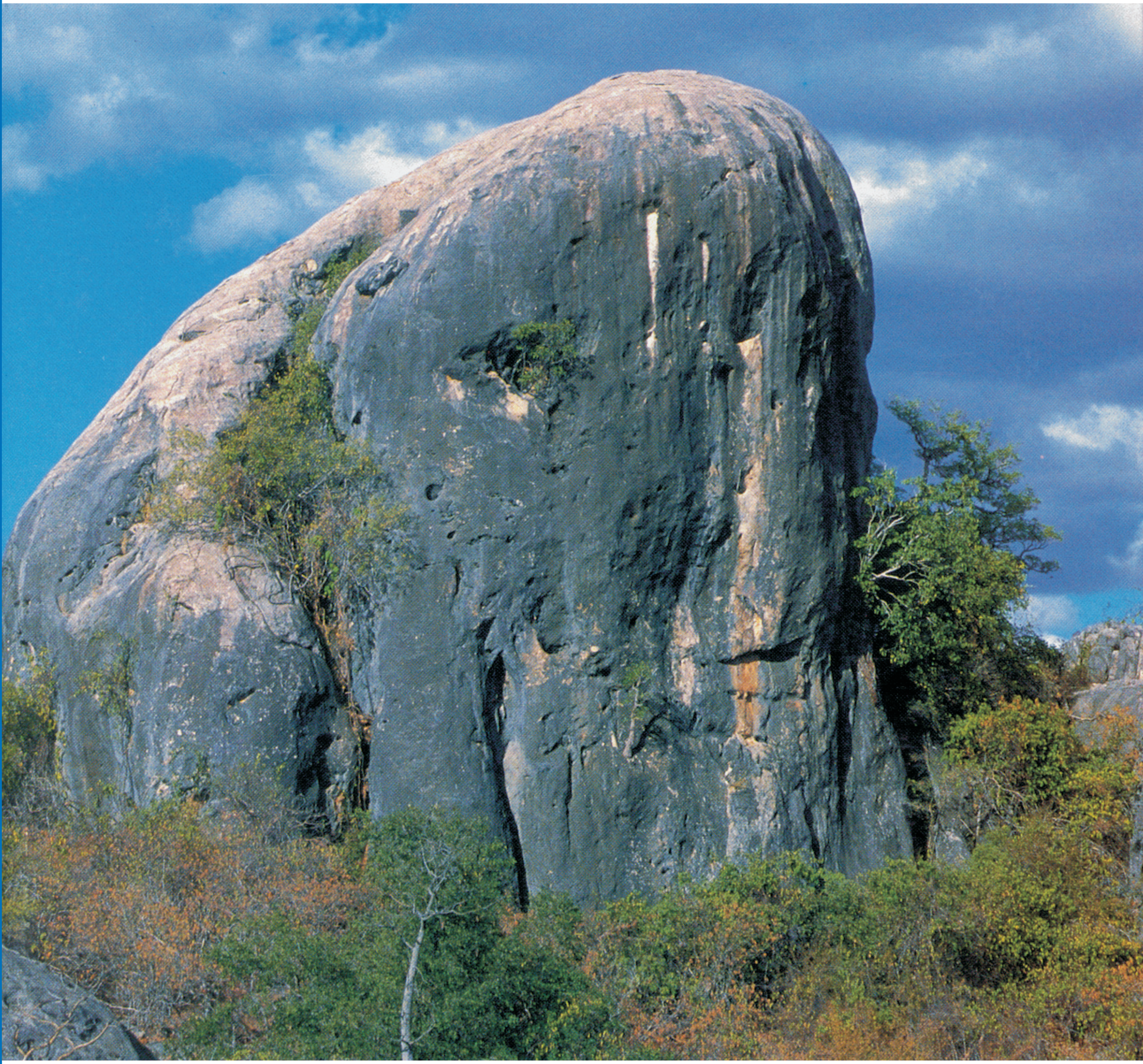
Rocks and Landscapes of the Chillagoe District

W.F. WILLMOTT and D.L. TREZISE



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Rocks and Landscapes of the Chillagoe District

by

W.F. Willmott and D.L. Trezise

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Cover Photo: Dome Rock east of Chillagoe town, a remnant pinnacle of marble (see excursion description).

THIS BOOKLET

Chillagoe is remarkable for its spectacular landscape of jagged limestone towers, and its extensive cave systems. This individual character is enhanced by its mining origins and often controversial history, with interesting remains such as the smelter site.

As might be expected for a mining district, it has a complex geological history, and there are many rocks, minerals and landscapes in addition to the limestones to interest the visitor. This booklet aims to give a straightforward, non-technical explanation for visitors wanting a basic understanding of the geological framework of the district, and how the mineral deposits. and landscapes, have formed. Several routes are suggested along which typical examples of the rocks can be seen. Some geological terms may be unfamiliar, but the glossary at the end should assist.

The booklet concentrates on rocks other than the limestones, as details on these and their caves are available from leaflets published by the National Parks and Wildlife Service, the 'Chillagoe Souvenir Guide' by Les Pearson, and issues of Tower Karst, the journal of the Chillagoe Caving Club.

The geological history presented here differs somewhat from that previously assumed for the district, as it incorporates the findings from current on-going research by the Department of Mines in the region, some of which are yet to be published.

THIS REPRINT

Since this booklet was compiled, certain new facts have come to light and interpretations of the origins of some of the rocks have been revised. It has not been possible to update the text and figures for a second edition, but the following changes should be noted.

In Section 1, page 1, the Nundah Granodiorite is now known to be considerably younger than the Dargalong Metamorphics, with an age of about 434 million years (earliest Silurian).

In Section 2, pages 3–6. The Chillagoe Formation and its limestone beds are no longer thought to have been deposited on a shallow continental shelf, with some of the limestone slumping down into deep water. It is believed that most of the siliclastic sediments were deposited in relatively deep water (below wave base) towards the western margin of the Hodgkinson Basin, which was being opened up by crustal extension and down-faulting. Basalt lava was also erupted on to the sea floor. However the limestone was deposited in shallow water on mounds and ramps on the summits of fault blocks, surrounded by deep water. The limestone and deep-water sediments have been brought into proximity by later compression and fault movements.

In 'Formation of the Mineral Deposits' on pages 12–13, it should be understood that the Ruddygore Granodiorite is not the only mineralising body, and it is used as an example only. Several phases of mineralisation have been noted in the Red Dome mine and elsewhere, although there is disagreement about which intrusions they are related to . At Red Dome the upper breccia is now believed to have resulted from explosive, intrusion-related mineralising fluids, and not from later surface collapse. The mine ceased production in 1998, and although other prospects were located, they did not prove economic.

In 'Where to See the Rocks', pages 20–26 it should be noted that the directions, accessibility and visibility of sites have not been re-checked and some may no longer be current.

HISTORY AND NATURE OF THE ROCKS

There are three main groups of rocks in the district. The oldest forming flat country southwest of Chillagoe, were formed many hundreds of millions of years ago as part of the ancient (Precambrian) Australian continent. The second, forming the hilly country around Chillagoe town itself (including the limestone bluffs) were sediments deposited in an ocean off the eastern edge of this continent about 400 million years ago; these have since been crumpled and raised above sea level. The third group, forming flat country with some rocky hills north and east of Chillagoe, are granitic rocks which cooled beneath the surface from molten magma that penetrated the Earth's crust about 300 million years ago. Some other minor rock groups occur locally. The extent of the main rock groups is shown on the accompanying map.

To understand the various groups of rocks present, it is best to trace their origins in sequence through the different episodes of geological history[1] in which they were formed.

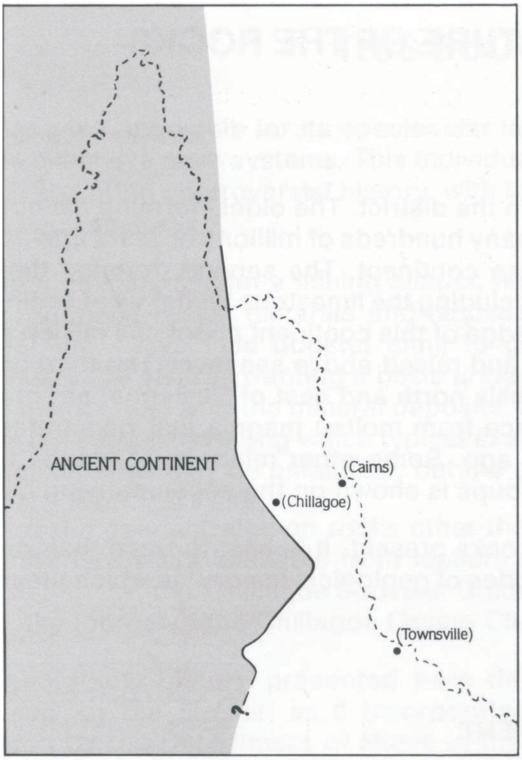
1. THE ANCIENT AUSTRALIAN CONTINENT

Before about 600 million years ago (in Precambrian times), the main eastern edge of the Australian continent was much further west than at present. It has subsequently grown eastward during several cycles of volcanic activity, laying down of sediments, and mountain building, possibly related to movements between the Earth's crustal plates.

Some of the very old rocks of this ancient continent can now be seen south-west of Chillagoe — the **Dargalong Metamorphics**[2]. These are metamorphic rocks (chiefly gneiss, schist and amphibolite) that have been recrystallised (changed) from sediments (and possibly some volcanic lavas and old granitic rocks), by intense heat and pressure deep within the earth's crust. Very little is known about their history, but the last main metamorphism (recrystallisation) is believed to have occurred about 1500 million years ago. The original sediments may have been considerably older. During this metamorphism, or possibly later, pods of molten rock (magma) formed deep within the earth's crust, and were squeezed upwards to higher levels, where they solidified slowly to form coarse-grained granitic rocks. Some of these can be seen south-west of Chillagoe — the '**Nundah Granodiorite**'.

1 As the vast span of geological time makes it difficult to visualise past events in a time frame we can comprehend, geologists have divided it into a number of Periods, with traditional names (eg. Devonian). It has not been possible to avoid these names entirely here, but the time scale included later in the booklet shows the Periods against millions of years before the present, and the geological events of the Chillagoe district superimposed.

2 Geologists group rocks of similar type and relative age into 'rock units' with formal names — these reflect the dominant rock types and the places where they are best exposed.



1. The old continent existing here at this time was composed of ancient rocks of Precambrian age. They were originally sediments, but very little is known about the conditions under which they were laid down, or how they came to be recrystallised to metamorphic and granitic rocks.

Dargalong Metamorphics — the rocks

Metamorphic rocks with a pronounced foliation (mineral layering) produced by minerals recrystallising in a preferred direction while under pressure.

- **Biotite gneiss** — Coarsely banded black and white rock composed of white layers of quartz and feldspar, black layers of biotite mica flakes, and locally, pink garnet grains. Large crystals of white feldspar up to 8 cm long common — these are called ‘augen’ (eyes).

- **Biotite and muscovite schist** — silvery grey, finely foliated (layered), with abundant mica flakes (black biotite, silver muscovite), and quartz and feldspar.

- **Amphibolite** — black to greenish black, fine to coarse grained, hard, compact, composed of dark hornblende and white plagioclase feldspar, with pink garnet grains common in places. Probably metamorphosed basalt lavas or dykes of dolerite that had penetrated into the surrounding sediments.

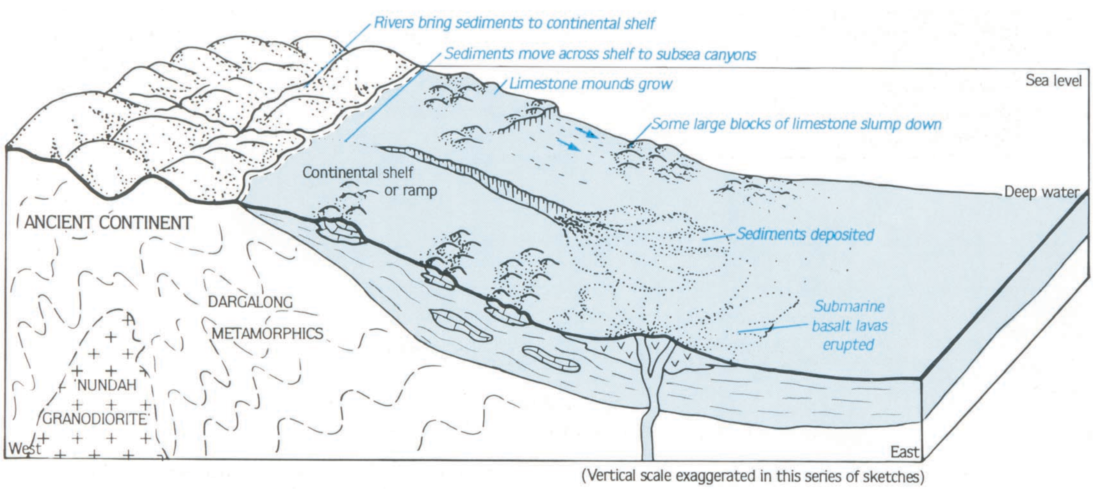
‘Nundah Granodiorite’ — the rocks

Light coloured granitic rocks crystallised from molten rock.

- **Granodiorite** — light cream, medium grained with large silvery flakes of muscovite mica, a few black flakes of biotite, quartz and relatively large grains of white potassium feldspar.

2. SEDIMENTS DEPOSITED OFF THE EDGE OF THE CONTINENT

From about 420 to 360 million years ago (Silurian to Devonian Periods) an area of deep water developed to the east of the old continent (the Hodgkinson Basin). The edge of the land was partially submerged to form a shallow continental shelf, or sloping ramp. There is conflicting evidence as to the exact nature of this shelf or ramp, and it is still a matter of debate amongst geologists. On the one hand, there are bodies of limestone which are consolidated from corals and other organisms usually believed to have lived in shallow water; but on the other, some sediments appear typical of moderately deep water conditions. Most of the limestone bodies appear to have been deposited in place, but others appear to have slumped into their present position from higher up the ramp or shelf.



2. 420–360 million years ago. Sediments and lavas deposited in deep water off edge of old continent.

To generalise, it would seem that sediments brought down by rivers of the old continent were initially deposited on parts of the upper shelf or ramp. Periodically, some became unstable, and avalanched down the slope into deeper water to the east, usually in canyons or channels cut into the slope, in highly mobile muddy currents. Some volcanic activity produced basalt lavas which were incorporated into the sequence of sediments. In places, patches of chert (silica) built up from gradual accumulation of the siliceous skeletons of sponges (in shallow water), or of microscopic marine animals called radiolaria, (in deeper water), as well as from possible chemical deposition of silica from the sea water in localities enriched in silica from nearby basaltic eruptions.

THE SEA FLOOR AT CHILLAGOE IN SILURIAN TIMES

If you were transported 400 million years back in time to the ancient Chillagoe seas a diving expedition would show some startling differences from the present seas.

*The only fish (**A**) would be primitive jawless types. Other swimming animals might be jellyfish (**B**) or strange finger-sized eel shaped creatures (**C**) whose tiny amber coloured 'teeth' (conodonts) lie scattered on the sea-floor. Instead of crabs, trilobites (**D**) scuttle about.*

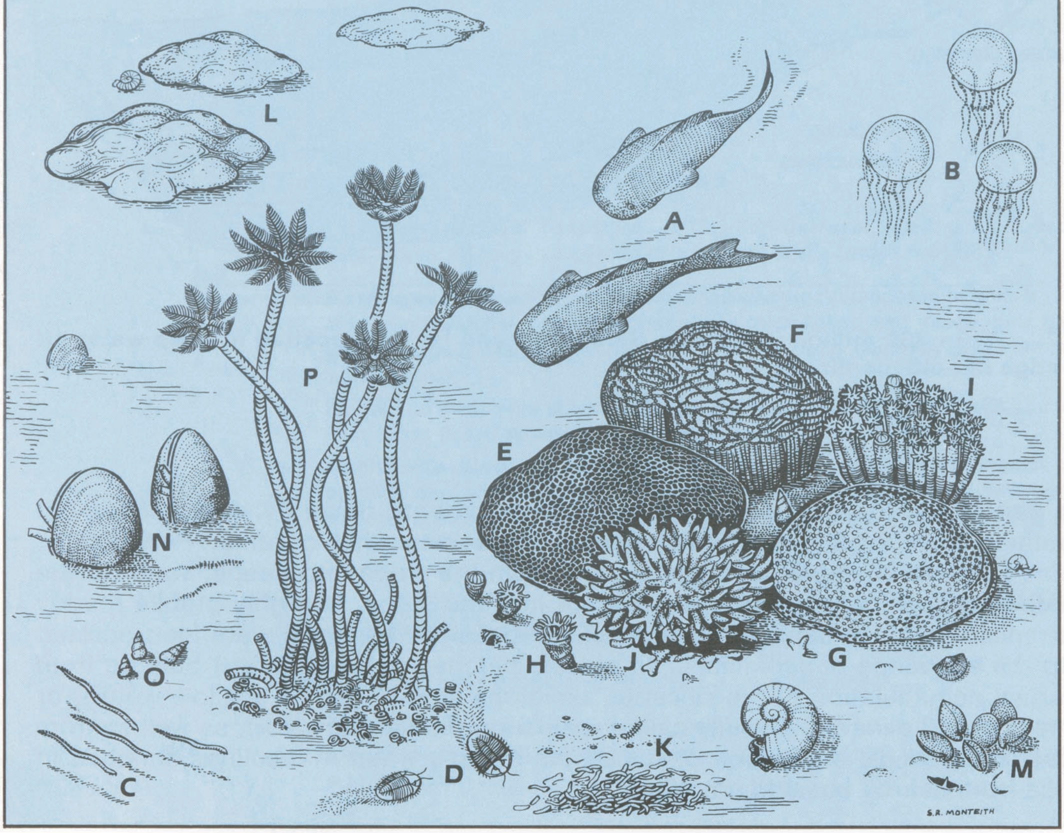
*In places a variety of stony corals grow. Some are solitary (**H**) with a tentacled animal, similar to an anemone, producing a funnel shaped skeleton. However most corals are colonial and consist of many small individual polyps, combining to secrete a hard skeleton. The polyps are much smaller than those of modern corals. Some of the different colonial types are: honeycomb corals (**E**), chain corals (**F**). sun corals (**G**), pipe corals (**I**), branching corals (**J**).*

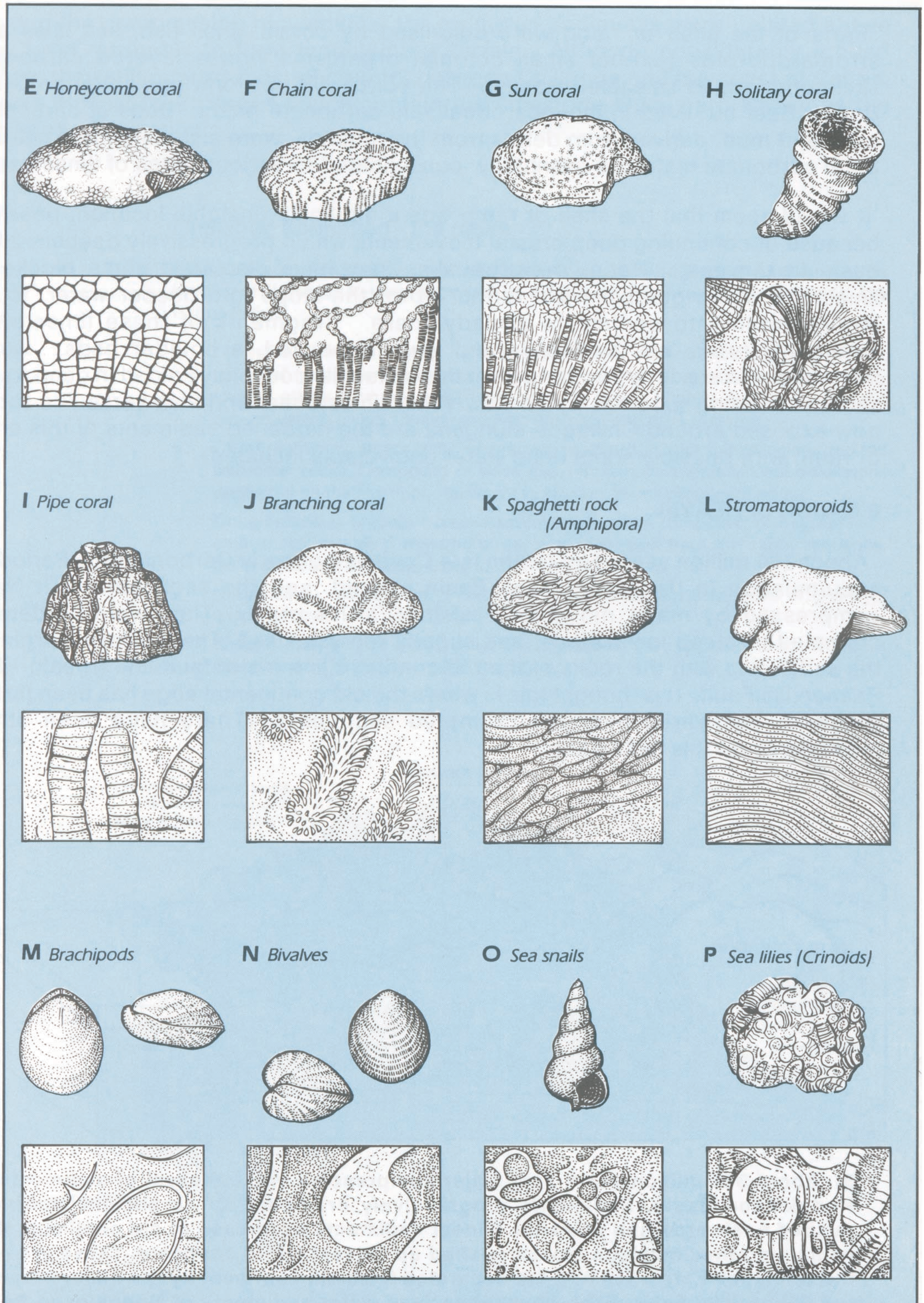
*On the sea floor are masses of long thin spaghetti shaped material (**K**) (amphipora), and large rounded or flat sheeted stony bodies (**L**) (stromatoporoids); you may have trouble deciding, along with today's geologists, if these are plant or animal in origin.*

*There is a variety of shellfish, from the relatively immobile brachiopods (**M**) and bivalves (**N**) which filter out plankton, to the sea snails (**O**) (gastropods) which actively search for their food.*

*Occupying some large areas are stalked sea lilies (**P**) (crinoids) whose arms are covered with fine hairs and mucus to trap plankton. Generally only fragments of their stalks are preserved.*

The fossils at Chillagoe are skeletons of these animals now embedded in a matrix which has almost the same hardness and chemical composition. Thus the fossils rarely weather out as whole individuals but appear as changes of texture and colour within the rocks.





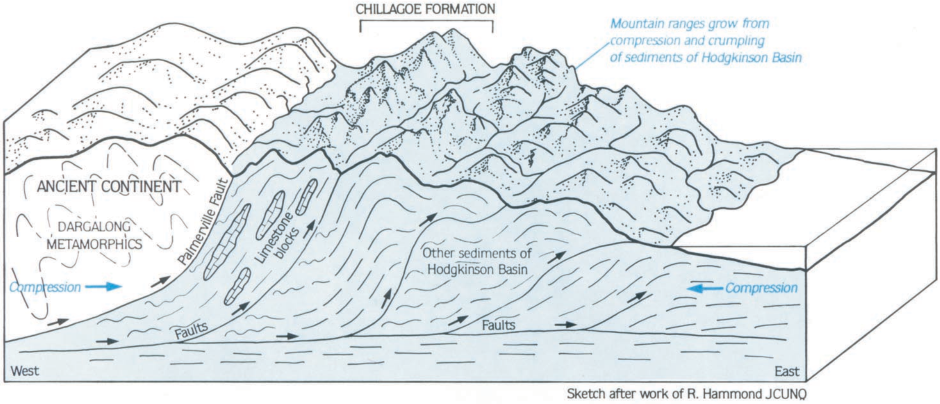
(The illustrations in the boxes are the same scale as the fossils in the rocks)

Parts of the shelf or ramp were colonised by corals, shell fish, sea lilies and stromatoporoids (extinct small colonial organisms whose layered carbonate skeletons formed sizeable masses). The corals did not form reefs like the Great Barrier Reef but lived in mounds of calcium carbonate muds. Beds of carbonate sand and mud, derived from debris from the mounds, were also deposited nearby. Such carbonate materials eventually consolidated to various types of limestones.

It would seem that the shelf or ramp was a markedly unstable location, possibly because of continuing deep crustal movements which progressively deepened the basin in the east. Periodic earthquakes may have displaced some blocks of limestone which gradually slid further down the slope into deeper water, to be incorporated into sediments already there. Fragments of these limestones commonly broke off the blocks and were deposited in boulder beds. Large fluctuations in sea level resulting from this instability could have aided in deep water sediments being followed by shallow water limestones, and visa versa. The rocks now exposed around Chillagoe–Mungana are the hardened sediments of this shelf or ramp with possibly some deep water equivalents included.

3. MAJOR UPHEAVAL

About 360 million years ago (in the late Devonian or early Carboniferous Periods), accumulation in the Hodgkinson Basin ceased, and the sediments in it were compressed by major movements of the Earth's crust. They were hardened, crumpled to steep inclinations, and slightly recrystallised. The western margin of the sediments with the rocks of the old continent is a major fault line (break) — the Palmerville Fault. It is thought this is where the old continental edge has been thrust (pushed) eastwards over the crumpled sediments. (There have been other movements on this fault since.)



3. About 360 million years ago. Major compression and upheaval of sediments of Hodgkinson Basin. Sediments progressively crumpled up as ancient continent pushed eastwards and upwards. Oldest sediments from base of old continent slope containing the limestone blocks pushed up closest to old continent. These are now the Chillagoe Formation and are separated from old continent by the major break of the Palmerville Fault. Slightly younger deep water sediments of Hodgkinson Basin crumpled up further east.

During the compression movements, the crumpled sediments were uplifted above sea level, probably to form mountainous terrain. Although considerably eroded since, they still occupy most of country between Chillagoe and the coast at Cairns. Those closest to Chillagoe which contain the limestone blocks are known as the Chillagoe Formation.

Chillagoe Formation — the rocks

Steeply inclined, hardened sediments of mainly shelf origin with beds and large blocks of limestone, now exposed in a long belt between Almaden and the Palmer River.

- **Limestone** — medium grey, hard, granular, either solid, banded, or fragmented, traces of fossils common. Some beds are resistant to erosion and form rocky towers, others form low pavement outcrops only. Slightly soluble in rain and groundwaters, giving solution-grooved outcrops and cave systems.

- **Chert** — light grey, cream, very fine grained, very hard, in thick bands, or interbedded with other rocks. Composed of silica (SiO) from microscopic siliceous skeletons deposited on the sea floor. Resistant to erosion, forms prominent ridges.

- **Conglomerate, breccia** — coarse sedimentary rocks composed of fragments of other rocks, including metamorphics, and sediments from the same sequence. Some thick and extensive beds form rocky ridges.

- **Greywacke** — medium grey, hardened coarse sediment composed of grains of quartz, feldspar and other rocks.

- **Basalt** — dark grey or brown grey, fine crystalline rock, originally lava. Weathers deeply, outcrops poorly around Chillagoe.

Present exposed extent of Chillagoe Formation.

4A. VIOLENT VOLCANIC ERUPTIONS

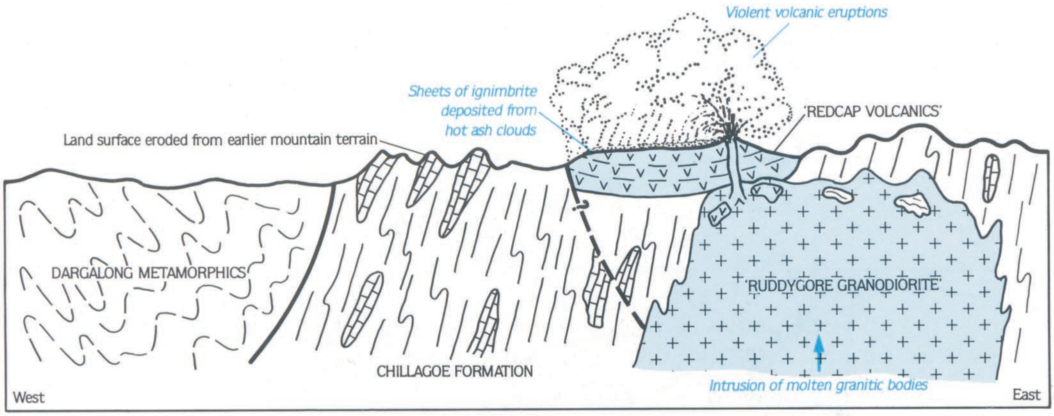
After the upheaval of the sediments, the region was stable for a time and the mountain ranges were eroded. Between 310 and 270 million years ago, however, (late Carboniferous to early Permian Periods) several episodes of heating deep in the lower crust led to local melting and the formation of pods of molten magma of granitic composition.

The pods of magma squeezed their way upwards; where they reached the surface the magma was erupted from volcanoes as clouds of hot ash and gas. The ash fell to ground, and welded together while still hot to form hard compact rocks called ignimbrite (welded tuff). Some of these are exposed at the smelters at Chillagoe — the '**Redcap Volcanics**'. Other extensive ignimbrites form the Featherbed Range to the north-east.

'Redcap Volcanics' — the rocks

Thick sheets of ignimbrite form the hills at the Smelters site and other rugged areas near Mount Redcap north of Mungana.

- **Ignimbrite** — medium grey, fine grained, very hard, no beds or layers visible. Small crystals of quartz, feldspar, and flakes of biotite in very fine background. Specimens appear similar to granite, but small crystals in fine-grained background characteristic.



4A,4B. 310–270 million years ago. Violent volcanic eruptions, and intrusion of granitic rocks deep below the surface.

4B. INJECTION OF GRANITIC BODIES

Not all the magma generated in the heating episodes reached the surface. Probably the great bulk halted within the crust, where it cooled and crystallised slowly to granitic rocks, with the individual mineral crystals growing up to 3cm long. However, some smaller bodies in the shape of plugs or dykes solidified much more quickly to fine grained rhyolite (fine-grained equivalent of granite).

When granitic rocks crystallise, some elements combine with the common rock-forming minerals more readily than others; metallic elements such as copper, lead, silver, zinc, and arsenic, as well as fluorine resist this process and tend to become concentrated in the remaining magma and associated fluids. These may eventually solidify as part of the granitic body or migrate into the surrounding rocks. Some of these concentrations form economic ore bodies (see Formation of the Mineral Deposits).

Subsequently the granitic rocks have been exposed at the surface as erosion has removed the cover of surrounding rocks. The larger bodies have been given names depending on location and composition — the most extensive in the Chillagoe area is the '**Ruddygore Granodiorite**'.

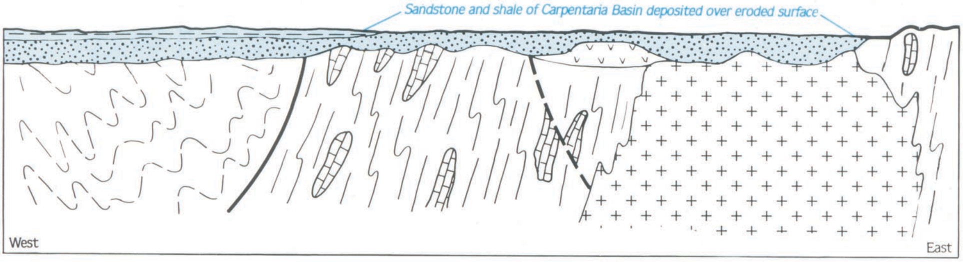
'Ruddygore Granodiorite' — the rocks

- **Granodiorite** — grey, medium-grained, even-grained rock, very hard, weathers to rounded boulders. Black flakes of biotite and hornblende crystals amongst irregular quartz and feldspar grains. Rounded darker inclusions up to 15 cm across of fine- grained biotite and hornblende-rich diorite are common.

5. BROAD SEDIMENTARY BASIN FORMS TO THE WEST

After the injection of the granitic rocks, the continent remained stable over a long period of time, until early in the Cretaceous Period (about 140 million years ago). Then a broad area to the west began to sink slowly. Sediments eroded from the land were washed into this depression (the Carpentaria Basin), gradually accumulating and consolidating into sandstone, siltstone and shale. At first they were mainly sands deposited on broad river plains and estuaries, but as the basin continued to sink, the sea entered, and the later finer grained sediments sandstones, mudstones, shales) were deposited under marine conditions.

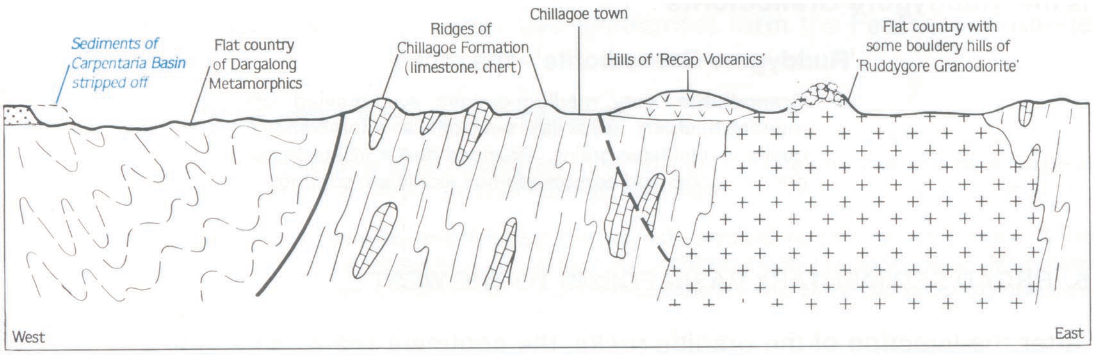
The sediments can now be seen covering the older rocks about 50km north-west of Mungana, from where they extend westward to beneath the present Gulf of Carpentaria. Remnants of the early sandstones form isolated hills and mesas closer to Mungana on the Blackdown road west of Rookwood station. It is thought equivalents to these sediments once covered the whole Chillagoe–Mungana district (even capping the high Featherbed Range to the north-east) , and that they were since stripped off by erosion. Some remnants have been found in the Mungana area.



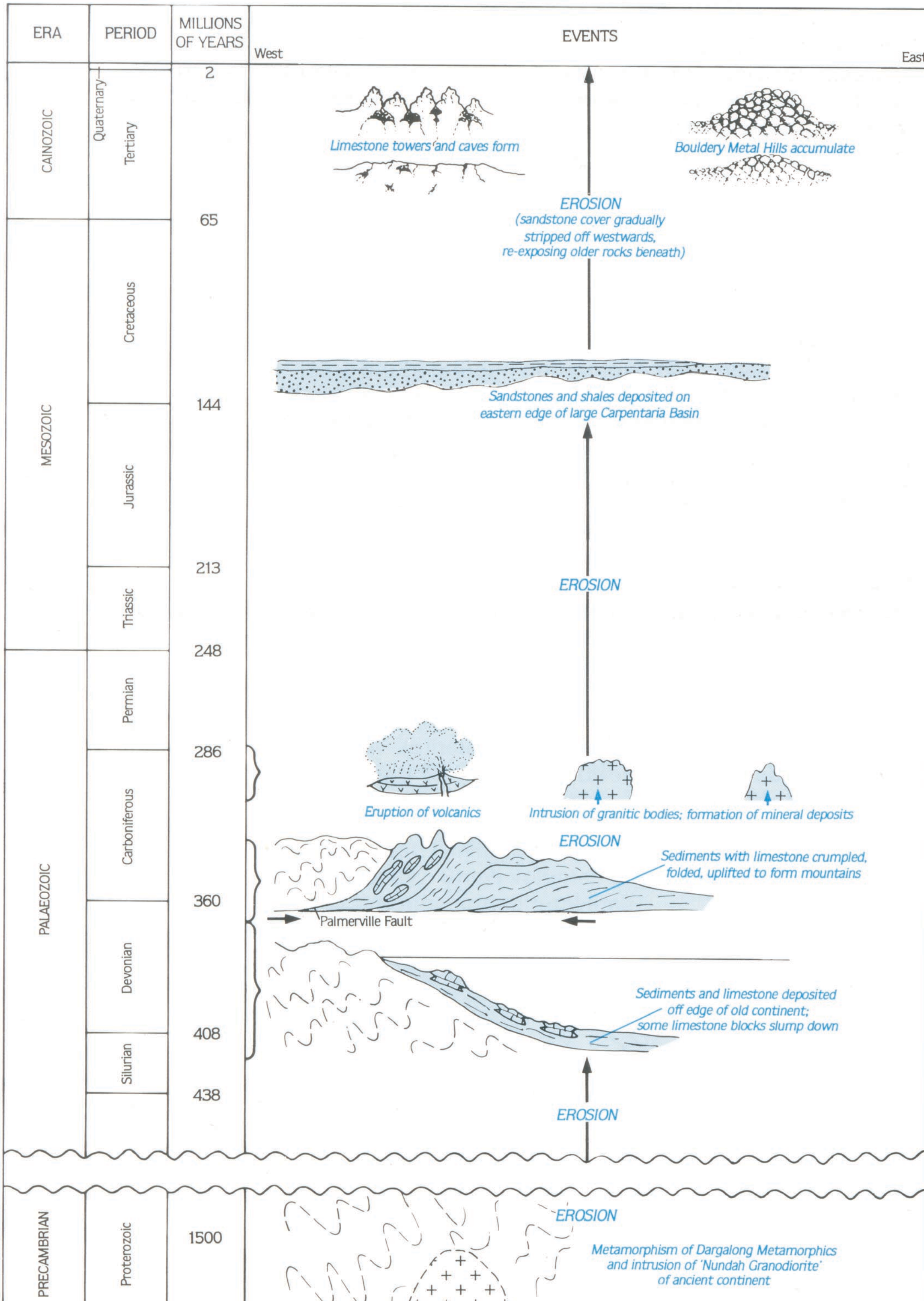
5. 140 million years ago. Sediments of Carpentaria Basin blanket area.

6. EROSION FORMS THE PRESENT LANDSCAPE

After the early Cretaceous Period, the land gradually rose, and the sea retreated to the west. Erosion of the sediments on the more elevated eastern margin of the Carpentaria Basin, such as around Chillagoe, commenced and the older basement rocks were gradually re-exposed. Erosion of these older rocks has since formed the present landscape (see below).



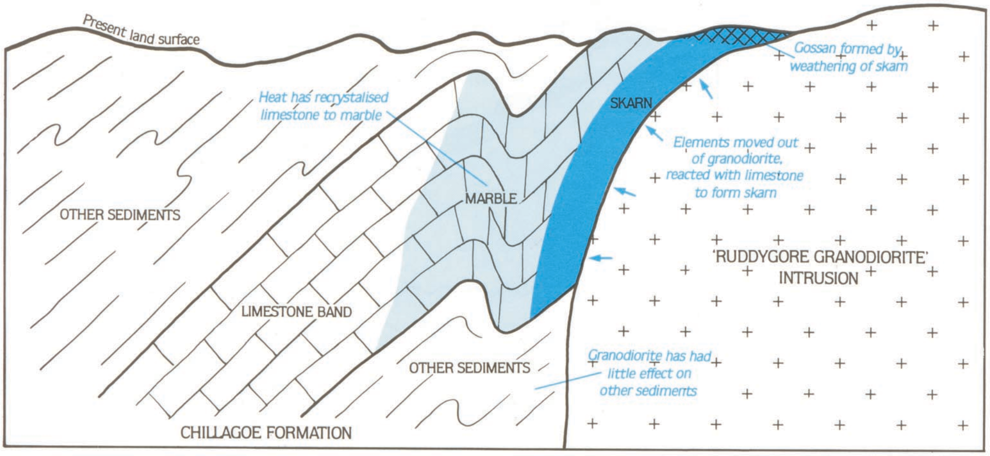
6. 80 million years ago to present. Erosion forms the present landscape.


ERA
PERIOD
MILLIONS OF YEARS
EVENTS
West
East
CAINOZOIC
MESOZOIC
PALAEOZOIC
PRECAMBRIAN
Quaternary
Tertiary
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Proterozoic
2
65
144
213
248
286
360
408
438
1500
Limestone towers and caves form
Bouldery Metal Hills accumulate
EROSION
(sandstone cover gradually stripped off westwards, re-exposing older rocks beneath)
Sandstones and shales deposited on eastern edge of large Carpentaria Basin
EROSION
Eruption of volcanics
Intrusion of granitic bodies; formation of mineral deposits
EROSION
Sediments with limestone crumpled, folded, uplifted to form mountains
Palmerville Fault
Sediments and limestone deposited off edge of old continent; some limestone blocks slump down
EROSION
EROSION
Metamorphism of Dargalong Metamorphics and intrusion of 'Nundah Granodiorite' of ancient continent

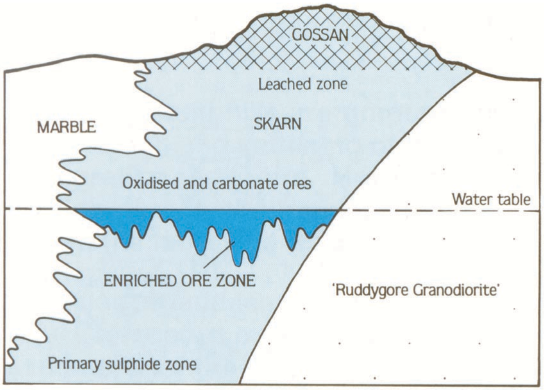
FORMATION OF THE MINERAL DEPOSITS

Chillagoe has been noted for its economic mineral deposits and has had a history as a mining and smelting town which was most active from 1888 to 1927. Base metal deposits predominated, that is, copper, lead (with silver) and zinc, but gold, tin, wolfram and molybdenum also were produced from the district. Considered objectively, production from the mines was not very significant in comparison with other major mining centres, and came mainly in small quantities from hundreds of small mines. Only a few, such as the Lady Jane, Girofla and Zillmanton (between Chillagoe and Mungana) and the Ruddygore were significant. Even in the heyday of the field there were problems with the supply of ore and profitability of the smelters. After 1929 most of the ore treated at the smelters was imported from other districts, and they finally closed in 1943. The new Red Dome mine near Mungana has recently reactivated exploration interest in the area.

Geologically, the ore minerals were mainly introduced by late-stage fluids that accompanied the granitic bodies during their injection into the surrounding rocks. The heat of the granitic bodies and the fluids modified the adjacent rocks in narrow zones along their margins. Most rocks such as chert, greywacke, conglomerate, and ignimbrite show only minor effects (mainly fine recrystallisation) but the limestones were much more reactive, and were considerably changed in these marginal or 'contact' zones. Fluids rich in silica and other elements migrated from the granitic bodies and reacted with calcium carbonate of the limestones to form calcium silicates, such as garnet, pyroxene, epidote, wollastonite and other unusual minerals, as well as iron oxides (magnetite, haematite). These together form material called **skarn**. Other valuable metallic minerals in the granitic fluids also moved out, and were deposited in some skarns as sulphides (copper as the mineral chalcopyrite; lead as galena; zinc as sphalerite). At the surface, weathering of such skarns produces hard knobbly masses of dark brown iron oxides and silica (**gossans**); these crop out as low, long ridges above the skarn along the contact zones.



Formation of skarn and marble adjacent to granitic rocks.



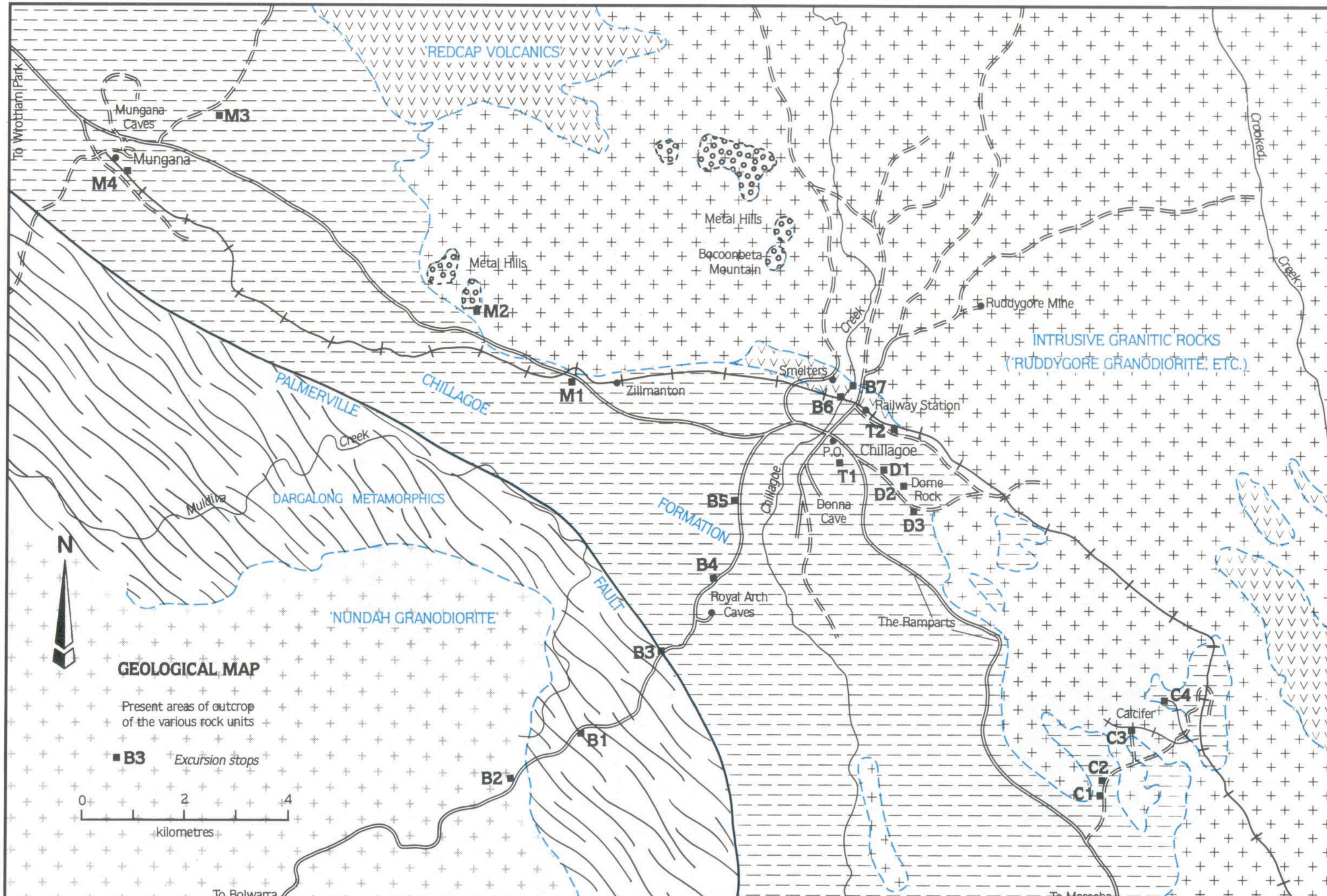
Weathering of skarn zone to give enriched ore.

Thus most of the mineral deposits in the Chillagoe region were in thin, narrow skarn zones adjacent to granitic bodies. The sulphide minerals were very localised in the skarns, and were usually only economic to work where they had been oxidised and concentrated by weathering processes close to the surface.

However, the recently discovered Red Dome deposit near Mungana is significantly larger. There, a number of rhyolite dykes intruding marble have caused a sizeable zone of skarn containing gold, copper and silver minerals. The upper part of the deposits consists of broken rock (breccia), which may have formed by solution and collapse of marble and skarn during a long period of surface weathering preceding the burying of the district by sediments of the Carpentaria Basin in the Cretaceous Period. Only rarely were the granitic rocks themselves mineralised; the most notable area was at the Ruddygore mine.

Heating effects from the granitic bodies have been more widespread than the chemical changes and combined with the high pressures prevailing at the depths of injection, have transformed large volumes of limestone to white granular marble. Mining of deposits of marble near Chillagoe for decorative blocks, tiles, and ornaments has commenced recently. Small volumes of unrecrystallised limestone are also mined at Chillagoe to produce agricultural lime.

More details of the mineral deposits and mining history can be found in other publications, such as those suggested in the Further Reading list.


REDCAP VOLCANICS
To Wrotham Park
Mungana Caves
M3
Mungana
M4
Metal Hills
Bocoonbeta Mountain
Metal Hills
M2
Ruddygore Mine
Creek
INTRUSIVE GRANITIC ROCKS
('RUDDYGORE GRANODIORITE, ETC.)
Crooked
Creek
Smelters
B7
Railway Station
B6
M1
Zillmanton
PALMERVILLE
CHILLAGOE
T2
Chillagoe
P.O.
T1
D1
D2
Dome Rock
D3
Donna Cave
Chillagoe
Creek
Mulditta
DARGALONG METAMORPHICS
B5
FORMATION
B4
Royal Arch Caves
N
'NUNDAH GRANODIORITE'
FAULT
The Ramparts
B3
GEOLOGICAL MAP
Present areas of outcrop of the various rock units
B3 Excursion stops
0 2 4
kilometres
B1
B2
C4
Calcifer
C3
C2
C1
To Bolwarra
To Mareeba

FORMATION OF THE LANDSCAPE

All mountains and hills are gradually worn down by the agents of erosion, first by decomposition and softening of the rocks, and then by removal of fragments by run off into creeks and rivers. However, it is often not realised how closely the pattern of erosion, that is, the framework of the landscape, is related to the types of rocks that form the land, and their history.

The Chillagoe landscape as we see it today probably began to form as long ago as the late Cretaceous or early Tertiary periods (80–50 million years ago), as the blanket of sandstone of the Carpentaria Basin began to be stripped back westwards. As the older rocks beneath were revealed, landscape patterns typical of each rock unit developed (see sketch 6).

The gneiss of the Dargalong Metamorphics and granitic rocks of the 'Nundah Granodiorite' are relatively uniform and decompose readily, and hence have formed relatively uniform, flat to undulating country with no pronounced ridges. I n contrast, the beds of the Chillagoe Formation vary markedly in resistance to erosion. As they are steeply inclined, prominent long linear ridges are formed on the more resistant rocks, such as limestone and chert.

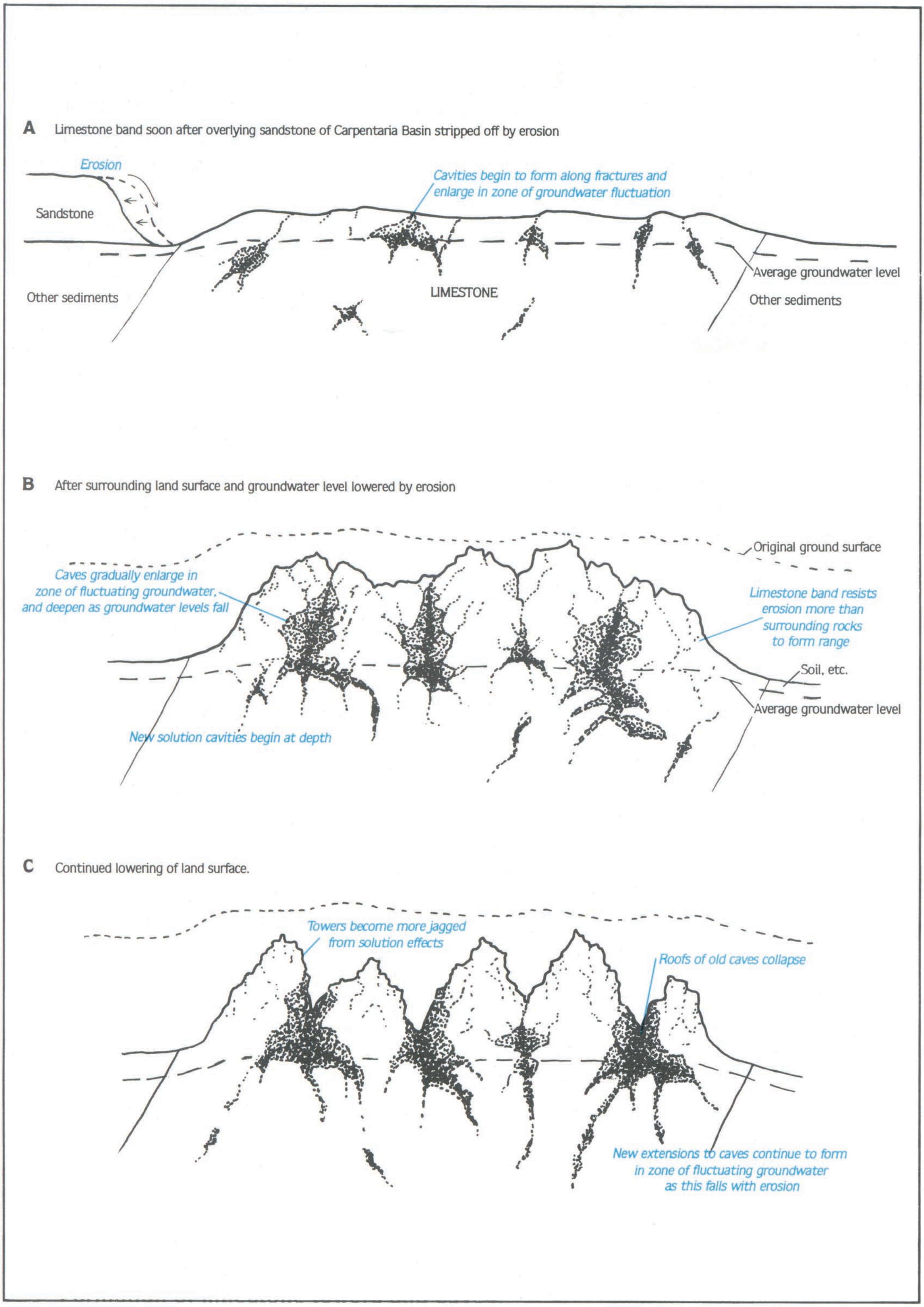
To the north-east, the thick rhyolitic ignimbrites of the Featherbed Range are particularly resistant to erosion, and have remained as a mountainous block. More isolated areas of similar rocks, such as the 'Redcap Volcanics' near Chillagoe, form prominent rocky hills, like those beside the Smelters. Patterns of erosion on the granitic rocks were more variable; large areas were worn down to a flat sandy plain, but some prominent boulder-stream hills remain in places, probably where the rocks were less fractured.

The limestone towers and caves

Landscapes on limestone are termed karst topography and the characteristic limestone towers of Chillagoe are consequently called tower karst. There has been a great deal of debate on the way the towers and their caves have formed, but the main processes seem clear.

The limestone, composed of calcium carbonate in thick relatively unfractured masses is resistant to chemical and mechanical decomposition, and thick beds have a tendency to remain as rocky ridges with little soil formed. These ridges or towers probably began to form soon after the sandstone of the Carpentaria Basin was stripped off, but some may have pre-dated these sediments, and been buried by them.

Despite its resistance, the limestone is soluble in rain and groundwater, which are mildly acidic from dissolved carbon dioxide from the air or decaying vegetation. Solution commences along cracks and fissures, and is most active just below the ground



Formation of limestone towers and caves

surface, where there are seasonal fluctuations in the groundwater levels (water tables). Cavities are gradually produced there and enlarged.

As the surrounding ground surface is slowly lowered by erosion over millions of years, the groundwater levels fall, leaving behind the former caves and gradually dissolving out their floors and new deeper passages. At the same time, rain water with dissolved calcium carbonate percolates into the caves from above. On surfaces exposed to the air, release of carbon dioxide, or evaporation of the water, leaves behind the carbonate in the form of cave decorations (stalactites and stalagmites, etc). With time, the roofs of some caves collapse, forming broad depressions in the centres of the towers.

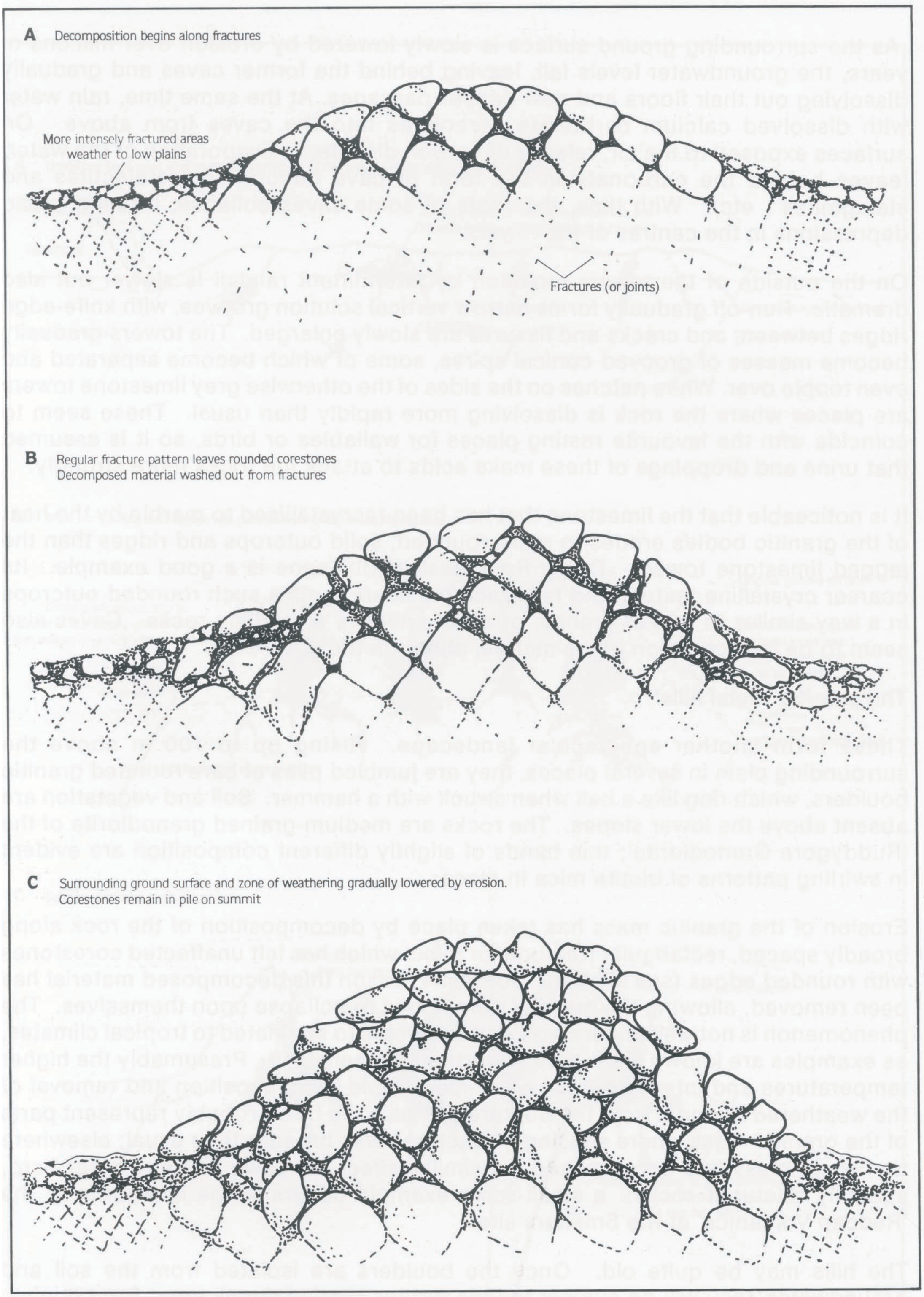
On the outside of the towers, solution by intermittent rainfall is slower but also dramatic. Run-off gradually forms narrow vertical solution grooves, with knife-edge ridges between, and cracks and fissures are slowly enlarged. The towers gradually become masses of grooved conical spires, some of which become separated and even topple over. White patches on the sides of the otherwise grey limestone towers are places where the rock is dissolving more rapidly than usual. These seem to coincide with the favourite resting places for wallabies or birds, so it is assumed that urine and droppings of these make acids to attack the rocks more strongly.

It is noticeable that the limestone that has been recrystallised to marble by the heat of the granitic bodies erodes to more rounded, solid outcrops and ridges than the jagged limestone towers. Dome Rock east of Chillagoe is a good example. Its coarser crystalline texture and few fractures seem to give such rounded outcrops in a way similar to that of granite, or other uniform, crystalline rocks. Caves also seem to be less common in the marble, although they do occur.

The granitic 'metal hills'

These form another spectacular landscape. Rising up to 100m above the surrounding plain in several places, they are jumbled piles of bare rounded granitic boulders, which ring like a bell when struck with a hammer. Soil and vegetation are absent above the lower slopes. The rocks are medium-grained granodiorite of the 'Ruddygore Granodiorite'; thin bands of slightly different composition are evident in swirling patterns of biotite mica in places.

Erosion of the granitic mass has taken place by decomposition of the rock along broadly spaced, rectangular fractures or joints which has left unaffected corestones with rounded edges (see sketch). For some reason this decomposed material has been removed, allowing the mass of corestones to collapse upon themselves. The phenomenon is not well understood, but it appears to be related to tropical climates, as examples are known elsewhere in northern Queensland. Presumably the higher temperatures and intense rainfall allow more rapid decomposition and removal of the weathered material from the fracture planes. The hills probably represent parts of the granitic mass where spacing of fractures was broader than usual; elsewhere the whole mass has decomposed. A similar effect is known in some other hard, sparsely frac-



Formation of ‘metal hills’ in areas of granitic rocks.

tured rocks; a small-scale example occurs in the ignimbrite of the 'Redcap Volcanics' at the Smelters site.

The hills may be quite old. Once the boulders are isolated from the soil and groundwater, they will be subject to little further erosive attack apart from rainfall. As the surface of the surrounding plain is gradually lowered by erosion, and the weathering zone in the granitic hills is similarly lowered (with the soft weathered material being washed out from between the boulders), more and more boulders are left piled up on the surface.

The property of ringing when hit is probably due to the relatively fine grainsize, the lack of stress-dissipating microfractures in the boulders, and the lack of soil or soft weathered rock between the boulders. Isolated bare limestone blocks on the limestone towers will also ring.

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3 Available from the Department of Natural Resources and Mines, GPO Box 2454, Brisbane, Qld 4001

4 Out of print

WHERE TO SEE THE ROCKS

Several driving routes starting from Chillagoe are suggested where typical examples of the rocks, minerals and landscapes can be seen. It is hoped that at some future time the stopping points might be designated by markers, but until then it is necessary to measure odometer distances from the starting point, which is the Chillagoe Post Office. Old mine sites have been avoided because of the dangers of numerous open shafts, particularly to children.

IMPORTANT. Please preserve and protect our geological heritage. Inspect the outcrop sensibly, and take samples only where necessary. It is only good manners to leave the site tidy, and available for future visitors.

Note that some of the sites away from main roads are on grazing land of Elders Resources Limited. The company is agreeable to visitors, but has indicated that 'No liability or responsibility will be assumed or accepted by the land holders (Elders Resources Limited and/or subsiduary companies) for any injuries, or property damage occurring on land controlled by this Company'. Please respect the land owners' interests by keeping vehicles to defined tracks, avoiding disturbance to cattle, and taking any rubbish away with you.

Some stops involve short walks away from the road, and this can result in spear grass seeds in socks and thin trousers, etc. Sneakers without socks are an alternative to boots and leggings for the short distances involved.

BOLWARRA ROAD–CHILLAGOE ROUTE

This route shows examples of all the rock units around Chillagoe as well as illustrating the landscapes. It is laid out in the order of oldest rock to youngest; consequently the first stop is 9.7km south-west of the town on the Bolwarra road, and the excursion finishes back in the town. The round trip distance is about 26km. See accompanying map for locations of stops.

Starting at the Post Office (*note odometer reading*), head west along the main Mungana road to cross Chillagoe Creek, avoid the Smelter turn-off, then turn left at the major junction onto the Torwood–Bolwarra Road (1.5km out). Continue on this road, avoiding the turn-off to Royal Arch Caves further along on the left.

Stop B1. 9.7km from Post Office. Boulders on left side of road on ridge crest, just before left hand turn leading down to creek crossing.

The flat country around here is formed on the Dargalong Metamorphics of the ancient, Precambrian, Australian continent. The boulders are of banded biotite **gneiss**. The foliation, or layers, can be seen, in which the minerals grew in one direction, because of the great pressures involved in the recrystallisation from original sediments. The black flakes are of biotite mica, and the large white crystals which are characteristic of this gneiss, are of feldspar. Pink crystals that may be seen in places are garnet. Fresher outcrops of gneiss are in the creek bed further on.

Nearby are boulders of fine grained black **amphibolite**. This is composed of small crystals of black hornblende and some white feldspar, and probably results from recrystallisation of basalt lava or a dolerite dyke within the original sediments.

Continuing, just after crossing Muldiva Creek (10.9km from P.O.), there is a marked change to a very poor, white sandy soil with stunted vegetation. This is formed on the 'Nundah Granodiorite', an old granitic body which penetrated the Dargalong Metamorphics, probably in Precambrian times.

Stop B2. 11.4km from the Post Office. Boulders on the right of the road.

Light coloured **muscovite granodiorite** of the 'Nundah Granodiorite'. Note the large flakes of silvery muscovite, set amongst white quartz and feldspar. The quartz, feldspar and muscovite contain few of the elements needed for formation of good soil (such as calcium, magnesium and iron) and hence the poor soils and vegetation around here. White opaque quartz littering the surface comes from quartz dykes and veins cutting the granodiorite.

Turn around at this point (*note odometer reading*). Return towards town.

Stop B3. About 4.7km from turn around point. Just past a small gully about 300m past Cave Creek.

Beginning of steeper ridge country. This is the approximate location of the Palmerville Fault, the major break marking the edge of the old Precambrian continent (lower flat terrain behind us) with the younger sediments of the Chillagoe Formation (ahead). Unfortunately the rocks around here are decomposed and the actual fault cannot be seen.

Continuing, the road passes through ridges of various types of sediments of the Chillagoe Formation.

Stop B4. 6.4km from turn around point. Base of walking track to Bluff Lookout.

The ridge of this lookout is a resistant band of **chert** of the Chillagoe Formation — scree and rubble of this very fine-grained, very hard rock can be seen at the base. The hike to the top (300m, 20 minutes up) gives a good panorama of the landscapes. The lookout ridge itself is within the belt of long ridges formed by the steeply inclined beds of the Chillagoe Formation. The limestone ridges of this formation are particularly clear, rising above low valleys developed on surrounding easily weathered muddy and sandy sediment. To the south-west, from where we have come, the low undulating country of the Dargalong Metamorphics of the old Precambrian continent can be seen; the sharp line of the Palmerville Fault between this and the ridges of the Chillagoe Formation is obvious. In the opposite direction, flat land on the far side of Chillagoe town is formed on the granitic rocks of the 'Ruddygore Granodiorite', with only the few resistant parts forming the bouldery Metal Hills. In the far distance is the Featherbed Range, formed by a large mass of rhyolitic volcanic rocks.

Stop B5. About 8.4km from turn around point. Boulders beside road and nearby in low flat area.

These are of **greywacke** of the Chillagoe Formation, a coarse mixed sediment which weathers more readily than the interbedded chert, limestone, and conglomerate, and hence forms lower, flat areas. On the left side it is particularly coarse; included fragments of limestone have dissolved out to leave holes.

Continuing. Deadmans Rock, a small **limestone** tower of the Chillagoe Formation is passed on the right (9km from turning point). Continue back towards town, cross Chillagoe Creek, turn left into Frew Street, then first left again towards the Smelters Caravan Park, then continue further to cross the railway line near its bridge over Chillagoe Creek.

Stop B6. Parking area on left just past railway line, then 50m further on, concrete steps to creek.

Rock bar of rhyolitic **ignimbrite** of the 'Redcap Volcanics', which were erupted onto the rocks of the Chillagoe Formation in this area in late Carboniferous times (about 310 million years). The ignimbrite is very fine, with numerous small crystals of quartz and feldspar in fine background; it is very hard, welded together while still hot from its origins in red hot ash clouds.

The rock bar is partly covered by light grey deposits of recent **travertine limestone**, which forms in shallow pools or dams. This is calcium carbonate that has been deposited from the limey waters of the creek in places where they evaporate locally, such as over the rock bar .

Beside the stairs is a hard cream rocky material — this is calcrete, which forms from calcium carbonate being deposited in the soil layers in areas of limey soils and relatively dry climates.

Continue 400m down to the end of this road, past the Council pumping station.

Stop B7. Creek bed below end of road. Rounded outcrops here and downstream are of **granodiorite** of the 'Ruddygore Granodiorite' intrusion, which penetrated into both the Chillagoe Formation and 'Redcap Volcanics' beneath the surface and has been exposed by erosion. It is medium-grained and pinkish grey, with small black grains of biotite and hornblende. Note the different appearance and composition from the 'Nundah Granodiorite' seen at Stop B2.

Just upstream, a junction between granodiorite and ignimbrite of the 'Redcap Volcanics' can be seen in a few outcrops just above water level. It is relatively sharp, but not particularly obvious, as the ignimbrite has been slightly recrystallised and hardened for about 30cm from the contact with the granodiorite. These effects are far less than where the same granodiorite has intruded limestone, as can be seen at other stops.

MUNGANA ROAD ROUTE

This route shows interesting features of the limestones of the Chillagoe Formation and of the granitic rocks of the'Ruddygore Granodiorite'. It finishes at Mungana, so can be combined with a visit to the Mungana Caves. Round trip 42km.

Starting at the Post Office (*note odometer reading*), head west along the main Mungana Road to cross Chillagoe Creek, avoid the Smelters turn-off, and turn right at the next major intersection towards Mungana.

Continuing, the quarries on either side of the road are worked for limestone for burning for agricultural lime at the limeworks near the Smelters.

Stop M1. 5.6km from Post Office. Low ridge on left beside road.

Good example of a **skarn 'contact' zone** at the junction of the 'Ruddygore Granodiorite' and limestone of the Chillagoe Formation. Boulders of granodiorite can be seen to the right of the road, and a small bluff of limestone on the left. In between is the narrow skarn zone, expressed at the surface here by a low ridge of ironstone, or **gossan**. This is mainly composed of iron oxides which have accumulated at the surface from the weathering and decomposition of the skarn. Unweathered skarn minerals themselves are not exposed here, but can be seen at other stops.

The old **Shannon copper mine** was sunk on this zone further along, but produced little ore. In contrast, a similar zone to the east on the opposite side of the railway hosted the ore body of the Zillmanton mine, which was one of the major producers of the district.

Continue along main road, crossing the railway.

Stop M2. 7.75km from Post Office. Stop beside cleared area on right past a gully. Walk to bouldery Metal Hill visible 300m across flat to right.

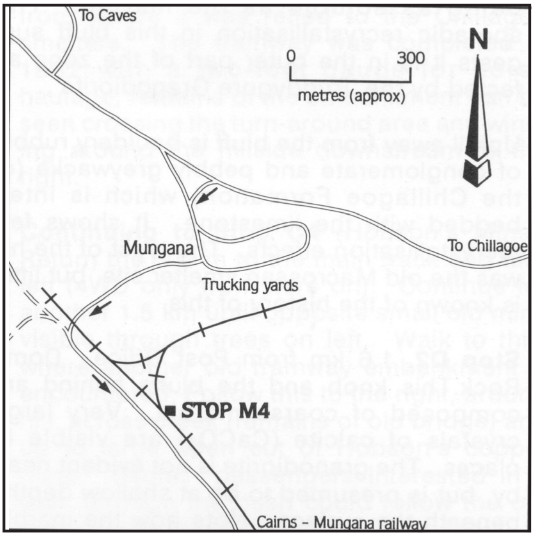
The strange character of these hills of granodiorite boulders (of the 'Ruddygore Granodiorite') is even more striking close up. Their possible origin is described in the section on Landscape. A climb to the top, where the metallic 'ring' seems strongest, is rewarding, but requires substantial footwear.

WARNING: The climb is not really suitable for small children because of the wide gaps between boulders, and the number of loose unstable ones.

Continuing further along the road, at 15.15km from the Post Office, take a track off to the right.

Stop M3. 1.4km down this track. To the right, small limestone towers are on the opposite side of a small creek. Walk around the left side of the most prominent tower to its rear.

These towers are composed of large limestone boulders consolidated together, which are strikingly obvious in their vertical faces. Fossil corals (solitary and colonial) can be seen here, but are more obvious in a second row of bluffs just behind. These bouldery limestones



could have developed when limestone beds of slumped down into deeper water, breaking up on the way.

Continuing, return to the main road, and turn right towards Mungana. After 0.95km, turn left towards the Mungana trucking yards, then right onto a track after about 0.2km, before reaching the yards. Continue, cross the railway line, turn left, and continue for about 0.35km (see sketch).

Stop M4. Fossil locality. Walk back across the railway line near the siding switching lever.

To the right, beside the line are slabs of limestone containing abundant fossils. These are of animals that lived on limestone mounds on the shallow continental shelf or ramp in the Silurian to Devonian periods, between about 420 and 400 million years ago.

The closely packed small rounded and oval shapes are cross sections of stems of animals called **crinoids**. These were like modern sea lilies (see sketch). The upper cups were delicate, and only fragments of the stems are preserved here. Also present are cross-sections of **stromatoporoids**, a group of ancient colonial organisms that cemented fine calcareous skeletons, and cross-sections of solitary and colonial **corals**. These are similar to corals growing on reefs today, but are of ancient forms that are now extinct. Some crescent shaped cross-sections are of shellfish of the ancient **brachiopod** group.

To continue to the Mungana Caves, return to the main road, turn left, and the caves turnoff is not far on the right.

DRIVE TO DOME ROCK

This short route shows rocks and landscapes of the marble, which formed when the granitic rocks of the ‘Ruddygore Granodiorite’ heated and recrystallised the limestone of the Chillagoe Formation.

The round trip is 4.6km; the track may be rough in places, but is suitable for cars with care.

Starting at the Post Office (*note odometer reading*), continue 0.65km back along the main road to Mareeba.

At the edge of town (100km/h sign), continue on a track straight ahead, instead of veering to the right along the bitumen.

Stop D1. 1.2km from Post Office. tower on left of track. Small tower on left of track.

At the far end (east side) of the tower just beside the track, the limestone is dark grey and only slightly recrystallised.

It contains contorted, dark brown bands of chert which stand out in relief, not being soluble like the limestone.

On the uphill side of the bluff (away from the road) the limestone has been much more recrystallised. Most is now a white, coarse **marble**, but there are veins and seams of light grey, blady crystals of **wollastonite**, a calcium silicate. These have grown where there have been silica impurities in the limestone, or where silica-rich fluids from the granodiorite penetrated the limestone. The wollastonite stands up from the surface, not being as soluble as the marble. The sporadic recrystallisation in this bluff suggests it is in the outer part of the zone affected by the 'Ruddygore Granodiorite'.

Uphill away from the bluff is bouldery rubble of conglomerate and pebbly greywacke (of the Chillagoe Formation) which is interbedded with the limestone. It shows few recrystallisation effects. The crest of the hill was the old Macrossan smelter site, but little is known of the history of this.

Stop D2. 1.6km from Post Office. Dome Rock. This knob and the bluffs behind are composed of coarse marble. Very large crystals of calcite ($CaCO_3$) are visible in places. The granodiorite is not evident nearby, but is presumed to be at shallow depths beneath the surface. Note how the marble bluffs are far less jagged and more rounded than those of limestone — this is probably caused by reduced solubility of the coarser crystals and a different mechanical weathering pattern.

Stop D3. 2.3km from Post Office. Marble mining and Atherton Mine.

a) Marble block cutting operation on the left. This is a private operation and the area should not be entered without permission.

b) On the right side of the track, the old **Atherton mine** is on the hillside above the fence. This was one of the earliest small copper mines worked in the district, situated in a skarn zone formed at the junction of the limestone (now marble) and granitic rocks. Some boulders of granodiorite near the mine suggest a small outcrop, and that it is at shallow depths. The olive-green **garnet rock** of the skarn can be seen in parts of the excavation (with brown gossan above), and on the spoil heaps are boulders of light grey, green-grey impure marble with garnet, pyroxene and wollastonite. Only a few coatings of the bright green mineral **malachite**, derived by weathering from copper sulphides, indicate that any metallic minerals were present.

DRIVE TO THE CALCIFER AREA

This is an area of historic as well as geological interest. Calcifer was the site of the first smelter on the Chillagoe field, erected by John Moffat in 1894. This site and remains of tramways that transported ore from two mines nearby can still be seen.

The road to the final stop is not suitable for conventional cars. The round trip is about 32km, but could be done on the return journey to Mareeba.

Start at the Post Office (*note odometer reading*) and head back on the Mareeba Road.

Continuing, at about 4.5km the spectacular towers of The Ramparts are on the right. These are of limestone formed by large rounded boulders (some larger than 1m across), recrystallised to marble by the heat of nearby granitic rocks. Boulders of the 'Ruddygore Granodiorite' can be seen left of the road. At the contact there is a thin skarn zone along which several small lead-silver- copper mines were sunk.

At about 10.65km, turn left onto a track opposite a marble block excavation, continue for 300m and take a left fork.

Stop C1. 75 km from Post Office.

a) Small tower on left of track. The limestone has been recrystallised by the heat of granitic rocks, showing crude banding. The dark grey patches are of **marble** (coarse calcite crystals), the light grey, rough bands with a blady texture are of **wollastonite**, and the brown bands and knobs are of **chert**. The wollastonite and chert stand out on the weathered surface in comparison with the more soluble marble.

b) On the right side of the track is a skarn zone between the marble and granitic rocks, which form the low hills on the right. A small pit exposes olive-green **garnet** of the skarn and there are traces of bright green **malachite**, which indicates the presence of copper sulphides. Some cobbles of red-black **haematite** are lying around.

Stop C2. Some 300m past Stop CI.

The track passes to the right of a marble block excavation in coarse blue marble. The pit is a private operation and should not be entered without permission, but excavated boulders can be seen adjacent to the track.

Continuing, at 12.95km from the Post Office, take a track branching left and continue for about 600m to a turn-around area.

Stop C3. Old Calcifer smelter site.

The Calcifer smelters were on the opposite side of the creek from the turn-around area, sited to take advantage of a natural spring in the creek. Essentially a small preliminary works, they operated for several years after 1894, treating ore from nearby mines such as the **Boomerang** (not far upstream to the west), **Hobsons** (to the north-east), and **Harpers** (to the east of the Railway line), as well as from some more distant mines. There is little of them now remaining, but fragments of slag can be seen on the ridge crest of the site. Similarly, little can be seen of the small town site that existed south of the creek about the turn-around area.

With the opening of the new Chillagoe smelters in 1901, the Calcifer smelters closed, and it was necessary to construct a tramway to take the ore from the Boomerang mine to the Harper siding on the new Chillagoe Railway, from where it was railed to the Chillagoe smelters. The tramway was completed in 1902 with a two-foot gauge for horse haulage; remains of the embankment can be seen crossing the turn-around area and winding around the hillside downstream to the right.

Continuing to Stop C4 (Hobson's Mine). Return the 600m to the main track and turn left (4WD only from here on). Continue for another 1.5km until opposite small old mine visible through trees on left. Walk to this, where another old tramway embankment is encountered. Follow this to the right, around hill, across creek (remains of old bridge) and up to large open cut of Hobson's copper mine. {Note: passengers interested in a walk through the bush could follow the old Boomerang tramway from the smelters, to meet their vehicle 700m further around where the tramway crosses the track.)

Stop C4. Hobson's Mine

This is in a large skarn zone adjacent to granitic rocks, which is composed of fine green **garnet** and brown-black **magnetite**; specks of bright green **malachite**, weathered from copper sulphides, can be seen throughout.

The first ore mined was high grade, won from an enriched near-surface weathered zone, but later at depth the grades become uneconomic, and the material was used only as a fluxing ore for the Chillagoe smelters.

DRIVE AND HIKE TO LARGER METAL HILLS

One example of a Metal Hill is included the drive to Mungana relatively close to the road (Stop M2). This additional excursion is suggested for the more energetic and adventurous who may like to tackle a larger hill further out in the bush. The possible origin of these hills has been discussed in the section on Landscape.

Drive to the Smelters, and go to the far left hand side of the slag heap, where a track descends the heap. *Note odometer reading here*. Continue along this track, which should usually be suitable for conventional cars with care. Avoid any tracks to the right.

At a point 2.4km from the start, a creek crossing marks the limit for conventional vehicles.

Walk from here, along the track, crossing the creek and skirting around the end of a small ridge. Past this the first of the Metal Hills (Mount Bocoonbeta) can be seen several hundred metres through the trees on the left, walk across from here. If 4WD is available, cross the creek and continue further along the track to 4.85km from the Smelters (avoiding a track on the right). At this point, one of the highest Metal Hills is closer to the track.

OTHER FEATURES AROUND CHILLAGOE TOWN

TI. Ridge above water reservoir. Hike up to rocky crest from back of Chillagoe Caravan Park, or from end of street beside the historical museum.

The highest ridge crest is formed by a steeply inclined band of coarse conglomerate of the Chillagoe Formation, composed of large fragments of chert and other sedimentary and metamorphic rocks. At the northern end of the ridge, past the reservoir, the conglomerate passes into a thick bed of hard chert.

The ridge crest is a good landscape vantage point — besides the limestone bluffs, the rounded marble knob of Dome Rock is to the east, and the Smelter site and the jumbled granite boulders of the Metal Hills are to the north. Far to the north-east is the rugged mountain block of the volcanic rocks of the Featherbed Range.

T2. Old Silica quarry. Drive to the Railway Station, and then head back right (east) on a track parallel to the railway line, on the town side of it (don't cross line and avoid any tracks to the right). Stop at the base of a rubble strewn hill about 600m past the station.

On the left side of the hill between the track and the railway is an old quarry in a thick band of **chert** of the Chillagoe Formation. This was worked to supply silica for flux (to promote melting at lower temperatures) in the smelting operations. Contorted banding visible in the chert may have been caused by slumping in the silica-rich sediment while it was still soft on the ocean floor, or by the later crumpling movements when the whole Chillagoe Formation was uplifted, deformed and steeply inclined. Some veins with well formed quartz crystals cut the chert in places; these may have resulted from recrystallisation by the heat of the nearby granodiorite (exposed on the high hill on the far side of the railway line, beyond a belt of ignimbrite in the foreground).

Ignimbrite and granodiorite in Chillagoe Creek. See Stops B6 and B7 on Bolwarra Road–Chillagoe route.

GLOSSARY

Amphibolite	A dark metamorphic rock consisting mainly of hornblende and plagioclase crystals; commonly recrystallised from basalt lavas, or basalt or dolerite dykes.
Basalt	A dark grey or black, fine grained volcanic rock usually erupted as lava flows.
Basin	A segment of the crust which has gradually sunk and in which sediments have accumulated.
Bedding	The succession of beds, or layers, which result from successive pulses of sediment being deposited.
Biotite	A black or dark brown, platy mica mineral.
Breccia	A coarse sediment consisting of large angular fragments.
Calcrete	Hard, white irregular rock, composed of calcium carbonate cementing gravel, sand or soil particles, in a soil profile.
Carboniferous	The period of geological time extending from about 360 to 290 million years ago.
Chert	A rock composed of very fine-grained silica.
Conglomerate	A coarse sediment consisting of large rounded gravel and cobble fragments; a consolidated gravel.
Contact	The junction or boundary between two different rock types.
Continental shelf	Low, lying portions of the continental margin covered by the sea and marine sediments.
Cretaceous	The period of geological time extending from about 145 to 65 million years ago.
Crust	The outer layer of the Earth's surface.
Crystallisation	The process through which crystals grow and separate from a liquid.
Decomposition	The breaking down of rock by chemical and physical processes involved in weathering at the surface.
Devonian	The period of geological time extending from about 410 to 360 million years ago.
Diorite	A dark variety of granitic rocks, composed mainly sodium-calcium feldspar, hornblende and biotite, little potassium feldspar or quartz.
Dolerite	Black rock similar to basalt lava, but occurring in dykes, etc, and generally coarser grained.

Dyke	A steep narrow body of intrusive rock cutting through surrounding rocks.
Epidote	A group of complex, yellow-green, calcium silicate minerals.
Fault	A major fracture in rocks or the Earth's crust along which the two sides have been displaced.
Feldspar	A family of common rock, forming minerals consisting of silica, alumina, potassium, sodium and calcium.
Flux	Any substance or mixture which lowers the melting point of ore in smelting operations.
Foliation	Fine banding in rocks caused by segregation of different minerals Into separate layers.
Garnet	A family of complex aluminium silicate minerals, with high contents of calcium, magnesium and iron. Colours vary depending on chemical content.
Gossan	A hard dark brown iron-oxide rich material, which forms on the surface of metallic ore deposits from weathering and oxidation of the underlying skarn and metallic sulphide minerals.
Gneiss	Coarsely banded, black and white metamorphic rock, formed under high pressures and temperatures.
Granitic rocks	Relatively coarse-grained, intrusive, igneous rocks composed mainly of quartz, feldspar and mica. Crystallised from molten material.
Granodiorite	A variety of granitic rock in which sodium-calcium feldspar predominates over potassium feldspar.
Greywacke	A medium to coarse-grained sedimentary rock composed of fragments of other rocks, feldspar and quartz.
Haematite	Heavy, red-black mineral; an oxide of iron (Fe_2O_3).
Hornblende	A family of dark, complex aluminium silicate minerals, with varying proportions of calcium, sodium, magnesium and iron. Form elongate prismatic crystals.
Igneous rocks	Formed from solidification of molten material generated within the Earth, either in intrusions (plutonic) or at the surface (volcanic).
Ignimbrite	A rock consolidated from volcanic fragments erupted in large violent explosions, and later welded together by their own heat, to form thick hard compact sheets.
Intrusion	A body of molten rock that has penetrated into other rocks and solidified beneath the surface.
Joint	A prominent fracture plane in rocks.
Lava	Molten rock poured out from volcanoes.

Lenses Tapering, discontinuous patches of sediments.

Limestone Sedimentary rock consisting mainly of calcium carbonate, often in the form of shell and coral debris.

Magma Molten rock generated within the Earth.

Magnetite Heavy black, magnetic mineral with metallic sheen; an oxide of iron (Fe_3O_4).

Malachite Bright green copper carbonate mineral ($Cu_2CO_3(OH_2)$) which results from weathering of copper sulphides in ore deposits.

Marble Recrystallised limestone.

Metamorphism Process of transformation and recrystallisation of rocks by pressure and/or heat; new minerals commonly developed in new orientations.

Mica A family of platy, sheet like silicate minerals.

Mudstone A fine-grained sedimentary rock consolidated from mud with little banding or bedding evident.

Muscovite A white or silver-coloured platy mica mineral.

Permian The period of geological time extending from about 290 to 250 million years ago.

Plagioclase A family of calcium-sodium feldspar minerals.

Precambrian All geological time before the start of the Cambrian period about 600 million years ago.

Pyroxene A family of dark, complex aluminium silicate minerals with varying proportions of iron, magnesium calcium and sodium.

Quartz Crystalline silica (SiO_2), a common rock forming mineral.

Recrystallisation Formation of new minerals in a rock by destruction of old, commonly by changes in pressure and/or temperature.

Rhyolite A light coloured volcanic rock with a high proportion of silica.

Schist A medium-grained metamorphic rock, with a well developed, fine foliation or layering usually formed by mica minerals.

Shale A fine sedimentary rock with a pronounced thin layering.

Silica Silicon dioxide (SiO_2),

Siliceous Silica rich

Silurian The period of geological time from about 440 to 410 million years ago.

Skarn Rocks developed from chemical reactions between limestone and fluids from adjacent granitic bodies; usually consist of calcium silicates such as garnet, pyroxene, wollastonite, etc, and iron oxides, and commonly contain sulphide ore minerals.

Smelting Extracting metal from ore by melting, and driving off sulphur.

Tertiary The period of geological time extending from 65 to 2 million years ago.

Travertine Calcium carbonate, usually light coloured and banded, deposited from lime rich surface and groundwaters.

Vein Fracture cutting across rocks and filled with minerals.

Weathering The physical, chemical and biological processes that cause rocks exposed to the weather to decay and change into soil-like materials.

Wollastonite Light coloured calcium silicate mineral ($CaSiO_2$) commonly found in skarns and recrystallised limestones near granitic bodies.