* although the obvious contribution that northwest Queensland will make to north Queensland's development will not be ignored.

## Exploration and Mining

A sustainable mining industry requires than resources need to be found to replace those mined otherwise production must fall. An expanding industry requires additional resources as well as suitable markets and favourable economic conditions. Commodities such as bauxite and silica sand have large enough known resources in north Queensland to either maintain or increase production. Greenfields exploration is therefore not an important factor for these two commodities whose futures lie in the supply and demand cycle. Kaolin's future will depend on marketing and may be favoured by closeness to Asian markets; Australia is competing against large existing producers with large resource bases.

For most of Queensland's mining history north Queensland has been the largest producing area for gold in the state. However, recent discoveries such as Vera-Nancy, Nolan's-Sarsfield, and Eldridge need to be balanced against the recent closure of Red Dome and Georgetown and the near depletion of Mount Leyshon (about two years mine life remaining). There are a number of known resources but many of these are marginal and are certainly not favoured by the current low gold price ($US320-330). There are also a number of promising prospects. In the short term, production will be maintained, but the future resources need to be found particularly those in the 1 000 000oz range.

Exploration tends to favour the existing empirical models for gold mineralisation in north Queensland, but there has been recent interest in a Cadia-style model given some similarities between north Queensland and the Lachlan Fold Belt in New South Wales. Given the widespread and diverse occurrence of gold in north Queensland, the prospects of locating large as well as small gold deposits are high. Alluvial deposits are likely to provide only small production levels.

North Queensland still contains large resources of hard rock and alluvial tin. Interest is refocussing on these tin resources as the price of tin continues to recover and oversupply is reduced. The withdrawal of small miners from alluvial tin mining provides an opportunity for large, low grade deposits to be mined as tenure will be available over larger areas. Tungsten is another commodity with resources available, including the scheelite deposit at Watershed Grid, and which may once again be mined in north Queensland.

The base metal mine at Thalanga has a limited future (about five years) and with the closure of Red Dome, the future of base metal mining is not promising unless new production can be obtained. Feasibility studies continue at Balcooma/Dry River, Reward and Mungana. There is also potential for further discoveries.

The presence of a Coalition government in Canberra has generated renewed interest in the Ben Lomond and Maureen uranium deposits. Although Ben Lomond is quite rich, it is a low tonnage deposit compared to other undeveloped deposits in Australia and its location in the Keelbottom Creek-Burdekin River drainage area creates some environmental problems. Its proximity to a major port, Townsville, gives it an advantage over more remote deposits.

Coal resources exist as thermal coal near Pentland and coking coal at Bathurst Range, although the use of the later as a thermal coal has been proposed. The future development of these deposits will probably hinge on future energy developments in north Queensland (see below). The provision of natural gas to north Queensland would have an adverse impact on possible uses of these deposits. Oil shale at Julia Creek is a potential resource once the technology and economics of shale oil production is proved; Rundle, near Gladstone, will provide the benchmark for success or failure. Julia Creek oil shale has a significant vanadium and lesser molybdenum resource associated with it. The offshore Queensland Plateau and Queensland and Townsville Trough have potential for hydrocarbons and the technology already exists to drill at the depths of water covering these areas.

Industrial minerals such as limestone, dimension stone, dolomite, perlite, and structural clays are already mined in north Queensland. As north Queensland becomes a more mature economy with increased manufacturing, industrial minerals will

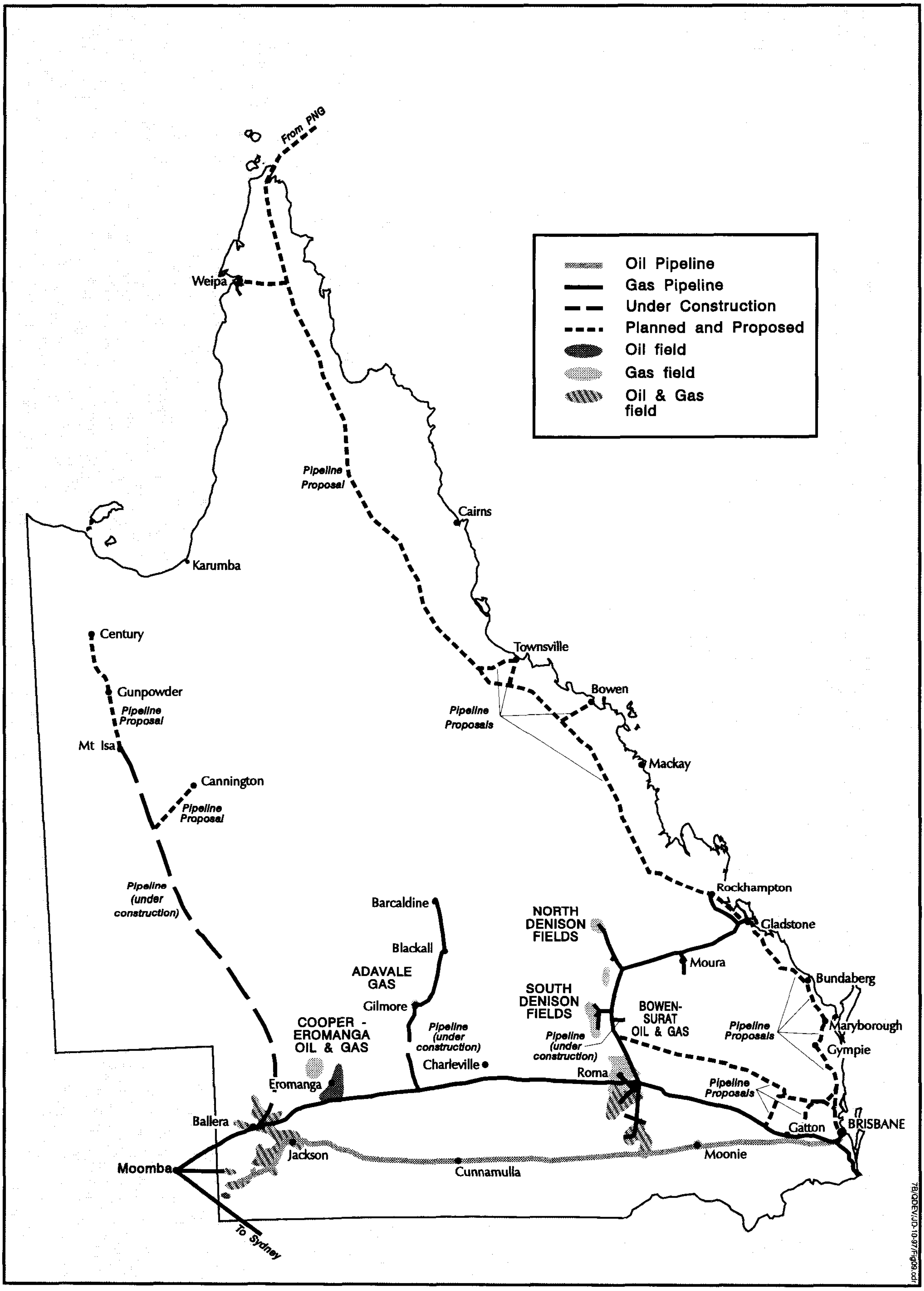



*Figure 9. Present and proposed natural gas pipelines in Queensland.*

increase in importance and additional resources will need to be found.

Once native title issues are resolved, exploration in north Queensland should remain healthy despite competition from other states and overseas. North Queensland has high prospectivity, a culture of mining, expanding infrastructure and proximity to Asian markets. North Queensland is also well placed to continue to service exploration and mining in Southeast Asia.

### Exports

North Queensland's future can not be separated from that of Northwest Queensland as Townsville is the outlet for all northwest Queensland's current and near future mineral production except for Century which will use the port of Karumba which falls on the wester boundary of the north Queensland area discussed in this paper. As production grows in the Mount Isa area so will the port of Townsville grow. Townsville will also be the outlet for the high analysis fertilisers to be manufactured by WMC from its phosphate deposit at Phosphate Hill near Duchess. Cairns should continue as an important supply base for Southeast Asia. Bauxite and silica sand exports will probable increase over time.

### Value Adding and Manufacturing

North Queensland can be more than a quarry and an export port for primary mineral products. North Queensland can profit from value-adding to mineral products and developing a larger manufacturing base. Townsville already has a copper refinery and a nickel refinery with a zinc refinery under construction, but this should be only the start for further development. The critical element is the supply of suitably priced energy as north Queensland has the other resources needed to develop an industrial base as we have already seen. Changes in the electricity supply industry will have beneficial effects. A proposal by Chevron to pipe natural gas from Papua new Guinea to central Queensland via north Queensland (Figure 9) and speculation about gas from the Northern Territory being piped to Townsville will, if they come to fruition, have the potential to underwrite significant industrial development in the north.

## CONCLUSIONS

North Queensland has a long mining history which contributed significantly to the Queensland economy. The industry is currently sound. The future of north Queensland will rely partly on its natural resources, but also on the supply of energy. The supply of natural gas will provide north Queensland with the opportunity to develop in its own right and not be seen as simply a port for the northwest. North Queensland has a future and it will be in primary and secondary production.

## REFERENCES


BAIN, J.H.C. & DRAPER, J.J., 1997a: North Queensland Geology. *AGSO Bulletin* **240**; *Queensland Geology* **9**.

BAIN, J.H.C. & DRAPER, J.J., 1997b: *Atlas of North Queensland Geology*. Australian Geological Survey Organisation and Geological Survey of Queensland.

BEAMS, S.D. (Editor), 1995: Exploring in the tropics: mineral deposits of north-east Queensland: geology and geochemistry. *James Cook University of North Queensland, Department of Earth Sciences, Economic Geology Research Unit Contribution* **52**.

DAINTREE, R., 1872: Notes on the geology of the Colony of Queensland. *Quarterly Journal of the Geological Society of London*, **28**, 278–317.

FITZGERALD, R., 1982: *From the Dreaming to 1915: A History of Queensland*. University of Queensland Press, St Lucia.

HENDERSON, R.A. & STEPHENSON, P.J. (Editors), 1980: *The Geology and Geophysics of Northeastern Australia*. Geological Society of Australia Inc., Queensland Division, Brisbane.

JACK, R.L., 1879: Report on the geology and mineral resources of the district between the Charters Towers Goldfield and the coast. *Geological Survey of Queensland, Publication* **1**, 1–28.

JACK, R.L., 1886: Geological Map of Queensland, on the scale of 32 miles to an inch. *Geological Survey of Queensland Publication* **30**.

JACK, R.L. & ETHERIDGE R., 1892: Geology and Palaeontology of Queensland and New Guinea. *Geological Survey of Queensland Publication* **92**.

JUKES, J.B., 1847: *Narrative of the surveying voyage of H.M.S. Fly*. T & W Boone, London.



**Reference for this paper:**

**DRAPER, J.J., 1997: Key issues for Australian minerals and energy – a Queensland Perspective. *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 119-131.**

*Derek Andrews*

Ports Corporation of Queensland

# Providing Port Infrastructure in Queensland

## INTRODUCTION

His Majesty's colonial brig "Amity" arrived in Moreton Bay on Friday 10 September 1824 carrying the troops and convicts who were to be the first white settlers in the then most northern settlement of the colony of New South Wales. John Oxley the Commanding Officer and Chief of the expedition was directed to carry out certain works to determine the adequate nature of Brisbane as a port. Subsequently further exploration along the coastline resulted in the development of a number of other ports which allowed for the influx of settlers who were primarily interested in farming and mining. Since that time, the development of Queensland and the development of its ports have been linked.

Today, the way in which ports in Queensland are developed and managed is carried out under the *Transport Infrastructure Act.* Sections dealing with ports are the means by which a port area is declared and the port limits defined. This requires an Executive Council minute which also nominates the port authority for the area. If development is required in or near any of those sites, then the nominated port authority would carry out that work, though in the case of nearby development, the port limits may need to be extended.

For the last 30 years or so, new ports have been managed by the Ports Corporation of Queensland (through their predecessor, the Harbours Corporation) which also undertook the port development. The future application of the Act is a matter for the Queensland Government through the Department of Transport. However, the Ports Corporation has a history of successful port development within Queensland and would hope to continue that role.

The Corporation has overseen the development of the port of Hay Point (including the Dalrymple Bay Coal Terminal), Abbot Point, Lucinda, Mourilyan, Cape Flattery, Weipa and is working on the redevelopment of Karumba. Other port developments in prospect are facilities for the mining of bauxite by Alspac and for the Skardon River kaolin mine. Significant port development and re-development is also carried out by other Queensland port authorities.

The Corporations have developed a level of organisational capability and a culture based on delivering appropriate outcomes. We believe we will be able to contribute to future port development in Queensland and perhaps in other parts of the world. Today, the port system in Queensland ships more than 130 million tonnes of cargo each year through 14 major trading ports, providing the manufacturing, agricultural and mining industries with effective access to the world's markets.

## QUEENSLAND'S PORT SYSTEM

The provision of port infrastructure in Queensland is closely related to the way the port system is structured. There are eight port authorities. The Ports Corporation of Queensland is the only port authority in the state with responsibility for multiple ports. The ports are the coal ports of Hay Point and Abbot Point; the sugar ports of Lucinda and Mourilyan; the bauxite port of Weipa; the emerging port of Karumba, which has a live cattle trade and will be the port for the Century Zinc project; Cape Flattery which exports silica sand; and the community ports of Thursday Island and Quintell Beach. There are also a number of non-trading ports which have been retained for possible future development.

The other port authorities are Brisbane, Bundaberg, Gladstone, Rockhampton, Mackay, Townsville and Cairns.

## OBLIGATIONS AND AUTHORITIES

The Ports Corporation of Queensland is primarily focussed on strategic issues and infrastructure development within its ports. Maintaining navigable port depths is a major responsibility while port navigation is controlled by the Regional Harbour Masters of Queensland Transport. Stevedoring, towage and the operation and maintenance of bulk handling facilities and other operational services are provided by port users.

In conducting its business, the Corporation is subject to relevant legislation and government policy. Government ownership is represented through two Shareholding Ministers — the Treasurer and the Minister for Transport.

The Corporation was constituted in 1993 by an order of the Governor-in-Council under provisions of the Harbours Act 1955. On 1 July 1993 it assumed management and control of 14 ports previously administered by the Harbours Corporation of Queensland. From 1 July 1994 the organisation became subject to the Government Owned Corporations Act 1993 and a port authority under the Transport Infrastructure Act 1994. Under the GOC Act, activities are governed by:

- an agreed charter,
- a Statement of Corporate Intent which is agreed to annually between the Board and Shareholding Ministers, and
- a five-year Corporate Plan.

The Shareholding Ministers appoint the Board of Directors and approve the Statement of Corporate Intent which sets the business objectives each financial year. They may act jointly to issue directions to the Board. The Minister for Transport has specific powers under the Transport Infrastructure Act to:

- approve land use plans, and
- approve the disposal of any freehold land or the exercise of tenure greater than 25 years over any Corporation strategic port land.

These arrangements now apply to all other Queensland port authorities.

## OBLIGATIONS AND POWERS

Port Authorities do not make government policy, they are required to conform to it. Port Authorities have some obligations and powers, mainly under the three elements of legislation — Transport Infrastructure Act, Government Owned Enterprises Act and Marine Pollution Act. As developers and facility managers, the authorities must abide by all State and federal laws and regulations. A Port Authority is a Government Agency only in some legislation. In other legislation, Port Authorities are exempt from particular provisions.

## EMERGING OPPORTUNITIES

The Ports Corporation of Queensland works to maintain an understanding of the needs of the emerging opportunities we face in this State and the need to be prepared to provide port infrastructure to meet the requirements of port users. It is particularly conscious of the demands which are brought on by new mining developments and the crucial part port infrastructure plays in the total chain and the need to ensure the timing of port infrastructure provision matches the requirements of industry.

## PORTS REQUIRE SPECIAL LOCATIONS

There are very few suitable locations for ports and the ones that are available should be dedicated to that use. Port development and the port locations are influenced by cargo availability, transport links, availability of suitable coastal land, access to deep water for manoeuvring and berthing ships and safe access to sea-lanes. Other uses can be satisfied at other locations which are suitable for more general uses.

Ports make a specific and very important contribution to the national economy. Community interest is best served by providing safe, cost-effective, world-class competitive ports. Ports work co-operatively with their neighbours and local communities to minimise impacts. Other development interests such as tourism and recreation can be satisfied away from port operations and ship manoeuvring areas.

## MISSION STATEMENT:

The Corporation will provide safe, cost effective, competitive sea port services to existing and potential port users.

The Corporation's management of ports will:

- be in accordance with Government policies,
- generate planned profit in current and future years,
- develop and maintain appropriate port facilities and infrastructure, organisational resources and technology,
- maximise trade, provided commercial rates of return are achieved, and
- minimise environmental impacts of port operations and development.

## PORT DEVELOPMENT

Following the identification of a port need the Corporation carries out its role by providing to potential port users:

- assistance with project feasibility studies,
- access to port land,
- project finance,
- planning permission,
- engineering design and construction,
- environmental management,
- dredging and other approvals, and
- ongoing maintenance and port development programs.

*Attachment 1* provides an overview of the major steps in the process.

### Expansion Strategy

The strategy for adding additional capacity will be in accordance with a master plan developed by the Ports Corporation in consultation with the operator. Generally, incremental capacity is added only as it is needed to avoid existing port users paying for over-capitalised facilities.

### Technology

Where appropriate, the new facilities should utilise proven, "state of the art" technology. Untried technology will not usually be installed. Any new technology installed must be cost-effective in terms of the additional benefits provided.

## GOVERNMENT AND PORT AUTHORITIES AS DEVELOPERS

Issues of strategic infrastructure planning and the State's commitment to development require ongoing close relationships with Government. The wider community is concerned about coastal development. All of Queensland's ports operate in sensitive, environmentally important areas such as the Great Barrier Reef Marine Park. It is essential that the Port Authorities be included in the processes of Government. If the relationship is not effective then the capability for appropriate development is diminished. Irrespective of the port developers' structure, their relationship with Government needs to be co-operative and on-going.

## GOVERNMENT POLICY IMPACTS ON QUEENSLAND PORTS

To effectively deliver appropriate outcomes, Port Authorities seek the ability to deal directly with port users. However, in some cases, the emerging legislative position is not clear and this causes uncertainty and some concern for Port Authorities and their customers. Issues currently of particular concern, or which require attention are:

- cost of finance,
- proposed Integrated Planning Legislation,
- Native Title Assessment,
- environmental matters,
- Commonwealth permits for relocation of dredge material,
- inability to enter into site agreements for construction projects, and
- pilotage.

All of these issues will be addressed and resolved, but others will arise. In order to develop its responses in policy consultation, the Ports Corporation considers both its mission statement and the key question, "How will this make Queensland's ports more effective, more competitive?" This provides a mechanism for reducing unintended unfavourable outcomes arising from change processes.

Some issues require elaboration:

## Environmental Management and the Approvals Process

These processes have a significant impact on port authorities because of the often sensitive planning and environmental matters associated with port developments.

Some of the most forward thinking and innovative environmental management initiatives occurring in Queensland are being implemented by port authorities. There is an absolute commitment to responsible environmental management. However, as an example, the suggestion that administration of Section 86 approvals may be transferred to Local Authorities causes some concerns. Section 86 approvals, with their indemnities and cultural clearances, should be administered by very knowledgeable agencies.

Issues associated with major projects and their impact on land use and appropriate port development need to remain a simple, clear, consultative "one-stop" process involving the whole of Government. Coincidently, the way it is now administered by Port Authorities already provides just such a system. It is not clear that the new Integrated Planning Legislation will allow this effective process to continue.

## Dredging Permits

Apart from State permits pertaining to dredging, international treaty obligations require the Commonwealth to issue permits for the relocation of dredged material onto the seabed.

This process is being reviewed. There is a possibility of improved outcomes:

- process that ensures continuity of dredging into the future,
- clearer, quicker approval and appeal processes,
- a reduced need for consultants' reports, and
- removing the impact of the EPIP Act, which now results in the port developer being required to justify the environmental practices of every environmentally significant port user, even though these companies have already complied with all the State and Federal Government requirements.

If the review returns the powers to the State, the EPIP Act would probably no longer apply.

## Pilotage

Cabinet has approved that pilotage services be devolved to port authorities and planning is now well advanced to ensure the most is made of the opportunity. There are three main overarching principals being applied by the Corporation:

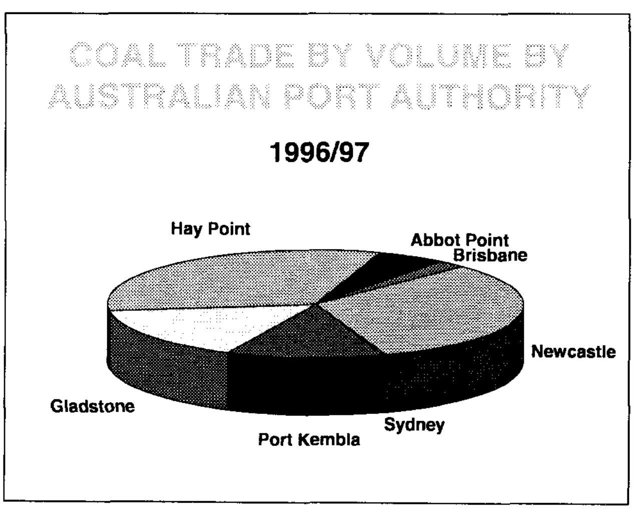
- the pilotage service is at least of an equivalent standard to the existing service,
- charges for pilotage services in individual ports fully reflect the cost of the service for those ports, and
- the level of service, in both continuity and quality, should in no way be compromised.

New arrangements should be in place by early 1998 and at the end of an initial three year period there will be a fully commercial and viable pilotage service available at all Corporation ports. The Corporation intends to establish a separate business unit or subsidiary company, providing initial management support to the entity, to facilitate the transition.

# COAL INFRASTRUCTURE AND DEVELOPMENTS

In 1996/97 Queensland exported a record of almost 79Mt of coal. These exports are worth about $4.56 billion, of which a considerable amount flows back to the State and also generates thousands of jobs. The coal trade by volume by Australian port authorities highlights the significant trade through Queensland.

Queensland is serviced by four modern, world-class coal ports, containing a total of six terminals. They are strategically located along the Queensland coastline and linked to the State's coal mines by the Queensland Rail network. I am of the view that we do not need



## COAL INFRASTRUCTURE DEVELOPMENTS

| PORT | ACTUAL SHIPMENTS 1996/97 (mtpa) | PORTS CAPACITY 1997 (mtpa) | CAPACITY POTENTIAL FOR THE YEAR 2005 |
|---|---|---|---|
| ABBOT POINT | 6 | 12 | 40 |
| HAY POINT | 47 | 53 | 75 |
| GLADSTONE | 24 | 30 | 45 |
| **QUEENSLAND TOTAL** | **77** | **95** | **160** |

new coal ports. However, we will need to install more capacity within the existing ports to meet the future market needs and we need to be able to bring that capacity on in a timely manner to allow the mining companies to maximise the market opportunities.

The table shows the existing shipments and capacity after committed expansions and potential capacity of the State's three major coal export ports.

After the current committed expansions are completed, the basic infrastructure (rail and port) is in place to provide for incremental expansion as required for new mines. Usually the additional infrastructure changes can be made within the timeframe of a new mine development. However, urgent demands can be placed on port infrastructure by the expansion of existing mines. Generally, this is addressed by close liaison with mining companies and providing a small amount of capacity in excess of commitments.

## CURRENT AND PROPOSED MAJOR PORT INFRASTRUCTURE WORKS

The following is a summary of the major port infrastructure works under way or proposed across Queensland. The list is not comprehensive and the projects and figures are only indicative.

### Ports Corporation of Queensland

*In Progress*
Dalrymple Bay Coal Terminal (Stages 3 and 4) $210 million
Karumba Dredging $10 million

*Emerging*
Dalrymple Bay Coal Terminal (Stage 5) $50 million
Weipa Port Development
Pennyfather Wharf
Port Services infrastructure

Since 1994, the Corporation has invested, on the average, about $100 million annually to maintain and develop port infrastructure.

### Townsville

BHP Concentrates Loading Facility $70 million
Carpentaria Minerals Province Opportunities Transport Corridor
Korea Zinc infrastructure

### Cairns

About six individual developments
$300 million (total)

### Gladstone

R G Tanna Coal Terminal new stockpile $8.5 million
Auckland Point No. 4 Wharf $8.5 million
Outer Harbour Channel deepening $6 million

## ROLES FOR THE PRIVATE SECTOR

The following summarises some of the roles for the private sector in port development:

Consultants

- port plans,
- facility masterplans,
- facility design,
- tendering,
- environmental studies, and
- port and terminal studies.

Finance

- funding to port authorities or lessees.

Industry

- construction
- sub-contractors
- manufacture of components
- maintenance and operating supplies

- power supplies.

Port Services providers

- terminal and port management
- pilotage
- towage
- launches.

In Queensland, much of the port infrastructure is built and operated by the private sector. It is likely that the future will see more private sector involvement and new relationships such as partnering and build/operate arrangements.

## AN ADAPTABLE ORGANISATION

The Ports Corporation of Queensland continues to place great emphasis on being adaptable and responsive to the needs of customers and the wider external environment. The Corporation has changed extensively and continues to improve since it was formed. The organisation is able to learn and adapt to the needs of the business environment and will positively respond to the inevitable future changes.

The Corporation's Organisational Structure is included as *Attachment 2.*

## PORT OPERATION CONCERNS

The development of port facilities must consider the effective long term use of the port infrastructure. Port Authorities in Queensland are working to improve these outcomes. High priority must continue to go to improving port competitiveness. Among the desired outcomes are lower charges by Port Authorities, improved tug operations, contestable pilotage services, improved terminal operating efficiency and capacity utilisation as well as improved integration of the transport systems.

## GROWTH PROSPECTS

Despite the recent disturbances in some Asian economies, which have been widely reported, Asia remains and we expect will remain, a strong growth region, which will almost certainly translate to growth opportunities for this state.

The most likely outcome is that free trade, coupled with modest growth in large, developed countries will continue to generate growth in Asia. This will create demand in emerging economies for things such as electricity, steel, cement and infrastructure as well as clothing and food. This in turn will allow Australian exports to grow. Port infrastructure will be required to service that trade growth.

In general, bulk ports will plan for annual cargo increases of between 4-6% over the next five years. Specific commodities will impact on a port by port basis, including the effect of new projects.

## CONCLUSION

Australia's economic growth will continue to be largely dependent on increased bulk exports. The mineral sector is the major contributor to this growth. Consequently the approval processes for construction of new mines and infrastructure will need to support the projected increase in exports to achieve the expected economic growth.

Beyond 2000, Ports Corporation believes that establishing an integrated, supportive transport system will commit everyone in the transport chain to guaranteeing that cargo will be kept secure and delivered on time at a competitive price. Supportive on-going relationships throughout the chain may be the key to the future success of the individual transport enterprises.

It is also important that Queensland continues to deliver particular outcomes:

- appropriate port developments are finished on time, within budget and provide the specified outcomes
- ports are managed to become more competitive across all of the operational areas
- government continues to support port development and operation as a significant contributor both to the State's economic wellbeing and economic development.

Queensland's Port Authorities have a proven track record in delivering port developments. They will continue to adapt to provide for those needs into the future.

**Reference for this paper:**

**ANDREWS, D., 1997: Providing Port Infrastructure in Queensland. *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 133–140.**

ATTACHMENT 1

# Ports Corporation of Queensland

## Organisation Structure

The Ports Corporation has a total core staff of 32, headed by a Chief Executive Officer. In addition, temporary staff and consultants are routinely engaged on both short and long term assignments, for specific tasks and major development projects. Total staff numbers therefore fluctuate from time to time.

The 32 core staff are made up of 10 field staff based at a number of the Corporation's ports throughout Queensland, and 22 staff, including all Managers, based at Head Office. The Ports Corporation has a policy of keeping staff numbers to a minimum through the use of advanced technology and management practices.

**PORTS CORPORATION BOARD**

**Chief Executive Officer**
*Derek Andrews*

**Manager Planning & Human Resources**
*Paul Blewonski*

**Project Officer**
*Catherine Williams*

**Executive Assistant**
*Tina Marsh*

**Communication Manager**
*Gary Campbell*

**Engineer**

**Administrative Officer (Finance & Admin)**
*Mary Dewar*

**Administrative Officer (Management Support)**
*Raelene Cain*

**Engineering Manager**
*Martin McAdam*

**Area Officer-in-Charge (Hay Point)**
*Brenda Kemp*

**Engineering Assistant**
*Michael Dow*

**Information Custodian**
*Mark Taylor*

**Administrative Officer (Engineering)**
*Brenda Dimmock*

**Port Supervisor Northern (Abbot Pt)**
*John Martin*

**Area Officer**
*James Miller*

**Operations Superintendent**
*Tycho Buningh*

**Area Officer**
*Kelvin Power*

**Operations Manager**
*Brad Fish*

**Property Officer**
*Peter Mackrodt*

**Port Supervisor Far Northern (Lucinda)**
*Neil Utting*

**Area Officer-in-Charge (Mourilyan)**
*Wayne Anzolin*

**Project Officer**
*Kristin Rafferty*

**Area Officer**
*David Ahboo*

**Port Supervisor Thursday Island**
*Greg Kirk*

**Area Officer**
*Joe Yamashita*

**Environment Manager**
*Steve Raaymakers*

**Environmental Projects**
*Steve Hillman*

**Administrative Officer**
*Louisa Takai*

**Accountant**
*Ann MacKinnon*

**Finance & Administration Manager**
*Graham Rawlings*

**Accounts Receivable Officer**
*Phil Wixted*

**Accounts Payable Officer**
*Herma Long*

**Principal's Representative (DBCT Expansion)**
*Bob Edwards*

**Project Team**

## ATTACHMENT 2

# Business Growth Schematic

Monitored by
individual proponent

**Influencing factors:**
- *Commodity market*
- *Economic trends*
- *Government policy*
- *Government agencies*
- *Potential proponents*
- *Potential resource*
- *Product sales*

**Monitored by PCQ to:**
- *Identify opportunities*
- *Identify proponents*

**Expansion**
Need for additional facilities is being considered by existing customers

**Development**
Need for new or additional facilities is being considered by a new customer or new project

**PCQ's Assessment:**
Does PCQ involvement result in best overall logistical systems?

Is PCQ's involvement feasible in relation to:
- *investment and pricing*
- *navigation*
- *land use*
- *environmental management*
- *other transport modes*

**Prepare for emerging opportunities:**
- *land*
- *master planning*
- *facility design*
- *environmental plan*
- *promotional plan*
- *finance*
- *organisational resource*

**Feasibility study with proponents:**
- *preliminary design*
- *environmental studies*
- *consultation*
  - *government*
  - *stakeholders*

Full assessment of environmental impacts & development of management regime. Obtain approvals.

Design facilities

Establish user agreement. Licence operators requirements?

Arrange project finance

Project approvals

Construct

Operate facilities

**Further Information**

**Ports Corporation of Queensland**
**GPO Box 409 Brisbane Qld 4001**

**Telephone 07 3224 7088**
**Facsimile 07 3224 7234**

**PORTS CORPORATION QUEENSLAND**

*Peter Matheson*

**Calliope Metals Pty Ltd**

# Nickel in Queensland

## INTRODUCTION "WHY NICKEL?"

Nickel is a heavy grey metal commonly found in the earth's crust. It earned its name in the middle ages in the Hartz Mountains in Germany when medieval miners and metallurgists dealt with "Old Nick's" metal when they tried to smelt copper and found this rogue metal from hell.

It is important today as an essential element in the huge family of alloys known as "stainless steel". From 65% to 70% of all new nickel produced finds its way into austenitic and duplex stainless steels and other high nickel alloys.

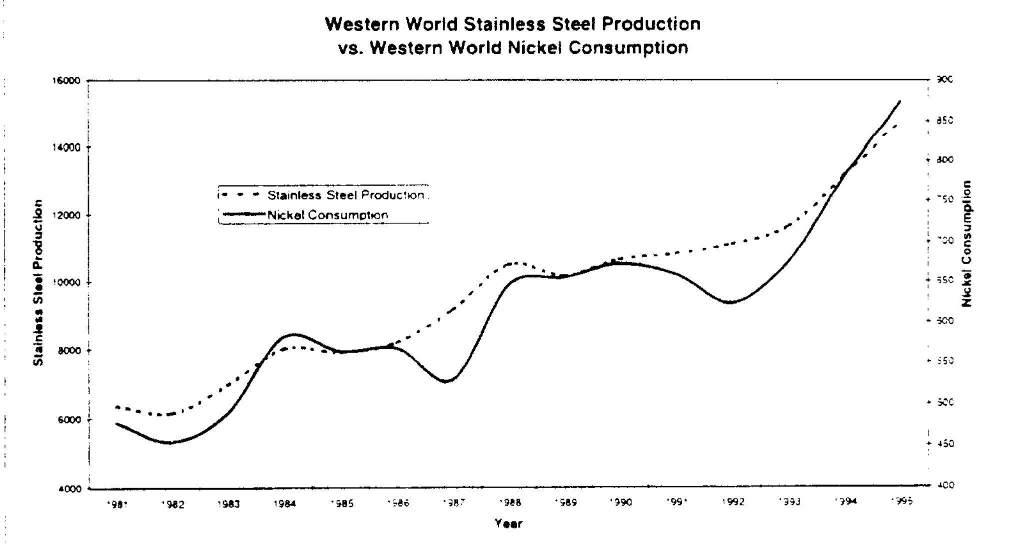
Nickel adds corrosion resistance to these alloys and increases the workability of the steel, eg. it would be very difficult to deepdraw the common one piece domestic sink without the properties nickel imparts to the steel. So if a company is engaged in producing nickel, it is really taking a fundamental place in the stainless steel producing industry. Stainless is one of the great success stories of the 20th century. It is important to both the developed and the developing world.

In developed countries it finds extensive uses in architectural, food processing and preparation, and environmental applications, where cleanliness and corrosion resistance are paramount. In developing countries the emerging middle class finds a more fundamental use for this alloy in its household utensils and other quality of life applications.

For example, India has built a stainless-producing industry of about 600 - 700,000 tonnes per year around holloware - pots and pans - which are much sought after by middle class households.

Stainless steel has enjoyed an historic growth rate over the past 30 years of over 5%p.a., with an increase to over 7% in recent years. Figure 1 illustrates this.

Demand like this requires around 30,000 tonnes of new nickel a year to keep pace




Sources: World Stainless Steel Statistics, Published by Inco Europe Ltd and World Bureau of Metal Statistics.

*Figure 1.*

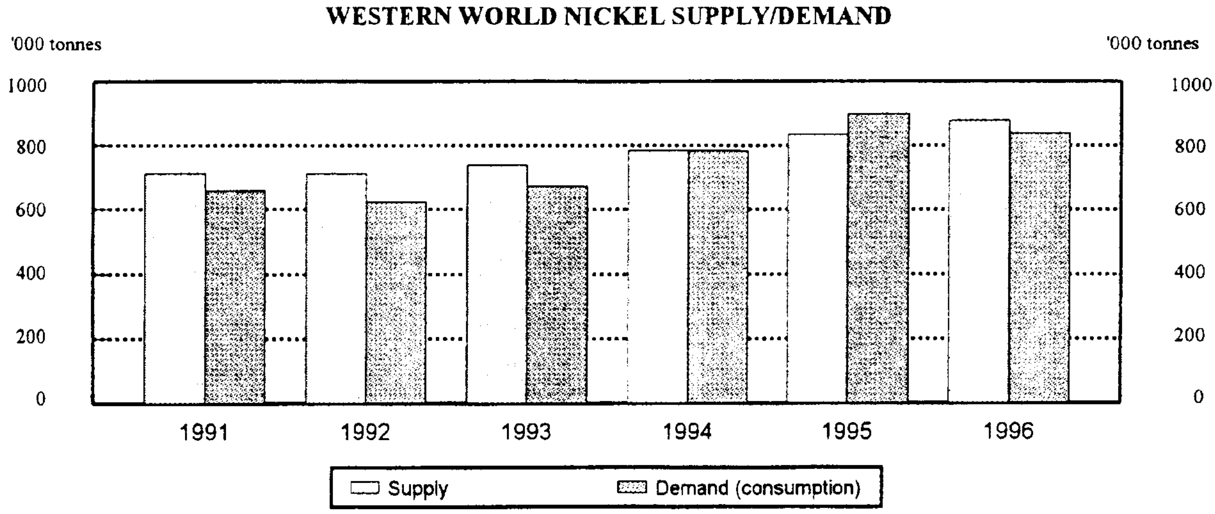



*Figure 2.*

without any consideration for recycling scrap stainless steel which also forms an important part of the raw material cycle of this industry. This requirement is the factor fuelling the "new nickel" boom evident in this country both from existing suppliers and newcomers into the industry. Figure 2 indicates supply and demand for nickel on the planet in recent years.

Queensland, it can be said, is prominent in both nickel and cobalt production and potential. Before we press on with a closer look at Queensland, let's consider two interesting asides.

Firstly nickel and cobalt metal, which sit alongside each other on the periodic table, usually appear together in both laterite and sulphide forms of nickel ore in nature and are notoriously difficult to separate in extractive metallurgy. Cobalt possesses some quite unique properties, e.g. cobalt alloys figure prominently in the hot end of gas turbine manufacture and command a substantial price premium (currently US$22 to $25 per pound). Over the past 22 years, Queensland has been a substantial producer of basic cobalt and currently supplies 6% of world requirements. This is likely to continue and increase.

Secondly, world stainless melt production last year was about 16 million tonnes. Australia produced none of this and its only local supplier, BHP closed its cold rolling mill and left the industry in May of this year. This is a tragedy for Australia and the challenge, indeed the opportunity, is before us here in Queensland to do something about it. Can the concept, epitomised by the ghost of Gladstone Special Steel, rise phoenix like to match a new nickel project with impeccable connections to Greek mythology and also in Gladstone and put Australia back on the slate as a stainless steel producer.

## BASIC GEOLOGY

Nickel (and with it cobalt) is found in two basic forms in nature.

A) Sulphide Form (40% of world's nickel resources): Production from sulphide sources is most common among existing producers. These sources are represented by a series of mineral groupings usually found underground and in hard rock. The nickel occurrence is quite often very high (2% to 8%), which often compensates for the high cost of underground mining. This form of nickel is represented in Australia by WMC's Kambalda and Agnew deposits (massive sulphides) and Mt Keith (disseminated sulphide, e.g. low grade - in this case about 0.55% Ni). Mt Keith relies on open cut techniques in hard rock more akin to iron ore mining than conventional open cut to keep its costs in hand.

B) Laterite form (60% of world's Nickel resources): Lateritic ores are formed mainly in the equatorial belt by a natural weathering process involving ground water movement which dissolves small particles of metal in the mineral profile and redeposits and agglomerates these usually lower in the profile. This form of geological occurrence is usually, but not always, found in the tropics. Extensive deposits exist in New Caledonia, Indonesia and Cuba, for example.

Queensland has (had) two classical working examples of metal rich laterites:

- Weipa, which remains a major producer of aluminium ore feeding the huge refining and aluminium metal production capacity at Gladstone, and
- Greenvale, now mined out, which supported the significant nickel/cobalt producing centre at Yabulu, NQ controlled by QNI for almost 20 years.

## NICKEL OCCURRENCES IN QUEENSLAND

To the best of my knowledge, there have been no significant nickel sulphide discoveries made in Queensland to date.

Laterite is another story. In the late 1960s, Inco, the Western world's largest nickel producer, became involved in a major confrontation with its workforce in Sudbury, Ontario, Canada. The strike was protracted, leading to shortages of nickel and substantial price hikes for the metal. A world-wide search for new sources of nickel resulted with Queensland receiving more than its share of attention from the explorers. Two major and a number of minor finds resulted.

The first major find was Greenvale, which was discovered by Metals Exploration Ltd geologists in 1967. It had a geological reserve of about 50 million tonnes at 1.5% nickel. This was located around two adjacent topographical features and went on to form the ore source for Queensland Nickel Pty. Ltd.'s Yabulu refinery (Figure 3). It was mined out over the period 1974 - 1995 and played a significant part in the economic growth of the region and the State over that period.

The second major find is attributed to a joint venture between BHP/Inco, which explored and drilled mineralisation in the Marlborough (north west of Rockhampton) area over the period spanning the late sixties/early seventies. The joint venture's assessment of the geological reserve was similar to Greenvale. However, unlike Greenvale, the mineralisation is scattered over a lot of Central Queensland and there is no evidence this author has seen of an economical mine plan being developed by BHP/Inco. Exploration work ceased in mid-1970s and the leases eventually returned to the State Mines Department. They were acquired by QNI in the early 1980s and were studied as a possible replacement for Greenvale as feed for the Yabulu refinery.

This study demonstrated the poddy nature of the deposit and proposed the two largest pods, Canoona and Brolga, as suitable for mining. QNI did eventually mine some of this ore, but abandoned the operation in 1995.

QNI apparently dropped the remainder of the Marlborough leases which have more recently been acquired by Preston Mining NL and Cobra Resources. Preston's stated intent is to further drill the mineralisation and to study the development of a nickel processing facility in the area.

During the major exploration phase in the 1970s, a number of small deposits were identified, mainly in North Queensland. These include:

- Minnamoolka
- Valley of Lagoons
- Gunnawarra
- All north of Greenvale; and
- Lucknow in the Greenvale area.

Some of these are currently under the control of companies such as Metallica Minerals and Cobra. They all appear to be the eroded remnants of much larger deposits and contain about 5 to 10 million tonnes of ore grading up to 1.5% Ni. None appear to be of a size to develop an economic refining facility. However, from time to time, they excite the interest of junior miners and explorers.

## NICKEL PRODUCTION

Queensland Nickel Pty Ltd constructed a nickel refinery based on the Greenvale ore over the period 1971/1974. The company, then a joint venture between Australian Metals Exploration Pty Ltd and American Freeport Mineral Company Inc., then ran the operation through some extraordinarily difficult times until 1985 when Bond interests acquired the project.

The process technology, (reduction roast, ammonia/ammonium leach, sulphide precipitation leading to a nickel oxide Class II product and a mixed nickel cobalt sulphide by-product) was supplied by Freeport and was based on its involvement in similar technology at Nicaro, Cuba in the post World War II era.

The process at start-up was energy intensive (1,000 tonnes of oil fuel a day) and provided only moderate metal extraction efficiencies on Greenvale ore (nickel in the mid-70% and cobalt in the mid-40%).

A program of continuous improvement was initiated on day one and I understand, continues to this day 23 years later. This led to many minor improvements and several major events. These included:

- Conversion of about half of the energy requirements from fuel oil to coal (1980/81) funded from, essentially, cobalt-related income.
- Introduction of ammonium solvent extraction process (ASX) funded from production related income (1988/89) and, more lately, the introduction of higher value nickel and cobalt products funded from cash flow, which were logical developments from the ASX process.

I don't wish to dwell on the vicissitudes of the early years of this project - this will be the subject of a future book. However, having lived through it and, in part or whole having had the responsibility for it, some points need to be made.

- The project's biggest failing was its timing. It was near last in a race won by WMC's Kambalda in the period 1968/1974.
- It was energy intensive in a period in the world's history which endured two oil shocks. The income which should have paid off debt and given a return to shareholders found its way into the treasuries of the middle east oil barons.
- It was highly geared with most borrowings in foreign currencies against a high Aussie Dollar.
- Its ore grades were average and metal recoveries low.

There are lessons in all of these areas for the "Want-to-be"s of today but more of this a little later. This project's most significant achievement in its survival was the conversion of ore feed from 'owned' to 'bought' by acquiring ore from New Caledonia and Indonesia.

This has enabled the foreign currency earning base in Townsville to continue beyond the demise of its ore body at Greenvale into the infinite future.

QNI has now merged with Gencor to form a large nickel/cobalt producing group and has essentially passed into the control of this South African based company. Since its public float and listing on the Australian Stock Exchange QNI has been a profitable enterprise, not insignificantly as a result of its major role as a cobalt producer.

However, without the skill, support, dedication and tenacity of a very large group of people through the 1970s & 80s this project would have died. There are also lessons in these experiences - let us not forget these or the people who kept this project alive.

## OTHER PROJECTS

The lessons of QNI's past plus its good points have been incorporated in the concept of the Calliope project concept based in Gladstone. I declare an interest as the company's Chairman.

Queensland is particularly suited to fostering value added projects like Calliope and QNI. The State has most of the ingredients (power and gas, water, industrial land and deep water ports) to support this sort of activity. Indeed, the Weipa/Gladstone example in the aluminium industry started it all, in recent times.

Calliope Metals Corporation is a Canadian company, dual listed on the Australian Stock Exchange and the Vancouver (B.C.)'s Stock Exchange. Its shareholder base is largely Australian.

## THE CALLIOPE NICKEL PROJECT

The company is undertaking a Feasibility Study for the development of a nickel/cobalt processing facility in Gladstone, Queensland using pressure acid leach technology to process lateritic ore transported from New Caledonia. This study should be completed by the end of 1997 at which time an investment decision will be made. The facility could be producing nickel and cobalt metal by early 2000.

TABLE 1

| CALLIOPE NICKEL PROJECT | |
|---|---|
| Ore Purchased | 2.0 Million wet tonnes/a |
| Plant Feed | **1.28 Million dry tonnes/a** |
| Production | 19650 tonnes Nickel/a<br>1950 tonnes Cobalt/a<br>59000 tonnes Ammonium Sulphate/a |
| Capital Expenditure | A$460 million |
| Annual Sales | A$280 million |
| Annual Operating Cost | A$152 million |
| Annual operating Surplus | A$128 million |
| Net production Costs | US$1.27 per pound |
| Capital Cost per annual pound of Nickel and Cobalt ( as equivalent Nickel) | US$5.90 per pound |

**ASSUMPTIONS**
Nickel Sale Price
Cobalt Sale Price
US$0.75 = A$1.00
US$1.00 = FF5.0

## ORE SUPPLY

The company has negotiated conditional long term contracts with two New Caledonian mining companies for the supply of up to 1.5 million wet tonnes/approximately 1 million tonnes, dry basis) of lateritic ore per annum to Gladstone suppliers of nickel ore to other treatment plants.

## GLADSTONE SITE

The Queensland government has agreed to make available for the project a 140 hectare site within 2 kilometres of Fishermans Landing Jetty in Gladstone, Queensland. The site is well located with power, water, gas, and a wharf, all available for use by the project. The Gladstone Port Authority has agreed to provide a suitable ore unloading facility for use by the company. Gladstone is located on the Queensland coast 550 kilometres west of New Caledonia.

## TECHNOLOGY

The Company has secured an exclusive licence in eastern Australia to utilise Sherritt' s pressure acid leach technology. Sherritt is providing process design and full technical assistance now and during the construction and commissioning phases.

Figures 3 and 4 show the geography of the proposal and a typical view of Gladstone Harbour.

To round off this description of Calliope, the likely production capital and operating costs and returns are shown in Table 1.

## QUEENSLAND'S POTENTIAL AS A NICKEL AND COBALT PRODUCER

The current and probable production of nickel and cobalt from QNI and Calliope translated to the year 2000 would see Queensland moving to take a significant place in world production of these strategic metals. Table 2 illustrates what this could mean.

TABLE 2

| COMPANY | QNI | CALLIOPE | QUEENSLAND |
|---|---|---|---|
| Ni tpa | 26637* | 19650t | 46287 |
| Co tpa | 1425* | 1950t | 3375 |
| Nickel % world production | 3% | 2.2% | 5.5% |
| Cobalt % world production | 6% | 8.2% | 14.2% |
| *1996 production levels<br>Projected production first full year. | | | |

**Reference for this paper:**
**MATHESON, P., 1997: Nickel in Queensland. *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 141–145.**

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# Environmental considerations in the future Queensland energy and mining industries

## SUMMARY

This paper looks at the possible environmental requirements for energy and mining industries over the next 30 years. The major social and economic variables such as population, mineral production and gross state product are continuing to increase at rates between 2% and 8% per year. These rates of increase are not sustainable and will be constrained by resource limits , international agreements or catastrophic events. A closer scrutiny of environmental performance can be expected. A number of recent socio-economic scenarios are described and their implications for predicting environmental requirements are explored. Ways the industry and government can influence the nature of future environmental considerations are discussed.

## INTRODUCTION

Queensland has a history of more than 150 years of mining, but only during the last 30 years has consideration of the environment become a significant issue for the mining industry. This paper examines the present interest in the environment and attempts to predict the level and type of environmental considerations that will be required in the mining and energy industries over the next 30 years.

Most of those in the mining industry 30 years ago were totally unprepared for the very rapid rise of environmental expectations. This situation has changed; most in the industry now understand environmental principles such as ecologically sustainable development, polluter pays, the waste hierarchy, and rehabilitation. However, there are still concerns in the industry that the environmental movement will continue to demand more and more, and this will make the industry non-viable in a few years time. The industry would be greatly assisted if it knew how much more or less influence the environment will have so that the industry can plan and invest with greater certainty.

This paper will try to unlock the door to the future to reveal possible environmental requirements for the energy and mining industries. Many people in these industries will be familiar with the geological principle of uniformitarianism, which is summed up as "the present is the key to the past". Unfortunately when we try to predict the future, the present is more like a keyhole through which we get a glimpses of what might happen. These glimpses may be misinterpreted because we cannot see the whole picture in context. Although we cannot provide a definitive picture of the future, this paper explores ways in which our predictions can be improved. It will do this by examining four approaches to determining the future. These are:

- empirical studies of recent trends,
- analysis of why there have been recent changes,
- scenario development, and
- proactive measures such as planning and legislation development.

## EMPIRICAL STUDIES OF RECENT TRENDS

The most relevant trends for the mineral industry's future might be population, measures of economic activity (e.g. gross domestic product), and the extent of pollution. In less than 100 years the population of

Queensland has grown from about 0.5 million to almost 3.5 million. The current annual growth rate of about 2.5% is showing little evidence of falling. It corresponds to a doubling of the population every 28 years. At that rate Queensland will have a population of 7 million in 30 years.

By comparison the Gross State Product for Queensland at factor cost has been increasing at between 6% and 8% per year. If that trend were to continue, in 30 years time Queensland's economy would be eight times as big as at present. The increase in exports from Queensland has also been dramatic: rising from $813 million in 1964-65 to $17,838 million in 1994-95. Taking inflation into account, this still represents a 570% increase over 30 years. The value of mining in Queensland increased 30 fold over the last 30 years, corresponding to an 800% increase in constant $ terms.

The increase in the quantities of minerals mined varied considerably, e.g. coal (x22), gold (x11), zinc (x8), silver (x3), lead (x3), copper (x3), and mineral sands (x3); while tin went down (x0.04). New coal and base metal mines are being developed so there is reason to believe growth will continue, provided there are sufficient buyers. The value of electricity and gas sales in Queensland increased 45 fold over the last 30 years, corresponding to more than a ten-fold increase in constant $ terms.

What effect has this increased population and development had on the Queensland environment? Almost two thirds of Queensland's native vegetation is classified as substantially cleared or thinned, mostly for agriculture or livestock. For some land cover types the proportion is much higher and the remnant vegetation is under pressure from further clearing and die-back. Clearing not only poses a risk to the floral biodiversity but also reduces the habitat for native fauna. There are additional effects of the urban sprawl near the larger cities on the local environment through feral animals, siltation and pollution of streams, air pollution and noise.

The mining industry is directly responsible for a very small part of these effects because mining activities have disturbed only about 0.1% of the State. This is comparable to the area of the State that grows cotton and close to one quarter the area of wheat, sugar or hay production. Mining has indirectly affected a larger but hard to estimate area which is disturbed by urban areas, transport, water supplies and other services that have grown because of mining.

Because mining is a transient land use, it is possible to rehabilitate the disturbed areas after they are mined. Approximately half of the area disturbed by metalliferous mining in the last 30 years has been rehabilitated and almost a quarter of the area disturbed by coal mining has been rehabilitated. Commitments in Environmental Management Overview Strategies that are now lease conditions will ensure that mining remains a major contributor to revegetation as the amount of rehabilitation continues to grow.

Even an eight fold increase in mineral production, that could be extrapolated from trends described above, will leave mining as a minor cause of vegetation loss compared to agriculture and urban development. However, the cumulative pressure on uncleared land will ensure very close scrutiny of clearing for any new mining project. This factor alone will ensure that environmental interest will remain at a high level in the next three decades. This will be intensified by mining in more densely populated areas.

The effects of mining on water quality have rarely been documented in Queensland. Specific cases such as Mount Morgan, tin mines on the Atherton Tableland, and some of the old abandoned gold mines have caused localised pollution problems. The most common form of pollution is acid mine drainage that results from the oxidation of sulphide bearing rocks. The acidic solutions tend to mobilise iron and heavy metals which can adversely affect aquatic systems. The Department of Mines and Energy has an ongoing program to manage those abandoned sites which are considered to pose a significant risk to the environment. This is a long term program that may well be operating 30 years from now.

Current mining practice and regulation have made discharges of polluted water from operating mines exceptionally rare. Extensive flood rains in northern Queensland earlier this year showed that the current design practice of providing sufficient water storage to contain a 1 in 100 year flood event is effective. One mine where the rainfall greatly exceeded this amount was inundated but the contaminants were rapidly diluted or precipitated from the water in an area close to the treatment plant. On the basis of the current activities, water quality should improve as the major sources of pollution are rehabilitated. More detailed investigations of the effects of mining on groundwater are likely to become more frequent.

Air quality is affected by dust from mining and gas emissions from smelters and power stations. The most contentious emission recently has been sulphur dioxide. It would probably be a surprise to many that monitoring by the Department of Environment at Mount Isa since 1983 shows that, despite a significant increase in metal produced by the smelters, air quality has generally improved, e.g. there are fewer days per year when the town area is affected by the smelter gasses. This is partly due to improvements to the Air Quality Control System that MIM Ltd established in 1979 and partly due to improved smelter technology. A proposed sulphuric acid plant will reduce total sulphur dioxide emissions by 80%.

Another air quality issue that is of particular interest to the energy industry is the enhanced greenhouse effect. There is no doubt that carbon dioxide content of the atmosphere has increased by 30% in the last 150 years. Monitoring at Mouna Loa in Hawaii for the past 50 years, and at Cape Grim in Tasmania and in Antarctica for about 20 years confirm the continuing trend which would see carbon dioxide levels in the atmosphere double within 30 years. Although the carbon dioxide levels would then be about one tenth what they were during the Cambrian Period, some climatic changes are predicted by the experts.

In order to minimise such changes, the UN Framework Convention on Climate Change is seeking international agreement to legally binding targets for the reduction of greenhouse gas production. One proposal for discussion at the Kyoto meeting in December would require a reduction by 2010 to levels of emission that are 15% below the 1990 levels. Queensland would receive fairer treatment through a differentiated approach that takes account of the available alternatives, efficiency of the current generators of greenhouse gases and the export of products which have required energy to produce, such as refined metals.

## ANALYSIS OF THE TRENDS

An inherent problem with trend analysis of a multi-variable function is ensuring that there is enough control on the variables that are not being considered. If there are two independent variables affecting the function being measured we move from a two dimensional curve to a three dimensional surface (provided the relationships are continuous). With three independent variables we are dealing with hyperspace. Trying to line up a trend in hyperspace to a future timeframe is fraught with difficulty, especially if the underlying relationship changes or is discontinuous.

For several of the trends described above, it was noted that a change to one underlying assumption, such as the technology used, can make a major difference to the predictions drawn from trend lines. Analysis of the factors that control the trends may remove some of the uncertainty and provide more robust predictions.

The trends which gain the most interest are the exponential growth curves. Exponential growth can only continue if the supply of resources keeps up with the demands of the growing population or economy. Malthus recognised this almost 200 years ago. Ecologists have observed what happens when the supply is inadequate: the growth rates begin to decrease and populations reach a relatively steady state until some other environmental change occurs. In nature, it is typically food that limits the population growth, although some plant communities may be limited by the available energy (e.g. sunlight in a muddy river or rainforest) and some animals may be limited by physical resources (e.g. space in a turtle rookery).

There are various mathematical models which approximate these observations (eg the Gompertz curve and the more general logistic or "s" shaped curve). However, the unpredictability of nature and human inventiveness are additional factors which need to be considered. For example, a new technology can result in major changes in the relationship between production and resources. Similarly, a change to Government policies or a war can influence the industrial or social setting.

Despite failing to predict some of the changes that have occurred since it was published 25 years ago, *The Limits to Growth* prepared the international community for a constrained future. The response has included the Bruntland Commission which introduced the concept of sustainable development to the World in its 1987 report titled *Our Common Future*; the United Nations Conference on Environment and Development (Rio Earth Summit, 1992) which set the World environmental agenda for the 21st Century;

and the Framework Convention on Climate Change.

In order to refine predictions of the future importance of the environment to our industries, the following factors will be analysed:

- interpreting measurements of environmental variables,
- globalisation,
- public awareness and confidence,
- technology transfer and business management practices, and
- government actions.

### Interpreting measurements of environmental variables

Looking at trends without examining the underlying controls can result in incorrect conclusions, such as unlimited exponential growth. Another misconception is that an increase in the total unrehabilitated area implies that progressive rehabilitation has not been occurring at mines. There are several reasons for this increase including:

- new mines opening,
- changing patterns of pre-clearing,
- poor weather conditions preventing seeding to finalise rehabilitation,
- mine plans at some large mines that necessitate a delay, and
- metalliferous mines which are unable to commence rehabilitation of plant sites and active waste disposal areas until the mine stops operation.

State of the Environment reports attempt to analyse the observed trends through a "pressure - state - response" model that attempts to identify the pressures or causes of change. The quality of the conclusions depends on the amount and quality of the data and the relevance of the analysis. State of the Environment reporting is in its infancy in Queensland. An inventory of available environmental data was collated in 1990, but there was little interpretation. The Environmental Protection Act 1994 requires a State of the Environment report for Queensland at least every four years. The first of these reports is nearing completion. It will provide a more detailed coverage than the *State of the Environment Report Australia* published by CSIRO in 1996 and the earlier Australian Bureau of Statistics compilations of environmental measures.

In the meantime we can analyse the trends discussed above in a simplistic way. The Queensland population growth has been dominated by net migration (mostly from other States). Jobs directly and indirectly created by mining are one of the reasons for the migration. The natural population increase in Queensland (and in other developed countries) is declining. This may be due to better contraception, economic pressure on families (which is forcing wives to work and to have children at a later age), and lower fertility (which may be a natural population control process or be related to pollution).

The population of many developing countries is continuing to grow, but despite this there is evidence that growth of the World population is declining. This would be expected to reduce the rate of growth of the demand for Queensland's minerals and that would have a flow-on effect on the Gross State Product. However, even if the World population remained constant, the demand for energy and minerals is likely to continue to rise for some time to meet the growing aspirations of the developing countries.

Predictions of the greenhouse effect could be improved by a better knowledge of the factors that cause the observed carbon dioxide trends. These trends are based on about 50 years direct measurements of carbon dioxide levels in the atmosphere at special monitoring stations and laboratory measurements which became reasonably precise about 100 years ago. There are also inferred data derived from core samples of Antarctic ice which extend the time series back more than 600 years, and carbonate deposits which extend the series back at least 500 million years.

The ice cores highlight the increase in carbon dioxide levels since the middle of last century. This is generally inferred to be a result of the industrial revolution but there are discrepancies with mass balance calculations and other significant causal factors may exist. If we look at the fluctuations over the last 200 000 years there are strong correlations between the inferred carbon dioxide levels, ocean temperature and sea level changes. This correlation does not prove a cause and effect relationship. All of these variables could be explained by some other process (such as solar radiation) and the present trends could be related to the end of the last ice age some 10 000 years ago.

Assuming that industrial processes are the major cause of the recent increase in carbon dioxide levels, we could expect the trends to be disrupted by the conversion to cleaner and more efficient electricity production techniques; mineral processing industry participation in the Greenhouse Challenge; and the forthcoming meeting of parties to the UN Framework Convention on Climate Change in Kyoto. For these reasons it would be unrealistic to predict a continuing exponential rise in the production of greenhouse gases for the next thirty years. There may be a parallel in the 1973 oil crisis which curbed the growth of oil usage.

There are many other factors that should be considered in the greenhouse debate. The causal relationship between carbon dioxide levels and global temperature needs more research. One effect of any global warming could be in an increase in the rate of carbon dioxide uptake by plants. Any sea level rises could increase coral growth which could result in more carbon being locked up in limestone.

Obviously we have a long way to go before we can make accurate predictions from these environmental data, even when there is agreement on the underlying pressures and effects.

## Globalisation

Globalisation takes many forms. Trade, travel, migration, investment, information and entertainment all contribute to the trend towards globalisation. Many environmental issues have a global scale, e.g. issues of climate change, ozone depletion and ocean pollution. Other issues with more local effects can receive global attention through well orchestrated media campaigns. For example, clearing the rainforests of the Amazon or Costa Rica have been widely publicised in Australia. The global interchange of information to the public through the Internet and through the global television networks allows a rapid comparison of local trends with data from around the World. Industry's access to global information affects the rate of technology transfer whether it relates to more efficient mineral treatment or alternative energy.

Globalisation is also manifested in international treaties and agreements. These result in more uniform environmental standards, especially for substances with global or international effects such as ozone depleting substances and the causes of acid rain.

Australia has been a strong supporter of international treaties in the past but has concerns about the greenhouse negotiations. Queensland has even more reason to be concerned because of the significance of coal mining and export to the State's economy. If greenhouse targets force other countries to reduce their coal usage to meet the greenhouse targets, the demand for coal will decrease and the price will almost certainly fall, possibly making some Queensland mines uneconomic.

Furthermore, Queensland uses large amounts of electricity for refining and smelting metals which are largely for export. If Australia has to meet the targets and developing countries do not have to, Australian smelters could close and the mineral processing industries would establish in developing countries. This is made even more significant because a high proportion of Queensland's electricity is generated from coal. If power stations are closed or converted to more expensive fuels, the standard of living of Queenslanders will be affected by the broad effects of the higher energy costs. A negative result from Kyoto could see a drastic change to the rapidly increasing coal mining industry which has been a major component of the State's economy in recent years.

## Public awareness and confidence

Although Queensland is the most decentralised of the Australian States, it is still a highly urbanised society. Mining tends to occur in the more remote parts of the State and is becoming more mechanised. For these reasons the majority of Queensland's population has little direct knowledge of the mining industry. Their images of the industry are derived from the TV screen, a medium that is easily captured by minority groups and ratings seekers who seek tales of conflict, corruption and irresponsible behaviour. The big stories are the catastrophes, major events that cause death or damage to property or the environment. Even though such events are unpredictable and infrequent, they leave lasting images which are skilfully used by interest groups to justify their causes.

Those who wish to maximise the impact for their cause try to relate their messages to the fears and aspirations of the people. Concerns about safety, health and food are high on the list of a needs hierarchy. Loss of property values, loss of productivity and diminishing resources for future generations are also sources of concern. Therefore it should not come as a surprise that establishing the belief that mining is associated with adverse effects on these basis needs is the prime goal of the opponents of mining. When the industry attempts to correct false information or to present the positive aspects of mining, such as jobs, export income, building materials for our homes and minerals to support our technological lifestyle, the industry is accused by its critics of spreading propaganda. In this climate of distrust, the public is demanding more information on the risks posed by all manner of activities.

In this regard, Australia is probably lagging at least ten years behind USA and European countries in providing information on industrial hazards to the community. In the mid 1970s, Freedom of Information laws in the USA allowed employees to get information from their employers.

In the early 1980s many States in the USA passed Hazard Communication/Worker Right-to-Know laws. The US Congress passed the *Emergency Planning and Community Right-to-Know Act* in 1986. It is better known as Title III of SARA, the *Superfund Amendments Reauthorisation Act.* This legislation provided various rights-to-know including the Toxic Release Inventory (which commenced in 1988). The equivalent Australian legislation is the National Environment Protection Measure for a National Pollutant Inventory (which will not commence before July 1998). Earlier this year the USEPA added 6100 facilities including metaliferous mines, electric utilities and petroleum bulk terminals to the existing list of 25 000 industrial sites that have to make annual reports on their discharges.

One of the significant changes in public attitudes over the last decade has been its increasing interest in the environmental management of the mining industry. A *Sunday Mail* compilation in 1989 of the top 50 environmental 'hot spots' identified by Queensland environment groups did not mention any issues relating to mining. The *Green Challenge, A Log of Claims* that was developed by the Environment Movement in Queensland, also in 1989, had only 5 mining issues which came at the end of the 102 issue list. The mining issues related to: impact assessment and public participation; exclusion of mining from national parks; lease conditions that mandate environment protection and rehabilitation of all mining tenure and are open to public scrutiny; and elimination of automatic renewals of mining tenements. The current media interest in mining issues suggests a significant lowering of public perceptions of the environmental performance of mining which is contrary to the actual improvement in performance.

This is in contrast to the Australian Bureau of Statistics publication *Environmental Issues: Peoples Views and Practices* which is based on samples of households in May 1992, June 1994 and April 1996. Over this four year period the proportion contending that the environment is as important as the economy has remained at about 70 % but there has been a noticeable increase in those who think the environment is less important than the economy (6.6% to 7.9% for all Australia and 8.8% to 8.9% for Queensland). There has also been a general decrease in the proportion expressing concern about aspects of the environment (75% in 1992, 69% in 1994 and 68% in 1996) but it is still considerably higher than a decade earlier (47% in 1986). ABS attribute the high response in 1992 to publicity for Rio Earth Summit.

In 1996, air pollution remained the most frequent issue of concern (being identified as a concern by approximately 32% of the population), ahead of ocean pollution, freshwater pollution, destruction of trees and garbage disposal (identified by about 23%). Conservation of resources was in 12th position, greenhouse 13th, overpopulation 14th, uranium 15th and sand mining 17th (but only a concern to about 2 % of the population). There has been a general fall in the proportion registering each concern of about 5 to 10% over the four years with most of the fall between 1992 and 1994. 44% felt that over the last 10 years the environmental quality had declined and 23% felt it had improved.

Unfortunately these surveys of public opinion do not cover a long enough period to give a reliable indication of the direction in which the public interest is currently moving. The marked increase in concern about the environment between 1986 and 1992 appears to have been followed by a slight decrease over the next four years. It is possible that this recent downward trend is only an adjustment for the enhanced interest caused by the Rio Earth Summit. The next survey which will be conducted early in 1998 could test that hypothesis. It may also show if there have been any lasting effects of the recent adverse publicity about mine rehabilitation and regulation issues.

### Technology transfer and business management practices

New technology may drastically change the production functions of an industry and should be identified where they could affect a trend line that is being investigated. Innovation is a complex phenomena which typically starts slowly and at different times in different countries or even within a firm. There are a number of practical reasons for this such as cost, age of existing plant, knowledge of the technology's existence, belief that it will work, skill to implement or support the technology, market acceptance of the product, and government regulation or support. The adoption (or adaption) of a new technology tends to follow the same logistic curve as found in nature. The use of a technology generally declines when a new superior technology appears in an industry or the market tires of the product.

The attitude of management has a major influence in determining whether new technologies will be sought and implemented. Management that supports active research programs is likely to be innovative. If it is seriously seeking best practice it would be implementing an Environmental Management Systems. Through the cyclic process of developing policies, action plans, monitoring and review the company will be adopting continuous improvement. Education and training are important elements of an Environmental Management System.

One of the critical elements in an effective Environmental Management System is accurate measurement. However, the cost of collecting data must be justified in terms of the scale of the environmental impact or potential liability to the agency. It is really an application of risk management. This is most effective if the results are published and the costs are fully integrated into the accounts so that they are specifically considered in decision making.

Business will still be driven by market forces. The demand for minerals is likely to continue with periodic fluctuations (and possibly some instability in the short term for coal). New mines are being developed and some will implement newer technologies. They will have to deal with changing environmental regulations. The innovative companies have begun to integrate environmental considerations into the core of their business activities. They have found which of the environment factors influence the interactions between themselves and their stakeholders, in particular those which deliver profits. They are measuring these elements and integrating them into their strategic and operational plans. They are realising that managing their environmental risks will provide significant long-term benefits which should not be overridden by short term financial considerations.

### Government actions

Government can influence the trends in a number of ways. It sets the legislative framework for many business and community actions. It provides incentives or disincentives through financial controls. It provides information. It also has major effects through its purchasing power and organisational structures.

A large part of the recent increased interest in environmental matters is related to new legislation. This relationship is likely to continue for several years while legislation relating to impact assessment, planning, environmental management and resource allocation is developed and reviewed. It is reasonable to predict that future legislative initiatives will take more than five years to develop because many recent legislative changes have taken at least that long.

Two of the reasons legislation takes so long – the expectations of the many stakeholders and the complex interactions between different policy areas – are no likely to change. Therefore we could look at the current legislative developments to provide some indication of the changes over the next five years but they tell us little of the legislative setting 30 years from now. Political responses to changes in community expectations and new issues can be quite rapid. It is hoped that the underlying principle of sustainable development continues.

## SCENARIO CONSTRUCTION

Economists and ecologists have recorded many variables that have shown continual increase when plotted as time series. A number of scenarios have been built on such data. The reliability of these trends as predictors of the future is limited. In 1798, Thomas Malthus published *An Essay on the Principle of Population* in which he proposed that population tends to grow faster than the supply of resources, resulting in decreasing living standards, famine, disease and war. Other early 19th Century economists countered this proposition with the belief that the price mechanism would ensure economic progress to keep up supplies.

More recently in 1972, the Club of Rome published *The Limits to Growth* which presented the results of computer simulation using a systems dynamics model. They predicted that non-renewable resources would run out within 100 years, resulting in a catastrophic collapse of the economic system, a decrease in food production and increased death rates. Even if the known amount of resources was doubled, the model suggested that the economy would still collapse, but in this case because of pollution.

If both the resource and pollution problems were solved, food would become the limit of growth.

Just as Malthus created controversy amongst his contemporaries, debate on The Limits to Growth continues today. Although the specific predictions were severely disrupted by the Mid East oil crises of the 1970s, economic development and resource use are still growing. This is not regarded as a problem by those with a more optimistic view of the future. A typical example would be Kahn & others (1976) who published an early response to The Limits to Growth titled *The Next 200 Years: A Scenario for America and the World.* They proposed that continuing technological development would push back the limits of nature, that population growth would flatten, and that solar energy would sustain a high level of economic development.

This flattening of the exponential growth curves is often noted in sales of a new product. The marketing profession call this the Product Life Cycle which begins with a few tentative sales in the innovation phase; goes through a phase of rapid growth; settles into a mature phase; and finally enters the decline phase (when the market tires of the product or a superior product appears). In many ways the interest in the environment within the community is similar to a commodity in the market place. One similarity is the competition which occurs in the minds of the community with many other possible interests. Marketers know that the community can only deal with a few issues over a short period of time and therefore strive to establish product recognition and loyalty as quickly as possible.

The following scenario depends on a simple product life cycle model. The model looks at the market potential of a product called the "Environmental performance of the mining industry". Following a marketing approach, the market is suggested to contain four broad segments: the general public; the conservation groups; parties directly affected; and the Government. The following table shows the characteristics of each segment, what it is looking for and the product features that would provide those consumer demands.

The producer of the "product" is the mining industry, represented by the directors, shareholders and environmental employees of the mining companies and their consultants. The "product" is stored and distributed by government agencies and the media. These suppliers have a wide range of objectives which may not always be consistent with the objectives of the mining industry.

The product is a relatively new commodity to most of the potential market. Although the opinion polls indicate a relatively high market penetration for environmental issues, those specifically related to mining were down near 2% of the population only a year ago. That has undoubtedly grown significantly and it would be interesting to know what proportion of the potential market is now a "consumer" and much growth remains in the market. A comparison with the characteristics of the product life cycle may assist in answering these questions.

The Introductory Phase is characterised by slow growth; a relatively simple product being distributed through existing channels; promotion being in the form of educating the market (building demand); and pricing either trying to extract excess profits quickly or being kept artificially low to ensure market penetration.

The Growth Phase is characterised by rapid growth; differentiated products as companies experiment to find the best product; development of selective distribution channels; increasing competition; promotion moving from informing to persuading; and pricing to meet competition.

The Maturity Phase is characterised by a uniform product; development of specialised distribution channels; competition focussing on brand name and service/customer support; promotion focussing on persuading; and pricing to meet competition through price cutting and special deals.

The Decline Phase is characterised by producers dropping out; highly specialised distribution channels or reliance on general

| MARKET SEGMENTS AND CHARACTERISTICS | CUSTOMER NEEDS | PRODUCT FEATURES |
|---|---|---|
| **General public**<br>Urban, 'baby boomers', low interest, majority | Health, jobs, no extra costs | Reports that identify risks and provide confidence |
| **Conservation groups**<br>Well educated, younger generation, high interest, small minority | A better World | Evidence of good environmental outcomes, detailed planning and information |
| **Parties directly affected**<br>Rural, mixed ages, specialised interest, minority | No costs, safely, health | Information, involvement, careful operators |
| **Government**<br>Conservative, younger to middle aged, regulatory interest, small minority | Meet regulations, no costs | Monitoring, reporting, good management |

systems; promotion focuses more on reminding the consumer; and the price continues to fall.

The available evidence such as newspaper articles, the variety of ways companies are reporting environmental performance, a requirement for annual environmental reporting being included in the Minerals Council of Australia Code of Practice, and changing government legislation would place the "product" somewhere in the Growth Phase. The variability in the product suggests that there may be significant growth left in the market for information on the environmental performance of the mining industry.

The marketing literature indicates that the product life cycle can be of almost any duration. That does not provide many clues about how long it will take for the product to reach maturity and begin to lose demand. It is also noteworthy that the duration of the product life cycle for one product may be different in different market segments. Some idea might be gained from the history of similar products. For example, the modern biological sciences commenced with the publication of *Systema Naturae* by Linnaeus in 1735 and reached their zenith in the late 19th Century, about 150 years later. Geology had its rapid rise in the 19th Century and a final boom in the 1960s; a period of more than 150 years.

More recently the computer sciences have been growing since the 1960s and hardly look like starting to level out after 40 years. If we take the 1970s as the beginning of the environmental sciences there would probably be at least 10 more years of growth in demand for environmental considerations in the mining and energy industries and the environment will continue to be significant factor for some years after that.

## CONTROLLING THE FUTURE

No marketing person is going to stand by and be dictated to by the market. There are ways the producer (the industry) and a distributor (government and/or the media) can influence the demand for the product (environmental performance of the industry).

A strategic approach is needed. The initial step would be to target the appropriate market segment and do the market research. If we pool our resources to develop a shared vision that leads to strategies and implementation plans we will have a better chance of achieving the objectives of the customer and the producer. Consultation will be one of the key techniques in the market research. A wide range of strategies are likely to be developed. The difficulty is identifying which will work.

Government can develop legislation that promotes environmental performance through the use of a variety of policy measures ranging from regulation to voluntary activities. It can also provide financial assistance, information, organisational and infrastructure support to industry, and provide publicity for good performance. To do this Government needs to focus on effective systems, simplifying data requirements, identifying emerging issues on the local and global scene, ensuring that sustainability is considered in decisions relating to development and the environment, enforcing the environmental regulations, and publicising the positive aspects of industry's environmental performance.

For the industry, there are issues related to responsible behaviour such as: developing and implementing environmental management systems which integrate environmental considerations into the heart of the business, monitoring their activities, reporting these results and acting on them to achieve best practice environmental management through ongoing continuous improvement.

If we have identified the problem correctly, the challenge is leadership and cooperation in moulding the best future. As stated in Principle 10 of the Rio Declaration, "Environmental issues are best handled with the participation of all concerned citizens, at the relevant level. ... each individual shall have appropriate access to information concerning the environment that is held by public authorities, including information on hazardous materials and activities in their communities, and the opportunity to participate in decision making processes".

## THE VISION OF THE INDUSTRY THIRTY YEARS ON

Continued population growth, increasing energy demands and increasing consumption of materials on a per capita basis should see continued growth in the Queensland mining sector. The sector could double its output over the next 30 years but it will not be able to double its emissions to the environment or other forms of environmental harm if we are to maintain our present quality of life. Industry will have to be cleaner.

There are signs that most of the major companies are aware of this and are prepared to make necessary changes voluntarily, rather than wait for regulations to be imposed on them. However, the public is sceptical of voluntary arrangements, particularly for an industry which has in past decades walked away from unrehabilitated mine sites, leaving situations which pose a risk to the environment. The current compromise, which is a mixture of self regulation and government command and control, is likely to continue for decades. That does not mean that the balance between the extremes will not change. It can only move towards self regulation if the public (and therefore the politicians) have trust in the industry performance. Lenders will also require a responsible approach to the environment to reduce their risk.

One of the keys to developing community trust will be through access to information on what the industry is doing. Industry must also be willing to listen to community views on what has value to them and how these values are under threat. The industry should have a basic philosophy that no one individual will be worse off as a result of the any mine development. Appropriate compensation will continue to be the responsibility of the company.

The Government will continue to review the regulatory framework to ensure it is fair to all, and to strive for best practice environmental regulation. The elements that might be targetted for continuous improvement include: certainty, cost effectiveness, efficiency, flexibility, integrity, practicability, transparency and consultation. One of the mechanisms that is likely to rise in importance is the environmental management system. Such systems will become more sophisticated and commonly will be integrated with the accounting and management systems of large businesses or be represented by environmental commitments in the business plans of small business.

**Reference for this paper:**
**WILSON, I.H., 1997: Environmental considerations in the future Queensland energy and mining industries. *In*, Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 147–156.**

*Wilson Cooper*

**Department of Tourism, Small Business and Industry**

# Minerals Processing in Queensland

## SUMMARY

Minerals processing transforms raw materials into high quality products with strict and measurable specifications, creating wealth by adding value to our mineral resources. It requires a culture amenable to value-adding industries, a supportive government adopting a regulatory environment conducive to investment, but conscious of the requirements for environmentally sustainable development. It requires infrastructure of available energy, land, water, and transport. It requires projects which are cost competitive, with superior technology, a skilled workforce with suitable training, and access to markets.

Mining and minerals processing industries are important in Queensland, with a combined average growth of about 17% a year. Both State and Federal Governments recognise their importance, actively encouraging industry developments, and moving to address industry requirements. The Department of Tourism, Small Business and Industry (DTSBI) has played its role through implementing strategies, including support for planning infrastructure, for resource developments, for research and development, as well as offering incentives and assistance, promoting projects in the minerals processing sector and proactively investigating key mineral industry opportunities.

Queensland's record in minerals processing is best illustrated through the key development nodes at central Queensland around Gladstone, at Townsville, in the Carpentaria-Mount Isa minerals province, as well as the statewide developments for specific commodity industries. The availability of mineral resources and natural gas for energy and as chemical feedstock is set to expand minerals processing through future industry opportunities.

## INTRODUCTION

Australia's inherent wealth has been largely built around its abundant mineral and agricultural resources heritage, and Queensland has more than its fair share of that abundance. To capitalise on that heritage, adding value to our resources instead of exporting unprocessed raw materials creates wealth for the whole community.

Queensland is responsible for around 20% of the total value of all minerals produced in this nation. Metallic and fuel mineral projects contribute most in mineral wealth to the state. In 1995-96 the annual value of mineral and energy production in Queensland was $6.05 billion. Of this, some $4.02 billion was in energy minerals, $1.79 billion in metallic minerals, and $239 million in industrial minerals. Some 54% of the State's export income is provided by the mining industry which directly employs around 19,000 people and indirectly around 40,000 (Department of Mines and Energy, 1996).

However, the true value of minerals to the State's economy is not only in the value of mineral production, but also in wealth created for the community through current and potential manufacturing applications via a strong processing sector, with consequent industrial development.

Processing of primary resources is an integral and fundamental part of a successfully developed economy and processing in chemicals and minerals makes a significant contribution to that development. Those economies in which the chemicals and minerals processing sector employs a high proportion of a country's workforce have a higher growth rate and maintained higher standards of living than those without that sector (Robert, 1991).

A major sector of Australian manufacturing is in added value processing activities. Minerals processing represents a significant part of that sector, and together with the mining industry, generates a large component of Australia's economic wealth. Mining and minerals processing remain Australia's major export earner, generating over $30 billion last financial year. The combined product value of mining and minerals processing operations in Queensland average growth of around 17% per year over the last decade (Department of Tourism, Small Business and Industry, 1996).

Process industries in Queensland include chemical, oil refining and minerals processing of base and precious metals and industrial minerals. Products manufactured from this sector include fertiliser, aluminium, glass/ceramics, cement and liquid fuels. Other important sectors are food processing, wood products, and fibre preparation in cotton ginning/spinning and wool scouring. The Department of Tourism, Small Business and Industry (DTSBI) has played a significant role in the development of these industries and its mission is to maintain that role into the future.

The importance of the industry is recognised by the State and Federal governments. Representatives have participated at the highest level, at the Prime Minister's Science Council (1990), at conferences such as the Australian Industry Council (AIC) Conference in Sydney (1991) and in the bi-annual Commonwealth-State Working Group on Resource Processing sponsored by the federal Department of Industry, Science and Technology (DIST), and spoken, along with industry representatives, on the importance and necessity of a strong, vibrant industry.

This paper reviews these factors as well as giving a view of Queensland's recent progress in minerals processing.

## PROCESSING CHARACTERISATION

Processing was defined by Wilde (1990) as the application of technology to remove unwanted substances from a resource and the use of energy and chemical reagents to change the nature of the target substance into a high quality product demanded by customers. Process industries in turn were described by Robert (1991) as those in which raw materials are transformed by a number of physical and chemical changes, characterised by manufacturing processes which cannot be easily varied because they are designed into plant and equipment with a high degree of automation to meet strict and measurable product quality specifications.

Processing of minerals to transform them to the 'high quality product demanded by customers' has been commonly termed 'value adding'. The application of those products into manufacturing or further processing, is further increasing their worth, or adding value. Minerals processing taken to its most commonly understood conclusion is production of refined metals from their complex minerals, such as aluminium from bauxite, steel from iron oxides and hydroxides, copper, lead and zinc from oxides, silicates and sulphides.

This does not account for the end result from processing of fuel minerals, or the wide range of industrial minerals. Processing of industrial minerals can include processes which could be interpreted as manufacturing, such as in ceramics. However, processing definitions exclude beneficiation or treatment of raw material to a more purified but untransformed product.

Processing in Queensland has mostly been applied only in adding value to our own abundant raw materials. However, there is now a developing industry processing imported ores, such as QNI's nickel and cobalt from Indonesian and Pacific Island laterites, and the proposed Calliope Metals Gladstone project which will do the same. As well, imported crude oils have been processed by both BP and Ampol at their refineries at the mouth of the Brisbane River since the 1960s.

Processing creates employment directly through the process venture and through resultant spin-off service industries, creating a ripple or multiplier effect. It creates a need for subsidiary industries, such as in research and development of new or improved processes and products, and in education and training to create a skilled workforce to operate the processes.

The chemical and minerals processing industries are interrelated. Both industries transform raw materials in continuous flow operations, and both have their origins in extraction activities. Both industries have claims to producing inorganic chemicals eg., alumina, synthetic rutile, caustic soda, and both are a fundamental part of the industrial infrastructure of any developed country.

Although there is an expectation in some quarters that minerals processing projects should be initiated from the resource owner, this is normally the exception, rather than the rule. Successful assembly of minerals processing projects is often undertaken by proponents outside the resource ownership sector. There is most often a technical reason for this. Process industries apply continuous or exacting processing operations which require skills and backgrounds of professionally trained chemical engineers and metallurgists with disciplines differing from those of earth science professionals.

## PROCESSING REQUIREMENTS

Many observations on requirements for a successful minerals processing industry, which can equally apply to most individual processing projects, have been offered by government, university and industry representatives in various publications and submissions (Australian Trade Development Council, 1980; Department of the Prime Minister and Cabinet, Prime Minister's Science Council, 1990; Innes, 1991). Experience within DTSBI and other agencies has led to similar conclusions, many of which are incorporated in Departmental strategies for project facilitation.

### Culture

A prime requisite for a successful processing industry is a culture which recognises and encourages value-adding to our mineral resources, with a clear vision as to why that is necessary and desirable, a vision of creating wealth for the community. It requires a sympathetic and supportive government attitude to enable suitable policy frameworks to be adopted. It requires a business and regulatory environment conducive to investment, to ongoing research and development, to improving education with recognition, encouragement and reward for science and engineering graduates, and an inclusive work environment supportive of value-adding industry, which appreciates the need for ongoing innovation and efficiency.

It also requires that industry adopt world's best practice consistent with the principles of economically sustainable development.

### Competitive projects

Even within such a cultural environment, the projects have to be competitive. They should be able to compete not only locally and in the national market, but also aim to be competitive on an international basis. Factors affecting that competition include the array of costs faced by organisations, the availability of infrastructure at low costs, the availability of suitable raw materials of appropriate quality and quantity, and effective economies of scale.

*Costs*

Continued success of minerals processing developments depend on whether costs can be contained to allow profitable production. The major outgoing costs include banking imposts, including the costs and difficulties in raising venture capital, costs of construction, labour, communication and administrative costs.

They include government imposts levelled by three layers of government - payroll tax, corporate taxes, FBT, rates, charges etc., as well as import tariffs levied on machinery and goods not manufactured in Australia. They include the costs of compliance with State Government regulation and legislation, mainly concerned with increased environmental constraints through the EPA (Department of Environment), EMOSs (Department of Mines and Energy), and EISs and community consultation processes (Department of Local Government and Planning, Department of the Premier and Cabinet).

As well, State and Commonwealth governments can incur multiple incursions on an organisation through administrative time in completion of forms, surveys and regulatory requirements, and are often seen as impediments to investment.

*Infrastructure*

Infrastructure developments required include:-

- provision of power and access to gas and coal fuels (Figure 1);
- integrated transport corridors which include roads, rail, sea ports and air transport;
- the provision of adequate water supplies to satisfy services to industries;
- access to serviced land with appropriate zonings derived from appropriate land-use planning expertise.

*Raw materials*

Raw materials for the processing are mostly available from Queensland sources. They should preferably be of a high quality and

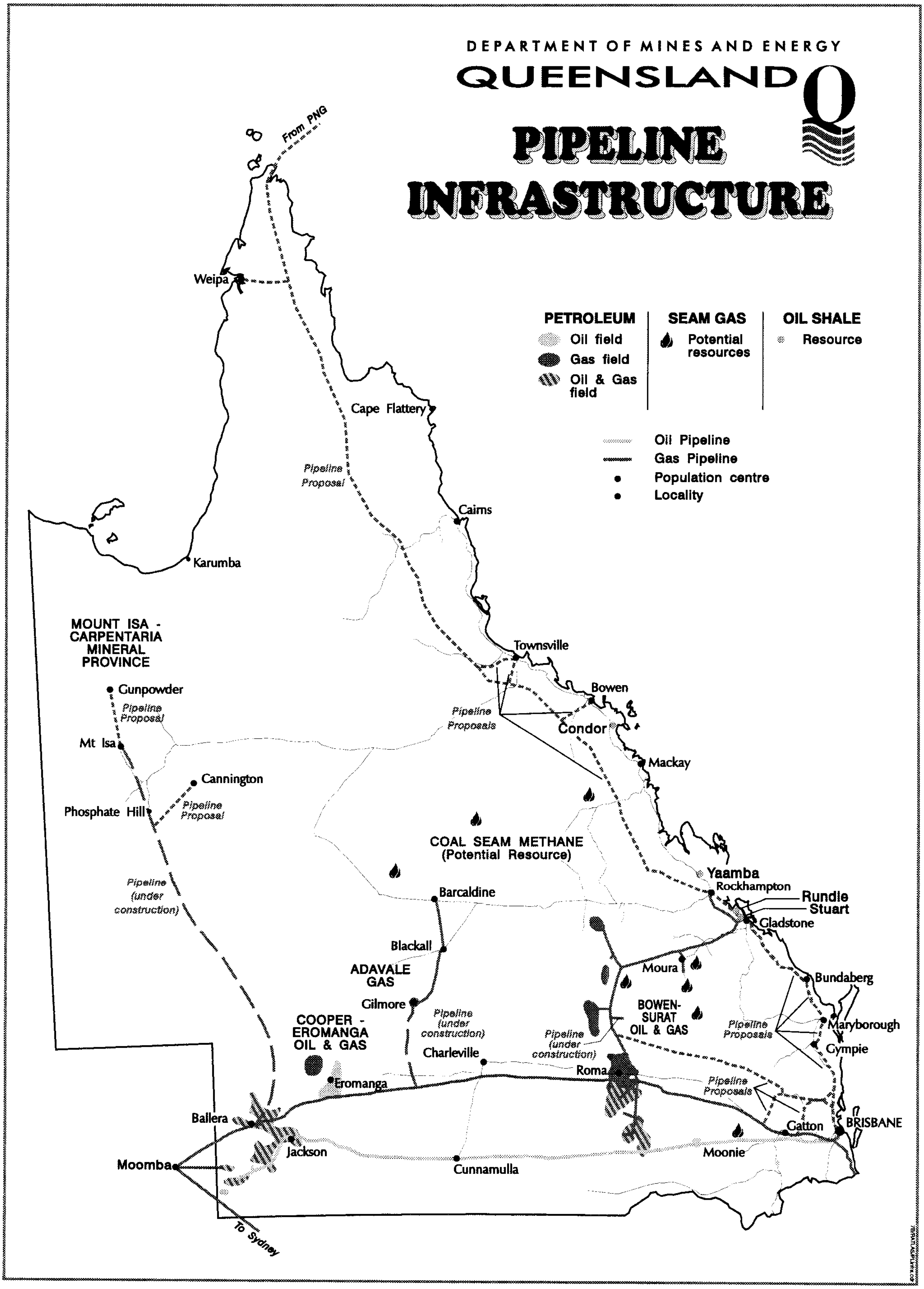
DEPARTMENT OF MINES AND ENERGY
QUEENSLAND
PIPELINE INFRASTRUCTURE
PETROLEUM
Oil field
Gas field
Oil & Gas field
SEAM GAS
Potential resources
OIL SHALE
Resource
Oil Pipeline
Gas Pipeline
Population centre
Locality
From PNG
Weipa
Cape Flattery
Pipeline Proposal
Cairns
Karumba
MOUNT ISA - CARPENTARIA MINERAL PROVINCE
Gunpowder
Pipeline Proposal
Mt Isa
Cannington
Phosphate Hill
Pipeline Proposal
Townsville
Bowen
Pipeline Proposals
Condor
Mackay
COAL SEAM METHANE (Potential Resource)
Pipeline (under construction)
Yaamba
Rockhampton
Rundle
Stuart
Gladstone
Barcaldine
Blackall
ADAVALE GAS
Moura
Bundaberg
Gilmore
BOWEN-SURAT OIL & GAS
Pipeline Proposals
Maryborough
COOPER - EROMANGA OIL & GAS
Pipeline (under construction)
Pipeline (under construction)
Gympie
Charleville
Roma
Eromanga
Pipeline Proposals
Ballera
Gatton
BRISBANE
Jackson
Moonie
Moomba
Cunnamulla
To Sydney

*Figure 1.*

available in quantity to ensure minimising costs of processing, sourced from rich deposits appropriately beneficiated before supply. In cases where material is imported, such as lateritic nickel and cobalt from Indonesia and the Pacific, the same requirements apply.

## Technology

Technology is most important, as it creates a competitive advantage which can be sustained if renewed and refreshed.

*Superiority*

The projects should incorporate technology superior to their competitors, either developed to meet specific needs in a research and development program, or purchased to incorporate current best practice available. There should be the potential for continuous improvements, in renewing the technology or development of innovative processes or approaches. Superior technology can also create a fundamental quantum shift in competitive positions with consequent improvement in performances. Without improvement, competitors will overhaul the methods initially adopted and on which success is dependent.

Government provides a powerful role in support and encouragement of research into innovative developments of superior technology with direct involvement in the Queensland Centre for Advanced Technology (QCAT) and the Queensland Manufacturing Institute (QMI) discussed later.

*Education and training*

There should be a skilled workforce, either available for employment on the project or capable of being trained in the appropriate skills to cope with the level of superior technology in order to maintain the project.

Relevant training should be available through courses offered pertinent to the industry, best developed as a cooperative effort in a client-provider association. Training should also be available for professional training for eventual management roles, for management skills and financial capability. Most important here is the need to encourage and reward science and engineering graduates to drive future processing industries.

*Market access*

There has to be access to markets to be able to realise appropriate sales. Market access can be difficult with tariff and non-tariff barriers faced by exporters. Australia has a history of exporting raw materials to overseas-based minerals processing industries. With increasing moves into processing, industry must be cautious in needlessly upsetting trading partners by attempting to export processed products into markets in competition with our raw material customers. As well, Australian Governments continue to encourage foreign governments to reduce tariff barriers to 'level the playing field'. It is hoped that success will eventuate. Meanwhile, processors may be able to alleviate some of these problems by investigating joint venture partnerships with overseas companies and encourage policy makers to lessen restraints on such ventures when it can be demonstrated that clear benefit accrues to Australia.

# PROCESSING INDUSTRIES INITIATIVES

There are a number of initiatives in which the private sector and Government have been active in attempting to attract private sector investment in minerals processing to develop industries which will add value and enhance employment prospects.

## Private Sector Role

Processing industries have developed in Queensland as a result of investment decisions by the private sector. Those decisions were based on the viability of the project, depending on a whole range of factors which impinge on the cost structures of the project. The main areas for minerals processing in Queensland have developed at central Queensland, centred on Gladstone, at Townsville and most recently, in the Carpentaria-Mount Isa minerals province of northwest Queensland. In this area, the recent mineral discoveries and the provision of infrastructure needs with a natural gas pipeline have added a new dimension to the potential for processing in that area.

## Government Role

State and Federal Governments are highly supportive of investments in mining, processing and refining of minerals, as it has been amply demonstrated that developments which these investments engender will further stimulate enterprises in processing and manufacturing industries, creating wealth through value adding to our abundant resources. The state is actively engaged in encouraging expansions of these industry sectors.

DTSBI's origins and involvement in manufacturing and processing industries come from the Queensland Government actively encouraging industry development from the formal beginnings of industrial assistance in 1929. This was in response to unemployment of the Great Depression. A history of those developments and Departmental evolution was given by Fitzpatrick (1981).

Industry policy was in place for directing the war effort in 1939-45, and specific developments were commemorated in a recent Departmental publication (Department of Business, Industry and Regional Development, 1995). More recently, governments maintained the industry brief through creating a specific industry department in 1963, the Department of Industrial Development, which has evolved to its latest form and appellation, the Department of Tourism, Small Business and Industry (DTSBI), but with a similar role in assisting manufacturing, commerce and industry. Minerals processing has been part of that role for almost 30 years.

At a federal level, DIST has had a brief for minerals processing involvement as part of its role. Each State and Territory government has an equivalent department or section of department devoted to over viewing minerals processing, all with the intention of promoting and encouraging the minerals processing industry.

There has been continuing liaison between representatives of all State governments and the Federal government, with a constituted Commonwealth-State Standing Joint Study Group operating since the late 1970s (Department of Industry Development, 1979) responsible for encouraging further processing of raw materials and for examining potential for industry establishment or expansion, and preparation of policy on assistance. Currently, the Commonwealth-State Working Group on Resource Processing meets bi-annually to resolve appropriate issues arising on minerals processing. One meeting each year is scheduled at a location with minerals processing industries, enabling delegates to maintain an industry liaison and experiencing first hand, industry set-ups, factors and issues.

***Department Role***

The Department of Tourism, Small Business and Industry's role is to advance the growth and development of not only minerals processing. It has an overall role of progressing business and industry throughout the state. The Service Delivery Division of the Department is responsible for, among other things,

- developing key industrial sectors;
- identifying business and investment opportunities in the industrial and service sectors; and
- facilitating investment in those sectors through the Operations sub-program of the Division.

The Department's involvement in minerals processing has primarily been on a project basis. Minerals processing is considered an important and key industrial sector which the Department has encouraged and serviced with a series of strategies. These have been developed and implemented to suit the projects, and include infrastructure planning, a range of incentives and assistance, support for strategic resource developments, for research and development, project promotion, and investigation of key mineral industry opportunities.

Key mineral industry opportunities include specific initiatives such as the currently developed Industrial Minerals Initiative, and the Mining Chemicals Investment Brief. This strategy is currently being developed to proactively identify and encourage mineral industry development opportunities not only in processing but also in resultant or integrated opportunities from mining through to manufacturing.

DTSBI's leadership and success in facilitating processing industries has been due to its ongoing successful liaison with industry, and active encouragement of industry participation. It has recognised that processing industries of minerals and chemicals are closely related and can develop their own synergy. Furthermore, it has also consistently sold the message over many years on the world stage, that Queensland had planned infrastructure, and general cultural, economic and political conditions conducive to welcoming investment.

## GOVERNMENT STRATEGIES, DIRECTIONS AND INITIATIVES

Strategic directions and initiatives in minerals processing and energy resource development have been developed by the Government from experience over many years as well as reference to and cooperation with other agencies. Specific examples of policies, plans and initiatives undertaken by DTSBI which are considered important and have impacted on value adding to Queensland's mineral and energy resources have evolved into the strategies discussed in some detail below.

### Infrastructure Planning and Development

Successful processing industries require an adequate and reliable infrastructure of water, power, integrated transport and port facilities, and serviced land. Planning for such infrastructure for future industries has been promoted as a whole of Government initiative, with active participation by DTSBI and the Co-ordinator General (COG) over the last three decades, with input from other lead agencies such as Treasury, Department of Mines & Energy from its extensive knowledge and commodity databases and energy responsibilities, the Department of Primary Industries and Department of Natural Resources (DPI and DNR) with water resources responsibilities, and Transport for integrated transport with Main Roads, Queensland Rail and the various responsible Port Authorities.

The assistance and willingness of agencies in Queensland to investment in infrastructure has been recognised as very supportive of project investment development. However, a major key to success was the decision as to where infrastructure should be provided, with a plan developed for an integrated array of infrastructure elements — gas, power, water, transport and land — being made available at selected key development sites. Directors in the responsible agencies were also confident that industry at sites such as Gladstone would most likely create a synergy of their own, developing a critical mass of processing activity which would attract other industry (personal communication, Grahame Baker, September 1997).

*Energy*

Representation on the Standing Committee of Cabinet on Planning and Infrastructure Co-ordination, the Queensland Energy Advisory Council, the Government Gas Committee and the Coalbed Methane Working Group has provided DTSBI the opportunity for input into energy-related decisions for the Government (Department of Business, Industry and Regional Development, 1992). Strong and consistent exploration and development results for Queensland's coal, oil, gas and oil shale resources form the basis for a strong energy sector.

*Coal and Electricity*

The abundance of thermal coal resources has allowed large increases in electricity generating capacity for driving the processing industry with competitive electricity prices, especially with the development of the aluminium industry in Gladstone. Developments in the coal industry infrastructure such as electrified rail, well developed port facilities and encouragement to invest, has in turn allowed the growth of the power generating industry.

However, future developments in the energy sector will be affected by deregulation of both the electricity and gas industries as recommended by the Hilmer Report on competition. It is anticipated that a free market regime may produce more competitive pricing structures than those currently in place.

*Natural gas*

The gas pipeline strategy was developed after consultants studies in the mid 1980s revealed that Western Australia and Victoria had greater development potential because of their gas resources, and industry was being attracted there (pers. comm. Grahame Baker). The Government Gas Committee with DTSBI representation at Director level initiated discussions with petroleum and gas explorers with a view to development of a gas pipeline network. This network would service primarily the Brisbane-Gladstone region, with a long term view of a connection for the Carpentaria-Mount Isa region. Currently, pipelines interconnect gas reserves from southwest Queensland to Mount Isa, east to Brisbane and service the Gladstone area and further north to Rockhampton. Spur pipelines also contribute gas from the Denison Trough in central Queensland and coal seam gas from the Bowen Basin coal resources.

It is proposed that there will be further interconnections and extensions of these systems. As well, there is a proposed line from Papua-New Guinea via Cape York to Gladstone currently under consideration, with potential to supply a proposed alumina refinery of Comalco in Gladstone and gas-fed power stations in far north Queensland.

The role of natural gas in the developments in Gladstone is discussed later.

*Water*

Access to water services are an essential requirement for processing industries. DTSBI has had representation on the water boards of the main development areas of the State, with input through the long standing membership of DTSBI ex-Director, Mr Grahame Baker, on the Gladstone Area Water Board for the central Queensland region, input on the Mount Isa Water Board for the Lake Julius regional water distribution, as well as planning contributions on the Burdekin Falls Dam program.

*Gladstone*

DTSBI representation on the Gladstone Area Water Board has enabled direct input into water needs for minerals and chemical processing, for smelting and refinery developments, and ensured that forward planning for building and developments on the Awoonga Dam accounted for volumes required for industry uses.

*Mount Isa*

The Department had input into the Mount Isa Water Board from the mid 1970s for the developments of the Lake Julius dam. Long term water resources planning was always required for potential growth in the Carpentaria-Mount Isa minerals province to ensure water needs were to be satisfied for major minerals and chemical processing projects, and the infrastructure study in the early 1990s of this region, the Carpentaria-Mount Isa Minerals Province Study (CMIMPS) confirmed those needs. The latest developments, such as the Ernest Henry mine and WMC's phosphate fertiliser production will benefit from that input.

*Land*

DTSBI has responsibility to ensure that suitable serviced land is available to meet Queensland's future industrial development needs. This was part of the intention of the original legislation for industrial assistance in 1929 (Fitzpatrick, 1981) and a network of Industrial Estates throughout the State has been developed in major metropolitan as well as regional centres. The Industry Location Scheme provides a land service which has evolved from schemes which originally incorporated factory building, servicing and financial incentives, progressing towards a currently developing system of commercialisation, more attuned to market demands.

Minerals processing industries in the Gladstone area have been located to date on DTSBI's industrial estates. The Department has provided major support for the Gladstone Industrial Land Study which has resulted in further reservation of a large area of land west of Gladstone at Aldoga as a State Development area suitable for major processing industries.

*Transport*

DTSBI has an involvement in planning for road and rail upgrades, ports and port loading facilities impacting on key industrial areas. A cost effective and efficient transport system network has been pursued by the Government. Input at the Director-General level with membership of the Standing Committee of Cabinet on Planning and Infrastructure Co-ordination has ensured that requirements of an integrated system for transport has been available for the processing industry, not only for the responsibilities of industrial estates but for all areas. There is a strong focus on commercial delivery for transport infrastructure across all methods and services.

## Support for Strategic Resource Development

DTSBI has recognised the importance of long term planning and provision of support for the development of strategic mineral and energy resources in this State. Two important development proposals were the Light Metals Centre, and the Steel Complex.

*Light Metals Centre Proposal for Gladstone*

A think tank of government and industry representatives developed the concept of the Light Metals Centre (LMC) about the early 1990s through investigating possibilities for future Gladstone developments. Details were fleshed by the Centre for Advanced Materials Processing (CAMP) with funds provided by the Premier's Department. Results of deliberations were recorded in 1992 and later reissued as a prefeasibility study (Centre for Advanced Materials Processing, 1994).

Strong support and assistance in infrastructure and facilitation were advocated for Gladstone to host processing of the light metal suite of aluminium, magnesium and titanium in the face of expected strong international competition for these industries. Queensland has significant and world scale deposits of the ores of these light metals. Bauxite from Weipa is mined for alumina and aluminium production in Gladstone; magnesite is mined from Kunwarara north of Rockhampton for magnesium metal as well as magnesia production; and ilmenite and rutile which contain titanium oxide occur in heavy mineral sand deposits in coastal dunes from north to south, Shoalwater Bay, Byfield, Middle Island, Hummock Hill Island and Agnes Waters, with ilmenite occurring inland at Goondicum near Monto, southwest of Gladstone.

Support for the light metals is crucial for Australia because of world wide opportunities in the die casting industries for automotive components (Department of Industry, Science and Technology, 1995a).

*Aluminium*

Queensland has a fully integrated aluminium industry, from bauxite mining, alumina refining and aluminium smelting. Alumina from the Queensland Alumina Limited (QAL) refinery in Gladstone is smelted at the nearby Boyne Island aluminium smelter, owned by Comalco (majority shareholder) and several Japanese companies forming Boyne Smelters Ltd. Aluminium metal is cast as ingots or alloyed and cast as billet; most is shipped to Japan or South-East Asia. In 1995, Comalco began work on the third potline, adjacent and parallel to the two existing reduction lines. The new line began production in August 1997, and will increase output from 240,000tpa to nearly 490,000tpa, making it Australia's largest and one of the largest in the world.

Some of the future plans for the aluminium industry were outlined in an aluminium foundry investigation funded by DTSBI (George Fisher Foundry Systems, 1995) which investigated hot metal transfer from Boyne Island smelter to direct alloying or casting industries, such as die cast components and engine blocks for the motor industry. Full investigations of aluminium and the automotive industry was outlined by the Department of Industry, Science and Technology (1995b).

If Gladstone is successful in securing Comalco's proposed alumina refinery with the decision on siting currently under consideration, and with increased alumina production with Alcan's Ely project at Weipa coming on line, then Gladstone will be the world's premier alumina-aluminium site and would further attract manufacturing industries.

*Magnesium*

Australian Magnesium Corporation Pty Ltd (AMC), a subsidiary of Queensland Metals Corporation (QMC) and the Normandy Group, is constructing a $73 million magnesium metal pilot plant at Gladstone, and is finalising investigations into a full scale plant for $800 million to produce some 90,000tpa of magnesium metal. Contractural arrangements have been made with the Ford Motor Company to supply 45, 000tpa for 10 years from the commercial operation. The project is based on a novel process developed by the CSIRO which promises to make the AMC project the world's lowest cost producer of magnesium.

Magnesium's potential lies in the metal's high strength, light weight, low ductility and other properties which enable the die cast manufacture of precision parts. Future industry potential currently being pursued by AMC is in establishing a die casting facility, with potential for die casting applications in the automotive and structural industries (Department of Industry, Technology & Regional Development, 1993).

Significant and positive Government support and assistance was provided with long term DTSBI representation at Director level on the industry-government formed Magnesite Task Force. As well, DTSBI provided seed funding to ensure the formation of CAST, the Centre for Alloy & Solidification Technology, a Co-operative Research Centre (CRC) now established at the University of Queensland at St Lucia and at QCAT, the Queensland Centre of Advanced Technology, at Pinjarra Hills.

Later a Magnesium Die Casting R&D Project was formed in the Department of Economic Development and Trade (DEDT), with Major Project Status being conferred on the proposal by the COG's Major Projects Committee in 1997. DTSBI provided facilitation for the construction of the magnesium metal plant on the Yarwun Industrial Estate.

Further research into manufacturing is provided by the Queensland Manufacturing Institute (QMI) which was an initiative of DTSBI, enabling development of rapid prototyping techniques and other related fields, thus providing support to innovative light metals developments.

*Titanium*

The original Light Metal Centre concept for Gladstone envisaged production of titanium metal from ilmenite sand mined from dune and beach deposits of heavy mineral sand from Shoalwater Bay, Byfield, Middle and Hummock Hill Islands and Agnes Waters.

A series of feasibility studies has been completed on titanium metal and titanium dioxide pigment production for the Gladstone area. Minproc Holdings Ltd, from which Ticor is derived, proposed in the early 1990s a 10,500tpa titanium metal plant adjacent to the company's sodium cyanide plant, using patented Ginatta electrolytic technology.

During the same time, Tioxide Australia Pty Ltd considered a 60,000tpa titanium dioxide pigment plant, drawing chlorine from ICI's chemical complex plant ( manufacturing sodium cyanide, caustic soda-chlorine, and ammonium nitrate in separate operations) on the Yarwun Industrial Estate for use in the chloride process.

Most recent investigations have been those of RZM into feasibility of a synrutile plant in Gladstone to process their Byfield ilmenite. Unfortunately the deposits of Byfield as well as those of the adjoining Shoalwater Bay area have been alienated by both Federal and State Government decisions on future land uses in those areas. Those decisions effectively halted considerations of titanium for the LMC at that time. However, future processing opportunities for titanium could eventuate from Monto Minerals' plan to investigate ilmenite processing after they have begun mining the Goondicum resource.

***Steel complex***

Steel making has been considered and investigated as a development strategy with the experience of facilitating proposals in the 1980s and '90s. Gladstone consistently has attracted attention as the prime steel manufacturing site because of a well developed infrastructure and international port facilities, the availability of coking coal, metallurgical grade limestone, as well as iron ore as titaniferous magnetite deposits west of the Gladstone and Rockhampton areas, and commercial ilmenite.

Further iron sources were investigated in the late 1980s for the various steel projects. There is a synergy in steel production with a synrutile plant, in that 50% byproduct of synrutile production is iron oxide, suitable as basic feedstock for the manufacture of carbon, special and stainless steels and ferro alloys.

*Gladstone Special Steel*

Gladstone Special Steel Corporation Limited, a consortium of the West German Ferrostaal and Theiss Contractors of Brisbane, proposed processing scrap steel in electric arc furnaces to produce high alloy and stainless special steels with continuous casting and rolling. Finished product was to be rod and bar. However, the project did not eventuate with Ferrostaal pulling out because of developments in the political situation in Germany with reunification.

Developments since that time with BHP ceasing production of stainless steels and changing market conditions appear to favour renewed interest in this type of project.

*China Steel*

Australia, Canada and Malaysia were considered in the late 1980s by China Steel of Taiwan for an overseas expansion of their conventional steel making, with Gladstone being chosen as the Australian site. China Steel made a decision in 1990 to proceed with the project in Malaysia. Gladstone could support the project at competitive costs, but Australia did not have the domestic market, resulting in the economics favouring Malaysia at that time. Subsequently China Steel shelved the Malaysian project and proceeded with a major expansion at its existing Kaohsiung plant in southern Taiwan.

The exercise in presentation of Gladstone as the site was valuable for Queensland in that studies undertaken for the project confirmed that Gladstone has the basic infrastructure and cost structures to support world class processing projects (Baker, 1991).

## Promotions

A major strategy for the Department has been world-wide promotion of Queensland's resources and processing capabilities through presentations on the current situation and potential for ongoing processing developments, and publication of that information.

***Presentations***

International interest in Queensland's potential for mining, minerals and chemical processing, and manufacturing industries has been encouraged by constant promotion at the highest level in government. This was enthusiastically carried out at Director and Principal Adviser level in DTSBI by the Department's representative until 1996, Mr Grahame Baker. These presentations and contacts were targeted at both domestic and overseas companies, at professional associations and at Government committees and bureaucracies through personal networking with strong professional and technical knowledge of the requirements which would encourage the private sector and the Government to invest in the State.

The theme is being continued with his successor, Mr Bob Gannon, and is repeated and replicated by other Departmental officers in their presentations and facilitation activities to overseas and domestic delegations and individuals, as well as by other government departments.

*Targeted presentations*

Targeted investment briefs with specific information on competitive advantages for locating in Queensland are produced for particular companies which may have expressed interest in investing in Queensland. This information, packaged as The Best Location series, provides the company with a case scenario which includes economic data, labour facts, infrastructure, available government assistance and possible site locations.

*Presentation papers*

Specific papers have been produced for conference presentations over many years. Most recently, papers promoting industrial minerals and ceramics in Queensland were published in the international journal, *Industrial Minerals*, and in a series titled *Mineral Industry Development Opportunities* produced by the Department, and in conference proceedings (Cooper & Baker, 1996; Cooper, Cullen & Baker, 1996a,b)

Industry booth presentations were given at conferences demonstrating the Department's involvement with processing of industrial minerals as part of the Industrial Minerals Initiative.

***Publications***

*Projects Queensland*

The hard copy backup for the promotional presentations has included the publications with information on progress in the processing industry in the State. "Projects Queensland" is the Department's major annual publication which provides the business community and the general public with authoritative information on the major manufacturing, minerals processing, mining, large scale infrastructure as well as tourism and traded services projects. Individual projects listed in the publication generally represent investments in excess of $10 million. Information presented is derived from company interviews and contacts as well as responses to a proforma questionnaire sent out by the Department. Three categories are used — projects under study, projects committed and those completed during the previous year. "Projects Queensland" has been published continuously since 1980 as "Major Development Projects and Proposals in Queensland" and is in high demand both throughout Australia and overseas.

*Business Opportunities Profiles*

A series of profiles are prepared each year to give an overview of the State's key industry sectors. Specific information has been compiled by leading industry specialists on market trends, structural changes, major corporate players and, most importantly, emerging investment opportunities within Queensland.

The profiles are sent out on international mailing lists to over 2000 companies and individuals. They are also provided to delegations, Queensland and Australian Government overseas offices, and targeted intending investors who may benefit from information for investment opportunities. One of those profiles is on the minerals processing industry.

All documentation of both the Projects Queensland and the Business Opportunities Profiles is on the Department's web page, http://www.dtsbi.qld.gov.au.

## Incentives and Assistance

DTSBI offers incentives and assistance to help in the establishment of major industrial projects in Queensland. Services include rapid response project coordination, targeted information packages to attract major projects, and financial incentives packages for certain major projects.

*Project Facilitation Services*

The Project Facilitation service is provided to clients whose projects are formulated into a specific opportunity which has established its pre-feasibility and which is considering a Queensland location. Services can include assistance in a state-wide site selection, discussions with infrastructure providers on supply capabilities and project requirements, advice and assistance on development approval processes at State and local government agencies, and assistance with management of State Impact Assessment Processes for environmentally significant activities.

*Investment Co-ordination Service*

The Investment Co-ordination service includes the provision of:

- advice on the Queensland investment environment to clients, including international business visitors;
- investors with information packages, including the Business Opportunities Profiles;
- facilitation services for joint ventures and strategic alliances with Queensland companies; and
- facilitation services for locating venture capital.

*Queensland Investment Incentive Scheme*

This scheme is targeted at projects which require a financial package of Government support to overcome some impediment to entry to the State or the market. The financial package can involve assistance with payroll tax and land tax, stamp duty and establishment and infrastructure costs. These incentives are subject to an application and a process of assessment by an Incentives Committee before successful applicants are made a formal offer of assistance.

## Support for Research and Development

The Government through the Department has an ongoing belief that Queensland industry has to attain world's best practice to be globally competitive. Research and development is one way to reach that target.

The Department is committed to assisting in promoting research and development through a series of innovative approaches, including sponsoring of QCAT, QMI, and developing a series of Technology Parks.

*QCAT*

QCAT was established in 1990 at Pinjarra hills in Brisbane as a co-operative venture between the CSIRO and the Queensland Government with the aim of developing a world class centre of excellence to expand and diversify research and development in the mineral exploration, mining, energy and related metals manufacturing industries.

CSIRO divisions operating as QCAT based Research Groups in Exploration & Mining, Coal & Energy Technology, Minerals and Manufacturing Science & Technology, have been co-located with a number of CRCs and specific research groups.

Magnesium has been of particular interest to DTSBI, with a major venture by industry, the Commonwealth Government and the Department in the form of the Australian Magnesium Research and Development Project (AMRDP), set up to establish a new industry based on Queensland's Kunwarara magnesite deposits, currently worked and developed by QMC.

Further developments have included the formation of CAST, the Co-operative Research Centre for Alloys & Solidification Technology, and the Magnesium Foundry Project.

CAST was formed to promote research in alloy design, solidification metallurgy and casting technology for aluminium and magnesium, through the collaboration of AMRDP, CSIRO, the University of Queensland, Comalco Foundry Products, Manufacturing Sciences and Technology and Australian Automotive Technology Centre.

Collaboration of CSIRO and AMRDP formed the Magnesium Foundry Project, to develop refining and casting technology for magnesium metal to commercial stage for ingot production.

The Magnesium Project and CAST will develop in conjunction with the advanced manufacturing technology of the QMI to advance a fully integrated magnesium metal and component industry for the State over the next decade.

*QMI*

To maintain and progress the connection between research and development in the minerals field to manufacturing end product, a research establishment was required. The QMI was set up in 1993 as a DTSBI initiative for developing innovation in manufacturing techniques. It is a joint venture between DTSBI, CSIRO, the Queensland University of Technology (QUT) and Queensland TAFE. It provides applied research and development facilities, technology support services and advanced technical training in manufacturing which is available to the manufacturing industry and can improve product development to best practice and state-of-art outcomes.

QMI's capabilities include stereolithography and rapid prototyping, development of prototype tooling related to injection moulding, squeeze casting, die casting and injection casting techniques, all of which can be applied to inventive developments and innovative improvements in tooling for processing industries.

*Technology Parks*

Science and technology parks are positive ways to develop a 'cluster' or 'hot spot' of companies dedicated to innovative ideas, world class research, technology development and commercialisation of new products. DTSBI has developed a technology park network which encourages new industry developments.

## Investigation of Key Mineral Industry Opportunities

DTSBI's approach to development of strategic manufacturing and processing sectors involves undertaking sectoral analyses to identify opportunities for investment.

Since the early 1990s, the Department has maintained a strong interest in development in the minerals processing consumables industry, recognising the interdependence of the chemicals and minerals processing industries. The most recent work in this area identifies project specific investment opportunities which are being target marketed to international chemical companies. Similarly in the area of industrial minerals, DTSBI has over recent years undertaken a comprehensive investigation of a range of projects from resource opportunities to manufacturing activities.

*Mining Chemicals Opportunities Initiative*

A study on the investment opportunities in the minerals processing consumables industry was commissioned by the Department in 1991 (Department of Business, Industry and Regional Development, 1991). Minerals processing consumables were defined in the study as chemical products and explosives. The report by Minproc Engineers Pty Ltd identified a range of manufacturing opportunities for chemical components for the minerals processing industry, with possible import substitution and export potential strongly featured. The study included methods of manufacture, the balance of supply and demand, competition, environmental considerations and prospects for Queensland manufacture. Priorities were accorded to a number of opportunities which fitted the study's criteria.

At the time of the study, conditions were not suitable for pursuing most of those priorities. However, progress in development of the Carpentaria-Mount Isa minerals province with its important base metal deposits and the gas pipeline to Mount Isa to service those developments has acted as a catalyst for action. DTSBI invited stakeholders in the chemical, minerals processing and mineral industries to revisit and review the priorities in 1996 and 1997 in examining specific chemical consumables. Based on this input from industry specialists and market intelligence, key opportunities were identified in three principal areas — flocculants, carbon disulphide and sulphur based chemicals. Detailed Project Investment Briefs have been developed to encourage investment in local production.

The flocculant study has progressed to the stage where interested companies are assessing market conditions for a suitable entry point to begin production. One application being considered is for flocculating suspended clay from Australian Kaolin NL's proposed Skardon River Kaolin Project north of Weipa.

The Project Investment Briefs and market opportunities presentations for carbon disulphide ($CS_2$) and sulphur-based chemicals are progressing.

$CS_2$ is an important feedstock for producing xanthates, which in turn are used in froth flotation for separating sulphides and gangue in base metal processing to produce sulphide concentrates. However, $CS_2$ is a difficult chemical to handle and transport, so that xanthates are best produced in conjunction with the $CS_2$ plant.

Sulphur-based chemicals such as sulphites, sulphides, bisulphites etc. have a wide range of applications including minerals processing, agricultural chemicals, pulping for paper manufacture, tanning and food container sterilisation.

The raw materials for $CS_2$ and sulphur-based chemicals include natural gas, sulphur from sulphides or natural gas, sulphuric acid from smelter gases, ammonia produced from natural gas, and caustic soda. Most or all of these are, or will be, available at a number of sites — Mount Isa, Townsville, Gladstone, as well as Brisbane, each with its own advantages. It bodes well for Queensland development opportunities that not only are the raw materials available, but markets are evolving with mine developments both domestically and in southeast Asia.

*Industrial Minerals Initiative*

The Industrial Minerals Initiative was established to expand and diversify mining, minerals processing and manufacturing using the State's industrial minerals resources.

A preliminary study in 1995 of the industrial minerals industry revealed that most opportunities for growth in Queensland would be realised from ceramics, absorbents, abrasives, fillers, pigments, agriculture and construction industries, with concentration on import substitution and value-adding.

Key business opportunities were identified and formulated as part of ongoing study into the strategies to further develop the initiative. The opportunities were recognised as three distinct segments - the physical elements of mining, processing, and associated manufacturing, the intellectual requirements of research and development as well as education and training, necessary to support the physical elements, and the market elements of identifying opportunities for investment, for import substitution and export growth, and of promoting the initiative objectives.

A review of the individual opportunities within the physical elements and intellectual requirements revealed that a significant number were mainly concerned with the ceramic industry, with emphasis on specialist clays (especially kaolin), on clay bodies, and on refractories based on magnesite, alumina and zircon.

Further studies, including a scan of interested industries and the results of DTSBI networking with industry specialists, confirmed the importance of the ceramic industry as being an engine for processing and manufacturing developments. Prioritisation of opportunities elevated the porcelain and refractory sectors to head a list of prospective investigations.

Earlier studies showed container and flat glass sectors of the glass industry (unpublished DTSBI report) did not offer opportunities for expansion and was not an important priority for Queensland development at this stage.

Consultants are currently progressing Project Investment Briefs on the porcelain and refractory opportunities with a view to marketing findings to industries targeted in the original scan.

## KEY DEVELOPMENTS

The largest and most important developments in the minerals processing industry in Queensland have been the establishment and ongoing development of Gladstone as a major industrial site, the renewal of interest in the Carpentaria-Mount Isa minerals province of northwest Queensland with a range of new mineral discoveries, and the associated smelting and refining operations and developments in zinc, copper and nickel-cobalt processing in Townsville.

Developments outside these nodes occur around Gladstone in central Queensland, in the Brisbane region of southeast Queensland, in southwest Queensland, in north Queensland around Townsville and into Cape York Peninsula. Details of the projects discussed have been published in the Projects Queensland series (1980 to 1997) of DTSBI, in the Queensland Minerals and Energy Review series (1992 to 1997) of DME, and in annual reports of DTSBI and DME.

### Central Queensland Projects

Gladstone as well as the adjoining Calliope Shire is the centre of industrial developments in central Queensland, but increasingly important developments are occurring outside the original area of industrialisation. Gladstone has attracted a range of minerals processing industries such as aluminium smelting, alumina refining and chemical production based on its mineral and energy resource base, significant industrial and urban infrastructure and the advantage of a natural deep water harbour of Port Curtis.

However, the development of Gladstone has only occurred since the 1960s, with two major decisions acting as the catalyst. They were the signing in 1960 of the first Japanese contracts for the supply of 500,000tpa of Kianga coal from the Bowen Basin which were to be shipped through Gladstone, and Comalco's decision in 1963 to construct the world scale alumina refinery to process bauxite from Weipa (Baker, 1991).

The major processing developments were minerals processing, but with increasing availability of natural gas and coal seam gas, chemical processing for the mining industry is becoming more important.

*Natural gas*

Gas stands as the next catalyst for increased industrial developments for Gladstone and central Queensland, including its role as a source of energy as well as a chemical feedstock. The building of natural gas pipelines to Gladstone and Rockhampton has already proved to be a leverage for the next phase of development.

The 516km gas pipeline from Wallumbilla near Roma to Gladstone via the Denison Trough added a new dimension to the growth of process industries in central Queensland in the early 1990s, and the addition of the 756km South West Queensland Pipeline connecting from the Cooper-Eromanga Basin at Ballera in the southwest to Wallumbilla in 1996, and the extra coal seam gas has extended that further.

The Chevron proposal for a natural gas pipeline from Papua-New Guinea down through eastern Queensland would substantially open up many more processing opportunities.

QAL provided the base load , but the availability of gas ensured by Government encouragement and support for interested but reticent companies was instrumental in those companies committing to establishing their operations at Gladstone. ICI Australia Operations Pty Ltd (ICI) proceeded with the $80 million sodium cyanide and caustic soda/chlorine plant on the Yarwun Industrial Estate when assured that gas supply would be available. Gas provides methane feedstock for 25,000tpa sodium cyanide production. ICI also produces ammonium nitrate at the plant for explosives. BHP was planning a $230 million, 140,000tpa ammonium nitrate plant at Moura west of Gladstone in the Bowen Basin coal fields, but announced in early October it would not participate in the development but hand over to its partners in that venture, the Norwegian group Dyno Nobel (Courier Mail, page 25, 3 Oct 1997).

Further developments for sulphur-based chemicals for mining chemical applications as discussed above could benefit from siting in this area.

*Minerals*

Minerals processing has been advantaged as well by the introduction of natural gas and stands to benefit greatly if long term gas supplies are available for proposed future developments, such as the Comalco proposal for an alumina refinery.

*Alumina*

QAL is a consortium of four major aluminium producers - Comalco Limited, Kaiser Aluminium & Chemical Corporation, Pechiney Australia Pty Ltd and Alcan Queensland Pty Ltd. Some seven million tonnes per annum is processed at what is the world's largest alumina refinery, producing some 10% of the world's alumina from bauxite mined from Weipa on the western coast of Cape York Peninsula. Alumina production is distributed proportionally to the shareholding companies, but there are restrictions in the QAL agreement on final alumina uses.

Comalco has planned to expand its alumina production by building a new alumina refinery, with an initial production capacity of 1.0 million tpa, and for a fully expanded plant of some 4.0 million tpa. It will cost $1.5 billion to build the first stage, and $4 billion with the expansion. The extra bauxite will be derived from doubling mine production at Weipa. Comalco intends to enter chemical, abrasive and refractory markets as well as expanding aluminium production from the extended Boyne Island smelter and supplying smelters in Australia (Tomago and Bell Bay) and overseas.

The refinery proposal is currently Gladstone's and Australia's most sought after project. However, the site for the refinery has not been finally decided and will either be in Gladstone or Sarawak in Malaysia, where plentiful gas supply is available. The decision will depend mostly on availability and cost of natural gas. There is a proposed gas pipeline from

Papua-New Guinea by Chevron, which will also provide gas for a Townsville power station and other individual projects en route to Gladstone. As well, recent new gas discoveries in southwest Queensland which can be supplied through the newly completed network enhances the outlook for long term gas supply in Gladstone and should satisfy one of Comalco's concerns. Comalco expects to make its decision by December 1997.

Alcan South Pacific Pty Ltd is also planning to expand its alumina output by mining and shipping 2.5 million tpa bauxite from its planned Ely mine north of Weipa of which 1.8 million tpa will supply Alcan's share of QAL and 0.7 million tpa to Alcan's Aughinish Alumina Plant in Ireland.

*Magnesia*

Queensland Metals Corporation mines and beneficiates magnesite from their large open-cut mine at Kunwarara, 70km north of Rockhampton. The resource of cryptocrystalline magnesite, which includes the Kunwarara deposit along with its continuation into the adjoining Yaamba deposit, is the largest of its type in the world.

The beneficiated material is further processed into magnesia in caustic calcined, deadburned and electrofused forms at the QMAG plant at Parkhurst in Rockhampton. Gas for calcining is supplied from an extension of the pipeline from Gladstone. Off peak electricity supply is available for the electrofusing process.

Queensland Metals Corporation Limited, in conjunction with joint venture partners from both Government and private enterprise, has developed a range of applications for magnesite, magnesia and derived products. A series of business units has been created to deal with specific product-industry groupings.

At QMAG, the processed material is applied in deadburned and electrofused forms for refractory products for the steel industry. The refractories are considered to be a world bench mark for quality;

- ENVIROMAG has developed a range of magnesia based products for pollution control;
- FLAMEMAG has concentrated on production of flame retardant products;
- CEMAG has researched new forms of magnesium-based cements and various forms building products; and
- MAGMETAL has developed through to the Australian Magnesium Corporation as the magnesium metal project plant for Gladstone.

*Cement*

Queensland Cement Limited has almost completed its $300 million upgrade and expansion of the company's Gladstone cement manufacturing operations at the Fishermans Landing clinker plant. At 1.6 million tpa, the new plant will more than double QCL's existing production capacity at Gladstone. The developments will ensure upgrading of the company's limestone mining at East End to the west, and the new integrated rail line transport connection. This will replace the original slurry pipeline for ore transport. Silica sand from the company's Tannum Sands deposit south of Gladstone will be blended with limestone at the East End mine site before transport of the charge 30km to the plant.

The new clinker plant is designed to produce consistent high quality product for customers in northeast Australia, and provide significant export potential for markets in South-East Asia and the Pacific region. This development will also enable the company to phase out its existing south Queensland operation at the Darra cement plant in Brisbane, which depends on dredging the diminishing and contentious resource of coralline limestone in Moreton Bay.

*Oil Shale*

Southern Pacific Petroleum (SPP), its twin Central Pacific Minerals (CPM) and Canada's Suncor are building the Stage 1 oil shale demonstration plant on the Stuart oil shale deposit adjacent to the Yarwun Industrial estate just north of Gladstone. Estimated cost of the plant is $250 million. The demonstration plant is designed to extract hydrocarbon fuels of naphtha and low sulphur fuel oil from oil shale. Its processing capacity is designed to produce some 1.4 million barrels a year. On construction of the planned Stage 2, the plant will be producing over 20 million barrels of oil a year. The *in situ* resource of oil shale in the Stuart deposit is some 3.0 billion barrels at a 50 litre per tonne cut off grade.

***Chemicals***

**Ticor**, and its partner Dupont, are expanding the sodium cyanide plant for the gold industry of Australia the Pacific and southeast Asia at its Yarwun plant.

**ICI** is currently producing ammonium nitrate for explosives, sodium cyanide for gold mining and caustic soda/chlorine on the Yarwun Industrial Estate north of Gladstone. Raw materials are in part provided from natural gas.

Despite **BHP**'s exit from the ammonium nitrate project at Moura, it is expected the project will progress under Dyno Nobel.

## Mount Isa area projects

The Carpentaria-Mount Isa minerals province of northwest Queensland is one of the most mineralised regions in the world, particularly for copper, lead and zinc as well as silver and gold. The region is known to contain about 28% of the world's known lead and zinc reserves, 5% of the world's silver resources, 1.5% of the world's copper reserves and major phosphate deposits. Mining and processing of base metals has been conducted in the region for over 70 years based on the mining giant MIM at Mount Isa.

Although the Mount Isa Inlier and surrounding areas had been explored and prospected with moderate results, it was new geological modelling and remote sensing techniques which revealed a spate of major deposits in the late 1980s and early '90s of silver-lead-zinc and copper-gold across the field which reinvigorated interest in the area.

Investment opportunities have been identified with the developments in the Carpentaria-Mount Isa minerals province of northwest Queensland (Department of Tourism, Small Business and Industry, 1997).

### *Infrastructure*

The Carpentaria-Mount Isa Minerals Province Study was instigated as a joint industry and government initiative which concluded that significant infrastructure was needed to fully exploit the area's potential. Natural gas was recognised as the prime requirement for stimulation of minerals mining and processing. Construction began in 1997 on the 810km gas pipeline from Ballera in the southwest Queensland gas fields to Mount Isa. This will provide competitively priced energy for the northwest. The pipeline which is expected to be operational by April 1998 will allow the existing Mica Creek Power Station at Mount Isa to be converted from coal firing to a gas fired operation, allow upgrading of the power line from Mount Isa to Cloncurry for power input into the Ernest Henry mine development.

Completion of a $52 million, 110km water pipeline from Lake Julius to the Cloncurry area is also a significant addition to the infrastructure for mining in the region.

The Century Zinc Mine Project proposes to pump concentrates in slurry form via an underground pipeline, 300km from the mine site to the port of Karumba in the Gulf of Carpentaria. Slurry would be dewatered at the port and transferred by barge to ships offshore for export.

### *Mining operations*

Operating base metal mines in northwest Queensland include **Mount Isa Mine** (copper-lead-zinc-silver), **Hilton** (silver-lead-zinc), **Selwyn/Mount Elliott**, **Eloise** and **Osborne** (copper-gold) and **Gunpowder**, **Great Australia** and **Mount Cuthbert** ( cathode copper). Production figures are provided by the Department of Mines and Energy (1996).

Mount Isa is one of the world's largest mining and metallurgical complexes, producing copper anode, crude lead-silver, zinc and zinc-lead concentrates.

Anode copper is cast in the copper smelter which uses Isasmelt technology involving oxygen injection. Silver-lead and zinc ores mined from Mount Isa and Hilton are treated with flotation methods to separate lead and zinc concentrates, the lead smelter processing the lead-silver concentrates in Mount Isa to crude lead-silver cast ingots. Copper anode and lead ingots are railed to Townsville, the copper refined in Townsville at MIM's Stuart Copper Refinery, the lead shipped to Europe for refining and further processing. Zinc concentrates are sold on the open market.

Selwyn/Mount Elliott, Eloise and Osborne have on-site treatment facilities to process their copper-gold ore using conventional flotation methods to produce sulphides concentrates. Currently these are shipped for further processing through Townsville.

The Gunpowder, Great Australia and Mount Cuthbert mines produced cathode copper by using solution extraction and electrowinning technologies (SX-EW). At Gunpowder, the operation involves *in situ* and surface heap leaching of copper, with the copper sulphate solution introduced to electrowinning tanks. The future preferred processing route is to produce copper concentrate which then would be leached in agitated tanks to produce high grade copper solution for electrowinning (Department of Mines and Energy, 1996).

*Development projects*

Most developments are for base metal mines. The fertilizer and cement proposals for industrial minerals are the exception.

*Base metal projects*

The **Ernest Henry** copper-gold deposit north of Cloncurry, an MIM/Savage Resources joint venture, was opened in October 1997. Ore will be concentrated on site and transported to Mount Isa for smelting. As well, the **Enterprise Deep Copper Mine** of MIM at Mount Isa will be processed on site. The smelter will be progressively expanded to cope with increased production.

The **George Fisher** zinc-lead-silver deposit of MIM is some 23km north of Mount Isa, 3km north of Hilton. Feasibility studies are scheduled for completion by the end of 1997. Future production is expected with ore processed and smelted at Mount Isa.

**Cannington** silver-lead-zinc deposit of BHP Minerals Ltd is scheduled for commencement in late 1997, producing some 6% of the world's silver output. Concentrates from flotation methods will be shipped through Townsville, with zinc production expected for the Korea Zinc refinery currently under construction in Townsville.

**Century Zinc** near Lawn Hill northwest of Mount Isa, discovered by CRA and now being acquired by Pasminco Ltd, is a zinc-lead-silver deposit. It will annually produce some 7% of the world's zinc output. Ore will be concentrated by froth flotation to zinc and lead sulphides concentrates on site and slurried by pipeline to Karumba on the Gulf of Carpentaria for export for further processing to Europe.

Pasminco has also purchased the **Dugald River** zinc-lead-silver deposit northwest of Cloncurry from CRA. Currently the deposit is being evaluated for development.

**Lady Loretta** northwest of Mount Isa is a zinc-lead-silver deposit owned by Buka Minerals Ltd. Production from underground mining is expected in 1999 with ore smelted on site using Ausmelt Ltd technology.

The **Woolgar** (gold), **Trekelano** (copper-gold), **White Range** (copper-cobalt-gold) and **Westmorland** (uranium) deposits are also being evaluated. The **Young Australia** mine of Electrometals Mining Ltd was trialing a copper heap leaching set-up for an SX-EW operation. As well, Electrometals Mining Ltd in a joint venture with Mount Cobalt Mining Pty Ltd has installed an electrowinning treatment facility to process cobalt tailings from Mount Cobalt, 60km south, to produce an expected 200kg cobalt per day.

*Industrial minerals developments*

High analysis phosphate fertilizer project of Western Mining Corporation (WMC) is currently being developed to produce diammonium phosphate (DAP), monoammonium phosphate (MAP) and triple superphosphate (TSP) at Phosphate Hill, 130km southeast of Mount Isa.

High analysis fertilizer manufacturing requires the production of the intermediate phosphoric acid which is produced from sulphuric acid and phosphate rock. DAP and MAP are produced by reacting phosphoric acid with ammonia in two different ratios. TSP is produced by reacting phosphoric acid with phosphate rock. Annual production is expected to be 760,000 tonne in Stage 1 and 1,010,000 tonne in Stage 2.

The raw materials required are:

- phosphate rock mined from WMC's extensive Phosphate Hill deposit;
- smelter gases for the production of sulphuric acid from the copper and lead smelters at Mount Isa, from the proposed Qsmelt smelter at Phosphate Hill, and possibly from the Korea Zinc refinery in Townsville;
- natural gas used as feedstock for the ammonia plant via the pipeline from the Cooper-Eromanga Basin of south-west Queensland.

**Undilla Lime and Cement project** of Westgold Resources NL is being investigated for the feasibility of establishing a $76 million cement and lime plant at Mount Isa after the company identified a major resource of high grade limestone.

Limestone would be used as a smelter flux, a mine run-off neutraliser and for production of lime for use as a metallurgical reagent and waste-water neutraliser and cement. The project would service the major base metal mining developments in the region.

### Townsville Projects

Townsville has been the port for minerals export from the Carpentaria-Mount Isa minerals province and from the north Queensland hinterland.

*Smelting and refining*

The three major projects are for smelting and metal refining. Their Townsville locations are well sited for import of ores and for export of finished product.

*Stuart Copper Refinery*

MIM's **Stuart Copper Refinery** is Queensland's major processor of copper, refining anode copper from MIM's Mount Isa operations to high grade copper sheet for export through the Port of Townsville. The refinery is a world leader in electrolytic copper refining technology. Commissioned in 1959, the refinery was originally designed to produce cathode copper as well as a range of wire, rod and billet products for direct sale. Production capacity was 50,000tpa in the original design (Saint-Smith & Campbell Jenkins, 1962), but a series of extensions to the tank house has current production in the order of 175,000tpa. Studies into further expansions of the refinery have indicated that capacity will be increased to cope with increased copper concentrates production from northwest Queensland.

*Korea Zinc*

Korea Zinc, operating through its subsidiary as Sun Metal Corporation, has begun construction of the world's most technically advanced zinc smelting and electrolytic zinc refinery complex at Stuart, 15km south of Townsville, at a cost of $500 million. The plant is designed to operate as a custom smelter, treating zinc concentrates drawn from the Carpentaria-Mount Isa minerals province and base metal mines of north Queensland. BHP's Cannington project is expected to be one major source. The operation will add value to Queensland's zinc exports.

The capacity of Stage 1 will be 170,000tpa of zinc and 325,000tpa of sulphuric acid. Eventual capacity will be 350,000tpa zinc with a proportional output of sulphuric acid.

*QNI*

**QNI's** Yabulu plant north of Townsville produces high grade nickel metal and other high grade nickel and cobalt products by hydrometallurgical extraction of the metals from nickel silicate laterite ore. The plant has a capacity of 30,000tpa of nickel. The refinery sourced laterite ore from the Greenvale mine some 225km northwest of Townsville, then from Yaamba north of Rockhampton until 1993 with exhaustion of resources. Ore is now imported from Indonesia and New Caledonia, treating some 3.3 million tpa.

Efficiency of ore handling has improved with a $51 million dedicated facility at the Port of Townsville with strict controls for automatic train loading. This plant is using ammonia leach technology rather than the acid leach proposed for the Calliope Metals nickel and cobalt project in Gladstone. Each method reflects the chemical constituency of the nickel ores to be processed.

## OTHER DEVELOPMENTS

There are many developments in Queensland outside the nodes detailed as Key Development Areas. These are discussed under commodity headings, as there are a number of projects within a commodity grouping located across the State, but with generic processing methods. These industries and specific projects are also discussed in some detail in Projects Queensland (Department of Tourism, Small Business and Industry, 1996b; 1997a), Cooper, Cullen & Baker (1996a, b) or in DME publications such as the Minerals and Energy Review series, Queensland Government Mining Journals, and those concerning mineral commodities.

***Bauxite***

*Weipa bauxite*

The main bauxite deposits in Queensland are those in the Weipa district on the west coast of Cape York Peninsula. Mining leases are held over deposits around Weipa by Comalco, at Ely, 25km north of Weipa by Alcan, and at Aurukun 120km south by Pechiney. Only **Comalco** is mining bauxite.

Bauxite is mined by front-end loader, transported to the processing plant where it is beneficiated by washing and screening to remove quartz and clay particles, then stockpiled in various grades. The company produced over 9Mt of beneficiated bauxite, most of which is shipped to QAL for refining in Gladstone, and some to an alumina plant partly owned by Comalco in Sardinia.

About 250,000tpa of beneficiated bauxite is sent to Korea for aluminium trihydrate production for use in ceramics, as a paper filler, and as a fire retardant. In addition, up to 150,000tpa is calcined on site at Weipa by firing in a diesel fuelled rotary kiln at a range of temperature settings to manufacture various calcined grades. Most is exported for use in abrasives and in refractories.

### *Silica and mineral sands*

#### *Silica sand*

Almost 3.0 million tpa of silica sand is produced in Queensland with a value of about $30 million. Production was mainly from Cape Flattery, the largest silica sand mine in Australia, by **Cape Flattery Silica Mines Pty Ltd**, and North Stradbroke Island by **ACI Industrial Minerals**, with lesser amounts from Moreton Bay from **Industrial Sands (Qld)**, Ningi just north of Brisbane by **Southern Pacific Sands Pty Ltd**, Coonarr near Bundaberg from **Bundaberg Metal Industries Pty Ltd** and **Eastern Smelting (Qld) Pty Ltd**, and Tannum Sands south of Gladstone by **QCL**.

Sand is usually worked by endloader or dredged, then transported to a processing plant. Organic matter or oversized material is screened, then sand is wet processed in a stationary mill to remove heavy minerals, and stockpiled after cyclone treatment to remove excess water. Further treatment may involve sieving to size material or to remove shell matter, and drying in a rotary kiln to remove all moisture. Most is exported or used domestically in the glass, foundry and chemical industries. Tannum Sands material is used for cement manufacture.

#### *Heavy mineral sands*

**Consolidated Rutile Limited** (CRL) is the major mineral sands miner in Queensland, producing concentrates of titanium bearing minerals, ilmenite and rutile, and zircon concentrates from their leases on North Stradbroke Island. The mineral-bearing sand is mined by hydraulic cutter-suction dredge and the heavy fraction is concentrated in an onboard plant using cones and spirals.

Mineral concentrates are barged across Moreton Bay to the company's dry separation plant in Brisbane. The concentrate is split into its component mineral fractions using magnetic and electrostatic methods which are bagged or sold in bulk. Almost all the rutile and ilmenite are exported for titanium white pigment production, with some run-of-mine material used for abrasive blasting. Zircon is micronised to zircon flour in the company's Brisbane plant for ceramic uses. Most is consumed by the joint venture partner in ceramics, SEPR Australia.

Currumbin Minerals Pty Ltd processes heavy minerals concentrates with electrostatic and magnetic methods at Currumbin from their NSW operations and spot sells separated rutile, ilmenite, and zircon concentrates. The company also processes zircon for the ceramics industry, with research and development into zircon-based ceramic products.

### *Ceramics*

Minerals processing in the ceramic industry involves clay preparation in the traditional field of structural clay, and more sophisticated treatment for advanced ceramics.

#### *Structural clay*

Clay preparation for brick and paving can involve open cut mining of clay and shale material from a number of different operations, transport to the central works site, and crushing and blending materials in set proportions for the specific prepared clay bodies. In an automated works, the blended material is vacuum extruded as a clay column, then wire cut to units which are automatically stacked on a kiln car, fired in a tunnel kiln, cooled and stacked for transport.

Southeast Queensland production accounts for over 70% of the State's total, with production dominated by four main manufacturers, **PGH**, **Boral**, **Austral Bricks** and **Nubrik** with plants in Brisbane, Ipswich, Cooroy, and Toowoomba. Other production occurs mainly at Bundaberg (**Wide Bay Brickworks Ltd**), with smaller works at Rockhampton, Mackay, and Townsville areas. The small but strong pottery manufacturing sector is located mainly in southeast Queensland.

#### *Advanced ceramics*

**SEPR Australia** is Queensland's main advanced ceramics operation in Brisbane, casting monolithic zircon-alumina ceramics (ZAC) shapes for refractories and abrasive resistant applications. The major raw materials for ZAC are zircon from the CRL's adjacent mineral sand processing plant, and alumina from the QAL alumina refinery at Gladstone. The technology involves electro-fusion of the alumina and zircon at high temperature for casting into specific shapes for their particular application.

Applications include the manufacture of the unique cruciforms for heat exchange systems for glass furnace regenerators and wear resistant ceramics for applications in the mining industry, for linings in processing plants, shiploaders and power stations.

### *Absorbent clays and minerals*

*Bentonite*

Bentonite clay is selectively mined for different grades of product then processed at the mine site by spreading for drying, dried further in a rotary kiln, and packaged for dispatch. Major markets for bentonite are for binding stockfeed, for drilling mud for the oil and gas industry, for foundry moulding sand, for sealing, diaphragm wall construction and waste containment and in ceramics.

**Australian Bentonite Ltd,** owned by Commercial Minerals Ltd as part of the Normandy Group, operates Australia's largest bentonite mine and processing plant at Gurulmundi, 350km west of Brisbane. The capacity is 120,000tpa of bentonite products. One specialist use approved only for Australian Bentonite Ltd is for an approved animal stock medicine.

Smaller producers are **Idemitsu South Queensland Coal Pty Ltd** (Ebenezer Mine, southeast of Rosewood) and **Jeebropilly Open Cut** coal mine (southeast of Rosewood), **United Minerals Corporation**, formerly Queensland Bentonite and **Miles Bentonite** in the Miles district, and **PCP Douglass Pty Ltd** at Yarraman, all processing moderate amounts of bentonite mostly for stockfeed, pelletisers, binders and absorbents.

*Other absorbents*

Diatomite: Diatomite is worked by **Mount Sylvia Mining Pty Ltd** at Black Duck Creek, about 100km southwest of Brisbane in a small open cut operation. The mined lump material is calcined in a gas fired rotary kiln, then crushed, sized and packaged for dispatch.

**Siliceous kaolinite**: A highly leached kaolinite and opaline silica rock with excellent absorbent qualities is worked and processed by **Queensland Kaolin Mines Pty Ltd** (trading as Ausorb) of Duaringa west of Rockhampton. The material is processed by opencut mining, then calcined in a gas fired rotary kiln. The company markets the material for pet litter and industrial absorbents.

### *Kaolin clay*

Kingaroy Kaolin operates a relatively small plant of about 15,000tpa capacity using kaolin from deposits worked by Nyora Mining around Kingaroy, about 200km northwest of Brisbane. The clay is blunged, degritted, filter pressed then reconstituted in slurry form or dried and pelletised for packaging. Four core products are traded under the 'Kingwhite' tradename, for the filler and coating market, and for applications in ceramics.

### *Limestone*

Limestone is mined mainly for the cement industry, with other uses in lime production, the alumina industry and as a pigment and filler.

*Cement*

Cement is produced from a blended mixture of limestone, ironstone, clay and silica sand fired in a rotary kiln fuelled on gas to form clinker, which in turn is crushed, then blended with limestone and gypsum to form cement.

Queensland Cement Ltd (QCL) has plants in three coastal locations. The largest of these is the Fishermans Landing plant at Gladstone which is serviced by the company's East End quarry, the largest limestone operation in Queensland. The next is QCL's Darra works where limestone derived from two fossil coral reefs in Moreton Bay is dredged and barged 55km up the Brisbane River to the Darra plant for cement manufacture.

The QCL Rockhampton plant trading as **Pacific Lime** manufactures lime and speciality white cements using limestone resources from their Mount Etna mine to the north of the city and is investigating magnesite as a magnesium cement source.

*Lime*

David Mitchell Limited is a specialist lime manufacturer, with plants all around Australia. Lime kilns at Townsville and Ootann in northern Queensland service the needs for lime in the mining and sugar industries. The company has most of the limestone operations in southern Queensland, mining and processing limestone for the agricultural industry, glassmaking and for stockfeed. Lime is manufactured by firing limestone to drive off $CO_2$, leaving CaO or quick lime, or further treated with water forming slaked lime [$Ca(OH)_2$].

**Frost Enterprises** mines a high quality limestone at Taragoola, 25km southwest of Gladstone. The limestone is railed to the QAL alumina refinery for lime manufacture for use in the Bayer process.

*Pigments and fillers*

Omya Southern operates a mine of very high quality white limestone at Bajool northwest of Gladstone. This material is crushed to a fine white powder and shipped to Geelong in Victoria for reprocessing for white pigments mainly in paper coating.

## FUTURE PROCESSING OPPORTUNITIES

There are a number of development opportunities described below which are in the proposal stage. Some of these proposals illustrate the growing connection and synergies which are developing with access to resources.

### Processing proposals

*Nickel and cobalt refining — Calliope Metals*

**Calliope Metals** is approaching final approval for a $460 million nickel and cobalt refinery sited on the Yarwun Industrial Estate. The project will use Sherritt technology for high pressure acid leaching of imported New Caledonian, nickel-rich lateritic ore. The initial plant configuration will involve a single autoclave processing 1.2 million tpa dry laterite ore to produce 38,000tpa of mixed sulphide intermediates containing 20,000t nickel with 2000t cobalt. The sulphuric acid required for the leaching process will either be produced by burning imported sulphur or obtained from smelter gas sources about to come on stream. The plant will be extended to produce refined nickel and cobalt metal by chemical precipitation.

*Qsmelt*

A number of proposals have been suggested for constructing a second copper smelter in the Mount Isa region. However, **Queensland Minex NL**, a subsidiary of Mineral Commodities NL who are developing the Trekelano copper-gold deposit, has progressed the proposal to an Initial Advice Statement. The proposal is for a copper smelter at either Phosphate Hill or the Cloncurry area to service the regional producers of copper concentrates, Selwyn, Osborne, Eloise and Trekelano (by 1998) for the production of copper matte (63% copper) and slag.

Exhaust gases would be ducted to an acid plant to produce commercial sulphuric acid which could be made available as a feedstock for phosphate production at the WMC phosphate fertilizer project, for regional SX-EW copper producers, or BHP Minerals for the Cannington Project.

*Titanium*

The concept of production of titanium metal from ilmenite sources in central Queensland as developed in the original LMC strategy proposal for Gladstone is now more feasible than in the early 1990s.

Metallic titanium production requires pure titanium pigment and metallic magnesium. Cost effective production can be managed if a plant were to operate in synergy with a magnesium plant and a pigment operation. The magnesium plant is now a reality at Gladstone, and the Goondicum resource has the potential to support a synthetic rutile plant and a consequent pigment operation.

A synrutile plant produces $TiO_2$ with low iron oxide impurity from ilmenite. The synrutile is converted to $TiCl_4$ or 'tickle', which is oxidised to produce pure white titanium dioxide pigment, or can be used to produce titanium metal by reducing $TiCl_4$ with metallic magnesium. The next step required for titanium metal production is to encourage pigment production in Gladstone.

**Monto Minerals NL** has identified a large ilmenite resource derived from the weathering of titaniferous magnetite associated with gabbro of the Goondicum crater and alluvium of the upper Burnett River derived from that feature. The ilmenite resource has the potential to be a suitable feedstock for a synthetic rutile plant and for pigment production. As well, dune and beach deposits of heavy mineral sand from Middle and Hummock Hill Islands, and Agnes Waters in central Queensland could still be available, even though those of Shoalwater Bay and Byfield are now alienated. Material is also available from CRL's North Stradbroke Island operations off Brisbane.

*Aluminium Fluoride project*

Depco-TRH Pty Ltd plans a $100 million project with the main focus on fluorine technology. It involves the integration of three major components — a 30,000tpa spent potlining plant, a 50 megawatt gas turbine, and a 50,000tpa aluminium fluoride plant. Fluorine chemicals from the recycling of spent aluminium smelter potlining from the NSW smelters at Tomago (Pechiney-CSR) and Kurri Kurri (Capral, formerly Alcan), along with imported calcium fluoride and sulphuric acid from smelter gases, are part of the input for the manufacture of aluminium fluoride ($AlF_3$). Aluminium fluoride is added to the electrolytic bath for aluminium smelting.

Fluorine technology developed in this process can then be used to produce ultra clean coal (UCC) by chemical removal of mineral matter (ash). The UCC is fired in an aero-derivative industrial gas turbine for cogeneration of power. It can also be used for cathode block and anode manufacture for aluminium smelters. Excess waste heat from this process can also be directed to synergetic industrial uses.

*Skardon River Kaolin*

The Skardon River kaolin deposit is about 100km north of Weipa. Estimated resource of *in situ* kaolin and sandy kaolin is about 53 million tonnes. The proposed plant will have a 200,000tpa production rate with further proposals for 400,000tpa in Stage 2. The operators, **Australian Kaolin NL**, have established an operating pilot plant at Cairns, with plans to have commercial quantities available before the year 2000.

Production will be of high quality, high brightness water-washed kaolin and calcined kaolin for the Asian paper coating markets.

*Ely bauxite*

Alcan South Pacific Pty Ltd proposes to mine its leases at Ely north of Weipa to produce its own beneficiated bauxite to supply its proportion to the QAL refinery and also for Aughinish Alumina Limited in Ireland. Material will be mined by open cut, beneficiated and exported through a new off-shore port facility.

## Further proposals

Incited Ltd, the fertilizer manufacturer, has just completed the ammonia plant uprate at Gibson Island in Brisbane, using natural gas as feedstock. As well as producing prilled urea and high analysis phosphate fertilizers, the plant supplies ammonia to the ICI chemical plant at Yarwun for ammonium nitrate production. The ICI plant has undergone expansion to increase ammonium nitrate output for mine explosives.

**Queensland Fertilizer Assets Ltd (QFAL)** will build a granulated urea plant at Wallumbilla 40km east of Roma using natural gas as feedstock. The plant will also manufacture anhydrous ammonia and ammonium nitrate.

**Balcooma** base metals project near Greenvale, northwest of Townsville, has resources of copper, lead and zinc which are being investigated for a possible open cut and underground operation. Treatment facilities would include an onsite concentrator to process ore using conventional flotation processing methods to produce a range of separate sulphide concentrates.

The **Mining Chemicals Opportunities Initiative** and the **Industrial Minerals Initiative** will generate future developments in sulphur chemicals and in ceramics respectively through the DTSBI-initiated investigations which are currently proceeding.

## CONCLUSIONS

Queensland has had success in developing and attracting minerals processing industries to the State because of an ongoing cooperative relationship between the private sector and the Government. The State and Federal governments have moved to address the issues which would enable minerals processing industries to develop. The most successful has been the provision of infrastructure in a culture amenable to industrial development, with support for initiatives as well as research and development.

Early success in Gladstone, Mount Isa and Townsville areas has been in refining and smelting projects. Renewed interest has occurred with the spectacular success in the discovery of new base metal deposits in the Carpentaria-Mount Isa minerals province, and the development of the natural gas fields and coal seam gas deposits which can supply energy as well as chemical feedstock.

The catalysts for the next stage will be the extension of the natural gas supply network to service the State, providing energy and feedstock for the significant new developments in Queensland, building up a synergy of interdependence which is creating the critical mass for a successful and vibrant minerals processing industry.

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## REFERENCES

AUSTRALIAN TRADE DEVELOPMENT COUNCIL, 1980: *Minerals processing. A comparative study of trade and related aspects affecting the further development of Australia's trade in processed minerals*. Australian Government Publishing Service, Canberra.

BAKER, G.L., 1991: Gladstone Queensland. An Australian success story for Raw materials processing. *In, Institution of Engineers, Australia, Central Queensland Conference*, Gladstone, September 1991.

BAKER, G.L., 1995: Industry development in Queensland. *In Proceedings of Third Australian Stainless Steel Development Association (ASSDA) Conference*, Sanctuary Cove.

CENTRE FOR ADVANCED MATERIALS PROCESSING, 1994: Light metal industries prefeasibility study. Centre for Advanced Materials Processing, Brisbane.

COOPER, W. & BAKER, G.L., 1996: Industrial Mineral Opportunities in Queensland. *In,* Mesozoic Geology of the Eastern Australia Plate Conference. Geological Society of Australia Inc., Brisbane - *Extended Abstracts* **Number 43**, 147--53.

COOPER, W., CULLEN, J.F. & BAKER, G.L., 1996 a: Queensland's industrial minerals - on top down under. *Industrial Minerals*, **343** (April), 85–107.

COOPER, W., CULLEN, J.F. & BAKER, G.L., 1996 b: Queensland's industrial minerals - on top down under. A review of materials and opportunities. *In* Cooper, W.(Editor) *Mineral Industry Development Opportunities. 1. Industrial Minerals in Queensland,* 1–22.

DEPARTMENT OF BUSINESS, INDUSTRY AND REGIONAL DEVELOPMENT, 1991: Investment opportunities in the minerals processing consumables industry in Queensland. Unpublished report produced by Minproc Engineers Pty Ltd for the Department of Business, Industry and Regional Development, Brisbane, June 1991.

DEPARTMENT OF BUSINESS, INDUSTRY AND REGIONAL DEVELOPMENT, 1992: Reference manual incorporating the Statement of Affairs. Unpublished document, Department of Business, Industry and Regional Development, Brisbane.

DEPARTMENT OF BUSINESS, INDUSTRY AND REGIONAL DEVELOPMENT, 1995: *Queensland industry at war*. Department of Business, Industry and Regional Development, Brisbane.

DEPARTMENT OF INDUSTRY DEVELOPMENT, 1979: *Annual Report Department of Industry Development 1978-79*. Department of Industry Development, Brisbane.

DEPARTMENT OF INDUSTRY, SCIENCE AND TECHNOLOGY, 1995 a: *The Australian die casting industry. Opportunities for growth*. A report prepared for the Department of Industry, Science and Technology by David J. Lewis & Associates Pty Ltd. Department of Industry, Science and Technology, Canberra, June.

DEPARTMENT OF INDUSTRY, SCIENCE AND TECHNOLOGY, 1995b: *Aluminium. Growth opportunities in the automotive industry*. A report prepared for the Department of Industry, Science and Technology by David J. Lewis & Associates Pty Ltd. Department of Industry, Science and Technology, Canberra, September.

DEPARTMENT OF INDUSTRY, TECHNOLOGY & REGIONAL DEVELOPMENT, 1993: *Magnesium. Opportunities for Australian industry*. A report prepared for the Department of Industry, Technology & Regional Development by David J. Lewis & Associates Pty Ltd. Department of Industry, Technology & Regional Development, Canberra, May.

DEPARTMENT OF MINES AND ENERGY, 1996: *Queensland Minerals and Energy Review, 1996-1997*. Department of Mines and Energy, Brisbane.

DEPARTMENT OF THE PRIME MINISTER AND CABINET, PRIME MINISTER'S SCIENCE COUNCIL, 1990: *Value-adding in the Australian minerals industry*. Papers presented at the third meeting of the Prime Minister's Science Council, Parliament House, Canberra, 29 October 1990. Australian Government Publishing Service, Canberra.

DEPARTMENT OF TOURISM, SMALL BUSINESS AND INDUSTRY, 1996a: *Business Opportunities. Mineral Processing Industry*. Department of Tourism, Small Business and Industry, Brisbane.

DEPARTMENT OF TOURISM, SMALL BUSINESS AND INDUSTRY, 1996b: *Projects Queensland. Major development projects and proposals in Queensland, Australia.* Department of Tourism, Small Business and Industry, Brisbane, Issue No.**16**.

DEPARTMENT OF TOURISM, SMALL BUSINESS AND INDUSTRY, 1997a: *Projects Queensland, Australia.* Department of Tourism, Small Business and Industry, Brisbane, Issue No.**17**. 1997–98.

DEPARTMENT OF TOURISM, SMALL BUSINESS AND INDUSTRY, 1997b: *Business Opportunities. North West Queensland Minerals Province.* Department of Tourism, Small Business and Industry, Brisbane (in preparation).

INNES, J.A., 1991: Adding value in the Australian minerals industry - impediments and opportunities. Presentation at *United Nations Industrial Development Organisation Conference (UNIDO)*, Adelaide, 3rd/4th December.

IRCC PTY LIMITED & CROOKS MICHELL PEACOCK STEWART (QLD) PTY LTD, 1987: Queensland resources. Problems, strategies and opportunities for development. Ircc Pty Limited & Crooks Michell Peacock Stewart (Qld) Pty Ltd, Brisbane.

FITZPATRICK, D.E., 1981: The Department of Commercial and Industrial Development. A brief history. Department of Commercial and Industrial Development, Brisbane.

GEORGE FISHER FOUNDRY SYSTEMS, 1995: Report on the light metals casting project at Gladstone, Queensland. George Fisher Foundry Systems, Brisbane.

ROBERT, J., 1991: The chemical industry - the missing link in minerals processing. *AIC Conference*, Sydney, March, 1991.

SAINT-SMITH, J.C. & CAMPBELL JENKINS, J., 1962: The design, construction and operation of the Townsville, Australia copper refinery. Presentation paper to the *Metallurgical Society of the American Institute of Mining Metallurgical & Petroleum Engineers* at their annual meeting, New York, February 1962.

WILDE, R.J., 1990 : Marketplace realities in adding value to Australia's minerals. *In, Value -Adding in the Australian Minerals Industry.* Papers presented at the third meeting of the Prime Minister's Science Council Parliament House, Canberra, 29 October 1990. Australian Government Publishing Service, Canberra.

**Reference for this paper:**
**COOPER, W., 1997: Minerals Processing in Queensland. *In*, Beeston, J.W. (Compiler): *Proceedings for the Queensland Development 1997 Conference*, 13-14 November, Brisbane, Department of Mines and Energy, 157–181.**