Queensland Government
Natural Resources and Mines

GEOLOGY OF THE COOPER AND EROMANGA BASINS, QUEENSLAND

Edited by JJ Draper

Contributors to NGMA Cooper–Eromanga Basins Project at Department of Natural Resources and Mines:
C Davies, JA Dingwell, O Dixon, JJ Draper, ARG Gray, PM Green, AL Heim, KL Hoffmann, JL McKellar, M McKillop

email: john.draper@nrm.qld.gov.au
www.dme.qld.gov.au

Address for correspondence:
JJ Draper
Queensland Department of Natural Resources and Mines
GPO Box 194, Brisbane, QLD.
Australia, 4001

Published by the Queensland Department of Natural Resources and Mines

ISSN 1039-5555
ISBN 0 7345 2411 0
Production editing: JW Beeston
Graphics: LM Blight, JJ Draper, MJ Fitzell, M McKillop, T Moore
Desktop publishing: SA Beeston
Issued: March, 2002

REFERENCE:

DRAPER, J.J. (Editor), 2002: Geology of the Cooper and Eromanga Basins, Queensland. *Queensland Minerals and Energy Review Series*, Queensland Department of Natural Resources and Mines.

CONTENTS

FIGURES

TABLES

APPENDIX

ABSTRACT

The Cooper and Eromanga Basins in Queensland and South Australia are the major oil and gas producers onshore in Australia. Gas is dominant in the Permian–Middle Triassic Cooper Basin and oil in the Jurassic–mid-Cretaceous Eromanga Basin.

The Cooper Basin in Queensland was deposited on rocks of the Thomson Fold Belt which are Cambrian to Ordovician in age and laterally equivalent to the Warburton Basin in South Australia. Rocks of the Thomson Fold belt were deformed in the mid to Late Ordovician. Two periods of granite emplacement occurred subsequent to deformation of the Thomson Fold Belt. Early Devonian S-type granites form an arcuate belt beneath the southern part of the Cooper Basin in both Queensland and South Australia. Late Carboniferous S-type granites occur mainly in South Australia beneath the Nappamerri Trough. Cooling of the Late Carboniferous granites was the probable trigger for initiation of the Cooper Basin.

Sedimentation began in the Cooper Basin in the earliest Permian with deposition of the fluvio-glacial Merrimelia Formation. The conformably overlying Tirrawarra Sandstone represents glacial outwash and reworked Merrimelia Formation. Both these units have very limited distribution in Queensland. The fluvial coal measures of the Patchawarra Formation conformably overlie the Tirrawarra Sandstone. This unit is widespread in the Cooper Basin in Queensland. A fine-grained mainly lacustrine unit, the Murteree Shale, overlies the Patchawarra Formation, although its distribution is restricted to the southern Cooper Basin in Queensland. The overlying coal-bearing Epsilon Formation has a similar restricted distribution and is of deltaic origin. Lacustrine deposition resulted in the formation of the Roseneath Shale which is overlain by the deltaic Daralingie Formation. The mid-Permian is marked by a widespread unconformity, the Daralingie Unconformity. Overlying the unconformity is the Toolachee Formation, which is the most widespread of the Permian units. It is a coal-bearing fluvial unit. The Late Permian–Early Triassic Arrabury Formation conformably overlies the Toolachee Formation. It is a fluvial sequence with some redbeds. As a result of a north-west shift in the depocentre of the Cooper Basin, the fluvial Tinchoo Formation partly overlies the Arrabury Formation and partly basement. A period of folding followed. Basalts intrude Late Permian and Triassic rocks in the southern Cooper Basin in Queensland.

Renewed subsidence resulted in the formation of the Eromanga Basin. In the Late Triassic, a fluvial unit, the Cuddapan Formation, was deposited over the folded older Triassic rocks. This unit was areally restricted. Unconformably overlying the Cuddapan Formation is the Early Jurassic Poolawanna Formation, which represents fluvial-lacustrine deposition. Fluvial rocks of the Hutton Sandstone conformably overlie the Poolowanna Formation. The conformably overlying Birkhead Formation was deposited under fluvial-lacustrine conditions. Rocks of the unconformably overlying Adori Sandstone were deposited under fluvial conditions. The Adori Sandstone passes upwards into fluvial-lacustrine rocks of the Westbourne Formation. The Hooray Sandstone contains both fluvial and lacustrine sequences and straddles the Jurassic – Cretaceous boundary. The Hooray Sandstone is laterally equivalent to the "upper Namur Sandstone" and the Murta Formation, which were deposited under similar conditions. Paralic and nearshore marine deposition resulted in the formation of the Cadna-owie Formation. Marine conditions continued with the deposition of the Wallumbilla Formation and the overlying Toolebuc Formation. Likewise, the Allaru Mudstone was deposited under shallow marine conditions. Marine conditions ceased during the deposition of the Mackunda Formation, with the overlying Winton Formation deposited entirely under fluvial and lacustrine conditions. Major folding followed deposition of the mid Cretaceous Winton Formation resulting in termination of sedimentation in the Eromanga Basin.

Widespread fluvial deposition occurred in the Late Palaeocene to Early Eocene in the Lake Eyre Basin. The Glendower Formation and Marion Formation were deposited in Queensland and the Eyre Formation in South Australia. Widespread weathering occurred in the Oligocene followed by warping and folding in the Late Oligocene or Early Miocene. Fluvial and lacustrine deposition occurred during the Middle Miocene to Early Pliocene. Quaternary deposits comprise residuum and dune, alluvial and lacustrine sediments.

The Cooper Basin contains numerous gas fields and minor light liquid hydrocarbons. The Eromanga Basin, on the other hand, contains a number of oil fields but only a few gas fields. Oil generation and

expulsion occurred dominantly in the mid-Cretaceous with minor expulsion in the Late Permian and late Tertiary. Generation was predominantly from coals and disseminated organic matter in the Cooper Basin, with limited generation from Eromanga Basin rocks; very few Eromanga Basin rocks have been buried to suitable depths. The proximity of Eromanga Basin oil and gas fields to underlying Permian rocks also indicates a predominant Permian source. In Queensland, the major source rocks in the Cooper Basin are the coal measures of the Patchawarra, Epsilon and Toolachee Formations. These units also contain the main reservoir rocks. Permian shale units and Triassic rocks provide the main seals. Anticlinal and fault-controlled traps are major targets with stratigraphic traps also being targeted. In the Eromanga Basin, source rocks are present in the Poolowanna, Birkhead, Westbourne and the Murta Formations. All units below the Wallumbilla Formation contain reservoirs with many multi-pool fields. The Hutton Sandstone and Hooray Sandstone are the most significant reservoir rocks. Locally, sealing occurs where fine-grained lacustrine rocks are present. Regional sealing is provided by the Cretaceous marine mudstones. Eromanga Basin traps are generally anticlinal often with fault control.

INTRODUCTION

The Cooper and Eromanga Basins (Figure 1) are the main onshore petroleum producing basins in Queensland and South Australia. Table 1 shows the proved and probable reserves for the Queensland portions of the basins. Since these basins are not constrained by state borders, a project was commenced in 1996 under the auspices of the National Geoscience Mapping Accord (NGMA) to develop a hydrocarbon generation model for the basins as a whole. The contributing organisations were Queensland Department of Mines and Energy (QDME), which is now the Department of Natural Resources and Mines (NR&M), Primary Industries and Resources south Australia (PIRSA), Australian Geological Survey Organisation (AGSO), New South Wales Department of Mineral Resources (NSWDMR) and the Northern Territory Department of Mines and Energy (NTDME). A progress report was published by Green (1997). The hydrocarbon model was published as interactive CD ROM (Deighton & others, in preparation).

Table 1: Proved and Probable Reserves to 30 June 1998

Unit	Gas ($\times 10^6$ m^3)	Oil (ML)	Condensate (ML)	LPG (ML)
Cooper Basin				
Patchawarra	25,409(42)	9(2)	2723(42)	2335(39)
Epsilon	4,508(13)		414(13)	432(14)
Toolachee	37,311(38)	25(2)	2559(41)	1861(40)
Toolachee/Patch	1,083(1)		19(3)	59(3)
Nappamerri	537(2)		58(2)	131(2)
Eromanga Basin				
Poolowanna	18(2)	833(8)		
Hutton	1,394(3)	13,154(29)	178(3)	115(3)
Birkhead	430(1)	597(19)	17(1)	2(1)
Adori		73(3)		
Westbourne		1,387(10)		
Hooray/Namur		1,082(12)		
Murta		1,286(31)		
Wyandra		62(1)		

() number of pools

As part of the project, integrated seismic horizon maps were prepared for the top Cadna-owie Formation (C horizon), top Permian (P horizon) and base Cooper Basin–base Eromanga Basin (Z horizon).

This report is an outline of the geology of the Cooper and Eromanga Basins in Queensland (Figure 2 shows the project area) and a summary of the petroleum geology.

As part of the report a number of maps were prepared. Basic isopach maps were prepared using formation tops picked on a consistent basis for all the wells in the project area.

Sand and shale thickness was determined using the equation:

$$V_{sh} = (GR-GR_{min})/(GR_{max}-GR_{min})$$

for each lithostratigraphic formation. Formational members were not treated as individual units but included in the formation. A Vshale log was generated with Geolog software with values ranging from 0–1. Sand thickness was determined where shale values were <0.3 and shale thickness where values >0.3 occurred. Shale percentage values were determined by (V_{sh}/T) 100.

The Wyllie equation was used to determine porosity values because the sonic log was all that is required. Density logs were not available in many older wells and where density logs were available in general were not run through the whole hole.

$$\Phi_S=(\Delta t-\Delta t_{ma})/(\Delta t_f-\Delta t_{ma})$$

where

Φ_S = porosity

Δt_f = Fluid Transit Time, value used 188.976µs/f

Δt_{ma} = Matrix transit time, value used 55.5041µs/f

The values for unit thickness, sand thickness, shale thickness and percentage, and porosity were gridded using Petrosys software. Anomalies were investigated and checked for errors within the logs such as data spikes.

GEOLOGICAL SETTING

JJ Draper

The Cooper and Eromanga Basins are both intra-cratonic basins. The Cooper Basin immediately overlies the Cambrian–Ordovician Warburton Basin and Cambrian–Ordovician meta-sedimentary rocks of the Thomson Fold Belt and contains Permian to Middle Triassic non-marine sedimentary rocks. The Eromanga Basin, which overlies the Cooper Basin and the Thomson Fold Belt in the project area, contains Jurassic non-marine and Cretaceous non-marine and marine rocks. The temporal relationship between the basins is shown in Figure 3. The basins have a complex structural history and a number of hypotheses have been proposed for their origin. The main structural elements are shown in Figure 4. Basement structures appear to play a major role in the formation and structure of both basins.

BASEMENT ELEMENTS

In terms of the mega-elements (Shaw & others, 1995; Shaw & Palfreyman, 1995) that make up the Australian craton, the Cooper Basin predominantly overlies the Tasman mega-element, and also overlaps the South Australia mega-element (Figure 5). Since the Tasman mega-element is a younger (Palaeozoic) orogenic/fold belt, it is likely that South Australia and Central Australia mega-elements (Proterozoic) underlie the Tasman mega-element beneath the Cooper Basin. The Cooper Basin and the adjacent portion of the Eromanga Basin, therefore, overlie an area with a complex crustal history.

The smaller crustal elements (Shaw & others, 1995; Shaw & Palfreyman, 1995), which underlie the Cooper Basin and the Eromanga Basin in the project area (Figure 6), reflect the complexity inherent in the mega-element distribution. The main crustal element is the Thomson Fold Belt, but, in the southern part of the project area, a geophysically distinct unit, the Bourke Province, is present. The Bourke Province has a younger geophysical overprint than the Thomson Province and marks an area separating the Thomson Fold Belt from the Lachlan Fold Belt. An area of the Worominta Province underlies the Cooper Basin in South Australia. The gravity trend that marks the contact between the Thomson Fold Belt and the Bourke Province coincides with the younger Gidgealpa–Merrimelia–Innaminka (GMI) trend and the Jackson–Naccowlah–Pepita (JNP) trend (Figure 6). Meixner & others (1999, 2000), using both magnetic and gravity data, identified differences in the nature of the basement across the GMI trend. The basement rocks are separated by a steeply, south-east dipping fault which Meixner & others considered to have controlled the formation of the GMI trend. The fault has a throw of about 3.5km.

PRE-COOPER BASIN GEOLOGICAL HISTORY

The oldest rocks beneath the Cooper Basin in South Australia are those of the Arunta Complex (Parker *in* Drexel & others, 1993, p18) representing the Central Australia mega-element; the extent of the distribution of these rocks is unknown. It is also likely that rocks of the Curnamona Craton occur under the basin in South Australia. The fault identified by Meixner & others (1999, 2000) may represent the contact between the Arunta Complex and the Curnamona Craton. Little is known about pre-Palaeozoic rocks under the Thomson Fold Belt in Queensland.

The Wonaminta Province extends to near the southern margin of the Cooper Basin in South Australia. This is part of the Kanmantoo Fold Belt (Scheibner, 1974) of the Tasman Fold Belt System. The Kanmantoo Fold Belt contains Neoproterozoic to Ordovician sedimentary and volcanic rocks deformed in the Delamerian Orogeny and modified by subsequent orogenies. Beneath the Cooper Basin in South Australia and partly in Queensland, the Warburton Basin contains rocks of a similar age to the younger rocks of the Kanmantoo Fold Belt, but is less deformed. Parker (*in* Drexel & others, 1993, page 23) described the Warburton Basin as providing the connection between the deeper marine rocks of the Kanmantoo Fold Belt and the intra-continental basins to the west (for example, the Amadeus Basin). Most of the Cooper Basin in Queensland is directly underlain by Thomson Fold Belt rocks; the relationship between the Kanmantoo Fold Belt, the Warburton Basin and the Thomson Fold belt is the subject to conjecture and ongoing debate (Scheibner, 1996; Murray, 1994).

The geology of the Warburton Basin in South Australia has been described by Gatehouse (1986), Gravestock & Gatehouse (*in* Drexel & Priess, 1995, pages 31–34), Sun (1996, 1997, 1998, 2001) and Sun & others (1994). The lowest unit, the Pando Formation (Gravestock in Gravestock & others, 1995, page 7), contains shale, sandstone and siltstone and is assumed to be Early Cambrian based on the presence of burrows. The Pando Formation interfingers with the overlying Early Cambrian Mooracoochie Volcanics, which comprise acid and basic lavas, tuffs and volcaniclastic sedimentary rocks interbedded with minor shallow marine sedimentary rocks. Overlying the Volcanics unconformably is an unnamed dolomite unit of early Middle Cambrian age. The Kalladeina Formation, which ranges in age from Middle Cambrian to Early Ordovician, is a mixed carbonate – siliciclastic unit and unconformably overlies the unnamed dolomite. It is overlain by a red bed sequence, the Innamincka Formation, whose upper age is not defined, but is probably middle or early Late Ordovician. The Innamincka Formation and uppermost Kalladeina Formation pass laterally into the Dullingari Group in the south of the basin. The Dullingari Group comprises turbiditic quartzose sandstone, shale and siltstone and has an upper age of Middle Ordovician or early Late Ordovician.

A number of ages have been proposed for the deformation of the Warburton Basin sequence. Gravestock & Flint (*in* Drexel & Priess, 1995, page 61) favoured a mid-Carboniferous deformation whilst earlier workers such as Roberts & others (1990) favoured an Ordovician event. An Early Silurian deformation was proposed by Gatehouse (1986). The only control is that the emplacement of Late Carboniferous granites – deformation must have occurred between the Late Ordovician and Late Carboniferous. The area is likely to have been affected by more than one deformation during this time and may have been affected by events in the Tasman Fold Belt System and in central Australia.

Murray (1994) studied the Thomson Fold Belt beneath the Cooper Basin in Queensland. He recognised possible Innamincka Formation sedimentary rocks in several wells. The bulk of the Thomson Fold Belt rocks are similar to those of the Dullingari Group. Although there is no direct age control, a Cambrian to Ordovician age is likely given this correlation. An upper age limit for the Thomson Fold Belt is provided outside the project area by the presence of latest Ordovician post-orogenic granites. Folding and metamorphism preceded emplacement of these granites. If the Thomson Fold Belt was deformed in the late Middle to Late Ordovician, it would be expected that at least part of the Warburton Basin would have been affected by the deformation.

The age of granites below the Cooper Basin provides an enigma with different ages on each side of the state border (Figure 7). The two dates shown for South Australia are from the Big Lake Suite and are ion microprobe dates (SHRIMP). The date from Moomba 1 is 323±5Ma and from MacLeod 1 is 298±4Ma (Gatehouse & others, 1995). The dates in Queensland are K–Ar dates on muscovite. The age in DIO Ella 1 is 408±2Ma and in TEA Roseneath 1 is 405±2Ma (Murray, 1994). All dated granites beneath the Cooper Basin are S-type granites. At Tibooburra, in New south Wales, an I-type granite has an age of 410Ma (*in* Scheibner, 1996). Using the AGSO Timescale (Young & Laurie, 1996), the Queensland granites are Early Devonian whereas the South Australian granites are mid to latest Carboniferous. Regional gravity data (Figure 7) show that the Devonian granites and Carboniferous granites occur within discrete arcuate belts (see Meixner & others (2000) for the distribution of these granites in South Australia).

The Early Devonian granites coincide with widespread extension in the Thomson Fold Belt (Evans & others, 1990) with the formation of the Adavale Basin and the Warrabin and Barolka Troughs (Figure 8). The earliest sequences in the Adavale Basin are intermediate continental volcanics and red beds. Finlayson & others (1990) discuss the possibility of mafic underplating of the crust during this extensional phase. The Adavale Basin was subsequently deformed in the Middle Carboniferous although Finlayson & others (1990) have described the "Quilpie Orogeny" as occurring during the Early to Middle Carboniferous, postulating movements of tens of kilometres along westward dipping, mid-crustal ramps during the orogeny.

It is clear that, despite the relatively rudimentary nature of the knowledge of basement events beneath, and adjacent to, the Cooper basin, the area has been subjected to a complex history. Structural grain developed during this earlier time has imposed its influence on Cooper Basin formation and subsequent structures.

A number of authors have focussed on prominent north-west and north-east trending lineaments (for example, Campbell & O'Driscoll, 1989; Hill & Gravestock *in* Drexel & Priess, 1995, page 78; Apak & others, 1997). Major magnetic trends support the north-east trend (Figure 6). However, gravity trends and regional gravity suggest arcuate trends (Figure 6) as well as lineaments. Arcuate trends may better reflect previous thrusting or compressive events as well as pre-existing basement structures. Regional gravity data (Figure 7) shows that the Devonian granites and Carboniferous granites occur within discrete arcuate belts.

PALYNOLOGICAL BIOSTRATIGRAPHY AND AGE OF THE COOPER AND EROMANGA BASINS

JL McKellar

In the present work (under the subheading "Age" in the succeeding sections), the late Palaeozoic–Mesozoic biostratigraphy of the Cooper and Eromanga Basins is considered largely in terms of the palynostratigraphic nomenclature established by Price & others (1985), Filatoff & Price (1988) and Price (1997) for these and equivalent basins in central and eastern Australia. The spore-pollen and dinocyst schemes of Helby & others (1987) have also been utilised to reference particular parts of the Mesozoic section, and additionally, for the Jurassic in the Eromanga Basin, the biozones formally established by McKellar (in press) in the adjoining Surat Basin have been referred to (Figure 10).

The AGSO Phanerozoic Timescale Wallchart (AGSO, 1996) has been employed as a basis for dating the succession in the Cooper and Eromanga Basins, although with the various modifications outlined by McKellar (in press). Nonetheless, for the Permian–Triassic (Palaeozoic–Mesozoic) boundary, the numerical age of 251Ma is adhered to. In the AGSO Timescale, this age was based on a mean $^{238}U/^{206}Pb$ age of 251.2±3.4Ma from ion-microprobe dating of zircons from the Chinese Permian–Triassic boundary succession at Meishan (Claoué-Long & others, 1991). This accords with the age of 251.4Ma tentatively adopted for the boundary by the Subcommission on Permian Stratigraphy (Wardlaw, 1999, 2000; after Bowring & others, 1998). However, in relation to the limited SHRIMP dating that has been undertaken in the Denison Trough, south-western Bowen Basin (Roberts & others, 1996, 1997; compare Draper & Fielding, 1997), a 251Ma age for the system–era boundary leads to considerable uncertainty as to its stratigraphic location in eastern Australia. This results from the ages of 250.1±2.8Ma and 250.1±2.2Ma, which have been obtained by Roberts & others from the Black Alley Shale (Figure 9), a unit which occurs significantly below all previous placements of the Permian–Triassic boundary in the Bowen Basin.

From a biostratigraphic perspective, and contrasting with the AGSO Timescale, McKellar (in press) arbitrarily positioned the Permian–Triassic boundary above the base of (and within) the *Protohaploxypinus microcorpus* "Oppel" Zone [of Helby (1973) and Helby & others (1987); =palynological unit APP6 (of Price, 1997); Figure 9, this volume]. The lower limit of this zone (and APP6) represents the base of the latest Permian(?)–Triassic–early Hettangian(?) *Alisporites* (*Falcisporites*) Superzone/ Microflora (of Helby & others, 1987, fig. 3). Retallack (1995, 1999), on the other hand, sited the Permian–Triassic boundary coincident with the base of the *microcorpus* Zone. In the Denison Trough, the system–era boundary (following McKellar, in press) approximates or equates with the sequence boundary between the Bandanna Formation (and equivalents) and the Rewan Group; in some regions of the Bowen Basin, it may occur in the basal part of the Rewan Group, because of the mildly diachronous nature of the contact between the Bandanna Formation and the Rewan Group (Figure 9). This contact nevertheless represents the traditional lithostratigraphic location of the Permian–Triassic boundary in the basin, the equivalent in the Sydney Basin being the formation boundary common to the Narrabeen Group and the underlying coal measures (for example: David, 1950; Dickins & Malone, 1973). In the Cooper Basin, in the present study, the Permian–Triassic boundary is thus located within the lower/basal part of the Callamurra Member of the Arrabury Formation (Nappamerri Group) [Figures 3, 9]. Other workers (Price & others, 1985; Helby & others, 1987; Price, 1997; Alexander & others, 1998) place the Permian–Triassic boundary somewhat higher in the succession, generally at the base of the succeeding palynostratigraphic zone [palynological unit PT1/APT1 of Price & others (1985) and Price (1997); *Lunatisporites pellucidus* "Oppel" Zone of Helby (1973) and Helby & others (1987)]. Such placement, in the Cooper Basin, occurs at a higher stratigraphic level in the Callamurra Member.

There is also some dispute over the numerical age of the Carboniferous–Permian boundary and its relationship to the palynostratigraphic zones applied to the Cooper Basin. In Figures 3 and 9, this Period–System boundary is placed at 298Ma and palynological unit APP12 (and the Merrimelia Formation at the base of the Cooper Basin succession) is placed entirely within the Permian (variously following: Roberts & others, 1996; AGSO, 1996; Gravestock, 1998; McKellar, in press). Other authors, however, regard palynological unit APP12 as spanning the Carboniferous–Permian boundary and consider the Merrimelia Formation to do likewise, occupying a significant part of the Stephanian (Alexander & others, 1998; G. Wood, personal communication). Moreover, in the tentative timescale proposed by the Subcommission on Permian Stratigraphy (Wardlaw, 1999, 2000), the Carboniferous–Permian boundary has been assigned the somewhat younger age of 291.6Ma, apparently based on the same parameters/constraints available to Roberts & others.

Granite emplaced below the region that was to become the Cooper Basin has yielded a SHRIMP $^{238}U/^{206}Pb$ zircon age of 298±4Ma (Gatehouse & others, 1995; for granite in the McLeod 1 drillhole, Nappamerri Trough). Gravestock & Jensen-Schmidt (1998) have suggested that this (highly weathered/ hydrothermally altered) granite was exposed on the initially irregular floor of the Cooper Basin only 10 million years after emplacement. Deighton & Hill (1998), on the other hand, have broadly referred a ~300Ma age to it and suggested that Cooper Basin sedimentation was initiated only 5–10 million years subsequently.

If the above-cited SHRIMP date for the granite and the 298Ma age for the Carboniferous–Permian boundary are both valid, the Merrimelia Formation and its contained palynofloras are entirely earliest Permian in age, irrespective of whether granite exposure occurred in 5 million or 10 million years (or longer). This, however, does not exclude the possibility that palynological unit APP12 extends down into the latest Carboniferous.

Alternatively, if the age of 291.6Ma is followed for the Carboniferous–Permian boundary, the Merrimelia Formation would be either latest Carboniferous–earliest Permian or entirely earliest Permian in age; a 10-million-year exposure time, however, still almost entirely confines the formation to the Permian, considering a maximum 302Ma (298+4Ma) age for the pluton.

COOPER BASIN STRATIGRAPHY

ARG Gray & JL McKellar

The stratigraphy of the Cooper Basin is summarised in Figure 11.

GIDGEALPA GROUP

Definition and Nomenclature

Kapel (1966) proposed the name Gidgealpa Formation for "a sequence of Permian sediments intersected in petroleum exploration wells". The Gidgealpa Formation was subsequently elevated to group status (Kapel, 1972) and subdivided, in ascending order, into the Tirrawarra Sandstone and the Patchawarra, Moomba and Toolachee Formations. Gatehouse (1972) formally defined the Gidgealpa Group and replaced the Moomba Formation by defining and naming its components, the Murteree Shale, Epsilon Formation, Roseneath Shale and Daralingie beds (Alexander & others, 1998). Morton & Gatehouse (1985) redefined the type section of the Toolachee Formation and replaced the term Daralingie beds with Daralingie Formation. Gravestock & others (1995), following the recommendation of Williams & Wild (1984), redefined the Gidgealpa Group to include the Merrimelia Formation, which previously was regarded as underlying the Gidgealpa Group. The base of the Merrimelia Formation, where present, constitutes the base of the Gidgealpa Group and the top of the Toolachee Formation, where present, the top of the Gidgealpa Group (Gravestock & others, 1995).

Rock Types

The Gidgealpa Group is completely non-marine and is characterised by coal measures, especially within the Patchawarra, Epsilon and Toolachee Formations. The coal measures are separated by lacustrine shales and siltstones. Quartz-rich sandstones within the coal measures form excellent gas reservoirs in many parts of the basin. The Merrimelia Formation at the bottom of the Gidgealpa Group is of glacial origin and is composed mostly of conglomerate, sandstone, conglomeratic mudstone, siltstone and shale.

Relationships

The Gidgealpa Group unconformably overlies Middle Carboniferous and older sedimentary, igneous and metamorphic rocks, and is conformably overlain by the Late Permian–Triassic Nappamerri Group or disconformably by younger sedimentary rocks of the Eromanga Basin. A widespread unconformity (the Daralingie unconformity) occurs within the mid-Permian succession.

Thickness

The Gidgealpa Group is thickest (from 300m to >800m) in the south-western part of the Cooper Basin in Queensland, in the Nappamerri Trough south of the JNP Trend. A thickening of the Gidgealpa Group is also evident in wells drilled on the JNP Trend where thicknesses of 200m to >400m have been met compared with thicknesses of mostly <100m in wells adjacent to the JNP Trend. In the northern and north-eastern Cooper Basin north of the JNP Trend and on the southern flanks of the Cooper Basin in Queensland, the unit is mostly from 50m to <150m thick. Thickest intersections of the Gidgealpa Group are 893m in DIO Innamincka 2 and 804m in SSL Kappa 1. Figure 12 shows the variation in thickness and the distribution of the Gidgealpa Group.

Age

The Gidgealpa Group ranges in age from Early to Late Permian (palynological units APP12 to APP5 of Price, 1997; detailed hereunder for the constituent formations; also see Figures 3, 9).

MERRIMELIA FORMATION

Nomenclature

The name Merrimelia Formation was first applied by Martin (1967) to "a heterogeneous rock formation deposited between the unconformity surface which developed after the Bowning(?) Orogeny and the overlying Gidgealpa Formation". After further studies, the Merrimelia Formation is now defined as the suite of glacigenic rocks which comprises the lowest formation of the Gidgealpa Group (Alexander & others, 1998).

Rock Types

The Merrimelia Formation is composed of conglomerate, diamictite, sandstone, conglomeratic mudstone, siltstone and shale, commonly green–grey. Rapid facies transitions can occur with each lithotype. Sedimentary, metamorphic, igneous and pyroclastic clasts have been identified petrologically (Alexander & others, 1998).

Wireline Log Character

The Merrimelia Formation has been intersected in only a few wells in Queensland. In these wells, the gamma-ray logs show a variable response and this reflects the changes in lithology. There is insufficient coverage of the unit by wireline logs in Queensland for any distinctive trends to be identified.

Relationships

The Merrimelia Formation unconformably overlies either basement metasediments or rocks of the Cambrian–Ordovician Warburton Basin or ?Devonian Barolka Trough. It forms an intertonguing relationship with the overlying Tirrawarra Sandstone and the two formations are difficult to separate, particularly in South Australia. Because of this intertonguing relationship, the Merrimelia Formation and Tirrawarra Sandstone have been combined to provide the isopach map in this report (Figure 13).

Thickness

Maximum thickness of the Merrimelia Formation intersected to date is 84m in DIO Pepita 2 on the JNP Trend. Over 50m were intersected in the Challum Gas Field in the same area. The maximum thickness could however be greater. In the nearby FPN Tallalia 1 well, drilled in 1970, the Merrimelia Formation may be about 170m thick, but there is doubt where basement was met in this well. The exact thickness of the Merrimelia Formation cannot be determined until this is decided. Further east and to the south, isolated intersections of the Merrimelia Formation were mostly in the order of 20m. A continuously cored section of grey–green conglomerate and lesser sandstone, considered to be Merrimelia Formation equivalent, was obtained in the lowermost 40m of GSQ Thargomindah 2 east of the Jackson Oil Field. A combined isopach map for the Merrimelia Formation and Tirrawarra sandstone is shown in Figure 13.

Age

Palynofloras from the Merrimelia Formation are conformable largely with palynological unit APP121, although the basal part of unit APP122 also appears to be represented in some uppermost sections of the formation (Price, 1997; G. Wood, personal communication). An Early Permian [Asselian–early Sakmarian(?)] age is suggested (Figures 3, 9, this volume; also see introductory discussion under *Palynological Biostratigraphy and Age of the Cooper and Eromanga Basins*).

Distribution

In Queensland, the Merrimelia Formation occurs mainly in the western part of the basin, in the Nappamerri and Arrabury Troughs and on the flanks of the JNP Trend. Elsewhere, the formation occurs as a few isolated remnants in basement hollows.

Depositional Setting

The Merrimelia Formation is a complex mosaic of glacial facies in which the Tirrawarra Sandstone (*sensu stricto*) and Merrimelia Formation (*sensu stricto*) interfinger (Williams & Wild, 1984). The various facies types, ranging from proglacial fluvial outwash deposits, termino-glacial fluvial deposits and varvites to delta front debris flows and deep water lacustrine deposits, have resulted directly from the action of glacial meltwater and sediment output (Alexander & others, 1998). As the glacial influence waned, “Tirrawarra type” and Merrimelia sediments were deposited in an interfingering manner.

TIRRAWARRA SANDSTONE

Nomenclature

The “Tirrawarra Formation” (Kapel, 1972) was first used for a sandstone in the lower part of the Gidgealpa Formation. Subsequently, Gatehouse (1972) raised the Gidgealpa Formation to group status and changed the name Tirrawarra Formation to Tirrawarra Sandstone.

Rock Types

The Tirrawarra Sandstone consists mainly of white to pale brown, fine- to coarse-grained and pebbly sandstone with locally common interbeds of conglomerate and minor interbeds of carbonaceous siltstone, shale and coal. Sandstone is massive and is flat or planar cross-bedded with a siliceous or kaolinitic matrix (Gravestock & others, 1995).

Wireline Log Character

The Tirrawarra Sandstone has been intersected in only a few wells in Queensland. In these intersections, the formation is characterised by generally low gamma-ray values, low to moderate resistivity values and slow travel times on the sonic log. The occasional high gamma-ray response is commonly associated with conglomerate. Very slow travel times reflect the few thinly interbedded coal seams.

Relationships

In South Australia, the Tirrawarra Sandstone is commonly conformable with both the underlying Merrimelia Formation and the overlying Patchawarra Formation. An interfingering relationship with both these formations has been demonstrated (Alexander & others, 1998). In Queensland, such relationships cannot be demonstrated with certainty because limited data. On the northern flank of the JNP Trend in the Macadama–Mahl area, the Tirrawarra Sandstone appears to unconformably overlie basement of the Warburton Basin. In other wells where the Tirrawarra Sandstone overlies the Merrimelia Formation, the relationship is uncertain.

Thickness

The intersections of the Tirrawarra Sandstone in Queensland wells ranged in thickness from 30 to 40m. It could be ~70m thick in FPN Tallalia 1 well. In the designated reference section in Tirrawarra 1 well in South Australia, the Tirrawarra Sandstone is 44m thick (Alexander & others, 1998).

Age

The Tirrawarra Sandstone (*sensu stricto*) has yielded Early Permian (late Asselian – early Sakmarian) palynofloras that had been assigned previously to the upper APP121–basal APP21 palynological succession (Price, 1997). Although only limited biostratigraphic data are available from the formation in Queensland, associated assemblages from Core 2 in DIO Pepita 1 were considered by Williams & Wood (1984) to be upper Stage 2 (=palynological unit APP12) to probably lower Stage 3 (=palynological unit APP21) in age. However, these authors did not record the Stage 3 index, *Pseudoreticulatispora pseudoreticulata*, but reported forms very close to it. The latter are now known to represent *Pseudoreticulatispora confluens* (G. Wood, personal communication), the index for a biounit, the *P. confluens* Zone (=palynological unit APP122 of Price, 1997), which was recognised and defined subsequently (Foster & Waterhouse, 1988; Backhouse, 1991).

In Queensland, there is no definitive evidence for a lower Stage 3/APP21 age for the Tirrawarra Sandstone, which thus appears to be confined to unit APP12 and largely, if not entirely, to APP122 (Figures 3, 9, this volume). The same also seems to be the case for the formation in the Cooper Basin of South Australia, where APP21-bearing sandstone beds, previously considered to lie at the top of the Tirrawarra Sandstone, are now taken to represent the base of the Patchawarra Formation because of traces of coal in them (G. Wood, personal communication).

Distribution

In Queensland, the Tirrawarra Sandstone was intersected in only a few wells on the JNP Trend between the Queensland–South Australian border and eastward to approximately 141°25′E.

Depositional Setting

Originally regarded as a fluvial valley-fill deposit, the Tirrawarra Sandstone is now considered to have been deposited by meltwater streams flowing north from retreating glaciers, and as reworked unconsolidated Merrimelia sediments (Alexander & others, 1998).

PATCHAWARRA FORMATION

Nomenclature

The Patchawarra Formation (Kapel, 1972) was named after Patchawarra bore in South Australia and defined by Gatehouse (1972) as the interbedded sandstone, siltstone, shale and coal beneath the Murteree Shale and above the

Tirrawarra Sandstone, Merrimelia Formation or pre-Permian rocks (Alexander & others, 1998).

Rock Types

The Patchawarra Formation is composed of upwardly fining facies associations of sandstone, siltstone, mudstone and coal, with siltstone and mudstone mainly in the uppermost part of the formation. Sandstone is grey to brown, fine- to medium-grained and locally coarse-grained and pebbly. Authigenic quartz, kaolinite and dickite are common. Siltstone and mudstone are grey–brown to dark grey and carbonaceous. Coal occurs as laminae, thin seams and seams up to 16m thick (Gravestock & others, 1995).

Wireline Log Character

Upwardly fining facies are demonstrated on the gamma-ray log by upwardly increasing values. Interbedded coal seams are prominently displayed by high resistivity log values and slow travel times on the sonic log.

Relationships

In Queensland, the Patchawarra Formation either conformably overlies the Tirrawarra Sandstone or more commonly, unconformably overlies Merrimelia Formation or basement of metasediments, or rocks of the Warburton Basin or Adavale Basin equivalents.

In Queensland, in deeper parts of the basin in the south-west, in the Nappamerri and Tenappera Troughs and the intervening Orientos Anticlinal Complex, the Patchawarra Formation is conformably overlain by the Murteree Shale. In some southern parts of the basin, the upper Patchawarra Formation interfingers with the overlying Murteree Shale. In areas where the Murteree Shale becomes very sandy and loses its identity it cannot be distinguished from either the underlying Patchawarra Formation *(sensu stricto)* or overlying Epsilon Formation. In these wells, the whole interval has been regarded lithologically as uppermost Patchawarra Formation, although spore and pollen assemblages suggest equivalence with the Murteree Shale and Epsilon Formationm. In most other areas, particularly on the JNP Trend and northern parts of the basin, the Patchawarra Formation is unconformably overlain by the Toolachee Formation. In some southern parts of the basin, eroded remnants of the Patchawarra Formation are unconformably overlain by Eromanga Basin strata.

Thickness

Maximum thickness of the Patchawarra Formation could be up to about 550m in FPN Tallalia 1 on the southern flank of the JNP Trend near the South Australian border. However, it is possible that the Toolachee Formation constitutes the uppermost 20–30m of the section but there is insufficient palynological control to prove this. A possibly thicker section of Patchawarra Formation is present in the nearby DIO Innamincka 2 well where 747m of undifferentiated Gidgealpa Group, excluding possible Tirrawarra Sandstone and Merrimelia Formation equivalents, were intersected. Differentiation of the Gidgealpa Group is not possible in this 1965 well because of the lack of palynological control and the poor quality of the wireline logs compared with present-day standards. The next thickest intersection of the Patchawarra Formation is 363m in SSL Kappa 1 in the southern part of the basin.

Over most of the basin, the Patchawarra Formation is from 50–150m thick with some thickening (by up to 150m) evident along the JNP Trend and some southern parts of the basin. The Patchawarra Formation has been subjected to erosion in many parts of the basin and is mostly <100m thick north of the JNP Trend and in southernmost parts of the basin in Queensland.

Figure 14 shows the distribution and variation in thickness of the Patchawarra Formation. Distribution of aggregate sandstone thickness is shown in Figure 15 and porosity distribution in Figure 16. Shale thickness is shown in Figure 17 and coal thickness in Figure 18.

Age

The stratigraphically extensive Patchawarra Formation contains palynofloras that have been assigned to palynological units APP21, APP22, APP31 and APP32 (Price, 1997; G. Wood personal communication; Figures 3, 9, this volume). An Early Permian (mid-Sakmarian – Artinskian – early Kungurian) age is indicated for the formation.

Assigment of the upper Patchawarra Formation to units APP33 and APP41 and consequent lateral equivalence with the stratigraphically succeeding Murteree Shale, Epsilon Formation and lower Roseneath Shale have also been indicated previously by some authors. However, it is now known that such relationships are erroneous and result from the difficulty of distinguishing the coal-measures sequence of the Epsilon Formation from that of the Patchawarra Formation where the intervening Murteree Shale cannot be readily recognised (G. Wood, personal communication).

Distribution

The Patchawarra Formation is the second most widespread, after the Toolachee Formation, of the Permian units in the Cooper Basin in Queensland (Figure 14).

Depositional Setting

Upwardly fining facies from sandstone to siltstone, shale and coal, which dominate the unit, suggest that the Patchawarra Formation was deposited mainly by high sinuosity fluvial systems flowing northwards over a floodplain with peat swamps, lakes and gentle uplands (Alexander & others, 1998). The upwardly fining facies are interpreted as point bars, which are commonly stacked to form compound bars with internal scours. Upwardly coarsening packages which are fewer, are probably crevasse splay deposits. Deltaic, lagoonal and lacustrine environments, as a result of a broad lake inundating the Patchawarra floodplain, are interpreted for deposition of the upper part of the Patchawarra Formation (Gravestock & others, 1995; Alexander & others, 1998).

The Patchawarra Formation accumulated during the waning stages of the Early Permian glaciation and this is supported by the interfingering of the lower part of this unit, in some areas, with the underlying glacially-derived Tirrawarra Sandstone.

MURTEREE SHALE

Nomenclature

The Murteree Shale (Gatehouse, 1972), named after Lake Murteree in South Australia, was defined as a series of shales overlying the Patchawarra Formation and overlain by the Epsilon Formation. The Murteree Shale was originally regarded by Kapel (1972) to be the lowermost of three units constituting the Moomba Formation (Alexander & others, 1998).

Rock Types

The Murteree Shale consists of dark grey–brown to black, laminated, argillaceous siltstone and lesser fine-grained sandstone. Carbonaceous material, muscovite and fine-grained pyrite are characteristic of the unit (Gravestock & others, 1995).

Wireline Log Character

Uniformly high gamma-ray and density log values and mostly featureless, spontaneous potential, resistivity and sonic logs are typical of the Murteree Shale.

Relationships

The Murteree Shale conformably overlies the Patchawarra Formation and is conformably overlain by the Epsilon Formation. Intertonguing with the upper Patchawarra Formation occurs in some areas (Alexander & others, 1998). In some wells, the Murteree Shale is unconformably overlain by the Toolachee Formation as a result of renewed tectonic activity and erosion during the mid-Permian (Daralingie Unconformity).

Thickness

The Murteree Shale is fairly uniform in thickness in Queensland and is mostly <50m thick where it is not partly eroded (Figure 19). Maximum thickness intersected to date is 71m in SSL Moon 1 in the Tenappera Trough. In South Australia, the Murteree Shale averages ~50m and reaches a maximum thickness of 80m in the Nappamerri Trough (Alexander & others, 1998).

Age

Late Early Permian (Kungurian) palynofloras conformable with palynological unit APP32 are associated with the Murteree Shale (Price, 1997; Figures 3, 9, this volume). The formation may be, at least in part, a time equivalent of the Sirius Mudstone Member of the Cattle Creek Formation in the Denison trough, south-western Bowen Basin (Figure 9).

Distribution

The Murteree Shale is preserved in the south-western part of the Cooper Basin in Queensland adjacent to the South Australian border, in the Nappamerri and Tenappera Troughs and on the anticlinal trends which separate these troughs (Figure 19). The Murteree Shale is mostly absent on the JNP Trend.

Depositional Setting

A restricted sea of low salinity or a large freshwater lake have been proposed as two possible environments of deposition for the Murteree Shale. The latter is preferred as no acritarchs (of marine or non-marine affinity) or marine invertebrate fossils have been found. Parallel laminations, abundant disseminated organic matter, silt-sized pyrite and rare trace fossils all suggest a freshwater lake with restricted circulation as the environment of deposition for the Murteree Shale (Gravestock & others, 1995).

EPSILON FORMATION

Nomenclature

The Epsilon Formation (Gatehouse, 1972), named from Epsilon parish in south-west Queensland, was defined as a distinct unit overlying the Murteree Shale and overlain by the Roseneath Shale. Strata equivalent to the Epsilon Formation were originally included by Kapel (1972) as the middle of three distinct units within the Moomba Formation. The type section occurs between 2095.2m and 2136.9m in DIO Epsilon 1 in Queensland.

Rock Types

The Epsilon Formation comprises sandstone, siltstone, mudstone and coal in varying proportions. The sandstone is thinly bedded, fine- to medium-grained, moderately to very well-sorted, quartzose and consists of monocrystalline quartz with some chert, sedimentary rock fragments and polycrystalline quartz. Siltstone and mudstone are dark grey–brown, carbonaceous and slightly pyritic. Coal seams are extensive but rarely exceed 2–3m and are commonly <0.3m thick (Gravestock & others, 1995).

Wireline Log Character

The gamma-ray logs commonly show sandstones with upwardly-coarsening features (upwards decrease in values). Thin coal seams are identified by their high resistivity log values and slow travel times on the sonic log. On wireline logs, the Epsilon Formation is readily distinguished from the underlying Murteree Shale and the overlying Roseneath Shale, which are mostly very featureless.

Relationships

The Epsilon Formation conformably overlies the Murteree Shale and is conformably overlain by the Roseneath Shale with which some intertonguing occurs (Alexander & others, 1998). Strata equivalent to the Epsilon Formation have been included in the uppermost part of the Patchawarra Formation in some wells, in the absence of suitable lithological or palynological data. In some wells, the Epsilon Formation is unconformably overlain by the Toolachee Formation as a result of tectonic activity and erosion of the intervening units during the mid-Permian (Daralingie Unconformity).

Thickness

The Epsilon Formation is mostly 30–40m thick and, in deeper parts of the Nappamerri Trough, is >60m thick (Figure 20). It attains a maximum thickness of 92m in SSL Juno 1, in the eastern Nappamerri Trough. In South Australia, the Epsilon Formation reaches a maximum thickness of 156m in the Nappamerri Trough (Alexander & others, 1998). Aggregate sand thickness isopachs are shown in Figure 21, shale thickness in Figure 22 and coal thickness in Figure 23.

Age

The Epsilon Formation embraces late Early Permian (Kungurian) palynofloras conformable with upper APP32, APP33 and basal APP41 (Price, 1997; G. Wood, personal communication; Figures 3, 9, this volume).

Distribution

The Epsilon Formation is preserved mainly in the south-western part of the Cooper Basin in Queensland, adjacent to the South Australian border, in much the same area as the underlying Murteree Shale (Figure 20). The Epsilon Formation was also recognised in several wells on the eastern part of the JNP Trend.

Depositional Setting

Wireline log patterns suggest that the Epsilon Formation comprises mostly shoreface sands and deltaic and lacustrine deposits. The Epsilon Formation in the southern Cooper

Basin was divided by Fairburn (1992) into three depositional stages — a lower unit as a shoreline facies, a deltaic middle unit, and a lake or marine shoreline upper unit. The lower and upper units were attributed to regression of the lacustrine system which deposited the Murteree and Roseneath Shales. The middle unit was deposited by fluvially dominated deltas. Coal seams, which dominate the middle unit, were formed in flood plains and interdistributary swamps (Gravestock & others, 1995). Lang & others (2000) described a modern and an ancient analogue for the Epsilon Formation.

ROSENEATH SHALE

Nomenclature

The Roseneath Shale (Gatehouse, 1972), named from Roseneath parish in south-western Queensland, was defined as the shales and minor siltstones which conformably overlie the Epsilon Formation and are overlain conformably by the Daralingie beds or unconformably by the Toolachee Formation (Alexander & others, 1998). The Roseneath Shale was originally regarded by Kapel (1972) to be the uppermost of three distinct units forming the Moomba Formation. The type section occurs between 1956.8m and 2024.5m in TEA Roseneath 1 in Queensland.

Rock Types

The Roseneath Shale comprises light to dark brown–grey or olive–grey, laminated siltstone, mudstone and lesser sandstone. Siltstones are carbonaceous, micro-micaceous and contain concentrations of pyrite and siderite. Sandstone is light brown, fine-grained and rarely forms beds >1–2m thick (Gravestock & others, 1995).

Wireline Log Character

Wireline log responses are similar to those of the Murteree Shale in that gamma-ray and density log values are higher than those of the enclosing formations. Spikes on the density log may be due to pyrite or siderite (Gravestock & others, 1995). Spontaneous potential, resistivity and sonic logs are mostly featureless.

Relationships

The Roseneath Shale conformably overlies and intertongues with the Epsilon Formation and is overlain by and intertongues with the Daralingie Formation (Alexander & others, 1998). In several wells in the southern part of the Cooper Basin in Queensland, the Roseneath Shale is unconformably overlain by the Toolachee Formation because of erosion (Daralingie Unconformity).

Thickness

The Roseneath Shale is commonly 50–80m thick and reaches a maximum thickness of 99m in DIO Warnie East 1 in the southern part of the Nappamerri Trough (Figure 24). In the Jackson–Naccowlah East area it is commonly 20–30m thick.

Age

Palynofloral assemblages from the Roseneath Shale are attributable to the uppermost part of palynological unit APP33, APP41, and the basal part of APP42 (Price, 1997; G. Wood, personal communication; Figures 3, 9, this volume). A late Early – early Middle Permian [latest Kungurian(?) – Roadian (Ufimian) – early Wordian] age is suggested.

The palynological biostratigraphy (Figure 9) indicates that the Roseneath Shale was deposited at a time during the mid-Permian when there was compressional uplift in eastern Australia (and elsewhere along the Panthalassan/Pacific margin of Pangaea) [McKellar, in press]. As noted by the latter author, this contractional event represents onset of the Hunter–Bowen Orogeny (and coeval global orogeny), being marked by the "mid-Aldebaran" hiatus in the Denison Trough (south-western Bowen Basin). Presumably, the change from the Epsilon Formation to the Roseneath Shale symbolises the effect on internal depositional environments of this mid-Permian tectonism on the Greater Eastern Australian margin.

Distribution

The Roseneath Shale occurs mainly in the south-western part of the Cooper Basin in Queensland adjacent to the South Australian border, in the Nappamerri and Tenappera Troughs and on the anticline trends that separate them (Figure 24). The formation is also recognised on the eastern part of the JNP Trend.

Depositional Setting

The Roseneath Shale was probably deposited in a lacustrine environment similar to that of the Murteree Shale. Slump folds and reactivation surfaces in the lower part of the formation suggest high initial rates of deposition on an unstable slope (Gravestock & others, 1995).

DARALINGIE FORMATION

Nomenclature

The name "Daralingie beds" was applied by Gatehouse (1972) to a succession of sandstones, shales and coals overlying the Roseneath Shale and disconformably overlain by the Toolachee Formation (Alexander & others, 1998). Morton & Gatehouse (1985) raised the "Daralingie beds" to formation status. The name was derived from Daralingie waterhole on Strzelecki Creek in South Australia.

Rock Types

The Daralingie Formation consists of interbedded siltstone, mudstone, coal and minor sandstone. Siltstone and mudstone are light grey to black, carbonaceous and micaceous. Sandstone is light grey–brown, very fine- to fine-grained (rarely medium- or coarse-grained) with a white kaolinitic matrix and some carbonaceous inclusions (Gravestock & others, 1995).

Wireline Log Character

Only thin intersections (mostly <30m thick) of the Daralingie Formation have been met in Queensland wells, and this limits distinguishing wireline log characters. Contact with the underlying Roseneath Shale can generally be readily picked by an upward decrease in gamma-ray and increase in resistivity values. However, because of the marked similarity in rock types of the Daralingie Formation and the overlying Toolachee Formation, this boundary is difficult to pick on wireline logs. In Queensland wells, this is determined primarily from palynological data. Upwardly coarsening sandstone units can be seen on the gamma-ray signatures of some wells.

In thicker sections of the Daralingie Formation in South Australia, the formation is more readily distinguished from the Toolachee Formation on wireline logs by its thinner bedding, higher shale/siltstone content (higher average gamma-ray values) and by upwardly-coarsening sandstones (funnel-shaped gamma-ray log signatures) (Figure 3 in Morton & Gatehouse, 1985).

Relationships

The Daralingie Formation is conformable and transitional with the underlying Roseneath Shale. It is disconformably overlain by the Toolachee Formation.

Thickness

Erosional remnants of the Daralingie Formation are mostly 15–30m thick in Queensland where it reaches a maximum thickness of 96m in SSL Kappa 1 in the southern part of the Nappamerri Trough (Figure 25). In South Australia, the thickest sections are from 90m to 120m in the southern Nappamerri and Allunga Troughs (Gravestock & others, 1995).

Age

Palynofloras associated with the Daralingie Formation are encompassed by the uppermost part of palynological unit APP41 and unit APP42 (Price, 1997; G. Wood, personal communication; Figures 3, 9, this volume). A Middle Permian (Wordian) age is tentatively suggested.

Distribution

The Daralingie Formation occurs in the south-western part of the Cooper Basin in Queensland adjacent to the South Australian border, over much the same area as the underlying Roseneath Shale (Figure 25). It does not occur on the JNP Trend.

Depositional Setting

The Daralingie Formation was deposited during regression of the Roseneath Lake. Stacked upwardly-coarsening sandstones in the lower part of the formation, which is mostly that part of the unit preserved in Queensland, have been interpreted as delta-front bars and lake margin beach and shoreface deposits in the Moomba area in South Australia (Alexander & others, 1998).

TOOLACHEE FORMATION

Nomenclature

The Toolachee Formation, named by Kapel (1972), was defined by Gatehouse (1972). Subsequently, Morton & Gatehouse (1985) redefined the Toolachee Formation and restricted the formation to exclude that part of the disconformably underlying Daralingie Formation originally included, but not recognised in the type section in Toolachee 1 well (Alexander & others, 1998). It is the uppermost unit of the Gidgealpa Group.

Rock Types

The Toolachee Formation comprises interbedded sandstone, siltstone, mudstone and shale, commonly in upwardly fining packages in the lower part. Sandstone is buff to white, fine to coarse-grained, locally pebbly to conglomeratic, quartzose. Authigenic quartz overgrowths, kaolinite and patchy carbonate cement (siderite and calcite) occur. Siltstone, mudstone and shale are dark grey to grey–brown, massive to laminated, in part sideritic and contain plant fossils (Alexander & others, 1998). Coal seams are laterally continuous and mostly <3m thick in contrast to the thicker coal seams (up to 16m) in the Patchawarra Formation.

Wireline Log Character

Upwardly fining and upwardly coarsening packages, common in the lower and upper parts of the unit respectively, are evident on the gamma-ray log. High resistivity values with slow travel times on the sonic log reflect the coal seams.

Relationships

The Toolachee Formation disconformably overlies the Daralingie Formation and unconformably overlies older Permian and pre-Permian rocks. Where the Toolachee Formation unconformably overlies the Patchawarra Formation, the boundary is difficult to pick and generally can only be determined from palynology. However, on the wireline logs in a few wells, the average resistivity values are slightly higher for the Patchawarra Formation than they are for the Toolachee Formation. The Toolachee Formation is overlain conformably by the latest Permian–Early Triassic Arrabury Formation, or unconformably by Eromanga Basin strata (mainly in the southern part of the basin). The Toolachee Formation is extensively overlapped by Triassic strata in the northern part of the basin in Queensland.

For convenience and ease of mapping on seismic sections and wireline logs, the top of the Toolachee Formation is taken as the top of the uppermost coal seam as this is equivalent to the “P” seismic reflector.

Thickness

In the Cooper Basin north of the JNP Trend in Queensland, the Toolachee Formation, excluding one area, is mostly 25–50m thick (Figure 26). Immediately to the north of the JNP Trend in the area covered approximately by SSL Macadama 1 in the west, DIO Thurra 1 in the east and DIO Tartulla 1 in the north, the Toolachee Formation is commonly 100–130m thick. South of the JNP Trend, in the Nappamerri and Tenappera Troughs, thicknesses of 150m or more are commonly intersected. The Toolachee Formation reaches a maximum thickness of 190m in DIO Karwin 1 on the southern flank of the JNP Trend.

The aggregate sandstone thickness distribution is shown in Figure 27 with porosity distribution displayed in Figure 28. Aggregate shale thickness distribution is given in Figure 29 and shale percentage distribution in Figure 30. Aggregate coal thickness distribution is shown in Figure 31.

Age

The Toolachee Formation has yielded latest Middle(?)/late Capitanian(?)–Late Permian palynofloras largely conformable with palynological unit APP5 (Price, 1997; Figures 3, 9, this volume). Older (late Middle Permian/Capitanian) APP43 palynofloras have been reported from strata (“Munkarie beds”) considered to lie at the base of the formation in the southern Cooper Basin, both in Queensland and South Australia (Price, 1997; G. Wood, personal communication; Figures 3, 9, this volume).

Distribution

The Toolachee Formation is the most widespread of all the Permian units in the Cooper Basin in Queensland (Figure 26).

Depositional Setting

Environments of deposition of the Toolachee Formation have been studied intensively in South Australia (Gravestock & others, 1995). Two major facies associations and a third one which is locally developed (for example, in the Gidgealpa Field) have been recognised. The two major facies are: lower upwardly-fining, sandstone-dominated facies transitions up to 6m thick, deposited by mixed-load, northerly flowing, meandering streams and in back swamps on the floodplain; and upper frequently interbedded, thin, upwardly-coarsening facies transitions deposited in flood-basin lakes (Williams, 1984). Mudstone and coal seams dominate the latter. The multiple thin, upwards-coarsening packages represent overbank flooding and perennial flood-basin lakes. The locally developed, third facies association consists of coarse-grained, upwardly fining packages interpreted as high sinuosity alluvial channels. Lang & others (2000) described a modern and an ancient analogue for the Toolachee Formation.

NAPPAMERRI GROUP

Definition & Nomenclature

Papalia (1969) introduced the name Nappamerri Formation for the varicoloured Triassic-aged sediments conformably overlying the Gidgealpa Group (Toolachee Formation) in the Cooper Basin. He recognised four rock units in a composite section between DIO Mount Howitt 1 and Merrimelia 3. Youngs & Boothby (1985) proposed a new reference section for the Nappamerri Formation in Beanbush 1 in South Australia. They also recognised a four-fold subdivision, but it bore no relationship to that of Papalia (1969). Powis (1989) raised the Nappamerri Formation to group status and subdivided the Nappamerri Group, in ascending order, into the Arrabury Formation (with Paning and Wimma Sandstone Members) and the Tinchoo Formation (with Doonmulla and Gilpeppee Members). In amendments to the stratigraphy of the Arrabury Formation, Gray (2000) defined an additional member, the Callamurra Member, as the lowermost part. This necessitated redefinition of the Paning Member. The 'Callamurra Member' was first recognised by Channon & Wood (1989) in an unpublished paper compiled prior to the publication of Powis (1989).

The recognition and formal definition of the Callamurra Member was found necessary to overcome inconsistencies in lithostratigraphic correlation between Queensland and South Australian.

The stratigraphy of the Nappamerri Group is summarised below:

Group	Formation	Member
Nappamerri Group	Tinchoo Formation	Gilpeppee Member Doonmulla Member
	Arrabury Formation	Wimma Sandstone Member Paning Member Callamurra Member

Relationships

The Nappamerri Group conformably overlies the Gidgealpa Group (Toolachee Formation) over most of the basin. In northern parts, it overlaps the Gidgealpa Group and unconformably overlies basement metasediments or rocks of the Devonian Warrabin Trough. The Nappamerri Group is unconformably overlain by Eromanga Basin strata (Poolawanna Formation and Hutton Sandstone), and in some areas in the north, by eroded remnants of the Late Triassic Cuddapan Formation.

Thickness

The Nappamerri Group is thickest (from 250–450m) where it overlies the Permian Gidgealpa Group, particularly in the central to north-western parts of the present limits of Gidgealpa Group deposition (in the Windorah and Arrabury Troughs; Figure 32). In the southern and south-eastern parts of the Cooper Basin much of the Nappamerri Group has been removed by erosion following tilting in the mid–Late Triassic. Jurassic Eromanga Basin strata unconformably overlie the Permian in this area. The thickest intersection to date is 460m in SSL Whanto 1 in the Windorah Trough. The Nappamerri Group is >420m thick in the Macadama wells in the Arrabury Trough.

Figure 33 shows the distribution of aggregate sandstone thickness. Maps of aggregate shale thickness distribution (Figure 34) and percentage shale distribution (Figure 35) are also provided.

Age

Latest Permian (late Lopingian) to late Middle Triassic (Ladinian) palynofloras have been delimited in strata of the Nappamerri Group. These palynofloras and the attendant strata, which are detailed hereunder, embrace the APP6–APT3 succession of palynological units (Figures 3, 9).

ARRABURY FORMATION

Nomenclature

The Arrabury Formation was defined by Powis (1989) as the basal formation of the Nappamerri Group. Over much of the Cooper Basin in Queensland and South Australia, the Arrabury Formation can be subdivided into, in ascending order, the Callamurra and Paning Members and the Wimma Sandstone Member (Channon & Wood, 1989; Gray, 2000).

Rock Types

The Arrabury Formation consists of interbedded sandstone, siltstone and mudstone with some red bed characteristics. Siderite occurs as speckles, diffuse layers and as patchy cement. Sandstone is white to pale grey and brown, very fine- to medium-grained, well-sorted, sublabile in part quartzose and is variably dolomitic and calcareous. Siltstone and mudstone are pale grey to dark green–grey, in part variegated grey, green, red and brown, micromicaceous and rarely carbonaceous.

Wireline Log Character

The Arrabury Formation is characterised by high, "ragged" gamma-ray and density log character with then "blocky" sandstone interbeds (Gravestock & others, 1995).

Relationships

The Arrabury Formation conformably overlies Late Permian strata of the Toolachee Formation over most of the Cooper Basin in Queensland. In a few localised areas in the northern part of the basin, the Arrabury Formation unconformably overlies basement metasediments or rocks of the Devonian Warrabin Trough. The Arrabury Formation unconformably overlies the Innamincka Formation of the Warburton Basin in DIO Innamincka 3 on the JNP Trend near the Queensland–South Australian border. The Arrabury Formation is unconformably overlain by Eromanga Basin strata in the southern Cooper Basin, and by the Tinchoo Formation of the Nappamerri Group in the Cooper Basin north of the JNP Trend.

Thickness

The Arrabury Formation is thickest (200–350m) in the southern to central parts of the Cooper Basin in Queensland where it overlies the Nappamerri Trough south of the JNP Trend and the Arrabury and southern Windorah Troughs, north of the Trend (Figure 36). The thickest intersections drilled to date are 412m in DIO Innamincka 2 and ~380–390m in the Macadama wells in the Arrabury Trough. The Arrabury Formation thins gradually to the north by onlap onto the basement high. East of approximately longitude 142°30′E, and near the present south-eastern and north-western limits of deposition, the Arrabury Formation is mostly 50–100m thick.

Age

Spore-pollen assemblages indicate a latest Permian–Early Triassic–earliest Middle Triassic(?) [late Lopingian–Scythian–early Anisian(?)] age for the Arrabury Formation, which is assigned to the APP6–APT2 succession of palynological units (detailed below; Figures 3, 9).

Distribution

Excluding the south-eastern parts of the Cooper Basin, the Arrabury Formation is mainly confined to occurrence within the Permian subcrop limits (Figure 36).

Depositional Setting

The Arrabury Formation was probably deposited on a vegetated floodplain, with ephemeral lakes in lowlands and pedogenesis occurring in exposed areas. The floodplain was cut by low sinuosity rivers in north-east-south-west channel belts (Alexander & others, 1998).

Callamurra Member

Nomenclature

The Callamurra Member, the lowermost part of the Arrabury Formation, was informally defined by Channon & Wood (1989), but was not recognised by Powis (1989). Gray (2000) formally defined the Callamurra Member and acknowledged that Powis (1989) had included the Callamurra Member in the lowermost part of his Paning Member.

Rock Types

The Callamurra Member consists of dark grey carbonaceous mudstone and siltstone in the lowermost part, overlain by interbedded mudstone and siltstone with lesser sandstone. These overlying mudstones and siltstones are mostly organic-lean and are light grey to light brown, some are red–brown and mottled with these colours. Thinly-bedded sandstones, which tend to occur near the middle of the unit, are off-white, fine- to medium-grained, moderately sorted, quartzose, in part micaceous, with an argillaceous and siliceous matrix (Alexander & others, 1998; Gray, 2000).

Wireline Log Character

The gamma-ray log commonly displays an arcuate response with marginally higher values in the upper and lower parts of the unit, with the highest values in the lowermost part. Average values are higher than those of the overlying Paning Member. Resistivity log values are generally marginally higher than those of the overlying Paning Member, and the top of the Callamurra Member is commonly picked at a distinct ledge on the sonic log, which shows an observable decrease in travel time in the overlying unit. The spontaneous potential log is mostly featureless (Gray, 2000).

Relationships

The Callamurra Member conformably overlies the Toolachee Formation and, in South Australia, also unconformably overlies older rocks (Alexander & others, 1998). The boundary with the Toolachee Formation is generally taken at the top of the uppermost coal seam. The Callamurra Member is overlain, possibly disconformably in some areas, by the Paning Member. The top is picked where there is an increase upwards in fining-upward sandstone to mudstone interbeds. In some southern parts of the basin, Eromanga Basin strata unconformably overlie the Callamurra Member.

Thickness

The Callamurra Member is thickest in the south-western part of the Cooper Basin in Queensland where it overlies the Nappamerri and Arrabury Troughs (Figure 37). Maximum thicknesses intersected to date are from 160 to 170m in the Macadama area near the JNP Trend. Average thickness of the Callamurra Member in over 50 Queensland wells was 82m. The basal carbonaceous interval averaged in excess of 12m (Gray, 2000).

Age

The Callamurra Member is attributable primarily to palynological unit APP6, although the basal part of the succeeding unit, APT1 also appears to be represented [for example: SWC/2135.43m in DIO Yanda 1 (Wood & Williams, 1984a; assigned to unit Tr1a, =unit APP6 of Price, 1997); SWC/2271.37m in DIO Ballera 1 (Wood, 1985b; assigned to unit PP6, =unit APP6); SWC/2097.02m and SWC/2087.88 in SSL Munkah 4 (Wood, 1994; both assigned to unit PP6); and SWC/1834.29m in DIO Wackett 1 (Price, 1979; assigned to unit Tr1b, =unit APT1 of Price, 1997); Figures 3, 9, this volume].

A latest Permian (late Lopingian) to Early Triassic (early Scythian) age is suggested for the Callamurra Member/lower Arrabury Formation (Figures 3, 9). The transition to it from the underlying Toolachee Formation is the palynostratigraphic equivalent of the coal measures to Rewan Group transition in the Bowen Basin of eastern Australia (Figure 9). Hiatus associated with this interval in the Bowen Basin appears not to be present at the same chronostratigraphic level in the Cooper basin, but may be represented by apparent hiatus (embracing the disconformity referred to above) between the Callamurra Member and the succeeding Paning Member (Figure 9). This difference between eastern and central Australia may reflect the time taken for the effect of the compression along the Panthalassan margin at the end of the Permian (during the Hunter–Bowen Orogeny) to be transmitted to the interior of the Australian region. A similar explanation may account for the differences in timing between eastern and central Australia of the major mid-Permian hiatus within the Aldebaran Sandstone (Denison Trough, south-western Bowen Basin) and the hiatus between the Daralingie and Toolachee Formations (Cooper Basin) [Figure 9]. These time breaks can be related to the major contraction that occurred along the Panthalassan perimeter during the mid-Permian; in eastern Australia, the latter event has been used in definition of onset of the Hunter–Bowen Orogeny, and, from a large-scale perspective, it may correlate with the global regression that corresponds to the base of the Ufimian Stage of the Urals (McKellar, in press; also see discussion above under *Age* of the *Roseneath Shale*).

Distribution

The Callamurra Member is best developed in the south-western part of the Cooper Basin in Queensland (Figure 37). It thins to zero in a north-easterly direction and is absent east of approximately longitude 143°E and north of approximately latitude 25°45'S. At the South Australian border, the Callamurra Member is absent north of approximately latitude 27°S (Gray, 2000, Figure 1).

Environments of Deposition

The Callamurra Member was probably deposited on fluvial floodplains and in shallow perennial lakes with some higher energy pulses from meandering streams (Channon & Wood, 1989; Gray, 2000).

Paning Member (Restricted)

Nomenclature

Powis (1989) defined the Paning member as the lower part of the Arrabury Formation with a reference section between 2583m and 2851m in Paning 1 well in South Australia. Gray (2000), in a recent study of the Arrabury Formation in Queensland, recognised a further subdivision of Powis's Paning Member and formally defined the previously recognised "Callamurra Member" as the lowermost part of the Arrabury Formation. The Callamurra Member was not recognised by Powis (1989) but was included in his definition of the Paning Member. Consequently, Gray (2000) defined a new reference section for the Paning Member, restricting it to the interval between 2583m and 2716m in Paning 1, which is the upper part of Powis's original reference section.

Rock Types

The Paning Member consists of upwardly fining and some upwardly coarsening cycles of sandstone grading into siltstone and mudstone. Sandstones are buff to off-white, fine- to medium-grained and siltstones and mudstones are light grey, dark grey and brown.

Wireline Log Character

On the gamma-ray log, alternations of high and low values reflect the interbedded siltstone/mudstone and sandstone. The average value is lower than that of the underlying Callamurra Member and this reflects the greater percentage of sandstone. The average resistivity log value in many wells is marginally lower than that of the Callamurra Member and the average value on the sonic log indicates a slightly slower travel time for the Paning Member. The spontaneous potential log generally shows more features when compared with the response for the Callamurra Member. Reversed values are typical of the Paning Member in many wells (Gray, 2000).

Relationships

The Paning Member appears to conformably overlie the Callamurra Member but this is uncertain as there is evidence in core from South Australia to suggest that the contact with the Callamurra Member is at least locally disconformable (Alexander & others, 1998). The contact with the overlying Wimma Sandstone Member is conformable and is probably facies controlled in some areas (Gray, 2000). In the southern part of the Cooper Basin in Queensland, the Paning Member is unconformably overlain by Eromanga Basin strata in many wells.

Thickness

The Paning Member is 133m thick in the newly revised reference section in Paning 1. In Queensland it ranges from <100m to ~150m thick (Gray, 2000) (Figure 38). It is >200m thick in the Moomba Field in South Australia (Alexander & others, 1998).

Age

The Paning Member is broadly embraced by palynological unit APT2, although finer subdivisional relationships are generally far from clear because of limited data availability (Figures 3, 9). In LEA Earlstoun 1, however, Dettmann (1987c) reported a palynoflora from SWC/2280.5m that is conformable with palynological unit APT21 (of Price, 1997) and the *Protohaploxypinus samoilovichii* "Oppel" Zone (of Helby, 1973; Helby & others, 1987; Figure 9, this volume). Extension of the member, as delimited lithostratigraphically in the current project, into palynological unit APT1 is questionably suggested by the rich palynoflora recovered from SWC/2275.33m in DIO Durham Downs 2 (Wood & Williams, 1984b; assigned to the equivalent palynological unit, Tr1b). An Early Triassic (Scythian) age is indicated (Figures 3, 9).

Distribution

The Paning Member is the most widely distributed member of the Arrabury Formation (Figure 38) and it onlaps the Callamurra Member in the northern and eastern parts of the Cooper Basin in Queensland (Gray, 2000).

Depositional Setting

A floodplain environment with high sinuosity channels and localised shallow lakes is interpreted as the environment of deposition for the Paning Member.

Wimma Sandstone Member

Nomenclature

Powis (1989) defined and described the Wimma Sandstone Member as a sandstone-dominated sequence at or near the top of his Arrabury Formation. This relationship was in general supported by Gray (2000). Powis (1989) designated the reference section as occurring between 2779 and 2890m in the Wimma 1 well in South Australia.

Rock Types

The Wimma Sandstone Member consists dominantly of sandstone finely interbedded with pale to medium grey siltstone. The mudstone is buff to pale grey, fine- to medium-grained, quartzose.

Wireline Log Character

The average of the gamma-ray log values is lower than that of the underlying Paning Member and this reflects the higher sandstone and quartz content of the Wimma Sandstone Member. A tightly serrated gamma-ray log signature reflects the very thinly bedded siltstones and sandstones present in many wells. In other wells, a blocky signature is typical of the member. The average resistivity log value is commonly higher than that of the Paning Member and reversed values in some wells suggests the presence of saline water. A marginally slower travel time on the sonic log and reversed spontaneous potential log values, with values higher than those for the Paning Member, are typical of the Wimma Sandstone Member (Gray, 2000).

Relationships

The Wimma Sandstone Member conformably overlies the Paning Member and the boundary is facies-controlled in some areas. It is unconformably overlain by the Tinchoo Formation (Powis, 1989; Gray, 2000). In the Karmona East–Tartulla area, at approximately latitude 27°15′S, the Wimma Sandstone Member is unconformably overlain by Eromanga Basin strata (Gray, 2000; Figure 2).

Thickness

The Wimma Sandstone Member is mostly <100m thick in the Cooper Basin in Queensland (Gray, 2000) (Figure 39). The thickest intersection is 107m in SSL Monte 1 where the Member is unconformably overlain by Eromanga Basin strata near the unit's southern limit. East of approximately longitude 142°30′E, the Wimma Sandstone Member is mostly <60m thick. In the Patchawarra Trough in South Australia, the Member is >100m thick and it reaches a maximum thickness of 114m in Potiron 1 (Alexander & others, 1998).

Age

The limited palynological data from the Wimma Sandstone Member are indicative of a late Early–earliest Middle Triassic(?) [late Scythian–early Anisian(?)] age and assignment to unit APT2 [Price, 1997; Dettmann & Price, 1981b (core sample from 2330.80m in LON Kyabra 2); Jones & Wood, 1986 (SWC/2250.64m in DIO Macadama 1); Figures 3, 9, this volume].

Distribution

The Wimma Sandstone Member is restricted to the northern part of the Cooper Basin in Queensland, north of the JNP Trend (Figure 39) and mainly to the Patchawarra Trough in South Australia. It forms a south-west to north-east trending belt, ~70km wide (Channon & Wood, 1989; Powis, 1989).

Depositional Setting

The Wimma Sandstone Member was deposited by low-sinuosity rivers with the main channel axis orientated south-west to north-east along the Windorah and Arrabury Troughs in

Queensland and the Patchawarra Trough in South Australia.

TINCHOO FORMATION

Nomenclature

Powis (1989) defined the Tinchoo Formation as the uppermost unit of the Nappamerri Group and as "a fining upward succession of strata with variable sandstone development at the base". He defined a reference section as occurring between 2267m and 2422m in DIO Tinchoo 1and subdivided the Tinchoo Formation, in ascending order, into the Doonmulla and Gilpeppee Members. These members are readily recognisable in Queensland, but, in South Australia, the Tinchoo Formation is thinner because of erosion and the formation is represented mostly be the lower Tinchoo Formation (Doonmulla Member) (Powis, 1989, Figures 8 and 9).

Rock Types

The Tinchoo Formation consists of interbedded sandstone, siltstone, mudstone and minor coal, with sandstone dominant in the lower part of the unit and siltstone, mudstone and minor coal in the upper part.

Relationships

The Tinchoo Formation unconformably overlies the Arrabury Formation over much of the Cooper Basin in Queensland, north of approximately latitude 27°15′S. North-west of a north-easterly to south-westerly trending line (which approximates the zero edge of both the Arrabury Formation and underlying Permian) between AAP Frazerburgh 1 in the north and DIO MacKillop 1 in the south the Tinchoo Formation overlies basement metasediments or, in some eastern areas, rocks of the Devonian Warrabin Trough. The Tinchoo Formation is unconformably overlain by the Late Triassic Cuddapan Formation in central to northern parts of the basin (from the Mount Howitt area northwards) or by Eromanga Basin strata in other areas.

Thickness

The Tinchoo Formation is mostly from 125–200m thick (Figure 40). It is thickest in the Whanto–Tanbar area adjacent to the Windorah Trough where it reaches thicknesses of 258m and 263m. In South Australia, the Tinchoo Formation has been deeply eroded in many areas and reaches a maximum thickness of ~109m in Telopea 1 well (Alexander & others, 1998). Aggregate shale thickness distribution is shown in Figure 41.

Age

Middle Triassic (Anisian–Ladinian) spore-pollen assemblages have been derived from the Tinchoo Formation, which is conformable with palynological unit APT3 and equivalent biozones (detailed below; Figures 3, 9).

Distribution

In the northern Cooper Basin, the Tinchoo Formation is the most widespread Triassic unit (Figure 40). It overlaps the Early Triassic Arrabury Formation in the north-western and northern parts of the basin. This demonstrates a shift in the Triassic depocentre to the north that was first recognised by Powis (1989). The Tinchoo Formation is absent in the Cooper Basin in Queensland south of approximately latitude 27°15′S where it has possibly been removed in part by erosion. In South Australia, the Formation has been eroded from crests of major ridges and from the edge of the Cooper Basin (Alexander & others, 1998). It is preserved mainly in the area overlying the eastern part of the Patchawarra Trough in the northern Cooper Basin (Channon & Wood, 1989, Figure 11).

Depositional Setting

The lower part of the Tinchoo Formation, which is dominated by quartzose sandstones and interbedded siltstones and mudstones with mainly fining-upwards log signatures, was probably deposited in a high-sinuosity fluvial environment. The upper part, which is a fairly uniform succession of dense siltstones and mudstones (variably carbonaceous with minor coal development), was probably deposited in an extensive fluvio-lacustrine environment.

Doonmulla Member

Nomenclature

Powis (1989) defined the Doonmulla Member as the lowermost part of the Tinchoo Formation, which he defined in the same paper. He defined a reference section as occurring between 2336m and 2449m in DIO

Doonmulla 1. In the current study, it was found that the Doonmulla Member could be informally subdivided into lower and upper parts (Green, 1997, Figure 4).

Rock Types

Fining-upwards successions are commonly developed. The "lower Doonmulla Member" consists dominantly of sandstone with lesser interbedded siltstone and mudstone. The sandstone is fine- to medium-grained, grading to granule conglomerate, is quartz-rich, and is dominantly planar cross-bedded and planar bedded. Carbonaceous and micaceous partings occur in finer-grained sandstones (Alexander & others, 1998). The "upper Doonmulla Member" consists mainly of interbedded siltstone and mudstone, mostly horizontally laminated with very fine-grained sandstone stringers.

Wireline Log Character

On the gamma-ray log, fining-upwards log signatures are commonly developed. For the "lower Doonmulla Member", low average values interspersed with thin high gamma-ray values reflect quartz-rich sandstone interbedded with siltstone and mudstone. The fairly constant higher gamma-ray values in the "upper Doonmulla Member" reflect the dominant siltstone and mudstone lithologies. The resistivity log shows a moderate response with the average value higher for the "lower Doonmulla Member" than the "upper". Suppressed resistivity log values combined with reversed spontaneous-potential log values over parts of the "lower Doonmulla Member", indicate porous sandstone intervals, possibly containing saline water. The sonic log also differentiates the lower and upper parts of the member in many wells. The "lower Doonmulla Member" shows faster travel times than the "upper".

Relationships and Boundary Criteria

The Doonmulla Member of the Tinchoo Formation unconformably overlies the Arrabury Formation in the Cooper Basin in Queensland, north of approximately latitude 27°15′S. In north-western and northern parts of the basin, the Doonmulla Member unconformably overlies basement metasediments and Devonian-aged rocks of the Warrabin Trough respectively. The Doonmulla Member is conformably overlain by the Gilpeppee Member of the Tinchoo Formation in central parts of the northern Cooper Basin, or is unconformably overlain by the Late Triassic Cuddapan Formation (in the DIO Steward 1 well area) or Jurassic Eromanga Basin strata nearer the present limits of deposition of the Doonmulla Member.

The Doonmulla Member is distinguished from the underlying Arrabury Formation by a lower average gamma-ray log response, which reflects the higher quartz content of the Doonmulla Member, and by higher average resistivity log values. The resistivity and sonic logs over the Doonmulla Member are generally considerably more responsive than they are over the Arrabury Formation. The Doonmulla Member is distinguished from the overlying Gilpeppee Member by distinctive ledges in both the resistivity and sonic logs (values increase to the right for the Doonmulla Member). Powis (1989) used "a distinct decrease in resistivity at the base of the Gilpeppee Member" to separate the two members of the Tinchoo Formation.

Thickness

The Doonmulla Member is mostly 50m to >100m thick over most of the northern Cooper Basin (Figure 42). It is thickest in the Windorah Trough or south-central part of the basin, from DIO Tanbar 1 in the north to DIO Barrolka East 1 in the south and MIM Majestic 1 in the east, where thicknesses in excess of 120m are common. The maximum thickness of the Doonmulla Member is 182m in DIO Tanbar 1.

The "upper Doonmulla Member" maintains a fairly constant thickness of 25–40m.

Age

Middle Triassic (Anisian–early Ladinian) palynofloras from the Doonmulla Member are principally conformable with palynological unit APT3 (APT31–APT33), although the lower part of the member extends down into upper APT2 [Figures 3, 9, this volume; Price, 1997; Wood & Jones, 1986c (SWC/2284.47m in DIO Arrabury 2); Wood, 1986a (SWC/2336.6m in DIO Cook 1); Milne, 1986 (SWC/1537.00m and SWC/1534.00m in POG Teedeeldee 1); Islam & others, 1986 (SWC/2538.98m in AAP Fraserburgh 1); Dudgeon & Hos, 1986c (SWC/2560.32m in AAP Ethel 1)]. In terms of the zonation of Helby & others (1987), these palynofloras are equivalent to those in the upper *Aratrisporites tenuispinosus* "Oppel" Zone and the succeeding *A. parvispinosus* "Oppel" Zone (Figure 9).

In the upper part of the member ("upper Doonmulla Member") and in the succeeding Gilpeppee Member (detailed below), a number of palynofloras (of Ladinian age) have been assigned to the *Staurosaccites quadrifidus* "Oppel" Zone (of Dolby & Balme, 1976; Helby & others, 1987) [for example: SWC/1797.40m in HOA Mount Bellalie 1 (Morgan & Milne, 1985); SWC/2571.29m in DIO Russel 1 (Williams, 1985b); SWC/1527.60m, SWC/1520.00m and SWC/1514.50m in HOA Berellem 1 (Morgan, 1984b)]. They represent intermediate-latitude, mixed assemblages of the Ipswich Microflora, which developed in (higher-latitude) eastern Australia during the late Middle–Late Triassic, and the equivalent (lower-latitude) Onslow Microflora that existed in northern and western areas of the continent (Dolby & Balme, 1976; McKellar, 1977a-b, 1998, in press; de Jersey & McKellar, 1979, 1981).

Gilpeppee Member

Nomenclature

Powis (1989) defined the Gilpeppee Member as the uppermost part of the Tinchoo Formation which he defined in the same paper. He defined a reference section between 2352m and 2441m in DIO Gilpeppee 2.

Rock Types

The Gilpeppee Member consists of a relatively uniform sequence of dense siltstones with interbedded sandstone and coal present within the Member in northern parts of the basin (for example, in DIO Morney 1, DIO Ullenbury 1 and DGC Jade 1). The dense siltstones are light grey to green-grey and variably carbonaceous. Sandstones are light grey to light brown, very fine- to very coarse-grained, well-sorted with an argillaceous matrix and strong siliceous cement.

Wireline Log Character

The Gilpeppee Member is characterised mostly by fairly uniform high average gamma-ray log values and uniform resistivity and sonic log values. The resistivity log has a slightly lower average value than that of the underlying "upper Doonmulla Member" in some areas. Low gamma-ray and moderate resistivity values in the member in northern parts of the basin reflect the interbedded sandstone. A few small peaks on the resistivity and sonic logs indicate the presence of thin coal seams.

Relationships and Boundary Criteria

The Gilpeppee Member conformably overlies the Doonmulla Member and is unconformably overlain by the Late Triassic Cuddapan Formation in northern and north-western parts of the basin, or by Jurassic strata of the Eromanga Basin elsewhere.

The Gilpeppee Member is distinguished from the underlying "upper Doonmulla Member" by distinct ledges or a downward increase in values to the right in both the resistivity and sonic logs. In many wells, gamma-ray log values are higher in the "upper Doonmulla Member" than they are in the overlying Gilpeppee Member. The wireline logs, particularly the gamma-ray log, suggest that the "upper Doonmulla Member" and Gilpeppee Member are lithologically similar and should form the same unit. That is, the "upper Doonmulla Member" should be the lowest part of the Gilpeppee Member. This view is also supported by the distinct palynological relationship between the "upper Doonmulla Member" and the Gilpeppee Member as both units embrace palynofloras conformable with the *Staurosaccites quadrifidus* Zone (detailed herein). However, the present boundary between the "upper Doonmulla Member" and the Gilpeppee Member, as defined by Powis (1989), is very distinct on the resistivity log and forms an excellent marker horizon in the Triassic of the northern Cooper Basin.

Thickness

The Gilpeppee Member is mostly 45m to about 90m thick (Figure 43). It is thickest in the Gilpeppee-Denley area bordering the Yamma-Yamma Syncline and in the Clinton-Whanto area in the southern Windorah Trough where it is generally in >90m thick. Maximum thickness of the Gilpeppee Member is 106m in DIO Denley 1.

Age

The Gilpeppee Member of the upper Tinchoo Formation has yielded Ladinian palynofloras that are attributable to unit APT3 [equivalent to the *A. parvispinosus* "Oppel" Zone of Helby (1973) and Helby & others (1987)], being generally associated with the APT33-34 interval therein; also present are assemblages that have been assigned to the *Staurosaccites quadrifidus* Zone (of Dolby & Balme, 1976; Helby & others, 1987) [Price, 1997; Morgan, 1984b (HOA

Berellem 1, SWC/1508.5m); Dettmann, 1986 (LEA Byrock 1, cuttings/1851-1866m); Dettmann, 1987a (LEA Nymbah 1, SWC/1678.00m); Hannah, 1990 (DIO Yanbee 1, SWC/2317.09m, SWC/2303.98m)]. The latter zone, discussed above under Age of the underlying *Doonmulla Member*, has also been reported from the upper part of this lithostratigraphic unit.

An undescribed palynoflora derived from SWC/1794.36m in DIO Toby 1 was assigned a Late Triassic age by Filatoff (1987) and associated with palynological units PT4–PT5 [of Price & others (1985) and Filatoff & Price (1988); =APT4-APT5 of Price (1997)]. The lithostratigraphic relationships of this sample appear to be with the Gilpeppee Member (A.R.G. Gray), although the biostratigraphic determination suggests that it is younger. Uncertainty remains, however, because details of the assemblage are lacking.

UNNAMED BASALT

JJ Draper

Olivine basalt has been intersected in wells in the south-western Cooper Basin in Queensland (Figure 7). Age dating is equivocal with K-Ar dates of 227±3Ma and 100±9Ma (Murray, 1994). The stratigraphic position is variable indicating that the basalt is at least partly intrusive; this is further indicated by the absence of basalt in DIO Orientos 1 and its presence in DIO Orientos 2. DIO Lambda 1 bottomed in basalt, which was dated as 227±3Ma (Late Triassic). The basalt was overlain by Birkhead Formation. In DIO Warnie East, 165m of basalt is present in the Toolachee Formation. This basalt was dated as 100±9Ma. In SSL Kappa 1, 220m of basalt is present at the top of the Nappamerri Group and overlain by Hutton Sandstone. DIO Orientos 2 bottomed in basalt overlain by Adori Sandstone. DIO Orientos 1, <1km from Orientos 2, did not intersect basalt. Where Eromanga Basin units overlie the basalt, it is not known if the relationship is intrusive or progressive onlap.

Whilst a Late Triassic age is preferred, an Early Jurassic or younger age can not be discounted on the information currently available.

COOPER BASIN TECTONICS

JJ Draper & JL McKellar

The Cooper Basin is an intracratonic basin but there is little consensus on the mode of formation of the basin. Hill & Gravestock (*in* Drexel & Priess, 1995, page 79) used the intracratonic sag model previously advanced by Kapel (1966) and Battersby (1976). A purely compressional origin has been favoured by Kuang (1985), Apak & others (1997) and Sun (1997). Stanmore (1989) and Heath (1989) supported an extensional origin. Most authors recognise a strong association between the tectonic history of the basin and underlying structures.

The lack of consensus on the mode of formation of the Cooper basin reflects the poor knowledge of the mode of formation of intracratonic basins in general. Deming (1994) listed a number of alternate hypotheses:

- increase in crustal density from one or more phase transitions,
- rifting,
- mechanical subsidence due to isostatically uncompensated excess mass of igneous intrusions,
- tectonic reactivation along older structures, and
- "a combination of these or some other theory".

In essence, the mechanism of intracratonic basin formation is poorly understood. It is beyond the scope of this report to present a major tectonic model for the basin. The major features of the basin are outlined and a broad model proposed.

As discussed briefly above (page 5) the Cooper Basin area had a complex thermal history prior to formation of the basin. Relevant to the formation of the Cooper Basin are the Late Carboniferous granites beneath the Nappamerri Trough (see page 5 and Meixner & others, 2000) and possible ultramafic or mafic intrusives interpreted beneath the Patchawarra Trough possibly related to a mantle hotspot (Meixner & others, 2000). A thermal trigger for the basin seems probable combined with reactivation of existing structures.

Pivotal to the System change from the Carboniferous to the Permian are events which occurred at ~300Ma. These are related to the self-induced Pangaean thermal and geoid anomaly, which began to develop at about 320Ma (mid-Carboniferous), following onset of *definitive* formation of the Pangaean supercontinent (McKellar, 1998, in press; and cited references). The effects of continental collision were transmitted throughout Pangaea and, in the Australian region, are reflected in the Kanimblan and Alice Springs Orogenies (Veevers & others, 1994).

The more-or-less subhemispheric Pangaean landmass insulated the mantle and severely retarded heat loss from the Earth, leading to thermal uplift of, and the development of a stratigraphic gap (lacuna) on, the Pangaean platform during the Late Carboniferous (Veevers, 1990, 1993, 1994; Veevers & others, 1994; Veevers & Tewari, 1995). At the end of the period, southern Pangaea occupied high-latitude and polar regions, with a disproportionately larger segment of the supercontinent being located in the Southern Hemisphere (than in the Northern Hemisphere).

These developments created a mass imbalance in Earth's rotation and led to significant mantle stresses and crustal deformation from ~300Ma through the Permian and ensuing Triassic as this imbalance was corrected (McKellar, 1998, in press). Palaeomagnetic data indicate that at ~300Ma, there was a reversal in the direction of apparent polar wander (represented by the ~300Ma loop in the Australian late Palaeozoic apparent polar wander path; Klootwijk, 1996) and the onset of an apparent anticlockwise motion and northwards displacement of Pangaea (contrasting with a clockwise rotation during the preceding Carboniferous as the supercontinent was forming). In the European and eastern Australian regions, the onset of this anticlockwise regime was associated with widespread right-lateral transtension, which formed deep transtensional fractures, and led to the formation of wrench-induced sedimentary and magmatic basins and half-grabens, including those in the Bowen–Gunnedah–Sydney Basin system of eastern Australia. The formation of the Cooper and Galilee Basins and other Australian intracratonic basins was also most likely controlled by the same mantle-lithosphere stress regime (McKellar, 1998, in press). The deep crustal fractures, according to Veevers & others (1994, page 141), "provided a way into and through the neocratonic crust for magma ranging from S-type granite to rhyodacitic ignimbrite to basalt, with alkaline undersaturated rocks in some rifts". This latest Carboniferous–early Permian interval of extensional tectonism represented the first period of major heat loss from the Pangaean thermal anomaly (Veevers & others, 1994).

Eastern Australia and northern Queensland were dominated by extensional tectonics with the formation of rifts from the Late Carboniferous to Early Permian (Elliott, 1993; Bain & Draper, 1997; Korsch & others, 1998; Waschbusch & others, 1999). The Bowen–Gunnedah–Sydney Basins formed the Early Permian East Australian Rift System (Korsch & others, 1998). The direction of extension in the Bowen Basin was north-west–south-east (Elliott, 1993; Korsch & others, 1998). The extent to which the extensional regime on the margins of the continent was transferred into the craton is a matter of conjecture, but a number of basins did form on the craton at this time: Galilee Basin, Cooper Basin, Arckaringa Basin and Pedirka Basin. This widespread intracratonic basin formation would certainly be assisted by a widespread extensional regime. Only the Cooper and Galilee Basins received sedimentation beyond the early Early Permian.

Deposition of the Merrimelia Formation and Tirrawarra Sandstones was areally restricted with no indication of widespread rifting. The JNP Trend was not a positive feature at this time. Deposition of the Patchawarra Formation occurred over a much greater area. There is thickening of section along the JNP Trend indicating it was a negative rather than a positive feature. Its current elevated position is the result of subsequent inversion. Although there are compressive features in the Patchawarra Formation, this does not preclude thermal subsidence or isostatic adjustment as the main cause of subsidence. The compressional events may be superimposed. This is the case in the Bowen Basin where compression is recorded during the thermal subsidence phase and prior to foreland loading (Elliott, 1993: Korsch & others, 1998). Inversion of the underlying rift structures occurred in the Bowen Basin. Davidson (1995) documented world-wide contractional pulses in extensional basins. Given that the basement structures of the Cooper Basin are at high angles to likely extensional and compressional directions, transpression and transtension are probable.

The Murteree Shale, Epsilon Formation, Roseneath Shale and Daralingie Formation are generally restricted to the area south of the JNP Trend, although there is Roseneath Shale recognised at the eastern end of the JNP Trend. Erosion may have contributed partly to the now restricted distribution, but the nature of the facies (lacustrine and lacustrine deltas) and absence of remnants away from the present units suggests deposition was largely restricted to the south-west of the basin. Thermal subsidence was probably the ongoing control.

A major unconformity (the "Daralingie Unconformity") separates the Daralingie Formation from the overlying Toolachee Formation. The unconformity resulted from a major compressional event which resulted in reactivation of older structures and wrenching along the JNP Trend (Nelson, 1985; Apak & others, 1997). Uplift and erosion occurred. The Daralingie Unconformity is not unique to the Cooper Basin. A major unconformity within the Aldebaran Sandstone on the Bowen Basin (Figure 9) is considered to represent the onset of the Hunter–Bowen Orogeny (Stephens & others, 1996; Korsch & others, 1998) and the development of the Bowen Basin as a foreland basin. The Galilee Basin also contains a major unconformity at about this time (Hawkins & Green, 1993; Draper, *in* Bain & Draper, 1997, page 519).

The Toolachee Formation, deposited on the Daralingie Unconformity, covers a larger area than the other Permian units indicating increased subsidence areally. The mechanism of the subsidence is unclear, but is probably a continuation of thermal subsidence. There are minor contractional events during the deposition of the Toolachee Formation (Apak & others, 1997), possibly reflecting the Hunter–Bowen Orogeny. The thickest sedimentation was north and south of the JNP Trend.

The Early Triassic Arrabury Formation was deposited over largely the same area as the Toolachee Formation. Subsequent Triassic tilting has resulted in erosion along the south-east edge with contact between the Toolachee Formation and Eromanga Basin sediments providing a window for hydrocarbons to move from the Cooper Basin into the Eromanga Basin. The same general depocentre of the Toolachee Formation was occupied by the Arrabury Formation, suggesting a continuation of the underlying basin formation mechanism. The distribution of the members of the Arrabury Formation shows some variation. The Callamurra Member occurs in the south-west with the thickest areas also in the far south-west. The Paning Member has wide distribution but with the thickest areas in the far south-west. The Wimma Sandstone Member is restricted to the northern Cooper Basin, north of the JNP Trend.

The Middle Triassic Tinchoo Formation shows a distinct change in deposition area with the area of deposition and the main depocentre to the north and north-west of the Permian depocentres. The process of basin change probably began during Wimma Sandstone Member deposition, which was the first occasion major deposition did not occur south of the JNP trend. There was a widespread contractional event in eastern Australia (Korsch & others, 1998) at about the same time as the shift of depocentre. Since the depocentre is now well removed from the region of thermal relaxation, a different basin forming mechanism seems likely. The depositional pattern is basin-like rather than elongate and parallel to structural grain with a reduction of the area of deposition from the Doonmulla Member to the Gilpeppee Member. There is no evidence for thermal activity although a shift of hot spot activity could be a possible mechanism. Uplift of the southern Cooper Basin or regional tilting are other possible mechanisms. Following deposition of the Tinchoo Formation, a major compressional event occurred with uplift and erosion (Apak & others, 1997) effecting the end of deposition in the Cooper Basin. This event is widespread in eastern Australia (Korsch & others, 1998) and north-western Australia (Etheridge & O'Brien, 1994).

The Late Triassic or Early Jurassic basalts in the vicinity of the Nappamerri Trough indicate that the thermal regime had not totally waned. The balance of thermal to mechanical subsidence in the Triassic cannot be quantified at this point.

In summary, the tectonic history of the Cooper Basin is complex and poorly understood. Although thermal subsidence appears to play a major role, a number of other mechanisms are superimposed. Reactivation of existing structures was important. Craton wide events had their impact in the basin (Gallagher, 1990). Sediment subsidence also played a role. Since many of the external events were oblique to the structural grain, different tectonic styles are apparent in different parts of the basin.

EROMANGA BASIN STRATIGRAPHY

ARG Gray, M McKillop & JL McKellar

The stratigraphy of the Eromanga Basin is summarised in Figure 44. The Cuddapan Formation is discussed in this section as it post-dates closure of the Cooper Basin.

CUDDAPAN FORMATION

Nomenclature

The Cuddapan Formation (Powis, 1989) represents the final phase of Triassic sedimentation in the Cooper Basin region, but post-dates Cooper Basin deposition. It is a unit which could not be adequately placed by Powis into the Early to Middle Triassic Nappamerri Group. The Cuddapan Formation was defined as occurring between 2267m and 2319m in DIO Cuddapan 1 well. Alexander & others (1998) defined a reference section between 2645m and 2712m in Beanbush 1 well in South Australia.

The Cuddapan Formation is considered to be equivalent to the "Beanbush beds" of Price & others (1985) (Channon & Wood, 1989). It is correlatable to the Peera Peera Formation of the Simpson Desert Basin and to the lower part of the Leigh Creek Coal Measures (Powis, 1989).

Rock Types

The Cuddapan Formation consists dominantly of sublabile to quartzose sandstone in its lower part with interbedded grey to dark grey carbonaceous siltstone, mudstone and coal more prevalent in upper parts. Both upwardly fining and upwardly coarsening packages occur with upwardly fining dominant. Lithologically, the Cuddapan Formation is very similar to the overlying Poolowanna Formation.

Wireline Log Character

Upwardly fining and some upwardly coarsening intervals are evident on the gamma-ray log. Increased gamma-ray log and decreased resistivity log values in upper parts of the unit reflect the interbedded siltstone and mudstone. Coal seams are shown by peaks (slow travel times) on the sonic log.

Relationships and Boundary Criteria

The Cuddapan Formation unconformably overlies the Gilpeppee Member of the Tinchoo Formation in the Cooper Basin and is unconformably/disconformably overlain by the Poolowanna Formation.

The boundary with the underlying Gilpeppee Member of the Tinchoo Formation is generally very distinct and is shown by a marked decrease upwards in gamma-ray log values and increase in resistivity log values. Because of its lithological similarity to the overlying Poolowanna Formation, the boundary between the two formations is difficult to pick and identification relies mainly on palynological dating. Subtle differences evident are:

(1) The gamma-ray log response for sandstones of the Cuddapan Formation may be marginally higher.

(2) The average resistivity log values for the Cuddapan Formation are marginally lower.

(3) The Cuddapan Formation commonly displays slightly lower average travel times on the sonic log.

Thickness

The Cuddapan Formation is mainly from 20m to >50m thick (Figure 45). It is 52m thick in the type section in DIO Cuddapan 1 and reaches a maximum thickness of 55m in DIO Russel 1, some 115km further to the east. Isopachs suggest that the Cuddapan Formation has a depocentre centred on each of these two wells. However, as there are no data points between these wells, the Cuddapan Formation may have only one large west-east trending depocentre containing these two wells near each end.

Age

Palynofloras assigned to the Cuddapan Formation fall within the APT4 - APT5 palynostratigraphic succession of units (Powis, 1989; Price, 1997; Figures 3, 9, this volume]. As it does not appear that the formation extends stratigraphically as high as palynological unit APT522 and thus across the Triassic–Jurassic boundary, a Late Triassic [Carnian–Norian–(?)Rhaetian] age is indicated.

In DIO Russel 1, SWC/2452.72m yielded a palynoflora embracing *Annulispora folliculosa*, *A. microannulata*, *Duplexisporites gyratus*, *Semiretisporis denmeadii* and *Aratrisporites parvispinosus*, in association with pollen of *Falcisporites* (*Alisporites*) and *Striatopodocarpidites* (Williams, 1985b). At a lower level, represented by SWC/2497.23m (in strata assigned in the present project to the Cuddapan Formation, based on electric log correlation), *D. gyratus* and aff. *Polycingulatisporites* spp. were recorded by the latter author, together with *Staurosaccites quadrifidus*, *Lunatisporites acutus*, *Minutosaccus* sp., *Samaropollenites speciosus* (only tentatively identified) and dominant *Falcisporites*. The assemblage from the higher of these two samples was assigned to palynological unit PT4 (of Price & others, 1985; =APT4 of Price, 1997) and employed to infer correlation with the Peera Peera Formation (Simpson Basin) and the Ipswich Coal Measures in south-eastern Queensland. The lower palynoflora (SWC/2497.23m), on the other hand, was associated with the unit PT3-PT4 (APT3-APT4) interval and accordingly given a Middle to Late Triassic age. Williams was unable to differentiate between correlation with the (upper) Nappamerri Group and Upper Triassic strata (as APT4 indices were not recorded).

Species such as *Staurosaccites quadrifidus* and *Samaropollenites speciosus* are Tethyan elements of the Onslow Microflora, which developed and evolved in lower-palaeolatitude northern and western Australia during the Middle and Late Triassic (Dolby & Balme, 1976). This occurred as the Australian region (south-eastern Pangaea) moved into progressively northwards into lower latitudes during the period (McKellar, 1998, in press). In intermediate palaeolatitudes within the Australian sector of the supercontinent, including the Cooper–Eromanga Basin region, plants of the Onslow Province mixed with plants of the Ipswich Province (McKellar, 1977a-b, 1998, in press; de Jersey & McKellar, 1979, 1981). The latter occupied cooler, higher-latitude southern and eastern Australia and gave rise to miospores of the Ipswich Microflora (Dolby & Balme, 1976). Mixed Onslow-Ipswich assemblages also occur in the upper part of the unconformably underlying Tinchoo Formation ("upper Doonmulla Member" and the succeeding Gilpeppee Member).

Palynostratigraphic relationships of strata from the older part of the Cuddapan Formation are well represented by the interpretation drawn from the palynoflora recorded from SWC/2125.5m in NMX Warcanyah 1 (Hos, 1988b). This sample, which encompassed *Staurosaccites quadrifidus*, *Samaropollenites speciosus*, *Duplexisporites problematicus* (common) and *Craterisporites rotundus*, was correlated with the *Craterisporites rotundus* Zone (of de Jersey, 1975; Ipswich Microflora) and the *Samaropollenites speciosus* Zone (of Dolby & Balme, 1976; Onslow Microflora). Correlation with part of unit PT4 of Price & others (1985; =APT4 of Price, 1997) was also indicated, together with a Carnian–early Norian(?) age.

For the upper part of the Cuddapan Formation, APT51 (PT5.1) palynofloras have been reported from a number of wells including DIO Mount Howitt 2 (Wood, 1986b; SWC/1662.99m and SWC/1660.85m) and DIO Cuddapan 1 (Partridge, 1988b; SWC/2277.77m). These palynofloras are conformable with the (lower part of the) *Polycingulatisporites crenulatus* "Oppel" Zone (of de Jersey, 1975; Helby & others, 1987), which ranges from the early – mid-Norian into the early Hettangian(?) [Helby & others, 1987; de Jersey & Raine, 1990; Figure 9, this volume]. Wood correlated the Mount Howitt 2 palynofloras with the upper Peera Peera Formation and the Beanbush beds in South Australia. Correlatives in eastern Australia are found in the Eddystone beds (Surat Basin) and the basal Bundamba Group (Moreton Basin) [Figure 10].

Distribution

The Cuddapan Formation is areally restricted (Figure 45). It extends eastwards from Haddon Corner to about longitude 143° 30' E and between latitudes 25° 15' S and 26° 40' S. In South Australia, it is restricted to the Patchawarra Trough in the area around Wimma 1 well (Powis, 1989).

Depositional Setting

The Cuddapan Formation was deposited in a high sinuosity fluvial environment with overbank and coal swamp development in some areas.

POOLOWANNA FORMATION

Nomenclature

The Poolowanna Formation (Moore, 1986) is the lowest unit of the Eromanga Basin succession in the Poolowanna Trough of the Simpson Desert region of South Australia. The same unit was originally named the "Poolowanna beds" by Wiltshire (1978). The type section occurs between 2387m and 2593 m in Poolowanna 1 well.

Wireline log correlations from Poolowanna 2 near the type section, to Merrimelia 17 in the Cooper Basin, now show that the Poolowanna Formation extends across the Birdsville Track Ridge (Alexander & Kreig [*in* Drexel & Preiss, 1995]), Figure 9.14). In the type section, the Poolowanna Formation is conformably overlain by the Algebuckina Sandstone, whereas, on the Birdsville Track Ridge, it is conformably overlain by the Hutton Sandstone (Moore, 1986). Further east in the Cooper Basin region in South Australia, the Poolowanna Formation is overlain by or intertongues with the Hutton Sandstone (Alexander & Kreig [*in* Drexel & Preiss, 1995]).

Following a meeting between the Geological Survey of Queensland and the South Australian Department of Mines and Energy in Adelaide in 1996, designed to standardise stratigraphic nomenclature for the Cooper and Eromanga Basins, the Geological Survey of Queensland decided to adopt the South Australian name Poolowanna Formation for equivalent strata in the lower part of the Eromanga Basin succession in Queensland, informally named "basal Jurassic" by the Geological Survey of Queensland (1985) and Green (1997). The "basal Jurassic" is conformably overlain by the Hutton Sandstone. The name change was justified because the "basal Jurassic" can be correlated with the Poolowanna Formation in South Australia via wells straddling the border.

The Poolowanna Formation in Queensland has been subdivided informally into a lower, dominantly sandstone subunit and an upper dominantly mudstone subunit, which is areally extensive (Green, 1997).

Rock Types

In a completely cored section in GSQ Eromanga 1, the "lower Poolowanna Formation" (unnamed Early Jurassic–lower interval) comprises light grey to grey-brown, medium to very coarse-grained sandstone, which grades in places to granule conglomerate. The "upper Poolowanna Formation" (unnamed Early Jurassic–upper interval) consists of siltstone, mudstone and lesser amounts of light grey-green sandstone and coal, and minor light grey sandstone (Almond, 1983). The highest percentage of sandstone occurs where the Poolowanna Formation is thickest. In thinner sections of the Poolowanna Formation to the south, the shale percentage is increased. This is probably because of onlap and the pinching out of the "lower Poolowanna Formation" towards the zero edge.

Wireline Log Character

The "lower Poolowanna Formation" is characterised by low gamma-ray log values in contrast with higher average gamma-ray values for the "upper Poolowanna Formation". The resistivity and sonic logs for the "lower Poolowanna Formation" are characterised by higher resistivity values and higher velocity sonic values. An abrupt boundary with the "upper Poolowanna Formation" is found in many wells.

The "upper Poolowanna Formation" may include fining-upwards cycles (Coote, 1987). Higher gamma-ray log values with reduced resistivity log values and slower velocity sonic log values are indicative of the "upper Poolowanna Formation".

Relationships and Boundary Criteria

The Poolowanna Formation unconformably overlies Cooper Basin strata (both Permian and Triassic age) and basement metasediments or rocks of Devonian age. The dominant break is with the Triassic Cuddapan or Tinchoo Formations, the Permian Toolachee or Patchawarra Formations, or basement rocks.

The boundary with the Cuddapan Formation is difficult to pick because of lithological similarity and is best picked using palynology. A subtle slightly higher gamma-ray log value and lower average resistivity values (possibly because of saline water) may delineate the Cuddapan Formation. The break with the Permian can also be difficult to determine where the "upper Poolowanna Formation" overlies shale and coal of Permian age. In these wells, palynology is also the best method for picking the boundary. Other boundaries are distinct due to lower gamma-ray values, higher resistivities and higher sonic velocity values for the Poolowanna Formation.

The Poolowanna Formation is conformably overlain by the Hutton Sandstone. The Hutton Sandstone is differentiated from the Poolowanna Formation by a decrease in the average gamma-ray log value, a decrease in resistivity values, and an increase in the sonic velocity values. The subdivision is generally readily recognisable, but the boundary may be difficult to pick consistently due to the varying proportions of sandstone and mudstone in each unit (Basin Studies Subprogram, 1989).

Thickness

The main depocentre for the Poolowanna Formation is to the north-west of the Permian and Triassic depocentres and occurs as a broad east-west trending belt north-east of Haddon Corner extending to IOL Braidwood 1 (Figure 46). The maximum thickness of 165m was intersected in DIO Curalle 1 on the Curalle Dome. The "lower Poolowanna Formation" ranges from 10m in thickness in AOD Cumbroo 1–119m in DIO Curalle 1. The "upper Poolowanna Formation" ranges from 10m in DIO Buckaroola 1 to 66m at DIO Morney 1 on the Betoota Anticline.

The distribution of aggregate thickness of sandstone is shown in Figure 47, and, of sandstone percentage, in Figure 48. Figures 49 and 50 display the distribution of aggregate shale thickness and shale percentage respectively.

Age

In the Queensland sector of the Eromanga Basin, palynofloras from the Poolowanna Formation broadly fall within the APJ22 – APJ331 interval (Price, 1997; Figures 3, 10, this volume); they are thus Pliensbachian–Toarcian in age. The formation may extend lower in the section into unit APJ1 (of late Hettangian–Sinemurian age); but this is uncertain. Such, for example, is the case with the assemblage which was recovered by Islam & others (1986) from SWC/2482.29m in AAP Fraserburgh 1 and assigned to the lower *Classopollis torosus* Zone and unit PJ1 of Price & others (1985). As noted by Islam & others, the very poor palynomorph preservation could have precluded recognition of younger key species. Moreover, APJ1, APJ2 and lower APJ31 palynofloras can be difficult to differentiate from one another given the general rarity of APJ2 and APJ31 indices in their respective assemblages and the extreme dominance of cheirolepidiacean conifer pollen (*Corollina/Classopollis*) in the APJ1 – APJ2 – lower APJ3 succession, designated the *Corollina torosa* Abundance Zone by McKellar (1998, in press).

Generally, palynofloras from the Poolowanna Formation correlate with those in the uppermost Precipice Sandstone–Evergreen Formation succession in the Surat Basin. The upper Poolowanna Formation and the time-equivalent upper Evergreen Formation, the latter embracing the oolitic Westgrove Ironstone Member, were deposited as base level (and global sea level) rose to a peak in the early Toarcian, as a consequence of widespread rifting throughout Pangaea (McKellar, 1998, in press, and cited references). An attendant change in regional climatic conditions is reflected by major changes in the palynofloral succession, as the dominance of the xeromorphic and thermophilic, *Corollina/Classopollis*-producing plants ended with the advent of more humid conditions and competition from araucariacian conifers (McKellar, 1996, 1998, in press). This represents onset of the *Callialasporites turbatus* "Oppel " Zone (of Helby & others, 1987) and the *Araucariacites fissus* Association Zone (of McKellar, 1998, in press).

Distribution

The Poolowanna Formation overlies Triassic and Permian strata of the Cooper Basin in the north-west (Figure 46). South of the JNP Trend the Poolowanna Formation occurs as a few isolated remnants in hollows in Permian and Triassic strata of the Cooper Basin and in basement. Narrow southerly extensions occur across the JNP Trend and adjacent to it. Basin Studies Subprogram (1989) suggested that the narrow extensions may be the reflection of the Poolowanna Formation infilling a valley present in the old land surface preceding formation of the Eromanga Basin.

Depositional Setting

The Poolowanna Formation represents cyclical fluvial-lacustrine sedimentation. Channel sands from an easterly flowing, broad, meandering fluvial system were confined by old basement highs. Dominantly fine-grained clastic sediments in the "upper Poolowanna Formation" mark a rise in base level of erosion and this has been correlated with a Toarcian global rise in sea-level (Passmore & Burger, 1986).

HUTTON SANDSTONE

Nomenclature

The name, Hutton Sandstone, was first used by Reeves (1947) for sandstone outcropping north-west of Injune in the western part of the Surat Basin. The type section is near Hutton Creek north-east of Injune (Mollan & others, 1972). Kapel (1966) first applied the name to sandstone of 'Lower to Middle Jurassic age' in the Cooper Basin region (Alexander & Krieg, 1995). Presumably, the underlying Poolowanna Formation, where present, was included in this succession named Hutton Sandstone. The Hutton Sandstone throughout the project area was subdivided where possible, into lower and upper subunits (Green, 1997). These were named "lower and upper Hutton Sandstone" respectively.

Rock Types

The Hutton Sandstone in GSQ Eromanga 1 consists dominantly of sandstone with rarely interbedded siltstone and mudstone. Sandstone is light grey to light green-grey, quartzose to sublabile, rarely labile, medium- to coarse-grained, rarely coarse- to very coarse-grained, fairly sorted with an argillaceous, in part calcareous, cement. Bedding is thick to massive with poorly defined laminations present in some beds. Rip-up clasts of siltstone and mudstone are present (Almond, 1983). Towards the south-eastern edge of the project area, in GSQ Thargomindah 1-1A, the Hutton Sandstone contains conglomerate, which is grey to grey-green and consists of subangular to subrounded pebbles and granules set in a medium- to coarse-grained sandstone matrix. Siltstone and mudstone are grey to dark grey-brown, micaceous with rare plant fragments (Almond, 1986).

The "lower Hutton Sandstone" contains more siltstone and mudstone in comparison with the "upper Hutton Sandstone" and this is reflected in the greater variability in the log responses in the "lower Hutton Sandstone". The boundary between the two subunits is placed at the top of a persistent mudstone interval near the middle of the formation. The "upper Hutton Sandstone" is dominantly sandstone with a regular log response reflecting a uniform rock type (Green 1997). Hydrocarbon reserves occur mainly in the upper part of this subunit.

Wireline Log Characteristics

Wireline logs over this interval are generally characterised by a low gamma-ray response and a higher average resistivity response than that of the overlying Birkhead Formation. In wells south of the JNP Trend, there are reversed resistivity responses over the Hutton Sandstone interval, where resistivity values in sandstone are lower than that of the mudstones (Green & others, 1989).

The two-fold subdivision is defined on a variation in resistivity responses on wireline logs with the "upper Hutton Sandstone generally characterised by higher average readings than the "lower Hutton Sandstone". The consistent mudstone which separates the subunits is easily recognised on the gamma-ray and resistivity logs.

Relationships and Boundary Criteria

The Hutton Sandstone comformably overlies the Poolowanna Formation, but is more extensive. The Hutton Sandstone unconformably overlies Triassic and Permian strata of the Cooper Basin and basement in the south-east, Devonian strata of the Warrabin Tough in the north-east, and basement in the north-west.

The boundary between the Hutton Sandstone and the underlying Poolowanna Formation is picked from lower gamma-ray values and higher resistivity and sonic velocity values which typify the latter. Where the Hutton Sandstone unconformably overlies the Permian, is easily delineated because of the high shale and coal content of the latter.

The Hutton Formation is overlain conformably by the Birkhead Formation, which is delineated by an upwards increase in gamma-ray values, a decrease in resistivity values and by slower travel times.

Thickness

The Hutton Sandstone is predominantly from 90–210m thick (Figure 51). The maximum thickness intersected is 244m in MIM Wyerie 1, which is contained in a north-east trending depocentre (Figure 51) extending as far north as TMO Carella Creek North 1. The north-western part of the depocentre overlies the Poolowanna Formation depocentre. The distribution of aggregate sandstone thickness is shown in Figure 52 and, of sandstone porosity, in Figure 53.

Age

The Hutton Sandstone, from a palynostratigraphic perspective, generally falls within the unit APJ33 (APJ331-APJ332)-APJ4 succession, although the uppermost strata of the formation in some sections of the Eromanga Basin extend into the lower part of APJ5 (Price & others, 1985; Price, 1997; Figures 3, 10, this volume). Occurrences of APJ5 in the formation include SWC/1915.06m in DIO Ballera 1 (Wood, 1985b), SWC/1646.83m in DIO Marradong 1 (Filatoff & Price, 1987), SWC/1656.28m in DIO Copai 1 (Wood, 1987) and SWC/1373.43m in DIO Cacoory 1 (Hannah, 1988).

In terms of the palynostratigraphic scheme of McKellar (1998, in press), the Hutton Sandstone in the Eromanga Basin embraces the upper part of the *Araucariacites fissus* Association Zone, the *Camarozonosporites ramosus* Association Zone, *Retitriletes circolumenus* Association Zone, *Aequitriradites norrisii* Association Zone, *Contignisporites glebulentus* Interval Zone and the lower part of the *Murospora florida* Association Zone, the latter being equivalent to palynological unit APJ5 (Figure 10). A latest Early–Middle Jurassic (late Toarcian–Callovian) age is thus indicated for the Hutton Sandstone in this basin, contrasting with the situation in the Surat Basin, where APJ5 palynofloras have not been reported below the Walloon Coal Measures (Birkhead Formation equivalent). In the Surat Basin, the Hutton Sandstone does not appear to extend above the Bathonian (Figures 3, 10).

Distribution

The Hutton Sandstone is widespread throughout the project area, except in the north-west and south-east where it pinches out respectively on basement and possibly a thin Permian section or basement (Figure 51).

Depositional Setting

The Hutton Sandstone was deposited in a braided fluvial system and represents a series of stacked channel sands (Moore & others, 1986; John & Almond, 1987) Wilshire (1989) argued for aeolian and lacustrine reworking of sand brought into the basin by fluvial processes.

BIRKHEAD FORMATION

Nomenclature

The Birkhead Formation (Exon, 1966) was named after Birkhead Creek in the Eromanga Basin 40km north of Tambo. The type section was defined as the interval between 573m and 684m in AOP Westbourne 1. An additional 61m of section underlying Exon's (1966) defined interval was included in the Formation as a result of the continuous core obtained from GSQ Augathella 2-3R, drilled 1.5km east-south-east of AOP Westbourne 1 (Green & others, 1989). The revised type section therefore corresponds to the interval from 573m to 744m in AOP Westbourne 1.

Rock Types

The Birkhead Formation consists of interbedded sandstone and siltstone, and minor mudstone and shale. In GSQ Eromanga 1 the sandstone is light grey, labile to sublabile, predominantly very fine- to medium-grained, but a few beds of coarse-grained sandstone occur. It is commonly poorly sorted with bedding ranging from thin to massive. Some calcite cement is present, generally in the better sorted sandstone beds. Sedimentary structures are rare, but include cross-bedding and scour and fill structures. A few burrows and rip-up clasts are preserved in the sandstone (Almond, 1983). In GSQ Thargomindah 1-1A, the coarsest sandstone occurs at the bottom of the formation. Some sandstone beds contain minor small tabular siltstone and mudstone clasts (Almond, 1986).

The siltstones are grey to dark grey or brown, commonly sandy but poorly sorted and subfissile. The mudstone and shale are grey to black, and include minor thin coal beds up to 50mm in thickness. Carbonaceous laminae are present and sparse rootlets traces are preserved (Almond, 1983). In GSQ Thargomindah 1-1A the siltstone is slightly micaceous (Almond, 1986).

The Birkhead Formation shows a minor increase in sandstone content to the east and to the south of the project area. Hydrocarbons are produced from sandstones within the Birkhead Formation in several fields (for example, Toobunyah, Echuburra & Talgeberry fields).

Wireline Log Character

The wireline log signature for the Birkhead Formation is quite characteristic, with higher gamma-ray values, lower resistivity values and slower travel times than those of the underlying Hutton Sandstone and overlying Adori Sandstone. Coarsening upward sequences dominate in the lower part of the formation and fining upward sequences at the top of the Birkhead Formation. Sandstone beds can also have a blocky pattern.

Relationships and Boundary Criteria

The Birkhead Formation conformably overlies the Hutton Sandstone (John & Almond, 1987) and is unconformably overlain by Adori Sandstone (McKellar, 1998, in press). The boundary with the Hutton Sandstone is delineated by an upwards increase in gamma-ray values, decrease in resistivity values and slower sonic velocities.

Within some fields, a gradual transition from the quartzose Hutton Sandstone to the lithic labile Birkhead Formation sandstone exists, showing a change to a dual provenance, and indicating increased mid-Jurassic activity in the volcanic-arc off the Queensland coast (Watts, 1987).

The boundary with the Adori Sandstone is picked with lower gamma-ray values, higher resistivity values and faster sonic values. On wireline logs the boundary is commonly abrupt, which reflects the unconformity indicated above.

Thickness

The Birkhead Formation is predominantly between 40–100m thick (Figure 54). The maximum thickness intersected is 110m at AAP Tanbar 1 and PPL Regleigh 1, which were drilled in the north-east trending depocentre. Aggregate sandstone and shale thickness distribution is shown in Figure 55 and Figure 56 respectively.

Age

Palynofloras in the Birkhead Formation represent the upper part of palynological unit APJ4 [APJ42(?) - APJ43] and unit APJ5 (Price & others, 1985; Price, 1997; Figures 3, 10, this volume). They also fall within the succession embracing the uppermost part of the *Aequitriradites norrisii* Association Zone (although this is presently uncertain), the *Contignisporites glebulentus* Interval Zone, and the lower part of the succeeding *Murospora florida* Association Zone (of McKellar, 1998, in press), suggesting a late Middle Jurassic (late Bathonian–Callovian) age. In marginal areas of the Eromanga Basin, often only Callovian palynofloras of unit APJ5 are associated with the Birkhead Formation, indicating a high degree of diachronism (within the Bathonian–Callovian) of the lower boundary of this lithostratigraphic unit and the equivalent and interconnecting Walloon Coal Measures of the adjacent Surat and Moreton Basins (McKellar, 1998, in press; Figure 10, this volume).

Rare spinose acritarchs of the *Micrhystridium* type (very rarely *Veryhachium*) have also been reported from the Birkhead Formation (Williams, 1983c, 1984; Morgan & Milne, 1984; Dettmann, 1985a; Filatoff, 1985; Wood, 1985a; Morgan, 1985b, 1987a-b). These occurrences have been used to infer some brackish to marginal-marine influence, although these palynomorphs are not present in sufficient abundance to be confident of this. Moreover, as noted by Williams (1984), the palaeoenvironmental significance of acanthomorph acritarchs of (generally) a single species in such low numbers in assemblages comprising almost entirely terrestrially derived palynomorphs is not entirely clear; in the absence of marine dinoflagellates, it was suggested that they may be representative of a brackish depositional influence (provided they had not been reworked from older strata).

Distribution

The Birkhead Formation is widespread throughout the project area, except in the north-west and south-east where it pinches out on basement. The pinchout edge is only approximate because of the lack of well data.

Depositional Setting

The Birkhead Formation was deposited under fluvio-lacustrine conditions. Following deposition of the lower part of the unit, there was an influx of volcaniclastic sediments from the east (Lanzilli & Boult, 1996; Boult & others, 1998).

ADORI SANDSTONE

Nomenclature

The name Adori Sandstone was first used by Woolley (1941) for strata cropping out on Adori Hill, 35km east-north-east of Tambo in the south-eastern Eromanga Basin, where he measured a section (Exon, 1966). The name was first published by Hill & Denmead (1960). Exon (1966) defined the Adori Sandstone and measured another section at Adori Hill, which he proposed as the type section. He realised that his type section represented only the lower part of the Adori Sandstone.

The Adori Sandstone–Westbourne Formation interval has been grouped together by some authors because of the difficulty of delineating between the two formations (Alexander & Krieg, 1995). The absence of shales at the base of the Westbourne Formation is the main reason.

In the south-western part of the project area, near the southern flank of the Cooper Basin, the interval from top Birkhead Formation to base Murta Formation is very sandy and equivalents of the Adori Sandstone cannot be distinguished.

Rock Types

The Adori Sandstone is predominantly sandstone with minor siltstone and conglomerate. The sandstone is light grey to grey, very fine- to very coarse-grained, quartzose and becomes more labile towards the top of the formation. In GSQ Eromanga 1, garnet and mica are accessory minerals towards the top of the formation (Almond, 1983). In GSQ Thargomindah 1-1A, secondary calcite cement and subvertical calcite veins are also present towards the top of the unit (Almond, 1986). The Adori Sandstone fines upwards and the bedding ranges from massive to thinly bedded and laminated (Almond, 1983; 1986).

The siltstone is grey, thinly bedded and generally interlaminated and interbedded with very fine to fine-grained sandstone. In GSQ Eromanga 1, only rare thin beds of siltstone occur in the lower half of the Adori Sandstone, whilst laminae of siltstone and carbonaceous material are more common in the upper half of the formation (Almond, 1983).

Conglomerate in the Adori Sandstone in GSQ Thargomindah 1-1A occurs as thin to medium beds of matrix-supported, granules and pebbles in the middle of the Adori Sandstone. The pebbles consist of meta-sandstone and argillite and are subangular to subrounded (Almond, 1986). In GSQ Eromanga 1, a few thin pebble beds occur near the bottom of the Adori Sandstone (Almond, 1983).

Wireline Log Character

The Adori Sandstone is distinguished by low gamma-ray values and marginally higher resistivity values than the overlying unit, and a generally reversed spontaneous potential log. The sonic log shows considerable variation resulting from variable porosity within the unit.

Relationships and Boundary Criteria

The Adori Sandstone unconformably overlies the Birkhead Formation (McKellar, 1998, in press) and conformably overlain by the Westbourne Formation. The boundary with the Birkhead Formation is delineated readily with markedly lower gamma-ray log values and higher resistivity log values for the Adori Sandstone. The sharp contact on the wireline logs reflects the unconformable relationship. The sonic log response is varied but has predominantly faster travel times in the Adori Sandstone. The boundary with the overlying Westbourne Formation is picked with higher gamma-ray log values, lower resistivity log values and slower travel times for the sonic log in the Westbourne Formation. The spontaneous potential log over the Adori Sandstone has much higher values than for the Birkhead and Westbourne Formations.

The Adori Sandstone can be picked on wireline logs only if the Westbourne shales are present (Alexander & Krieg, 1995). In the south-western part of the project area the Namur Sandstone, Westbourne Formation and Adori Sandstone cannot be delineated as the units increase in sandstone content.

Thickness

Within the project area, the Adori Sandstone thickness is predominantly between 15–50m, with the depocentre being west of Haddon

Corner (Figure 57). The maximum thickness intersected is 55m in DIO Cacoory 1. Aggregate sandstone distribution is shown in Figure 58, and lateral porosity variation in Figure 59.

Age

The Adori Sandstone, in the main, has yielded palynofloras that are conformable with palynological unit APJ61 (Price, 1997; Figures 3, 10, this volume), although assemblages falling within the APJ5 interval have also been recovered from the formation by several authors including Wood (1986c; SWC/1946.45m in DIO Doonmulla 1) and Sajjadi & Playford (in press a-b). In terms of the palynostratigraphic scheme of McKellar (1998, in press), the formation embraces the Murospora florida Association Zone and/or only the lower part of the succeeding Retitriletes watherooensis Association Zone (Figure 10), indicating a late Middle(?) - early Late Jurassic [late Callovian(?)–Oxfordian] age.

In the Surat Basin, the Springbok Sandstone, together with the preceding, upper part of the Walloon Coal Measures and the lower part of the succeeding Westbourne Formation, embrace palynological unit APJ5 and the Murospora florida Association Zone (Figure 10). However, the Adori Sandstone–lower Westbourne Formation interval in the Eromanga Basin is commonly associated with the younger unit APJ6 and the equivalent Retitriletes watherooensis Association Zone (Figures 3, 10). This indicates not only a notable degree of diachronism (within the late Callovian–Oxfordian) of the Springbok and Adori Sandstones, which intertongue in the subsurface on the Nebine Ridge between the Surat and Eromanga Basins (Exon, 1976), but also the presence of unconformity between the Birkhead Formation and the Adori Sandstone in regions of the latter basin (McKellar, 1998, in press; Figures 3, 10, this volume). In the Surat Basin, an unconformable relationship also likely exists between the Walloon Coal Measures and the underlying Springbok Sandstone, although this is not resolved by the palynological biostratigraphy, as the common boundary between both formations occurs entirely within palynological unit APJ5 (and the Murospora florida Association Zone).

Termination of the Birkhead Formation–Walloon Coal Measures regime and the subsequent unconformable deposition of the Springbok and Adori Sandstones reflects the extensional tectonism associated with Argoland rifting and the “breakup unconformity” (E seismic-horizon event) on the north-western continental margin (McKellar, 1998, in press). Effects of this fragmentation are not only evident in all basins of the Westralian Superbasin, but are also recorded in the Thakkola region of the Nepal Himalaya by Callovian–Oxfordian hiatus and by the occurrence of a Callovian ferruginous oolite horizon, the distribution of which embraces southern Tibet and parts of the Indian subcontinent (McKellar, 1998, in press; and cited references).

Distribution

The Adori Sandstone is widespread throughout the project area, except in the far north-west and in the south-east where it pinches out on basement (Figure 57). The pinchout edge is only approximate because of the lack of well data.

Depositional Setting

The Adori Sandstone was deposited from a braided fluvial system (John & Almond, 1987; Williams, 1989). An alternative model proposed by Wiltshire (1989) suggests that the Adori Sandstone was the product of a pulsed sand supply to the postulated Lake Birkhead in South Australia.

WESTBOURNE FORMATION

Nomenclature

The name Westbourne Formation was first proposed and defined in an unpublished report by Amoseas Overseas Petroleum Limited on petroleum well AOP Westbourne 1, 42km south of Tambo (Gerrard, 1964). Exon (1966) formally defined the Westbourne Formation using information from the Amoseas work and incorporating some of his own field work. The type section is from 390m–503m in AOP Westbourne 1.

In the south-western part of the project area, the Westbourne Formation becomes very sandy and difficult to distinguish from the underlying and overlying formations. In a few wells in this area (for example, PPL Omicron 1), the Westbourne Formation is included in the Namur Sandstone as recently defined in South Australia and discussed below. In a few other wells in the project area the Adori Sandstone and Westbourne

Formation are grouped into the "Westbourne-Adori" unit because of the difficulty in separating the two formations (for example, DIO Phi North 1). In these wells the overlying Hooray Sandstone / "upper Namur Sandstone" can be distinguished.

Rock Types

The Westbourne Formation consists of fine to very fine-, rarely medium- to coarse-grained sandstone with moderate to poor sorting and is interlaminated and interbedded with grey to dark grey siltstone and shale. The sandstone is grey to grey-green and brown. In GSQ Eromanga 1 the sandstone is labile and commonly micaceous whilst in GSQ Thargomindah 1-1A to the south-west, it is quartzose to sublabile. Rare rip-up clasts and minor cross-bedding are present in some sandstone beds. The siltstone is grey, rarely light brown and contains mica and plant fragments in GSQ Thargomindah 1-1A (Almond, 1983; 1986).

Calcite cement is rare but is found in both sandstone and siltstone beds. Carbonaceous laminae occur, particularly in the silty sandstone. Soft-sediment deformation and convolute bedding are common throughout the formation. Water escape structures, flame structures, load casts and micro-faults are also present (Almond, 1983; 1986). Fining-upward sequences and a few coarsening-upward sequences also occur throughout the Westbourne Formation.

Wireline Log Character

The Westbourne Formation characteristically shows high gamma-ray values, especially in the upper part of the unit. This feature has been used for many years to identify the Westbourne Formation in the Eromanga Basin, especially in gamma-ray logged water bores. There is little variation in the resistivity values but the formation commonly displays slightly slower sonic velocity values than those for the Adori Sandstone and the "upper Namur Sandstone"/Hooray Sandstone.

Relationships and Boundary Criteria

The Westbourne Formation conformably overlies the Adori Sandstone and is overlain by and intertongues with the Hooray Sandstone and the "upper Namur Sandstone". Within the Eromanga Basin, the relationship between the Westbourne Formation and the Hooray Sandstone varies from being conformable to unconformable (Burger, 1989).

The boundary between the Adori Sandstone and Westbourne Formation is delineated by much higher gamma-ray values in the Westbourne Formation. Towards the south of the project area, the lower part of the Westbourne Formation becomes very sandy and hence this boundary is difficult to pick. Over most of the project area, the boundary with the "upper Namur Sandstone"/Hooray Sandstone is delineated by a sudden decrease upwards in gamma-ray values. However in the far south-western part, the Westbourne Formation passes laterally into the Namur Sandstone.

Thickness

Within the project area the Westbourne Formation is mainly between 70–130m thick (Figure 60). The maximum thickness was 166m at DIO Keilor 1 just north of the JNP Trend. The main depocentre overlies the Nappamerri Trough and the north-western portion of the JNP Trend and extends in a north-easterly direction. The distribution of aggregate sandstone thickness is shown in Figure 61. Distribution of aggregate shale thickness and percentage shale are shown in Figure 62 and 63 respectively.

Age

The palynoflora of the Westbourne Formation in the Eromanga Basin embraces palynological units APJ5 (upper part) and APJ6, commonly only the latter (Price & others, 1985; Price, 1997; Sajjadi & Playford, in press a-b; Figures 3, 10, this volume). These biozones are represented respectively by the *Murospora florida* Association Zone and the *Retitriletes watherooensis* Association Zone (of McKellar, 1998, in press; Figure 10, this volume), indicating a Late Jurassic (Oxfordian–Kimmeridgian–early Tithonian) age for the formation. Interbasin bio- and lithostratigraphic relationships (discussed above under *Adori Sandstone*) demonstrate diachroneity of deposition of the Adori Sandstone–Westbourne Formation sequence (Eromanga Basin) and the Springbok Sandstone–Westbourne Formation sequence (Surat Basin).

Strata assigned to the uppermost Westbourne Formation in some regions of the eastern Eromanga Basin have yielded latest Jurassic(?)–

earliest Cretaceous palynofloras conformable with palynological unit APK1 (APK11, APK12) and the equivalent *Ruffordiaspora* (al. *Cicatricosisporites*) *australiensis* Zone (of Burger, 1973, 1989; Helby & others, 1987) [Figures 3, 10]. Such occurrences of APK1 (and its subunits), provided they encompass in situ and correctly delimited palynomorph indices, are exemplified by the following records:

(a) for unit APK1: SWC/1031.00m in LEA Petworth 1 (Dettmann, 1985a), SWC/1273.00m in LEA Greymount 1 (Dettmann, 1985b), SWC/1309.12m in DIO Richie 1 (Dettmann & others, 1985), and SWC/1841.6m in DIO Hammond 1 (Wood & Williams, 1985),

(b) for unit APK11: SWC/1231.39m in DIO Hooley 1 (Filatoff, 1986a), SWC/1093.00m in PPL Toolerah Creek 1 (Morgan, 1986b), SWC/1444.75m in DIO Watson South 1 (Wood & Jones, 1986a), SWC/1510.89m in DIO Warnie East 1 (Wood & Jones, 1986b), and SWC/1487.42m in DIO Marradong 1 (Filatoff & Price, 1987), and

(c) for unit APK12: SWC/1276.5m in DIO Jackson 1 (Dettmann & Jones, 1985; based on the record of *Cyclosporites hughesii*), SWC/929.64 and SWC/27/907.08m in HEP Kooroopa 1 (Hos, 1985b), and possibly SWC/1409.6m in PPL Bundeena 1 (Morgan, 1987a; assigned to the lower *Cicatricosisporites australiensis* Zone/unit PK1.1, although *Cyclosporites hughesii* was reported in the attendant range chart).

These occurrences of APK1, particularly those of APK12, are seemingly anomalous and difficult to interpret. In relation to the Surat Basin, the APK1 (APK11-APK12) succession embraces the post-Westbourne Formation interval, which contains the Gubberamunda Sandstone, Orallo Formation and Mooga Sandstone (Price & others, 1985; Price, 1997; McKellar, 1998, in press; Figure 10, this volume). Based on the occurrence of *Cyclosporites hughesii* in the uppermost Orallo Formation in GSQ Roma 3 (Burger, 1974), palynological unit APK12 (which is defined by the appearance of this species; Price, 1997) occurs therein. Although it is presently uncertain, the APK11-APK12 boundary in the Surat Basin appears to lie in the upper Orallo Formation. This view is supported by the appearance in the upper part of the cited formation of *Laevigatosporites belfordii* (McKellar, unpublished data), a species also reported from the uppermost Westbourne Formation in the Eromanga Basin (for example: SWC/1273.00m in LEA Greymount 1; Dettmann, 1985b). In the latter basin, this species was employed by Burger (1989) to assist in definition of an "upper *Cicatricosisporites australiensis* Zone". The latter author has indicated that unit PK1.2 of Price & others (1985; =unit APK12 of Price, 1997) may coincide with this interval, as *Cyclosporites hughesii* seems to appear regularly at (about) the same level. Thus, it appears that APK1 strata assigned to the uppermost Westbourne Formation (in the Eromanga Basin) may be associated with the subsequent sedimentary cycle of deposition, which embraces the Hooray Sandstone (Eromanga Basin) and includes the Gubberamunda Sandstone and Orallo Formation (Surat Basin). Hiatus is therefore apparent between these "uppermost Westbourne Formation" strata and the underlying strata associated with the formation (Figures 3, 10). Detailed analysis of the associated litho- and biostratigraphic relationships, including better delineation of the palynological succession of species (and their taxonomic-morphographic limits) in this part of the section, in both the Surat and Eromanga Basins are required in order to confidently resolve the problem.

Green & McKellar (1996a-b interpreted the Westbourne hiatus to be an erosive event that removed previously deposited Westbourne Formation and resulted in incision into the top of the unit. They further submitted that subsequent infilling with volcano-lithic labile sediment formed what has been inadvertently interpreted as the upper part of the Westbourne Formation (in the Eromanga Basin).

Distribution

The Westbourne Formation is widespread throughout the project area except for the south-eastern part where it onlaps onto basement and pinches out (Figure 60).

Depositional Setting

The presence of large, well-preserved plant macrofossils and a dominantly fine-grained lithology with hummocky cross-stratification, which indicates a nearshore environment, suggests a dominantly lacustrine origin (Williams, 1989). The lower part of the unit represents the gradual change from a fluvial to lacustrine environment of deposition.

Wiltshire (1989) suggests a similar palaeogeography for both the Westbourne and Birkhead Formations with sediments transported by aeolian and fluvial processes from a source to the east.

HOORAY SANDSTONE

Nomenclature

The name, Hooray Sandstone, was first used by Woolley (1941) for sandstones outcropping in Hooray Creek, 19km north-east of Tambo in the eastern Eromanga Basin. The name was first published by Hill & Denmead (1960). Exon (1966) measured a type section for the "Hooray Sandstone" in the same creek, and like Woolley, recognised a lower and an upper "Hooray Sandstone". Because of the possibility of there being an unconformity between these two subunits, Exon did not consider the "Hooray Sandstone" to be a valid formation.

A cored and wireline-logged reference section of the "Hooray Sandstone", down-dip of Exon's measured section in Hooray Creek, was obtained in GSQ Tambo 2 (Wallin, 1974). In a recent study of the southern Eromanga Basin, a revised reference section for the Hooray Sandstone was nominated in GSQ Tambo 2 by Green & others (1989) and the unit was correlated into the current project area in the south-western Eromanga Basin. This correlation from near outcrop justifies the use of the name Hooray Sandstone in the subsurface of the Eromanga Basin in Queensland.

In the Cooper–Eromanga Basin area of south-western Queensland, the Hooray Sandstone in many wells has been informally subdivided by the Department into a lower "Namur Sandstone member" and an upper "Murta member" (John & Almond, 1987; Green & others, 1989). Petroleum companies operating in this area use a similar subdivision, but they extend the upper boundary of their "Murta member" to include the lowermost mudstone-dominated part of the overlying Cadna-Owie Formation, as defined by Senior & others (1975). In the northern and eastern Cooper–Eromanga Basin area, the Hooray Sandstone generally cannot be subdivided. Petroleum companies commonly call this unit the Namur Sandstone.

In the present study, the Hooray Sandstone was subdivided initially into members following the earlier authors. However in Figure 5 of a progress report on the present study, Green (1997) has upgraded the "Namur Sandstone member" and "Murta member" to formation status to conform with the recent upgrading of these members in South Australia by Gravestock & others (1995). In South Australia, these members were formerly regarded as being members of the now disregarded Mooga Formation.

Strata equivalent to the Hooray Sandstone in South Australia are now included in the upper part of the newly-defined Namur Sandstone and most of the overlying Murta Formation. The new Namur Sandstone, as defined, represents strata equivalent to the Adori Sandstone, Westbourne Formation and "Namur Sandstone member" in Queensland.

In order to avoid the introduction of a new name in Queensland, the term "upper Namur Sandstone" is now considered to be the most appropriate for the strata between the Westbourne Formation and the Murta Formation, previously referred to as "Namur Sandstone member" and Namur Sandstone (by petroleum companies).

The Murta Formation in South Australia and Murta Formation in Queensland are equivalent. However, in Queensland, the Murta Formation passes laterally into the upper part of the Hooray Sandstone *sensu stricto* (Figures 10, 44).

The Namur Sandstone *sensu stricto* and Murta Formation can be recognized in a few wells in southern Queensland near the South Australian border (*eg* in CDP Tualta 1 and PPL Omicron 1).

Rock Types

The Hooray Sandstone consists of sandstone with lesser siltstone and mudstone and minor coal. The sandstone is light grey to grey-green, sublabile to quartzose, micaceous and generally well-sorted. Garnets are present in, but not restricted to, the more quartz-rich sandstone, and they occur in discrete layers at some depths. Mica is most prominent in the silty sandstone beds (Almond, 1983; 1986).

The siltstones are grey, micaceous and laminated to thinly bedded. Burrows and soft sediment deformations occur most commonly where the siltstone is inter-laminated with sandstone. Plant remains, rootlets and rare coal seams usually occur in the siltier beds. Load casts, flame structures, and a few small sand dykes and small dewatering structures are also present (Almond, 1983; 1986).

The mudstone is grey to grey-brown, laminated, and slightly micaceous. It is slightly silty and moderately carbonaceous, with rare coaly rootlets. Coal interbedded with mudstone, occurs in seams up to 100mm thick (Almond, 1983; 1986).

Wireline Log Character

The Hooray Sandstone is generally characterised by lower gamma-ray, higher resistivity and sonic velocity values when compared to the Westbourne Formation and Cadna-owie Formation. The spontaneous potential values are also more positive than those of the bounding formations. The sandstone beds are blocky and a few are upwardly-fining.

Relationships and Boundary Criteria

Within the Eromanga Basin, the relationship between the Westbourne Formation and the overlying Hooray Sandstone varies from being conformable to unconformable (Burger, 1989). The boundary between the Hooray Sandstone and the overlying Cadna-owie Formation is conformable and transitional (Musakti, 1997).

The boundary with the Westbourne Formation is picked from a distinctive upwards decrease in the gamma-ray log values. The sonic log velocity and the resistivity values have a subtle upwards increase but this is not consistent across the basin. The spontaneous potential log generally has a reverse response at the boundary.

The boundary with the overlying Cadna-owie Formation is taken at the change from sandstone to siltstone which corresponds to a distinctive increase in the gamma-ray log and a reduction in resistivity log and sonic velocity values.

Thickness

Within the project area the Hooray Sandstone is predominantly between 90–165m thick (Figure 64 — composite of Hooray Sandstone, "upper Namur Sandstone" and Murta Formation). The Hooray Sandstone thins to the north-west and south-east of the project area. Aggregate sandstone thickness distribution is shown in Figure 65 (composite of Hooray Sandstone, "upper Namur Sandstone" and Murta Formation) and sandstone porosity distribution in Figure 66 (composite of Hooray Sandstone, "upper Namur Sandstone" and Murta Formation).

Age

The Hooray Sandstone embraces palynofloras that are attributable to palynological units APJ62 (apparently only the uppermost subunit, APJ622) and APK1, with the youngest strata assigned to the formation being contained within APK122; in some regions, the succeeding biounit, APK2, is represented (Price & others, 1985; Price, 1997; Burger, 1989; Figures 3, 10, this volume). Equivalent biostratigraphic units that encompass the Hooray Sandstone include the *Retitriletes watherooensis* Zone (of Backhouse, 1978; Helby & others, 1987; McKellar, 1998, in press; for unit APJ6), the *Ruffordiaspora* (al. *Cicatricosisporites*) *australiensis* Zone (of Burger, 1973, 1989; Helby & others, 1987; for unit APK1) and the *Foraminisporis wonthaggiensis* Zone (of Burger, 1973, 1989; Helby & others, 1987; for unit APK2). A latest Jurassic–earliest Cretaceous (early–mid-Tithonian–Berriasian–early Valanginian) age is indicated (Figures 3, 10).

The palynostratigraphy of the Hooray Sandstone has been broadly outlined by Burger (1989), who has recognised a number of hiatuses within the unit and indicated that its depositional history is very complex and difficult to unravel. Such a view is also implied herein in the discussion on the age of the underlying Westbourne Formation.

Distribution

The Hooray Sandstone is widespread throughout the north-east of the project area north of latitude 25°30′00"S.

Depositional Setting

The Hooray Sandstone is interpreted as being derived from a braided fluvial environment which was sourced predominantly from the north-east (Williams, 1989; Musakti, 1997).

"Upper Namur Sandstone"

Nomenclature

As discussed above, the Namur Sandstone as formally defined in South Australia (Gatehouse & others, 1995) encompasses the interval Adori Sandstone to Hooray Sandstone in Queensland. In most of the Queensland portion of the Eromanga Basin, Adori Sandstone and Westbourne Formation can be readily identified. Overlying the Westbourne Formation is the Hooray Sandstone and its lateral equivalents, the "upper Namur Sandstone" and the Murta Formation. The term "upper Namur Sandstone" is used to comply with the formal definition of the Namur Sandstone and to retain the connection with the widely, but informally used "Namur Sandstone member".

Rock Types

The "upper Namur Sandstone" consists dominantly of sandstone with minor interlaminated siltstone. In GSQ Thargomindah 1-1A (Almond, 1986), the sandstone is white to light grey-brown, medium-grained with some granites and pebbles, fairly to well-sorted, quartzose, micaceous with an argillaceous, in part, calcareous cement. It is visibly porous and, in part, friable. Mudstone and siltstone clasts and carbonaceous laminations occur throughout the sandstone. The siltstone is grey, laminated and contains mica and plant fragments.

Wireline Log Character

The "upper Namur Sandstone" characteristically shows a blocky gamma-ray response with low values, interspersed with higher value peaks and intervals, which reflect the interbedded siltstone and shale. On the resistivity log, the siltstones and shales have low values, whereas high resistivities occur over the sandstone intervals. Some sandstones show high resistivity and low sonic travel time peaks due to carbonate cement.

An upwardly-fining interval commonly occurs in the lower part of the unit.

Relationships and Boundary Criteria

Towards the southern margin of the Eromanga Basin in Queensland and in much of the South Australian portion of the Basin, the "upper Namur Sandstone" passes into the Namur Sandstone (*sensu stricto*). Where the "upper Namur Sandstone" is present in Queensland, it conformably to unconformably overlies the Westbourne Formation. Towards the north-east of the project area it passes laterally into the lower part of the Hooray Sandstone. It is conformably overlain by the Murta Formation.

The boundary with the Westbourne Formation is picked from a distinctive upwards decrease in the gamma-ray log values. The sonic log velocity and the resistivity values have a subtle upwards increase but this is not consistent. The spontaneous potential log generally has a reversed response at the boundary. The boundary with the Murta Formation can be picked by a sharp increase upwards in gamma-ray log values.

Thickness

Within the project area, the "upper Namur Sandstone" is mainly between 50–70m thick. It ranges from being <30m thick to >90m. The "upper Namur Sandstone" is thickest near the JNP Trend.

Age

The "upper Namur Sandstone", as interpreted herein, encompasses palynofloras of palynological units APJ62 (possibly only APJ622), APK11 and APK12 (Price & others, 1985; Price, 1997; Figures 3, 10, this volume). The formation also embraces the uppermost part of the *Retitriletes watherooensis* Zone (of Backhouse, 1978; Helby & others, 1987; McKellar, 1998, in press) and the lower part of the succeeding *Ruffordiaspora* (al. *Cicatricosisporites*) *australiensis* Zone (of Burger, 1973, 1989; Helby & others, 1987). A latest Jurassic–earliest Cretaceous (early–mid-Tithonian–Berriasian) age is suggested.

Distribution

The "upper Namur Sandstone" can be identified in the project area, mainly south of latitude 25°30′00"S.

Depositional Setting

The "upper Namur Sandstone" is interpreted to have been deposited in a braided fluvial environment.

Murta Formation

Nomenclature

The name "Murta Member" was first used by Nugent (1969) for a lacustrine (siltstone/shale) facies which interfingers with fluvial sandstones in the upper part of the Mooga Formation. In the same publication, the Westbourne Formation, Adori Sandstone and upper part of the Birkhead Formation are shown to interfinger with the lower part of the Mooga Formation.

Mount (1981) next published a description of the "Murta Member" with a type section from 1469m–1526m in Dullingari North 1 well in South Australia. He used the stratigraphic nomenclature adopted by Delhi Petroleum Pty Ltd, which subdivides the Mooga Formation into the Namur Sandstone and overlying "Murta Member". This differs from Nugent (1969) in that the "Murta Member" as defined by Mount (1981) does not interfinger with the upper part of the Mooga Formation but forms all of the upper part, and the upper boundary of the Mooga Formation or "Murta Member" is stratigraphically higher and occurs within the lower part of Nugent's overlying "Transition beds".

In Queensland, the name Hooray Sandstone is used with justification for strata equivalent to most of the upper part of the Mooga Formation in South Australia (now upgraded to Namur Sandstone and Murta Formation by Gravestock & others (1995)). As discussed above, the Hooray Sandstone had been subdivided by the Department, into "Namur Sandstone member" and the "Murta member", which was the procedure adopted by Delhi Petroleum Pty Ltd for the Mooga Formation in South Australia. However, the Department's pick for the top of the "Murta member" (now Murta Formation) in Queensland is lower than Delhi's and follows Nugent's (1969) pick for the top of the Mooga Formation. In this sense, overlying strata named the Cadna-owie Formation (formerly "Transition beds") remain as formally defined by Senior & others (1975). In addition, the lower boundary of the Hooray Sandstone is generally stratigraphically higher than that of the Mooga Formation. This is because in some areas in South Australia, the lower part of the Mooga Formation (now Namur Sandstone) encompasses equivalents of both the Westbourne Formation and Adori Sandstone from Queensland, and overlies the Birkhead Formation.

Since the "Murta member" of the Mooga Formation has been raised to formation status in South Australia and the name Mooga Formation disregarded (Gravestock & others, 1995), the use of the term Murta Formation is herein extended into Queensland.

Rock Types

The Murta Formation consists of interbedded and interlaminated sandstone, silty sandstone, siltstone and lesser mudstone, intraformational conglomerate and coal. In GSQ Thargomindah 1-1A (Almond, 1986), the sandstone is grey to light grey, sublabile to quartzose and mainly very fine-grained with some fine-grained intervals. The sandstone is commonly silty and micaceous. The siltstones are grey, micaceous and laminated to thinly bedded. Burrows and soft sediment deformation occur most commonly where the siltstone is interlaminated with sandstone. Plant remains, rootlets and rare coal seams commonly occur in the siltier beds. Load casts, flame structures, flaser bedding and a few small sand dykes and small dewatering structures are also present. The mudstone is grey to grey-brown, laminated, slightly micaceous. It is slightly silty and moderately carbonaceous, with rare coaly rootlets. Coal interbedded with mudstone, occurs in seams up to 10cm thick. The intraformational conglomerate consists of angular siltstone and mudstone clasts within the sandstone.

The Murta Formation can be recognised readily in the southern and south-western parts of the project area. In northern and north-eastern parts, mainly north of the Permian zero edge of the underlying Cooper Basin, the unit becomes very sandy and passes into the Hooray Sandstone.

Wireline Log Character

The Murta Formation contains both upwardly-fining and upwardly-coarsening intervals and has higher gamma-ray values and generally lower resistivity values when compared to the sandstones. Slower travel times on the sonic log are generally characteristic of the Murta Formation.

Relationships and Boundary Criteria

The Murta Formation conformably overlies sandstones of the "upper Namur Sandstone". The boundary between the Murta Formation and the overlying Cadna-owie Formation is conformable and transitional (Musakti, 1997). The Murta Formation passes laterally into the upper part of the Hooray Sandstone.

The boundary with the underlying sandstones can be picked by a sharp increase upwards in gamma-ray log values. The boundary with the Cadna-owie Formation is picked by an upwards increase in gamma-ray log values and a reduction in resistivity and sonic velocity log values.

Thickness

The Murta Formation is mainly between 60–85m thick with thickest development to the south-west of Jackson (Figure 67). In GSQ Tickalara 1 drilled at latitude 28°38′30"S; longitude 142°09′25"E, differentiation of the Eromanga Basin units below the Cadna-owie Formation, which overlie basement, is difficult. This is mainly because of the relative isolation of the bore, and thinning of the lower part of the Eromanga Basin section because of onlap. A possible correlative of the Murta Formation in this bore could be >100m thick.

In the western part of the project area up to the South Australian border, the Murta Formation thins to between 50–60m.

Age

Palynofloral assemblages of Early Cretaceous (late Berriasian–early Valanginian) age have been recovered from the Murta Formation, which has been assigned to palynological unit APK12 (Price & others, 1985; Price, 1997; Figures 3, 10, this volume). This biozone is equivalent to the upper part of the *Ruffordiaspora* (al. *Cicatricosisporites*) *australiensis* Zone (of Burger, 1973, 1989; Helby & others, 1987). Palynological unit APK2 (=*Foraminisporis wonthaggiensis* Zone of Burger, 1973, 1989; Helby & others, 1987) may be represented in the upper part of the formation, although this is presently uncertain. Unit APK11 (=PK1.1 of Price & others, 1985) has also been associated with some assemblages from the Murta Formation [for example: POG Conbar 1, SWC/1037.00m, SWC/1024.00m, SWC/1016.00m, SWC/1002.5m (Milne, 1985); DIO Munro 3, SWC/1209.14m (Partridge, 1989c)]; however, it has yet to be established whether or not this is a reflection of sporadic distribution (and apparent absence) of the APK12 index species (*Cyclosporites hughesii*) in parts of the APK12 succession.

Certain palynofloras from the Murta Formation also encompass rare to commonly occurring acritarchs, mainly *Microfasta evansii*, *Nummus* sp., and spinose acritarchs of *Micrhystridium*; rarely occurring dinoflagellates including *Batiacasphaera* sp./*Batiacasphaera macrogranulata* have also been reported (Hos, 1985a,c; Morgan, 1985b; Milne, 1986; Partridge, 1988a). In DIO Mooliampah West 1 (SWC/1245.41m, SWC/1232.61m) and DIO Munro 3 (SWC/1209.14m, SWC/1167.38m, SWC/1161.9m, SWC/1160.07m), Partridge (1989a,c) assigned microplankton assemblages to the *Gagiella mutabilis* Zone (of Backhouse, 1988; described from the Perth Basin), which he regarded as being equivalent to, or slightly younger than, the latest Berriasian–earliest Valanginian *Egmontodinium torynum* Interval Zone of Helby & others (1987). The occurrence of the *mutabilis* zone, according to Partridge, suggests a greater marine influence in the member than hitherto recognised. Overall, the palynological data indicate lacustrine to marginal-marine influences for the unit.

Distribution

The Murta Formation is not widespread throughout the project area and appears to be restricted to south of approximately latitude 25°30′00"S (Figure 67).

Depositional Setting

Ambrose & others (1982, 1986) suggested that the Murta Formation was deposited in an asymmetric basin formed by compaction of the underlying Cooper Basin. Isopachs (Figure 67) suggest that the depocentre may be to the south-east of the Cooper Basin.

The Murta Formation represents a decrease in depositional energy from the braided-fluvial deposits of the “upper Namur Sandstone” to meandering fluvial, flood plain and lacustrine environments (Musakti, 1997). The Murta Formation has been interpreted as consisting of fine-grained lacustrine facies, lacustrine delta and proximal delta facies, distal sublacustrine fan facies and proximal sublacustrine facies and possible shoreline sediments (Ambrose & others, 1982, 1986).

CADNA-OWIE FORMATION

Nomenclature

Paralic sandstones and siltstones containing foraminifera, which overlie the Algebuckina Sandstone and crop out in the south-western Eromanga Basin in South Australia, were named the Cadna-owie Formation by Wopfner & others (1970; see also Exon & Senior, 1976). This sedimentation represents the first effects of a world-wide Cretaceous marine transgression. A fluvially-derived sandstone, the Mount Anna Sandstone Member, occurs at the top of the succession in South Australia.

On gamma-ray logs, the Cadna-owie Formation can be traced readily from South Australia into Queensland where it is restricted to the subsurface. Since there was some doubt as to the lateral continuity of the Mount Anna Sandstone Member, a widespread sandstone unit in the same stratigraphic position in Queensland was named the Wyandra Sandstone Member by Senior & others (1975). The Wyandra Sandstone Member is a major aquifer in the Great Artesian Basin and is readily recognised on gamma-ray logs. The type section lies between 357m–373m in water-bore RN 2049, south-south-west of Charleville in the eastern Eromanga Basin.

Within the project area, the Cadna-owie Formation has been subdivided informally into "lower Cadna-owie Formation" and "upper Cadna-owie Formation" containing the Wyandra Sandstone Member.

Rock Types

Continuous core of the Cadna-owie Formation near the type section of the Wyandra Sandstone Member was obtained in GSQ Wyandra 1 (John, 1985). The Cadna-owie Formation consists of interbedded sandstone, siltstone, silty mudstone and mudstone.

The “lower” Cadna-owie Formation (“unnamed lower interval” from 453 to 498m in GSQ Wyandra 1; John, 1985) consists mainly of grey, light grey and green-grey silty mudstone, siltstone and sandstone. Silty mudstone and siltstone are sandy in part, thin to thickly bedded, micaceous and extensively churned in part. Sandstone which increases upwards, is light grey, very fine- to fine-grained, fairly sorted, thinly to very thickly bedded in part cross-bedded, lithic labile to quartzose-sublabile with an argillaceous, in part calcareous matrix. Sparse coal fragments and fine carbonaceous fragments and siltstone rip-up clasts occur.

The “upper Cadna-owie Formation” (Wyandra Sandstone Member of John (1985) from 393m to 453m in GSQ Wyandra 1; John, 1985) consists mainly of sandstone with minor siltstone near the top. The sandstone is light grey, fine- to medium-grained, thickly bedded, fairly to well-sorted, sublabile to lithic labile with an argillaceous, partly calcareous cement. The sandstone contains siltstone rip-up clasts and is mostly visibly porous throughout (John, 1985). The siltstone is light grey to grey, thinly bedded, micaceous, carbonaceous. Bedding is commonly churned with some burrowing.

Although GSQ Wyandra 1 was drilled only 10km from the type section of the Wyandra Sandstone Member in water-bore RN 2049, the Wyandra Sandstone Member could not be recognised readily because low gamma-ray log values characteristic of this member, and a distinct lithological change in the core, are not observed. According to Senior & others (1975), the Wyandra Sandstone Member is medium- to coarse-grained, in part pebbly, quartzose to sublabile porous sandstone with scattered carbonate cement. The Wyandra Sandstone Member produces petroleum in a few fields (for example, Ipundu, Ipundu North and Tarbat).

Wireline Log Character

The Cadna-owie Formation has characteristic and readily recognisable wireline log signatures and is a marker formation throughout the southern Eromanga Basin.

The “lower Cadna-owie Formation” has the highest gamma-ray and lowest resistivity response of the entire formation. From a basal 5–10m thick interval of high values, the gamma-ray log shows a constant decrease upwards which produces a characteristic 'bell' shape. This reflects the higher sandstone percentage.

The Wyandra Sandstone Member, where present, has low gamma-ray log values, high resistivity log values and fast travel times, which reflect the higher quartz content.

Relationships and Boundary Criteria

The Cadna-owie Formation conformably overlies the Hooray Sandstone or Murta

Formation and is conformably overlain by the Wallumbilla Formation.

The basal 5–10m thick interval of the “lower” Cadna-owie Formation which is dominantly silty mudstone with high gamma-ray log values has been interpreted by many company geologists to represent a basin-wide flooding event. This interval has been considered to belong to the uppermost part of the underlying Hooray Sandstone or Murta Formation. In this report the silty mudstone interval is considered to be the basal part of the Cadna-owie Formation as originally defined.

The boundary between the “lower” and “upper Cadna-owie Formation" can be difficult to pick in some wells. It is taken at the base of the first discrete sandstone bed which generally correlates with the first increase in noise upwards on the sonic log.

Contact with the Wyandra Sandstone Member is generally fairly abrupt on all logs and commonly produces a blocky response. This reflects the higher quartz content of the member.

Thickness

The Cadna-owie Formation is 60–90m thick over most of the project area east of longitude 141°00′E; it thins to being <40m thick north-west of DIO Betoota 1. The Cadna-owie Formation is thickest where it overlies the Permian of the Cooper Basin (Figure 68). In this part of the Eromanga Basin it is >100m thick in ~50% of the wells. Aggregate sandstone thickness distribution (Figure 69) and porosity distribution (Figure 70) maps do not include data in the north-west as suitable data points were unavailable.

Throughout the project area, the “lower Cadna-owie Formation” ranges from being about the same thickness as the “upper Cadna-owie Formation”, to being slightly thinner.

Age

The Cadna-owie Formation is associated with palynological units APK12 (only the uppermost part thereof), APK2 and APK31 (Price & others, 1985; Price, 1997; also see Williams, 1985c; Filatoff, 1986b–c, 1987; Dettmann, 1987b; Filatoff & Price, 1990; Figures 3, 10, this volume). Equivalent biounits are represented by the (upper part of the) *Cicatricosisporites australiensis* Interval Zone (of Burger, 1973; Helby & other, 1987), the *Foraminisporis wonthaggiensis* Interval Zone (of Burger, 1973; Helby & other, 1987), and the (lower part of the) succeeding *Cyclosporites hughesii* Interval Zone (of Dettmann & Playford, 1969; Helby & others, 1987).

Low-diversity microplankton (dinocyst and spinose- and non-spinose-acritarch) assemblages are variously present in, or absent from, strata associated with the formation, suggesting depositional conditions ranging from fresh- to brackish-water lacustrine to restricted/marginal marine (Dettmann & Price, 1982; Williams, 1983c, 1985a,c; Hos, 1985d, 1988a; Morgan, 1985a, 1986a,d, 1989; Morgan & Milne, 1985; Dudgeon & Hos, 1986b; Partridge, 1988b, 1989b]. The marine influence, however, is most pronounced in the upper part of the Cadna-owie Formation, which embraces the dinocyst *Odontochitina operculata* “Oppel” Zone (of Morgan, 1977; Helby & others, 1987) and the equivalent ADK17 dinocyst unit of Price (1997; Figure 3, this volume) [Dettmann, 1984b; Morgan & Milne, 1984, 1985; Hos, 1985a; Milne, 1986; Morgan, 1986c, 1987b]. In this part of the section, assemblages may encompass a high proportion of microplankton (up to 30–50%), often being dominated by spinose acritarchs, mainly of the *Micrhystridium* type. However, where the Wyandra Sandstone is developed, the marine influence appears to be more variable (Williams, 1985a; Dudgeon & Hos, 1986a; Milne, 1986; Dettmann, 1987d). Lower in the Cadna-owie Formation, dinocysts (often represented by *Batiacasphaera macrogranulata* or *Batiacasphaera* sp.) are rare and spinose acritarchs less frequent. Non-spinose acritarchs embracing *Microfasta evansii* and leiospheres, suggestive of lacustrine environments, are common at a number of levels throughout the unit (Filatoff, 1987).

Based on the biostratigraphic assignments cited above, an Early Cretaceous (Valanginian–early Barremian) age is indicated for the Cadna-owie Formation (Figure 3).

Distribution

The Cadna-owie Formation occurs throughout the project area but thins markedly in the far north-west (Figure 68).

Depositional Setting

The presence of shell fragments, microplankton and glauconite in a few wells support a paralic to shallow marine environment of deposition. The well-sorted quartzose Wyandra Sandstone Member is possibly a beach sand laid down by a shallow transgressive sea (Senior & others, 1975).

WALLUMBILLA FORMATION

Nomenclature

The name, Wallumbilla Formation, was proposed by Vine & others (1967) for marine fossiliferous mudstones, siltstones, limestones and minor lenticular sandstones outcropping in Wallumbilla Creek east of Roma in the western Surat Basin. The Wallumbilla Formation, in outcrop in both the Surat and Eromanga Basins, can be subdivided into the Doncaster and overlying Coreena Members. The formation forms the lower part of the Wilgunya Subgroup and is equivalent to the Roma Formation and lower part of the overlying Tambo Formation of Whitehouse (1955) (Vine & others, 1967). In South Australia, the Wallumbilla Formation can be equated, in ascending order, to the Bulldog Shale, Coorikiana Sandstone and the lowermost part of the Oodnadatta Formation (Moore & others, 1986).

Within the project area, the Wallumbilla Formation can be subdivided from wireline logs into “lower Wallumbilla Formation” and “upper Wallumbilla Formation”. The Doncaster and Coreena Members of the Wallumbilla Formation, which were defined in outcrop, could only be recognised in a few wells in the eastern part of the project area. The Coreena Member forms the upper part of the “upper Wallumbilla Formation”; the thinner Coorikiana Sandstone is equivalent to part of the Coreena Member.

Rock Types

The Wallumbilla Formation consists dominantly of interbedded grey to black mudstone, siltstone, sandy mudstone, green-grey sandstone and lesser cone-in-cone and concretionary limestone. Plant and marine shell fragments and a few marine macrofossils, mainly belemnites and small bivalves, are present throughout. Burrows, calcite-lined fractures and pyrite are common.

The “lower Wallumbilla Formation” comprises dark grey to black mudstone and limestone in approximately the lowermost 30m. This is overlain by interbedded and laminated mudstone, sandstone and sandy mudstone which form most of the subunit. The sandstone, which increases in percentage upwards, is green-grey, very fine-grained, labile lithic, glauconitic, micaceous with a calcareous matrix. Carbonaceous material and shell fragments occur throughout. In at least 10 wells south of latitude 28°00’S (for example, DIO Rho East 1, DIO Gryphon 1 and PPL Mungoora 1) an upwardly-coarsening sandstone, up to 10m thick, occurs at the top of the “lower Wallumbilla Formation”.

The “upper Wallumbilla Formation” comprises laminated and thinly bedded mudstone, siltstone and sandy mudstone and lesser sandstone, as in the lower subunit, overlain by sandstone with some interbedded siltstone and mudstone. The sandstone-dominated interval can be equated to at least the uppermost part of the Coreena Member. The sandstone is green-grey, very fine- to fine-grained (in uppermost part), and well-sorted. It is labile lithic, in part sublabile, with a partly calcareous, argillaceous matrix. Carbonaceous material occurs throughout, but shell fragments and marine macrofossils are restricted to the lower less sandy part of the subunit.

Wireline Log Character

Mudstones at the bottom of the Wallumbilla Formation are associated with an interval (up to 30m thick) of high gamma-ray values, reduced resistivity values and slow travel times on the sonic log. In most wells, the gamma-ray log values for this interval decrease upwards, which results in a 'bell' shape similar to that of the lowermost part of the underlying Cadna-owie Formation. This bottom interval of the Wallumbilla Formation is a good basin-wide marker.

Near the middle of the Wallumbilla Formation, gamma-ray values increase to a maximum, resistivity values decrease and there is a corresponding increase in travel times on the sonic log. These features combine to produce an overall “wasp-waisted” effect, particularly on the sonic and gamma-ray logs. This is a reflection of an upwards decrease, then increase in sandstone content.

In the uppermost part of the Wallumbilla Formation, a decrease in the average gamma-ray values, an increase in resistivity values and a decrease in travel times on the sonic log reflect the higher sandstone content. In a few wells, the Coreena Member of the Wallumbilla Formation can be identified.

Relationships and Boundary Criteria

The Wallumbilla Formation conformably overlies the Cadna-owie Formation and is conformably overlain by either the Toolebuc Formation, where present, or the Allaru Mudstone.

The boundary with the underlying Cadna-owie Formation is easy to pick and is taken at a sudden upwards increase in gamma-ray log values, a decrease in resistivity log values and an increase in travel times on the sonic log. The boundary between the "lower" and "upper" Wallumbilla Formations is taken primarily at the slowest travel time on the sonic log which, in a few wells, corresponds to a single sharp peak. In most wells this is near the middle of the Wallumbilla Formation and corresponds to the bottom of the "wasp-waisted" effect on the logs. High gamma-ray log values and an upwards decrease in resistivity log values also occur at this depth.

The boundary between the upper and lower subunits corresponds to the "D" horizon shown in cross-sections of wells in the Eromanga Basin in both South Australia and Queensland (Moore & others, 1986).

An upwards increase in gamma-ray log values, a decrease in resistivity log values and an increase in travel times on the sonic log mark the boundary between the Wallumbilla Formation and overlying Allaru Mudstone when the Toolebuc Formation is absent.

Thickness

The Wallumbilla Formation is 200 to >350m thick over most of the project area. It is thickest where it overlies the Permian of the Cooper Basin, and to the south (Figure 71). In these areas it is commonly 350 to ~375m thick. North-west of the Birdsville Track Ridge, the Wallumbilla Formation thins to <150m.

The "lower" and "upper" Wallumbilla Formations are of about equal thickness.

Age

The Wallumbilla Formation has yielded Early Cretaceous (Barremian–Albian) palynofloras indicative of marine, near-shore to marginal marine, and, occasionally, terrestrial environments of deposition (Williams, 1983b; Dettmann, 1984a, 1988; Dettmann & Jones, 1985; Price & others, 1985; Price, 1997). Miospore assemblages recovered from the formation in the Eromanga Basin are conformable with palynological units in the APK31 – APK5 succession (Price & others, 1985; Price, 1997; Figure 3, this volume). In terms of the palynostratigraphic scheme of Helby & others (1987), the Wallumbilla Formation embraces, in ascending stratigraphic order, the *Cyclosporites hughesii* and *Crybelosporites striatus* Interval Zones and the *Coptospora paradoxa* "Oppel" Zone [these three biounits being based on/modified from the zonal scheme of Dettmann & Playford (1969)].

Dinocyst assemblages are apparently attributable to units ADK17 to ADK22 (Price, 1997) and to the corresponding biounits of Helby & others (1987), which were newly instituted by those authors or modified from Morgan (1977): the *Odontochitina operculata* "Oppel" Zone at the base of the formation and the succeeding *Diconodinium davidii*, *Muderongia tetracantha*, *Canninginopsis denticulata* and *Pseudoceratium ludbrookiae* Interval Zones (Figure 3). Spinose acritarchs associated with these marine-microplankton palynofloras generally embrace *Micrhystridium* and *Veryhachium*.

Distribution

The Wallumbilla Formation occurs throughout the project area, but thins markedly in a north-westerly direction from a line trending north-east of Haddon Corner and paralleling the approximate northern limit of the Cooper Basin (Figure 71).

Depositional Setting

The abundance of shell fragments and some identifiable marine macrofossils indicate that most of the Wallumbilla Formation was laid down in a shallow marine environment. Transgressive marine conditions existed during deposition of much of the Wallumbilla Formation. However, towards the top of the formation, the presence of sandstones and siltstones containing abundant carbonaceous material, but lacking marine shell fragments, suggest deposition in paralic and fluvial environments during a regressive phase.

TOOLEBUC FORMATION

Nomenclature

The Toolebuc Formation was originally named by Casey (1959) as the 'Toolebuc Member' of the Wilgunya Formation in the Boulia area, north-western Eromanga Basin. Vine & others (1967) changed the name to 'Toolebuc Limestone' to indicate that carbonates dominate in outcrop. Senior & others (1975) proposed the name Toolebuc Formation because it forms a heterogeneous calcareous sequence between the relatively non-calcareous Wallumbilla Formation and the Allaru Mudstone.

The nominated type area of Casey (1959) is on the Boulia–Winton main road, 11km east of the Hamilton Hotel; the reference section is 10km west of Spring Creek artesian bore. Because the artesian bore could not be definitely located, a new type section was defined by Senior & others (1975). Their revised type section for the Toolebuc Formation is between 25.3m–35.8m in stratigraphic drill hole BMR Boulia 3A at longitude 140° 43′ 30"E, latitude 22° 47′ 00"S (Senior & others, 1975).

Rock Types

The Toolebuc Formation in GSQ Eromanga 1 consists predominantly of mudstone with thin layers of siltstone, sandstone and conglomerate towards the top of the unit. The mudstone is slightly silty, poorly sorted and poorly laminated. It contains sparse, small, disarticulated pelecypods and, more commonly, shell fragments which occur in lenticular clusters (Almond, 1983).

In other Departmental stratigraphic bores in the project area the mudstone contains fish fragments, ammonites, belemnites and bivalves. Carbonate cement and calcite veining occur sporadically throughout the mudstone. Pyrite occurs in nodules, thin layers or rarely as replacement of shells. Disseminated carbonaceous material and rare coalified wood are present in GSQ Thargomindah 3 (Gunther & Dixon, 1988). The Toolebuc Formation in GSQ Machattie 1 also contains some plant remains (Brain, 1987).

The Toolebuc Formation contains limestone (including coquinite) which is subordinate to black, calcareous, bituminous siltstone, labile sandstone, and shale. The limestone is absent in some areas (Senior & others, 1975), but in other areas, light grey calcite laminae are interbedded in mudstone (Ozimic, 1986; Moore & others, 1986). In addition, the Toolebuc Formation contains kerogenous and calcareous shale. The kerogenous shale displays abundant fine, dark brown, organic laminae set in a microcrystalline calcite and clay matrix. The kerogenous laminae are typically ~10mm thick (Ozimic, 1986). Uranium-bearing phosphate minerals associated with shell debris and uranium associated with organic matter are considered to cause the gamma-ray anomaly (Ozimic, 1986). Scheibnerova (1986) also referred to actinium being absorbed onto carbonaceous matter as another possible cause of the anomaly.

Moore & others (1986) and Ozimic (1986) delineated respectively four and two facies in the Toolebuc Formation. Moore & others (1986) based their facies groups on lithotypes, which can be correlated with gamma-ray and sonic log responses. Ozimic (1986) defined facies groups based on the coquinite to kerogenous shale ratio.

Wireline Log Character

The Toolebuc Formation is characterised by a high gamma-ray anomaly which stands out from the bounding formations and diminishes towards the south-eastern zero edge of the formation. The gamma-ray anomaly can have a serrated appearance and can change from double to single gamma-ray peaks. Where multiple peaks exist, one is usually more dominant. The gamma-ray anomaly can also have a blocky appearance towards the formation's south-eastern limit. Ozimic (1986) observed the following:

1. the gamma-ray log opposite kerogenous shale does not display a simple relationship to oil shale or grade,

2. the gamma-ray anomaly represents kerogenous shales, which may or may not contain phosphatised fish remains, and

3. the coquinites have very low gamma-ray responses.

Senior & others (1975) noted that the highest gamma-ray peaks generally coincide with organic-rich argillaceous sediments rather than limestone.

The Toolebuc Formation has generally higher resistivity log values than the bounding formations but the values vary across the basin. The sonic velocity log values are dominantly slower, but can also display a sharp increase towards the top of the formation. This sonic velocity peak generally corresponds to the top of the main gamma-ray anomaly. Ozimic (1986) used the sonic variation to determine high density layers (for example, coquinite and limestone), but found it less useful for determining kerogenous interbeds. The variation in the resistivity and sonic velocity log values becomes less towards the southern limit of the formation.

The log signature of the Toolebuc Formation can be mistaken for the stratigraphically higher "Allaru gamma-ray anomaly" for which there are no corresponding changes on the resistivity and sonic logs.

Relationships and Boundary Criteria

The Toolebuc Formation conformably overlies the Wallumbilla Formation and is overlain by the Allaru Mudstone (Moore & others, 1986). The boundary with the Wallumbilla Formation can be picked from an increase in the gamma-ray and resistivity logs and a decrease in the sonic velocity log.

The boundary with the Allaru Mudstone is determined primarily from the gamma-ray log where the values decrease upwards to the average baseline value for the Allaru Mudstone. The resistivity log values and the sonic velocity log values also decrease. The sonic velocity log values can also increase at the boundary where the sonic reversal does not exit (see wireline log characteristics).

Thickness

Within the project area the Toolebuc Formation is mainly between 20–45m thick (Figure 72). The maximum thickness of 65m is in POG Teedeeldee 1, which is located close to the south-eastern limit of the formation. The Toolebuc Formation does not have a main depocentre as such, but is generally thicker about Haddon Corner and in some north-eastern parts of the project area.

Age

The Toolebuc Formation is delimited palynostratigraphically by late Early Cretaceous (Albian) spore-pollen assemblages of units APK52 and APK6 [Price & others, 1985; Price, 1997; Figure 3, this volume; equivalent to the *Coptospora paradoxa* and *Phimopollenites pannosus* "Oppel" Zones of Dettmann & Playford (1969) and Helby & others (1987); also see and compare Moore & others (1986) and McMinn & Burger (1986)]. These Toolebuc spore-pollen palynofloras, however, are sometimes difficult to date because of a common paucity of terrestrially derived components, but, nonetheless, are better characterised by their generally more common microplankton (dinocyst and spinose-acritarch) content, which is suggestive of a near- to off-shore marine environment (Dettmann & Price, 1982; Morgan, 1984a-b). Spinose acritarchs usually include *Micrhystridium* and *Veryhachium*; and dinocysts are encompassed by unit ADK22 (Price, 1997) and the equivalent *Pseudoceratium ludbrookiae* Interval Zone of Helby & others (1987; modified from Morgan, 1977; Figure 3, this volume; also see: Morgan, 1980a–b; McMinn, 1983; McMinn & Burger, 1986; and Moore & others, 1986).

Foraminifera recovered from the formation are indicative of a late middle to early late Albian age (Haig, 1979).

Distribution

The Toolebuc Formation is extensive across the northern section of the project area and extends no further south than 27° 50′ S.

Depositional Setting

The Toolebuc Formation is considered to have been deposited in a restricted marine environment where the water was stratified with a permanent halocline below a layer of fresher water. The dark colour of the Toolebuc Formation and the absence of benthonic fauna and bioturbation suggest strong oxygen depletion in the lower part of the water column and possibly also in the substrate. The rate of deposition was slow, with conditions hospitable for organisms towards the surface of the water column (Moore & others, 1986). The presence of coquinite layers shows a zone of oxygenated waters close to shore or formed by wave action.

ALLARU MUDSTONE

Nomenclature

The Allaru Mudstone (Vine & others, 1967) forms the uppermost part of the Wilgunyah Subgroup of the Rolling Downs Group of

Whitehouse (1955). The formation was formerly named the Allaru Member of the Wilgunyah Formation of Vine & Day (1965). The name is derived from Allaru Homestead south of Richmond in the northern Eromanga Basin; the type area is along the main Richmond–Winton road, from Richmond south to Twenty-mile Creek (Vine & Day, 1965). The Allaru Mudstone can be correlated on wireline logs with the upper part of the Oodnadatta Formation in South Australia (Moore & others, 1986).

Within the project area, an interval with a high gamma-ray log response, similar to that of the underlying Toolebuc Formation, is present within the lower part of the Allaru Mudstone in a few wells. It is informally named the "Allaru gamma-Ray anomaly".

Rock Types

The Allaru Mudstone consists primarily of blue-grey mudstone, in part pyritic, with interbedded calcareous siltstone, cone-in-cone limestone and lesser sandstone. The sandstone, which is interbedded in the uppermost parts of the formation is grey, very fine-grained, laminated and thinly-bedded, labile lithic, in part calcareous, with carbonaceous partings. Marine macrofossils including bivalve shells, gastropods and belemnites occur throughout the Allaru Mudstone; fish remains occur sporadically.

Wireline Log Character

Mostly uniform gamma-ray, resistivity and spontaneous potential log signatures are characteristic of the Allaru Mudstone, except for the few wells in which the "Allaru Gamma-Ray Anomaly" is present (for example, DIO Yambee 1, HEP Takyah 1, GSQ Thargomindah 1-1A). In the fully-cored Departmental bore, GSQ Thargomindah 1-1A, the "Allaru gamma-ray anomaly" occurs between 369m–388m, with no corresponding changes on the resistivity and sonic logs. The same log features occur in the other wells containing the anomaly. The cause of the gamma-ray log anomaly is yet to be determined.

The presence of interbedded sandstone and siltstone in the uppermost part of the Allaru Mudstone in many wells is shown on the resistivity and sonic logs by a slight increase in values and decrease in travel times, respectively.

Relationships and Boundary Criteria

The Allaru Mudstone conformably overlies the Toolebuc Formation or the Wallumbilla Formation (when the Toolebuc Formation is absent), and is conformably overlain by the Mackunda Formation.

The boundary with the Toolebuc Formation is easy to pick and is taken where the gamma-ray values decrease upwards to the average baseline value for the Allaru Mudstone. The boundary with the Wallumbilla Formation, is taken at the upwards marked increase in gamma-ray log values, decrease in resistivity log values and increase in travel times on the sonic log. The boundary with the overlying Mackunda Formation is taken at the upwards decrease in gamma-ray and increase in resistivity log values and decrease in travel times on the sonic log. An increase in spontaneous potential values (generally reversed) commonly occurs at or near this boundary.

Thickness

The Allaru Mudstone is from 200 to >300m thick over most of the project area (Figure 73). It reaches thicknesses of 350–400m in a north-easterly to south-westerly trending depocentre, up to 100km wide, to the north of the northern Permian zero edge of the underlying Cooper Basin. This is a marked northerly shift of the depocentre to that of the older Wallumbilla Formation which mainly overlies the Permian of the Cooper Basin and also occurs further to the south.

The Allaru Mudstone thins to 100–150m in the north-western and south-eastern parts of the project area. The thinning in the far north-west is due mainly to erosion at outcrop.

Age

Palynofloras of mid-Cretaceous [late Albian–(?)early Cenomanian] age have been recovered from the Allaru Mudstone. They are predominantly attributable to unit APK6 (Price & others, 1985; Price, 1997: Figure 3, this volume) and the largely equivalent *Phimopollenites pannosus* "Oppel" Zone of Dettmann & Playford (1969) and Helby & others (1987). According to Price (1997, figure 12), the upper limits of the formation are encompassed by the basal part of APK7 in some regions of the basin; and, to Price & others (1985), the formation's base may extend down into the upper part of APK5 (APK52) and thus the corresponding *Coptospora paradoxa* "Oppel" Zone of Dettmann & Playford (1969) and Helby & others (1987). Unpublished records of APK5 in the Allaru Mudstone include the following: SWC/871.12m in DIO Naccowlah 1 (Dettmann & Price, 1981a), SWC/444.09m in DIO Wareena 1 (Filatoff & Price, 1981), and SWC/712.01m in DIO Munkarie South 1 (Dettmann, 1984b). The presumption, however, is that the recorded palynofloras are representative of the formation and are not lacking in the younger APK6 index, *Phimopollenites pannosus*.

Palynofloras from the Allaru Mudstone also generally embrace marine phytoplankton, which vary in abundance from rare to dominating components of individual samples, thus reflecting the varying marine influence in the associated depositional environment. Dinocyst assemblages are attributable to unit ADK22 (of Price, 1997) and the equivalent *Pseudoceratium ludbrookiae* Interval Zone (of Helby & others, 1987; modified from Morgan, 1977); spinose acritarchs, in the main, are represented by *Veryhachium*, as exemplified by SWC/762.00m and SWC/697.99m in DIO Gunna 1 (Williams & Price, 1983), SWC/708.00m in HOA Kyra 1 (Morgan & Milne, 1984), and SWC/637.64m in DIO Richie 1 (Dettmann & others, 1985).

Distribution

The Allaru Mudstone occurs throughout the project area with its thickest section in a north-easterly to south-westerly direction, paralleling the underlying Cooper Basin (Figure 73). It outcrops in the most north-western part of the project area.

Depositional Setting

The abundance of marine fauna with a large proportion of whole shells preserved, combined with a uniform mudstone lithology, suggests that the Allaru Mudstone was deposited in quiet-water, shallow marine conditions.

MACKUNDA FORMATION

Nomenclature

The name Mackunda Formation, formerly "Mackunda Beds" of Vine (1964), was proposed by Vine & Day (1965) for transitional beds deposited between the dominantly marine Wilgunyah Formation and the overlying fresh-water Winton Formation. Subsequently the Wilgunyah Formation was elevated to Subgroup status and the overlying Mackunda and Winton Formations were made part of the newly-proposed Manuka Subgroup (Vine & others, 1967). The Wilgunyah and Manuka Subgroups constitute the Rolling Downs Group of Whitehouse (1955).

The type area for the Mackunda Formation is in the headwaters of Mackunda Creek on Gnalta Station on the Mackunda 1:250 000 Sheet area (Vine & Day, 1965).

Rock Types

The Mackunda Formation consists of interbedded sandstone, siltstone and mudstone and lesser mud-clast intraformational conglomerate. Marine shell fragments and cone-in-cone limestone occur throughout the unit. Lode casts, calcite-filled fractures, disturbed bedding and minor nodular pyrite have been logged in core of the Mackunda Formation.

Sandstone is light green-grey, very fine- to, in part, fine-grained, well-sorted, laminated and thinly-bedded, labile lithic with an argillaceous and calcareous matrix. Carbonaceous partings are commonly developed. Mica and glauconite are accessory minerals. Siltstone and mudstone are grey to light green, laminated and thinly bedded, calcite-cemented in part, and contain numerous plant remains. Recognisable shell fragments are of *Inoceramus* sp.

Wireline Log Character

The Mackunda Formation is characterised by lower average gamma-ray log responses, higher resistivity log responses and faster travel times on the sonic log, than those of the underlying Allaru Mudstone. Sharp peaks on the resistivity and sonic logs indicate the presence of calcite cement/matrix. The spontaneous potential log over the Mackunda Formation varies from being almost featureless to a reversed response over much of the interval.

Relationships and Boundary Criteria

The Mackunda Formation conformably overlies the Allaru Mudstone and is conformably overlain by the Winton Formation. The boundary with the Allaru Mudstone is generally easy to pick and is taken at the upwards change to lower average gamma-ray log values, the increase in resistivity values and faster travel times on the sonic log. In quite a few wells, the upper part of the Allaru Mudstone is sandy and the boundary is transitional and harder to pick (for example, in TMO Towrah 1). In such wells, an upwards decrease in gamma-ray log values and faster travel times on the sonic log are used mainly to pick the Allaru–Mackunda boundary. This boundary appears to be facies controlled, as suggested by Moore & others (1986).

An upwards change in the sonic log baseline to slower travel times and the incoming of the first significant coal seam, which is evident on the resistivity and sonic logs, and is shown on the cuttings log, are used to pick the boundary with the overlying Winton Formation. This boundary coincides with the “M” horizon of Moore & others (1986) who lists a “subtly less irregular gamma-ray trace” for the Winton Formation as a criterion for defining the Mackunda–Winton boundary.

Thickness

The Mackunda Formation is 75 to >100m thick over most of the project area (Figure 74). In several parts of the Eromanga Basin overlying the Permian and Triassic of the northern Cooper Basin, the Mackunda Formation is mostly 120 to >150m thick (Figure 74). The unit thins to the north-west to its limit of outcrop, and to the north and south-east.

Age

The Mackunda Formation embraces mid-Cretaceous (late Albian–early Cenomanian) spore-pollen assemblages conformable with units APK6 and APK7 (Price & others, 1985; Price, 1997; Figure 3, this volume). Spinose acritarchs (*Micrhystridium*) and/or dinocysts are also present, generally as rare components, in some of these assemblages, supporting the suggestion (indicated below) that paralic - marginal-marine conditions existed in the environment of deposition [Morgan (1984a; SWC/578.00m in HOA Bodalla South 1); Morgan (1985a; SWC/478.00m in LEA Bodalla South 2); Morgan & Milne (1985; SWC/680.00m in HOA Mount Bellalie 1); Dettmann & others (1985; SWC/477.00m in DIO Richie 1)]. Occasional fluvial/lacustrine algae have also been noted (Dettmann & Jones, 1985; SWC/381.00m in DIO Jackson 1).

Williams (1983a) reported (but did not provide specific details of) a marine dinocysts assemblage from SWC/358.44m in DIO Morney 1, attributing it to Unit A of the *Endoceratium ludbrookiae* Zone (of Morgan, 1977, 1980a). The lower part of Morgan’s subunit was subsequently modified by Helby & others (1987) to represent their *Pseudoceratium ludbrookiae* Interval Zone (=ADK22 of Price, 1997; Figure 3, this volume). However, dinocysts, when present in the Mackunda Formation, are generally non-descript and long-ranging (Morgan, 1984a, 1985a), endowing them with little biostratigraphic value.

Distribution

The Mackunda Formation occurs throughout the project area except for the far north-western part, north of latitude 24°30"S and west of longitude 140°00"E (Figure 74).

Depositional Setting

The abundance of sandstone, marine macrofossils (mainly molluscs) and common benthonic foraminifera suggest that the Mackunda Formation was deposited in shallow marine and paralic environments. The presence of intraformational mud-clast conglomerate and the paucity of planktonic organisms indicate shallowing and restriction of the sea (Exon & Senior, 1976).

WINTON FORMATION

Nomenclature

Freshwater strata at the top of the Eromanga Basin succession in western Queensland equivalent to the Winton Formation were first referred to as “Winton Series” by Dunstan (1916). He considered the Winton Series to overlie the dominantly marine Rolling Downs Formation (Group).

The Winton Formation in its present context was first published by Whitehouse (1955) who defined the unit as “the blue shales and sandstones with intercalated coal seams met with in the bores in and about Winton”. The Winton Formation forms the upper part of the Rolling Downs Group.

Rock Types

The Winton Formation consists of interbedded sandstone, sandy siltstone, siltstone, mudstone and coal with minor intraformational conglomerate. The sandstone is grey to green-grey, very fine- to fine-grained, well-sorted, laminated to thinly bedded, labile lithic, with an argillaceous, partly calcareous matrix. Plant fragments, finely disseminated carbonaceous material and mica occur on most bedding planes. Coalified wood fragments are also present. The sandstone is friable and visibly porous in part (Coote, 1987). The intraformational conglomerate consists mainly of clasts of cream and grey mudstone and muddy siltstone. Siltstone, sandy siltstone and mudstone are grey, grey-brown and green, carbonaceous, micaceous with interlaminated coaly material and rootlets. Some pyrite is present. Coal is brown to black and is interbedded with carbonaceous mudstone.

Wireline Log Character

The Winton Formation is characterised by moderate gamma-ray and resistivity log responses and generally slow travel times on the sonic log. Intervals of relatively low gamma-ray and high resistivity log values reflect the interbedded sandstones. Coal seams are identified from spikes of high resistivity corresponding to spikes of very slow travel time on the sonic log. Gamma-ray logs run through the casing in the upper part of petroleum wells give a subdued response, and the casing shoe is shown where there is a marked change and an increase downwards in average gamma-ray log values.

Relationships and Boundary Criteria

The Winton Formation conformably overlies the Mackunda Formation and, in some areas, is unconformably overlain by the Tertiary Glendower Formation. The boundary with the Mackunda Formation is generally identified by a slight upwards increase in gamma-ray log values, a decrease in resistivity log values and a significant increase in travel time on the sonic log. The Mackunda–Winton boundary coincides with the “M” horizon of Moore & others (1986). The incoming of the first coal seam in the formation can also be used to help identify the unit from the Mackunda Formation.

Thickness

The Winton Formation is generally 400–1000m thick where it overlies the Permian and Triassic of the Cooper Basin (Figure 75). This is an erosional thickness. Some thickening is evident about the Tertiary-uplifted Betoota, Curalle and Morney Domes in the north-west, and about the Mount Howitt and eastern JNP Trends. The Winton Formation is thickest in a north-easterly to south-westerly trending depocentre extending from the South Australian border north of the JNP Trend to approximately Longitude 143°30′E. The Winton Formation thins markedly in the south-eastern and north-western parts of the project area where, in the latter region, it has an outcrop limit.

Age

Mid-Cretaceous [late Albian(?)–Cenomanian] palynofloras of the Winton Formation encompass spore-pollen assemblages attributable to palynological units APK6 and APK7 (of Price & others, 1985; Price, 1997; Figure 3, this volume) and the *Phimopollenites pannosus* and *Appendicisporites distocarinatus* “Oppel” Zones [of Dettmann & Playford (1969) and Helby & others (1987)]. Assignments to the latter two zones are represented by assemblages recovered from: SWC/330.40m in DIO Naccowlah 1 (Dettmann & Price, 1981a); SWC/440.00m in HOA Eromanga 1 (Dettmann & Price, 1982); SWC/291.08m in DIO Chookoo 1 (Williams, 1983b); and SWC/362.00m in HOA Bodalla South 1 (Morgan, 1984a).

Spinose acritarchs (*Micrhystridium*) are also present in low frequencies in occasional samples, suggesting a minor marine (or brackish) influence in the largely terrestrial environment of deposition [Dettmann & Price, 1981a (SWC/330.40m in DIO Naccowlah 1), 1982 (SWC/440.00m in HOA Eromanga 1)]. This influence, however, appears to have been somewhat variable in its development, as Williams (1983a) reported a dinocyst assemblage, which he assigned to Unit A of the *Endoceratium ludbrookiae* Zone (of Morgan, 1977, 1980a), from SWC/259.99m in DIO Morney 1. However, details of the marine phytoplankton present were not provided, and this determination, if valid, would represent the highest stratigraphic record of the zone.

Distribution

The Winton Formation occurs throughout most of the project area (Figure 75). In the north-west it is absent north of approximately latitude 25°00’S and west of approximately longitude 140°30’E, this being the present limit of outcrop, and boundary with the underlying Mackunda Formation. The thinning of the Winton Formation about the Betoota, Curalle and Morney Domes, which were effected by uplift in the Tertiary, indicates that the Winton Formation has undergone considerable erosion.

Depositional Setting

The lack of marine fossils and the presence of intraformational conglomerate, sandstone, siltstone and coal seams suggest that the Winton Formation was deposited in fluvial and lacustrine environments on a broad coastal plain as the Cretaceous sea withdrew.

EROMANGA BASIN TECTONICS

JJ Draper

Like the Cooper Basin, the mode of formation of the Eromanga Basin has been subject to much discussion but little consensus. The Eromanga Basin is a very large intracratonic basin (part of the larger Great Australian Basin), but has some features which are different to the "classical" intracratonic basin. The Cooper Basin tectonic subsidence curves (Deighton & others, in preparation) show the typical concave upward curves for intracratonic basins (Angevine & others, 1990). On the other hand, the Eromanga Basin has a concave down shape more typical of a foreland basin, which it clearly is not, as the most rapidly subsiding western part (Gallagher, 1990) is remote from any potential foreland loading.

Burger (1986) extended the sedimentary cycle - global sea level model for the Surat Basin (Exon & Burger, 1981) to the Eromanga Basin. There are inherent difficulties in applying the Exxon global sea level changes directly to fluvial sediments, and Exon & Burger (1981) admitted that, for the Surat Basin, only six depositional cycle were recognised for a period when there were nine major sea level cycles. They suggest that some of the sea level changes may have been too small to record or that local tectonism may have influenced the cycles. The application of sea level curves to the Eromanga Basin is fraught with the same difficulties, and the problem is particularly marked in the Cenomanian when, during a major world-wide sea level rise, the Eromanga Basin received fluvial sediments. The Australian craton was obviously elevated at this time.

Gallagher & Lambeck (1989) examined the Eromanga Basin using a back stripping technique. For the Jurassic rocks, the nearly linear trend of subsidence is consistent with a thermally based contraction mechanism. A passive, thermal mechanism was also favoured by Fielding (1996). The cause of the perturbation is unclear, although Gallagher (1990) discussed the possibility that the same thermal regime that caused the subsidence in the Cooper Basin also triggered the Eromanga Basin. The late Triassic or Early Jurassic basalts do suggest ongoing thermal activity in the area. Subsidence was more rapid in the Early Cretaceous, and this corresponded to the onset of rising global sea level. However, although sea level rise continued through the Cretaceous, in the Eromanga Basin there were the two major transgressive-regressive couplets associated with voluminous volcanic detritus. This suggests that the basin was overfilled and was effectively raised above sea level. The influx of the volcanic detritus appears to have played a major role in this process. Gallagher & Lambeck (1989) concluded that the sedimentary record in the Eromanga basin was the result of variation in sedimentary influx into a tectonically subsiding region, rather than primary global sea level changes.

According to Gallagher & Lambeck (1989), viscous drag and cooling of the overlying Australian plate caused by a cold subducting Pacific plate resulted in subsidence of the eastern Australian margin. Tectonic subsidence rates varied with subduction rates. Rebound of the Australian plate followed the cessation of subduction, resulting in uplift and erosion of the eastern Australian area. This provided the sediment to fill the Surat and Eromanga Basins in the mid-Cretaceous.

Other explanations of the formation of the Eromanga Basin include: the transmission of extensional, collisional or rotational plate boundary stresses to the plate interior, isostatic adjustments, changes of mantle heat flux beneath the plate interior and phase changes (Krieg & others, *in* Drexell & Priess, 1995). Deighton & others (in preparation) discuss a dynamic topography model based on Gurnis & others (1998). This model involves a cold detached slab being subducted beneath the craton in the Early Cretaceous. There are problems with all models; these are discussed in Deighton & others (in preparation).

It is beyond the scope of this report to resolve the detail of the tectonics of the Eromanga Basin. This report focuses on tectonic events within the project area. Unlike the Cooper Basin, there is little penecontemporaneous deformation in the Eromanga Basin, with the structuring occurring in the Late Cretaceous and the Tertiary.

The Late Triassic Cuddapan Formation, which is placed herein at the base of the Eromanga Basin, predates definitive establishment of the basin; this formation is restricted to a relatively small area (Figure 45) with the depocentre further north than that of the unconformable underlying Middle Triassic Tinchoo Formation. Subsidence of the underlying Tinchoo Formation was probably at least partly a control. A number of basins, some containing coal measures formed across eastern Australia at the same time (Fielding, 1996). These basins are predominantly extensional in origin. The Cuddapan Formation may have been controlled by craton-wide extension.

The fluvial-lacustrine Poolowanna Formation is the basal unit of the Eromanga Basin *sensu stricto*. It unconformably overlies the Cuddapan Formation and was deposited in restricted areas on an eroded basement. It has more than one depocentre, but only one occurs in the project area (Figure 46). There are no obvious local controls, although the depocentre is in the general vicinity of that for the Cuddapan Formation. Sediment compaction may therefore have played a secondary role. Fluvial-lacustrine Hutton Sandstone deposition was more widespread than that of the conformably underlying Poolowanna Formation. The depocentre in the project area (Figure 51) runs north-east–south-west parallel to a major gravity trend that it overlies.

Conformably overlying the Hutton Sandstone is the fluvial-lacustrine Birkhead Formation. Within the project area, the Birkhead Formation occupies much the same area as the Hutton Sandstone, with the main depocentre roughly coincident (Figure 54). Maximum subsidence rate is ~22m/my. The Poolowanna Formation, Hutton Sandstone and Birkhead Formation form a sedimentary package with similar controls on sedimentation. The package is capped by an unconformity (McKellar, 1998, in press; Figures 3, 10 this volume).

The Hutton Sandstone to Birkhead Formation transition is marked by a distinct change in provenance for the sediments (Whitford & others, 1994; Lanzilli & Boult, 1996). The Poolowanna Formation and Hutton Sandstone sediments have Nd/Sm model ages consistent with derivation from older craton sources. The sediments in the Birkhead Formation have a significantly younger model age indicating a contribution from a younger source. Fission track ages of apatite indicate that volcanic detritus in the Birkhead Formation is derived from a penecontemporaneous source (Boult & others, 1998).

Overlying the unconformity is the fluvial Adori Sandstone. Its deposition covers a slightly wider area than the underlying units, but the depocentre is poorly defined (Figure 57). Maximum subsidence rates are ~36m/my.

The conformably overlying, fluvial-lacustrine Westbourne Formation was deposited over a greater area than the underlying units and its depocentre within the project area reflects the thick underlying Permian sequence (Figure 60), suggesting compaction is a contributing factor in the sedimentation of the unit. The Westbourne Formation is capped by a regional unconformity (Burger, 1989; Green & McKellar, 1996a,b).

The fluvial Hooray Sandstone and the laterally equivalent fluvial “upper Namur Sandstone” and fluvio-lacustrine Murta Formation was deposited over an even greater area, and the thickest area of deposition run roughly north - south (Figure 64). There are no obvious local controls on sedimentation. The Hooray sandstone represents a fundamental change in depositional pattern as it does not pass upwards into finer grained fluvial-lacustrine rocks, but rather the paralic to shallow marine Cadna-owie Formation. This unit is widespread and, within the project area, has a depocentre roughly coincident with the Cooper Basin although the thickest parts do not overlie the thickest Permian sedimentary rocks (Figure 68).

The marine Wallumbilla Formation represents a transgressive-regressive couplet. It is widespread. A depocentre in the south-west of the project area (Figure 71) has no obvious local controls. The marine Toolebuc Formation is a relatively thin unit (<65m; Figure 72), which is strongly facies controlled. There are no obvious local tectonic controls.

The marine Allaru Formation represents the onset of more rapid subsidence and the main depocentre overlies that of the Poolowanna Formation, Hutton Sandstone and Birkhead Formation (Figure 73). The marine to paralic Mackunda Formation has a diffuse depocentre in the project area (Figure 74). The fluvial-lacustrine Winton Formation has the thickest portion overlying the Hutton sandstone depocentre (Figure 75), but is significantly affected by subsequent uplift and erosion.

An isopach of the whole Eromanga Basin sequence (Figure 76), less the uplifted and eroded Winton Formation, indicates that, despite the variability between units, the main depocentre overlies the depocentre established in the Triassic rather than the Cooper Basin proper.

On seismic sections, the shaley intervals above the Cadna-owie Formation show a very disrupted pattern over a large area of the basin (Cartwright & Lonergan, 1997). These authors argue that the pervasive disruptive pattern is caused by closely spaced minor extensional faults. In a localised 3-D seismic survey (Lake Hope) they demonstrated a polygonal pattern to the faults similar to features observed in Tertiary rocks in the North Sea. The polygonal, layer-bound faults in the North Sea have been hypothesised to be the result of shrinkage (Cartwright & Lonergan, 1997), in a process similar to syneresis (Dewhurst & others, 1999).

Following the deposition of the Winton Formation, the Eromanga Basin was deformed by a widespread contractional event (Hoffmann, 1989; Elliot, 1993; Korsch & others, 1998) followed by erosion and weathering (Callen & others, *in* Drexel & Priess, 1995, pages 188–194; Day & others, 1983). The timing of these events is constrained by the Cenomanian age of the Winton Formation and the formation of the Lake Eyre Basin in the late Palaeocene (Callen & others, *in* Drexel & Priess, 1995, pages 188–194). Korsch & others (1998) gave an age of 95–90Ma for deformation in the Bowen Basin. The age of the weathering (Morney Profile) was dated as 60±10Ma (Idnurm & Senior, 1978).

CAINOZOIC

JJ Draper

The Cainozoic geological history of the area is very important, not only for the sedimentation and weathering that occurred, but also for the structural changes that strongly influenced hydrocarbon generation and migration.

The Lake Eyre Basin has different nomenclature across state boundaries (Figure 77). The basal unit in the Basin is the Eyre Formation (Wopfner & others, 1974) in South Australia and the Glendower Formation (Whitehouse, 1954) and Marion Formation (Casey, 1959) in Queensland (descriptions below).

Following deposition of the Glendower Formation, a period of stability resulted in widespread weathering with the development of both laterite and silcrete surfaces (Day & others, 1983) in the Oligocene. This was followed by warping and folding of the duricrusts in the late Oligocene or early Miocene. The folding resulted in localised basins, which were filled by sediment in the Middle Miocene to Early Pliocene. In the project area the sediments have been named the Whitula Formation (description below). Chalcedonic limestones are present in the Birdsville–Betoota area; these are probably equivalent to the Austral Downs Limestone and Horse Creek Formation further north (Paten, 1964)

Quaternary deposits comprise residual deposits and dune, alluvium and lacustrine deposits. The stratigraphy, sedimentology and chronology of the Channel Country are described in Nanson & others (1988). The fluvial system is currently mud dominated replacing older sand dominated systems at ~85ka, as a result of a change to a more arid climate.

LITHOSTRATIGRAPHY

GLENDOWER FORMATION

Nomenclature

The Glendower Formation was named by Whitehouse (1954) after Glendower Station near Hughenden. The type section is 1.2km south of the station on the road to Prairie.

Rock Types

The unit contains quartzose sandstone, quartz pebble conglomerate, sandy conglomerate and minor siltstone and mudstone. Reworked clasts of Winton Formation occur at the base of the unit. The unit is heavily silicified and is often capped with silcrete. Silicified wood, tubules and root impressions are present.

Relationships and Boundary Criteria

The Glendower Formation unconformably overlies weathered Winton Formation. It is overlain by the Whitula Formation and Quaternary sediments. In the project area it is preserved mainly as isolated remnants. It is thought to be laterally equivalent to the Eyre Formation and the Marion Formation.

Thickness

The unit has a recorded thickness of ~70m, but the Eyre Formation is up to 145m thick.

Age

The age is not well constrained and is dated as Early Tertiary by superposition. The Eyre Formation is dated by palynology as early Late Palaeocene to Middle Eocene (Callen & others, *in* Drexel & Priess, 1995). Grimes (1980) suggested that the Glendower Formation was probably equivalent to the upper part of the Eyre Formation as the unit represented the final stage of a valley-filling episode.

Distribution

It is a widespread unit, although generally preserved as eroded remnants. The unit occurs throughout much of the central Eromanga Basin.

Depositional Setting

The sediments were deposited in a fluvial setting with flow from uplifted basin margins south-east towards the centre of the Lake Eyre Basin.

MARION FORMATION

Nomenclature

The Marion Formation was named by Casey (1959) after Marion Downs Station on the Georgina River 64km south west of Boulia. The type area is 22km west of Marion Downs Homestead on the Marion Downs to Herbert Downs road.

Rock Types

The unit comprises quartzose sandstone and quartz pebble conglomerate. Chert clasts are present and reworked lateratised sandstone clasts are present at the base of the unit. The rocks have been silicified and are capped by billy.

Relationships and boundary criteria

The unit unconformably overlies weathered Cretaceous rocks of the Eromanga Basin and is overlain by the Austral Downs Limestone. The similar rock types, similar mode of deposition and similar weathering history indicate broad correlation with the Glendower Formation and Eyre Formation.

Thickness

The maximum observed thickness is ~8m.

Age

The age is not well constrained. The Eyre Formation is early Late Palaeocene to Middle Eocene (see above).

Distribution

The unit occurs in the northern part of the project area as scattered remnants.

Depositional setting

Paten (1964) suggested the unit was deposited as fluvial sediments in erosion valleys of a drainage system. This was probably part of the Lake Eyre Basin.

WHITULA FORMATION

Nomenclature

The Whitula Formation was named by Senior (in Senior & others 1978, page 49). The formation was named for Whitula Creek, a south flowing tributary of Cooper Creek. The type section is in BMR Canterbury 4 between 1.5m–55m.

Rock Types

The unit contains interbedded quartzose sandstone, siltstone, mudstone and claystone with minor conglomerate. Lignite and gypsum are also present. Indurated layers resulted from slight silicification or ferruginisation.

Relationships and Boundary Criteria

Within the depressions, the unit unconformably overlies the Glendower Formation or weathered Winton Formation. On the margins of the downwarps, the unit onlaps the Glendower Formation. Quaternary alluvium conformably overlies the unit.

Thickness

The maximum recorded thickness is 160m, but the unit may be thicker in the downwarps.

Age

No direct age can be assigned due to the absence of preserved flora or microflora. The unit is probably equivalent to Late Miocene units in the Lake Eyre Basin in South Australia (Callen & others, *in* Drexel & Priess, 1995).

Distribution

The unit is confined to a number of interconnected downwarps, including the Wilson Depression, Cooper Syncline, Yamma Yamma Depression, Farrars Syncline and Thomson Syncline.

Depositional Setting

A fluvial to lacustrine setting is indicated. The unit formed in a drainage system flowing towards the centre of the Lake Eyre Basin.

TECTONICS

Although the Cainozoic of Australia is often seen as a stable period, the reality is that events at the margins (for example, the opening of the Tasman and Coral Seas, the continuing rifting apart of Australia and Antarctica, and the development of a foreland thrust belt in New Guinea) had an impact in the centre of the craton.

Hoffmann (1989) examined the post-Jurassic movements in the Eromanga Basin using seismic data. She noted that Cainozoic deformation was influenced by pre-existing basement features. Areas underlain by rocks affected by Devonian extension show greater displacement than areas with older basement. Because of the combination of extensional and compressional reactivation of pre-existing faults, it is difficult to define the timing of particular events. This difficulty is exacerbated by the weathered nature, and patchy distribution of the Cainozoic rocks.

For the Late Cretaceous to Palaeocene deformation, Hoffmann (1989) postulated east–west and north–south extension as a result of sagging associated with rifting in the Tasman Sea, together with isostatic adjustment. She attributed a north–south compressional deformation to collision of the Australian and Pacific plates, which resulted in thrust belt development in New Guinea from the Oligocene to mid-Miocene. An east–west compression, which affected the Canaway Fault, may have occurred between the Miocene and Recent, with uplift of the Eastern Highlands. Hoffmann (1989) estimated up to 890m of uplift of Eromanga Basin strata in the Late Cretaceous and Tertiary. Rodgers & others (1991), using velocity interval data (actual depth versus predicted depth), identified areas of major post Eromanga Basin uplift. Uplifts of up to 800m were estimated in the Mount Howitt area.

Moussavi-Hourami (1996), in a study of burial history of the Eromanga Basin in the vicinity of the Cooper Basin in South Australia, ascribed the period of deposition of Eyre Formation/Glendower Formation to sediment loading and compaction rather than tectonic activity. Subsidence also controlled deposition of the Whitula Formation and equivalents and Pliocene to Quaternary sediments.

The impact of subsidence on sedimentation can be seen in Figure 78, which has the seismic C Horizon as background. There is a strong correlation between the distribution of Quaternary alluvium of Coopers Creek and the areas of greatest subsidence in the Eromanga Basin. Likewise, the Whitula Formation is restricted to the same areas of subsidence. The high areas in the C Horizon correspond closely to the uplifted areas identified by Rogers & others (1991) and areas of non-Quaternary sedimentation.

A basin centred, topography-driven groundwater flow system developed in the Eromanga Basin in the Early Tertiary — this had a major impact on the thermal regime (Toupin & others, 1997). Prior to this, the ground water system had been compaction-driven. Erosion during the Tertiary caused a decrease in intensity of the groundwater system. Uplift around the margins of the Great Australian Basin and, in particular, the eastern margin has resulted in the development of another topography-driven groundwater system in the last 10 million years (the Great Artesian Basin). The topographic drive has decreased over the last 5 million years due to erosion in the recharge areas.

PETROLEUM GEOLOGY

ARG Gray & JJ Draper

The Cooper and Eromanga Basins in south-west Queensland and adjacent South Australia form Australia's premier onshore petroleum province. The reserves discovered in Queensland to the end of 1997 are shown in Table 2 along with the distribution of source, reservoir and seal rocks. The Eromanga Basin is predominantly oil bearing with minor gas. On the other hand the Cooper Basin is gas dominant with a considerable light liquid component. Boreham & Summons (1999) argued that the Cooper Basin was the dominant source for Cooper Basin and Eromanga Basin trapped hydrocarbons. The high level petroleum system for the basins is shown in Figure 79.

The hydrocarbon generation model developed for the South Australian and Queensland Cooper and Eromanga Basins (Deighton & others, in preparation) provides detail on source rocks, burial history and generation. This report is a brief review of the petroleum geology of the two basins in Queensland.

COOPER BASIN

Source Rocks

The coal measures of the Permian Patchawarra and Toolachee Formations, and to a lesser extent the Epsilon Formation, are the main source of the hydrocarbons generated in the Cooper Basin. The intervening Murteree and Roseneath Shales and the Daralingie Formation are not considered to contribute significantly as a source. The Murteree Shale is lean in organics compared with the Patchawarra Formation (Heath, 1989). However, in 5 wells in the Patchawarra Trough in South Australia in which cuttings from all formations of the Gidgealpa Group were sampled for petrographic analysis, the Murteree Shale was found to have the highest volume of dispersed organic matter (Smyth, 1983).

Land plant detritus is the dominant organic matter and the humic kerogen in the Permian coal measures is of both Type II and Type III. Organic matter is rich in vitrinite and inertinite (gas-prone macerals). The volume of liptinite (oil-prone macerals) is <20% (Jenkins, 1989).

The average total organic carbon (TOC) and hydrocarbon yield for all Cooper Basin source rocks, excluding coals, in Queensland and South Australia, are 3.9% and 6.9kg/t respectively. The Toolachee Formation locally averages 7.2% TOC and yields 15.7kg/t hydrocarbons (Jenkins, 1989).

The hydrocarbons generated in the basin were generally thought to have originated from the disseminated organic matter in the Toolachee and Patchawarra Formations (Hunt & others, 1989) although the possibility of coals acting as source rocks had been suggested (Smyth, 1983; Taylor & others, 1988). More recently, Boreham & Summons (1999) identified the coals and associated terrestrial matter as the main source rocks. The coals are also inertinite rich with lesser vitrinite and minor liptinite (<13%) (Taylor & others, 1988). If inertinite and vitrinite can generate hydrocarbons then the quantities of these macerals in the coal and as dispersed organic matter is sufficient to source the hydrocarbon accumulations in the basin.

Shale and coal thickness maps for the Patchawarra Formation (Figures 17, 18), Epsilon Formation (Figures 22, 23) and the Toolachee Formation (Figures 29, 31) show that the thickest potential source rocks are in the Nappamerri Trough and under, or adjacent to, the JNP Trend.

Small reserves of oil recovered from Permian reservoirs in several areas of the Cooper Basin in Queensland have been generated locally from Permian source rocks. The Naccowlah South field holds the largest initial primary recoverable reserves of oil at 19ML. Much of the oil reservoired in the overlying Eromanga Basin has been generated from the Permian succession (Alexander & others, 1988; Boreham & Summons, 1999), and this is reflected in the fact that almost all Eromanga Basin oil discoveries are in areas overlying or adjacent to the hydrocarbon producing Cooper Basin. The few gas discoveries in the Eromanga Basin probably were also sourced from the Cooper Basin, because potential source rocks in the

Table 2: Source, reservoir and seal rocks versus reserves by formation.

FORMATION	Gas ($x10^6 m^3$)	Oil (ML)	Condensate (ML)	LPG (ML)	SOURCE	RESERVOIR	SEAL
Eromanga Basin							
Winton Fm					lignite		
Mackunda Fm							
Allaru Ms							
Toolebuc Fm					Oil shale		
Wallumbilla Fm							
Cadna-owie Fm		62(1)					
Hooray Ss/"upper Namur Ss"/ Murta Fm		2,368(43)					
Westbourne Fm		1,387(10)					
Adori Ss		73(3)					
Birkhead Fm	430(1)	597(19)	17(1)	2(1)			
Hutton Ss	1,394(3)	13,154(29)	178(3)	115(3)			
Poolowanna Fm	18(2)	833(8)					
Cuddapan Fm							
Cooper Basin							
Tinchoo Fm	537(2)		58(2)	131(2)			
Arrabury Fm							
Toolachee Fm	37,311(38)	25(2)	2559(41)	1861(40)			
Daralingie Fm							
Roseneath Sh							
Epsilon Fm	4,508(13)		414(13)	432(14)			
Murteree Sh							
Patchawarra Fm	25,409(42)	9(2)	2723(42)	2335(39)			
Tirrawarra Fm							
Merrimelia Fm							
Devonian basins					*****		
Warburton Basin					*****		

() Number of fields ***** pre-Cooper Basin

Eromanga Basin are immature or, at best, only marginally mature for gas generation.

As the Permian is regarded as the source for much of the oil generated in the Cooper–Eromanga Basin region, the potential exists for significant oil discoveries to be made locally within the Cooper Basin (Yew & Mills, 1989). To date, the commercial oil discoveries in the Cooper Basin are few and, excluding the Tirrawarra Oil Field in South Australia, are relatively small.

The source potential is inferred to increase towards the Permian depocentres and maturity increases concentrically about the depocentres. Gas production starts at about R_o max = 1.% and dry gas at higher maturities of R_o max = 1.3% (Wecker & others, 1996).

In South Australia, a strong relationship exists between maturation levels and the presence of commercial gas fields. The shallowest significant Permian-reservoired gas is found at a maturity level of Rv = 0.8–0.9%. Above the maturity level of Rv = 0.9%, the volume of gas generated increases almost linearly with increasing maturation. The increase in maturity with depth also results in increasingly dry gas with increasing depth within individual fields (Heath, 1989).

Maturity distribution for the basal Patchawarra Formation is shown in Figure 80 (from Deighton & others, in preparation). Expulsion of gas (Figure 81) is from the main depocentres in the southern basin and from the northern area. The pattern for oil expulsion (Figure 82) is similar although less pronounced in the depocentres in the southern basin. The maturity data from the top of the Toolachee Formation (Figure 83) shows a similar pattern to that of the basal Patchawarra Formation with gas expulsion (Figure 84) and oil expulsion (Figure 85) in the main depocentres in the southern part of the basin and a large area in the northern part of the basin.

Little is known of the source potential of the Triassic succession in the Cooper Basin. The Gilpeppee Member of the Tinchoo Formation, which is described as a relatively uniform sequence of light grey to green-grey, variably carbonaceous siltstones with minor coal development in the upper part (Powis, 1989), could be a potential source rock.

Reservoirs

In the Cooper Basin in Queensland, the main reservoirs are in the Patchawarra and Toolachee Formations, and to a lesser extent (in south-western Queensland), the Epsilon Formation. The Early Permian Tirrawarra Sandstone contains very small reserves of oil at Pepita and also has some reservoir potential. At Marama, in the northern Cooper Basin, and at Epsilon near the South Australian border, gas is reservoired in the Triassic Nappamerri Group. In the southern Cooper Basin in South Australia, in addition to the above units, the Daralingie Formation and Merrimelia Formation (with interbedded Tirrawarra-type Sandstones) also contain reservoirs in some areas. There is hydrocarbon production from all sandstone-bearing units in the southern Cooper Basin (Heath, 1989). Porosities of the producing reservoirs range from 11–15% (Battersby, 1976).

In South Australia, significant stratigraphic reserves of hydrocarbons occur in the fluvio-deltaic Daralingie Formation (Morton, 1989), and the Merrimelia Formation is an oil reservoir at Malgoona (Chaney & others, 1997). The largest onshore Permian oil field in Australia is reservoired in the Tirrawarra Sandstone in the Tirrawarra Oil Field (Rodda & Paspaliaris, 1989). Although the above three formations produce commercial hydrocarbons in South Australia, their potential as reservoir units in Queensland, particularly the Daralingie Formation, appears to be limited. Basin studies suggest that most of the Daralingie Formation in Queensland has been removed by erosion. Nevertheless, the Merrimelia Formation and Tirrawarra Sandstone, which are now known to be closely related genetically (Chaney & others, 1997), should not be completely disregarded. In addition to the small Pepita discovery in the Tirrawarra Sandstone, significant reservoirs still could be discovered over the Merrimelia–Tirrawarra interval in the south-western Cooper Basin in Queensland.

Shallow Permian reservoirs are at a lower level of maturity than deeper Permian reservoirs at the same locality. To support this, wetter gas is found in shallower reservoirs. Dry Patchawarra gas is overlain by wet Toolachee gas at Dullingari in South Australia (Heath & others, 1989).

With respect to the Nappamerri Group, the sandstone-dominated middle part of the Triassic succession (Doonmulla Formation) which overlaps the Early Triassic shale and sandstone-dominated Arrabury Formation are dominantly quartzose and may have good reservoir potential in some areas. An oil reservoir discovered in the Middle Triassic in James 1 in South Australia, and a gas reservoir in DIO Mount Howitt 2 indicate that the Triassic contains reservoirs in some areas (Gray & others, 1994; Gray, 2000).

The **Patchawarra Formation** is probably the most important unit for hydrocarbon reservoirs in the Cooper Basin. In Queensland, 42 fields have gas and gas liquids reservoired in the Patchawarra Formation, compared with 38 fields which have reservoirs in the Toolachee Formation. Many of the fields produce from both. Although the Toolachee Formation has fewer pools, it contains more gas reserves in total. The largest gas field reservoired in the Patchawarra Formation in Queensland is at

Stokes with initial recoverable reserves of $4225m^3 \times 10^6$ as at 30 June 1998.

The Patchawarra Formation represents meandering stream, swamp, deltaic and lacustrine deposition. The best reservoirs are developed in channel and point bar deposits in structural/stratigraphic traps. Five chronostratigraphic units, together with unconformities, have been recognised within the Patchawarra Formation in South Australia (Apak & others, 1993).

In the northern Cooper Basin, the Patchawarra Formation is mostly <100m thick, whereas in the deeper south-western parts of the basin in Queensland it is probably up to 500m thick. Alluvial channels are composed of fine- to medium-grained quartz arenites, which show extreme diagenetic alteration resulting in quartz overgrowths, authigenic kaolinite, and calcite and siderite cements. Some primary porosity and extensive microporosity from the alteration of lithic and feldspar grains ensure there is adequate porosity (Wecker & others, 1996).

In South Australia, the porosity of the Patchawarra Formation in major troughs is 7% or less, but on depositional highs, is up to 13%. Porosities of up to 30% have been measured towards the southern Cooper Basin margin. A decrease in porosity with depth is apparent in both the Patchawarra and Nappamerri Troughs in South Australia (Heath, 1989). The same should apply for the Nappamerri and Windorah Troughs in Queensland. Permeability trends parallel the main structural elements of the basin. Also, permeability and porosity trends show decreasing reservoir quality from the south-west to the north-east in the Patchawarra Trough (Heath, 1989).

Gross sandstone thickness distribution and porosity distribution for the Patchawarra Formation are shown in Figure 15 and Figure 16 respectively.

Like the Patchawarra Formation, the **Toolachee Formation** is represented by alluvial channel and proximal splay sandstones, overlain by more distal splay and lacustrine to floodplain fine-grained sandstones and siltstones. The succession grades up to peat swamp deposition.

In the northern Cooper Basin in Queensland, the Toolachee Formation is mostly <50m thick compared with a thickness of 150m or more in south-west Queensland. The basal Toolachee Formation represents the highest energy deposits of the formation in the area and contains excellent reservoirs (Wecker & others, 1996). The reservoirs are generally contained in thick alluvial channel and point bar deposits. Aggregate sandstone thickness and porosity maps for the Toolachee Formation are shown in Figure 27 and Figure 28 respectively.

The lowermost part of the Toolachee Formation forms the main hydrocarbon-producing zone within the formation, particularly in the south-western and central Patchawarra Trough in South Australia (Apak & others, 1993). The largest gas field in South Australia is reservoired in the basal Toolachee Formation at Moomba (Fairburn, 1989).

In Queensland, the largest gas field reservoired in the Toolachee Formation is at Challum, with initial recoverable reserves of $14704m^3 \times 10^6$ as at 30 June 1998 (Scott & others, 2000).

Although the Patchawarra and Toolachee Formations contain the bulk of the gas reserves in Queensland, 13 gas and gas liquids fields exist in the **Epsilon Formation** in south-west Queensland. The largest field is Macadama with initial recoverable reserves of $860m^3 \times 10^6$ gas as at 30 June 1998. Three other fields contain gas in excess of $700m^3 \times 10^6$ (Scott & others, 2000).

Epsilon Formation reservoirs are considered to be unpredictable when compared with those of the Patchawarra and Toolachee Formations. In a study of the Epsilon Formation in the Cooper Basin in South Australia, six sand packages with reservoir potential were identified. The sandstones were found to be either laterally continuous sheet sands (or lake shoreline strand deposits) or discontinuous ribbon sands. The latter represent distributary channel deposits in prograding deltas. The major reservoirs are in the shoreface deposits (Fairburn, 1992). Gross sandstone thickness is shown in Figure 21.

Although the Early Triassic Arrabury Formation (lowermost Nappamerri Group) is regarded traditionally as a major seal to the underlying Permian, several recoveries of hydrocarbons from the **Arrabury Formation** show that it has some reservoir potential. Commercial quantities of gas are contained in the Paning Member (Middle Arrabury Formation) in SSL Marama 1 ST1 in the northern Cooper Basin, and within the Callamurra Member (lower Arrabury Formation) in two wells in the Epsilon Field in south-west Queensland. In this latter field, the sandstone reservoir, which is ~10m thick, is stratigraphically <30m above the top of the Late Permian Toolachee Formation. To date, these are two of the few known occurrences of a prominent sandstone body in the Callamurra Member, which consists dominantly of mudstone and siltstone (Gray, 2000).

Numerous shows and recoveries of hydrocarbons have also been obtained from the Arrabury Formation in South Australia. Oil flowed from the Wimma Sandstone Member (upper Arrabury Formation) in James 1 well, near the Queensland border, west-south-west of the Cook Oilfield.

The Middle Triassic Doonmulla Member at the bottom of the **Tinchoo Formation** (Powis, 1989), consists dominantly of fine- to medium-grained quartzose sandstone of fluvial origin; it unconformably overlies the Arrabury Formation. In drilling so far, the sandstones of the Doonmulla Member, which are lithologically and depositionally similar to those forming the majority of the hydrocarbon-producing reservoirs in the Cooper and Bowen Basins in Queensland, have been found to be mainly tight. The reason for this is unclear because there is very little core from the member. It is possible that the Doonmulla Member may have some undiscovered reservoir potential. This could be very significant in areas of the northern Cooper Basin where the member is separated unconformably from Permian source rocks by only a thin or even non-existent Arrabury Formation. Similarities could be drawn between this and the western Bowen Basin south of Roma where commercial gas production is obtained from the fluvial quartzose sandstones of the Middle Triassic Showgrounds Sandstone where this unit directly overlies Late Permian coal measures, the source of the gas.

Seals

In the south-western part of the Cooper Basin in Queensland, and in the main areas of Permian deposition in South Australia, the regional seal to reservoirs in the Patchawarra Formation is provided by the Murteree Shale, to the Epsilon Formation by the Roseneath Shale, and to the Toolachee Formation by the Nappamerri Group. Internal seals are also common in the Cooper Basin succession and this is evidenced by individually stacked reservoir sandstones having different gas-water contacts and hydrocarbon composition (Heath, 1989).

In the northern Cooper Basin, the Murteree Shale, Epsilon Formation and the Roseneath Shale are not present and the Patchawarra Formation is unconformably overlain by the Toolachee Formation. Flood-plain siltstones and shales in the Patchawarra and Toolachee Formations provide local seals (Wecker & others, 1996).

The latest Permian–Early Triassic Arrabury Formation generally provides an effective seal over much of the Cooper Basin for any hydrocarbons generated in the underlying Permian. It consists of interbedded and interlaminated siltstones, sandstones and mudstones in varying proportions and can be subdivided where possible into, in ascending order, the Callamurra, Paning and Wimma Sandstone Members (Channon & Wood, 1989; Gray, 2000).

A lot of the hydrocarbons reservoired in the Eromanga Basin are considered to have migrated there from a source in the underlying Permian succession. The subcrop limits of the Early Triassic Arrabury Formation are therefore important in determining the prospectivity of the overlying Eromanga succession (Heath, 1989). This applies particularly to the south-western part of the Cooper–Eromanga region in Queensland where most of the hydrocarbons have been discovered.

The Callamurra Member at the bottom of the Arrabury Formation is predominantly fine-grained and consists mainly of interbedded siltstones, mudstones and very fine-grained sandstones. It is traditionally regarded as a major seal directly overlying Permian source rocks, although the following inconsistencies (Gray, 2000) have been noted:

1. In Queensland, commercial quantities of gas flowed from the Paning Member of the Arrabury Formation overlying a thin (13m) Callamurra Member in SSL Marama ST 1, near the northern zero edge of the latter.

2. Gas flowed from a sandstone reservoir within the Callamurra Member in two wells in the Epsilon Field in south-west Queensland.

3. In South Australia, numerous shows and recoveries of hydrocarbons have been obtained from the Arrabury Formation (which includes the Callamurra Member at its base), in wells where the Permian is considered to have been the source.

In the Queensland portion of the Cooper Basin, the Callamurra Member of the Arrabury Formation is thickest in the Nappamerri Trough and it thins to zero in the northern and eastern parts of the basin (Figure 1 in Gray (2000)) (see Figure 37, this report).

In the northern Cooper Basin outside the Callamurra zero edge, the overlying and overlapping members of the Arrabury Formation and the Tinchoo Formation (uppermost Nappamerri Group) provide the seal for the underlying Permian. This post-Callamurra Member part of the Nappamerri Group is likely to be a less competent seal for the following reasons:

1. The Paning Member of the Arrabury Formation, which directly overlies the Callamurra Member, contains considerable amounts of interbedded sandstone and the Paning Member flowed gas at commercial rates in SSL Marama 1 ST 1 in the northern Cooper Basin.

2. The Wimma Sandstone Member of the uppermost Arrabury Formation consists dominantly of fine to medium-grained quartzose sandstone with minor interbeds of medium-grey siltstone and mudstone (Alexander & others, 1998). In 1988, oil flowed from the Wimma Sandstone Member of the Arrabury Formation in James 1 well in South Australia.

3. The Tinchoo Formation at the top of the Nappamerri Group unconformably overlies the Arrabury Formation and is a fining-upwards succession with sublabile to quartzose fluvial sandstones (Doonmulla Member) forming the lower part and the siltstone-dominated Gilpeppee Member, the upper part (Powis, 1989). The sandstone-dominated Doonmulla Member could provide access for hydrocarbons migrating from the Permian into the Eromanga Basin near the Permian zero edge (Gray & others, 1994).

Vertical migration of Permian-sourced hydrocarbons into Eromanga Basin reservoirs via a sandy Triassic sequence in the northern Cooper Basin region was first proposed by Gilby & Mortimore (1989). The Gilpeppee Member of the Tinchoo Formation, however, provides an effective seal over most of the central region of the northern Cooper Basin.

The percentage of shale in the Nappamerri Group is shown in Figure 35. The percentage of shale is very variable, suggesting that the Nappamerri Group will provide areas of excellent seal and areas of poor seal.

Traps

The exploration effort in the Cooper Basin has been, and still is, directed mainly towards drilling conventional anticlinal traps with 4-way dip and 3-way dip closures with fault control. In more recent years, several stratigraphic prospects have also been drilled, as exploration for conventional closures reaches a mature stage, particularly in South Australia (Heath, 1989). The size of the undrilled closures or prospects has naturally declined over the years because the larger prospects, being the more attractive, are generally drilled first. However, to offset the decrease in size of the prospects, improved seismic techniques, combined with innovative thinking, have facilitated the development of large untested structural/stratigraphic plays in the southern Cooper Basin in South Australia (Heath, 1989).

The potential for the future discovery of Permian oil and gas in the South Australian part of the Cooper Basin is seen still to depend on three play types — structural traps, fault traps and stratigraphic plays (Heath, 1989). The same would apply for the Queensland portion of the Cooper Basin. Stratigraphic plays, because they are the hardest to locate, have been the least explored (Nakanishi & Lang, 2001). In Queensland, updip pinchout traps of Permian reservoir sandstones on the flanks of the JNP Trend would offer the best prospects, especially on the southern flank of the structure where the thick section of mature Permian rocks in the nearby Nappamerri Trough could provide a source of hydrocarbons. Similarly, the flanks of the GMI Trend in South Australia offer the best prospects for stratigraphic accumulations (Heath, 1989). The combination of dramatic structural growth, thick sediment, and mature source rocks gives an ideal location for hydrocarbons to be trapped.

Recent Permian gas discoveries in the north-eastern Cooper Basin, in the vicinity of the Windorah Trough (Wecker & others, 1996), have shown that this relatively unexplored part of the basin could hold considerable reserves. A basal Toolachee Formation sandstone reservoir in faulted anticlinal prospects so far has produced the best results in this part of the basin. Non-conventional traps, such as low-side fault plays and stratigraphic plays, undoubtedly exist in the area as well, but cannot be confidently located from the current seismic data and coverage (Wecker & others, 1996). Stratigraphic plays are also likely to exist in the area of the Arrabury Trough, the other main area of Permian deposition in the Queensland part of the Cooper Basin.

Hillis & others (2001) discussed the possibility of deep basin gas within the Nappamerri Trough. The key to extracting such gas would be to identify depositional, diagenetic or structural 'sweet spots'.

EROMANGA BASIN

Source Rocks

In the currently-producing areas of the Eromanga Basin in south-west Queensland, the Poolowanna Formation, Birkhead Formation, Murta Formation and, to a lesser extent, the Westbourne Formation were regarded as having the most significant source potential (Wecker, 1989). Boreham & Summons (1999) identified the Birkhead Formation and the Murta Formation as the main Eromanga Basinsource rocks. However, they estimate that <25% of oil trapped in the Eromanga Basin is sourced from the basin. The Cooper Basin is the main source, but there may be a minor pre-Permian contribution. Depth of burial is the major problem, with few potential source rocks in the generation zone.

The **Birkhead Formation** displays the most favourable source rock richness of all the Jurassic units (Hawkins & others, 1989). It is also the thickest and most extensive source rock unit and the most hydrogen-rich unit (Jenkins, 1989). The Birkhead Formation is rich in Type III kerogen (Khorasani, 1987). Vitrinite is more common than inertinite, and within the South Australian and Queensland sectors, the liptinite content varies from 10–70%; it comprises mainly cutinite and sporinite (Jenkins, 1989). In south-western Queensland, north and east-trending hydrogen-rich liptinite facies in the Birkhead Formation appear to have been controlled indirectly by the underlying Devonian half-grabens and the easterly-trending Nappamerri Trough respectively (Hawkins & others, 1989).

Locally, the Birkhead Formation has an average TOC of 2.5% and a yield of 10.8kg/t hydrocarbons (Jenkins, 1989).

In National Energy Development and Demonstration Council (NERDDP) Project 914, the Birkhead Formation was found to have TOC values ranging from 0.75–6.3% and a yield of 0.16–30.86mg HC/g. Contrary to previous studies which have highlighted the importance of coal seams in the Birkhead Formation, stratigraphic studies by Green & others (1989) have not noted any significant coal occurrences. Accordingly, coal is unlikely to have contributed as a source of hydrocarbons in the Birkhead Formation (Hawkins & others, 1989).

The maturity map of the Birkhead Formation (Figure 86), prepared by Deighton & others (in preparation), shows two large mature areas, but gas expulsion (Figure 87) and oil expulsion (Figure 88) occurred in a very limited area.

The **Poolowanna Formation** contains smaller volumes of siltstone and shale than the Birkhead Formation and is not as widespread. Consequently, the Poolowanna Formation is not as important a source rock. Because of its lower stratigraphic position, there is a distinct increase in maturity in the Poolowanna Formation compared with other overlying Jurassic units in the same area (Khorasani, 1987).

Like the Birkhead Formation, vitrinite is more common than inertinite. Abundant vitrinite occurs in areas underlain by major synclines and troughs, in particular the Cooper Syncline and Ullenbury Depression (Windorah Trough) and the Arrabury Trough (the Poolowanna Formation is mostly absent from the area overlying the Nappamerri Trough). Liptinite facies are confined to an area west of the Canaway Fault and appear to be controlled by structural trends in the underlying Devonian Warrabin Trough.

The Poolowanna Formation has fair to excellent source richness with TOC values ranging from 0.6–17.9%. Potential yield values of 0.4–24.77mg HC/g indicate poor to excellent generation potential (Hawkins & others, 1989).

A maturity map for the Poolowanna Formation (Figure 89) from Deighton & others (in preparation) shows widespread maturity levels, but gas expulsion (Figure 90) and oil expulsion (Figure 91) were limited.

Compared with both the Birkhead and Poolowanna Formations, **Murta Formation** is low in source richness. TOC values range from 0.54–2.51% and this is near the lower limit of an effective source rock. The organic matter is terrestrial, oil-prone of Types II and III, and consists predominantly of sporinite, liptodetrinite and inertinite with lesser amounts of vitrinite. Hydrocarbon yields analyses show that this unit is an effective source rock at maturation levels of Vr = 0.5–0.6%, which is at the lower threshold of the oil generation window (Powell & others, 1989). Further evidence for a local source is the fact that where there are Murta oil occurrences, there is a general lack of hydrocarbon shows in the Jurassic units below the Murta Formation.

The **Westbourne Formation**, because of a perceived low source richness with TOC values ranging from 0.51–2.18% (Hawkins & others, 1989), is generally not considered to be an important source of Eromanga Basin hydrocarbons. Nevertheless, the stratigraphically higher Murta Formation with similar TOC values appears to be a hydrocarbon source in some areas. Inertinite is the dominant kerogen type over much of the central, northern and south-eastern parts of the Cooper–Eromanga Basin region in Queensland, whereas vitrinite facies, widespread in the underlying Birkhead Formation, occurs mainly in the south-west and in the area overlying the Nappamerri Trough. Liptinite facies, which are present in isolated areas, show alignment with older structures and also may be related to continued downwarping of the southern Cooper Syncline or Windorah Trough (Hawkins & others, 1989).

Maturation studies suggest that the Eromanga Basin succession at best is only marginally mature for gas generation (conventionally where R_o max = 1–1.3%). The deeper areas, those overlying the Nappamerri, Windorah and Arrabury Troughs, would offer the best prospects for both oil and gas generation from these potential source rock units, because of increased maturity. However, for oil generation, source rock studies, in conjunction with vitrinite reflectance measurements, suggest that initial oil generation within the Birkhead Formation may commence at about R_o max = 0.55%, and within the Murta Member of the Hooray Sandstone at approximately R_o max = 0.45% (Wecker, 1989). This is a somewhat lower level of maturity than the generally accepted oil generation window of R_o max = 0.7–1.0%. If oil is generated at this lower maturation level, then larger areas of the Eromanga Basin become prospective.

Reservoirs

In the Eromanga Basin, hydrocarbons have been discovered in all units below the Wallumbilla Formation. Characteristically, the Eromanga Basin has vertically stacked hydrocarbon pools, and ~50% of the fields contain more than one pool (Petroleum Resources Assessment and Development Subprogram, 1990). The widespread braided fluvial deposits of the Hutton and Adori Sandstones and the sandstones of the "upper Namur Sandstone" and the Hooray Sandstone generally show fair to excellent reservoir potential (Wecker, 1989). Braided, fluvially-deposited sandstones also typify the lower part of the Poolowanna Formation, but these sandstones are more restricted in aerial extent and were deposited only in the northern part of the project area. The best reservoirs in the braided fluvial deposits are associated with the coarser-grained sandstones. The porosity of this sandstone type, however, decreases with depth and distance from basin margins and from intrabasinal highs (Wecker, 1989). Gross sandstone thicknesses are shown in Figure 47 (Poolowanna Formation — see also Figure 48 for a sandstone thickness map), Figure 52 (Hutton sandstone), Figure 58 (Adori Sandstone) and Figure 65 (Hooray Sandstone). Porosity distribution is displayed in Figure 53 (Hutton Sandstone), Figure 59 (Adori Sandstone) and Figure 66 (Hooray Sandstone).

Both fluvial and lacustrine conditions prevailed during deposition of the Birkhead and Westbourne Formations, the Murta Formation, and the Cadna-owie Formation. These units, which are from the lower part of the Eromanga Basin succession, also produced hydrocarbons in the Cooper–Eromanga region. Typically, these formations contain a much higher proportion of interbedded siltstones and mudstones and the sandstones have a higher clay content, all of which reflect the environment of deposition. Reservoir horizons are more restricted in these units and tend to occur locally when compared with reservoirs in the braided fluvial deposits. Although the overall higher clay content reduces the reservoir potential, possible exceptions are in the Murta Formation and the upper Cadna-owie Formation (Wyandra Sandstone Member). High oil flow rates are recorded from the Wyandra Sandstone Member at Talgeberry (Wecker, 1989) and flows in excess of 2000 BOPD were obtained from sandstones <1m thick in the Murta Formation in the Dullingari North 1 oil discovery well in South Australia (Mount, 1981). Gross sandstone thicknesses for the Birkhead Formation are shown in Figure 55, for the Westbourne Formation in Figure 61, and the Cadna-owie Formation in Figure 69 (see Figure 70 for porosity distribution).

Oil is the dominant type of hydrocarbon reservoired in the Eromanga Basin but gas in commercial quantities has also been found in four fields in Queensland. Nevertheless, the first hydrocarbon discovery in the Eromanga Basin was gas in the “Namur Sandstone Member” of the Mooga Formation (now Namur Sandstone in South Australia) in Namur 1 in South Australia in 1976 (Armstrong & Barr, 1986). Gas was also the first hydrocarbon discovery in the Eromanga Basin in Queensland — in the Birkhead Formation in DIO Wackett 1 in 1978.

The underlying Permian coal measures are the likely source of this gas. Considerable quantities have probably migrated into Eromanga Basin reservoirs from the Cooper Basin but stripping and dissolution of the gas by the Eromanga aquifer system (and water-washing of the residual liquids phase) is likely to have occurred (Heath & others, 1989). The four gas fields in the Eromanga Basin in Queensland must have been protected from the flushing.

In Queensland, as at 30 June 1998, the Hutton Sandstone had produced by far the largest volume of oil (11,500ML) and from the greatest number of fields (31). The bulk of the oil was produced from 3 fields — Jackson (5485ML), Kenmore (1463ML) and Naccowlah West (1403ML). The next most productive units are the Westbourne Formation (1279ML) from 12 fields (with most oil from the Jackson area), the Murta Formation (1018ML) from 30 fields, and the “upper Namur Sandstone” and the Hooray Sandstone (812ML) from 14 fields. The Poolowanna Formation (761ML) from 13 fields (mostly from Bodalla South) and the Birkhead Formation (620ML) from 21 fields have produced most of the remainder (Scott & others, 2000).

In South Australia, the Birkhead/Hutton system and the Murta Formation have produced the bulk of the oil from the Eromanga Basin (Boult & others, 1998).

The **Hutton Sandstone** is widespread, both in outcrop and in the subsurface, and it is partly for this reason that it is the most important reservoir unit in the Cooper–Eromanga Basin region. In the top 20m of the Hutton Sandstone, which is the main hydrocarbon producing zone (up to the top 30m in the Jackson Field), the porosity ranges from 15–30%. However, over the central Windorah Trough and the Nappamerri and Patchawarra Troughs in South Australia, the porosity decreases to 9–12%, due mainly to diagenetic silicification. Average permeability for the Hutton Sandstone is from 0.5–3 darcies and up to 10 darcies has been measured (Wecker, 1989). Flow rates of 300–3000 BOPD, to a maximum of 3700 BOPD, and large water flows in artesian bores reflect the generally good to excellent reservoir potential of the Hutton Sandstone in many areas.

In a diagenetic study of the Hutton Sandstone in the southern Eromanga Basin in Queensland (Green & others, 1989), 3 distinct diagenetic zones were identified. In diagenetic order, the zones are (1) a dissolution zone, (2) a quartz overgrowth zone and (3) a compaction zone. The zones could be aligned to increasing depth with the dissolution zone occurring at shallow depths, the overgrowth zone at intermediate depths and the compaction zone at greatest depths. At the time of the study, all known hydrocarbon pools in the Hutton Sandstone were found to occur within the quartz overgrowth zone (Figure 17 in Green & others, 1989). In this zone porosities range from 10–25%.

Hydrocarbon accumulations appear to have occurred after the major phases of clastic diagenesis (Green & others, 1989). However, evidence in the form of hydrocarbon fluid inclusions associated with quartz overgrowths in several wells, indicates liquid hydrocarbon migration occurred prior to, and syncronous with, the formation of quartz overgrowths (Eadington & others, 1989). This suggests that there may have been two phases of overgrowth development and that some overgrowth development occurred relatively late in the diagenesis (Green & others, 1989).

Seals

A widespread regional seal to the hydrocarbons produced in the lower part of the Eromanga Basin succession is the thick section of Early Cretaceous marine strata, commencing with the Wallumbilla Formation. With the exception of the Coreena Member of the upper Wallumbilla Formation, and the Mackunda Formation at the top of the marine section (which contains water-bearing sandstones in some areas), the bulk of the marine section comprises a monotonous succession of tight siltstones, mudstones, shales and limestones with good sealing potential. In the southern Cooper Basin region in South Australia, the Coorikiana Sandstone, which occurs at a stratigraphic level equivalent to the upper part of the Wallumbilla Formation, also contains porous sandstones.

Siltstone-dominated formations such as the upper Poolowanna Formation, Birkhead Formation, Westbourne Formation and lower Cadna-owie Formation of the lower Eromanga Basin succession act locally as seals in some areas, but their regional competency is limited. Figure 50 is a map of shale per cent for the Poolowanna Formation and Figure 63, for the Westbourne Formation. Local sealing is evidenced by individually stacked pools occurring in many fields. For single fields, seal thicknesses of <20m have been found to be effective (Wecker, 1989).

If a mainly Permian source is assumed for the hydrocarbons reservoired in the Eromanga Basin, then the relatively low number of hydrocarbon pools associated with the Poolowanna Formation and Adori Sandstone are due primarily to poor sealing. This implies that the upper Poolowanna Formation and the Westbourne Formation provide only moderate sealing capacity. Because the bulk of the oil is reservoired in the Hutton Sandstone, the Birkhead Formation is therefore a relatively competent seal. This is somewhat contradictory in that the Birkhead Formation is one of the important secondary oil reservoirs in the Eromanga Basin sequence (Paton, 1986). The best seals in the Birkhead Formation are probably the sediments deposited in swamp and lacustrine environments. In the southern Cooper Basin these type of strata form Unit 2 which occurs between fluvially deposited Units 1 and 3 (Paton, 1986). In South Australia, most major oil flows and recoveries have been from channel sandstones in the older Unit 1.

In the Birkhead Formation, volcaniclastic sediments, which act as a weak seal, can be found as a diachronous influx across the productive parts of the Eromanga Basin. Volcaniclastic sediments are more prominent in the eastern part of the project area and can lie on an erosional surface at the top of the Hutton Sandstone (Boult & others, 1998).

Traps

Like the Cooper Basin, exploration in the Eromanga Basin has been, and still is, directed mainly towards drilling conventional anticlinal traps, some with fault control. In addition to the main structural control, a stratigraphic influence has been noted in several of the commercially significant hydrocarbon accumulations in the Eromanga Basin. In several fields for example Challum and Wackett, commercial hydrocarbons have been produced in the Eromanga and underlying Cooper Basins from the same structure.

In the Eromanga Basin, all major discoveries in south-west Queensland overlie, or are adjacent to, the underlying Cooper Basin. In the central part of the Cooper–Eromanga area, most discoveries in Queensland and South Australia are located marginal to, or are along, the lineaments between the Nappamerri, Windorah and Patchawarra Troughs (Wecker, 1989). Future activities will continue to be based largely on structural/stratigraphic plays in these areas.

Pool-size areas in Eromanga Basin traps are mainly in the range of 1–6km^2 and column heights range between 3–30m. Jackson is the largest oil field in the Eromanga Basin and the main Hutton Sandstone pool has an areal extent of 21km^2 and a column height of 40m (Wecker, 1989).

Smaller structural/stratigraphic accumulations are frequently found in other units downflank from the crestal pools. The oil discovered in the Wyandra Sandstone Member of the Cadna-owie Formation at Talgeberry shows a strong stratigraphic influence in the trapping (Torkington & Milenko, 1988).

Detailed wire-line log correlations have resulted in a uniform stratigraphic framework for the Eromanga Basin succession in southern Queensland (Green & others, 1989; Green, 1997). From these studies, there is a better understanding of the influence that stratigraphy and facies changes have made on the hydrocarbon accumulations already discovered. Exploration models based on stratigraphic variations can then be formulated.

Thinning onto pre-Eromanga basement of the older units (Birkhead Formation–Poolowanna Formation interval) appears to have influenced the hydrocarbon accumulations in this part of the section whereas facies changes seem to have controlled the accumulations in the younger units (Green & others, 1989).

According to the above authors, stratigraphic traps in the Eromanga Basin succession in southern Queensland are likely to occur:

a) near the zero edge of the “lower Poolowanna Formation” which is dominantly of sandstone,

b) where the Hutton Sandstone and Birkhead Formation are <140m and 70m thick respectively,

c) where V-shale for the Birkhead Formation ranges from 50–60%,

d) where sandstone is distributed throughout the Westbourne Formation,

e) where mudstone is common in the Murta Formation, and the upper sandstone bed is well developed, and

f) where sandstone beds at the top of the Cadna-owie Formation are distributed irregularly.

PETROLEUM SYSTEM

Although a number of distinct petroleum systems as defined by Magoon & Dow (1994) are present they overlap and are intermixed so that, for a regional discussion, it is simpler to deal with one petroleum system (Figure 79). As source rock distribution, charge and migration are better understood, then separate systems can be defined. The following section is a summary of the petroleum geology discussed above and of the major conclusions of Deighton & others (in preparation).

Within the Cooper basin in Queensland, coals and mudstones of the Patchawarra and Toolachee Formations are the main source rocks, with the Epsilon Formation also containing source rocks. Maturity is only achieved in the depocentres in the southern Cooper Basin and in part of the northern Cooper Basin. Within the Eromanga Basin, the Birkhead and Poolowanna Formations have the best source potential, with the Westbourne Formation and Murta Formation containing only marginal source rocks. Maturity is restricted to the deepest part of the Eromanga Basin.

In the Cooper Basin in Queensland reservoirs are restricted to the source rocks units, namely, the Patchawarra, Epsilon and Toolachee Formations. There are potential reservoir rocks in the Triassic sequence. In the Eromanga Basin there are numerous reservoir units and many fields have multiple pools. The Hutton Sandstone is the most important reservoir. The Poolowanna, Birkhead, Adori and Westbourne Formations, “upper Namur” and Hooray Sandstone and the Murta and Cadna-owie Formations, all contain reservoir rocks. Reservoir quality is generally diminished in areas of greater burial due to compaction.

Seals in the Cooper Basin are both local and regional. Gas fields in the Patchawarra, Epsilon and Toolachee Formation are confined by local seals of overbank and lacustrine origin. The fine grained units (Murteree Shale, Roseneath Shale) act as regional seals in the areas where they are present. The Triassic acts as a seal to the Permian sequence, but is not totally effective. Along the southern and south-east margins of the Cooper Basin, Triassic rocks are absent and the Toolachee formation is in direct communication with the Hutton Sandstone. The basal Callamurra Member of the Arrabury Formation is the most effective seal, but is absent in the eastern and northern areas of the Basin. The proportion of shale to sand is quite low in parts of the northern Cooper Basin suggesting that the seal may be suspect in places. In the Eromanga Basin, the Wallumbilla Formation acts as a regional seal. Although effective local seals are present in the lower Eromanga Basin sequence, the presence of multiple stacked pools indicates the lack of effective sealing within that part of the sequence.

Structural and stratigraphic traps in the Cooper Basin formed during deposition and major structures formed during mid- to Late Triassic folding. Compaction and draping over earlier structures formed structures during deposition of the Eromanga Basin sequence. The Eromanga Basin, and Cooper Basin, were folded by the Late Cretaceous contraction (between the Cenomanian and Late Paleocene). Two additional events occurred in the Cainozoic. Compression during Oligocene to mid-Miocene and later uplift of the eastern highlands affected the basins by modifying the earlier structures, in generating local uplift and in changing the Eromanga Basin from a compaction driven groundwater system to a topographically driven groundwater system. Although exploration has focussed on structural traps, significant potential exists for stratigraphic traps in the Cooper and Eromanga Basins. The Nappamerri Trough has potential for deep basin gas.

Generation and expulsion occurred mainly in the mid-Cretaceous (Deighton & others, in preparation), with very minor generation in the Permian and minor generation in the Cainozoic (Figures 92, 93). Primary migration would have occurred at the time of generation, but it is clear that secondary migration has occurred (Lowe-Young & others, 1996); Cainozoic changes to basin structure and hydrodynamic regime were the main drivers of secondary migration. Migration into the Eromanga Basin sequence in the south and south-eastern margins of the Cooper Basin was via a 'window' where Triassic rocks were absent. Oil at Inland indicates, however, that breaching of the Triassic seal and significant lateral migration have occurred, unless it the oil in that field is entirely Jurassic Sourced.

Although the preservation time is small, the hydrocarbons have been subjected to modifying influences. Both Cooper Basin and Eromanga Basin hosted gas show evidence of water washing (Boreham & others, 2001) as do Eromanga Basin oils. For the Eromanga Basin, this is not surprising given that it is an active artesian basin. The Cooper Basin acts as a closed system but with movement of water out of the troughs and intermixing with Eromanga Basin waters (Webster & others, 2000). An understanding of the palaeo-hydrodynamic and current hydrodynamic regimes (Senior & Habermehl, 1980) is important for determining migration paths.

Although the Cooper and Eromanga Basins represent mature exploration basins, potential still exists for further discoveries. Traditional targets will continue to be drilled, but will be progressively smaller pools. New plays such as stratigraphic plays and fracture plays may provide an avenue for larger discoveries. The hydrocarbons discovered to date represent only a small fraction of the hydrocarbon generated. Although the petroleum system is leaky because of the open nature of the Eromanga Basin, sufficient hydrocarbons were generated to fill all traps available. Finding the traps that have retained hydrocarbons is the challenge.

REFERENCES

AGSO, 1996: *Phanerozoic Timescale Wallchart: Australian and International Biozonations*. Version **96-1**; compiled by the Australian Geological Survey Organisation Timescale Calibration and Development Project Team, Canberra.

ALEXANDER, E.M., GRAVESTOCK, D.I., CUBITT, C. & CHANEY, A., 1998: Chapter 6. Lithostratigraphy and environments of deposition. *In* Gravestock, D.I., Hibburt, J.E. & Drexel, J.F. (Editors): The petroleum geology of South Australia. Volume 4: Cooper Basin. *Primary Industries and Resources SA, Report Book* **98/9**, 69–115.

ALLEY, N.F. & LINDSAY, J.M., 1995 (Compilers): Chapter 10. Tertiary. *In* Drexel, J.F. & Preiss, W.V. (Editors): The geology of South Australia. Volume 2, The Phanerozoic. *Geological Survey of South Australia, Bulletin* **54**, 151–217.

ALMOND, C.S., 1983: Stratigraphic Drilling Report – GSQ Eromanga 1. *Queensland Government Mining Journal*, **84,** 359–368.

ALMOND, C.S., 1986: Stratigraphic drilling report – GSQ Thargomindah 1-1A. *Queensland Government Mining Journal*, **87**, 68–77.

AMBROSE, G., SUTTILL, R. & LAVERING, I., 1982: A review of the Early Cretaceous Murta member in the southern Eromanga Basin. *In* Moore, P.S. & Mount, T.J. (compilers): *Eromanga Basin Symposium, summary papers*. Geological Society of Australia and Petroleum Exploration Society of Australia, Adelaide.

AMBROSE, G., SUTTILL, R. & LAVERING, I., 1986: The geology and hydrocarbon potential of the Murta Member (Mooga Formation) in the southern Eromanga Basin. *In* Gravestock, D.I., Moore, P.S. & Pitt, G.M. (Editors): Contributions to the geology and hydrocarbon potential of the Eromanga Basin. *Geological Society of Australia, Special Publication* **12,** 71–84.

ANGEVINE, C.K., HELLER, P.C. & PAOLA, C., 1990: Quantitative sedimentary basin modelling. *AAPG Continuing Education Course Notes Series* **32**.

APAK, S.N., STUART , W.J. & LEMON, N.M., 1993: Structural - stratigraphic development of the Gidgealpa-Merrimelia-Innamincka Trend with implications for petroleum trap styles, Cooper Basin, Australia. *The APEA Journal,* **33**(1), 94–104.

APAK, S.N., STUART, W.J., LEMON, N.M. & WOOD, G., 1997: Structural evolution of the Permian – Triassic Cooper Basin, Australia: relation to hydrocarbon trap styles. *American Association of Petroleum Geologists, Bulletin* **81**, 533–555.

ARMSTRONG, J.D. & BARR, T.M., 1986: The Eromanga Basin, an overview of exploration and potential. *In* Gravestock, D.I., Moore, P.S. & Pitt, G.M. (Editors): Contributions to the geology and hydrocarbon potential of the Eromanga Basin. *Geological Society of Australia, Special Publication* **12**, 25–38.

BACKHOUSE, J., 1978: Palynological zonation of the Late Jurassic and Early Cretaceous sediments of the Yarragadee Formation, central Perth Basin, Western Australia. *Geological Survey of Western Australia, Report* **7**.

BACKHOUSE, J., 1988: Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia. *Geological Survey of Western Australia, Bulletin* **135**.

BACKHOUSE, J., 1991: Permian palynostratigraphy of the Collie Basin, Western Australia. *Review of Palaeobotany and Palynology*, **67**, 237–314.

BAIN, J.H.C. & DRAPER, J.J., 1997: North Queensland Geology. *Australian Geological Survey Organisation, Bulletin* **240**, and *Queensland Department of Mines and Energy, Queensland Geology* **9**.

BASIN STUDIES SUBPROGRAM, 1989: Hydrocarbon Generation Potential, Southern Eromanga Basin, Queensland. Queensland Department of Mines.

BATTERSBY, D.G., 1976: Cooper Basin gas and oil fields. *In* Leslie, R.B., Evans, H.J. & Knight, C.L. (Editors): Economic geology of Australia and Papua New Guinea, 3, Petroleum. *Australasian Institute of Mining and Metallurgy, Monograph Series* **7**, 321–368.

BOREHAM, C.J., HOPE, J.M. & HARTUNG-KAGI, B., 2001: Understanding source, distribution and preservation of Australian natural gas: a geochemical perspective. *The APPEA Journal*, **41**(1), 523–548.

BOREHAM, C.J. & SUMMONS, R.E., 1999: New insights into the active petroleum systems in the Cooper and Eromanga Basins, Australia. *The APPEA Journal*, **39**(1), 263–296.

BOULT, P.J., LANZILLI, E., MICHAELSEN, B.H., McKIRDY, D.M. & RYAN, M.J., 1998: A new model for the Hutton/Birkhead reservoir/seal couplet and associated Birkhead-Hutton(!) petroleum system. *The APPEA Journal,* **38**(1), 724–744.

BOWRING, S.A., ERWIN, D.H., JIN, Y.G., MARTIN, M.W., DAVIDEK, K. & WANG, W., 1998: U/Pb zircon geochronology and tempo of the end-Permian mass extinction. *Science*, **280**, 1039–1045.

BRAIN, T.J., 1987: GSQ Connemara 1 – Preliminary lithologic log and composite log. *Queensland Department of Mines, Record,* **1987/51**.

BURGER, D., 1973: Spore zonation and sedimentary history of the Neocomian, Great Artesian Basin, Queensland. *In* Glover, J.E. & Playford, G. (Editors): Mesozoic and Cainozoic Palynology: Essays in Honour of Isabel Cookson. *Geological Society of Australia, Special Publication* **4**, 87–118.

BURGER, D., 1974: Palynology of subsurface Lower Cretaceous strata in the Surat Basin, Queensland. *Bureau of Mineral Resources, Australia, Bulletin* **150**, 27–42.

BURGER, D., 1986: Palynology, cyclic sedimentation, and palaeo-environments in the Late Mesozoic of the Eromanga Basin. *Geological Society of Australia, Special Publication* **12**, 53–70.

BURGER, D., 1989: Stratigraphy, palynology, and palaeoenvironments of the Hooray Sandstone, eastern Eromanga Basin, Queensland and New South Wales. *Queensland Department of Mines, Report* **3**.

CAMPBELL, I.B. & O'DRISCOLL, E.S.T., 1989: Lineament-hydrocarbon associations in the Cooper and Eromanga Basin. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia. Proceedings of Petroleum Exploration Society of Australia, Society of Petroleum Engineers, Australian Society of Exploration Geophysicists (SA Branches)*, Adelaide, 295–313.

CARTWRIGHT, J. & LONERGAN, L., 1997: Seismic expression of layer-bound fault systems of the Eromanga and North Sea Basins. *Exploration Geophysics,* **28**(3), 323–331.

CASEY, J.N., 1959: New names in Queensland stratigraphy. *Australian Oil and Gas Journal,* **5**(12), 31–36.

CHANEY, A.J., CUBITT, C.J. & WILLIAMS, B.P.J., 1997: Reservoir potential of glacio-fluvial sandstones: Merrimelia Formation, Cooper Basin, South Australia. *The APPEA Journal,* **37**(1), 154–176.

CHANNON, G.J. & WOOD, G.R., 1989: Stratigraphy and hydrocarbon prospectivity of Triassic sediments in the northern Cooper Basin, South Australia. Department of Mines and Energy, Confidential Envelope, 8126.

CLAOUÉ-LONG, J.C., ZHANG, Z., MA, G. & DU, S., 1991: The age of the Permian-Triassic boundary. *Earth and Planetary Science Letters*, **105**, 182–190.

COOTE, S.M., 1987: GSQ Blackall 2 – Preliminary lithologic log and composite log. *Geological Survey of Queensland, Record* **1987/12**.

DAVID, T.W.E., 1950: *The geology of the Commonwealth of Australia, Volumes 1–3*. Edward Arnold & Co., London.

DAVIDSON, J.K., 1995: Globally synchronous compressional pulses in extensional basins: implications for hydrocarbon exploration. *The APEA Journal*, **35**(1), 169–188.

DAY, R.W., WHITAKER, W.G., MURRAY, C.G., WILSON, I.H. & GRIMES, K.G., 1983: Queensland Geology. A companion volume to the 1:2 500 000 scale geological map (1975). *Geological Survey of Queensland, Publication* **383**.

DEIGHTON, I., HILL, A.J., DRAPER, J.J. & BOREHAM, C.J., in preparation: Burial and thermal geohistory analyses of the Cooper/Eromanga Basins.

DEIGHTON, I. & HILL, A.J., 1998: Thermal and burial history. *In* Gravestock, D.I., Hibburt, J.E. & Drexel, J.F. (Editors): The petroleum geology of South Australia. Vol. 14: Cooper Basin. *South Australia, Department of Primary Industries and Resources, Report Book* **98/9**, 143–155.

DE JERSEY, N.J., 1975: Miospore zones in the Lower Mesozoic of south-eastern Queensland. *In* Campbell, K.S.W. (Editor): *Gondwana Geology.* Papers presented at the Third Gondwana Symposium, Canberra, Australia, 1973. Australian National University Press, Canberra, 159–172.

DE JERSEY, N.J. & McKELLAR, J.L., 1979: Composition of palynofloras and taxonomic notes on selected species from GSQ Hughenden 1-2R, 5 and 6 (northern Galilee Basin). Geological Survey of Queensland, Record 1979/28.

DE JERSEY, N.J. & McKELLAR, J.L., 1981: Triassic palynology of the Warang Sandstone (northern Galilee Basin) and its phytogeographic implications. *In* Cresswell, M.M. & Vella, P. (Editors): *Gondwana Five – Selected papers and abstracts of papers presented at the Fifth International Gondwana Symposium. Proceedings of the Fifth International Gondwana Symposium, Wellington, New Zealand, 1980.* A.A. Balkema, Rotterdam, 31–37.

DE JERSEY, N.J. & RAINE, J.I., 1990: Triassic and earliest Jurassic miospores from the Murihiku Supergroup, New Zealand. *New Zealand Geological Survey, Paleontological Bulletin* **62**.

DEMING, D., 1994: Overburden Rock, Temperature, and Heat Flow. *In* Magoon, L.B. & Dow, W.G., (Editors): The Petroleum System – From Source to Trap. *American Association of Petroleum Geologists, Memoir* **60**, 165–186.

DETTMANN, M.E., 1984a: Preliminary palynological report - Jackson No. 1. Mines Administration Pty Ltd Palynological Laboratory Report No. 13/141. Report held by the Department of Natural Resources and Mines Queensland as CR 12790.

DETTMANN, M.E., 1984b: Palynology – Munkarie South No. 1. Mines Administration Pty Ltd Palynological Laboratory Report No. 13/198 as Appendix VI in DIO Munkarie South 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 13312.

DETTMANN, M.E., 1985a: Biostratigraphy, palaeoenvironments, and hydrocarbon source potential of Early Jurassic to Early Cretaceous sediments in Petworth No. 1, 890 – 1537m. Appendix V in LEA Petworth 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15298.

DETTMANN, M.E., 1985b: Biostratigraphy, palaeoenvironments, and hydrocarbon source potential of Greymount No. 1, 1215 – 1658.4m. Appendix V in LEA Greymount 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15643.

DETTMANN, M.E., 1986: Biostratigraphy, palaeoenvironments, and hydrocarbon source potential of Palaeozoic and Early Mesozoic sediments in Byrock No. 1, 1813m – 2042m. Appendix VI in LEA Byrock 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15637.

DETTMANN, M.E., 1987a: Biostratigraphy, palaeoenvironments, and hydrocarbon source potential of Nymbah No. 1, 1636m – 1795m. Appendix VI in LEA Nymbah 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 16693.

DETTMANN, M.E., 1987b: Biostratigraphy, palaeoenvironments, and hydrocarbon source potential of Jurassic and Lower Cretaceous sediments in Monler No. 1, 3130ft – 4920ft. Appendix 9 in HEP Monler 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 16942.

DETTMANN, M.E., 1987c: Biostratigraphy, palaeoenvironments, and hydrocarbon source potential of Permian, Triassic, and Jurassic sediments in Earlstoun No. 1, 2007m – 2356.7m. Appendix VI in LEA Earlstoun 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 16948.

DETTMANN, M.E., 1987d: Biostratigraphy, palaeoenvironments, and hydrocarbon source potential of Colesmore No. 1, 1084m – 1895m. Appendix V in LEA Colesmore 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 16998.

DETTMANN, M.E., 1988: Cretaceous sediments in GSQ Thargomindah 3, 842.57m – 1306.85m. Report held by the Department of Natural Resources and Mines Queensland as CR 16964.

DETTMANN, M.E., FILATOFF, J. & PRICE, P.L., 1985: Palynology - Richie No. 1. Delhi Petroleum Pty Ltd Palynological Laboratory Report No. 13/196 as Appendix IV in DIO Richie 1 Well Completion Report.

Report held by the Department of Natural Resources and Mines Queensland as CR 13254.

DETTMANN, M.E. & JONES, M.J., 1985: Palynology - DIO Jackson No. 1. Mines Administration Pty Ltd Palynological Laboratory Report No. 13/14. Report held by the Department of Natural Resources and Mines Queensland as CR 14327.

DETTMANN, M.E. & PLAYFORD, G., 1969: Palynology of the Australian Cretaceous: a review. *In* Campbell, K.S.W. (Editor): *Stratigraphy and Palaeontology: Essays in honour of Dorothy Hill*. Australian National University Press, Canberra, 174–210.

DETTMANN, M.E. & PRICE, P.L., 1981a: Palynology – Naccowlah No. 1. Mines Administration Pty Ltd Palynological Laboratory Report No. 13/132 as Appendix XVII in DIO Naccowlah 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 9463.

DETTMANN, M.E. & PRICE, P.L., 1981b: Palynological report – Kyabra No. 2. Mines Administration Pty Ltd Palynological Laboratory Report No. 238/3 as Appendix 1 in LON Kyabra 2 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 10019.

DETTMANN, M.E. & PRICE, P.L., 1982: Palynology report – Eromanga No. 1. Mines Administration Pty Ltd Palynological Laboratory Report No. 263/1 as Appendix 3 in HOA Eromanga 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 11049.

DEWHURST, D.N., CARTWRIGHT, J.A. & LONERGAN, L., 1999: The development of polygonal fault systems by syneresis of colloidal sediments. *Marine and Petroleum Geology*, **16**, 793–810.

DICKINS, J.M. & MALONE, E.J., 1973: Geology of the Bowen Basin. *Bureau of Mineral Resources, Australia, Bulletin* **130**.

DOLBY, J.H. & BALME, B.E., 1976: Triassic palynology of the Carnarvon Basin, Western Australia. *Review of Palaeobotany and Palynology*, **22**, 105–168.

DRAPER, J.J. & FIELDING, C.R., 1997: Discussion. SHRIMP zircon dating of the Permian System of eastern Australia. *Australian Journal of Earth Sciences*, **44**, 535–538.

DREXEL, J.F. & PRIESS, W.V. (Editors), 1995: The geology of South Australia. Volume 2, The Phanerozoic. *South Australian Geological Survey, Bulletin*, **54**.

DREXEL, J.F., PRIESS, W.V. & PARKER, A.J. (Editors), 1993: The geology of South Australia. Volume 1, The Precambrian. *South Australian Geological Survey, Bulletin* **54**.

DUDGEON, M.J. & HOS, D.P.C., 1986a: Palynological report on Takyah No.1. ECL Australia Pty Ltd Report No. R1/86/2 as Appendix 8 *in* HEP Takyah 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15398.

DUDGEON, M.J. & HOS, D.P.C., 1986b: Palynological report on Toobunyah No. 1. ECL Australia Pty Ltd Report No. R1/86/3 as Appendix 10 in HEP Toobunyah 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15327.

DUDGEON, M.J. & HOS, D.P.C., 1986c: Palynostratigraphy, source rocks and maturity in Ethel-1. ECL Australia Pty Ltd Report No. R2/86/2 as Appendix E in AAP Ethel 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15507.

DUNSTAN, B., 1916: Appendix B. Queensland geological formations. *In* Harrap, G.: *A School Geography of Queensland*. Department of Public Instruction, Brisbane.

EADINGTON, P.J., HAMILTON, P.J. & GREEN, P.M., 1989: Hydrocarbon fluid history in relation to diagenesis in the Hutton Sandstone, south-west Queensland. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia*. *Proceedings of Petroleum Exploration Society of Australia, Society of Petroleum Engineers, Australian Society of Exploration Geophysicists (SA Branches*), Adelaide, 601–618.

ELLIOTT, L.G., 1993: Post-Carboniferous tectonic evolution of eastern Australia. *The APEA Journal*, **33**(1), 215–236.

ETHERIDGE, M.A. & O'BRIEN, G.W., 1994: Structural and tectonic evolution of the Western Australian marginal basin system. *PESA Journal*, **22**, 45–63.

EVANS, P.R., HOFFMANN, K.L., REMUS, D.A. & PASSMORE, V.L., 1990: Geology of the Eromanga sector of the Eromanga-Brisbane Geoscience Transect. *In* Finlayson, D.M. (Editor and Compiler): The Eromanga-Brisbane Geoscience Transect: a guide to basin development across Phanerozoic Australia in southern Queensland. *Bureau of Mineral Resources, Australia, Bulletin* **232**, 83–104.

EXON, N.F., 1966: Revised Jurassic to Lower Cretaceous stratigraphy in the south-east Eromanga Basin, Queensland. *Queensland Government Mining Journal,* **67**, 232–238.

EXON, N.F., 1976: Geology of the Surat Basin in Queensland. *Bureau of Mineral Resources, Australia, Bulletin* **166**.

EXON, N.F. & BURGER, D., 1981: Sedimentary cycles in the Surat Basin, and global changes of sea level. *BMR Journal of Australian Geology and Geophysics,* **6**, 153–159.

EXON, N.F. & SENIOR, B.R., 1976: The Cretaceous geology of the Eromanga and Surat Basins. *BMR Journal,* **1**, 33–50.

FAIRBURN, W.A., 1989: The geometry of Toolachee Unit 'C' fluvial sand trends, Moomba Field, Permian Cooper Basin, South Australia. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia*. *Proceedings of Petroleum Exploration Society of Australia, Society of Petroleum engineers, Australian Society of Exploration Geophysicists (SA Branches)*, Adelaide, 239–250.

FAIRBURN, W.A., 1992: Geometry of reservoir trends in the Epsilon Formation sands, southern Cooper Basin, South Australia. *The APEA Journal,* **32**(1), 339–358.

FIELDING, C.R., 1996: Mesozoic sedimentary basins and resources in eastern Australia – a review of current understanding. *In* Mesozoic 96. Mesozoic Geology of the Eastern Australia Plate Conference, Brisbane, 1996. *Geological Society of Australia, Extended Abstracts* **43**, 180–185.

FILATOFF, J., 1985: Palynology report – Jackson 6. Delhi Petroleum Pty Ltd Palynological Laboratory Report No. 13/183 as Appendix VI in DIO Jackson 6 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 12466.

FILATOFF, J., 1986a: Palynology – Hooley 1. Delhi Petroleum Pty Ltd Palynological Report No. 13/327 as Appendix VI in DIO Hooley 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 14968.

FILATOFF, J., 1986b: Palynology report – Doonmulla No. 1. Delhi Petroleum Pty Ltd Palynological Laboratory Report No. 13/380 as Appendix IV in DIO Doonmulla 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15084.

FILATOFF, J., 1986c: Palynology – Mount Howitt No. 2, Early Cretaceous Section. Delhi Petroleum Pty Ltd Palynological Laboratory Report No. 13/386 as Appendix VII in DIO Mount Howitt 2 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15141.

FILATOFF, J., 1987: Palynology – Toby No. 1. CSR Oil & Gas Division, Palynology Facility, Palynological Laboratory Report No. 522/1 as Appendix IX in DIO Toby 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 16690.

FILATOFF, J. & PRICE, P.L., 1981: Palynology – Wareena No. 1. Mines Administration Pty Ltd Palynological Laboratory Report No. 13/131 as Appendix VIII in DIO Wareena 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 9549.

FILATOFF, J. & PRICE, P.L., 1987: Palynology – Marradong No. 1. CSR Oil & Gas Division, Palynology Facility, Palynological Laboratory Report No. 451/1 as Appendix VI in DIO Marradong 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 16707.

FILATOFF, J. & PRICE, P.L., 1988: A pteridacean spore lineage in the Australian Mesozoic. *In* Jell, P.A. & Playford, G. (Editors): Palynological and palaeobotanical studies in honour of Basil E. Balme. *Memoirs of the Association of Australasian Palaeontologists*, **5**, 89–124.

FILATOFF, J. & PRICE, P.L., 1990: Ipundu North #1 – Palynostratigraphy, Source Potential and Maturation. APG Consultants Report No. 398/5 as Appendix 10 in AMP Ipundu North 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 21165.

FINLAYSON, D.M., LEVEN, J.H., WAKE-DYSTER, K.D. & JOHNSTONE, D.W., 1990: A crustal image under the basins of southern Queensland along the Eromanga–Brisbane Geoscience Transect. *In* Finlayson, D.M. (Editor and Compiler): The Eromanga-Brisbane Geoscience Transect: a guide to basin development across Phanerozoic Australia in southern Queensland. *Bureau of Mineral Resources, Australia, Bulletin* **232,** 153–176.

FOSTER, C.B. & WATERHOUSE, J.B., 1988: The *Granulatisporites confluens* Oppel-zone and Early Permian marine faunas from the Grant Formation on the Barbwire Terrace, Canning Basin, Western Australia. *Australian Journal of Earth Sciences*, **35**, 135–157.

GALLAGHER, K., 1990. Permian to Cretaceous subsidence history along the Eromanga-Brisbane Geoscience transect. *In* Finlayson, D.M. (Editor & Compiler): The Eromanga - Brisbane geoscience transect: a guide to basin development across Phanerozoic Australia in southern Queensland. *Bureau of Mineral Resources, Australia, Bulletin* **232**, 133–152.

GALLAGHER, K. & LAMBECK, K., 1989. Subsidence, sedimentation and sea level changes in the Eromanga Basin Australia. *Basin Research*, **2**, 115–131.

GATEHOUSE, C.G., 1972: Formations of the Gidgealpa Group in the Cooper Basin. *Australasian Oil and Gas Review*, **18**(2), 10–15.

GATEHOUSE, C.G., 1986: The geology of the Warburton Basin in South Australia. *Australian Journal of Earth Science*s, **33**, 161–180.

GATEHOUSE, C.G., FANNING, C.M. & FLINT, R.B., 1995: Geochronology of the Big Lake Suite, Warburton Basin, north-eastern South Australia. *South Australia, Geological Survey. Quarterly Geological Notes*, **128**, 8–16.

GEOLOGICAL SURVEY OF QUEENSLAND, 1985: Eromanga Basin lithostratigraphic nomenclature. *Queensland Government Mining Journal*, **86**, 446.

GERRARD, M.J. 1964: Well completion report AOP Westbourne 1. Report held by Queensland Department of Natural Resources and Mines as CR1402.

GILBY, A.R. & MORTIMORE, I.R., 1989: The prospects for Eromanga oil accumulations in the northern Cooper Basin region, Australia. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia. Proceedings of Petroleum Exploration Society of Australia, Society of Petroleum engineers,* Australian Society of Exploration Geophysicists (SA Branches), Adelaide, 391–403.

GRAVESTOCK, D.I., 1998: Stratigraphic frameworks for correlation. *In* Gravestock, D.I., Hibburt, J.E. & Drexel, J.F. (Editors): The petroleum geology of South Australia. Vol. 4: Cooper Basin. *Primary Industries and Resources SA, Report Book* **98/9**, 117–128.

GRAVESTOCK, D.I., CALLEN, R.A., ALEXANDER, E.M. & HILL, A.J., 1995: *Strzelecki South Australia*. 1:250 000 Geological Series – Explanatory Notes Mines and Energy South Australia.

GRAVESTOCK, D.I. & JENSEN-SCHMIDT, B., 1998: Structural setting. *In* Gravestock, D.I., Hibburt, J.E. & Drexel, J.F. (Editors): The petroleum geology of South Australia. Vol. 14: Cooper Basin. *South Australia, Department of Primary Industries and Resources, Report Book* **98/9**, 47–67.

GRAY, A.R.G., 2000: Amendments to the stratigraphy of the Early Triassic Arrabury Formation in the Cooper Basin. *Queensland Government Mining Journal*, **101** (April), 32–38.

GRAY, A.R.G., GREEN, P.M., BRAIN, T.J. & SCOTT, S.G., 1994: The petroleum potential of the northern Windorah Trough, Queensland. *Queensland Government Mining Journal*, **95**, 13–27.

GREEN, P.M. 1997: Cooper–Eromanga Basins Project Progress Report. *Queensland Oil and Gas (Queensland Government Mining Journal July),* 39.

GREEN, P.M., BRAIN, T.J., JOHN, B.H. & ALMOND, C.S., 1989: Subsurface correlation of the Jurassic rocks of the southern Eromanga Basin, Queensland. *Queensland Department of Mines, Record* **1989/1**.

GREEN, P.M. & McKELLAR, J.L., 1996a: Stratigraphic relationships between latest Triassic - Early Cretaceous basins of southern Queensland. *In* Mesozoic 96. Mesozoic Geology of the Eastern Australia Plate Conference, Brisbane, 1996. *Geological Society of Australia, Extended Abstracts* **43**, 218–223.

GREEN, P.M. & McKELLAR, J.L., 1996b: Relationships between latest Triassic - Early Cretaceous strata in the Clarence-Moreton, Surat and Eromanga Basins. *Queensland Government Mining Journal*, **97**, 67–71.

GRIMES, K.G., 1980: The Tertiary geology of north Queensland. *In* Henderson, R.A. & Stephenson, P.J. (Editors): *The Geology and Geophysics of Northeastern Australia*. Geological Society of Australia, Queensland Division, Brisbane, 329–347.

GUNTHER, L.M. & DIXON, O., 1988: Stratigraphic drilling report – GSQ Thargomindah 3. *Queensland Department of Mines, Record* **1988/7**.

GURNIS, M., MUELLER, R.D., & MORESI, L., 1998: Dynamics of Cretaceous vertical motion of Australia and the Australian-Antarctic discordance, *Science* **279**, 1499–1504.

HAIG, D.W., 1979: Cretaceous foraminiferal biostratigraphy of Queensland. *Alcheringa*, **3**, 171–187.

HANNAH, M.J., 1988: Palynological analysis of Cacoory-1, Wilparoo Block, A.T.P. 259P – Queensland. Esso Australia Ltd Palaeontological Report 1988/3 as Appendix IV in DIO Cacoory 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 17944.

HANNAH, M.J., 1990: Palynological analysis of Delhi Petroleum Yanbee-1, Aquitaine B Block, ATP 259P, Queensland. Esso Australia Ltd Palaeontology Report 1990/16 in DIO Yanbee 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 21174.

HAWKINS, P.J., ALMOND, C.S., CARMICHAEL, D.C., SMITH, R.J. & WILLIAMS, L.J., 1989: Kerogen characterisation, and organic and mineral diagenesis of the potential source rocks in Jurassic units, southern Eromanga Basin, Queensland. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia*. *Proceedings of Petroleum Exploration Society of Australia*, Society of Petroleum engineers, Australian Society of Exploration Geophysicists (SA Branches), Adelaide, 583–599.

HAWKINS, P.J. & GREEN, P.M., 1993: Exploration results, hydrocarbon potential and future strategies for the northern Galilee Basin. *The APEA Journal*, **33**(1), 280–296.

HEATH, R., 1989: Exploration in the Cooper Basin. *The APEA Journal*, **29**(1), 366–378.

HEATH, R., MCINTYRE, S. & GIBBINS, N., 1989: A Permian origin for Jurassic reservoired oil in the Eromanga Basin. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia*. *Proceedings of Petroleum Exploration Society of Australia*, Society of Petroleum Engineers, Australian Society of Exploration Geophysicists (SA Branches), Adelaide, 405–416.

HELBY, R., 1973: Review of Late Permian and Triassic palynology of New South Wales. *Geological Society of Australia, Special Publication* **4**, 141–155.

HELBY, R., MORGAN, R. & PARTRIDGE, A.D., 1987: A palynological zonation of the Australian Mesozoic. *In* Jell, P.A. (Editor): Studies in Australian Mesozoic palynology. *Memoirs of the Association of Australasian Palaeontologists*, **4**, 1–94.

HILL, D. & DENMEAD, A.K., (Editors), 1960: The Geology of Queensland. *Journal of the Geological Society of Australia*, **7**.

HILLIS, R.R., MORTON, J.G.G., WARNER, D.S. & PENNEY, R.K., 2001: Deep basin gas: a new exploration paradigm in the Nappamerri Trough, Cooper Basin, South Australia. *The APPEA Journal*, **41**(1), 185–200.

HOFFMANN, K.L., 1989: The influence of pre-Jurassic tectonic regimes on the structural development of the southern Eromanga Basin, Queensland. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia*. *Proceedings of Petroleum Exploration Society of Australia*, Society of Petroleum Engineers, Australian Society of Exploration Geophysicists (SA Branches), Adelaide, 315–328.

HOS, D.P.C., 1985a: Palynological report on Tintaburra No. 7. ECL Australia Pty Ltd Report No. R10/85/1 as Appendix 11 in HEP Tintaburra 7 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15078.

HOS, D.P.C., 1985b: Palynological report on Kooroopa No. 1. ECL Australia Pty Ltd Report No. R11/85/1 as Appendix 11 in HEP Kooroopa 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15070.

HOS, D.P.C., 1985c: Palynological report on Minedella No. 1. ECL Australia Pty Ltd Report No. R11/85/2 as Appendix 8 in HEP Kooroopa 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15162.

HOS, D.P.C., 1985d: Palynological report on Talgeberry No. 2. ECL Australia Pty Ltd Report No. R11/85/4 as Appendix 11 in HEP Talgeberry 2 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15242.

HOS, D.P.C., 1988a: Palynology report on samples from 2466′ – 3530′ (751.6 – 1076m), Mugginanullah No. 1. International Stratigraphic Consultants Pty Ltd Report No. R2/88/7 as Appendix 8 in HEP Mugginanullah 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 17720.

HOS, D.P.C., 1988b: Palynology report on samples from Warcanyah No. 1, 1792m to 2423.5m. International Stratigraphic Consultants Pty Ltd Report No. R3/88/1 as Appendix 7 in NMX Warcanyah 1 Final Well Report. Report held by the Department of Natural Resources and Mines Queensland as CR 17722.

HUNT, J.W., HEATH, R.S. & MCKENZIE, P.F., 1989: Thermal maturity and other geological controls on the distribution and composition of Cooper Basin hydrocarbons. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia*. *Proceedings of Petroleum Exploration Society of Australia*, Society of Petroleum Engineers, Australian Society of Exploration Geophysicists (SA Branches), Adelaide, 510–523.

IDNURM, M. & SENIOR, B.R., 1978: Palaeomagnetic ages of Late Cretaceous and Tertiary weathered profiles in the Eromanga Basin, Queensland. *Palaeogeography, Paleoclimatology, Palaeoecology*, **24**, 263–277.

ISLAM, M.A., DUDGEON, M.J. & HOS, D.P.C., 1986: Palynostratigraphy, source rocks and maturity in Fraserburgh-1. ECL Australia Pty Ltd Report No. R3/86/1 as Appendix C in AAP Fraserburgh 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15408.

JENKINS, C.C., 1989: Geochemical correlation of source rocks and crude oils from the Cooper and Eromanga Basins. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia*. *Proceedings of Petroleum*

Exploration Society of Australia, Society of Petroleum Engineers, Australian Society of Exploration Geophysicists (SA Branches), Adelaide, 525–540.

JOHN, B.H., 1985: Stratigraphic drilling report – GSQ Wyandra 1 and GSQ Quilpie 1. *Queensland Government Mining Journal*, **87**, 29–43.

JOHN, B.H., & ALMOND, C.S., 1987. Lithostratigraphy of the lower Eromanga Basin sequence in south-west Queensland. *The APEA Journal*, **27**(1), 196–214.

JONES, M.J. & WOOD, G.R., 1986: Palynology – Macadama No. 1. Delhi Petroleum Pty Ltd Palynological Report No. 408/1 as Appendix VII in DIO Macadama 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15411.

KAPEL, A.J., 1966: The Cooper's Creek Basin. *The APEA Journal,* **6**(1), 71–75.

KAPEL, A.J., 1972. The geology of the Patchawarra area, Cooper Basin. *The APEA Journal,* **12**(1), 53–56.

KHORASANI, G.K., 1987: Recent geochemical evaluation of the central Eromanga Basin. *The APEA Journal*, **27**(1), 106–111.

KLOOTWIJK, C., 1996: Phanerozoic configurations of Greater Australia: Evolution of the North West Shelf. Part Two: Palaeomagnetic and geologic constraints on reconstructions. *Australian Geological Survey Organisation, Record* **1996/52**.

KORSCH, R.J., BOREHAM, C.J., TOTTERDELL, J.M., SHAW, R.D. & NICOLL, M.G., 1998: Development and petroleum resource evaluation of the Bowen, Gunnedah and Surat Basins, eastern Australia. *The APPEA Journal*, **38**(1), 199–236.

KUANG, K.S., 1985: History and style of the Cooper–Eromanga Basin structures. *Australian Society of Exploration Geophysicists, Bulletin* **16**(2/3), 245–248.

LANG, S.C., KASSAN, J., BENSON, J.M., GRASSO, C.A. & AVENELL, L.C., 2000: Applications of modern and ancient geological analogues in characterisation of fluvial and fluvial-lacustrine deltaic reservoirs in the Cooper Basin. *The APPEA Journal*, **40**(1), 393–415.

LANZILLI, E. & BOULT, P.J., 1996: The Hutton Sandstone to Birkhead Formation transition, Gidgealpa southern dome: showing an associated unconformity and provenance change from craton derived to volcanic-arc-derived sediment. *In* Mesozoic 96. Mesozoic Geology of the Eastern Australia Plate Conference, Brisbane, 1996. *Geological Society of Australia, Extended Abstracts* **43**.

LOWE-YOUNG, B.S., MACKIE, S.I., & HEATH, R.S., 1996: Geological controls on hydrocarbon accumulations in the Eromanga Basin, south west Queensland – a petroleum systems perspective. *In* Mesozoic 96. Mesozoic Geology of the Eastern Australia Plate Conference, Brisbane, 1996. *Geological Society of Australia, Extended Abstracts* **43**, 356–365.

MacPHAIL, M.K., ALLEY, N.F., TRUSWELL, E.M. & SLUITER, I.R.K., 1994: Early Tertiary vegetation: evidence from spores and pollen. *In* Hill, R.S. (Editor): *History of the Australian vegetation. Cretaceous to Recent*. Cambridge University Press, Cambridge, 189–261.

MAGOON, L.B. & DOW, W.G., 1994: The Petroleum System – From Source to Trap. *American Association of Petroleum Geologists, Memoir* **60**.

MARTIN, C.A., 1967: The Gidgealpa and Merrimelia Formations in the Cooper's Creek Basin. *Australasian Oil and Gas Journal,* **14**(2), 29–35.

McKELLAR, J.L., 1977a: Palynostratigraphy of core samples from the Hughenden 1:250 000 Sheet area, northern Galilee and Eromanga Basins. *Queensland Government Mining Journal*, **78**, 393–399.

McKELLAR, J.L., 1977b: Miospore assemblages from GSQ Hughenden 2R, 3-4R, 5 and 6. Geological Survey of Queensland, Record 1977/1.

McKELLAR, J.L., 1996: Palynofloral and megafloral indications of palaeoclimate in the Late Triassic, Jurassic, and Early Cretaceous of southeastern Queensland. *In* Mesozoic 96. Mesozoic Geology of the Eastern Australia Plate Conference, Brisbane, 1996. *Geological Society of Australia, Extended Abstracts* **43**, 366–373.

McKELLAR, J.L., 1998: Late Early to Late Jurassic palynology, biostratigraphy and palaeogeography of the Roma Shelf area, north-western Surat Basin, Queensland, Australia (including phytogeographic-palaeoclimatic implications of the *Callialasporites dampieri* and *Microcachryidites* microfloras in the Jurassic–Early Cretaceous of Australia, based on an overview assessed against a background of floral change and apparent true polar wander in the preceding late Palaeozoic–early Mesozoic). Department of Earth Sciences, University of Queensland, PhD Thesis, Volumes 1–3 .

McKELLAR, J.L. (in press): Late Early to Late Jurassic palynology, biostratigraphy and palaeogeography of the Roma Shelf area, north-western Surat Basin, Queensland, Australia (Including phytogeographic-palaeoclimatic implications of the *Callialasporites dampieri* and *Microcachryidites* microfloras in the Jurassic–Early Cretaceous of Australia: an overview assessed against a background of floral change and apparent true polar wander in the preceding late Palaeozoic–early Mesozoic). *Queensland Geology*.

McMINN, A., 1983: The Toolebuc Formation in the Eromanga Basin of New South Wales. *Quarterly Notes of the Geological Survey of New South Wales*, **50**, 1–7.

McMINN, A. & BURGER, D., 1986: Palynology and palaeoenvironments of the Toolebuc Formation (*sensu lato*) in the Eromanga Basin. *In* Gravestock, D.I., Moore, P.S. & Pitt, G.M. (Editors): Contributions to the geology and hydrocarbon potential of the Eromanga Basin. *Geological Society of Australia, Special Publication* **12**, 139–154.

MEIXNER, A.J., BOUCHER, R.K., YEATES, A.N., GUNN, P.J., RICHARDSON, L.M. & FREARS, R.A., 1999: Interpretation of geophysical and geological data sets, Cooper Basin region, South Australia. *Australian Geological Survey Organisation, Record* **1999/22**.

MEIXNER, A.J., GUNN, P.J., BOUCHER, R.K., YEATES, A.N., RICHARDSON, L.M. & FREARS, R.A., 2000: The nature of the basement to the Cooper Basin region, South Australia. *Exploration Geophysics*, **31**, 24–32.

MILNE, L., 1985: Palynostratigraphy and source rock assessment of Conbar No. 1. Appendix 10 in POG Conbar 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 16114.

MILNE, L., 1986: Palynostratigraphy and source rock assessment of Teedeeldee 1. Appendix 7 in POG Teedeeldee 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15273.

MOLLAN, R.G., FORBES, V.R., JENSEN, A.R., EXON, N.F. & GREGORY, C.M., 1972: Geology of the Eddystone and Taroom 1:250 000 Sheet areas and western part of the Mundubbera 1:250 000 Sheet area. *Bureau of Mineral Resources, Australia, Report* **142**.

MOORE, P.S., 1986: Jurassic and Triassic stratigraphy and hydrocarbon potential of the Poolowanna Trough (Simpson Desert region), northern South Australia. *In* Gravestock, D.I., Moore, P.S. & Pitt, G.M. (Editors): Contributions to the geology and hydrocarbon potential of the Eromanga Basin. *Geological Society of Australia, Special Publication* **12**, 39–51.

MOORE, P.S., PITT, G.M. & DETTMANN, M.E., 1986: The Early Cretaceous Coorikiana Sandstone and Toolebuc Formation: their recognition and stratigraphic relationship in the south-western Eromanga Basin. *In* Gravestock, D.I., Moore, P.S. & Pitt, G.M. (Editors): Contributions to the geology and hydrocarbon potential of the Eromanga Basin. *Geological Society of Australia, Special Publication* **12,** 97–114.

MORGAN, R., 1977: New dinoflagellate zones and a depositional model for the Great Australian Basin. *Quarterly Notes of the Geological Survey of New South Wales*, **28**, 10–18.

MORGAN, R., 1980a: Palynostratigraphy of the Australian Early and Middle Cretaceous. *Memoirs of the Geological Survey of New South Wales, Palaeontology*, **18**.

MORGAN, R., 1980b: Eustacy in the Australian Early and Middle Cretaceous. *Geological Survey of New South Wales, Bulletin* **27**.

MORGAN, R., 1984a: Palynology and visual geochemistry of Hudbay Bodalla South No. 1, Eromanga Basin. Appendix VIII in HOA Bodalla South 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 13872.

MORGAN, R., 1984b: Palynology and visual geochemistry of Hudbay Berellem No. 1, Eromanga Basin. Appendix VII in HOA Berellem 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 14197.

MORGAN, R., 1985a: Palynology and visual geochemistry of Hudbay Bodalla South No. 2, Eromanga Basin. Appendix VII in LEA Bodalla South 2 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 14142.

MORGAN, R., 1985b: Palynology of Pancontinental Honeytin-1, Eromanga Basin. Appendix C in PPL Honeytin 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15020.

MORGAN, R., 1986a: Palynology of four core samples, Offshore Oil Mirintu-1, Eromanga Basin. Report held by the Department of Natural Resources and Mines Queensland as CR 15375.

MORGAN, R., 1986b: Palynology of Pancontinental Toolerah Creek-1, Eromanga Basin. Appendix K in PPL Toolerah Creek 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15390.

MORGAN, R., 1986c: Palynology of four side-wall core samples, Offshore Oil Chesson-1, Eromanga Basin. Appendix 6 in OON Chesson 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15649.

MORGAN, R., 1986d: Palynology of four side-wall core samples, Offshore Oil Goallah-1, Eromanga Basin. Appendix 4 in OON Goallah 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15666.

MORGAN, R., 1987a: Palynology of Pancontinental Bundeena-1, Eromanga Basin. Appendix D in PPL Bundeena 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 16791.

MORGAN, R., 1987b: Palynology of Hartogen Toobunyah-5, Eromanga Basin. Appendix 9 in HEP Toobunyah 5 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 20565.

MORGAN, R., 1989: Palynology of Command Dilkera-2, Eromanga Basin. Appendix 9 in CDP Dilkera 2 Final Well Report. Report held by the Department of Natural Resources and Mines Queensland as CR 22044.

MORGAN, R. & MILNE, L., 1984: Palynology and visual geochemistry of Hudbay Kyra No. 1, Eromanga Basin. Appendix V in HOA Kyra 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 14352.

MORGAN, R. & MILNE, L., 1985: Palynology and visual geochemistry of Lasmo Mount Bellalie No. 1, Eromanga Basin. Appendix VI in HOA Mount Bellalie 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 14566.

MORTON, J.G.G., 1989: Petrophysics of Cooper Basin reservoirs in South Australia. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia*. *Proceedings of Petroleum Exploration Society of Australia*, *Society of Petroleum Engineers, Australian Society of Exploration Geophysicists (SA Branches)*, Adelaide, 153–163.

MORTON, J.G.G. & GATEHOUSE, C.G., 1985: A revision of the Toolachee and Daralingie Formations, Cooper Basin, South Australia. *Geological Survey of South Australia, Quarterly Geological Notes* **94**, 8–15.

MOUNT, T. J., 1981: Dullingari North 1 and oil discovery in the Murta Member of the Eromanga Basin. *The APEA Journal,* **21**(1), 71–77.

MOUSSAVI-HARAMI, R., 1996: Burial history of the Cooper Basin region in South Australia. *PESA Journal,* **24**, 57–76.

MURRAY, C.G., 1994: Basement cores from the Tasman Fold Belt System beneath the Great Artesian Basin in Queensland. *Queensland Geological Record* **1994/10**.

MUSAKTI, O.T., 1997: Regional sequence stratigraphy of a non-marine intracratonic succession; the Hooray Sandstone and Cadna-owie Formation, Eromanga Basin Queensland. Masters Thesis, Queensland University of Technology.

NAKANISHI, T. & LANG, S.C., 2001: The search for stratigraphic traps goes on — visualisation of fluvial-lacustrine successions in the Moorari 3D Survey, Cooper–Eromanga Basin. *The APPEA Journal*, **41**(1), 115–138.

NANSON, G.C., YOUNG, R.W., PRICE, D.M. & RUST, B.R., 1988: Sratigraphy, Sedimentology, and Late-Quaternary Chronology of the Channel Country of Western Queensland. *In* Warner, R.F. (Editor): *Fluvial Geomorphology of Australia*. Academic Press, Australia, 151–175.

NELSON, A.W., 1985: Tectonics of the Jackson-Naccowlah area, Cooper–Eromanga Basin, south-west Queensland, and their implications for hydrocarbon accumulations. *The APEA Journal*, **25**(1), 85–94.

NUGENT, O.W., 1969: Sedimentation and petroleum potential of the Jurassic sequence in the south-western Great Artesian Basin. *The APEA Journal* **9**(1), 97–107.

OZIMIC, S., 1986: The geology and petrophysics of the Toolebuc Formation and its time equivalents, Eromanga and Carpentaria Basins. *In* Gravestock, D.I., Moore, P.S. & Pitt, G.M. (Editors): Contributions to the geology and hydrocarbon potential of the Eromanga Basin. *Geological Society of Australia, Special Publication* **12**, 119–137.

PAPALIA, N., 1969: The Nappamerri Formation. *The APEA Journal*, **9**(1), 108–110.

PARTRIDGE, A.D., 1988a: Palynological analysis of Delhi Petroleum Wicho-1, Aquitaine 'B' Block, ATP 259P, south-west Queensland. Esso Australia Ltd Palaeontological Report 1988/5 as Appendix VI in DIO Wicho 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 17517.

PARTRIDGE, A.D., 1988b: Palynological analysis of Delhi Petroleum Cuddapan-1, Aquitaine 'C' Block, ATP 259P, south-west Queensland. Esso Australia Ltd Palaeontological Report 1988/10 as Appendix VII in DIO Cuddapan 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 17705.

PARTRIDGE, A.D., 1989a: Palynological analysis of Delhi Petroleum Mooliampah West-1, Total 1966 Block, ATP 259P, south-west Queensland. Esso Australia Ltd Palaeontology Report 1989/6 as Appendix XII in DIO Mooliampah West 1 Well Completion Report; also Appendix VII: Provisional palynology report No. 2, Mooliampah West-1. Report held by the Department of Natural Resources and Mines Queensland as CR 20113.

PARTRIDGE, A.D., 1989b: Palynological analysis of Delhi Petroleum Munro-1, ATP 259P, south-west Queensland. Esso Australia Ltd Palaeontology Report 1989/25 as Appendix VI in DIO Munro 1 Well Completion Report. Report held by Department of Natural Resources and Mines Queensland as CR 18087.

PARTRIDGE, A.D., 1989c: Palynological analysis of Delhi Petroleum Munro-3, ATP 259P, south-west Queensland. Esso Australia Ltd Palaeontology Report 1989/26 as Appendix IV in DIO Munro-3 Well Completion Report. Report held by Department of Natural Resources and Mines Queensland as CR 20142.

PASSMORE, V.L. & BURGER, D., 1986: Effects of eustatic sea-level changes on Early Jurassic deposition in the eastern Eromanga Basin. *Sediments Down Under. 12th International Sedimentological Congress, Canberra 1986*, 237.

PATEN, R.J., 1964: The Tertiary geology of the Boulia region, western Queensland. *Bureau of Mineral Resources, Australia, Report* **77**.

PATON, I.M., 1986: The Birkhead Formation – Jurassic petroleum reservoir. *In* Gravestock, D.I., Moore, P.S. & Pitt, G.M. (Editors): Contributions to the geology and hydrocarbon potential of the Eromanga Basin. *Geological Society of Australia, Special Publication* **12**, 195–201.

PETROLEUM RESOURCES ASSESSMENT AND DEVELOPMENT SUBPROGRAM, 1990: Petroleum Resources of Queensland (Review to June 30, 1989). *Queensland Resource Industries Review Series*, Department of Resource Industries, Queensland.

POWELL, T.G, BOREHAM, C.J., McKIRDY, D.M., MICHAELSEN, B.H. & SUMMONS, R.E., 1989: Petroleum geochemistry of the Murta Member, Mooga Formation, and associated oils, Eromanga Basin. *The APEA Journal,* **29**(1), 114–129.

POWIS, G.D., 1989: Revision of Triassic stratigraphy at the Cooper Basin to Eromanga Basin transition. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia. Proceedings of Petroleum Exploration Society of Australia, Society of Petroleum Engineers, Australian Society of Exploration Geophysicists (SA Branches)*, Adelaide, 265–277.

PRICE, P.L., 1979: Palynology – Wackett No. 1. Appendix IVa in DIO Wackett 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 7415.

PRICE, P.L., 1997: Permian to Jurassic palynostratigraphic nomenclature of the Bowen and Surat Basins. *In* Green, P.M. (Editor): The Surat and Bowen Basins, south-east Queensland. *Queensland Minerals and Energy Review Series*, 137–178.

PRICE, P.L., FILATOFF, J., WILLIAMS, A.J., PICKERING, S.A. & WOOD, G.R., 1985: Late Palaeozoic and Mesozoic palynostratigraphical units. CSR Oil & Gas Division, Palynology Facility, Palynological Laboratory Report 274/25. Report held by the Department of Natural Resources and Mines Queensland as CR 14012.

REEVES, F., 1947: Geology of the Roma district, Australia. *American Association of Petroleum Geologists, Bulletin* **34**, 1341–1371.

RETALLACK, G.J., 1995: Permian-Triassic life crisis on land. *Science*, **267**, 77–80.

RETALLACK, G.J., 1999: Postapocalyptic greenhouse paleoclimate revealed by earliest Triassic paleosols in the Sydney Basin, Australia. *Geological Society of America, Bulletin* **111**, 52–70.

ROBERTS, D.C., CARROLL, P.G. & SAYERS, J., 1990: The Kalladeina Formation – A Warburton Basin Cambrian carbonate play. *The APEA Journa*l, **30**(1), 166–184.

ROBERTS, J., CLAOUÉ-LONG, J.C. & FOSTER, C.B., 1996: Shrimp zircon dating of the Permian System of eastern Australia. *Australian Journal of Earth Sciences*, **43**, 401–421.

ROBERTS, J., CLAOUÉ-LONG, J.C. & FOSTER, C.B., 1997: Reply. SHRIMP zircon dating of the Permian System of eastern Australia. *Australian Journal of Earth Sciences*, **44**, 535-538.

RODDA, J.S. & PASPALIARIS, T.G., 1989: Tirrawarra and Moorari oil fields enhanced oil recovery schemes — further developments. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia.*

Proceedings of the Cooper and Eromanga Basins Conference, Adelaide. Petroleum Exploration Society of Australia, Society of Petroleum Engineers, Australian Society of Exploration Geophysicists (SA Branches), 121–130.

RODGERS, J., WEHR, F.L. & HUNT, J.W., 1991: Tertiary uplift estimations from velocity data in the Eromanga Basin. *Exploration Geophysics*, **22**, 321–324.

SAJJADI, F. & PLAYFORD, G. (in press, a): Systematic and stratigraphic palynology of Late Jurassic — earliest Cretaceous strata of the Eromanga Basin, Queensland, Australia: Part One. *Palaeontographica, Abteilung B*.

SAJJADI, F. & PLAYFORD, G. (in press, b): Systematic and stratigraphic palynology of Late Jurassic — earliest Cretaceous strata of the Eromanga Basin, Queensland, Australia: Part Two. *Palaeontographica, Abteilung B*.

SCHEIBNER, E., 1974: *Tectonic Map of New South Wales, scale 1:1 000 000*. Geological Survey of New South Wales, Sydney.

SCHEIBNER, E., 1996: Geology of New South Wales — Synthesis. Volume 1. Structural Framework. *Geological Survey of New South Wales, Memoir Geology*, **13**(1).

SCHEIBNEROVA, V., 1986 : Marine Cretaceous of the Great Australian Basin — foraminiferal and palynological zonations reconciled. *In* Gravestock, D.I., Moore, P.S. & Pitt, G.M. (Editors): Contributions to the geology and hydrocarbon potential of the Eromanga Basin. *Geological Society of Australia, Special Publication* **12**, 115–118.

SCOTT, S.G., KOZAK, A. & BRAIN, T.J., 2000: Petroleum Operations, Production and Reserves – Annual Report 1997/98. *Queensland Minerals and Energy Review Series.*

SENIOR, B.R., EXON, N.F. & BURGER, D., 1975: The Cadna-owie and Toolebuc Formations in the Eromanga Basin, Queensland. *Queensland Government Mining Journal*, **76**, 445–455.

SENIOR, B.R. & HABERMEHL, M.A., 1980: Structure, hydrodynamics and hydrocarbon potential of the Central Eromanga Basin, Queensland, Australia. *BMR Journal of Australian Geology and Geophysics*, **5**, 47–55.

SENIOR, B.R., MOND, A. & HARRISON, P.L., 1978: Geology of the Eromanga Basin. *Bureau of Mineral Resources, Australia, Bulletin*, **167**.

SHAW, R.D. & PALFREYMAN, W.D. (Compilers), 1995: *1995 Australia Crustal Elements (1:5 000 000 scale map) based on the distribution of geophysical domains*. Australian Geological Survey Organisation, Canberra.

SHAW, R.D., WELLMAN, P., GUNN, P., WHITAKER, A.J., TARLOWSKI, C. & MORSE, M.P., 1995: Australian crustal elements map. *AGSO Research Newsletter*, **23**, 1–3.

SMYTH, M., 1983: Nature of source material for hydrocarbons in the Cooper Basin, Australia. *American Association of Petroleum Geologists, Bulletin* **67**, 1422–1428.

STANMORE, P.J., 1989: Case studies of stratigraphic and fault traps in the Cooper Basin, Australia. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia. Proceedings of Petroleum Exploration Society of Australia, Society of Petroleum Engineers, Australian Society of Exploration Geophysicists (SA Branches)*, Adelaide, 361–369.

STEPHENS, C.J., HOLCOMBE, R.J. FIELDING, C.R. & GUST, D.A., 1996: Tectonic evolution of the eastern Gondwanaland margin during the late Palaeozoic and early Mesozoic. *In* Mesozoic 96. Mesozoic Geology of the Eastern Australia Plate Conference, Brisbane, 1996. *Geological Society of Australia, Extended Abstracts* **43**, 517–518.

SUN, X., 1996: Sequence stratigraphy, sedimentology, biostratigraphy and palaeontology of the eastern Warburton Basin (Palaeozoic), South Australia. University of Adelaide, Ph.D. Thesis.

SUN, X., 1997: Structural style of the Warburton Basin and control in the Cooper and Eromanga Basins, South Australia. *Exploration Geophysics*, **28**, 333–339.

SUN, X., 1998: Prediction of carbonate reservoirs and traps by applying sequence stratigraphy in the eastern Warburton Basin, South Australia, 1998. *The APPEA Journal*, **38**(1), 380–398.

SUN, X., 2001: Natural fractures of the southern Cooper and eastern Warburton Basins, South Australia *The APPEA Journal*, **41**(1), 201–222.

SUN, X., STUART, W.J. & WARREN, J.K., 1994: Stratigraphy and sedimentology of the Cambro-Ordovician successions, eastern Warburton Basin, South Australia. *PESA Journal*, **22**, 107–111.

TAYLOR, G.H., LIU, S.Y. & SMYTH, M., 1988: A new light on the origin of Cooper Basin oil. *The APEA Journal*, **28**(1), 303–309.

TORKINGTON, J. & MILENKO, M.I., 1988: A stratigraphic analysis of the Talgeberry Oilfield. *The APEA Journal*, **28**(1), 113–121.

TOUPIN, D., EADINGTON, P.J., PERSON, M., MORIN, P., WIECK, J. & WARNER, D., 1997: Petroleum hydrogeology of the Cooper and Eromanga Basins, Australia: some insights from mathematical modelling and fluid inclusion data. *American Association of Petroleum Geologists, Bulletin* **81**, 577–603.

VEEVERS, J.J., 1990: Tectonic-climatic supercycle in the billion-year plate-tectonic eon: Permian Pangean icehouse alternates with Cretaceous dispersed-continents greenhouse. *Sedimentary Geology*, **68**, 1–16.

VEEVERS, J.J., 1993: Gondwana facies of the Pangean supersequence. *In* Findlay, R.H., Unrug, R., Banks, M.R. & Veevers, J.J. (Editors): *Gondwana Eight: assembly, evolution and dispersal. Proceedings of the Eighth Gondwana Symposium, Hobart, Tasmania, Australia, 1991*. A.A. Balkema, Rotterdam, 513–520.

VEEVERS, J.J., 1994: Pangea: Evolution of a supercontinent and its consequences for Earth's paleoclimate and sedimentary environments. *In* Klein, G.D. (Editor): Pangea: Paleoclimate, tectonics, and sedimentation during accretion, zenith, and breakup of a supercontinent. *Geological Society of America, Special Paper* **288**, 13–23.

VEEVERS, J.J., CLARE, A. & WOPFNER, H., 1994: Neocratonic magmatic-sedimentary basins of post-Variscan Europe and post-Kanimblan eastern Australia generated by right-lateral transtension of Permo-Carboniferous Pangaea. *Basin Research*, **6**, 141–157.

VEEVERS, J.J. & TEWARI, R.C., 1995: Permian–Carboniferous and Permian–Triassic magmatism in the rift zone bordering the Tethyan margin of southern Pangea. *Geology*, **23**, 467–470.

VINE, R.R., 1964: Mackunda, Queensland — 1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* **SF54/11**.

VINE, R.R. & DAY, R.W., 1965: Nomenclature of the Rolling Downs Group, northern Eromanga Basin, Queensland. *Queensland Government Mining Journal*, **66**, 416–421.

VINE, R.R., DAY, R.W., CASEY, D.J., MILLIGAN, E.N., GALLAWAY, M.C. & EXON, N.F., 1967: Revised nomenclature of the Rolling Downs Group, Eromanga and Surat Basins. *Queensland Government Mining Journal*, **68**, 144–151.

WALLIN, C.I., 1974: Stratigraphic drilling report — GSQ Tambo 2. *Queensland Government Mining Journal*, **75**, 287–292.

WARDLAW, B.R., 1999: Notes from the SPS Chair. *Permophiles*, **35**, 1–2 (Newsletter of the Subcommission on Permian Stratigraphy, International Commission on Stratigraphy, International Union of Geological Sciences).

WARDLAW, B.R., 2000: Notes from the SPS Chair. *Permophiles*, **36**, 1–2 (Newsletter of the Subcommission on Permian Stratigraphy, International Commission on Stratigraphy, International Union of Geological Sciences).

WASCHBUSCH, P., BEAUMONT, C. & KORSCH, R.J., 1999: Geodynamic modelling of aspects of the New England Orogen and adjacent Bowen, Gunnedah and Surat Basins. *In* Flood P.G. (Editor): Regional Geology, Tectonics and Metallogenesis, New England Orogen. *Proceedings of NEO99*, Earth Sciences, University of New England, 203–210.

WATTS, K.J., 1987: The Hutton Sandstone-Birkhead Formation Transition, ATP 269P(1), Eromanga Basin. *The APEA Journal,* **27**(1), 215–228.

WEBSTER, M.A., BREW, J. & GRIMISON, A.G., 2000: Hydrodynamics in the Queensland sector of the Cooper/Eromanga Basins: Identifying non-conventional exploration plays using water pressure and chemistry data. *Proceedings of Society of Petroleum Engineers Asia Pacific Oil and Gas Conference and Exhibition* (on CD).

WECKER, H.R.B., 1989: The Eromanga Basin. *The APEA Journal*, **29**(1), 379–397.

WECKER, H.R.B., ZIOLKOWSKI, V. & POWIS, G.D., 1996: New gas discoveries in the northern Cooper Basin. *The APPEA Journal,* **36**(1), 104–115.

WHITEHOUSE, F.W., 1954: Cainozoic and later beds. Queensland Co-ordinator of Public Works, Report, 1–3.

WHITEHOUSE, F.W. 1955: The geology of the Queensland portion of the Great Australian Artesian Basin. Appendix G in Department of the Co-ordinator General of Public Works: *Artesian Water Supplies in Queensland*, Government Printer, Brisbane.

WHITFORD, D.J., HAMILTON, P.J. & SCOTT, J., 1994: Sedimentary provenance studies in Australian basins using Neodymium model ages. *The APPEA Journal*, **34**(1), 320–329.

WILLIAMS, A.J., 1983a: Palynology (preliminary report) — Morney No. 1. Appendix V in DIO Morney 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 9551.

WILLIAMS, A.J., 1983b: Palynological report — Chookoo No. 1. Delhi Petroleum Pty Ltd Palynological Report No. 13/182 as Appendix XII in DIO Chookoo 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 13118.

WILLIAMS, A.J., 1983c: Palynological report — Bycoe No. 1. Delhi Petroleum Pty Ltd Palynological Report No. 13/185 as Appendix V in DIO Bycoe 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 13033.

WILLIAMS, A.J., 1984: Palynological Report — Buckaroola No. 1. Delhi Petroleum Pty Ltd Palynological Report No. 13/197 as Appendix VI in DIO Buckaroola 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 13028.

WILLIAMS, A.J., 1985a: Ullenbury No. 1 palynological report. Delhi Petroleum Pty Ltd Palynological Report No. 13/244 as Appendix VIII in DIO Ullenbury 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 13720.

WILLIAMS, A.J., 1985b: Russel No. 1 palynological report. Delhi Petroleum Pty Ltd Palynological Report No. 13/255 as Appendix VII in DIO Russel 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 13985.

WILLIAMS, A.J., 1985c: Palynology of the Cadna-owie Formation in Kercummurra No. 1 and Boldrewood No. 1. Delhi Petroleum Pty Ltd Palynological Report No. 13/271 as: (a) Appendix VII in DIO Boldrewood 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 14349; and (b) Appendix VII in DIO Kercummurra 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 14355.

WILLIAMS, A.J. & PRICE, P.L., 1983: Gunna No. 1 palynological report. Delhi Petroleum Pty Ltd/Mines Administration Pty Ltd Palynological Report No. 13/177 as AppendixVI in DIO Gunna 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 12697.

WILLIAMS, A.J. & WOOD, G.R., 1984: Pepita No. 1 palynological report. Delhi Petroleum Pty Ltd Palynological Report No. 13/209 as Appendix IX in DIO Pepita 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 13541.

WILLIAMS, B.P.J., 1984: Reservoir geometry and alluvial architecture of the Toolachee Formation, Moomba Field, south Cooper Basin. *In* 7th Australian Geological Convention, Sydney, 1984. *Geological Society of Australia. Abstracts* **12**, 552–553.

WILLIAMS, B.P.J. & WILD, E.K., 1984: The Tirrawarra Sandstone and Merrimelia Formation of the southern Cooper Basin, South Australia — the sedimentation and evolution of a glaciofluvial system. *The APEA Journal,* **24**(1), 377–392.

WILLIAMS, L.J., 1989: Sedimentology of the Adori Sandstone in the Tambo Region, Central Queensland. *Queensland Department of Mines, Record* **1989/25**.

WILTSHIRE, M.J., 1978: Poolowanna No1 well completion report. South Australia Department of Mines and Energy, Open File Envelope, 317.

WILTSHIRE, M.J., 1989: Mesozoic stratigraphy and palaeography, eastern Australia. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia. Proceedings of Petroleum Exploration Society of Australia, Society of Petroleum Engineers, Australian Society of Exploration Geophysicists (SA Branches)*, Adelaide, 279–291

WOOD, G.R., 1985a: Naccowlah East No. 1 palynological report. Delhi Petroleum Pty Ltd Palynological Report No. 13/259 as Appendix IV in DIO Naccowlah East 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 14079.

WOOD, G.R., 1985b: Ballera No. 1 palynological report. Delhi Petroleum Pty Ltd Palynological Report No. 13/287 as Appendix VII in DIO Ballera 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 14469.

WOOD, G.R., 1986a: Palynology – Cook No. 1. Delhi Petroleum Pty Ltd Palynological Laboratory Report No. 13/324 as Appendix VII in DIO Cook 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15022.

WOOD, G.R., 1986b: Palynology – Mount Howitt No. 2. Delhi Petroleum Pty Ltd Palynological Laboratory Report No. 13/337 as Appendix VII in DIO Mount Howitt 2 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15141.

WOOD, G.R., 1986c: Doonmulla No. 1 palynological report. Delhi Petroleum Pty Ltd Palynological Report No. 13/340 as Appendix IV in DIO Doonmulla 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15084.

WOOD, G.R., 1987: Palynology – Copai No. 1. Delhi Petroleum Pty Ltd Palynological Laboratory Report No. 517/1 as Appendix III in DIO Copai 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 17728.

WOOD, G.R., 1994: Palynostratigraphy and kerogen analysis – Munkah No. 4. Santos Ltd Palynological Report No. 1993/22 as Appendix IV in SSL Munkah 4 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 25304.

WOOD, G.R. & JONES, M.J., 1986a: Palynology – Watson South No. 1. Delhi Petroleum Pty Ltd Palynological Laboratory Report No. 399/1 as Appendix VII in DIO Watson South 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 14971.

WOOD, G.R. & JONES, M.J., 1986b: Palynology – Warnie East No. 1. Delhi Petroleum Pty Ltd Palynological Laboratory Report No. 396/1 as Appendix VII in DIO Warnie East 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15395.

WOOD, G.R. & JONES, M.J., 1986c: Palynology – Arrabury No. 2. Delhi Petroleum Pty Ltd Palynological Laboratory Report No. 391/1 as Appendix IV in DIO Arrabury 2 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 15420.

WOOD, G.R. & WILLIAMS, A.J., 1984a: Yanda No. 1 palynological report. Delhi Petroleum Pty Ltd Palynological Report No. 13/214 as Appendix IX in DIO Yanda 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 13483.

WOOD, G.R. & WILLIAMS, A.J., 1984b: Durham Downs No. 2 palynological report. Delhi Petroleum Pty Ltd Palynological Report No. 13/219 as Appendix VII in DIO Durham Downs 2 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 13481.

WOOD, G.R. & WILLIAMS, A.J., 1985: Hammond No. 1 Palynological Report. Delhi Petroleum Pty Ltd Palynological Report No. 13/281 as Appendix IV in DIO Hammond 1 Well Completion Report. Report held by the Department of Natural Resources and Mines Queensland as CR 14467.

WOOLLEY, J.B., 1941: Geological report on the area north-east of Tambo. Report held by the Department of Natural Resources and Mines Queensland as CR 640.

WOPFNER, H., CALLEN, R.A. & HARRIS, W.K., 1974: Lower Tertiary Eyre Formation of the south-western great Artesian Basin. *Journal of the Geological Society of Australia*, **31**, 17–52.

WOPFNER, H., FREYTAG, I.B. & HEATH, G.R., 1970: Basal Jurassic-Cretaceous rocks of the western Great Artesian Basin, South Australia: stratigraphy and environment. *American Association of Petroleum Geologists, Bulletin*, **54**, 383–416.

YEW, C.C. & MILLS, A.A., 1989: The occurrence and search for Permian oil in the Cooper Basin, Australia. *In* O'Neil, B.J. (Editor): *The Cooper and Eromanga Basins, Australia. Proceedings of Petroleum Exploration Society of Australia, Society of Petroleum Engineers, Australian Society of Exploration Geophysicists (SA Branches)*, Adelaide, 339–359.

YOUNG, G.C. & LAURIE, J.R., 1996: *An Australian Phanerozoic Timescale*. Oxford University Press, Melbourne, Australia.

YOUNGS, B.C., & BOOTHBY, P.G., 1985: The Nappamerri Formation in the Cooper Basin, South Australia and south-west Queensland. *In* Lindsay, M.J. (Compiler): Stratigraphy, Palaeontology, Malacology; Papers in honour of Dr Nell Ludbrook. *South Australian Department of Mines and Energy, Special Publication*, **5**, 373–387.

GO BACK

OPEN REPORT

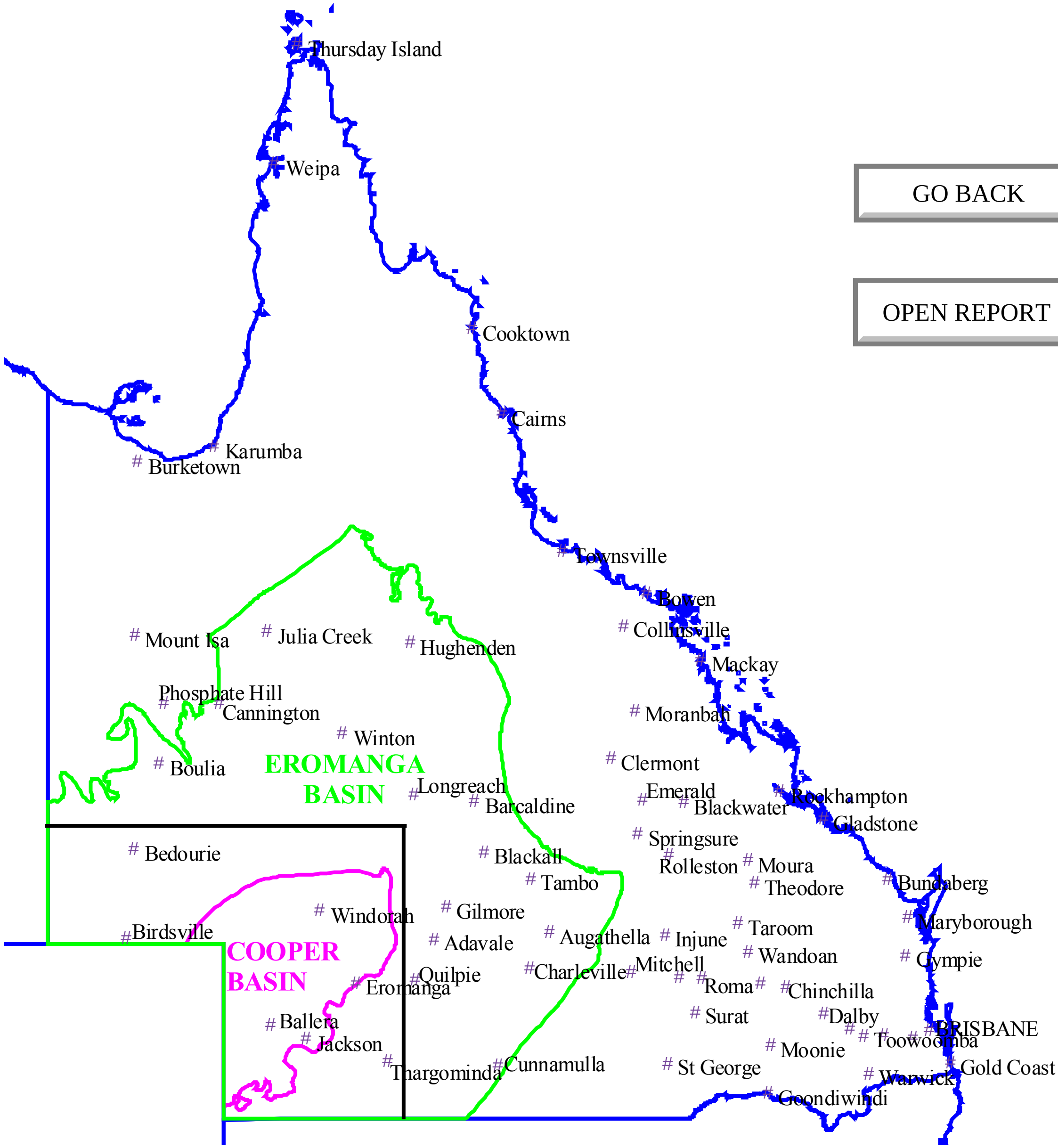


Figure 1: Location of Cooper - Eromanga Basins Project area

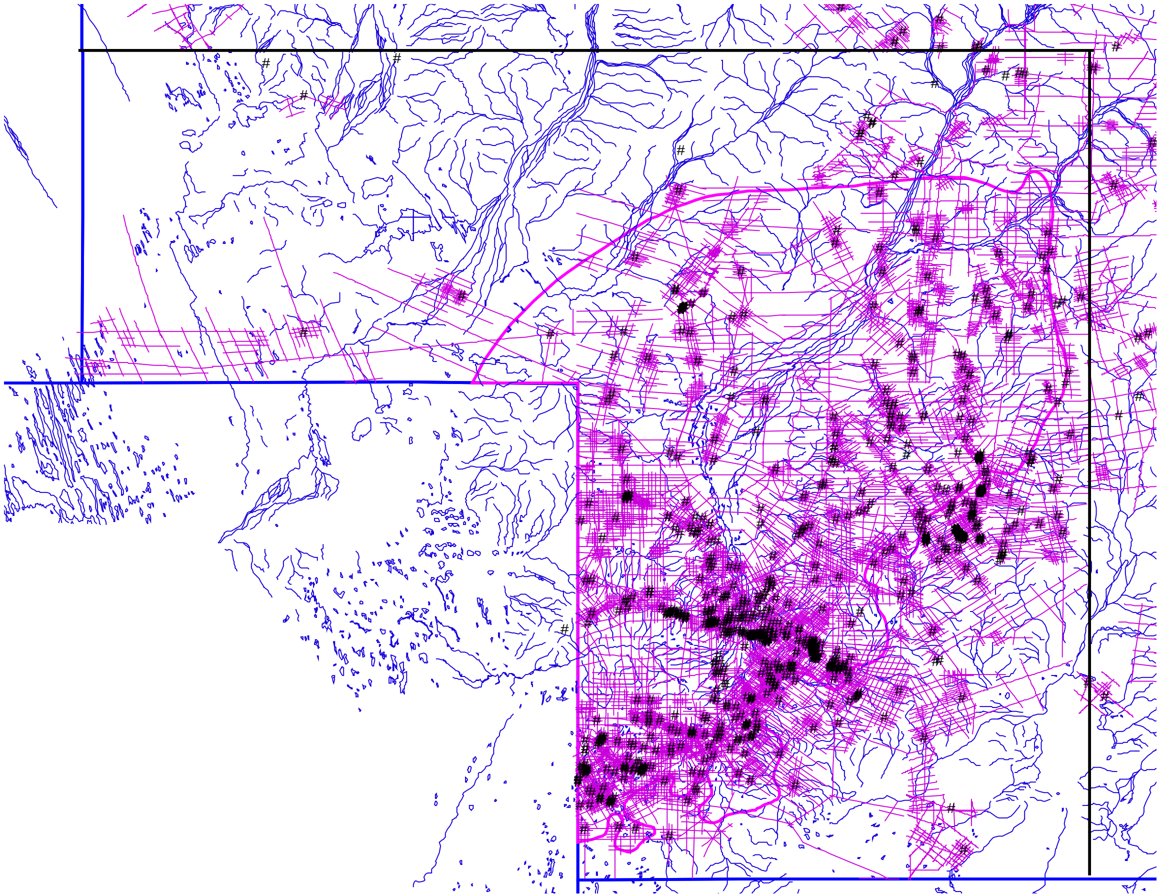


Figure 2: Project area showing drainage (blue), seismic lines (purple) and petroleum wells (black dots).

GO BACK OPEN REPORT

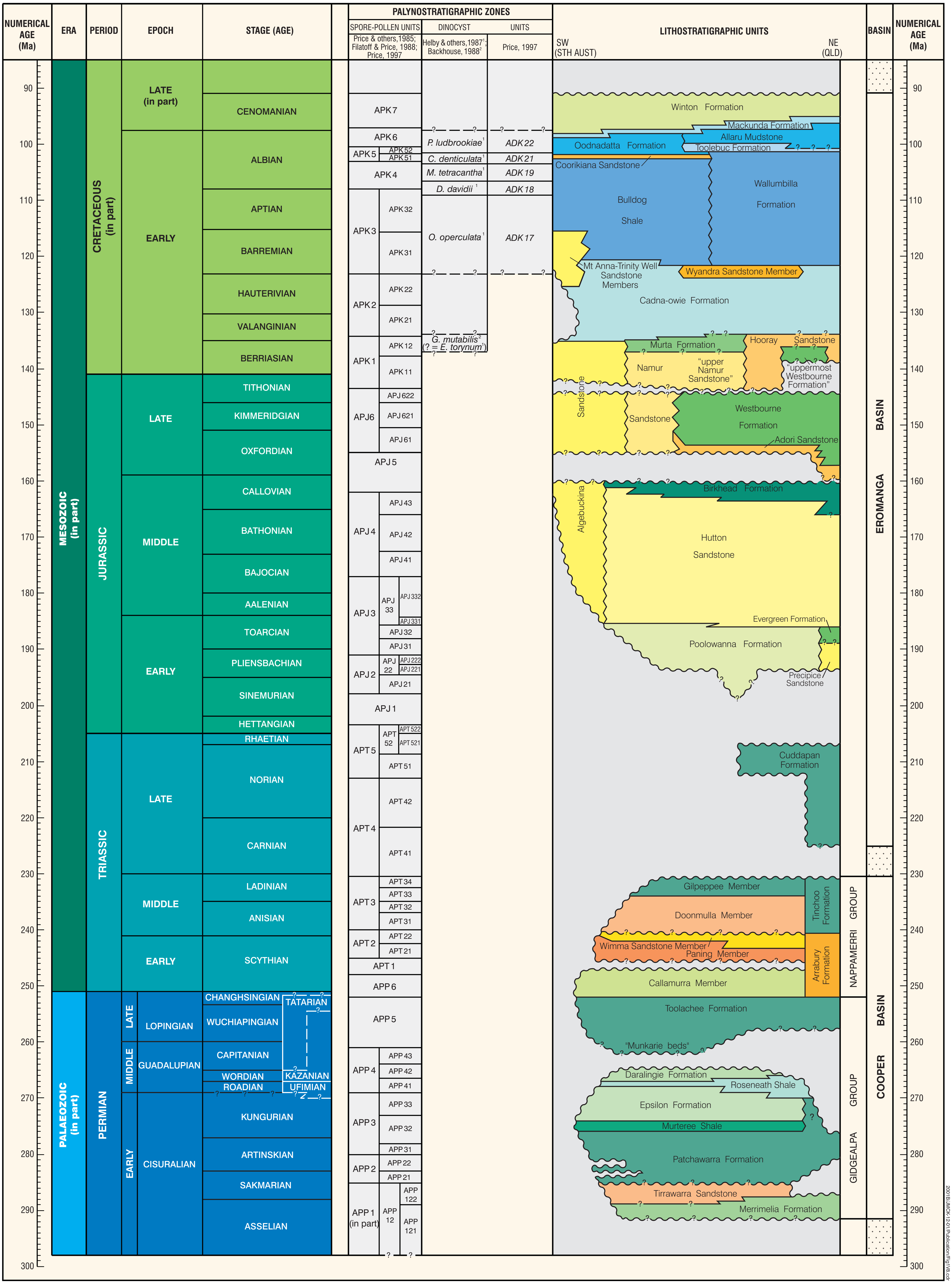
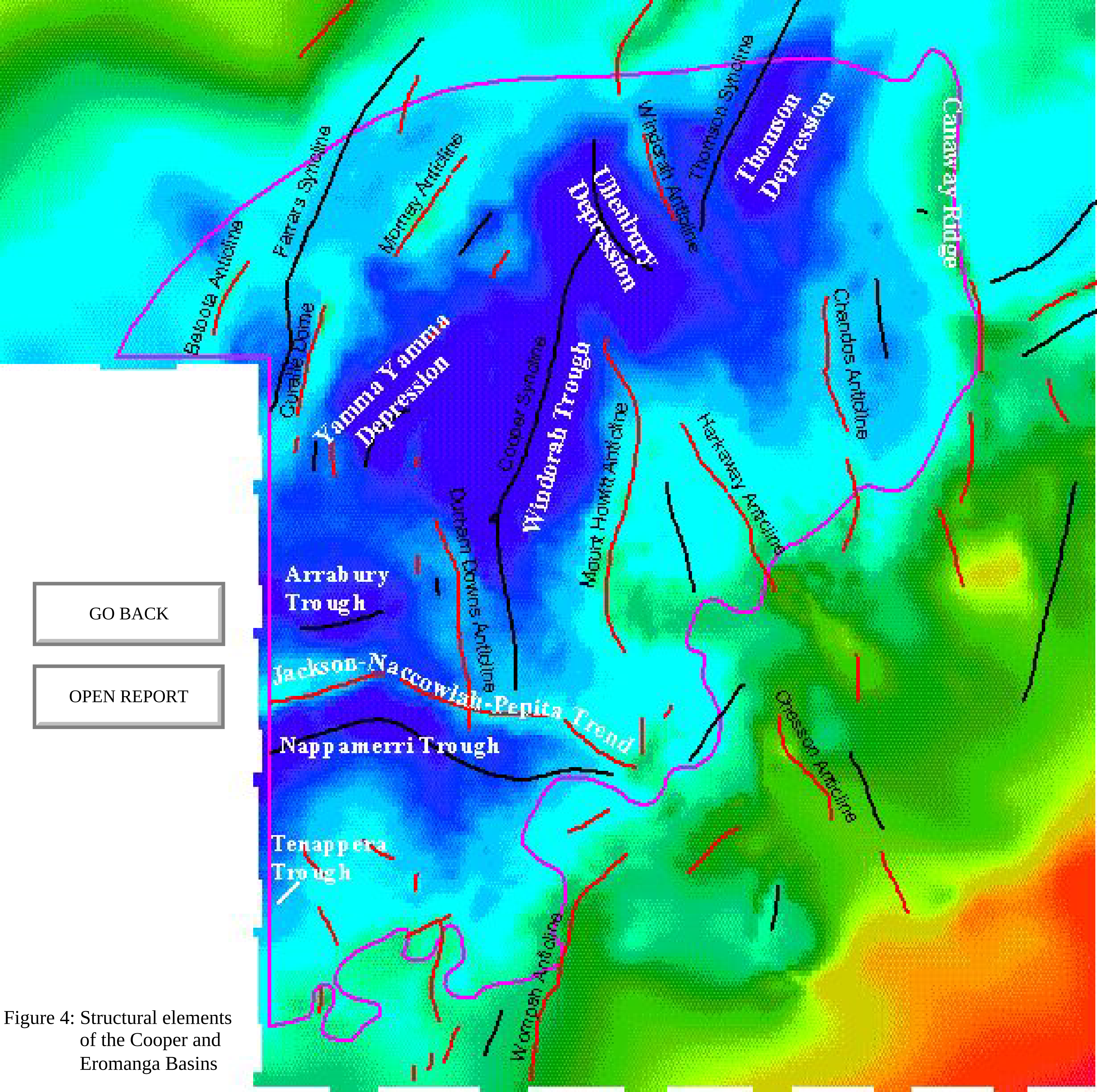


Figure 3. Late Palaeozoic-Mesozoic chronology and stratigraphy of the Cooper and Eromanga Basins (Queensland and South Australia)

Produced by J.L.McKellar, with input from Primary Industries and Resources South Australia, G.R.Wood (Santos Ltd) and P.L.Price (APG Consultants).
Timescale modified from AGSO Phanerozoic Timescale Wallchart (AGSO, 1996) and after McKellar (in press).

GO BACK

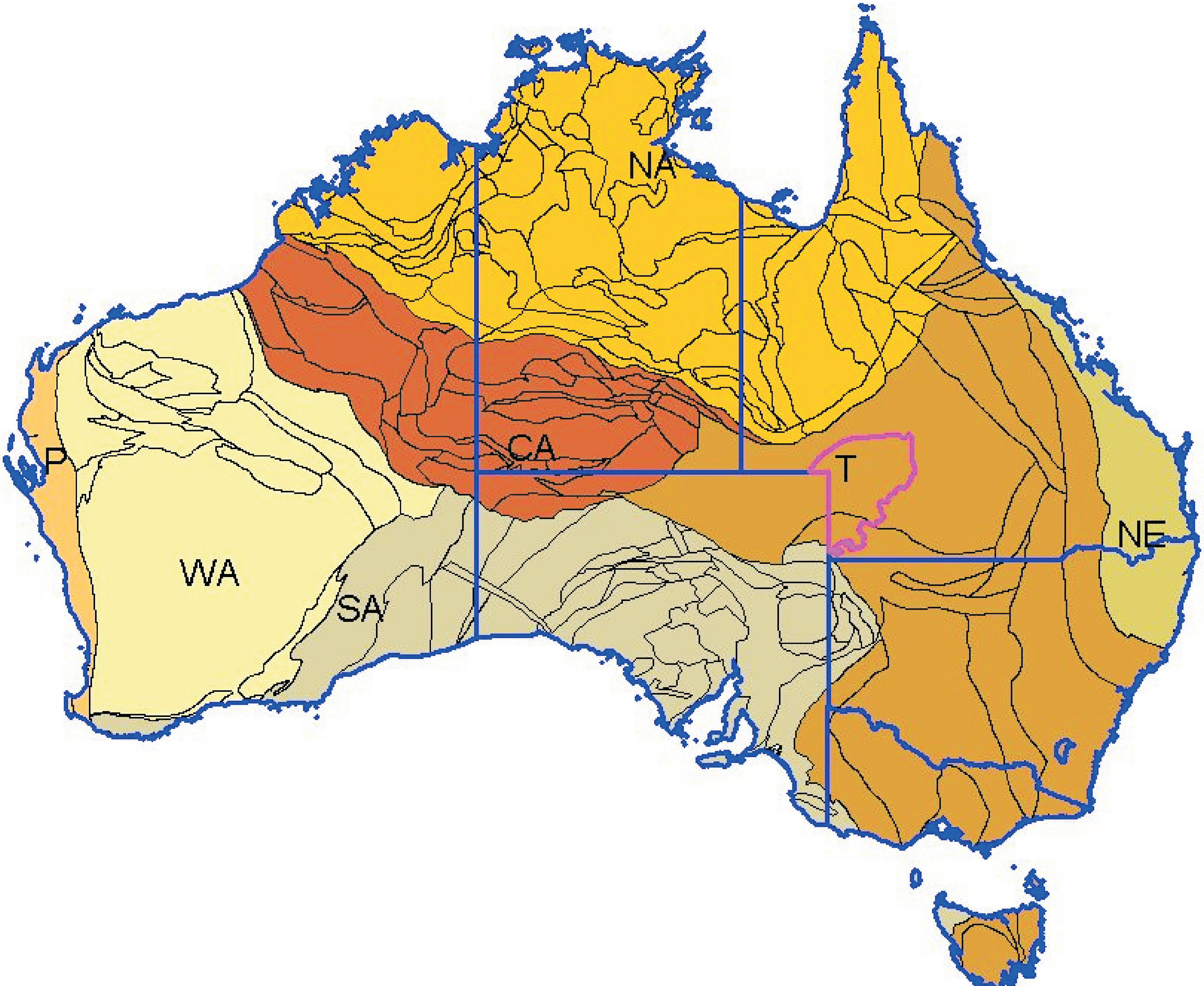
OPEN REPORT



GO BACK

OPEN REPORT

Figure 4: Structural elements of the Cooper and Eromanga Basins



GO BACK

OPEN REPORT

Figure 5: Mega-crustal elements of Australia with outline of Cooper Basin in Queensland (T-Tasman, SA-South Australian, CA-Central Australian, NA-North Australian, NE-New England).

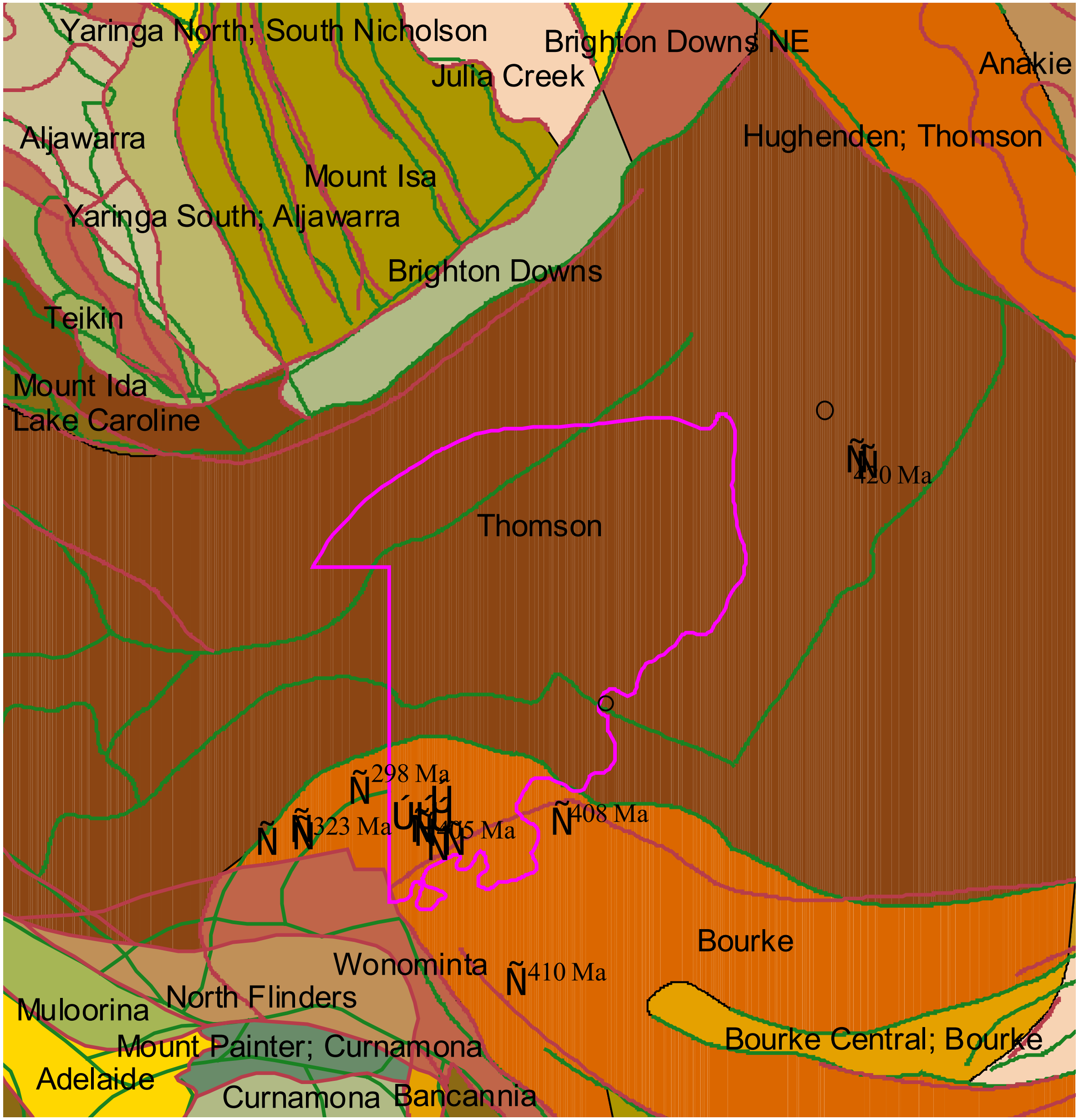
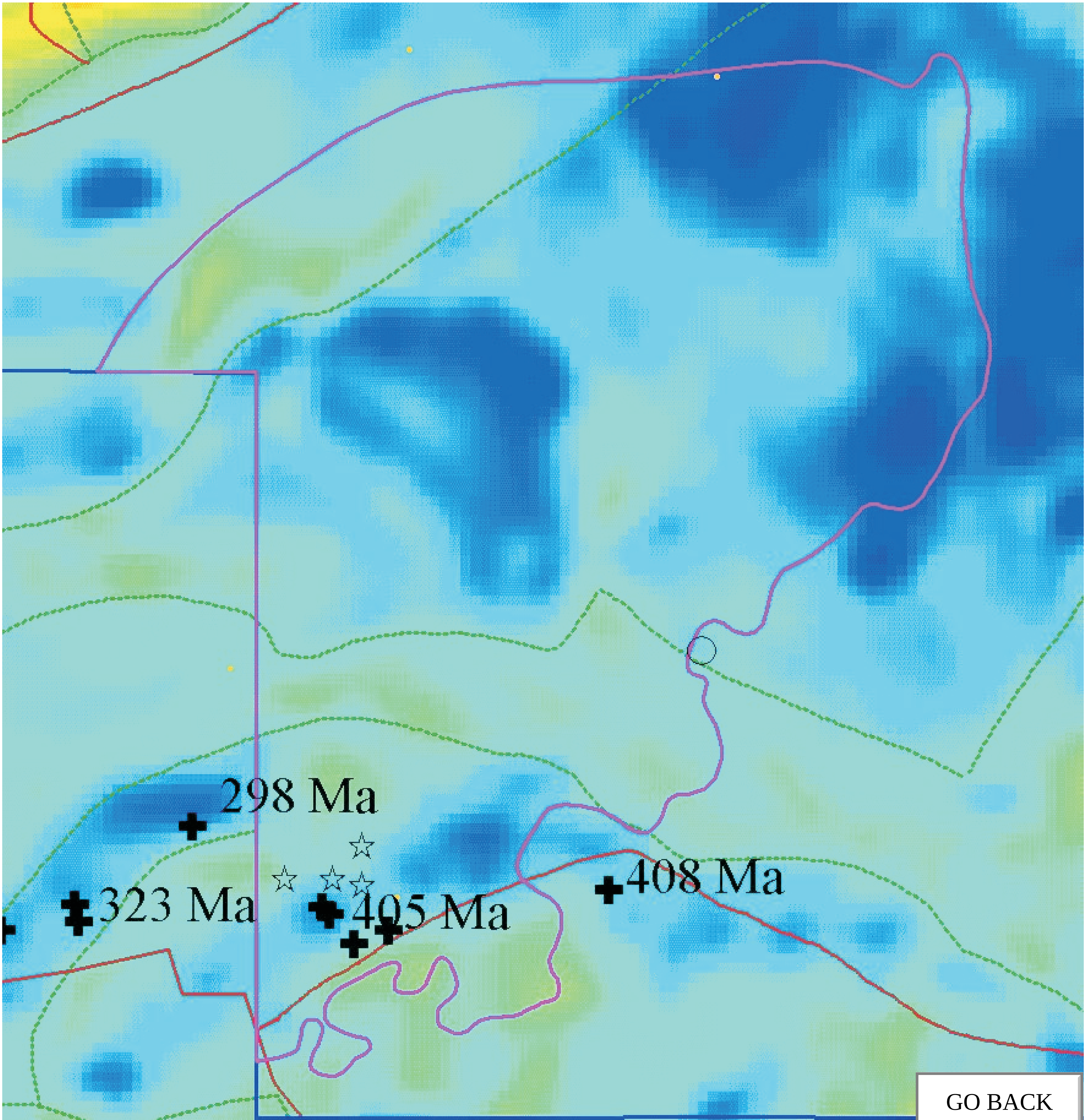


Figure 6: Crustal elements, Cooper Basin region (crosses - granites, stars - basalts).
Green lines are gravity trends and red lines magnetic trends
(from Shaw & others, 1995).

GO BACK

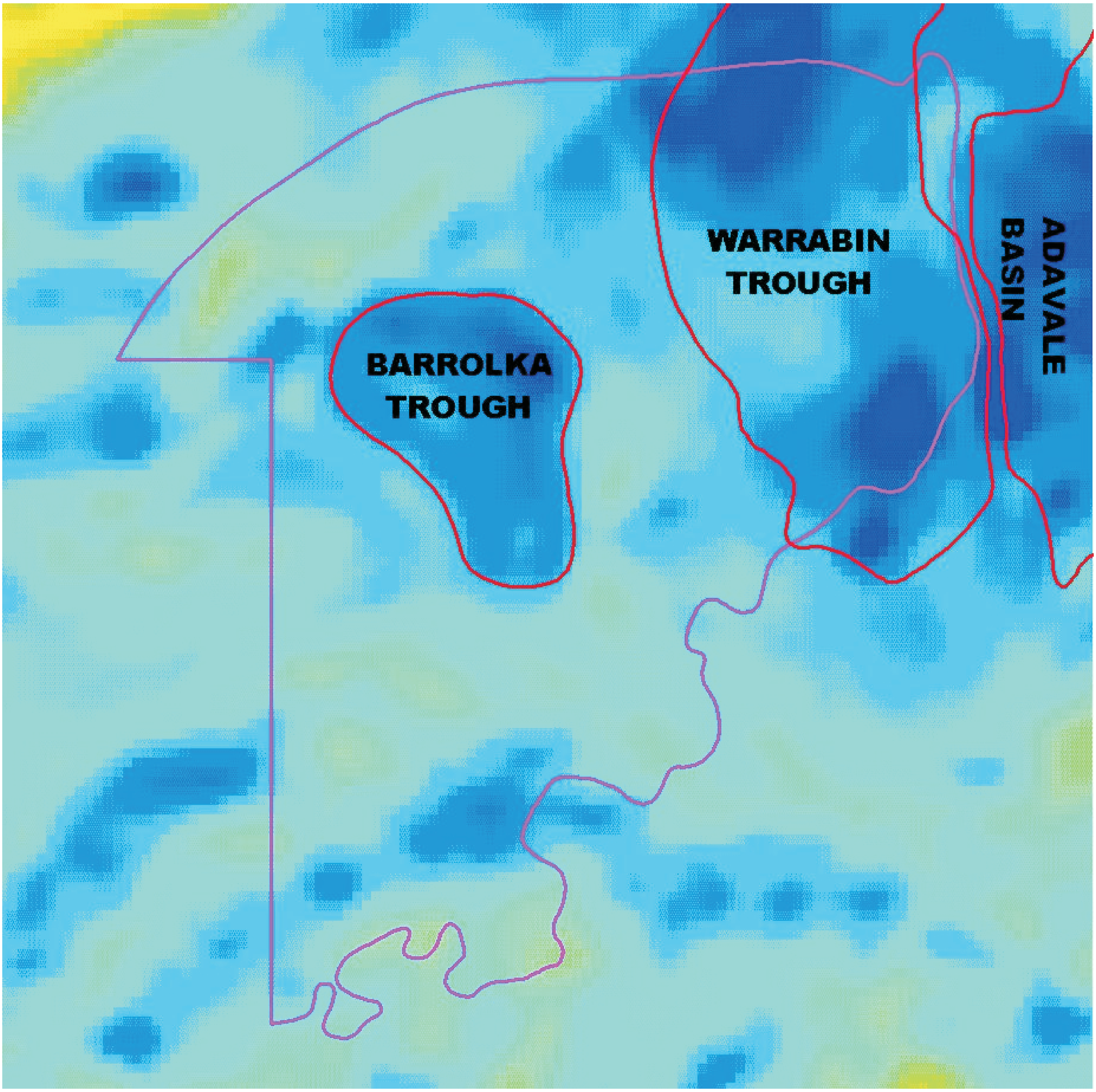
OPEN REPORT



GO BACK

Figure 7: Gravity image showing granite locations and ages (crosses) and location of basalts (stars). Green lines are gravity trends and red lines magnetic trends (from Shaw & others, 1995).

OPEN REPORT



GO BACK

Figure 8: Location of Devonian basins on gravity image.

OPEN REPORT

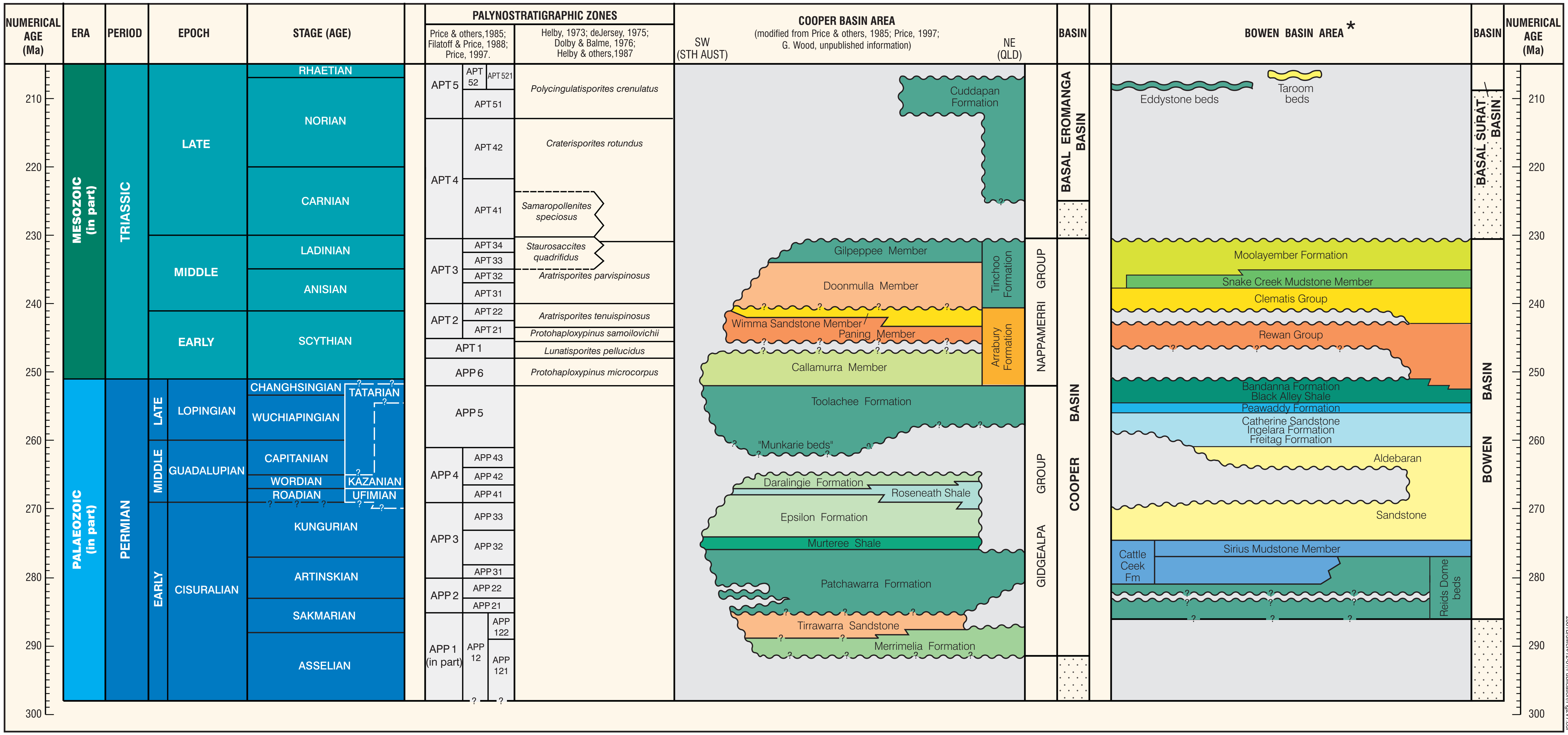


Figure 9: Permian-Triassic chronology and tentative palynostratigraphic relationships - Bowen and Cooper Basins.

* Bowen Basin section generalised for the Denison Trough (for the Permian) and the Denison Trough and Roma Shelf - Taroom Trough areas (for the Permian-Triassic transition and succeeding Triassic).
Timescale modified from AGSO Phanerozoic Timescale Wallchart (AGSO, 1996) and after McKellar (in press).

GO BACK

OPEN REPORT

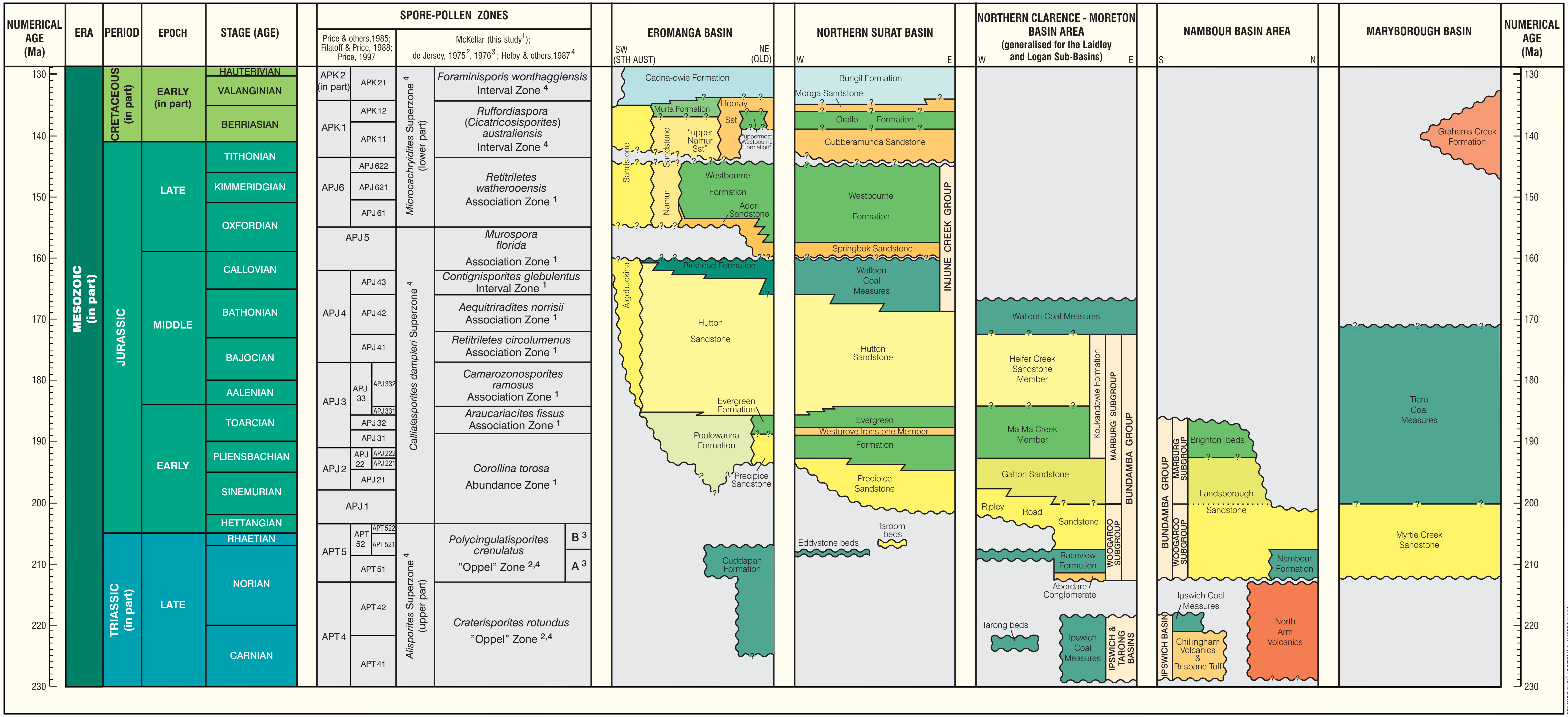


Figure 10: Late Triassic - Early Cretaceous chronology and palynostratigraphy: Eromanga, Surat, Clarence-Moreton, Nambour and Maryborough Basin regions.

Timescale modified from AGSO Phanerozoic Timescale Wallchart (AGSO, 1996) and after McKellar (in preparation).

GO BACK

OPEN REPORT

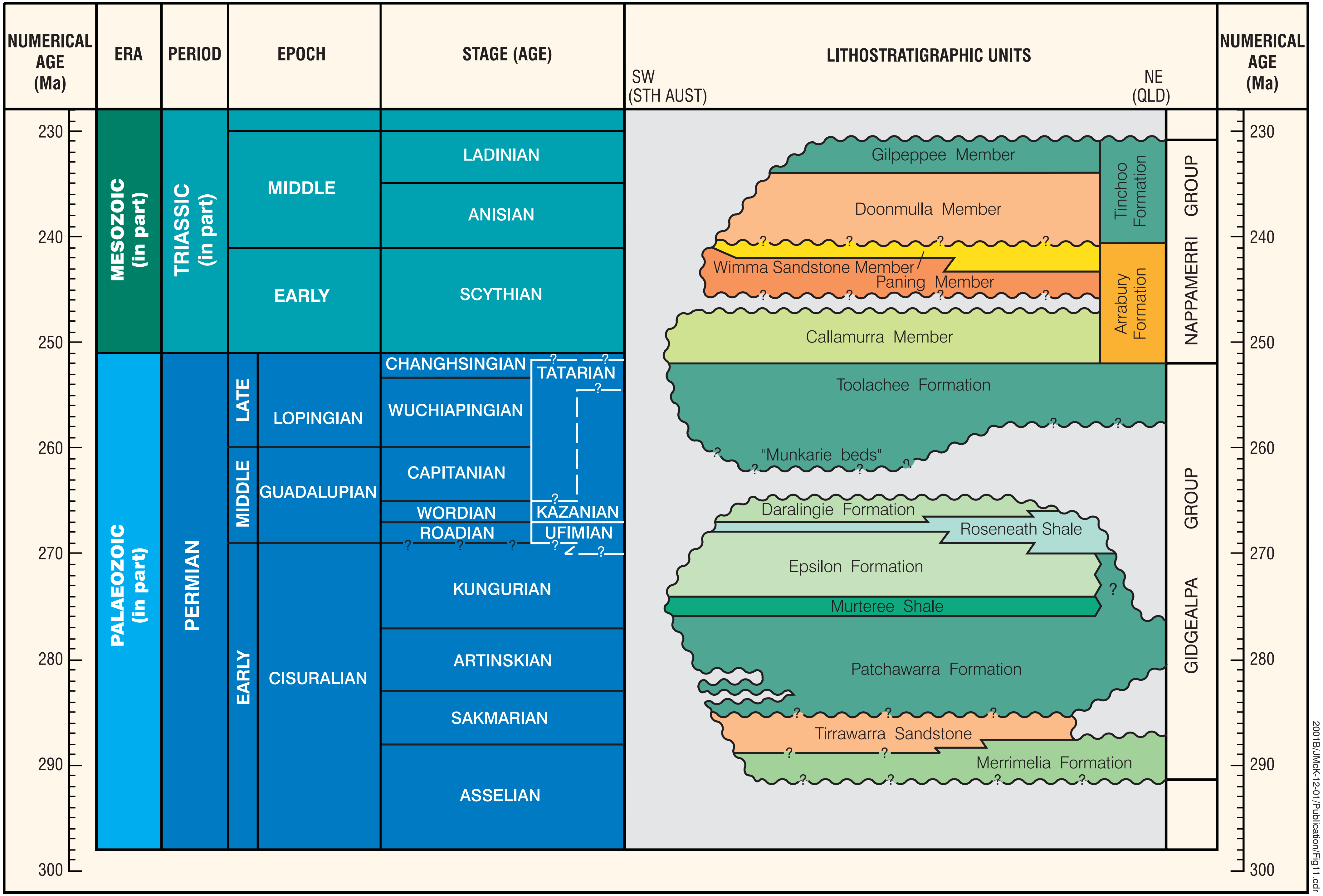
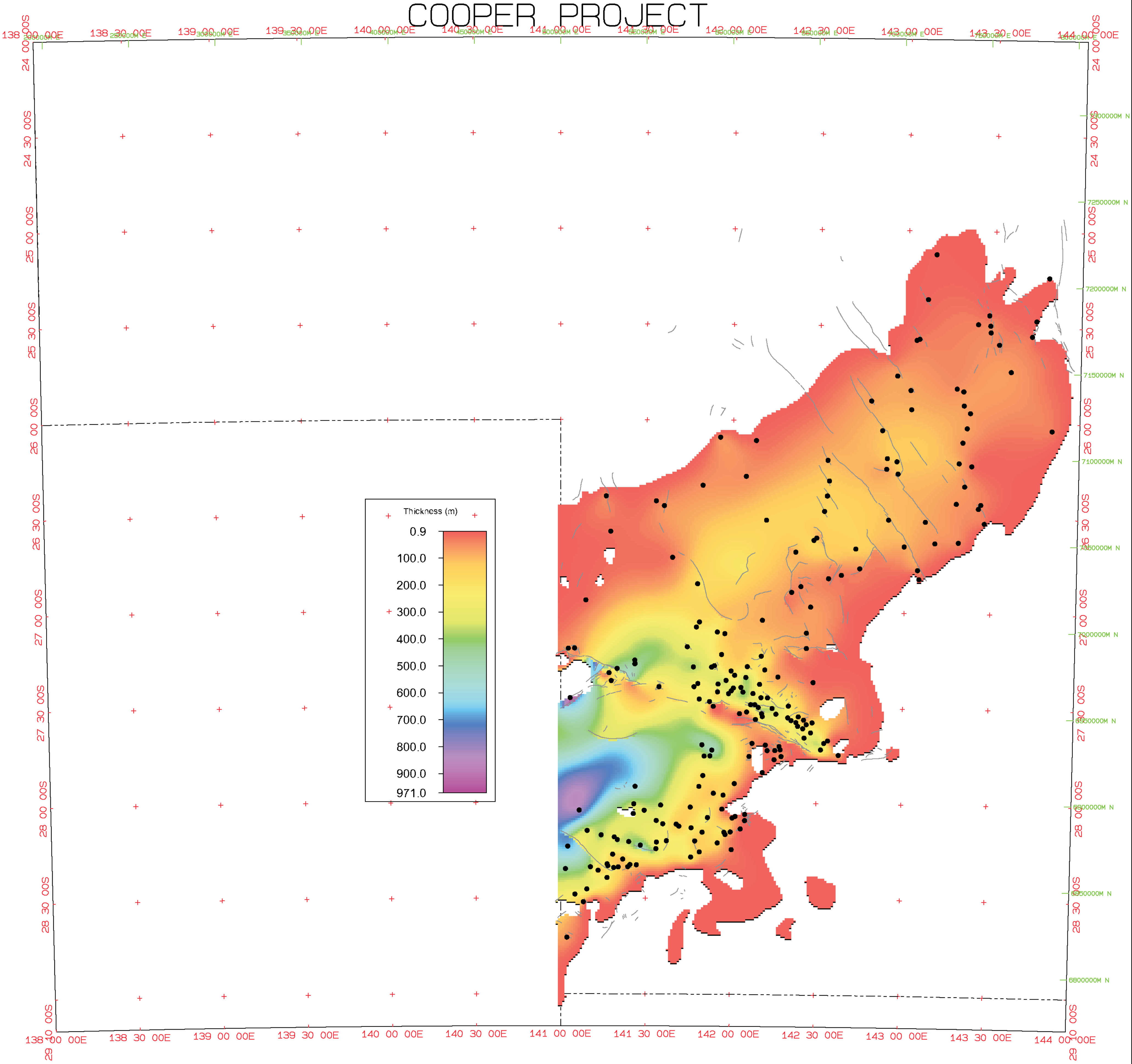


Figure 11: Stratigraphic column, Cooper Basin.

GO BACK

OPEN REPORT

COOPER PROJECT



GO BACK

Figure 12

OPEN REPORT

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Gidgealpa Group Isopach

COOPER PROJECT

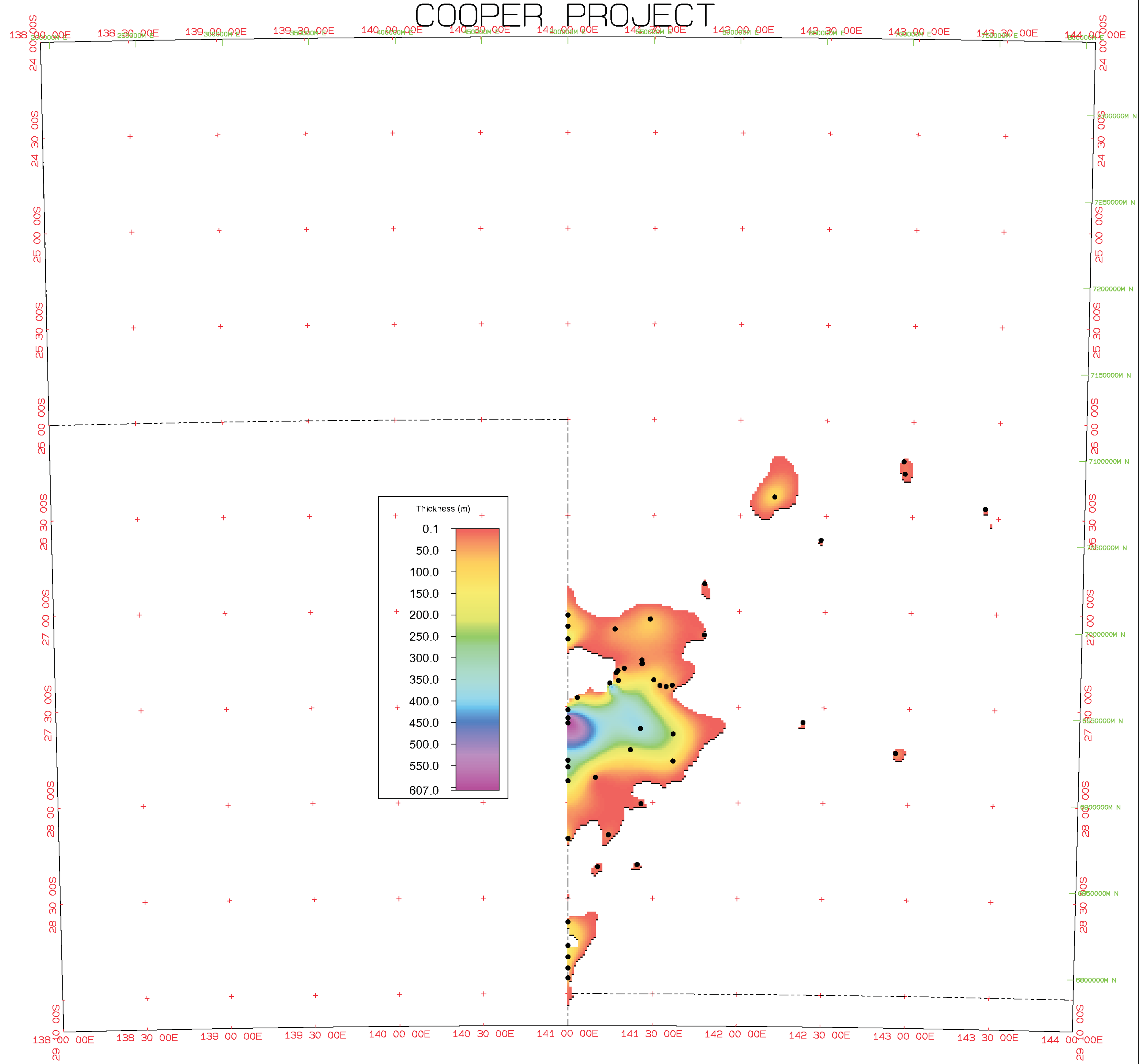


Figure 13

GO BACK

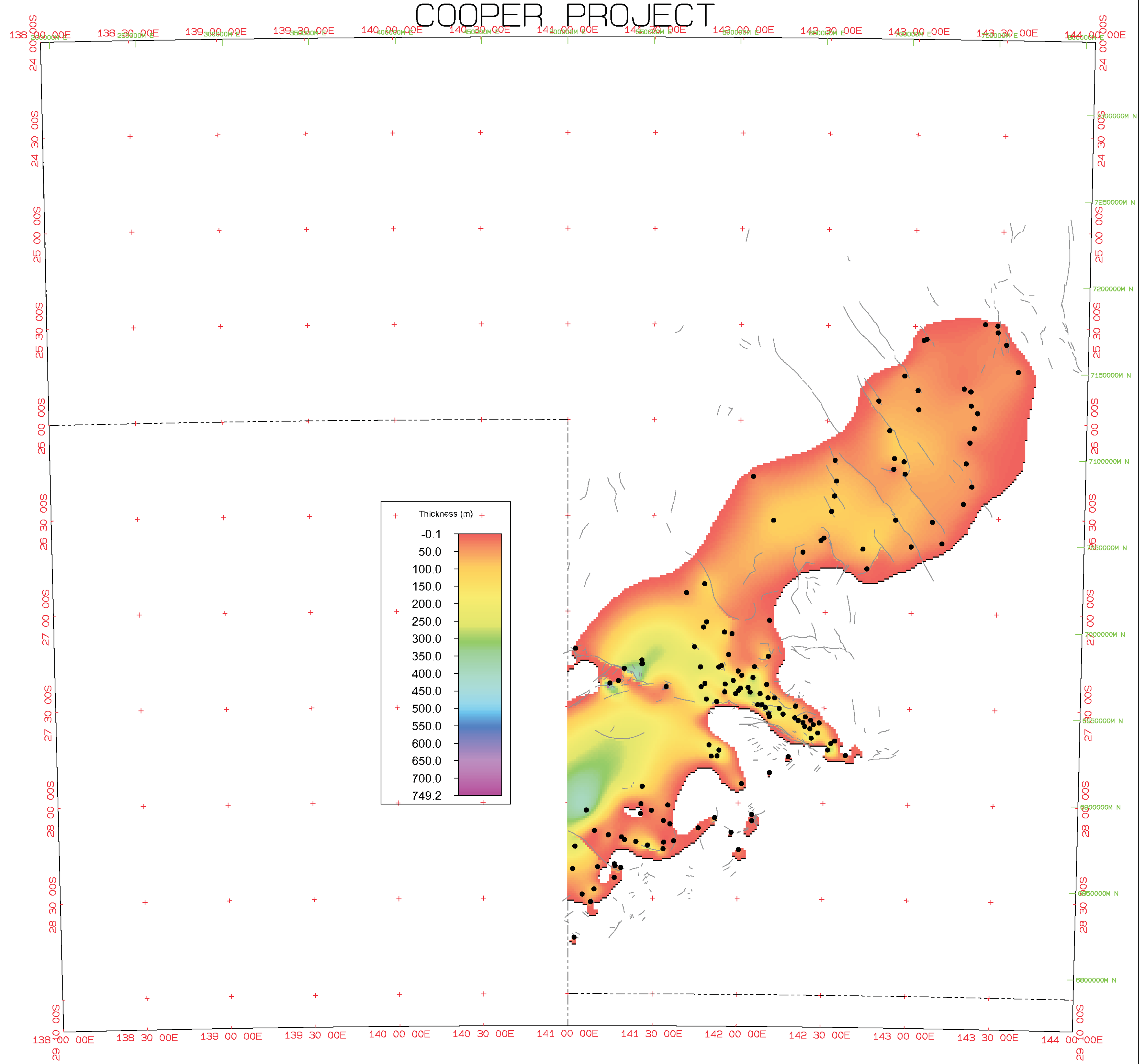
OPEN REPORT

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland
Tirrawarra Formation Merrimelia Sandstone Isopach

COOPER PROJECT



GO BACK

OPEN REPORT

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Figure 14

Geological Survey of Queensland

Patchawarra Formation Isopach

COOPER PROJECT

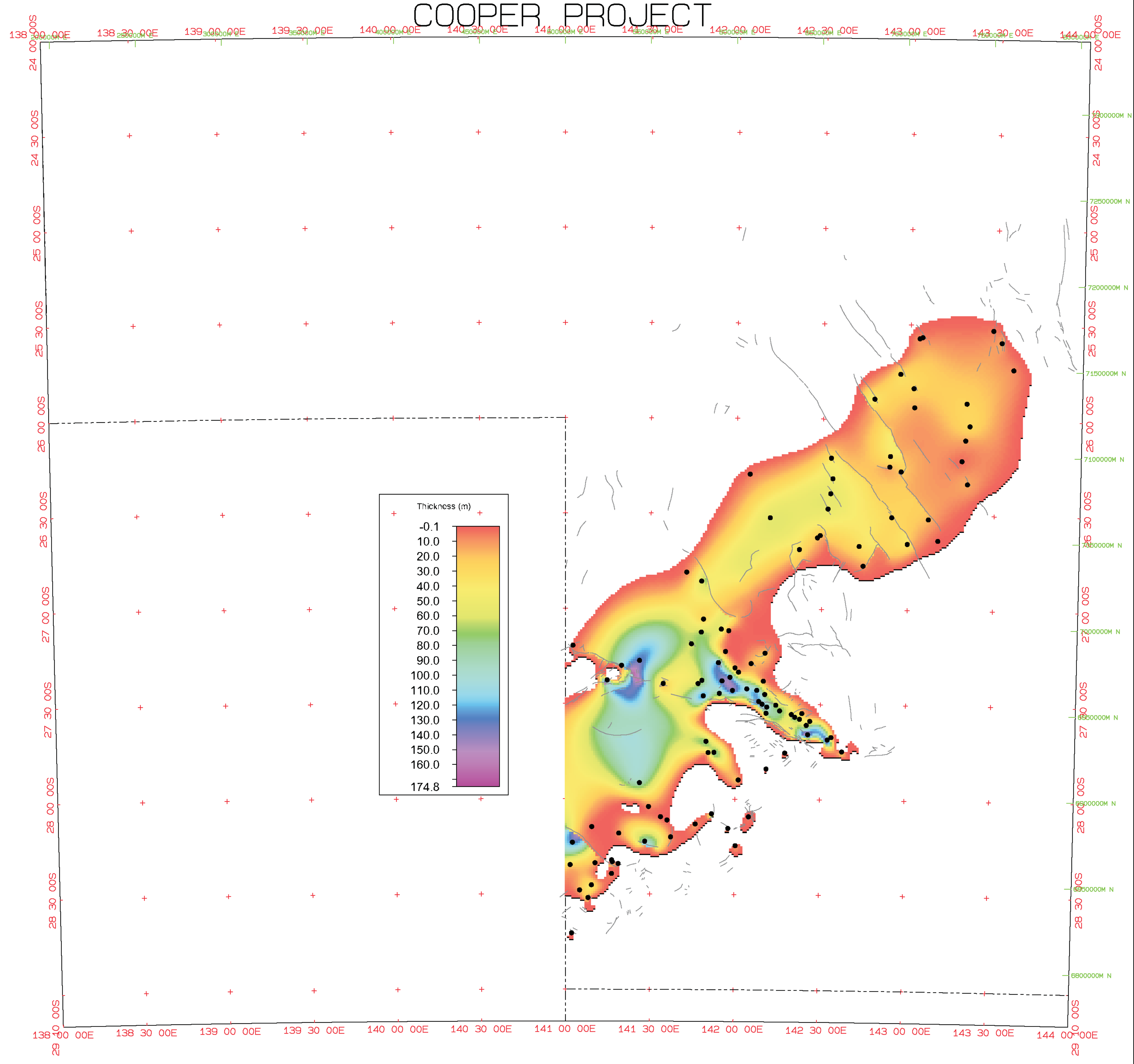


Figure 15

GO BACK

OPEN REPORT

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Patchawarra Formation Sand Isopach		

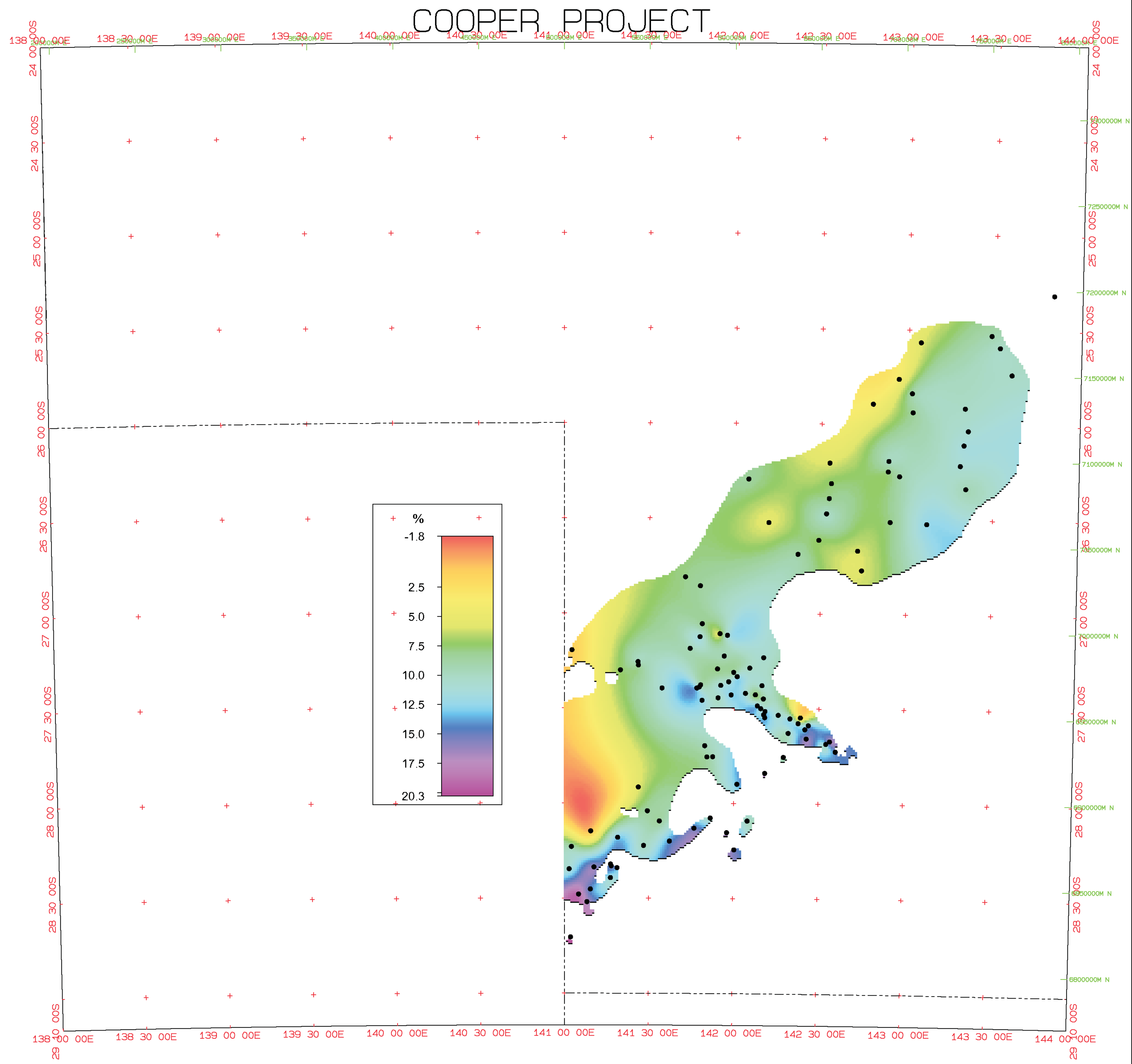


Figure 16

GO BACK

OPEN REPORT

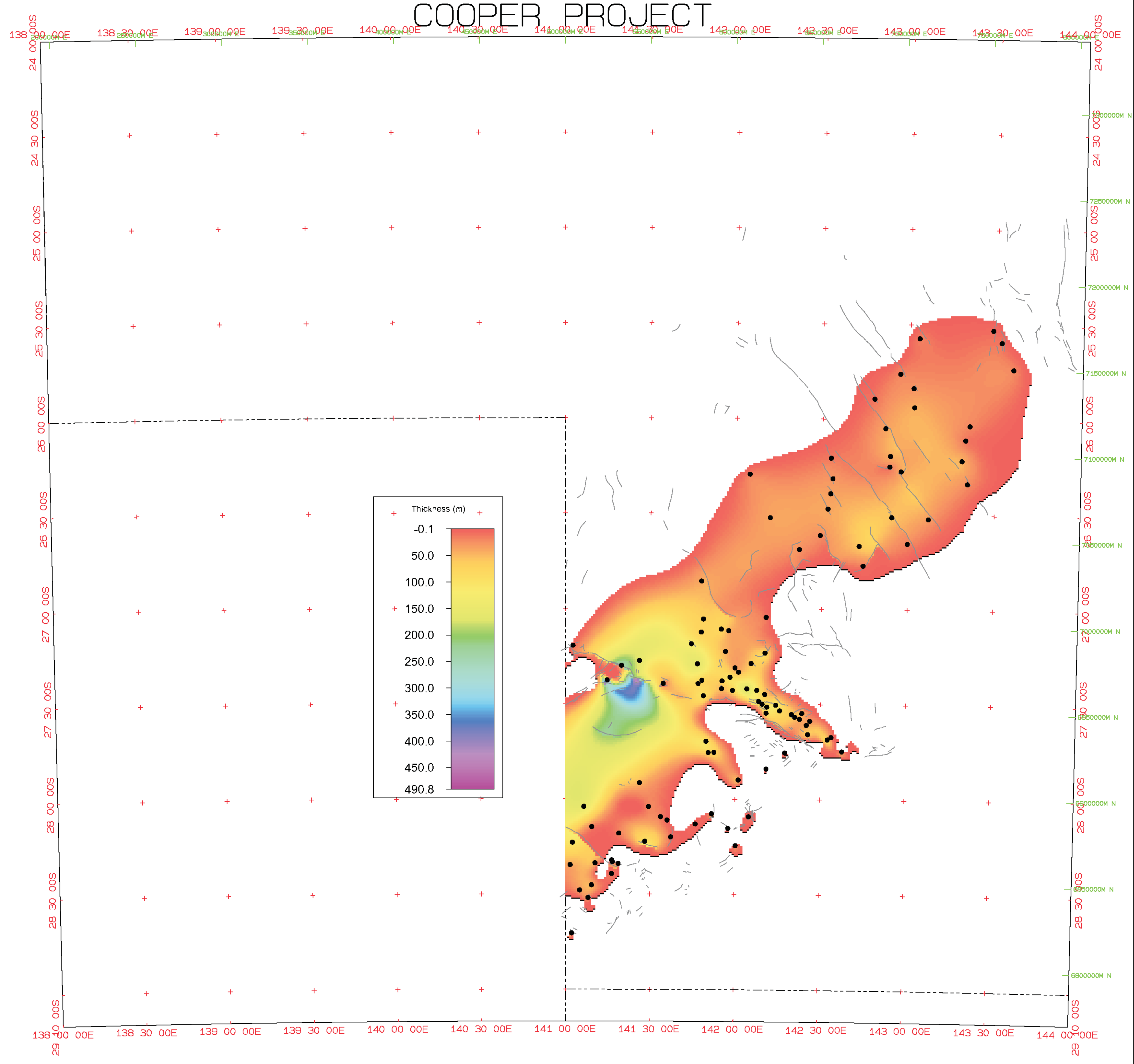
0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Patchawarra Sand Porosity

COOPER PROJECT



GO BACK

OPEN REPORT

Figure 17

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Patchawarra Formation Shale Isopach

COOPER PROJECT

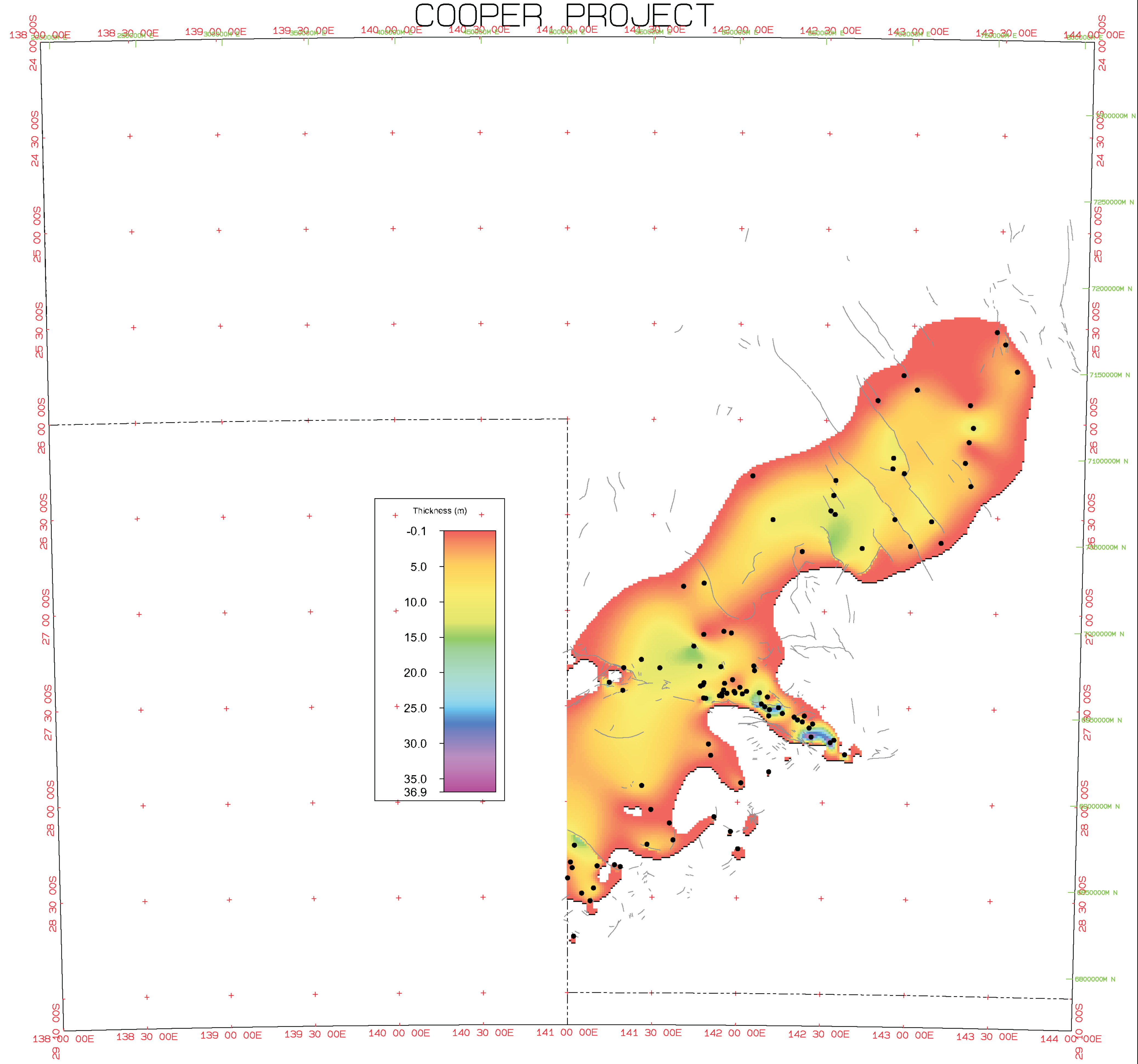


Figure 18

GO BACK

OPEN REPORT

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Patchawarra Formation Coal Isopach

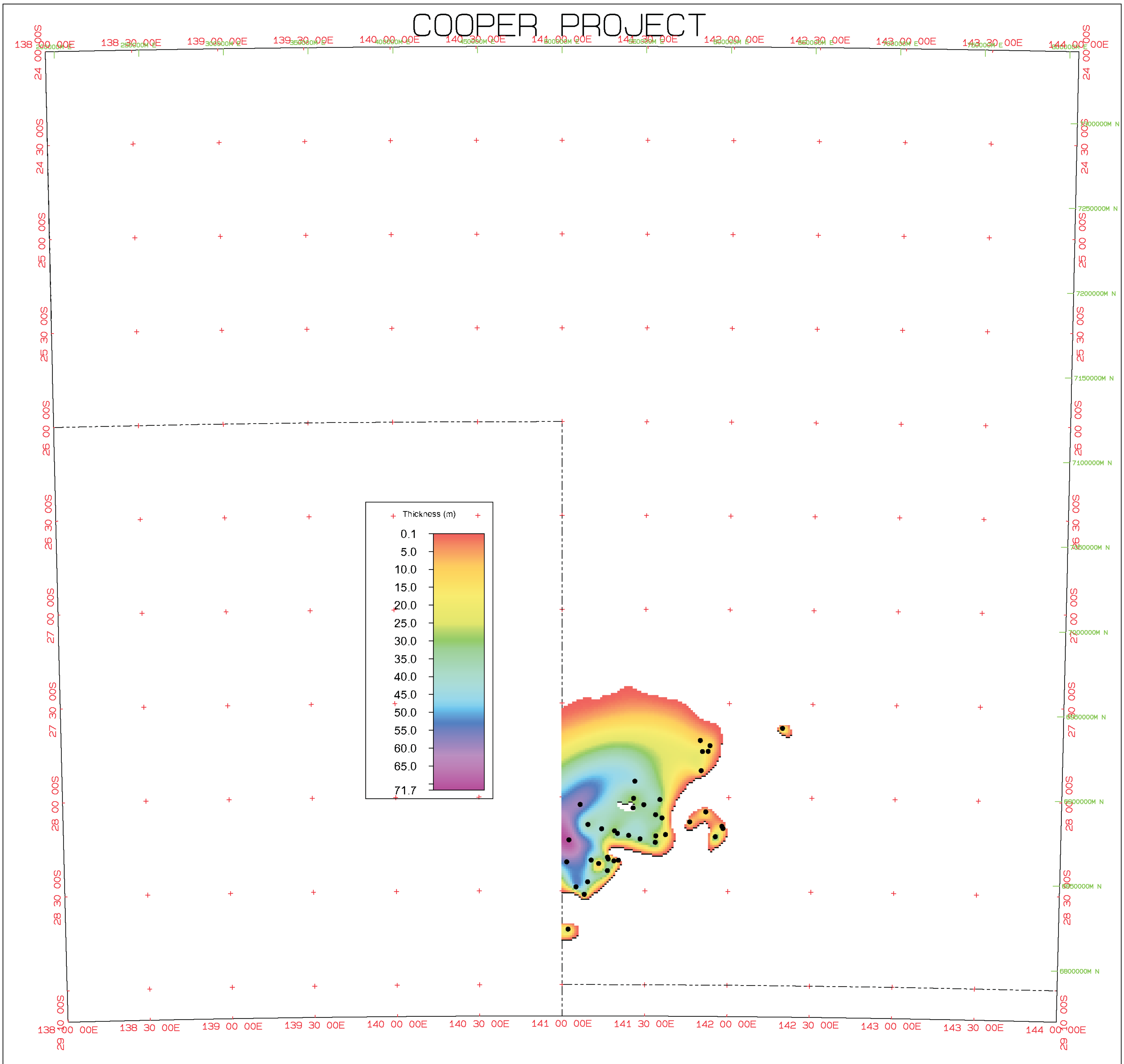


Figure 19

GO BACK

OPEN REPORT

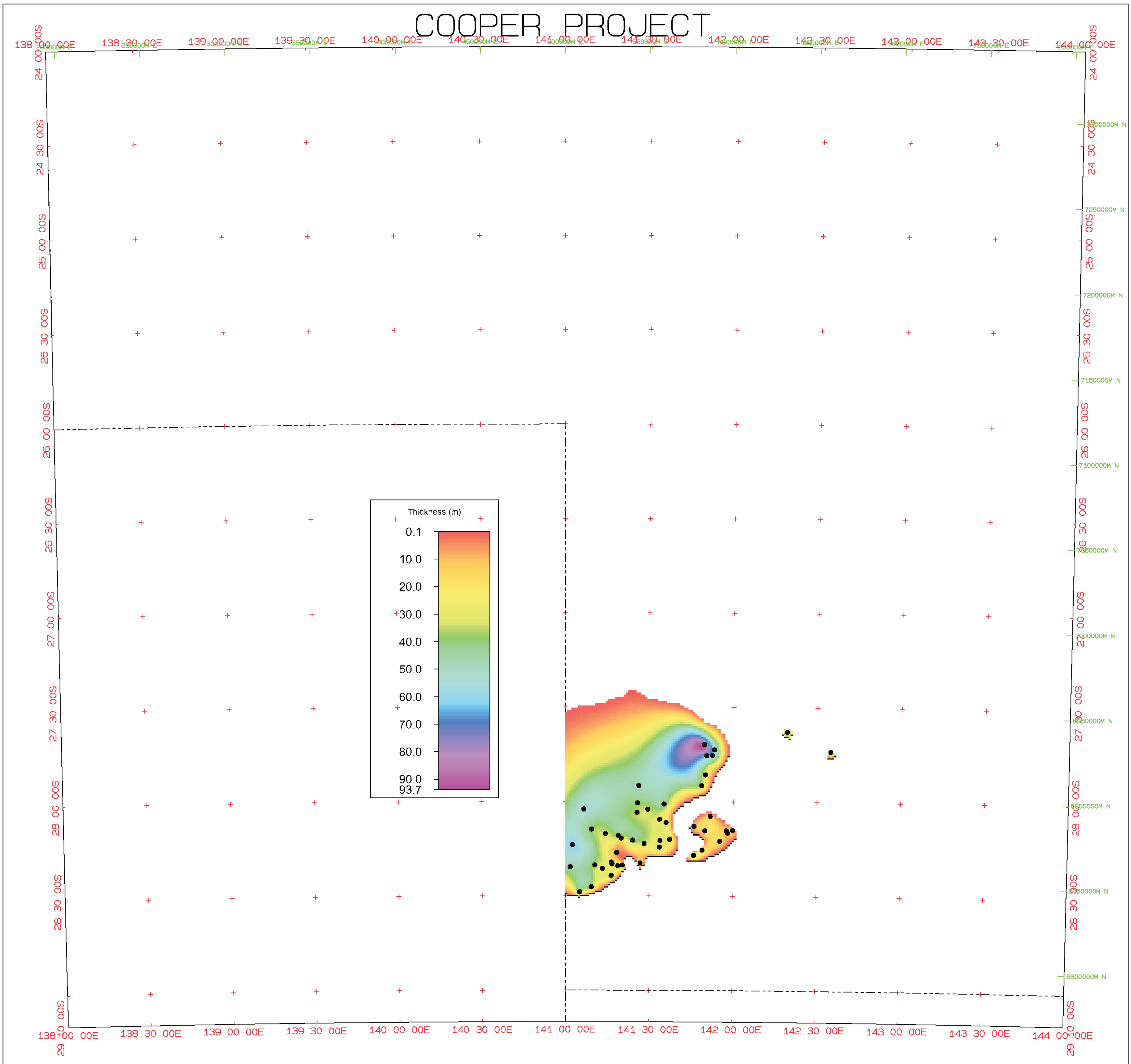
0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Murteree Shale Isopach

COOPER PROJECT



GO BACK

OPEN REPORT

Figure 20

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Epsilon Formation Isopach

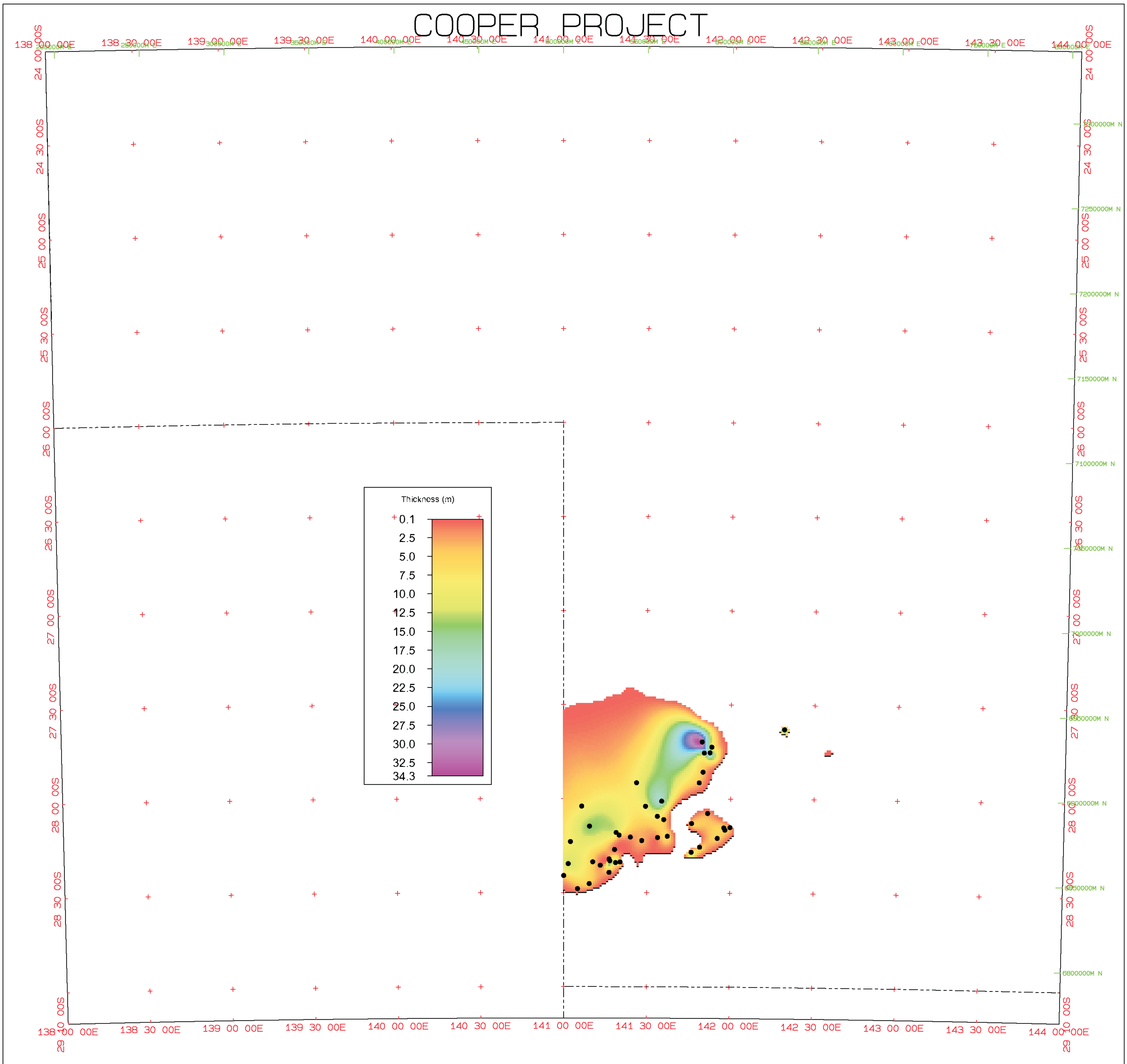


Figure 21

GO BACK

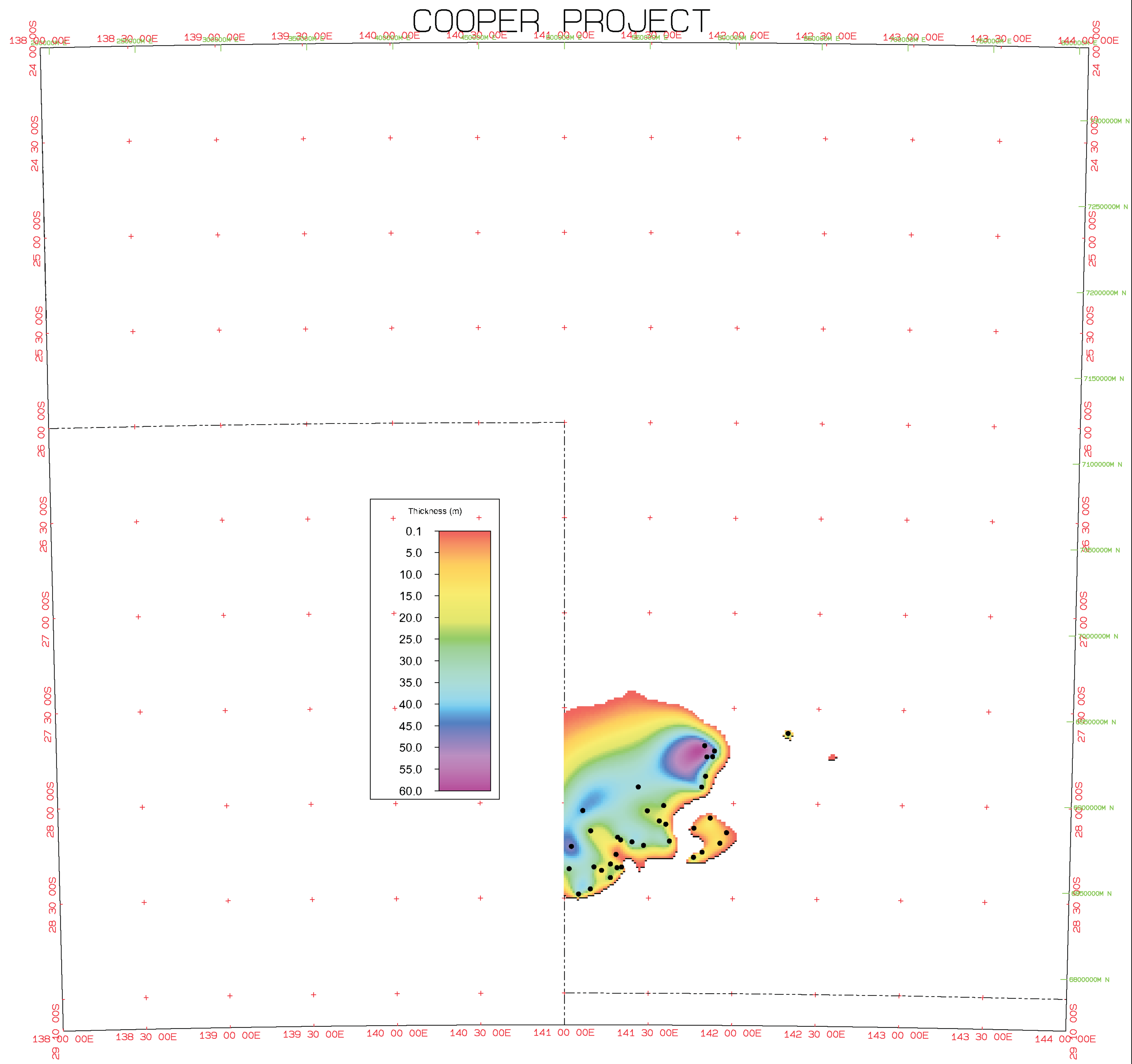
OPEN REPORT

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Epsilon Formation Sand Isopach



GO BACK

Figure 22

OPEN REPORT

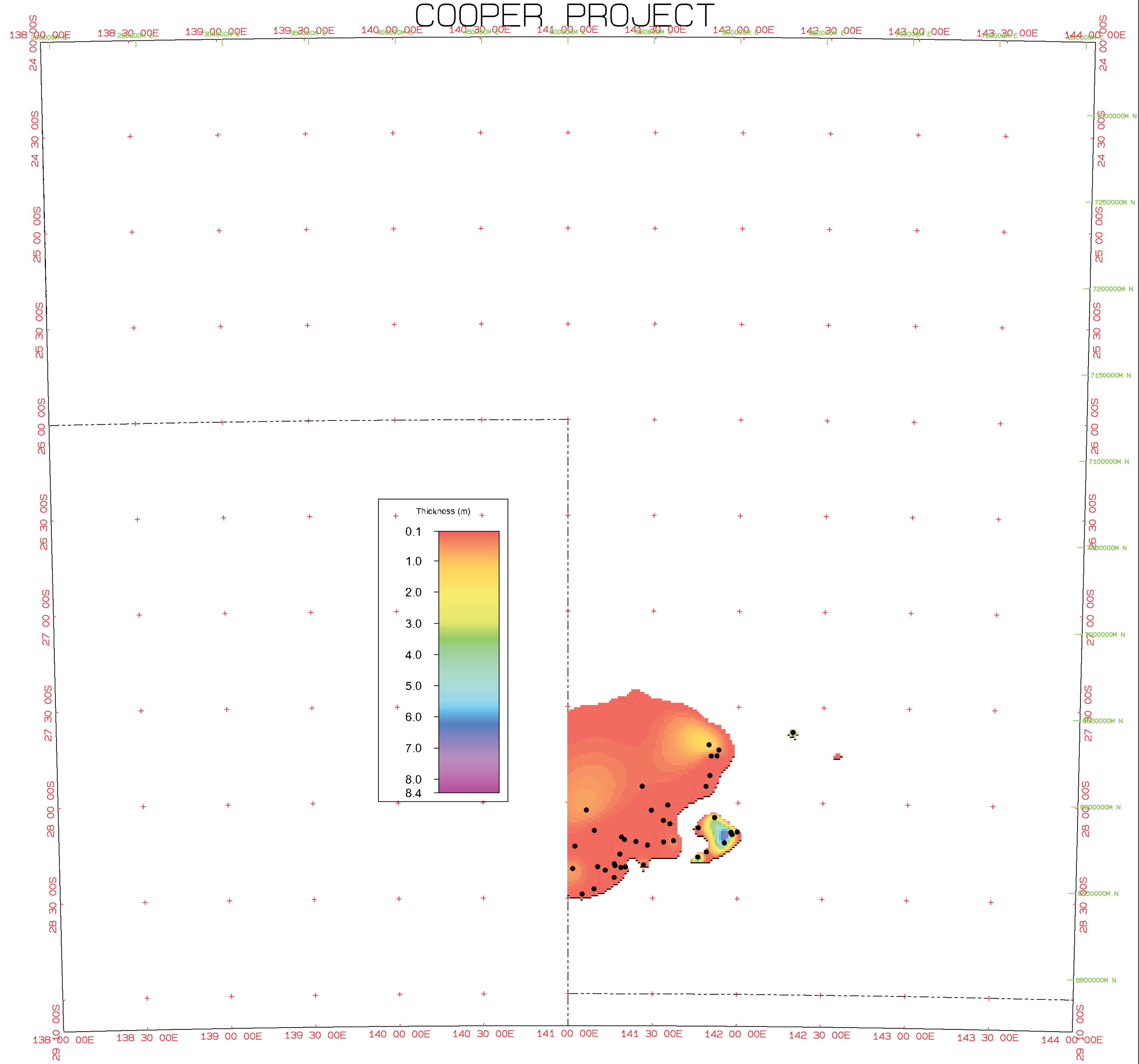
0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Epsilon Formation Shale Isopach

COOPER PROJECT



GO BACK

OPEN REPORT

Figure 23

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Epsilon Formation Coal Isopach

COOPER PROJECT

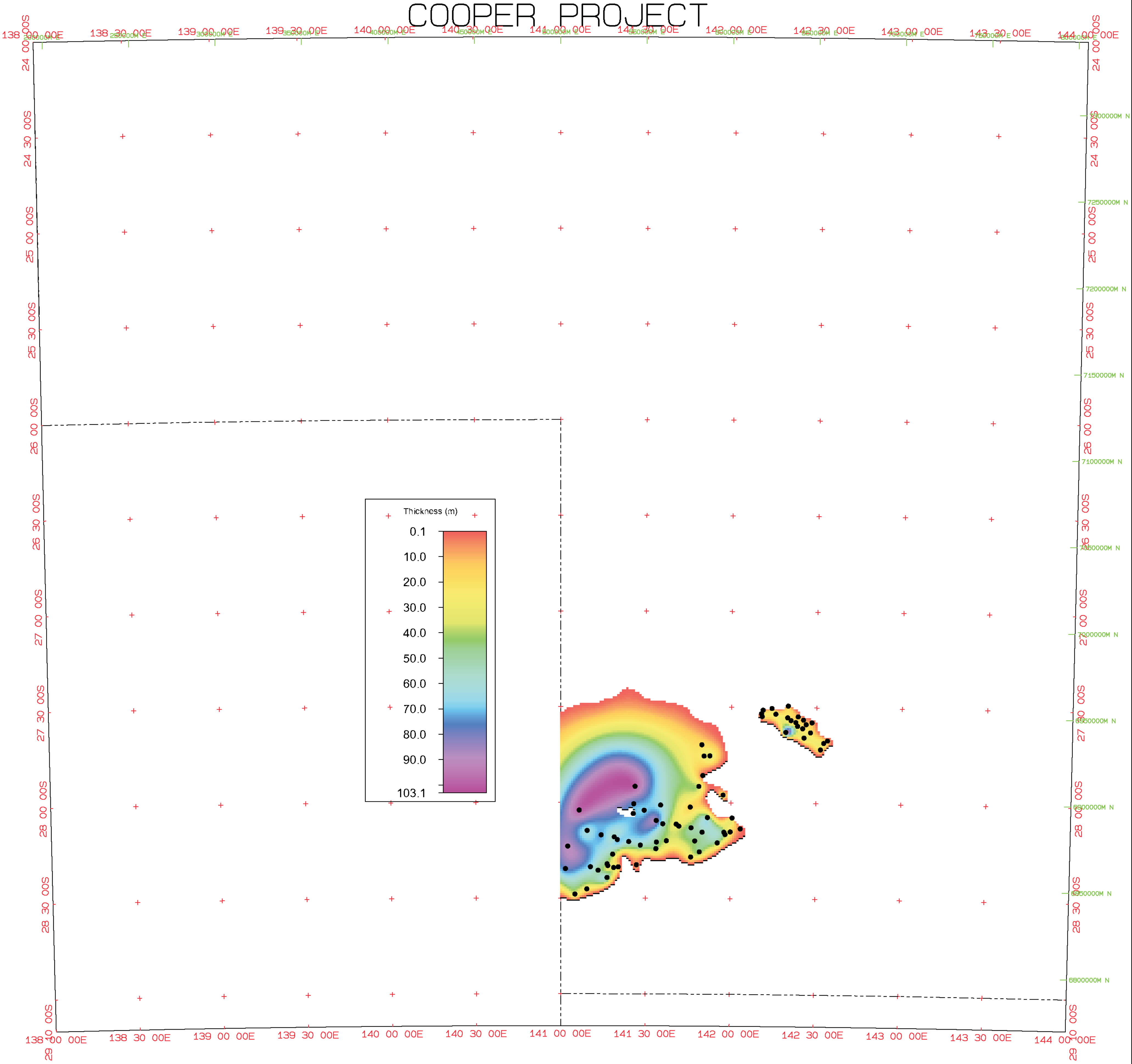


Figure 24

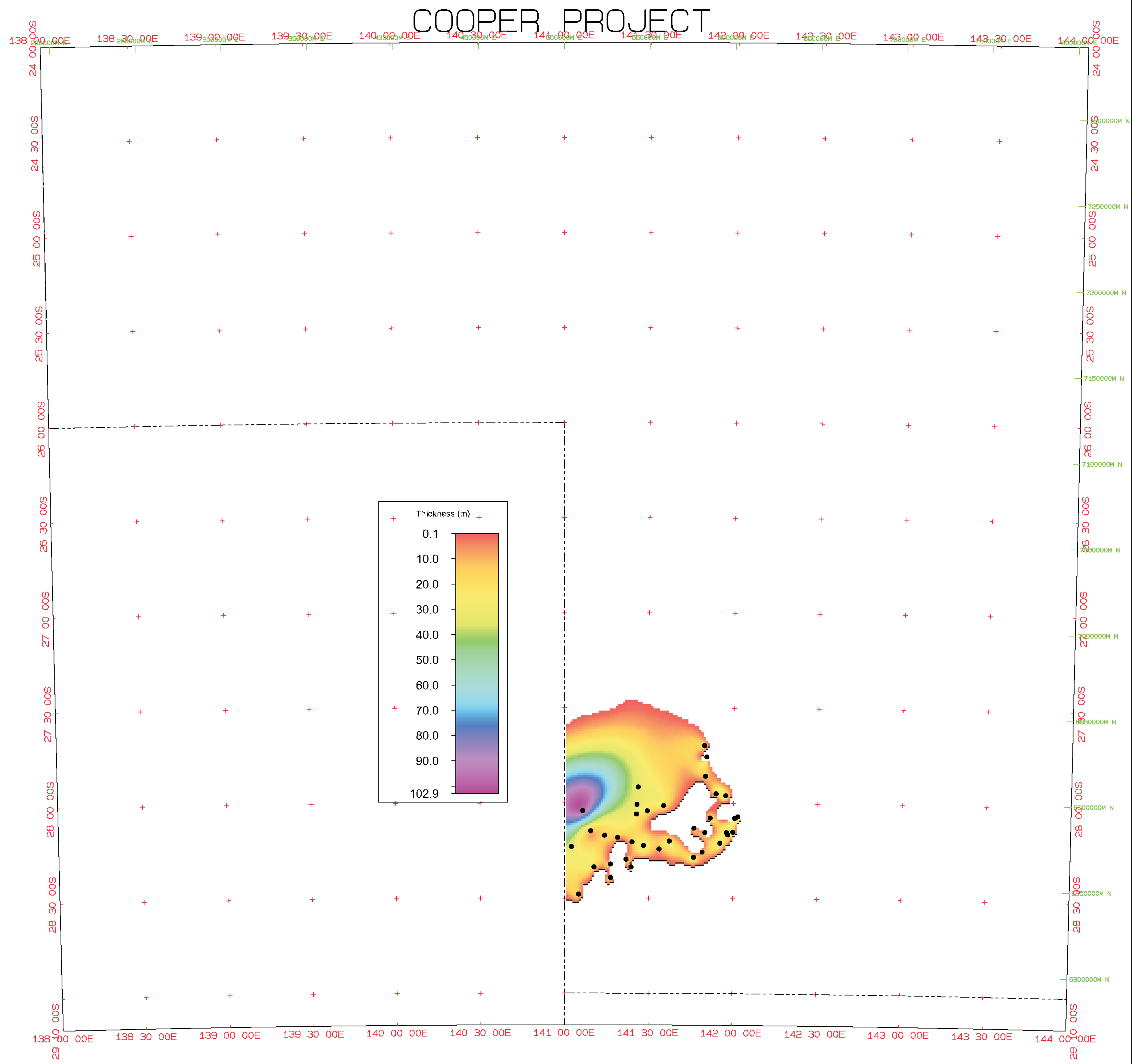
GO BACK

OPEN REPORT

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland
Roseneath Shale Isopach



GO BACK

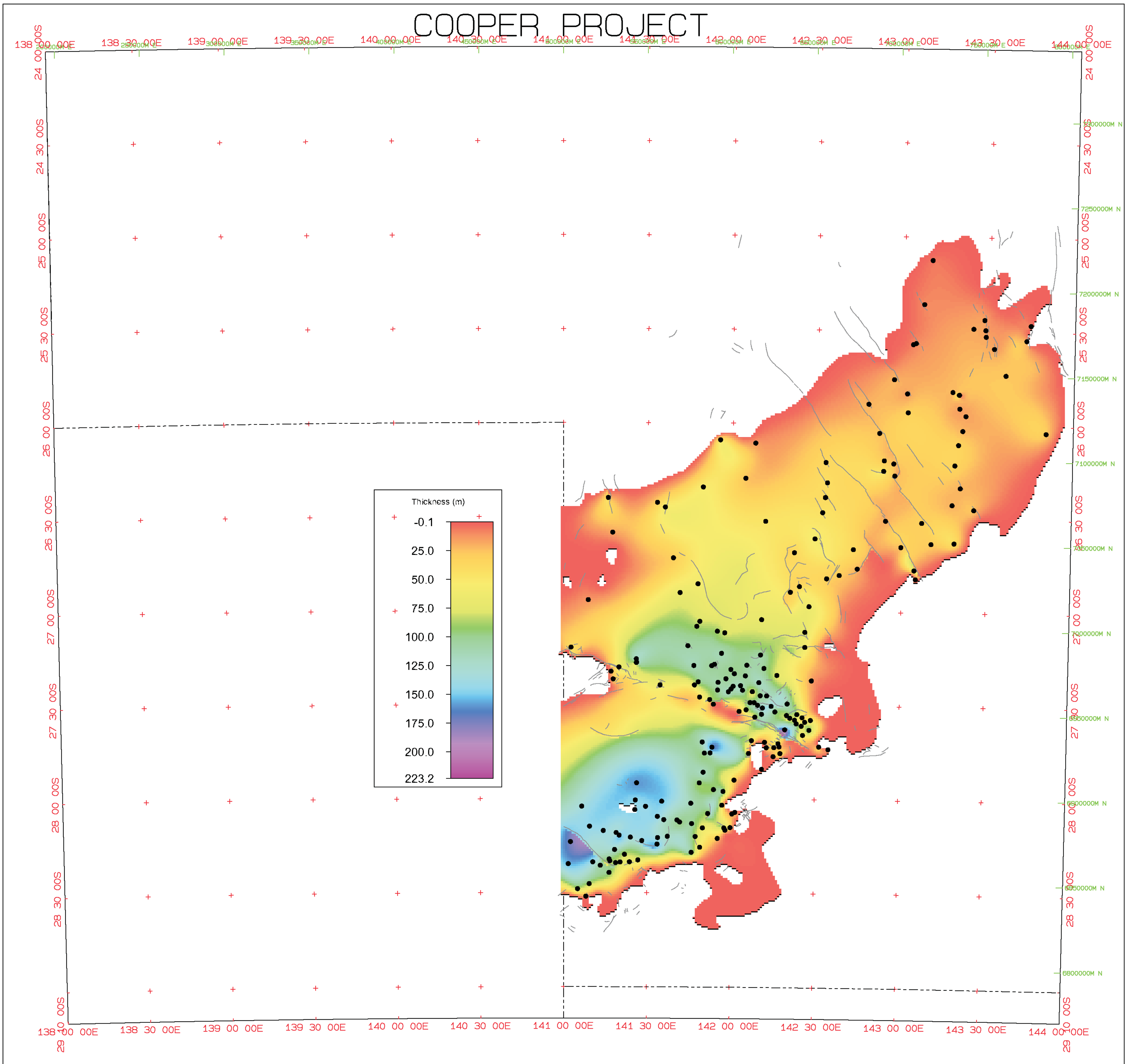
OPEN REPORT

Figure 25

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Daralingie Formation Isopach		



GO BACK

OPEN REPORT

Figure 26

0 20 40 60 80 100

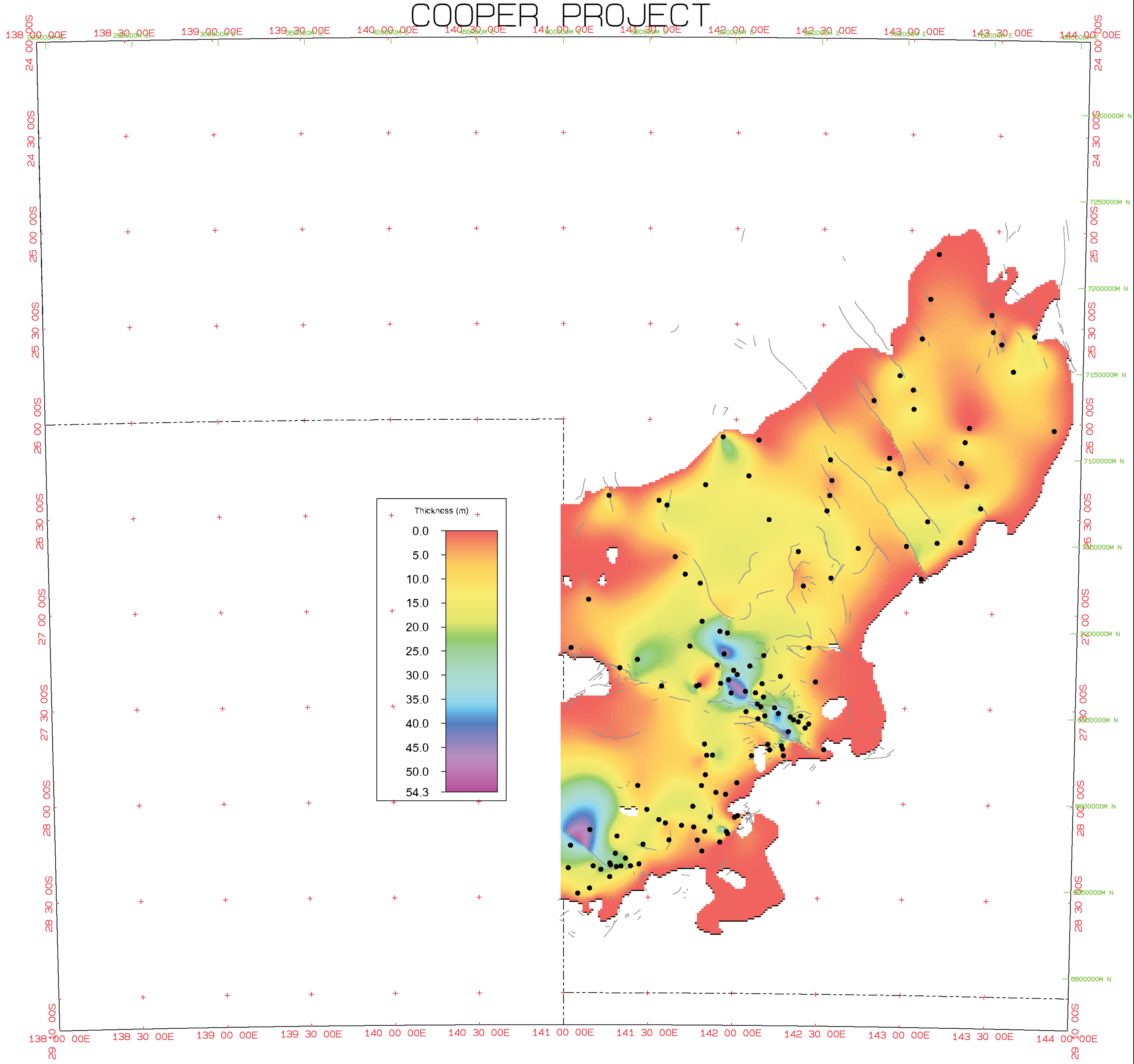
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Toolachee Formation Isopach

COOPER PROJECT



GO BACK

OPEN REPORT

Figure 27

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION

AUSTRALIAN NATIONAL SPHEROID

CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Toolachee Formation Sand Isopach		

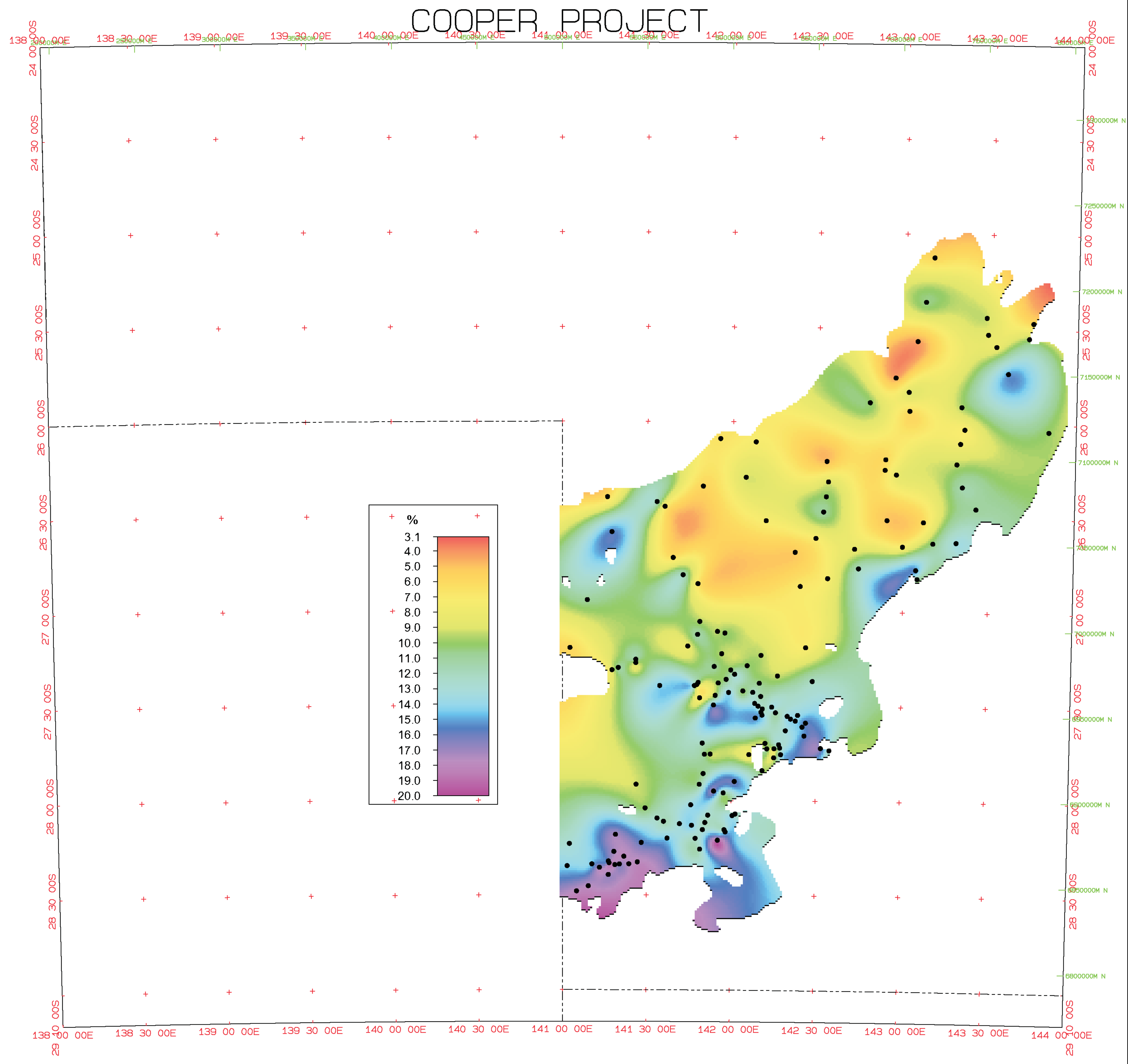


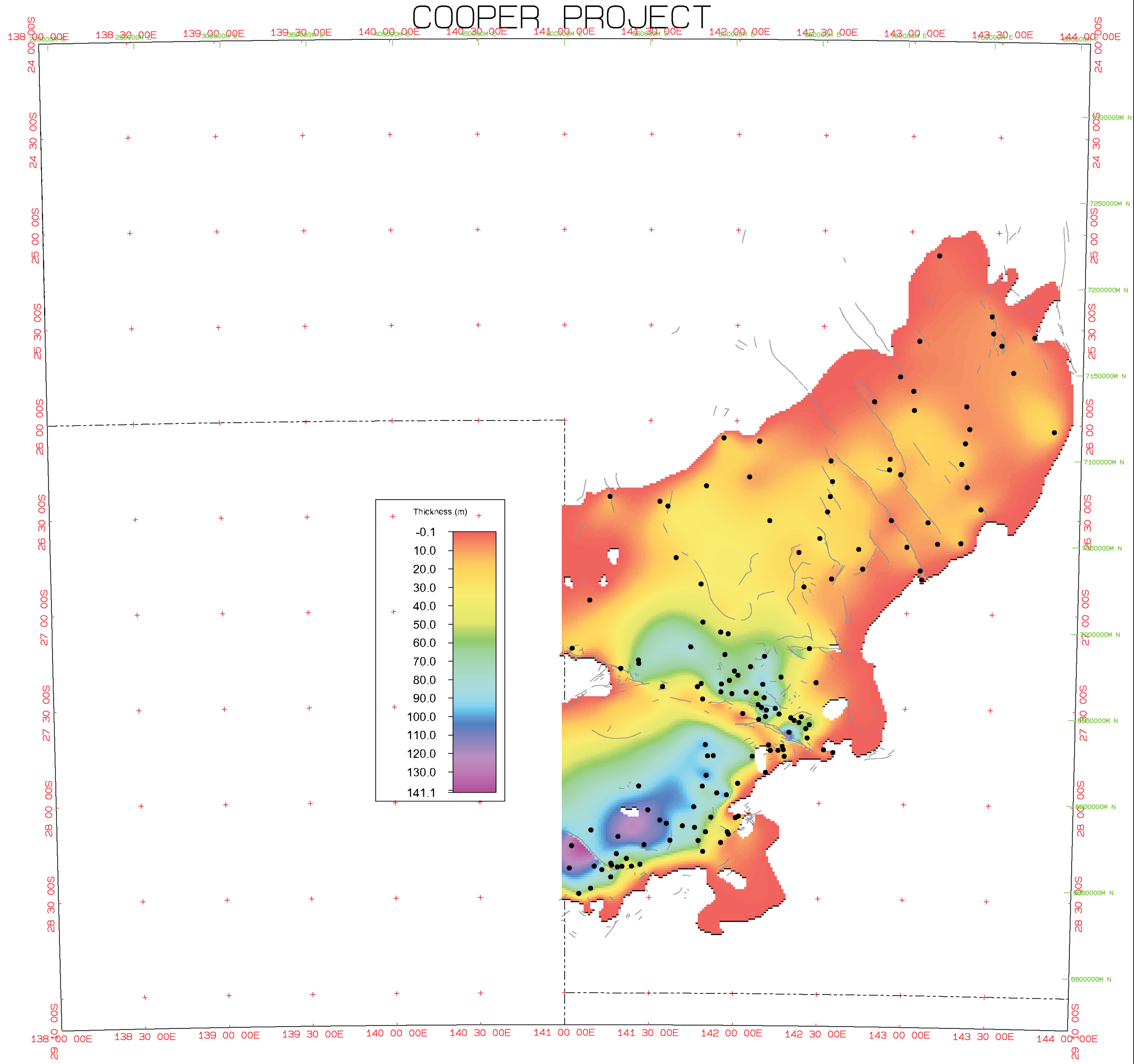
Figure 28

GO BACK

OPEN REPORT

0 20 40 60 80 100
KILOMETRES
UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Toolachee Formation Sand Porosity		



GO BACK

OPEN REPORT

Figure 29

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Toolachee Formation Shale Isopach

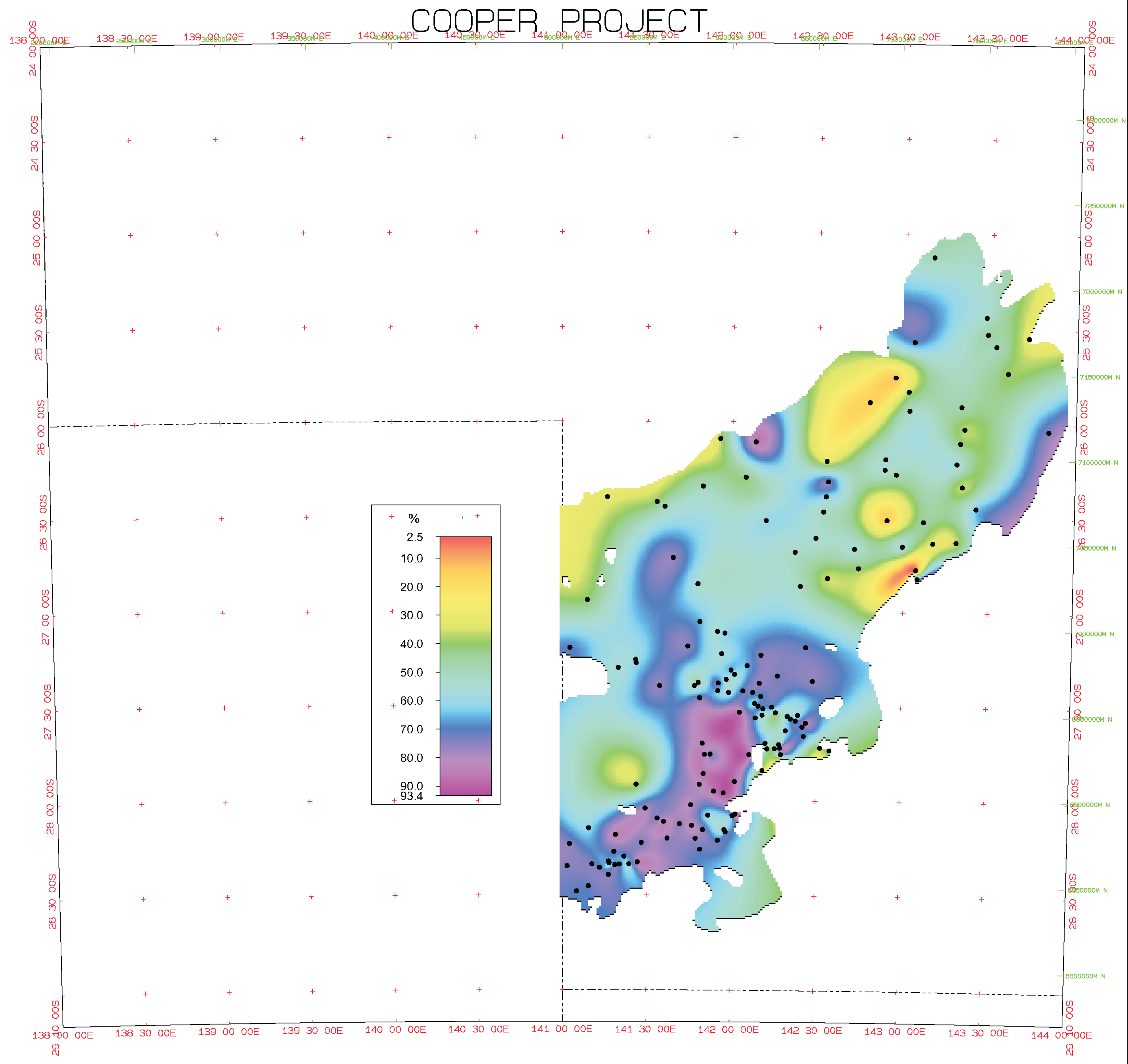


Figure 30

GO BACK

OPEN REPORT

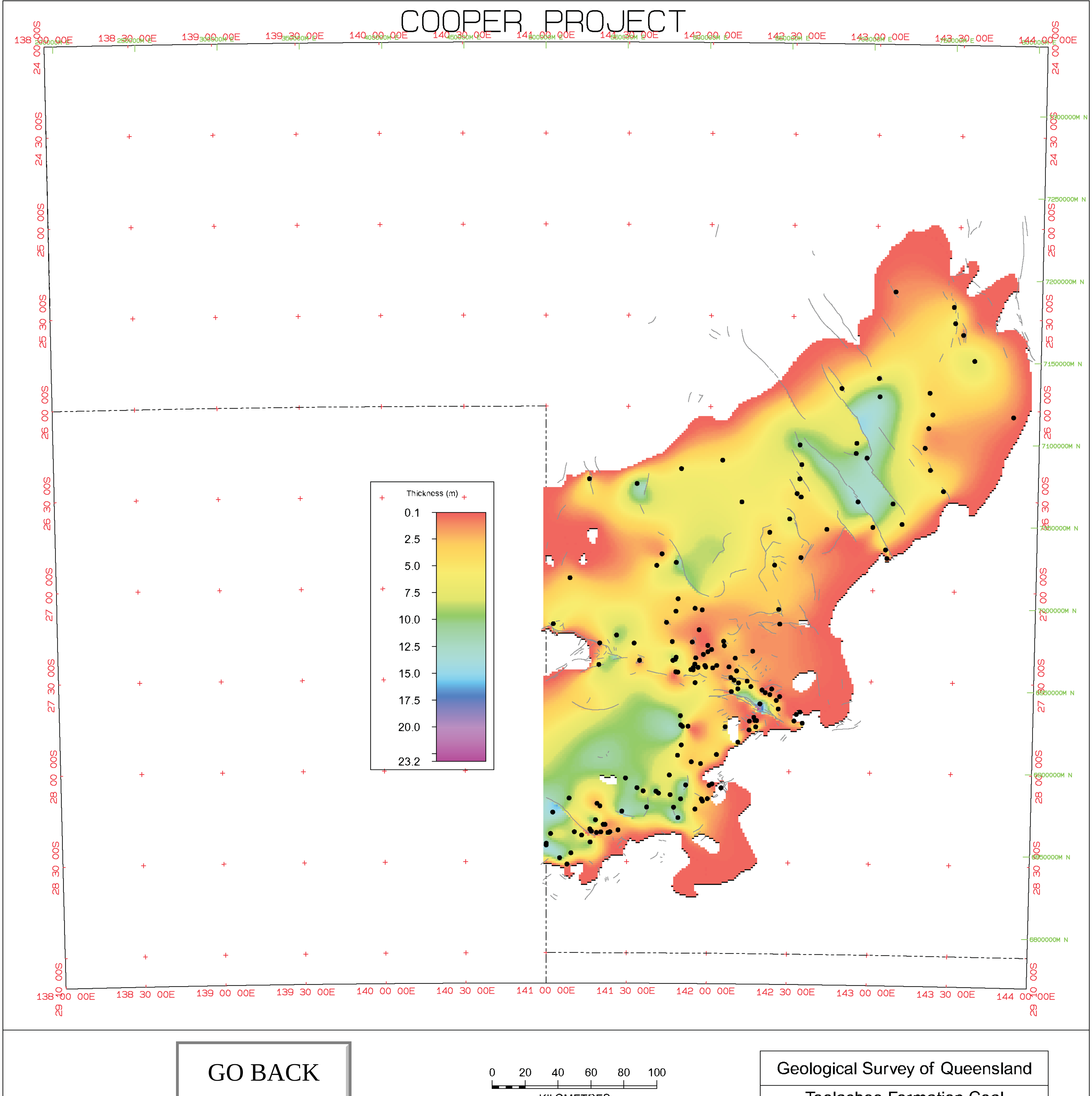
0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Toolachee Formation Shale Percent



GO BACK

Figure 31

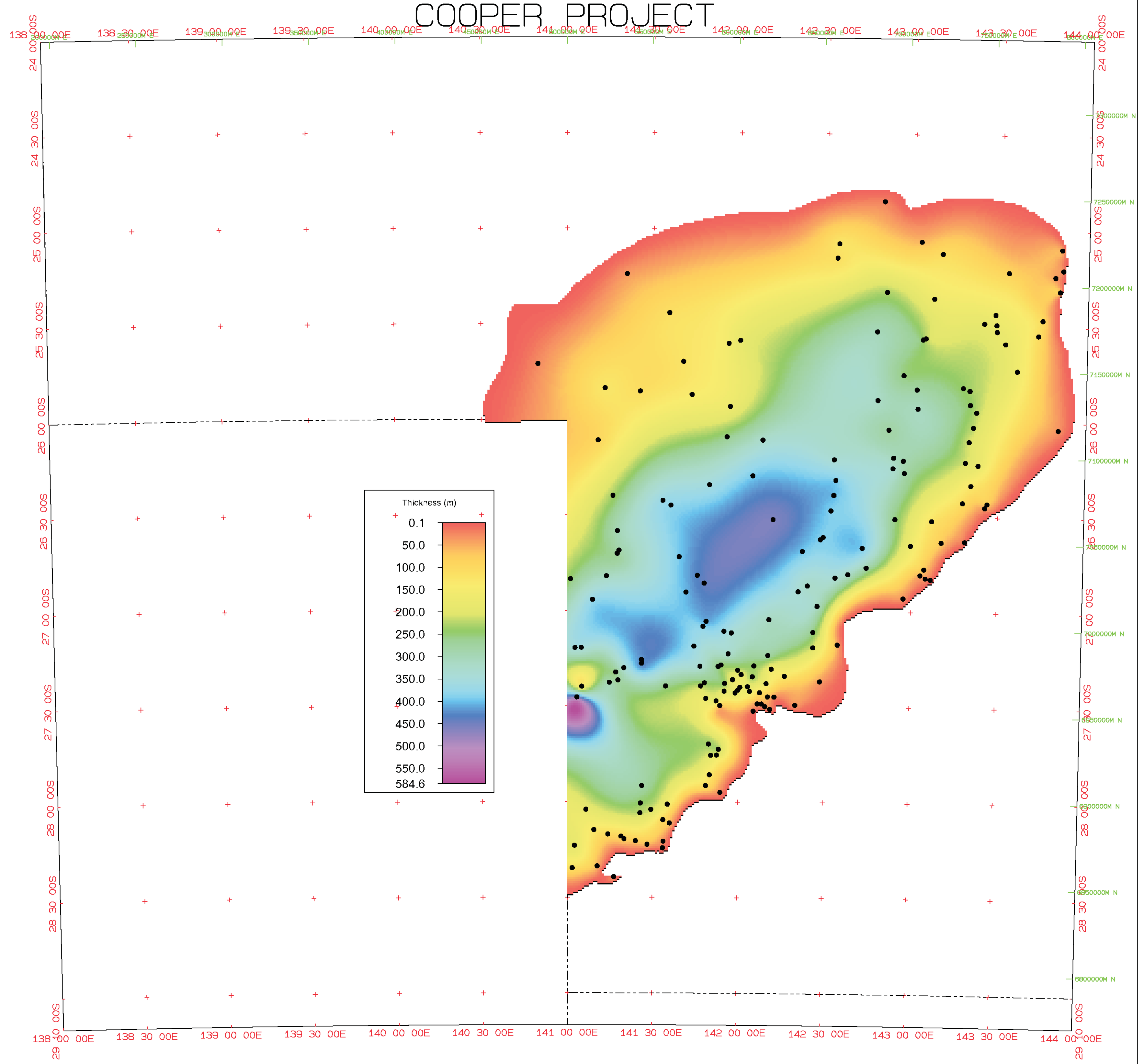
OPEN REPORT

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Toolachee Formation Coal Isopach

COOPER PROJECT



GO BACK

OPEN REPORT

Figure 32

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Nappamerri Group Isopach

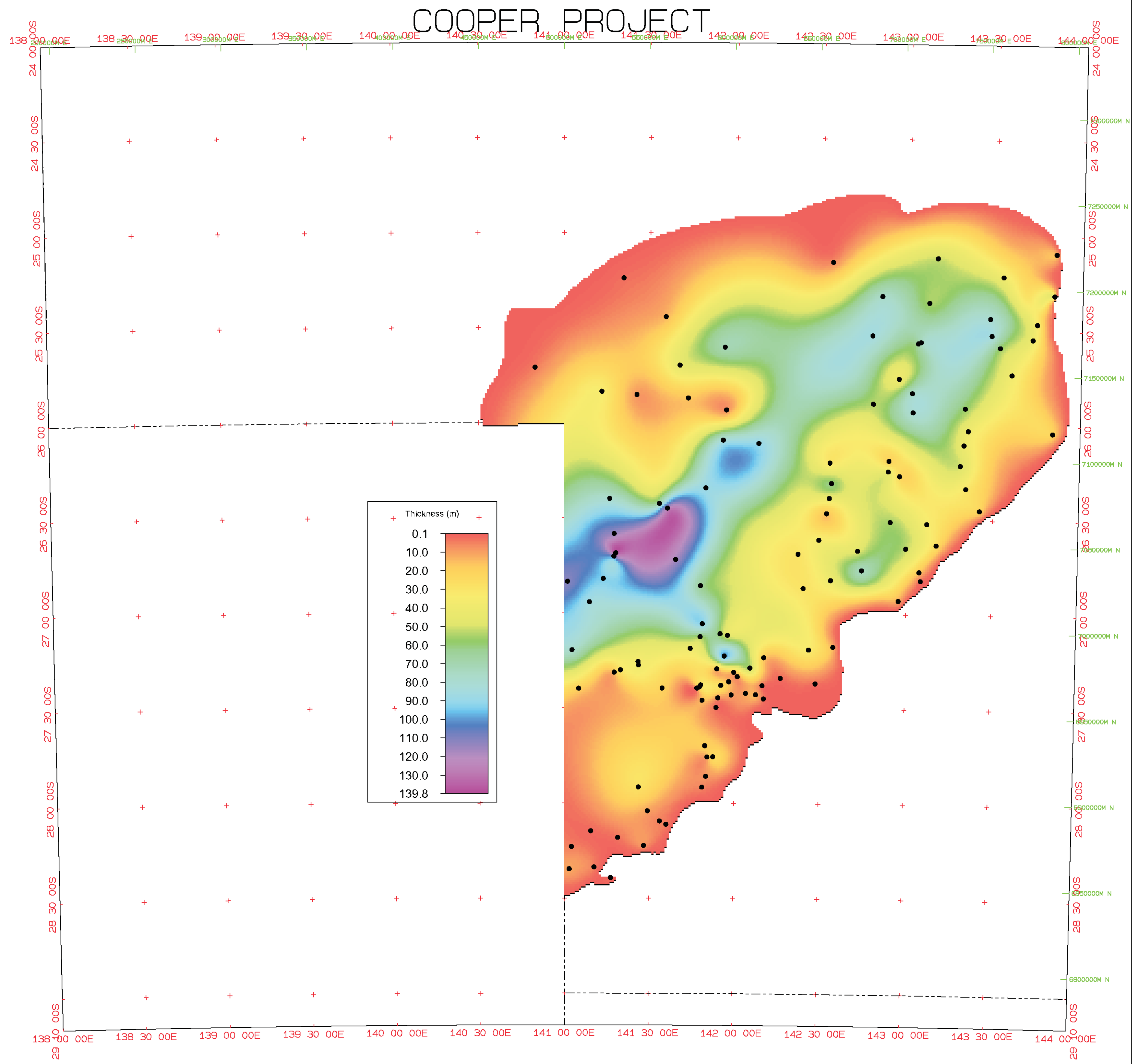


Figure 33

GO BACK

OPEN REPORT

0 20 40 60 80 100

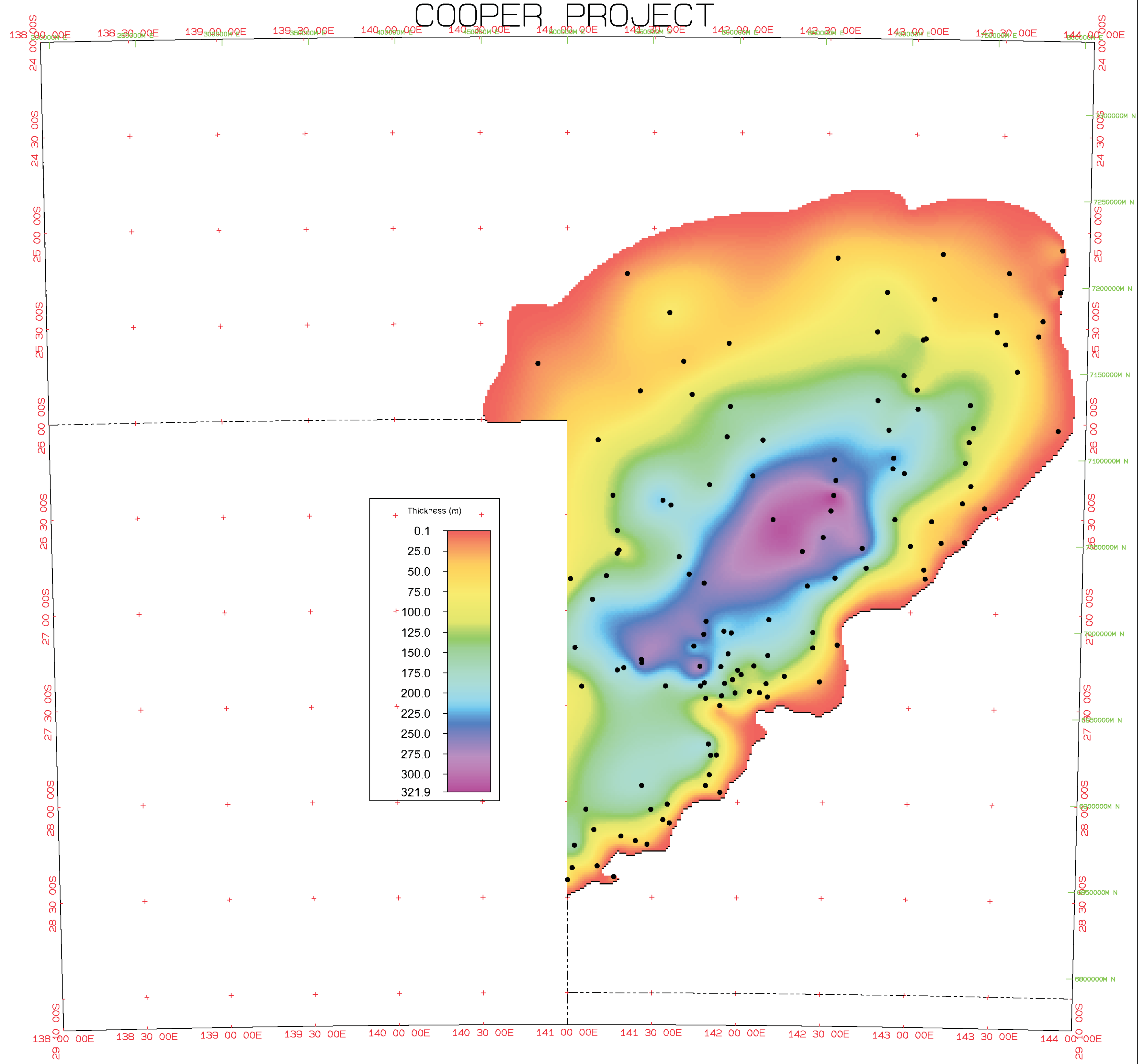
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Nappamerri Group Sand Isopach

COOPER PROJECT



GO BACK

OPEN REPORT

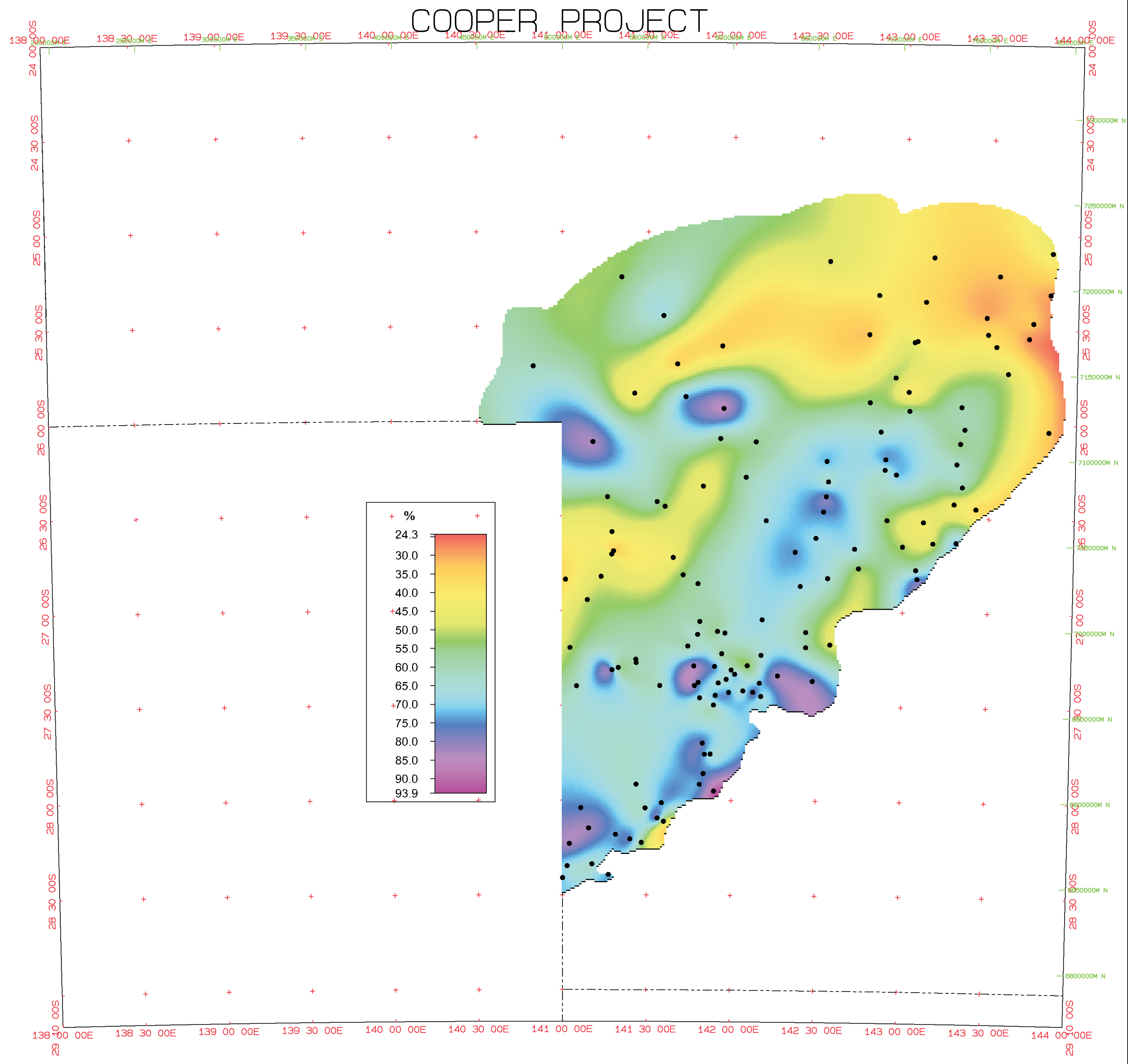
Figure 34

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Nappamerri Group Shale Isopach



GO BACK

OPEN REPORT

Figure 35

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION

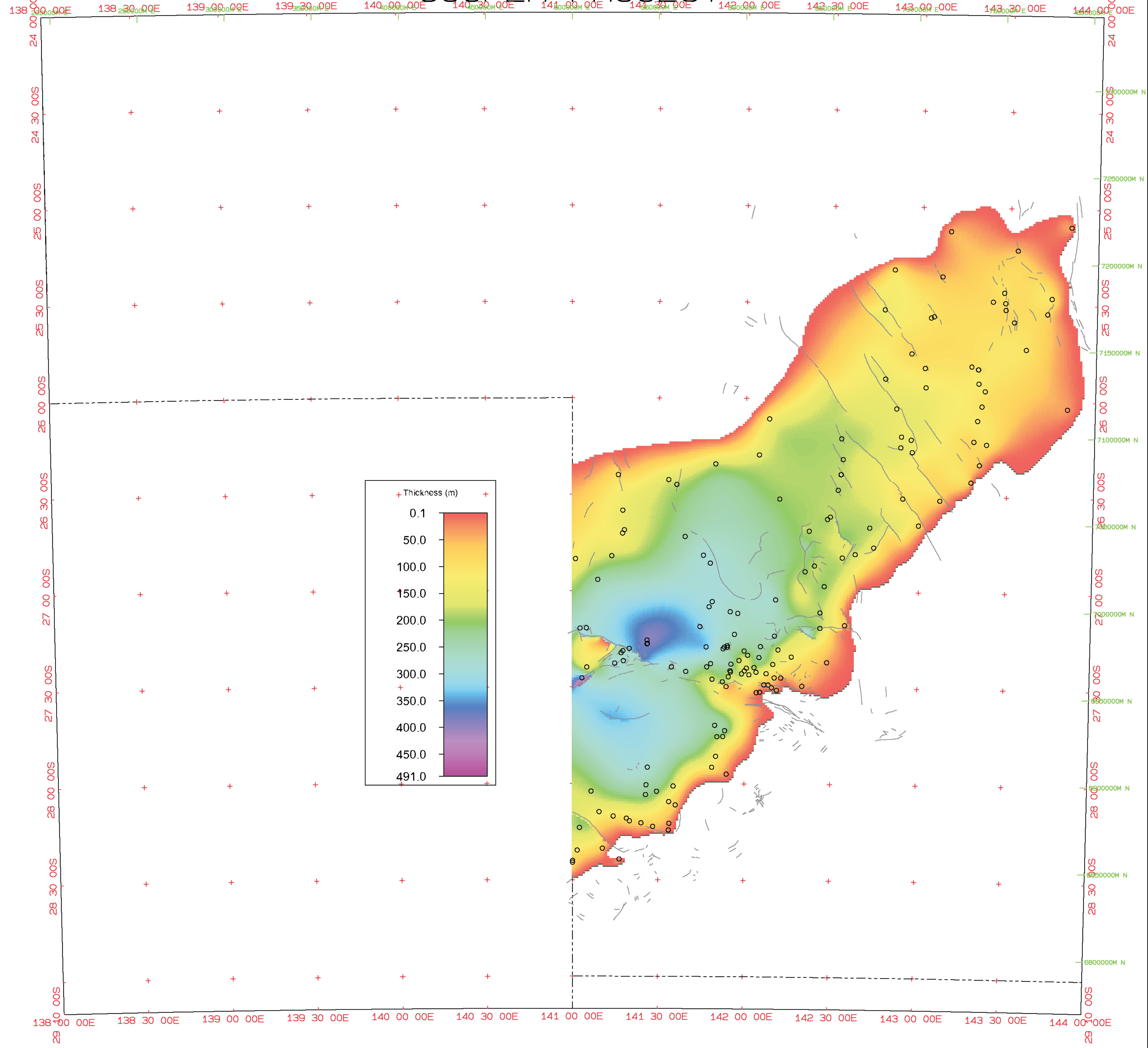
AUSTRALIAN NATIONAL SPHEROID

CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Nappamerri Group Shale Percent

COOPER PROJECT



GO BACK

OPEN REPORT

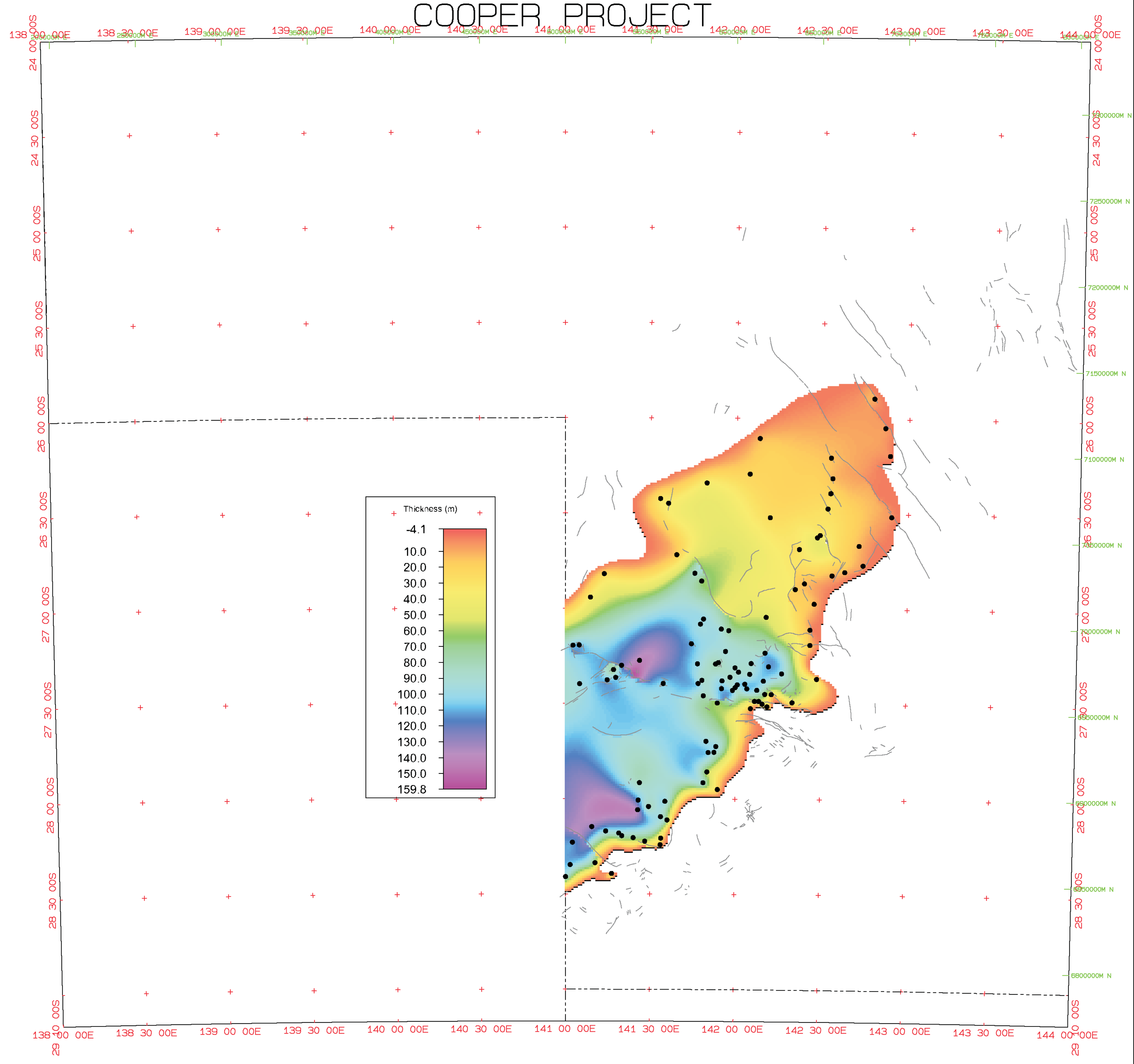
Figure 36

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Arrabury Formation Isopach		

COOPER PROJECT



GO BACK

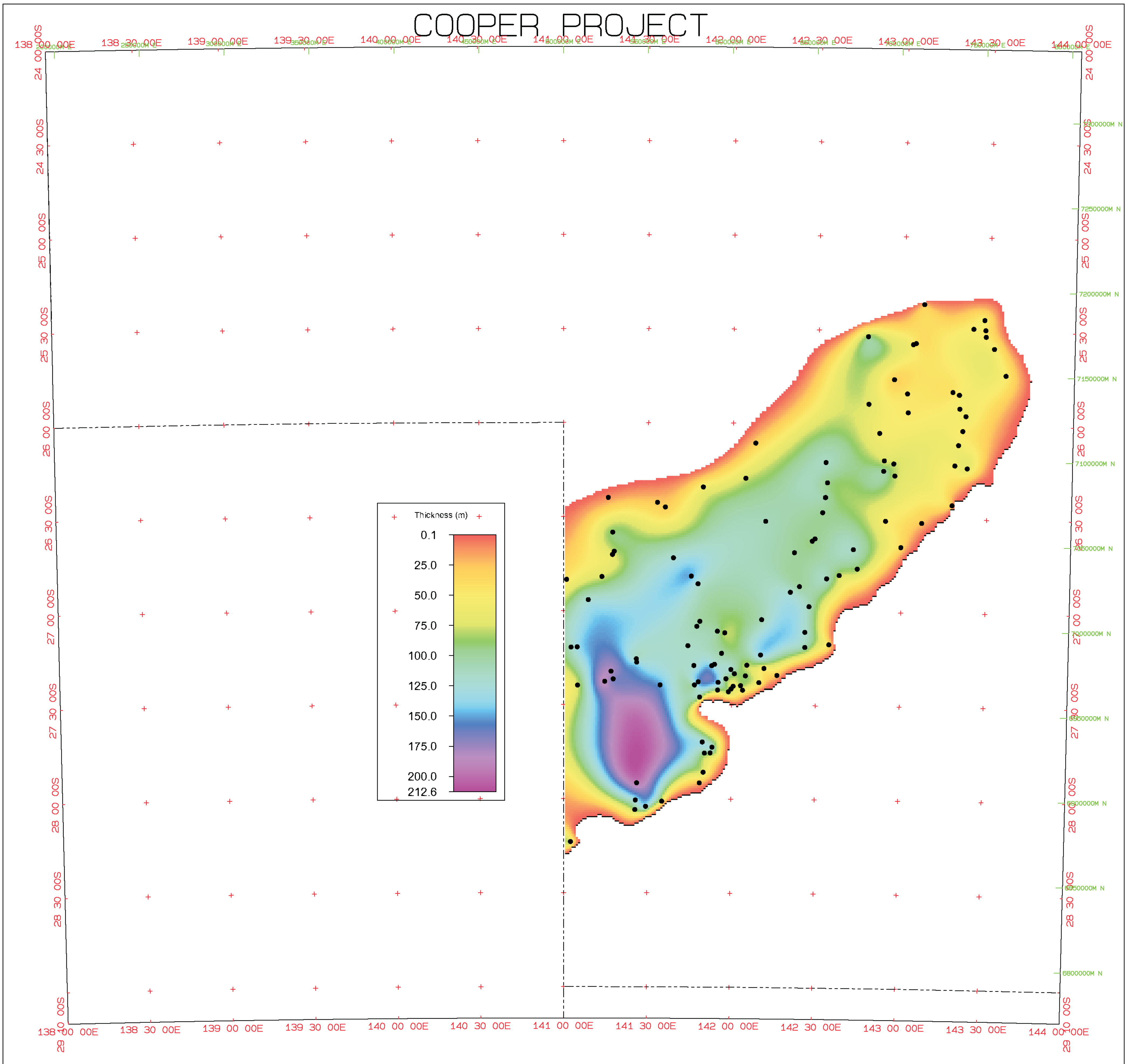
OPEN REPORT

Figure 37

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Callamurra Member Isopach		



GO BACK

OPEN REPORT

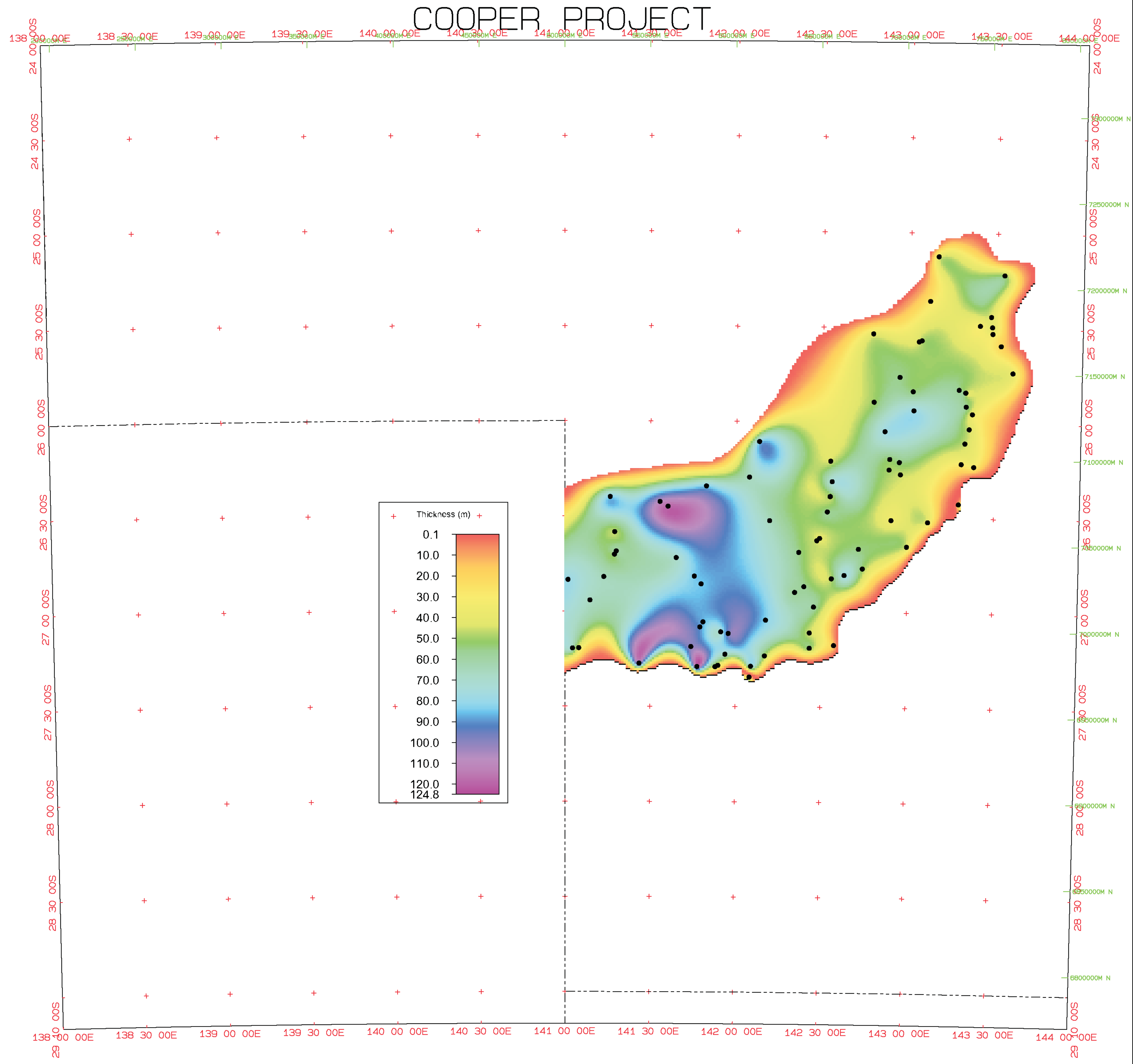
Figure 38

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Paning Member Isopach



GO BACK

OPEN REPORT

Figure 39

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Wimma Sandstone Member Isopach

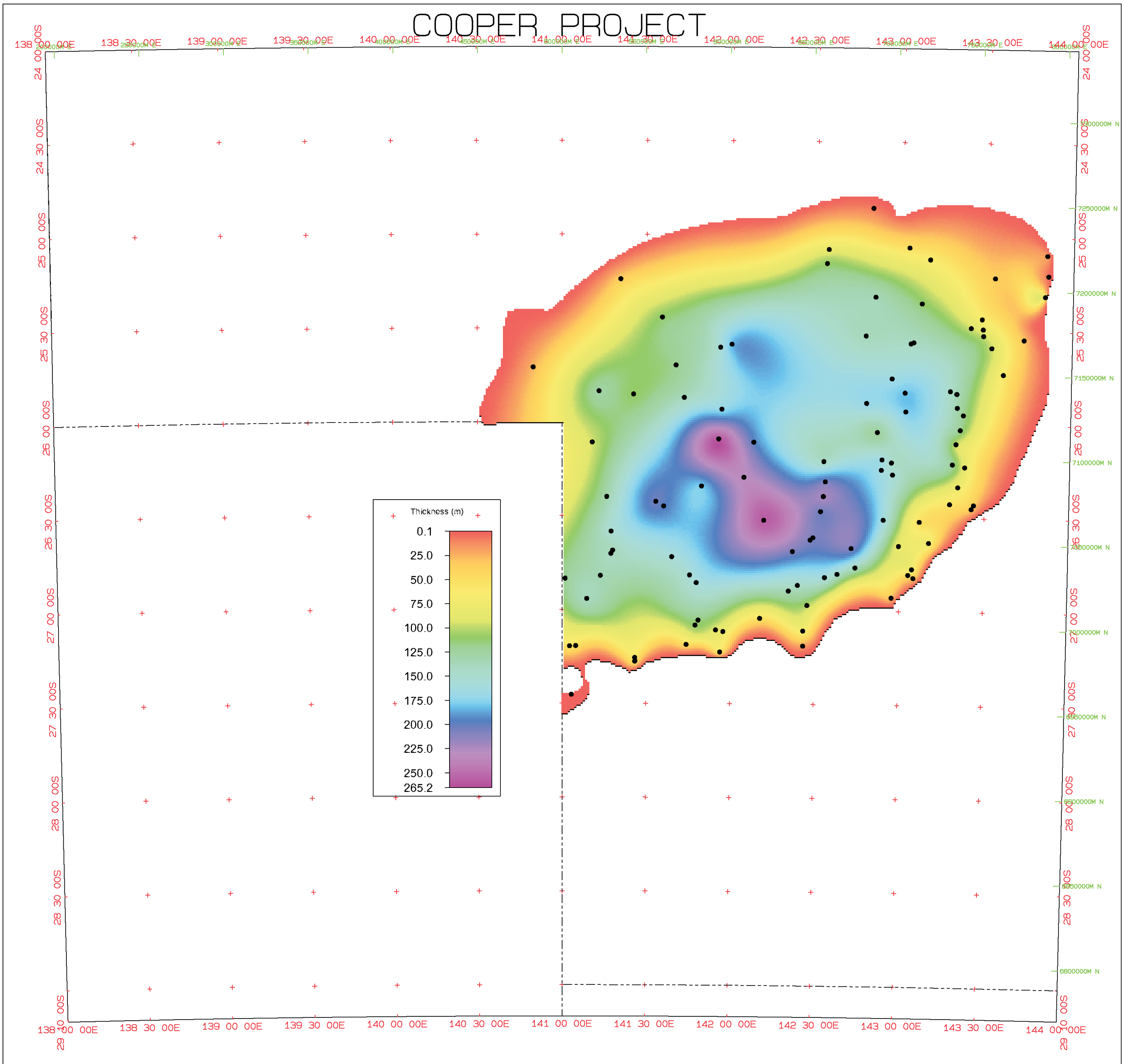


Figure 40

GO BACK

OPEN REPORT

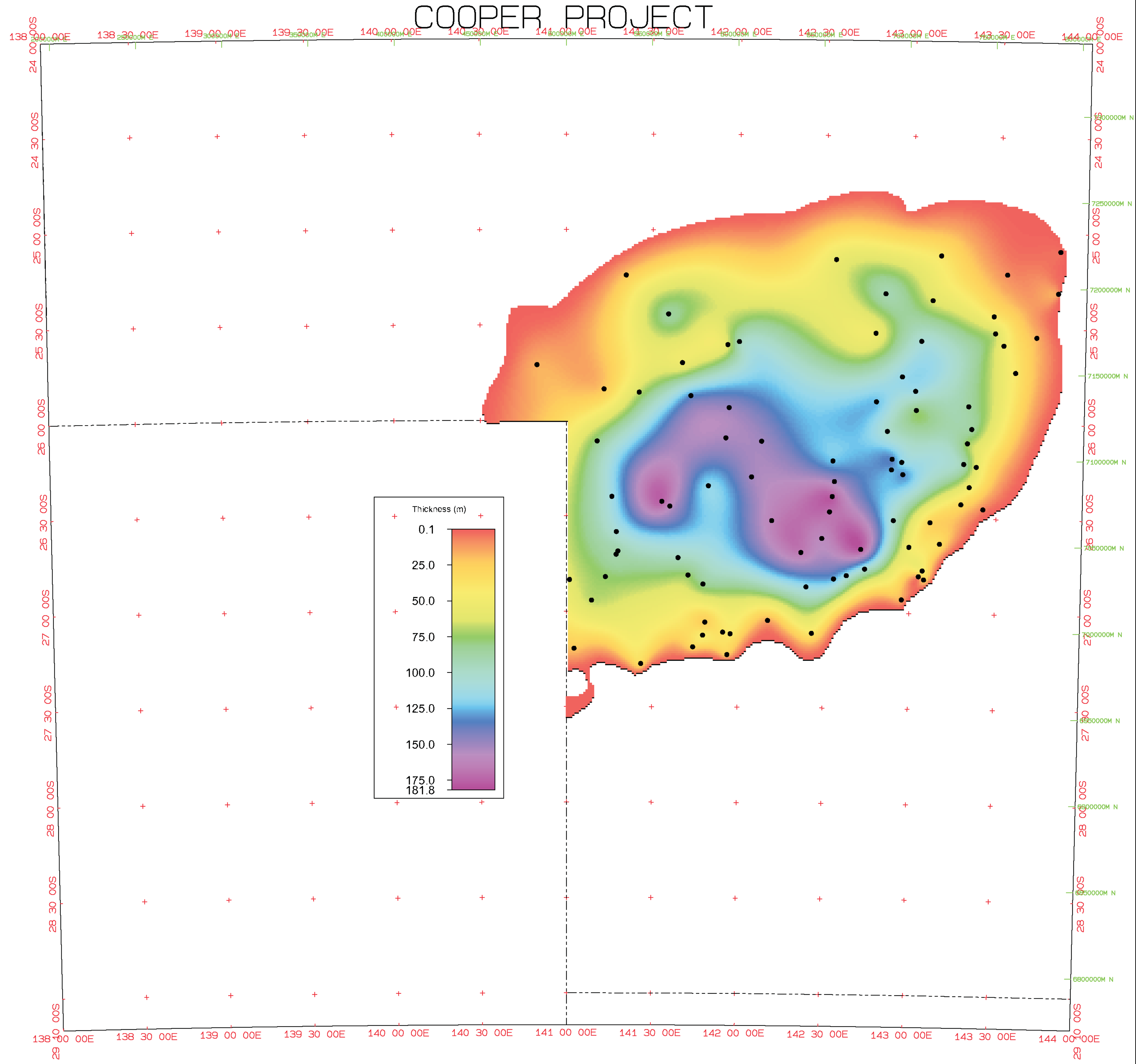
0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Tinchoo Formation Isopach



GO BACK

OPEN REPORT

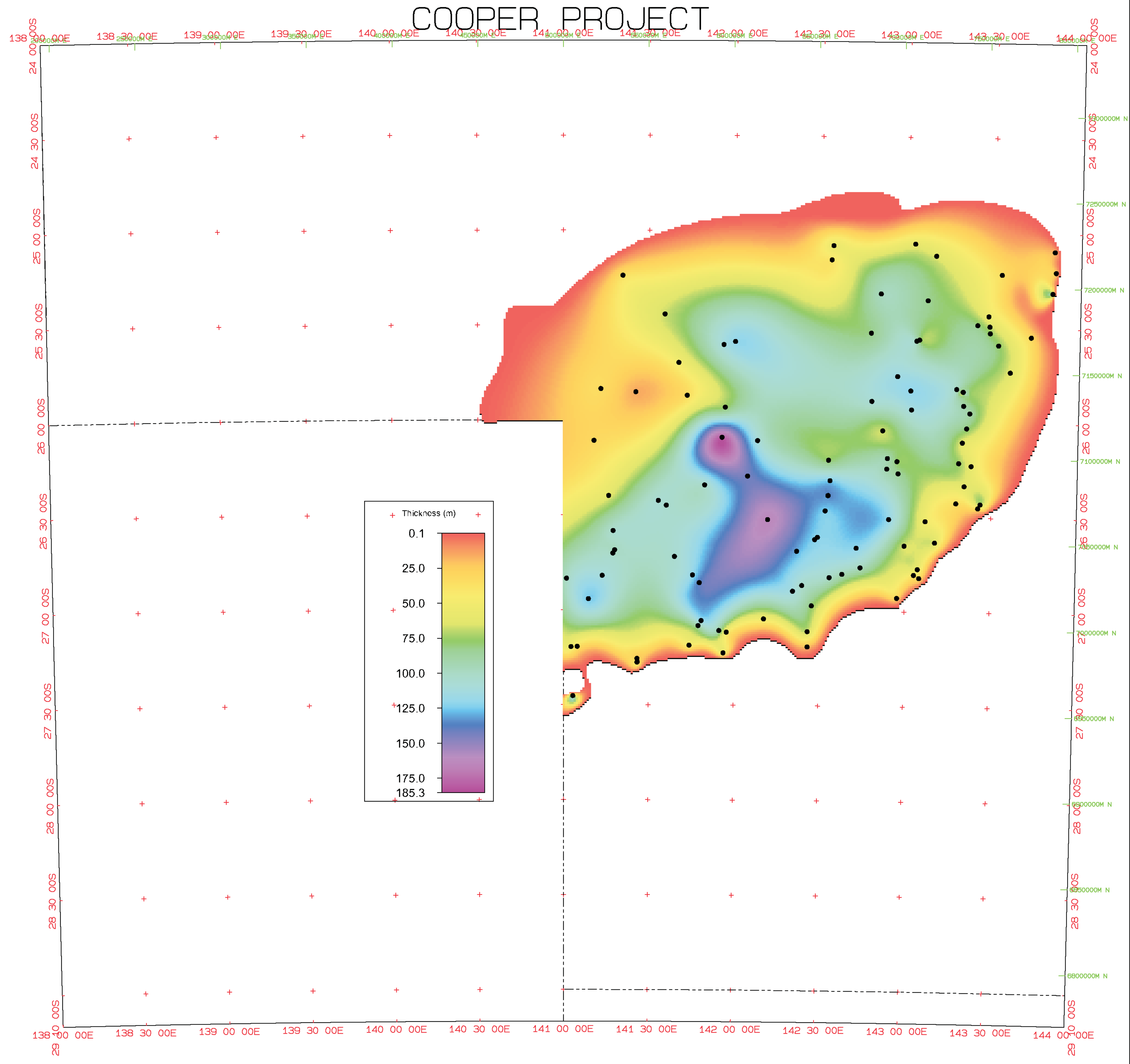
Figure 41

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Tinchoo Formation Shale Isopach



GO BACK

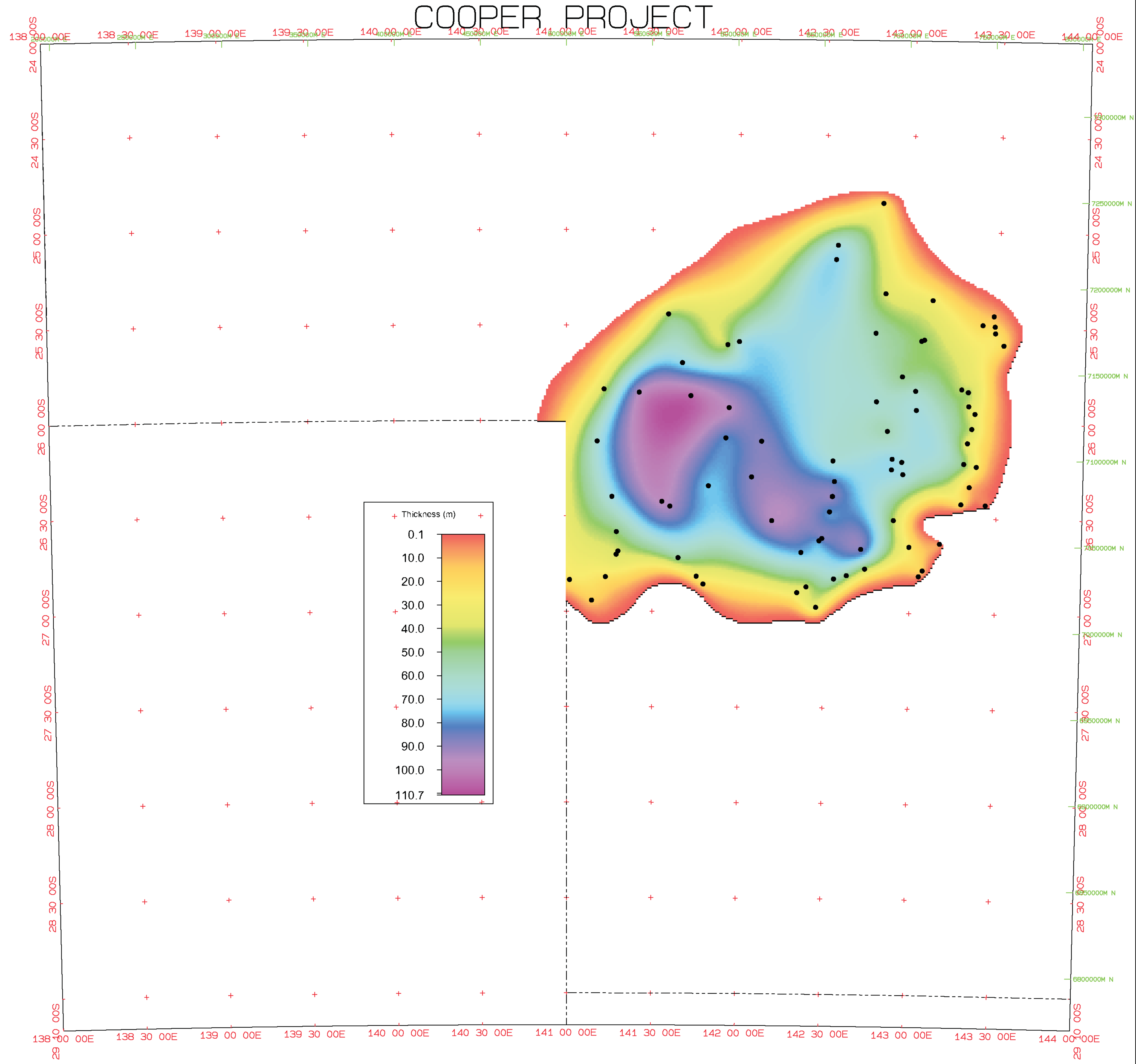
OPEN REPORT

Figure 42

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Doonmulla Member Isopach		



GO BACK

OPEN REPORT

Figure 43

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Gilpeppee Member Isopach		

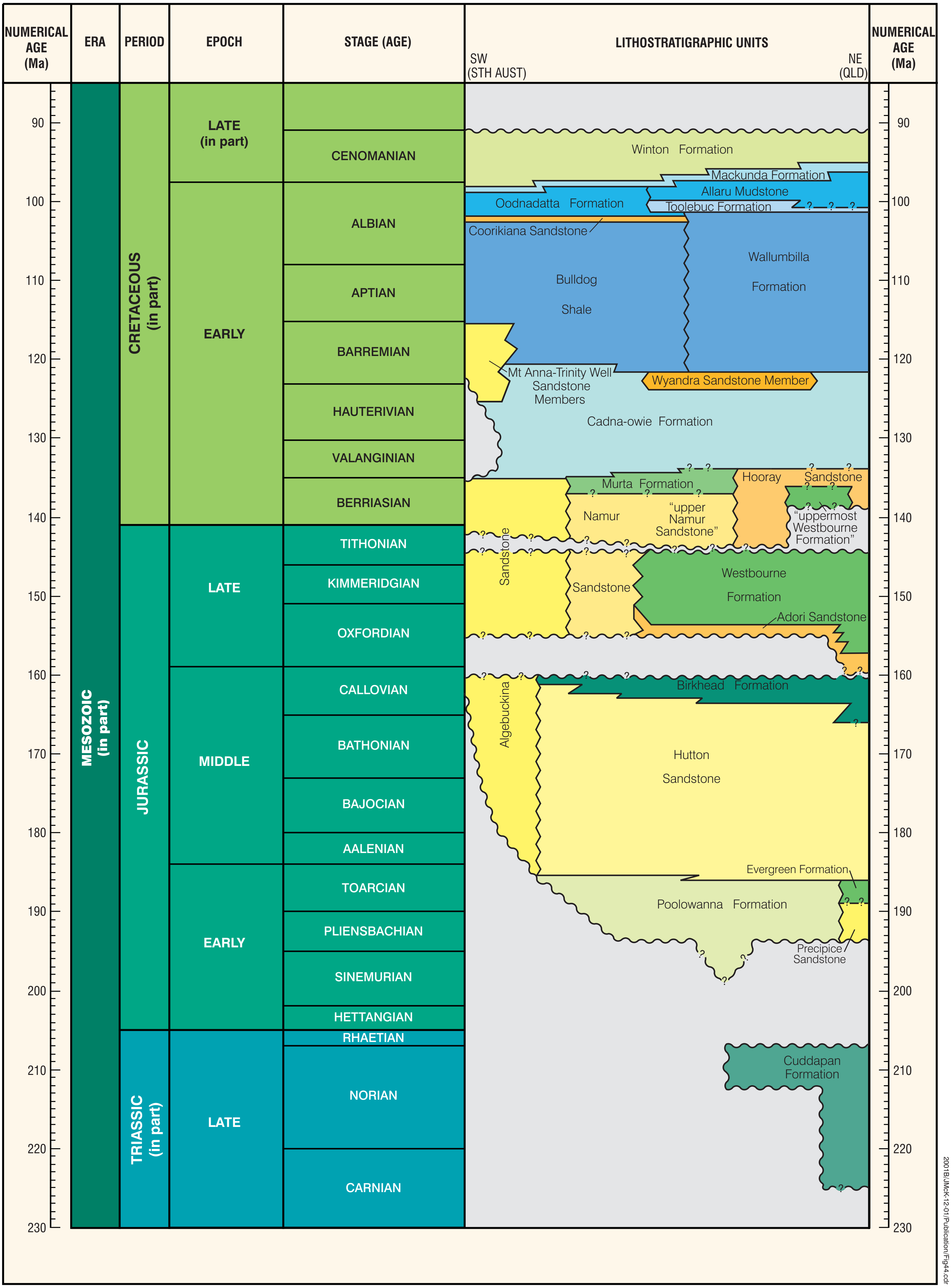
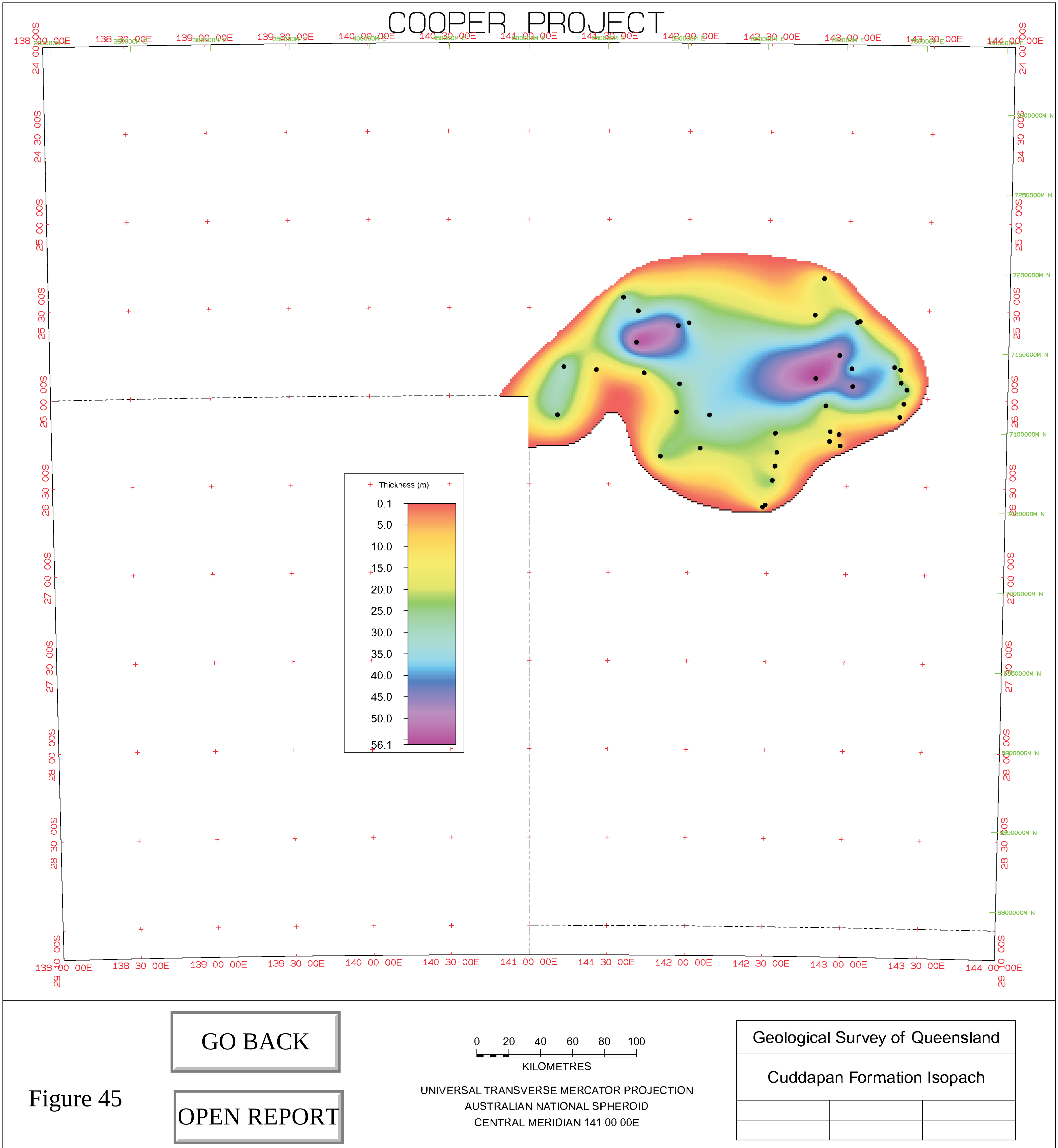


Figure 44: Stratigraphic column, Eromanga Basin.

GO BACK

OPEN REPORT



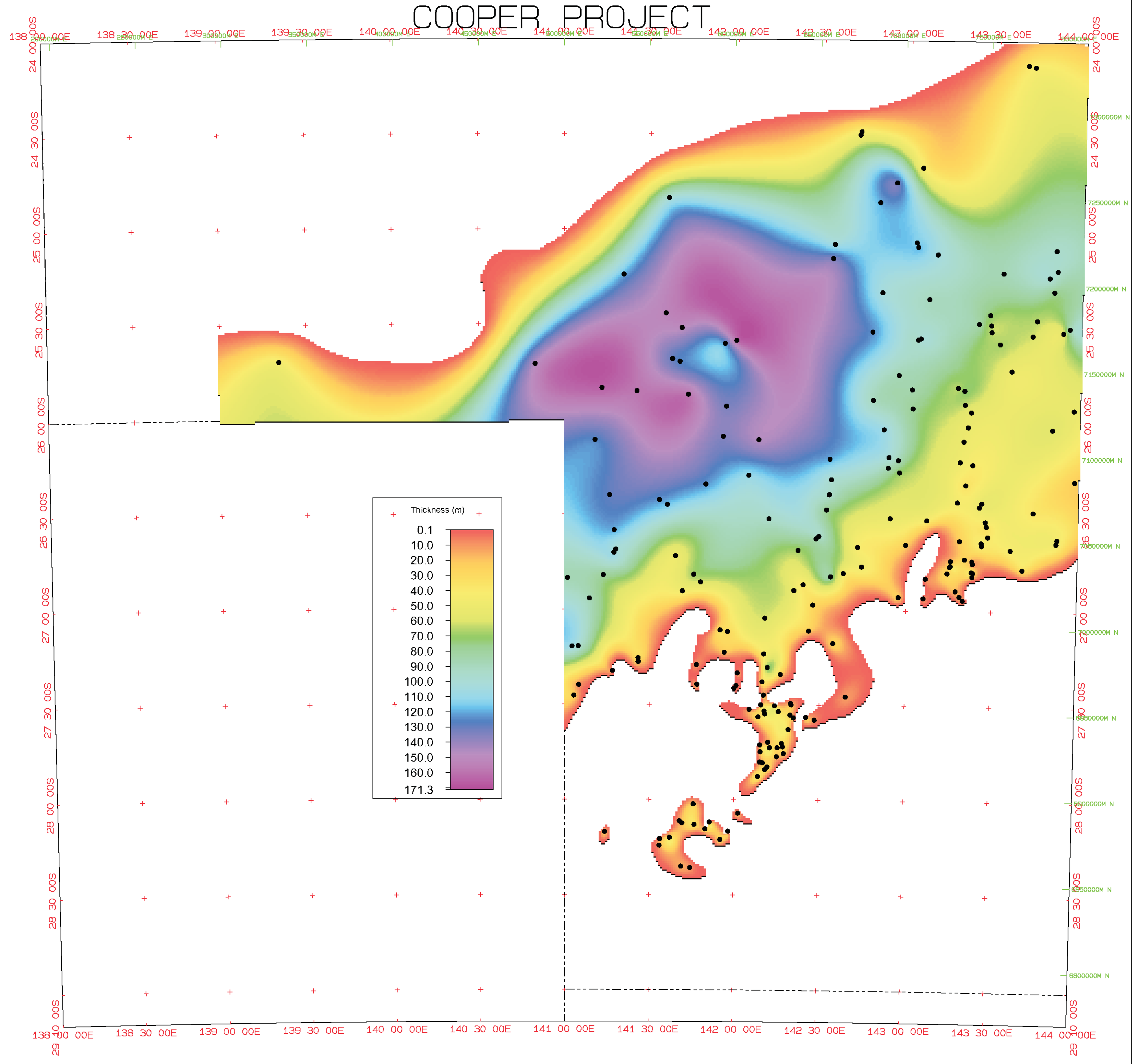
GO BACK

OPEN REPORT

Figure 45

Geological Survey of Queensland

Cuddapan Formation Isopach



GO BACK

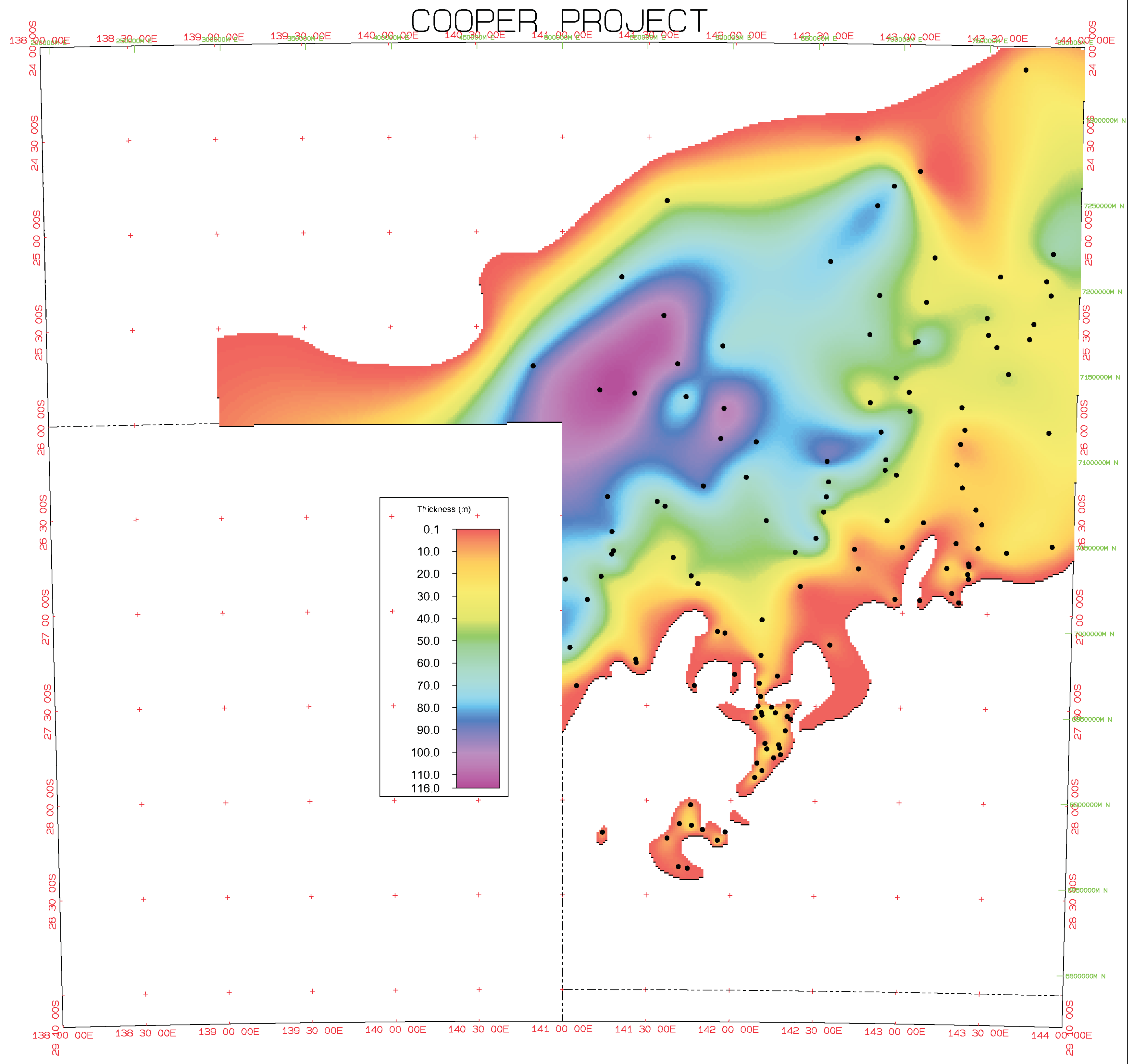
OPEN REPORT

Figure 46

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Poolowanna Formation Isopach		



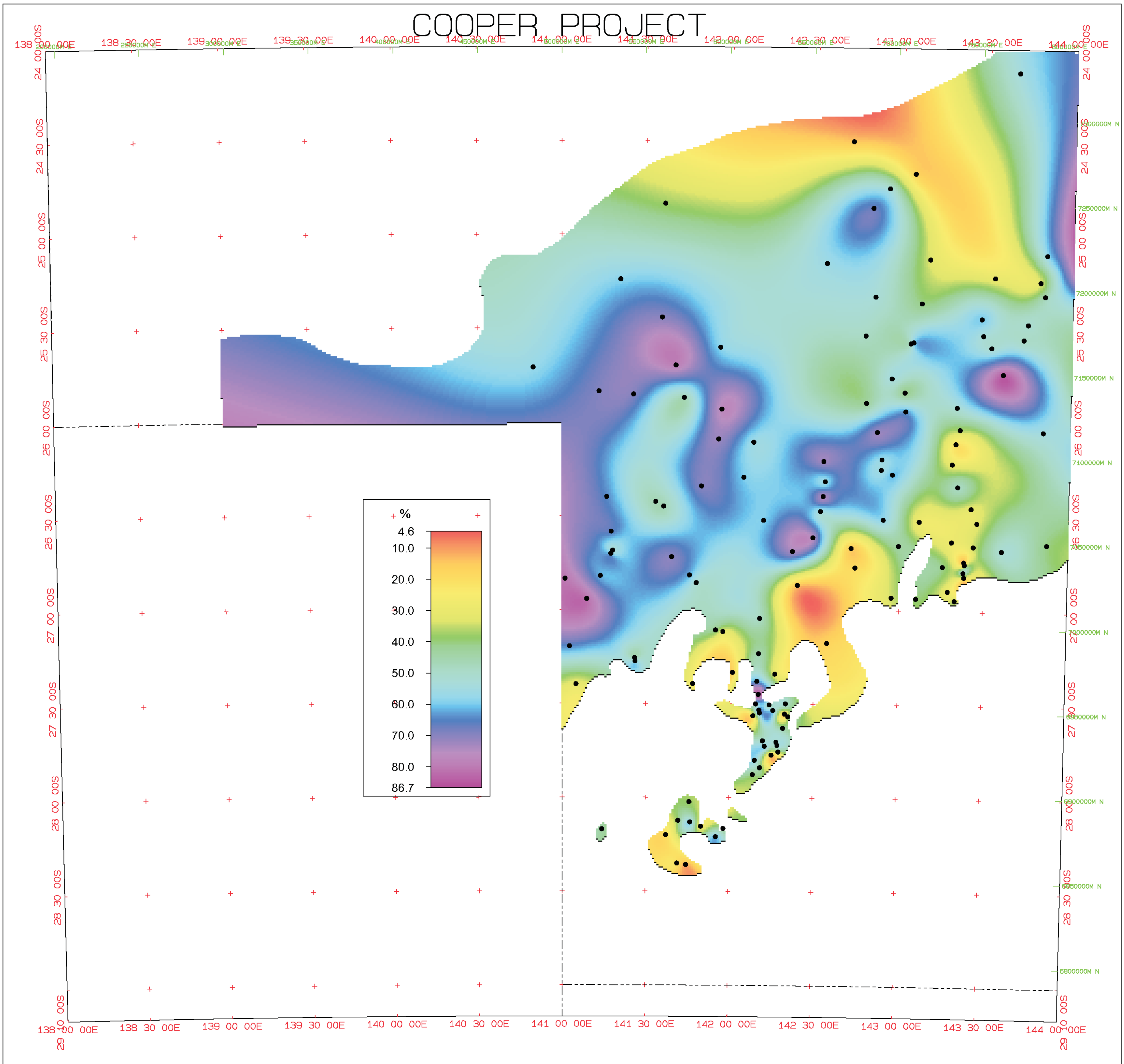
GO BACK

OPEN REPORT

Figure 47

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Poolowanna Formation Sand Isopach		



GO BACK

OPEN REPORT

Figure 48

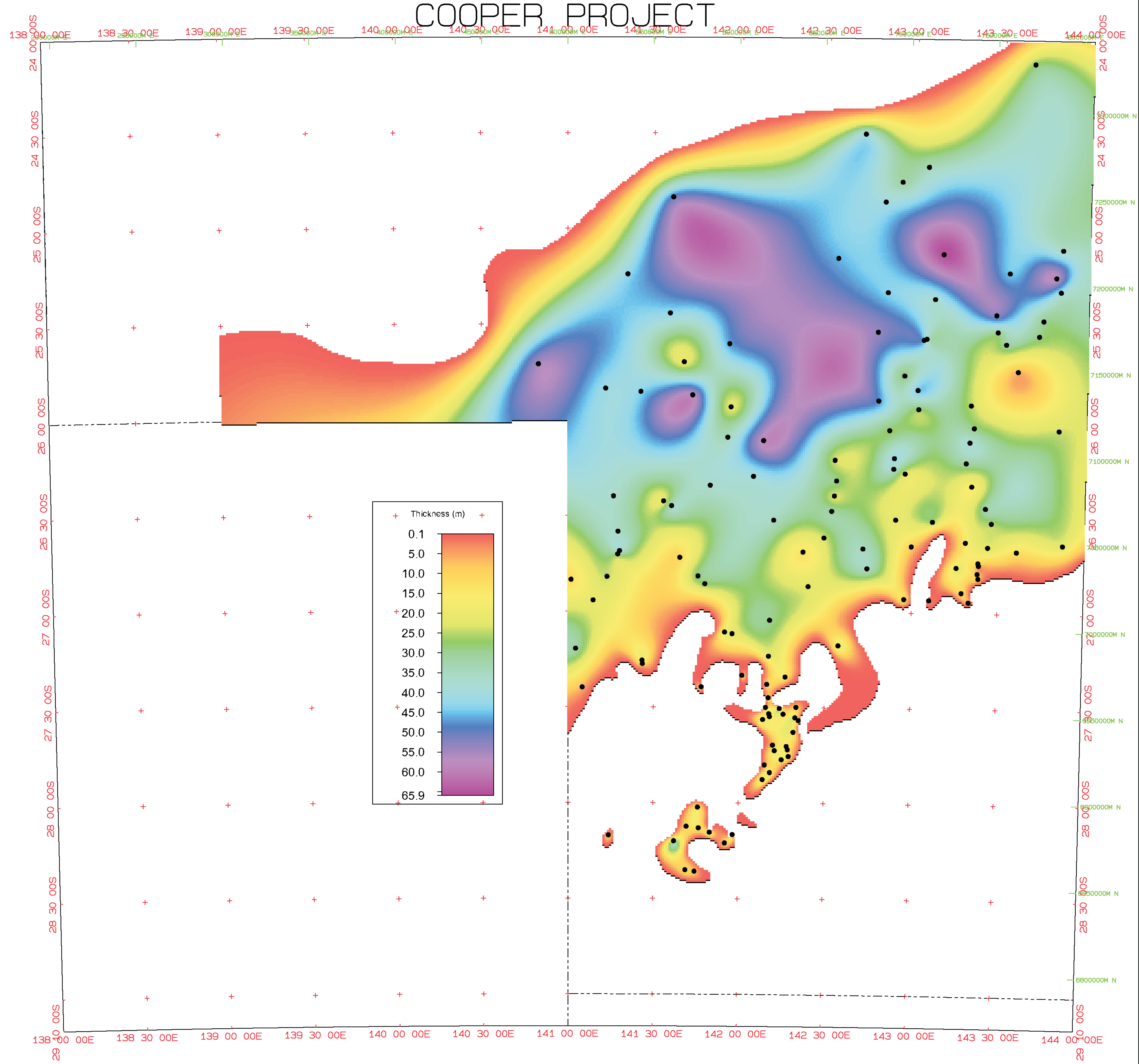
0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Poolowanna Formation Sand Percent		

COOPER PROJECT



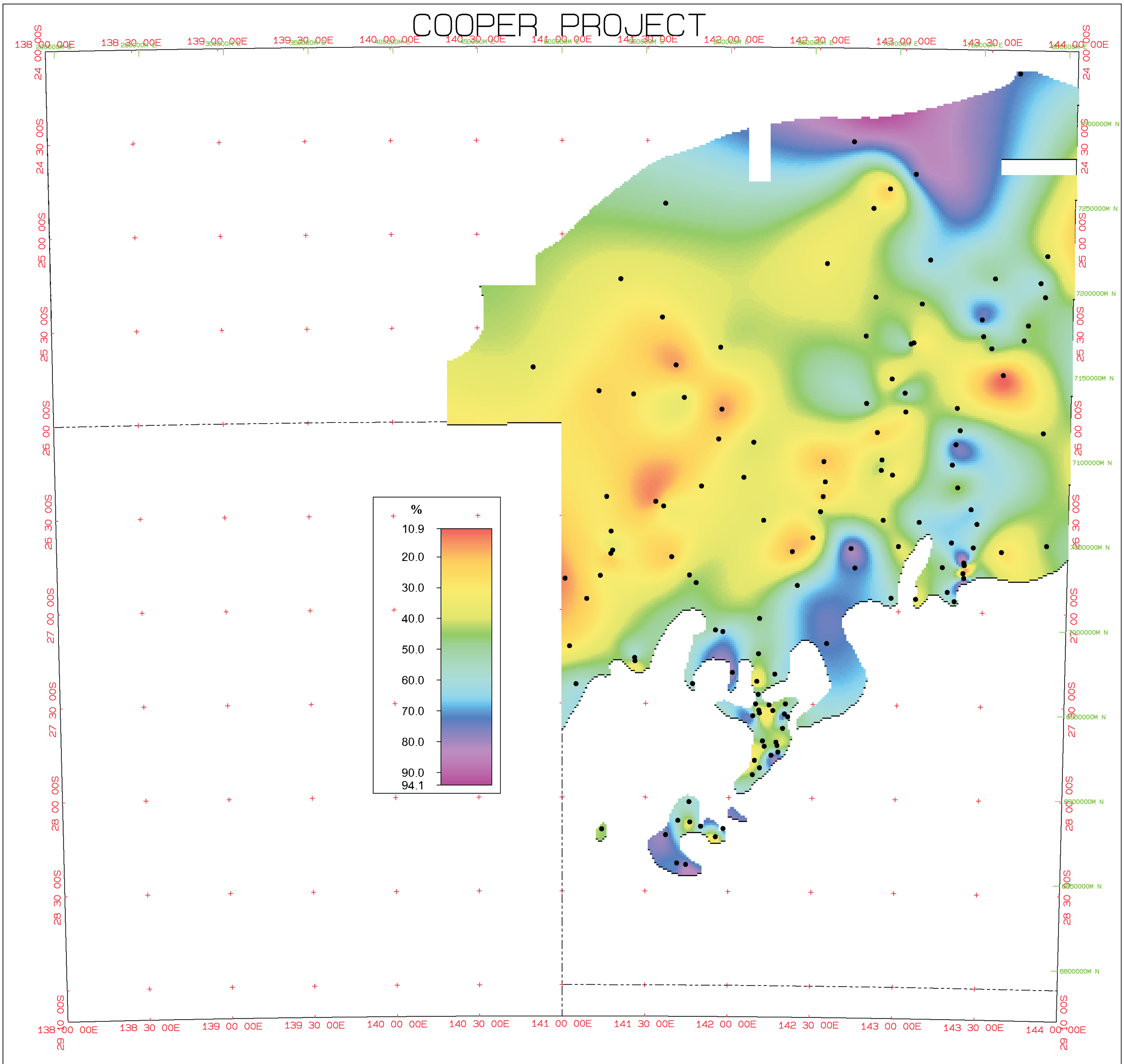
[GO BACK]

[OPEN REPORT]

Figure 49

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland
Poolowanna Formation Shale Isopach



GO BACK

OPEN REPORT

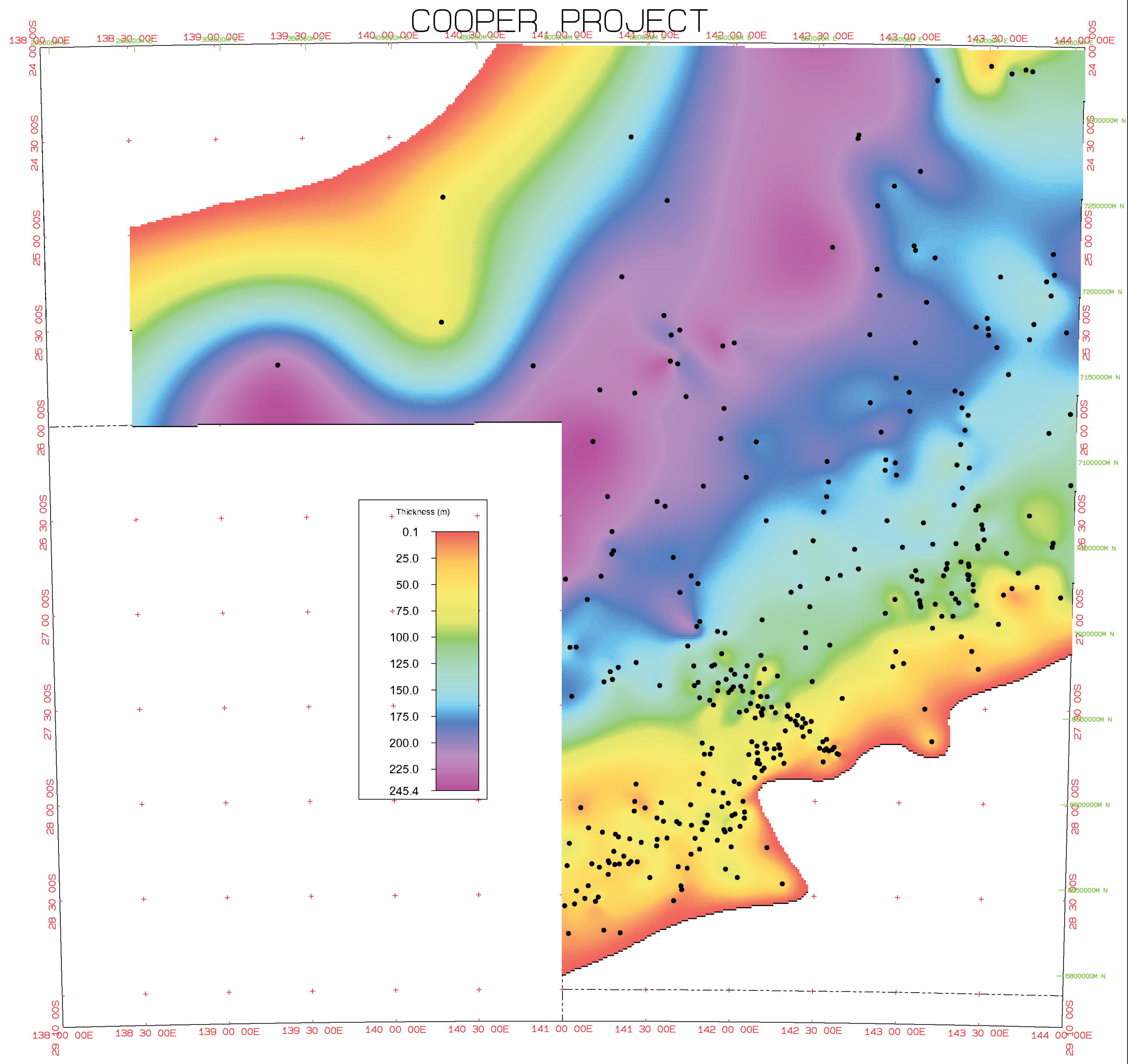
Figure 50

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland
Poolowanna Formation Shale Percent



GO BACK

OPEN REPORT

Figure 51

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Hutton Sandstone Isopach

COOPER PROJECT

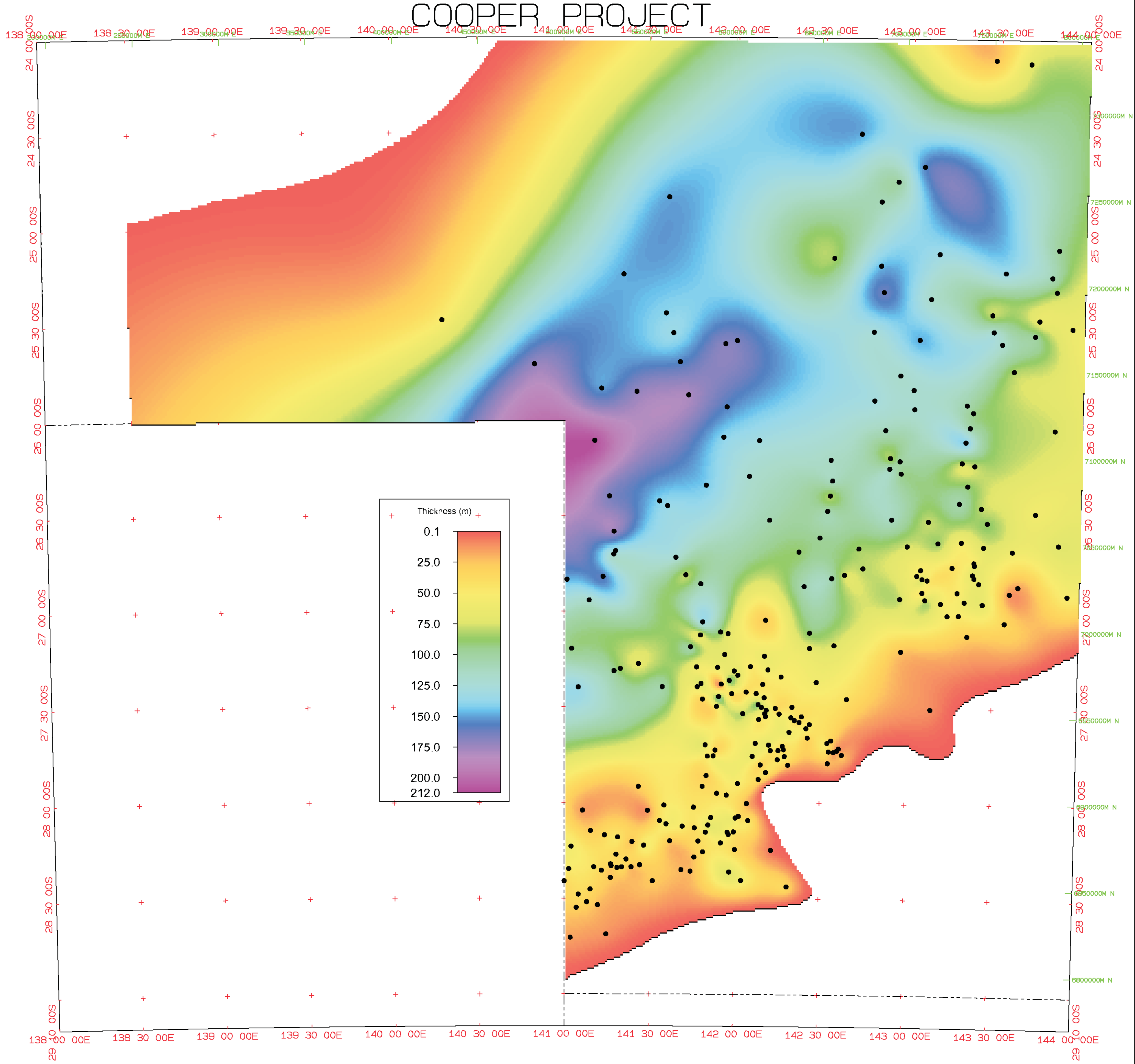


Figure 52

GO BACK

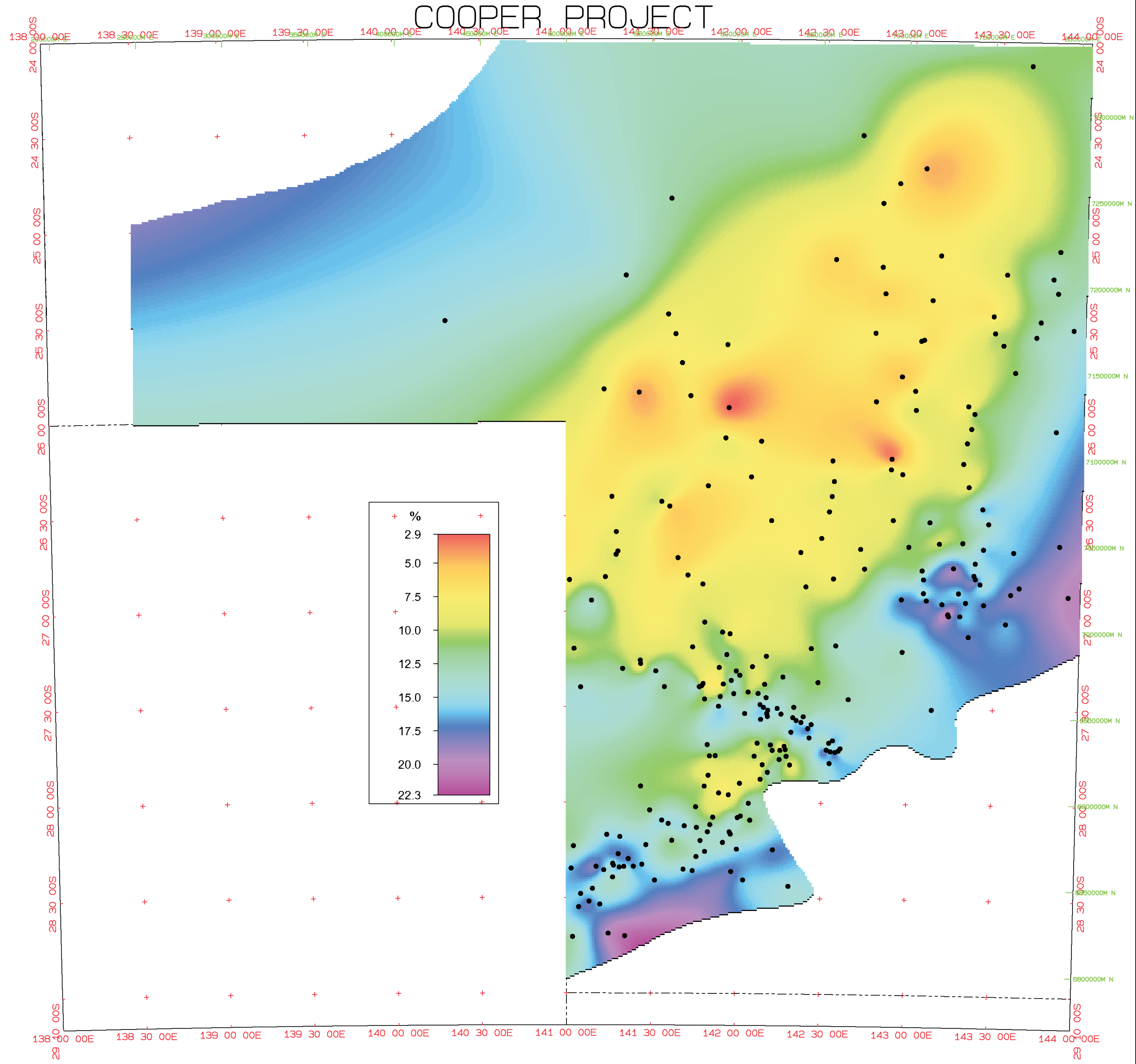
OPEN REPORT

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland
Hutton Sandstone Sand Isopach



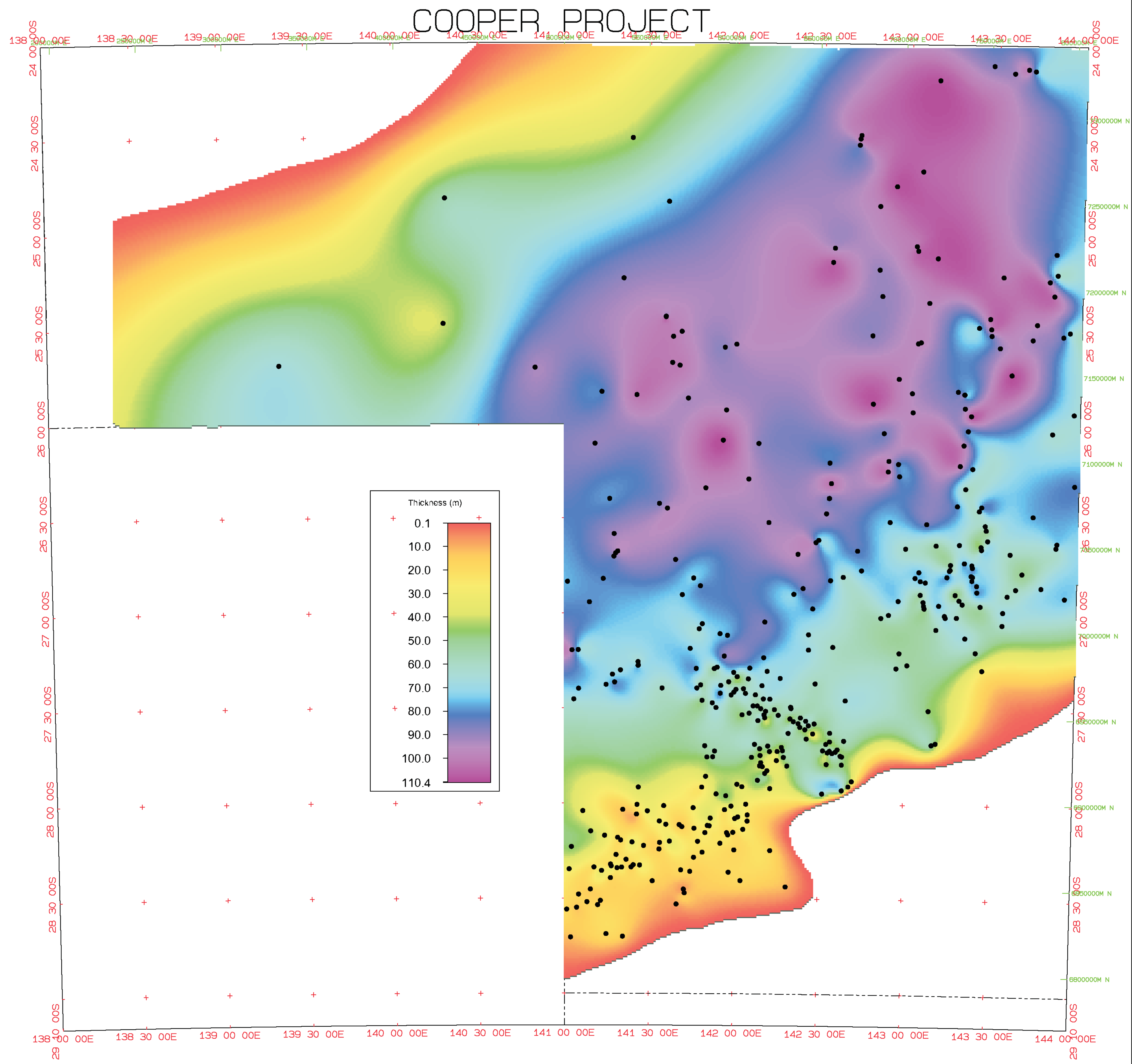
GO BACK

Figure 53

OPEN REPORT

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland
Hutton Sandstone Porosity



GO BACK

Figure 54

OPEN REPORT

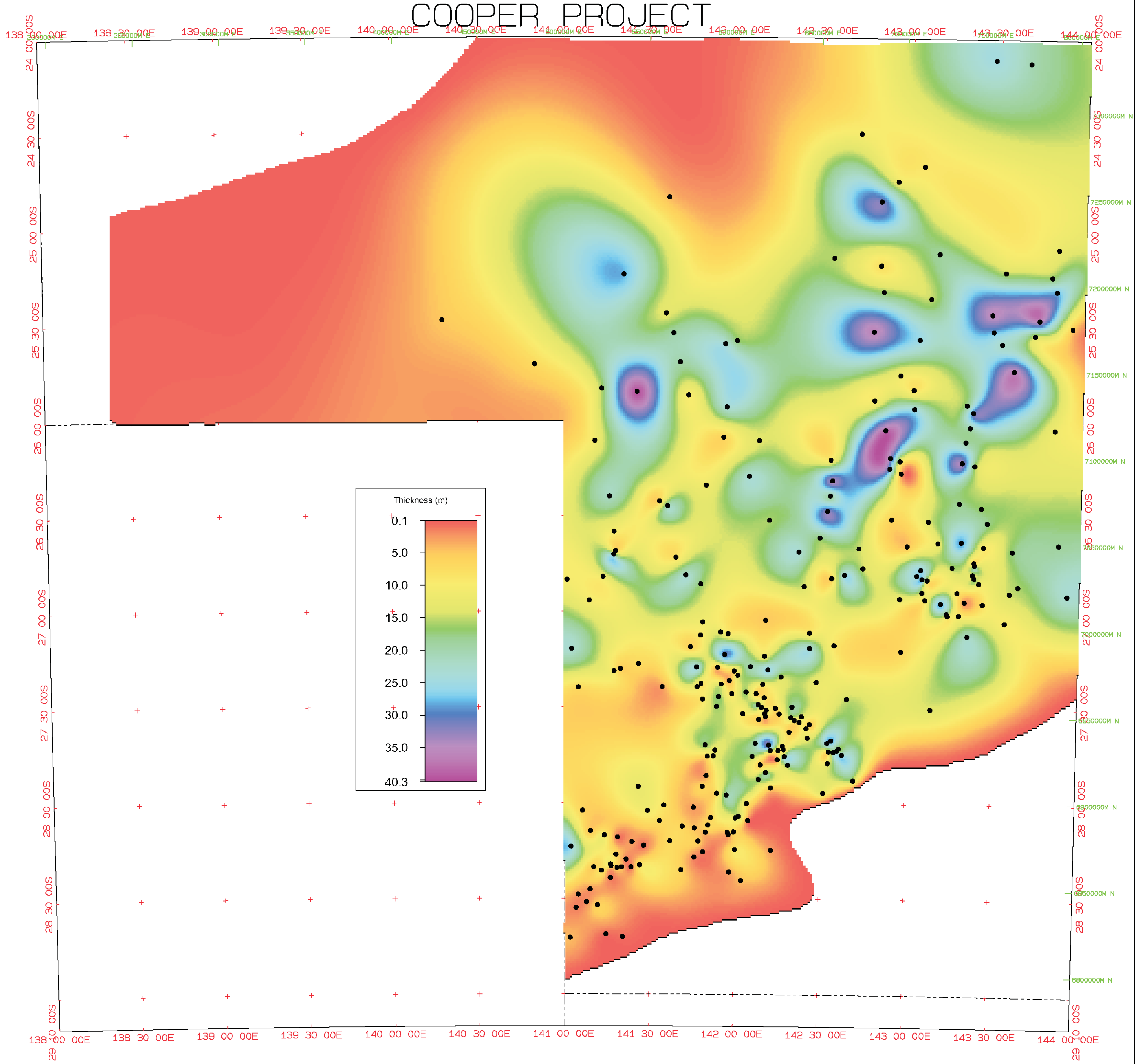
0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Birkhead Formation Isopach

COOPER PROJECT



GO BACK
OPEN REPORT

Figure 55

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland
Birkhead Formation Sand Isopach

COOPER PROJECT

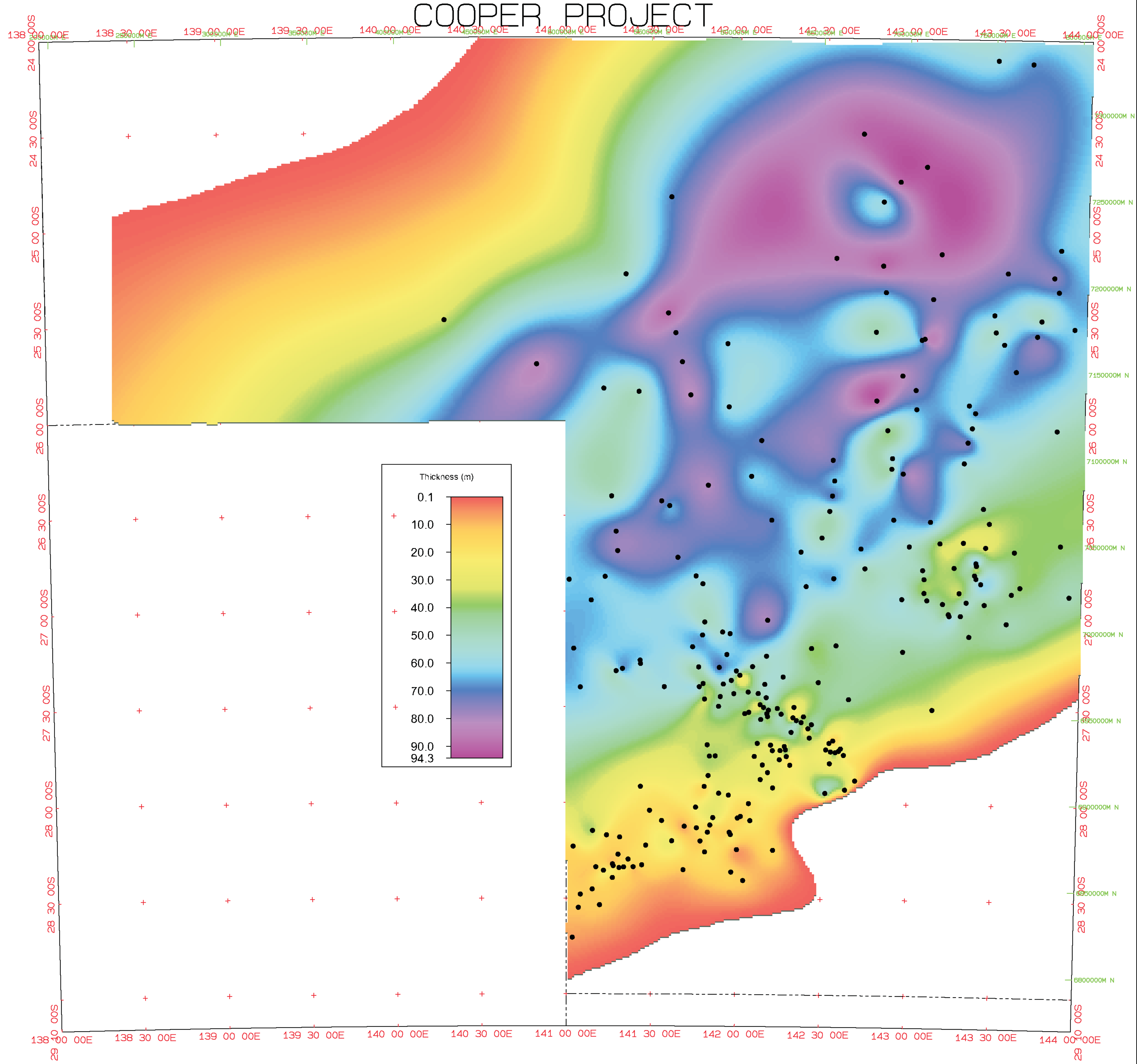


Figure 56

GO BACK

OPEN REPORT

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland
Birkhead Formation Shale Isopach

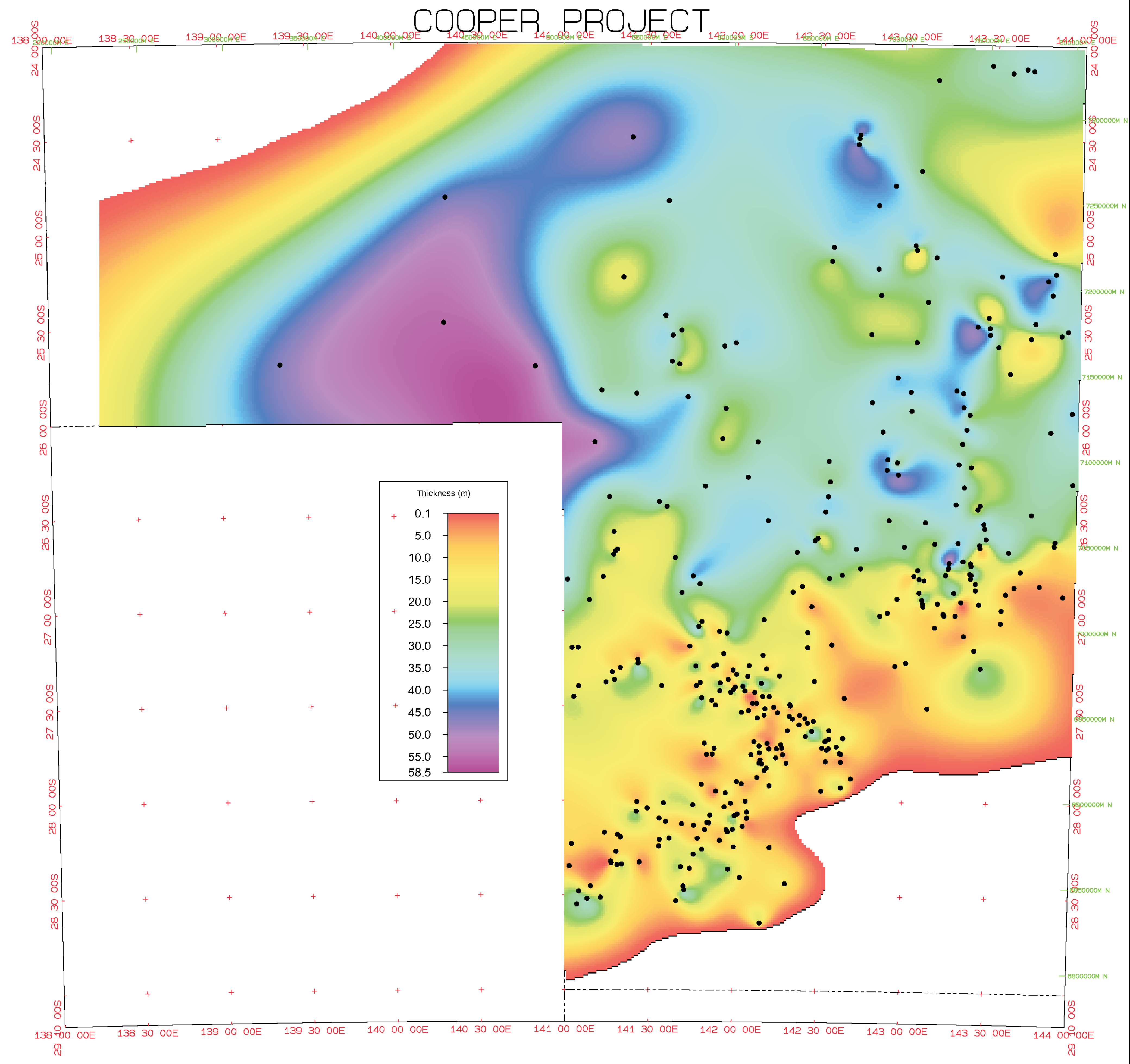


Figure 57

GO BACK

OPEN REPORT

0 20 40 60 80 100

KILOMETRES

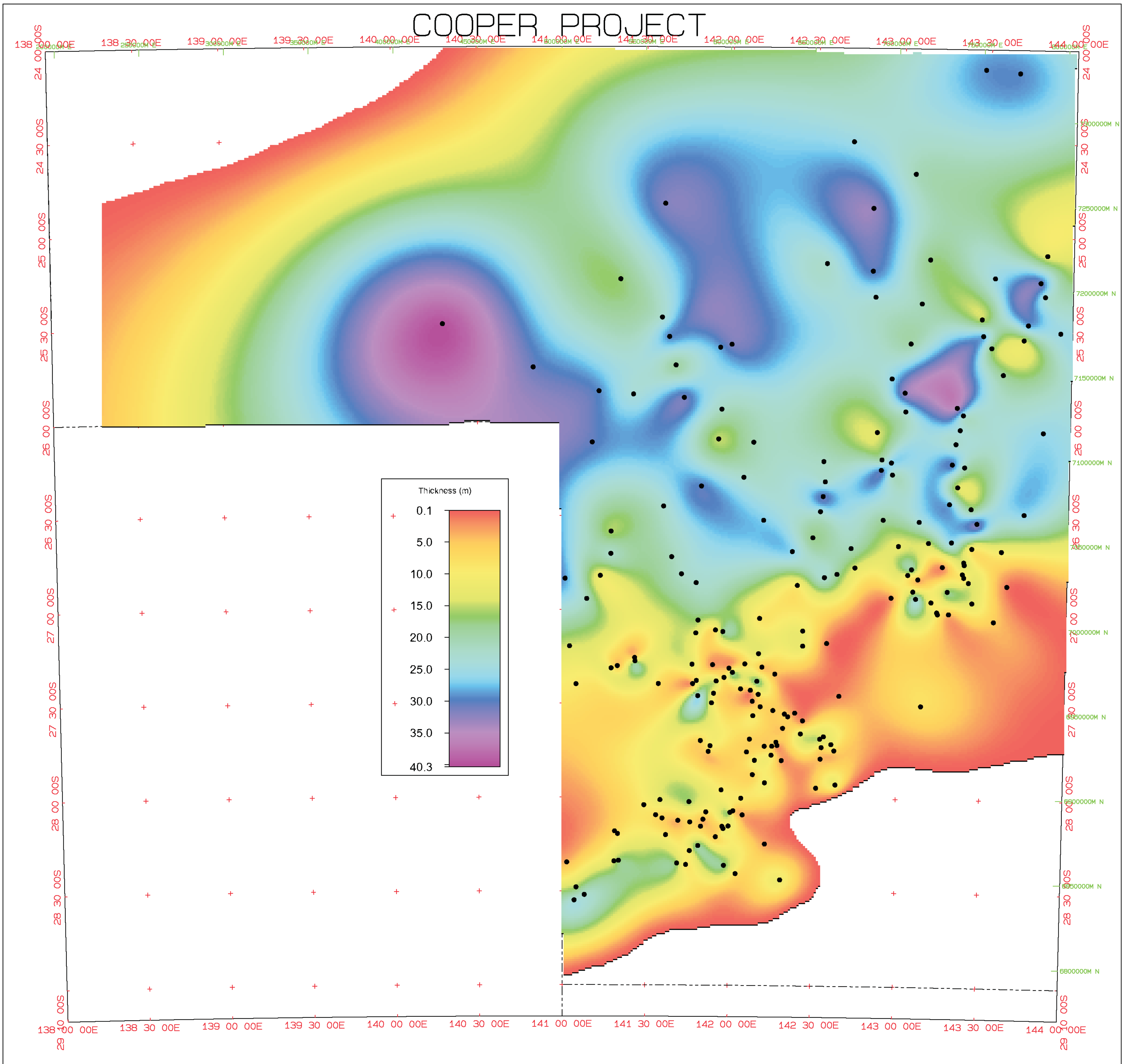
UNIVERSAL TRANSVERSE MERCATOR PROJECTION

AUSTRALIAN NATIONAL SPHEROID

CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Adori Sandstone Isopach



GO BACK

OPEN REPORT

Figure 58

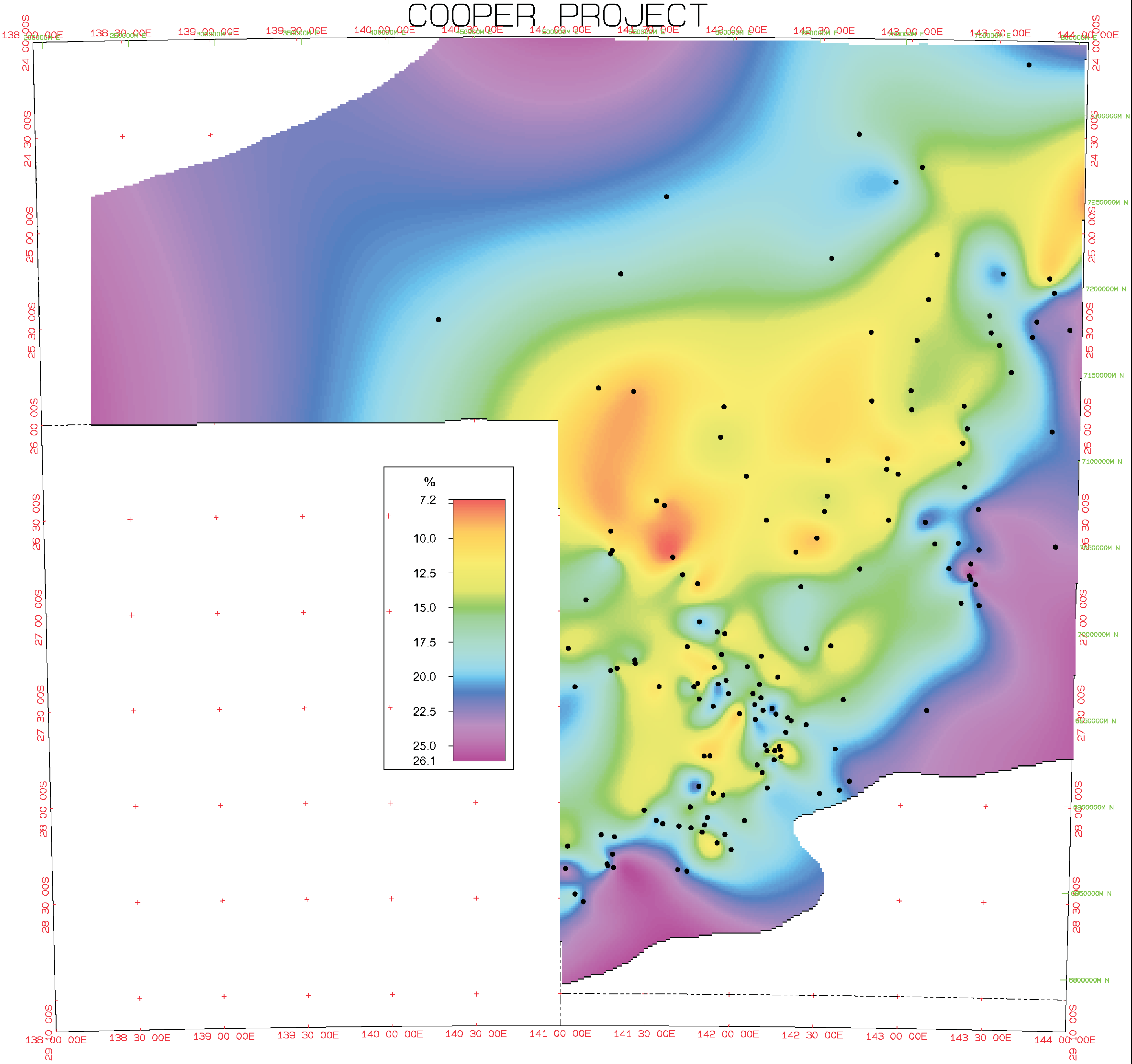
0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Adori Sandstone Sand Isopach

COOPER PROJECT



GO BACK

OPEN REPORT

Figure 59

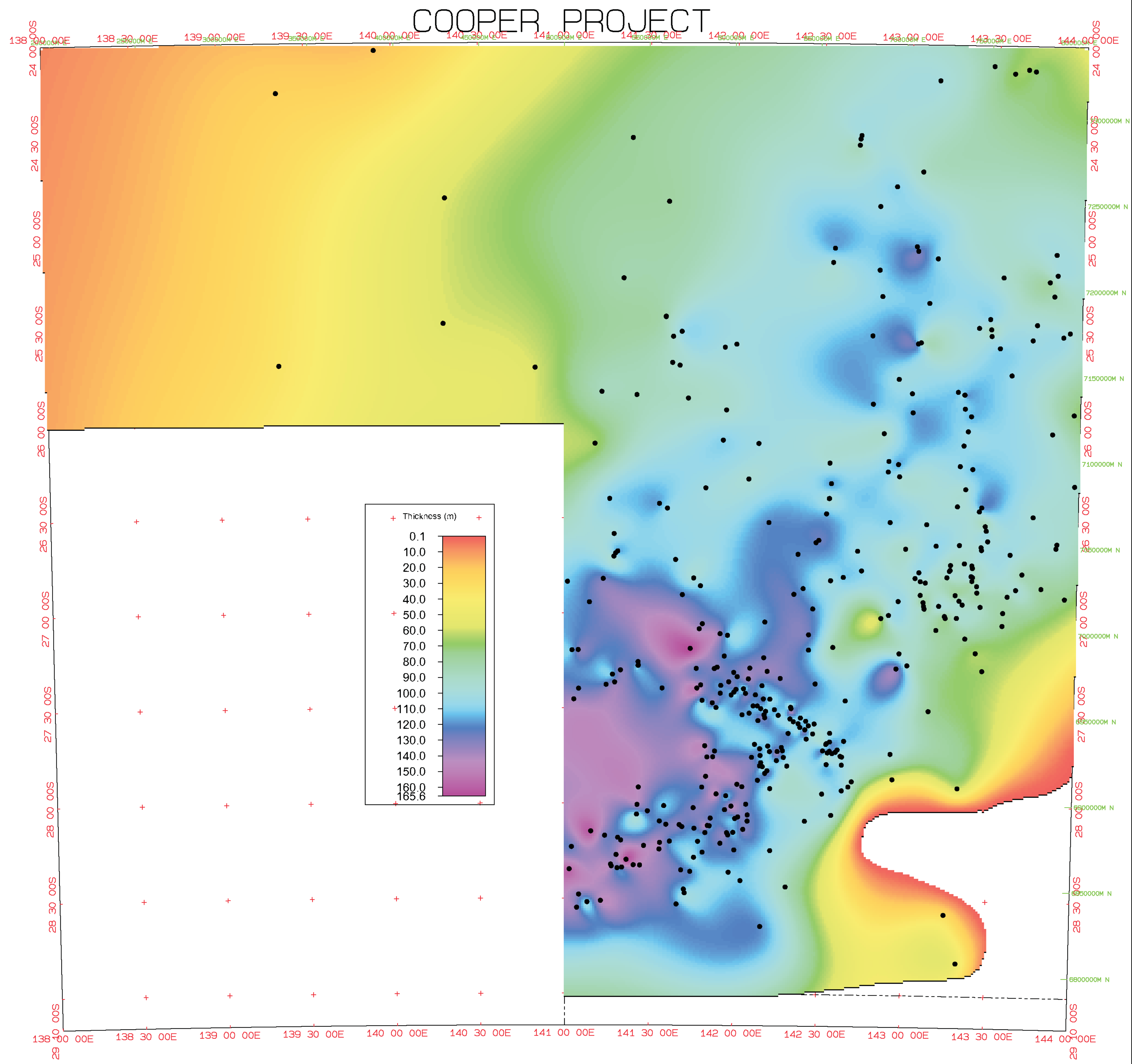
0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Adori Sandstone Porosity



GO BACK

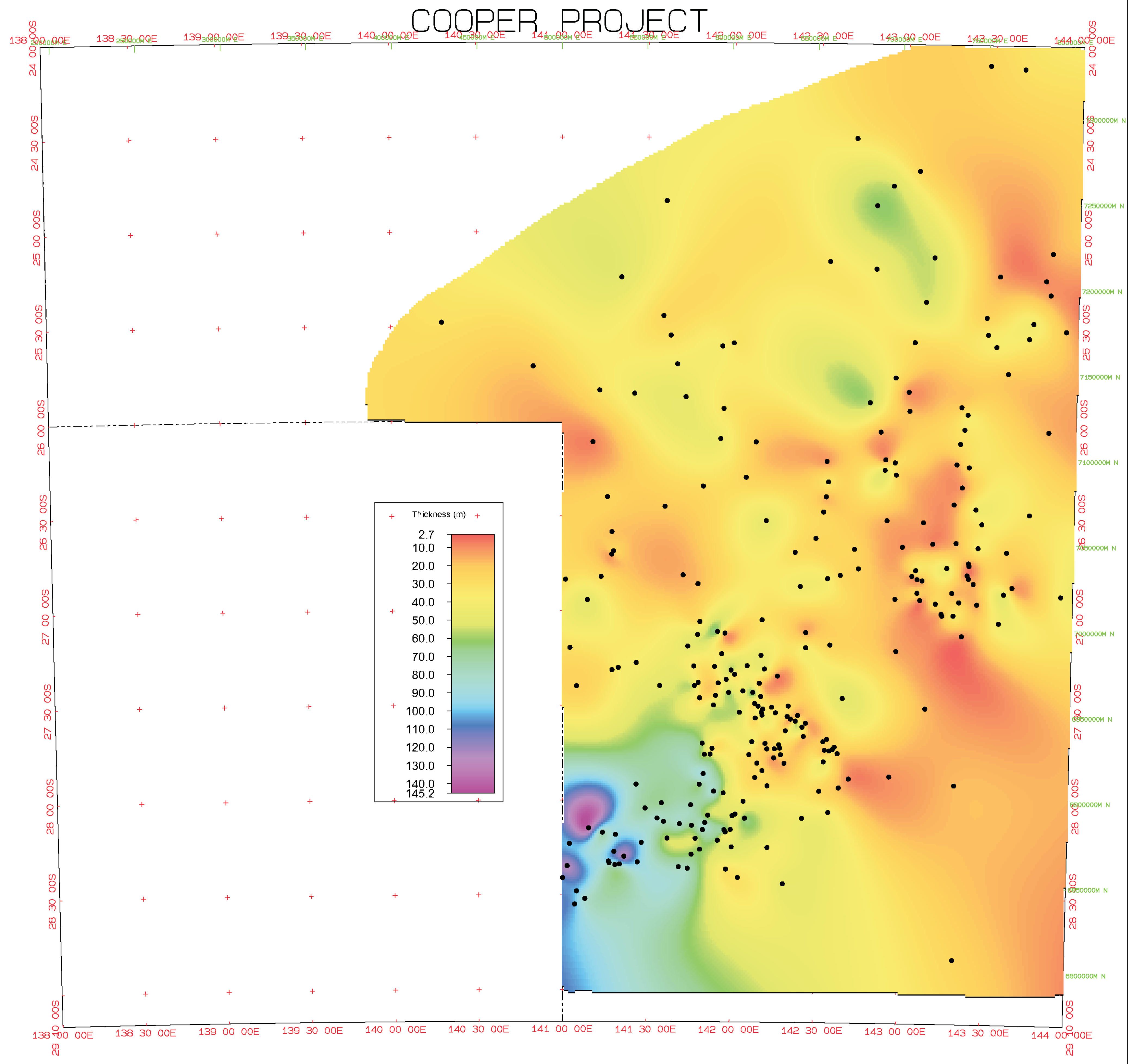
OPEN REPORT

Figure 60

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland
Westbourne Formation Isopach



GO BACK

OPEN REPORT

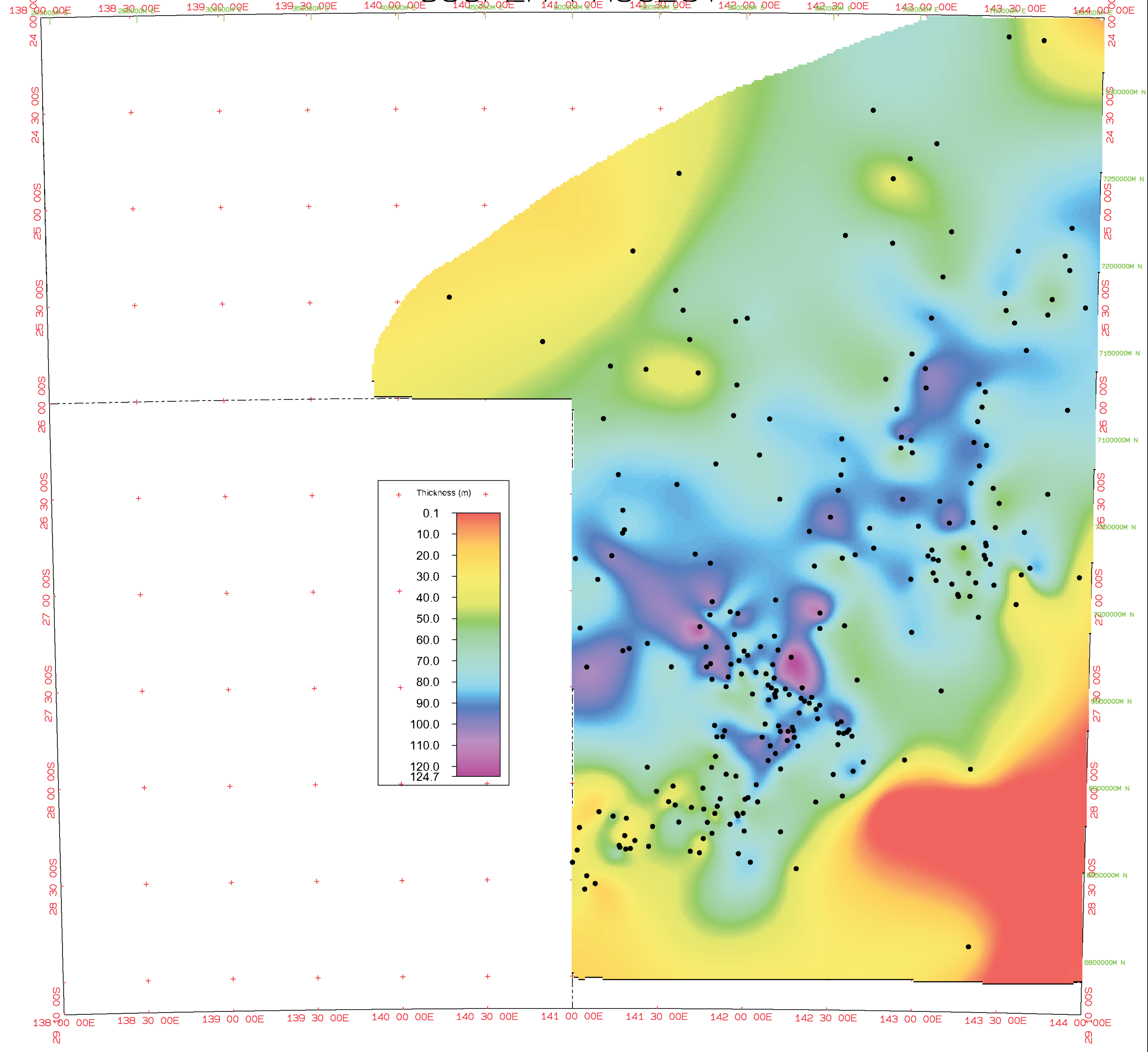
Figure 61

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Westbourne Formation Sand Isopach		

COOPER PROJECT



GO BACK

OPEN REPORT

Figure 62

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION

AUSTRALIAN NATIONAL SPHEROID

CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Westbourne Formation Shale Isopach

COOPER PROJECT

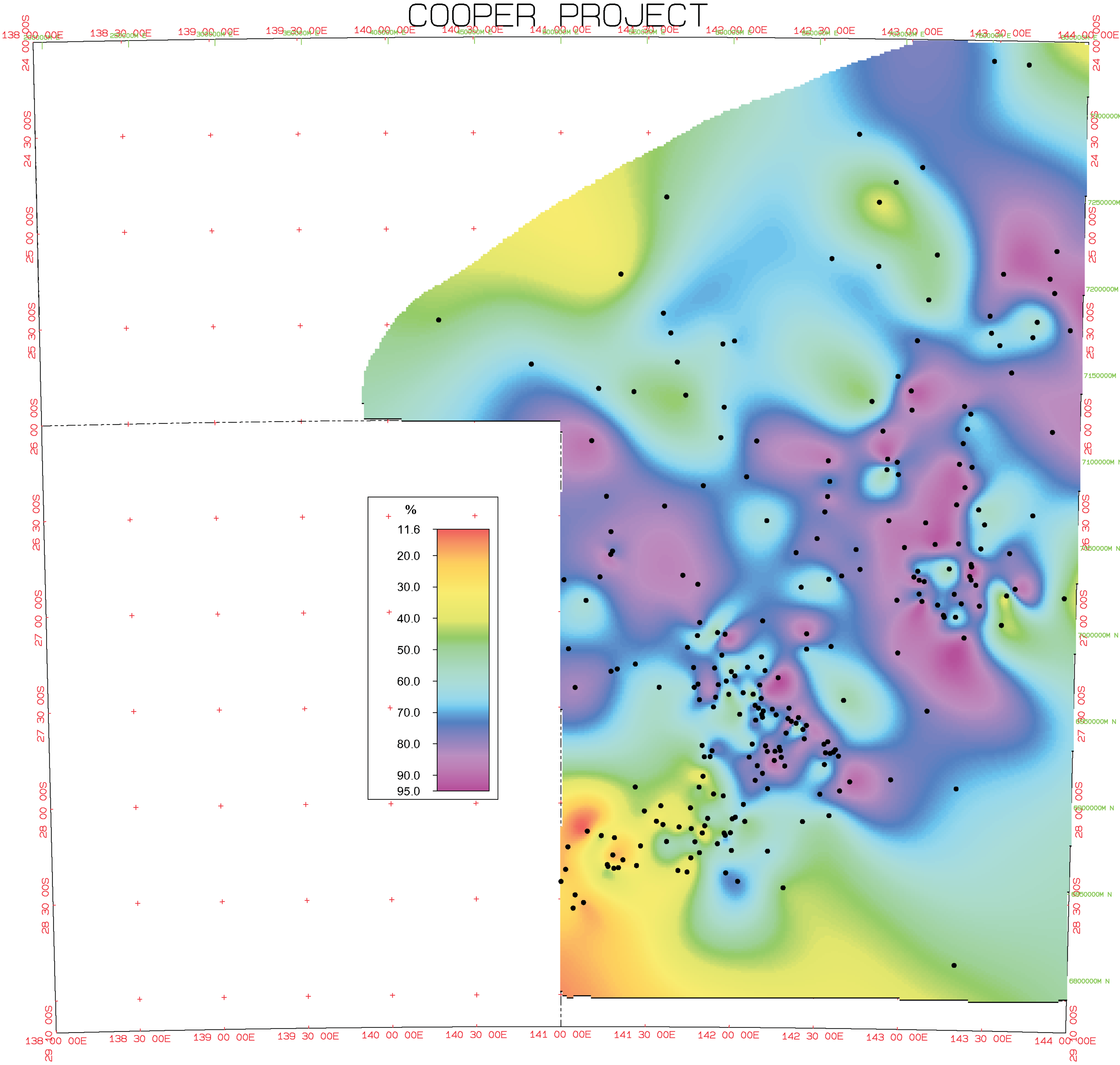
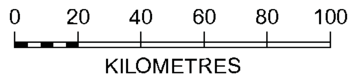


Figure 63

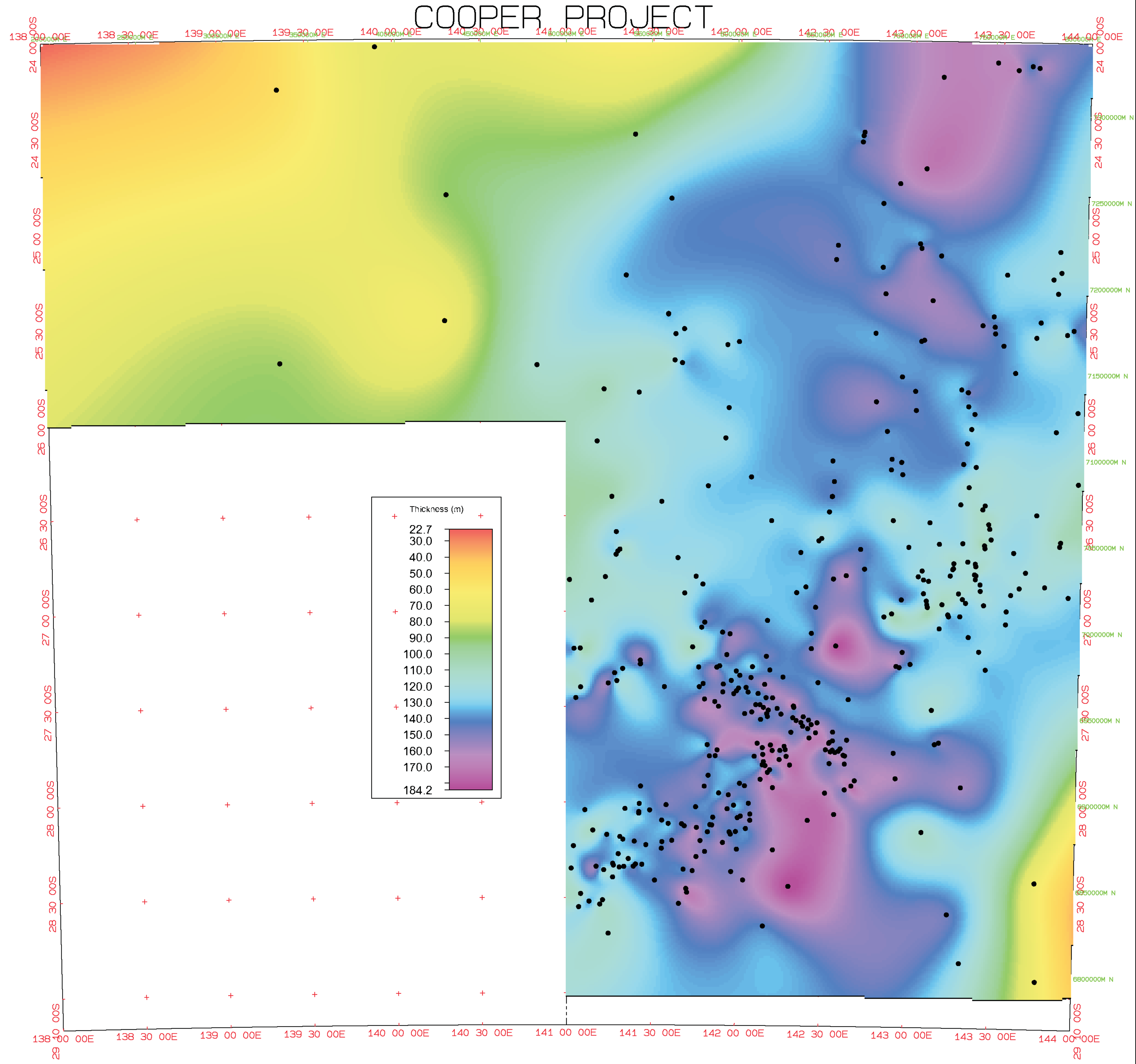
GO BACK

OPEN REPORT



UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Westbourne Formation Shale Percent		



GO BACK

OPEN REPORT

Figure 64

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Hooray Sandstone (and equivalents) Isopach

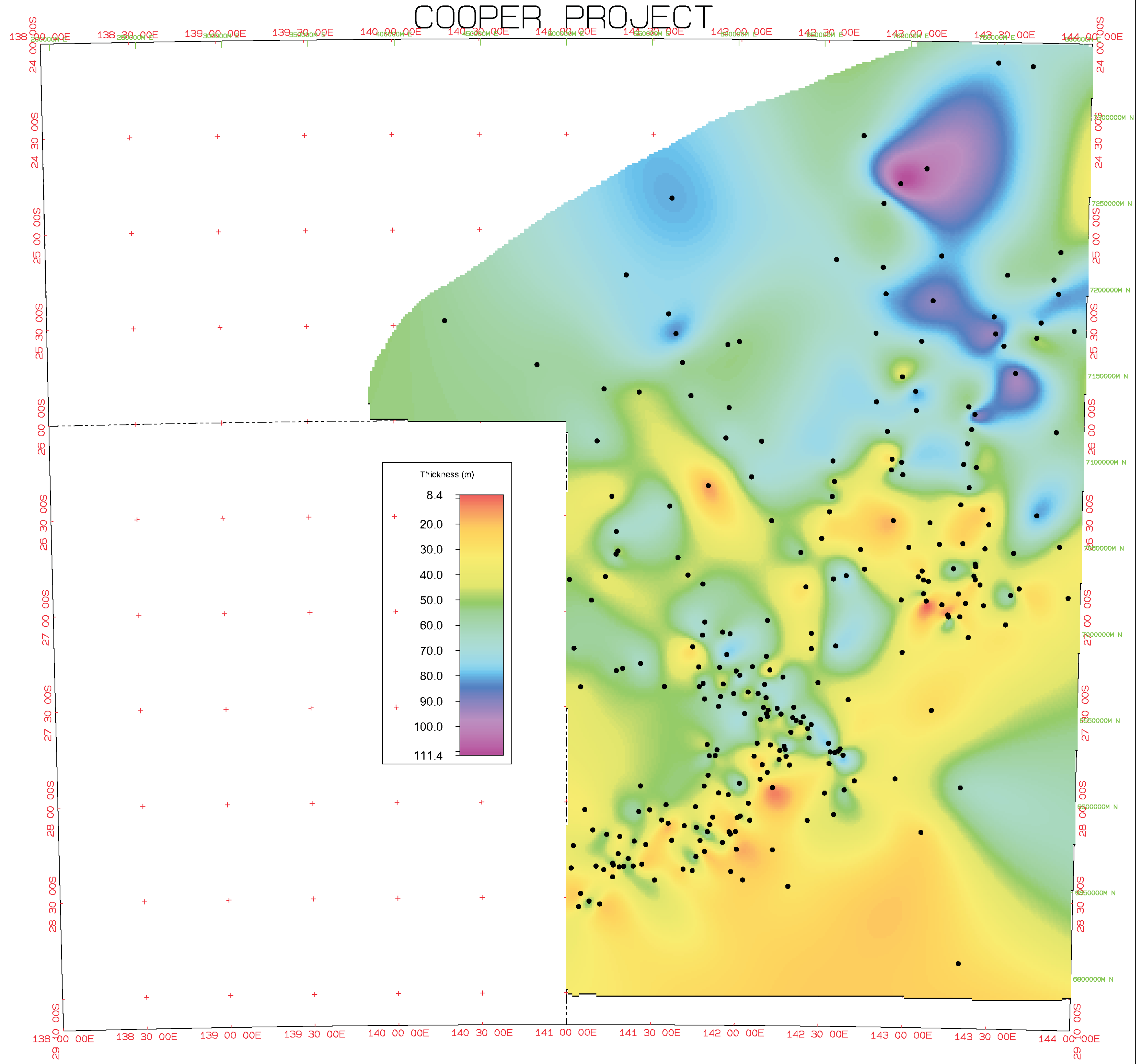


Figure 65

GO BACK

OPEN REPORT

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Hooray Sandstone (and equivalents) Isopach

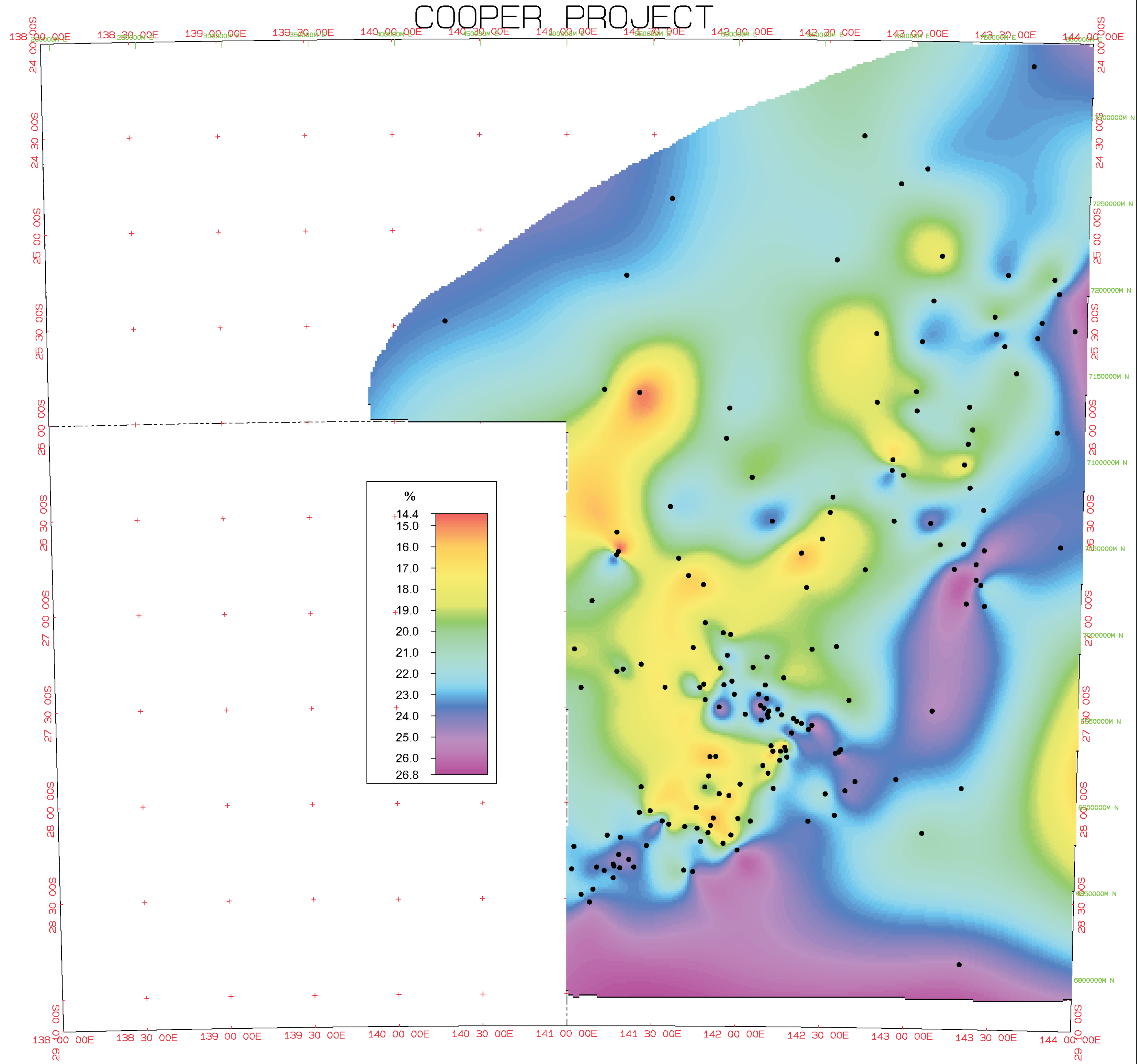


Figure 66

GO BACK

OPEN REPORT

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION

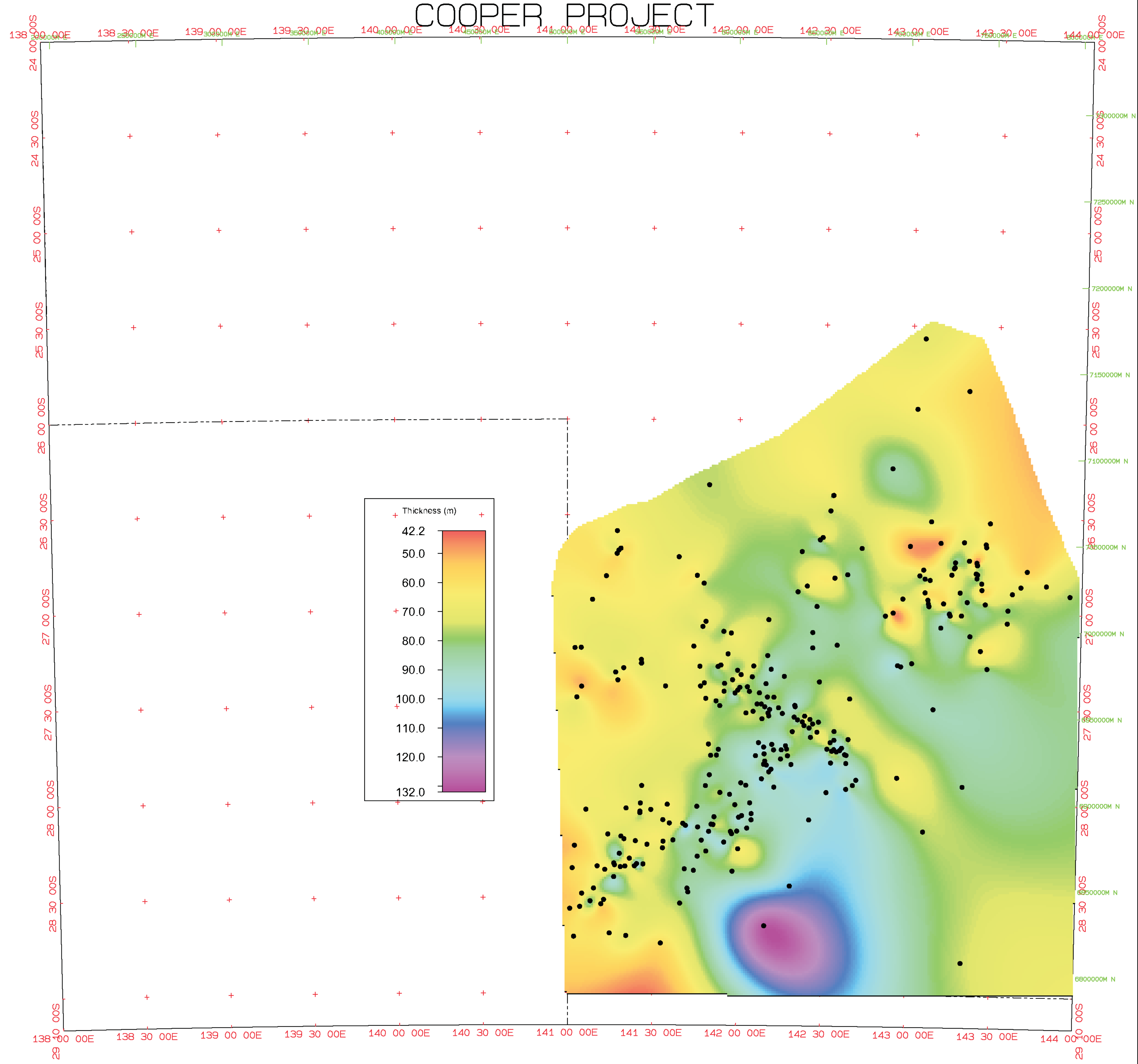
AUSTRALIAN NATIONAL SPHEROID

CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Hooray Sandstone (and equivalents) Isopach

COOPER PROJECT



GO BACK

OPEN REPORT

Figure 67

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Murta Member Isopach

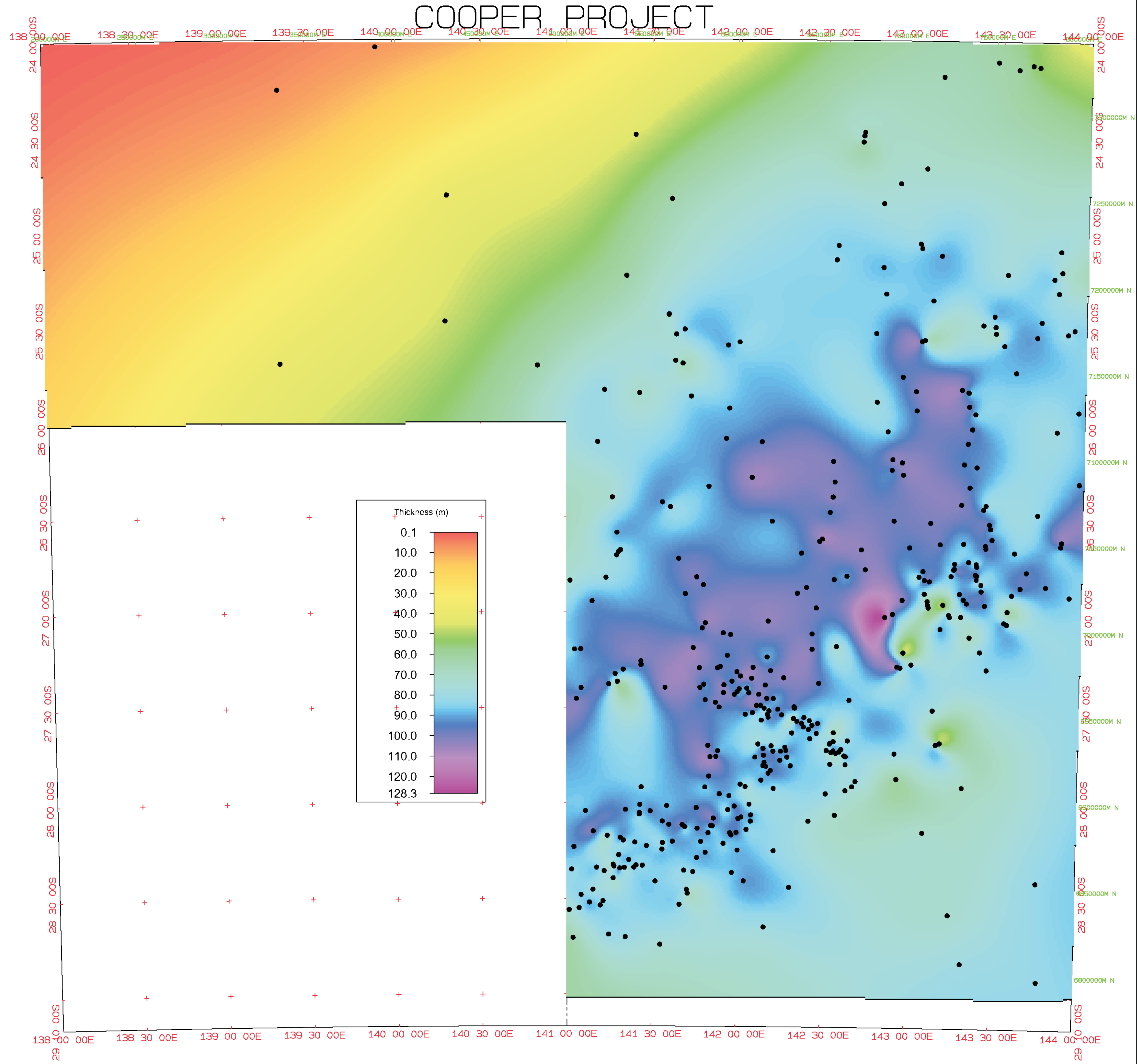


Figure 68

GO BACK

OPEN REPORT

0 20 40 60 80 100

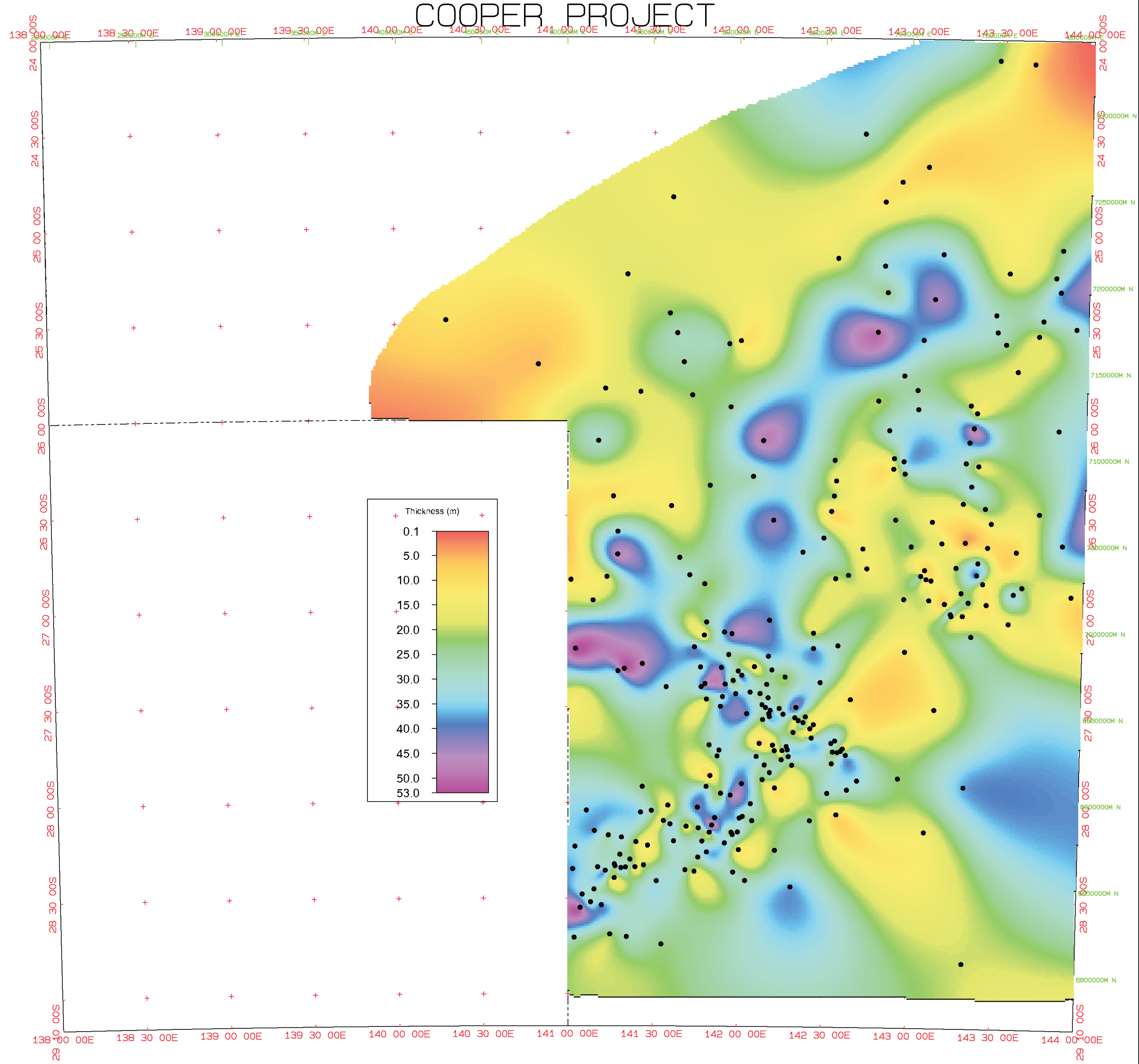
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Cadna-Owie Formation Isopach

COOPER PROJECT



GO BACK

OPEN REPORT

Figure 69

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Cadna-Owie Formation Sand Isopach

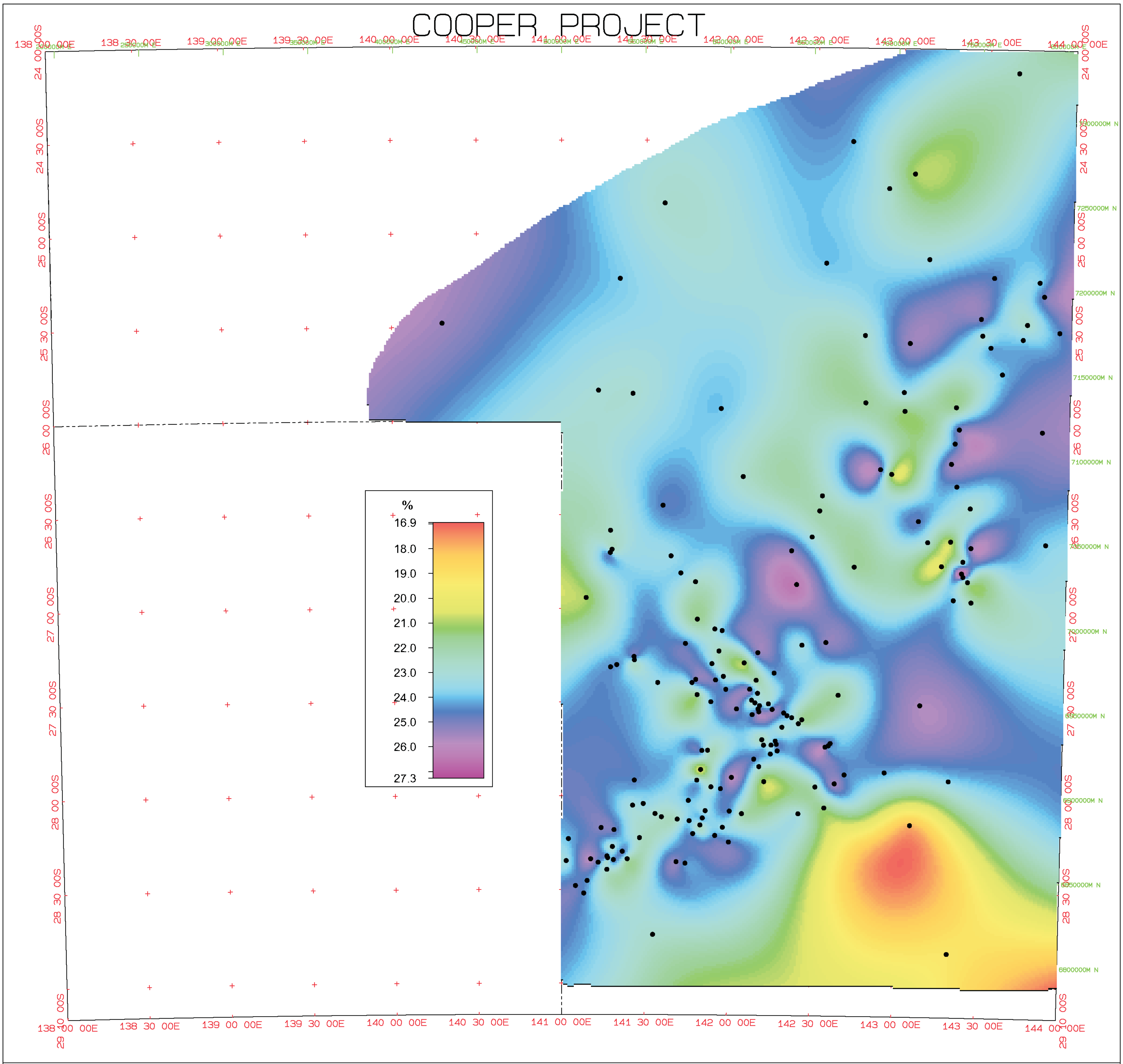


Figure 70

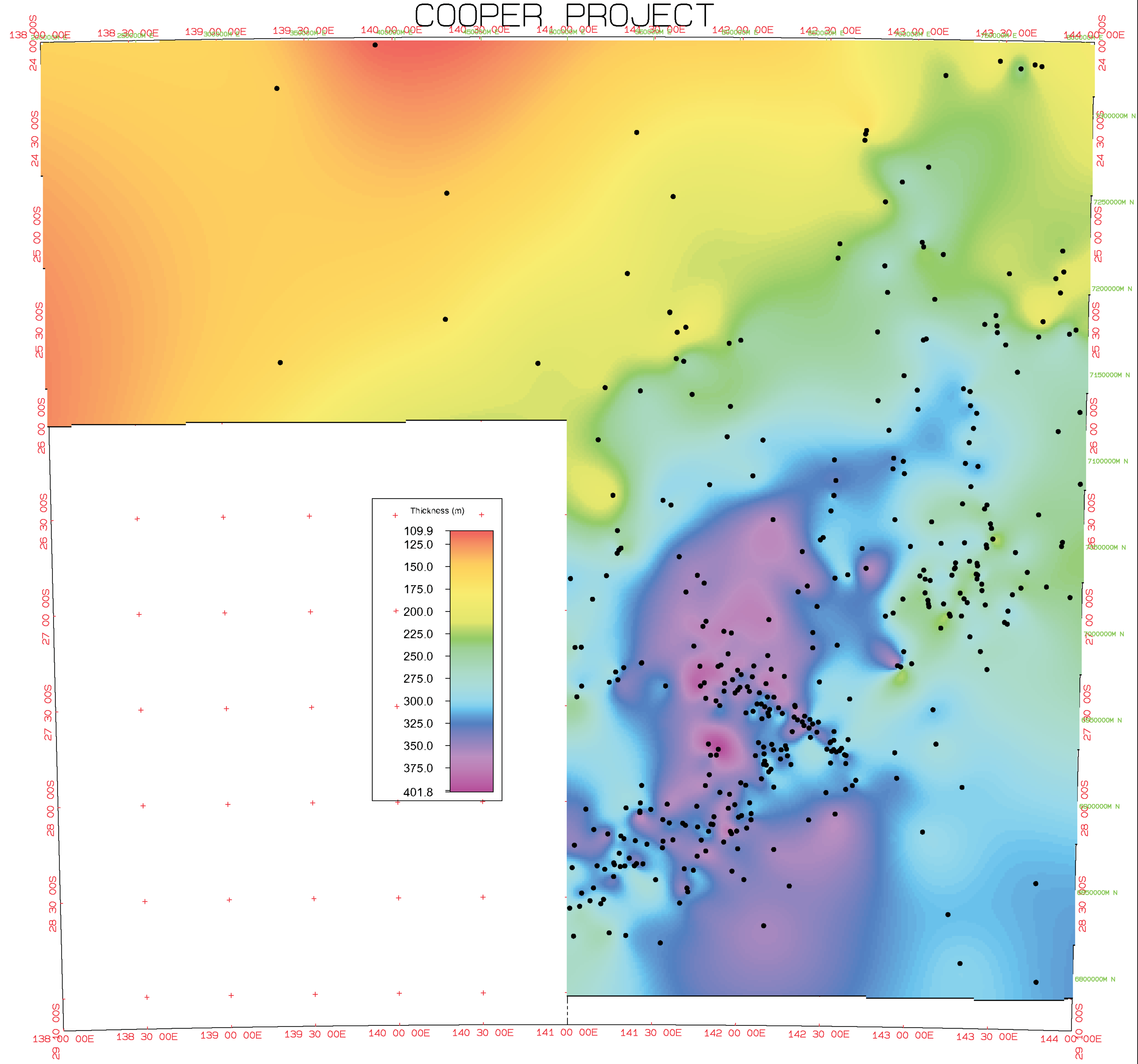
GO BACK

OPEN REPORT

Geological Survey of Queensland

Cadna-Owie Formation Porosity

COOPER PROJECT



GO BACK

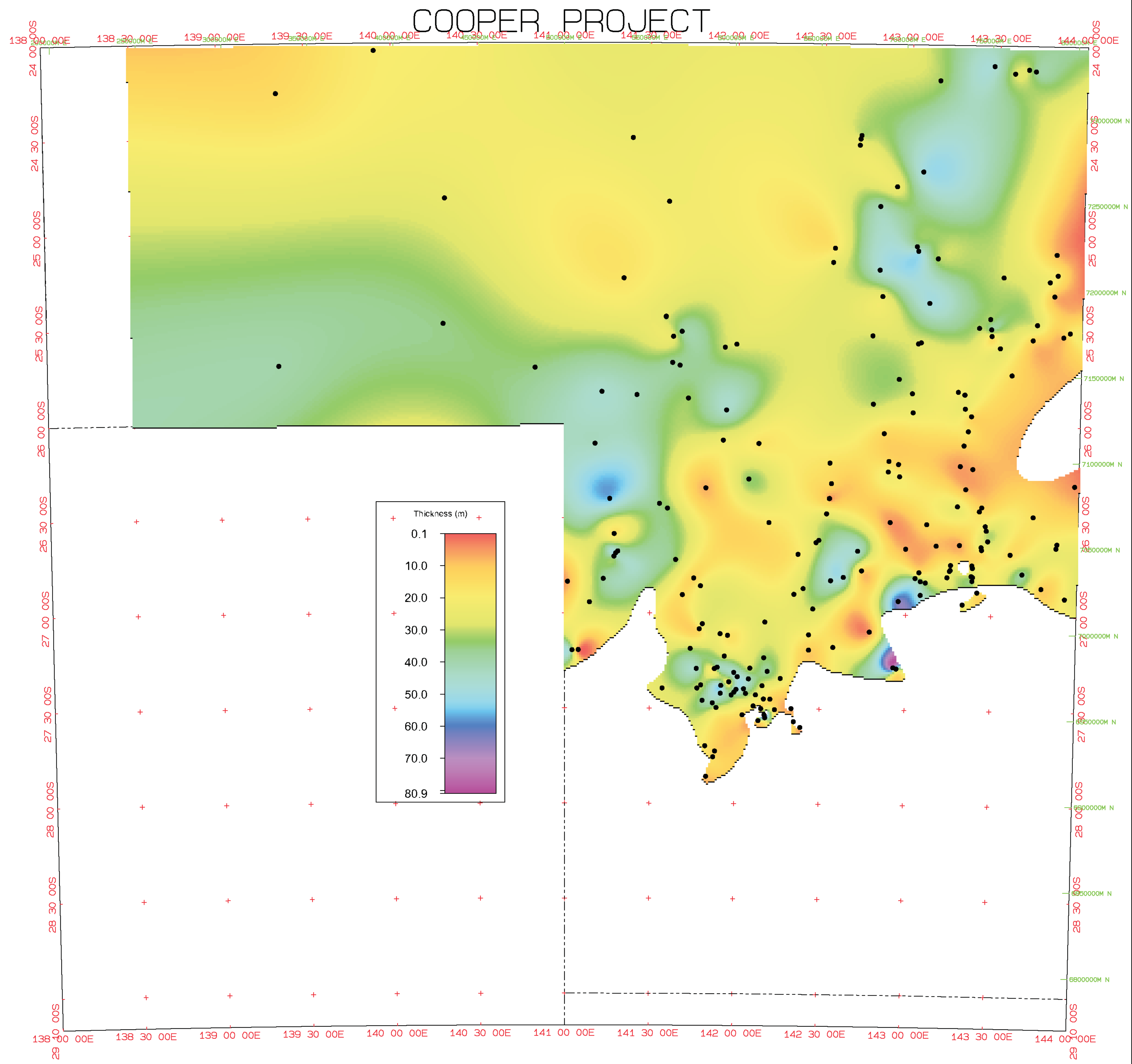
Figure 71

OPEN REPORT

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Wallumbilla Formation Isopach		



GO BACK

Figure 72

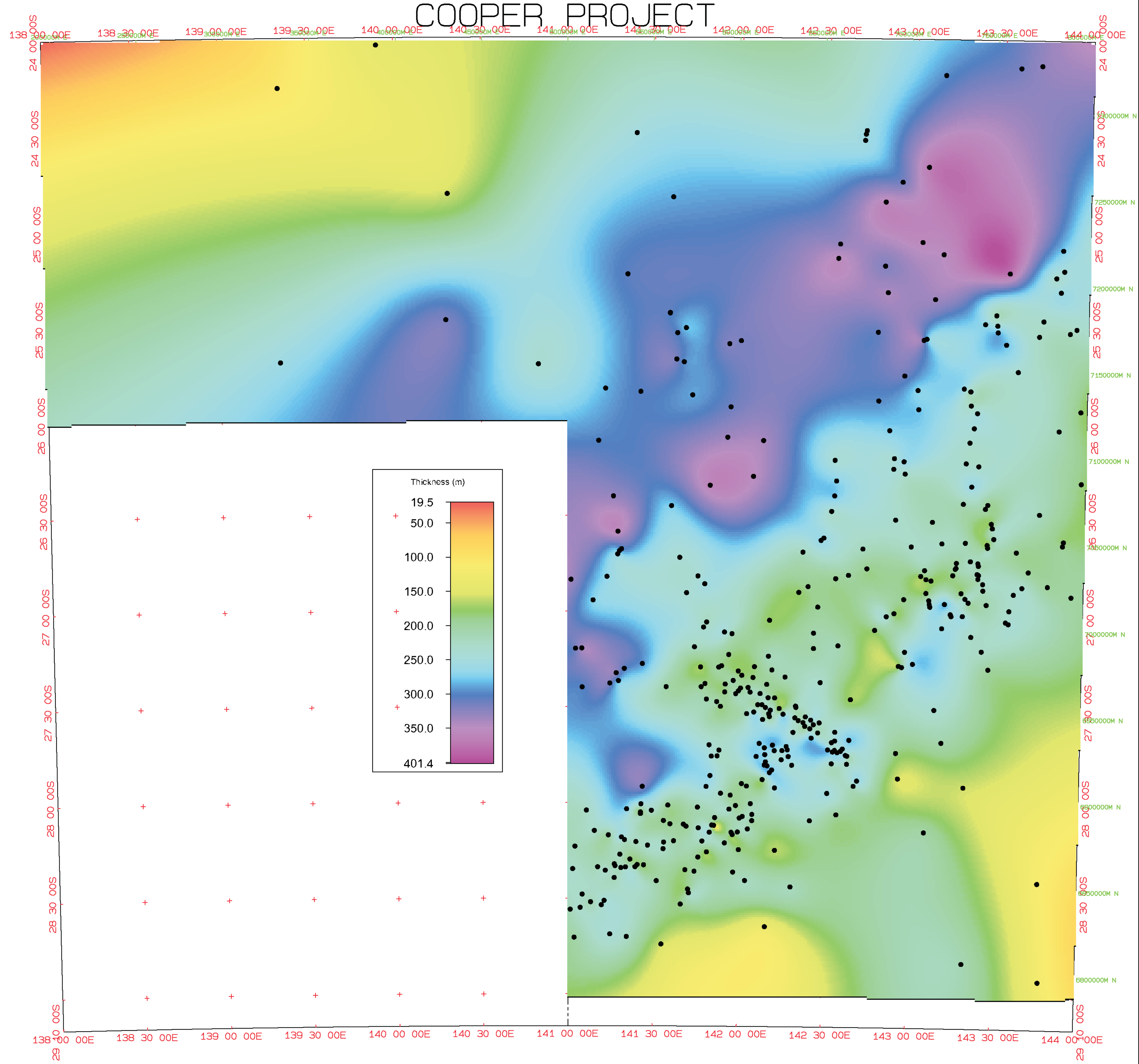
OPEN REPORT

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Toolebuc Formation Isopach		

COOPER PROJECT



GO BACK

Figure 73

OPEN REPORT

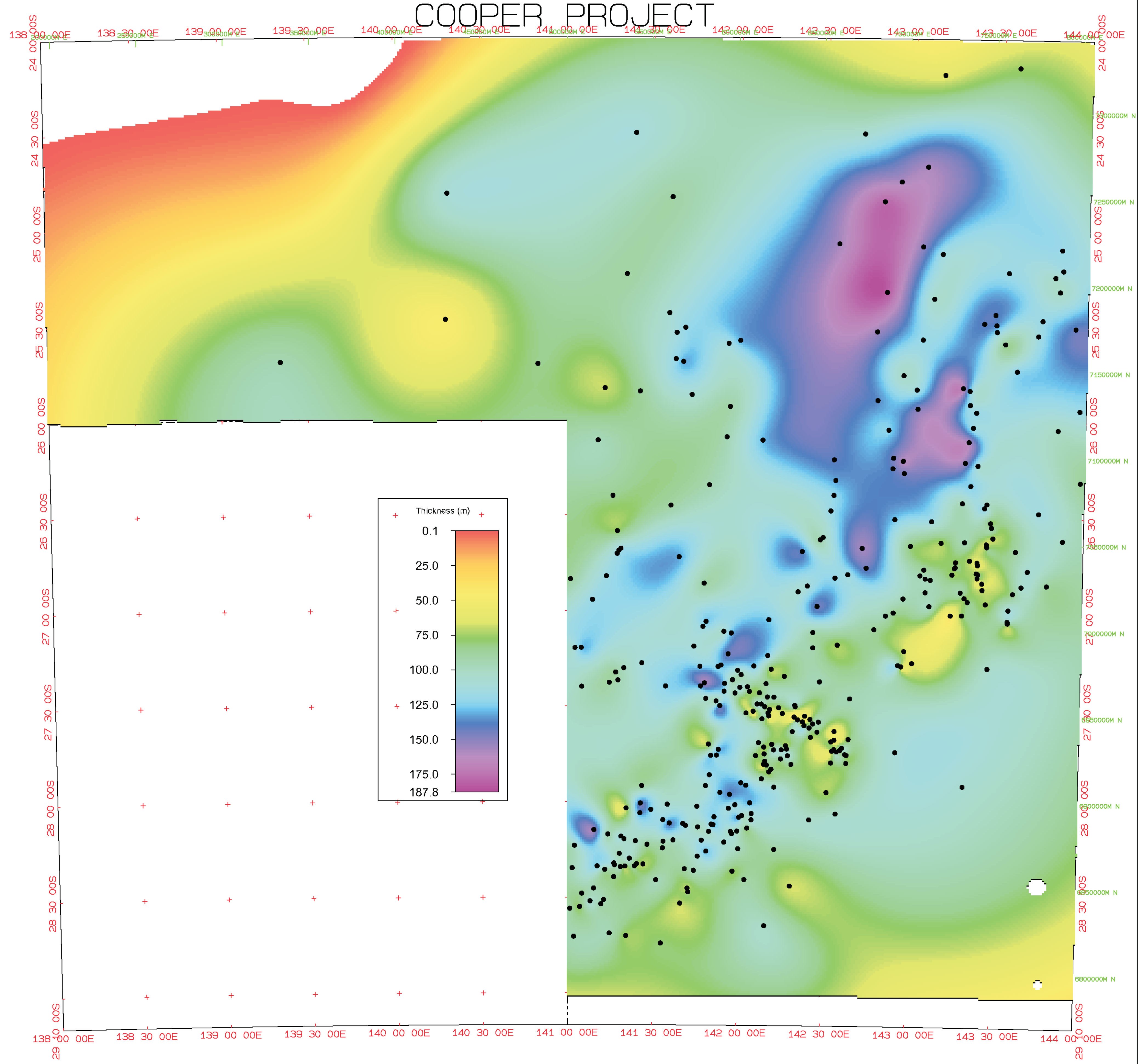
0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Allaru Mudstone Isopach		

COOPER PROJECT



GO BACK

OPEN REPORT

Figure 74

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland		
Mackunda Formation Isopach		

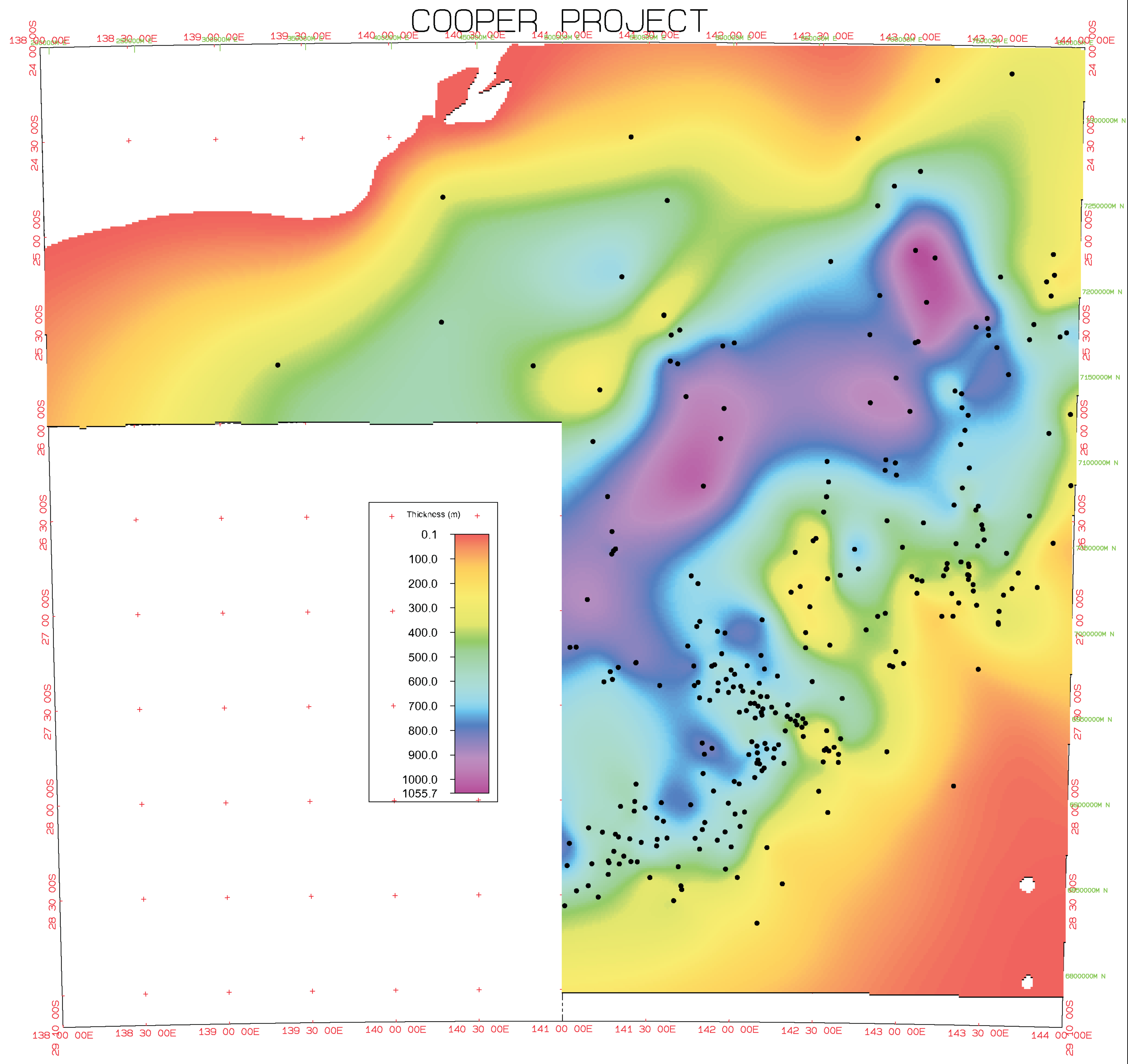


Figure 75

GO BACK

OPEN REPORT

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Winton Formation Isopach

COOPER PROJECT

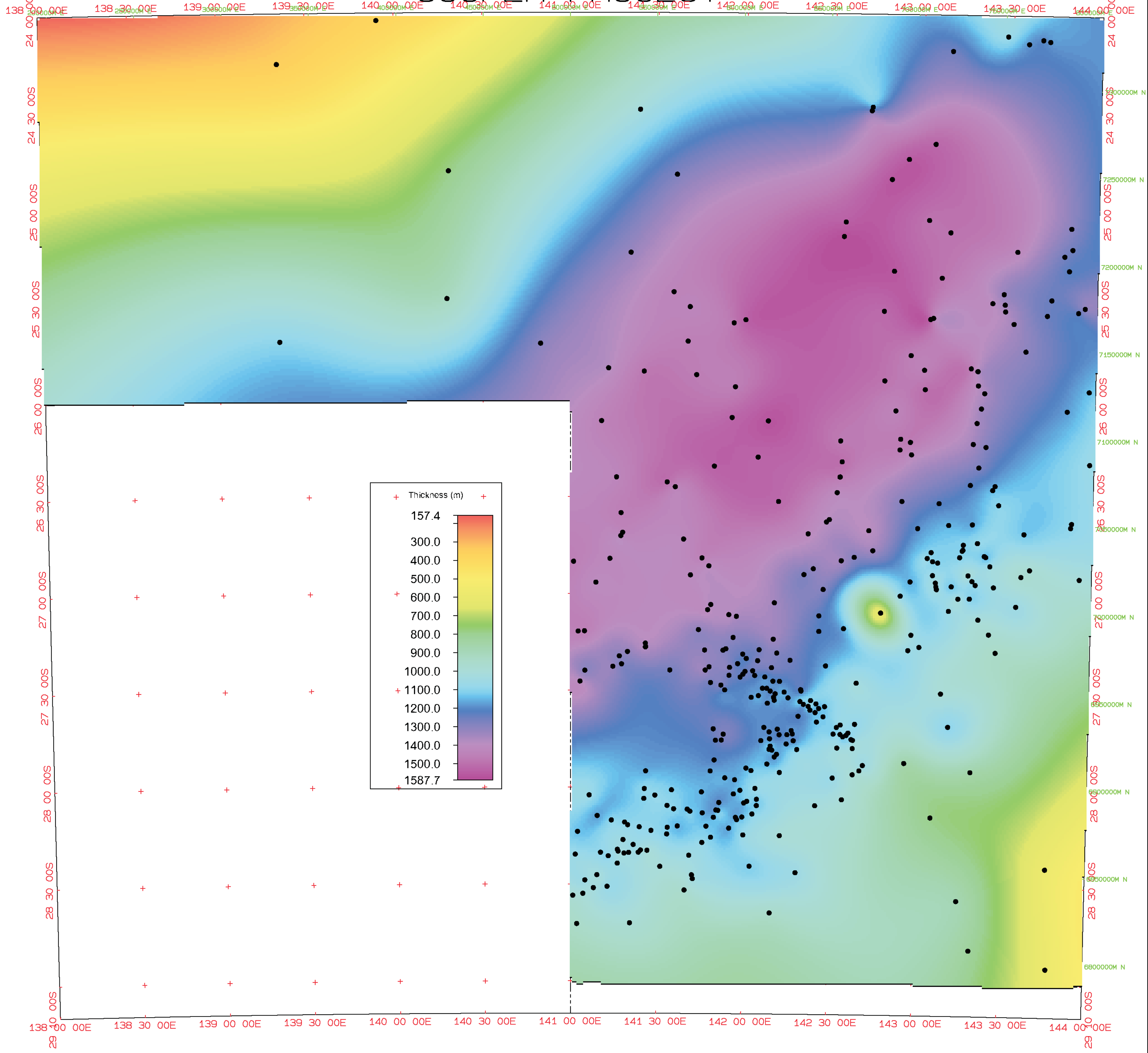


Figure 76

GO BACK

OPEN REPORT

0 20 40 60 80 100

KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

Geological Survey of Queensland

Base Poolowanna Formation to
Top Mackunda Formation Isopach

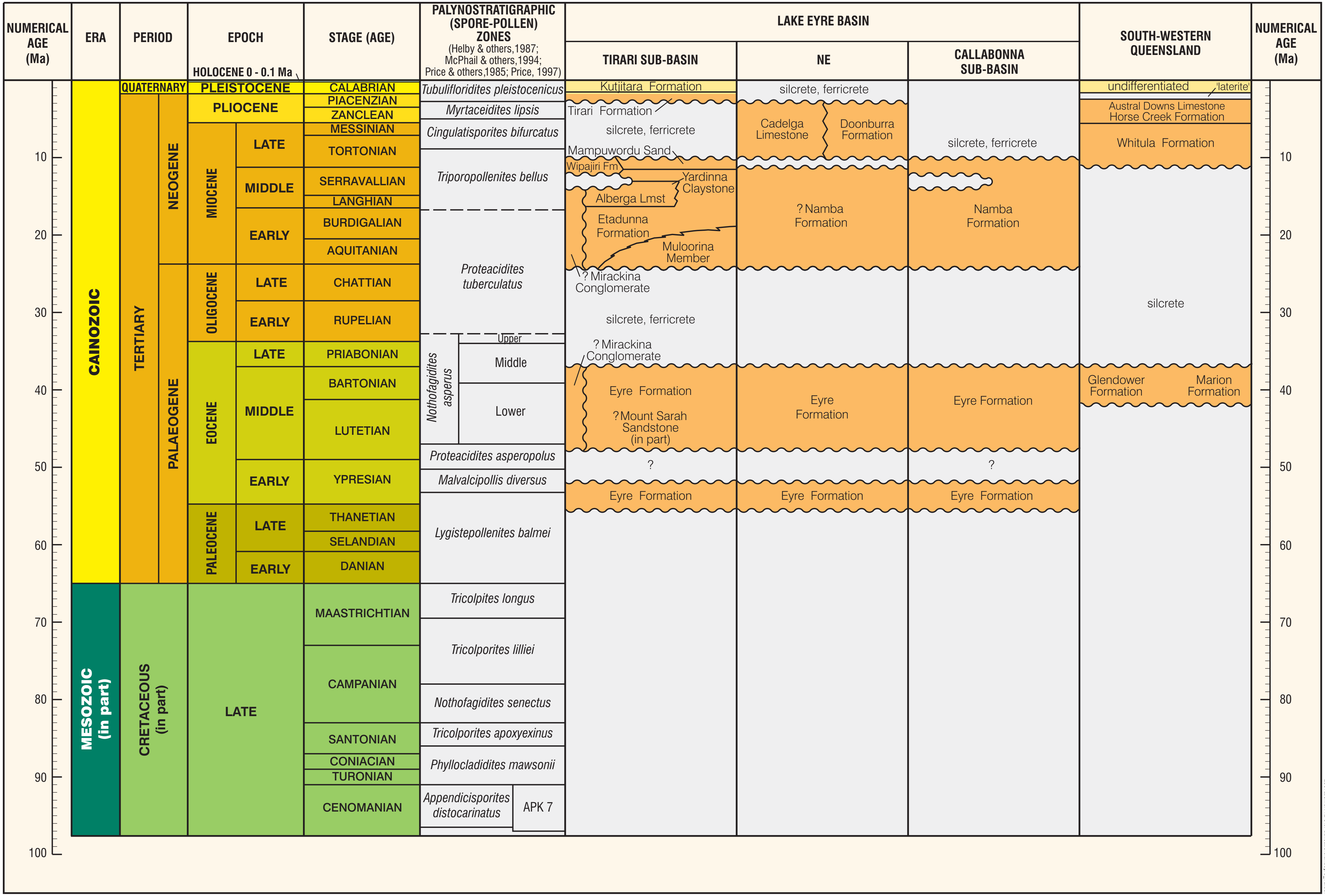
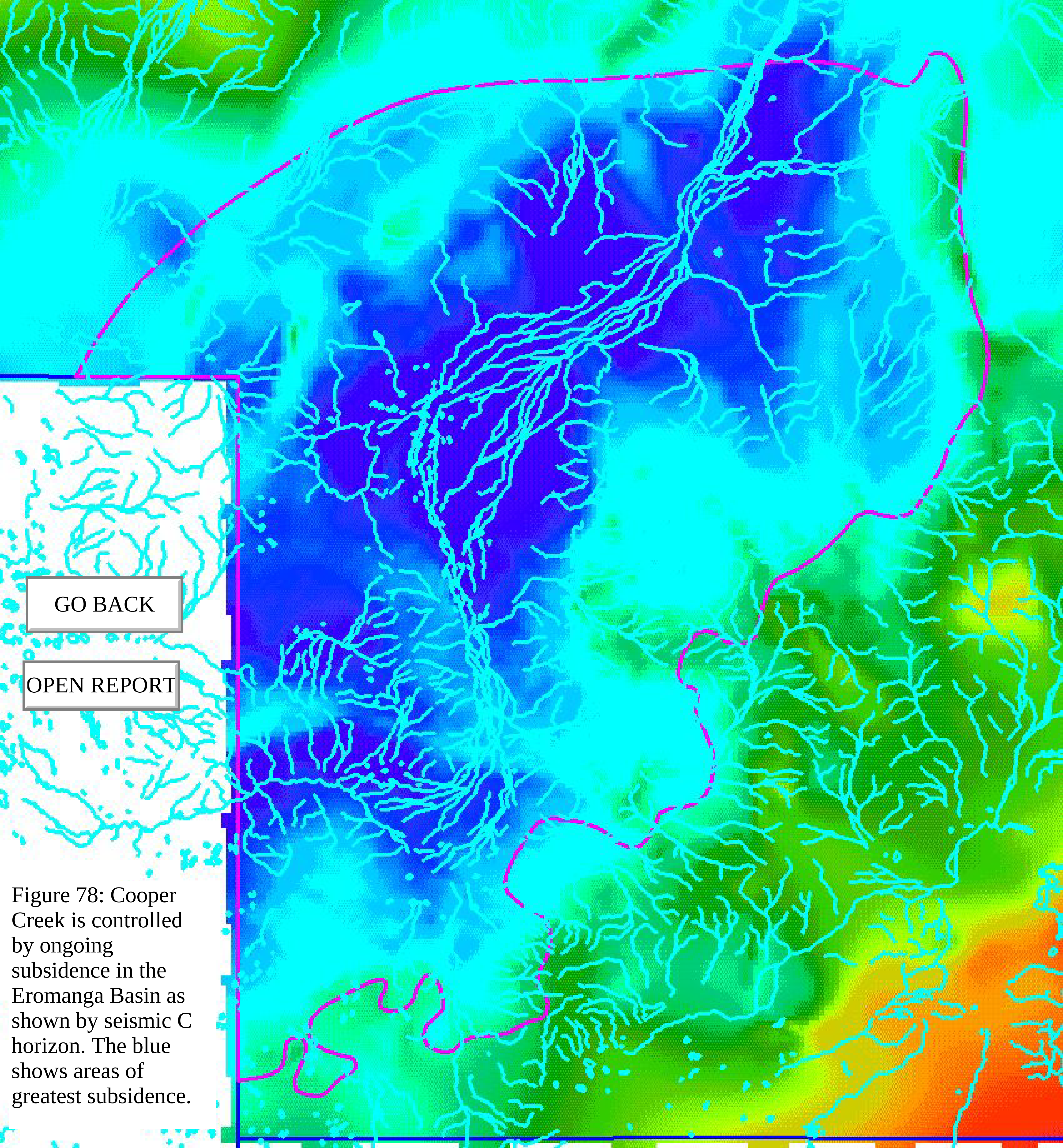


Figure 77 : Chronological stratigraphy of the Lake Eyre Basin (South Australia) and correlatives in Queensland.

Modified from Alley & Lindsay, *in* Drexel & Priess (1995, figs 10.2, 10.29) to conform with the AGSO Phanerozoic Timescale Wallchart (AGSO, 1996).

GO BACK

OPEN REPORT



GO BACK

OPEN REPORT

Figure 78: Cooper Creek is controlled by ongoing subsidence in the Eromanga Basin as shown by seismic C horizon. The blue shows areas of greatest subsidence.

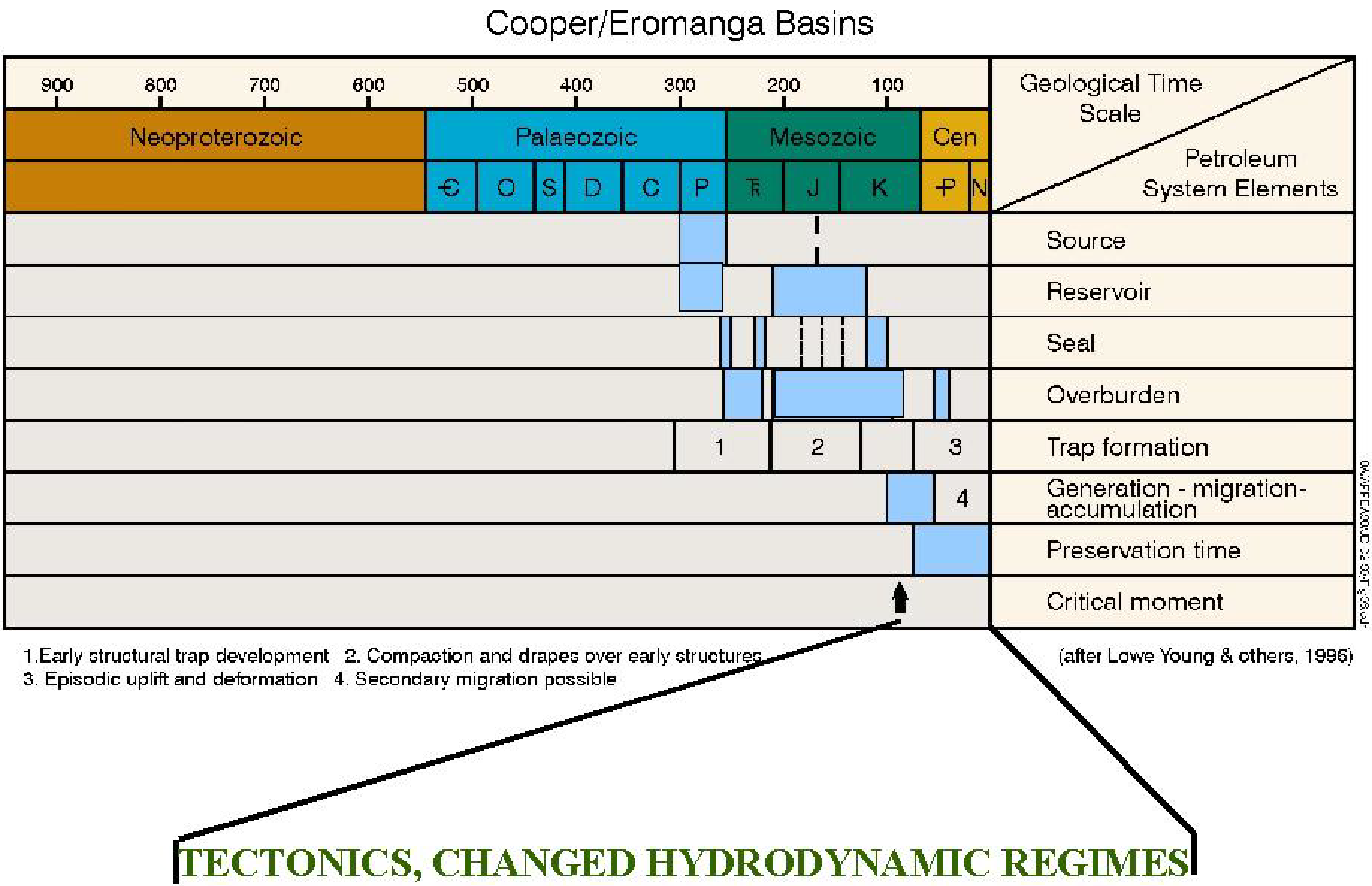


Figure 79: Cooper - Eromanga Basins Petroleum System.

GO BACK

OPEN REPORT

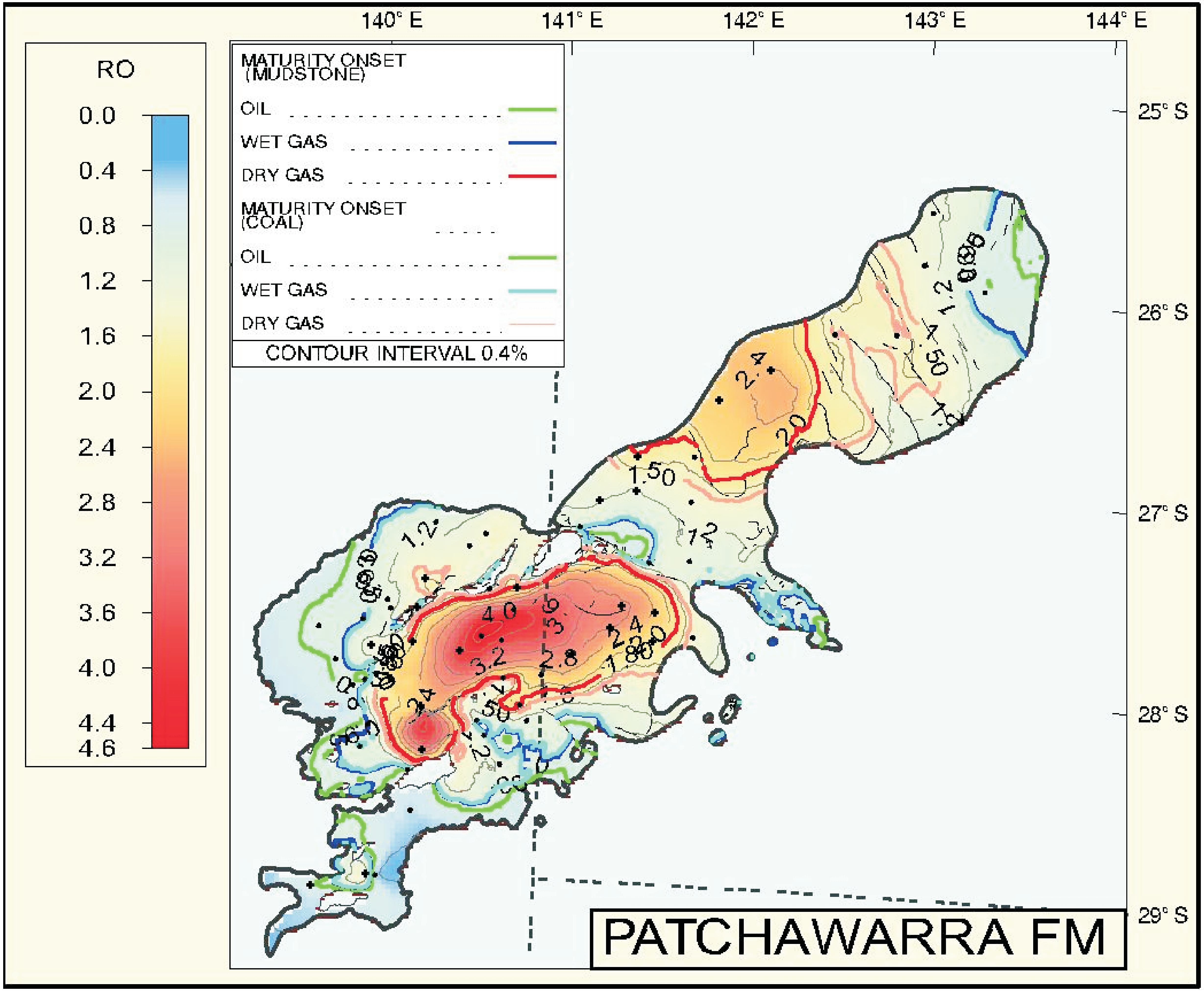


Figure 80: Maturity distribution – basal Patchawarra Formation (from Deighton & others, in preparation)

GO BACK

OPEN REPORT

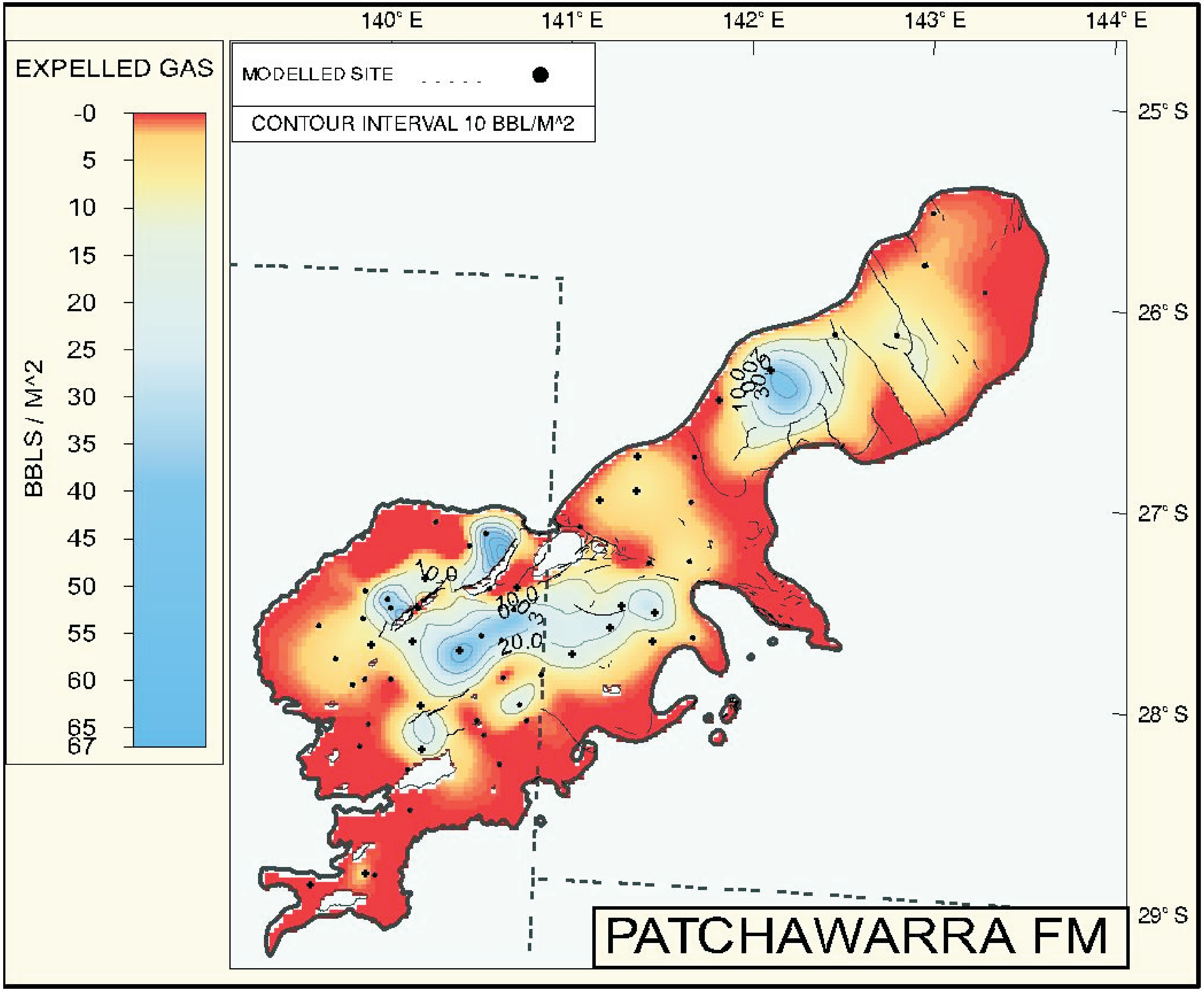


Figure 81: Gas expulsion – basal Patchawarra Formation (from Deighton & others, in preparation)

GO BACK

OPEN REPORT

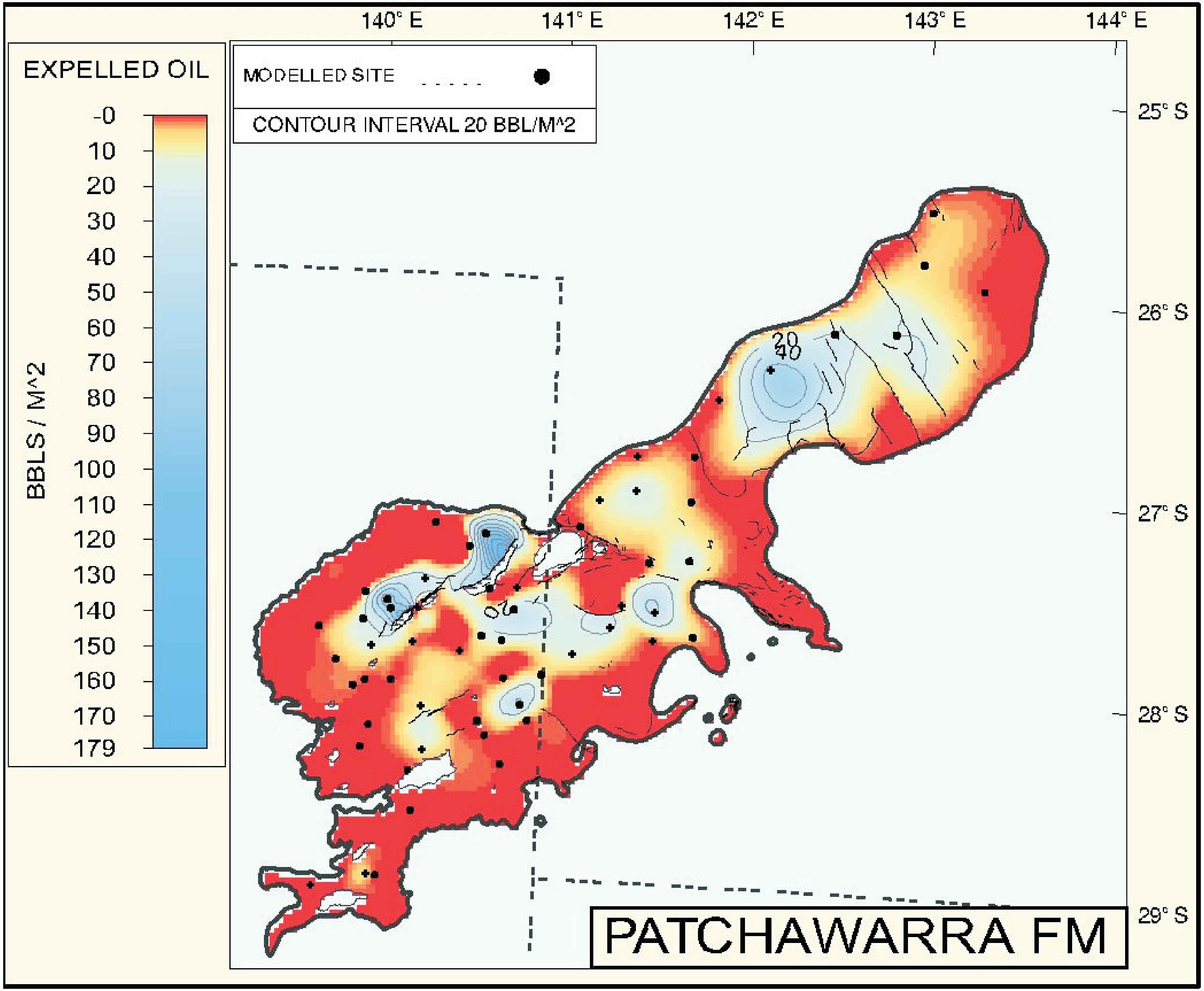


Figure 82: Oil expulsion – basal Patchawarra Formation (from Deighton & others, in preparation)

GO BACK

OPEN REPORT

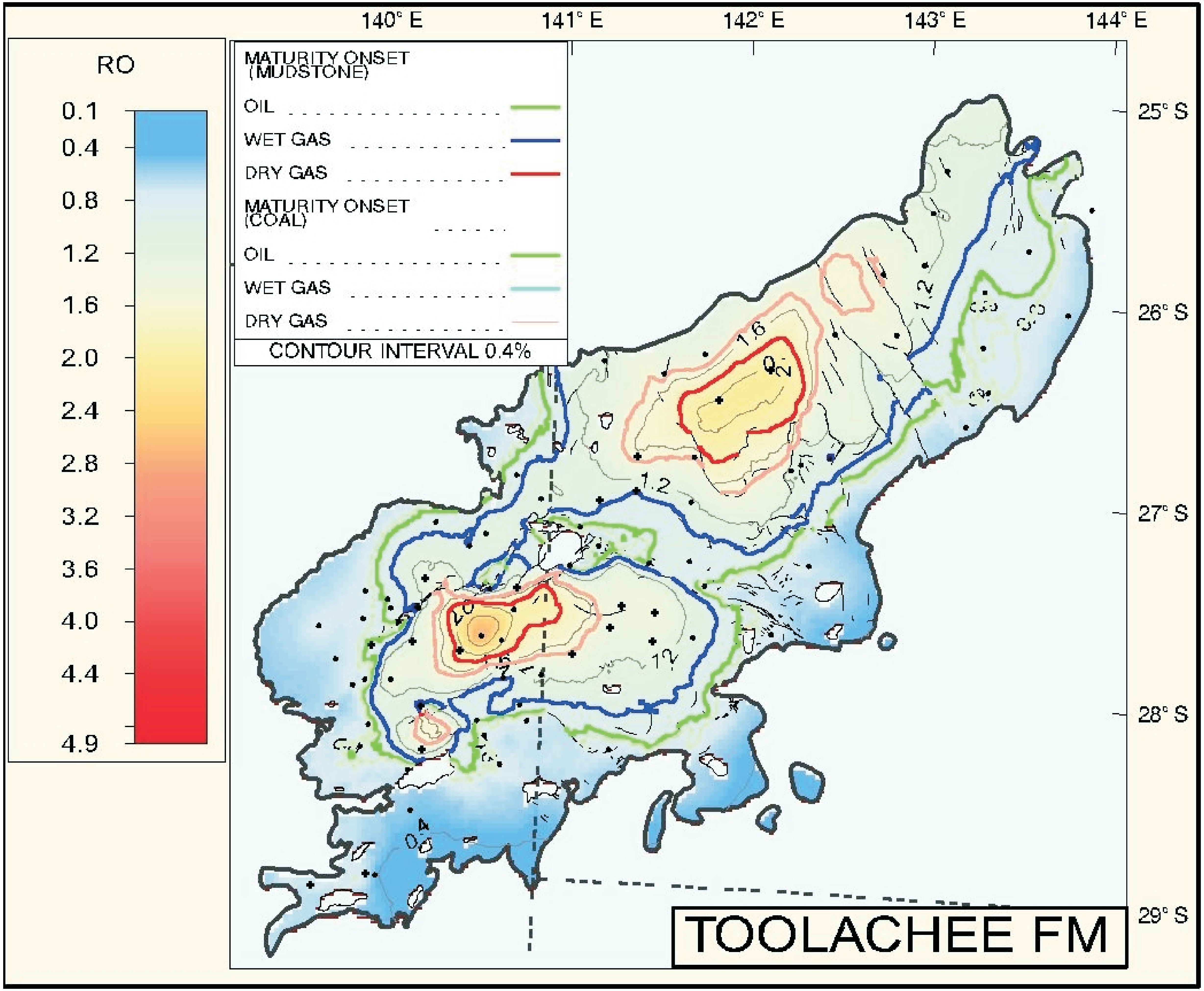


Figure 83: Maturity distribution – top Toolachee Formation (from Deighton & others, in preparation)

GO BACK

OPEN REPORT

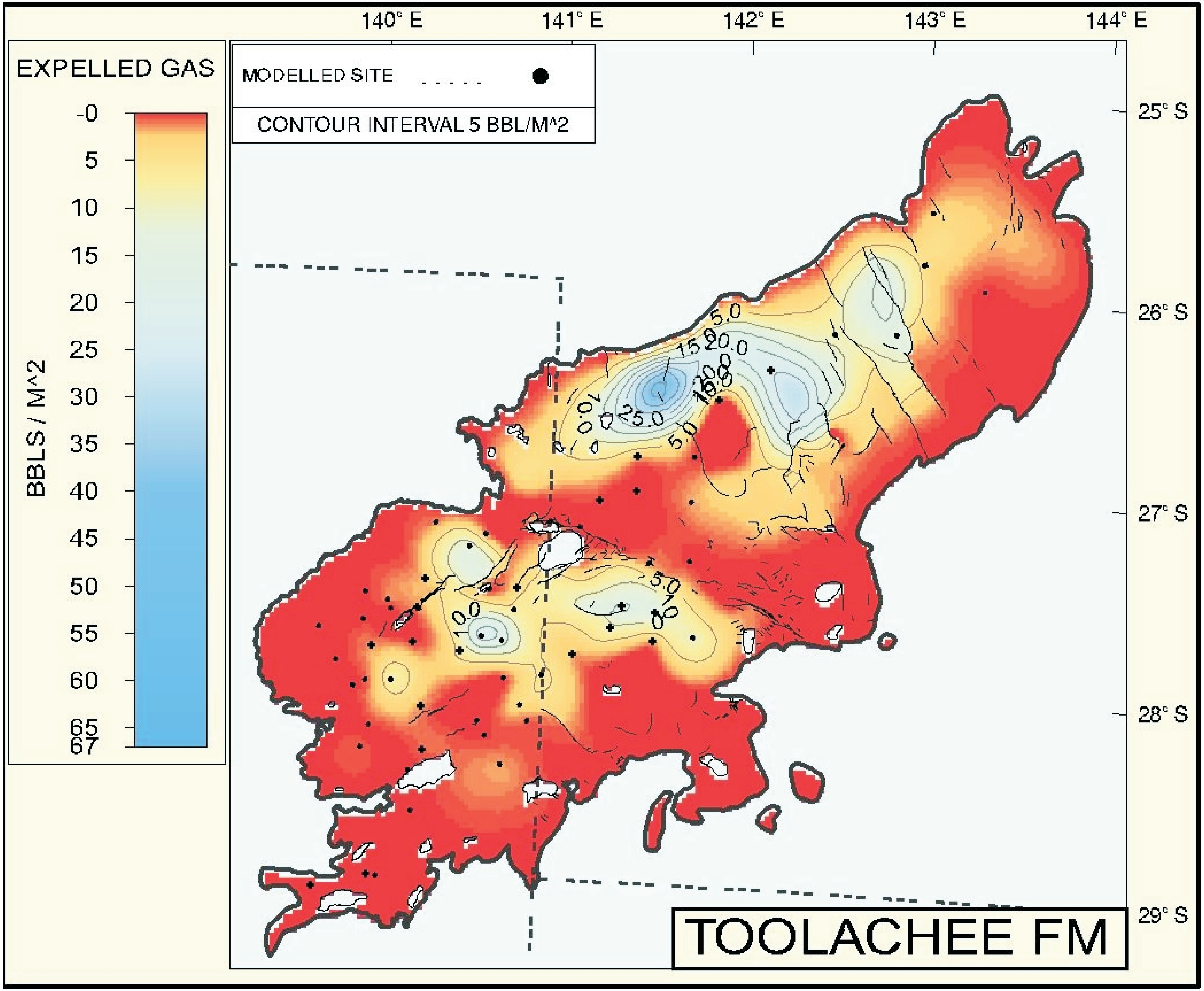


Figure 84: Gas expulsion – top Toolachee Formation (from Deighton & others, in preparation)

GO BACK

OPEN REPORT

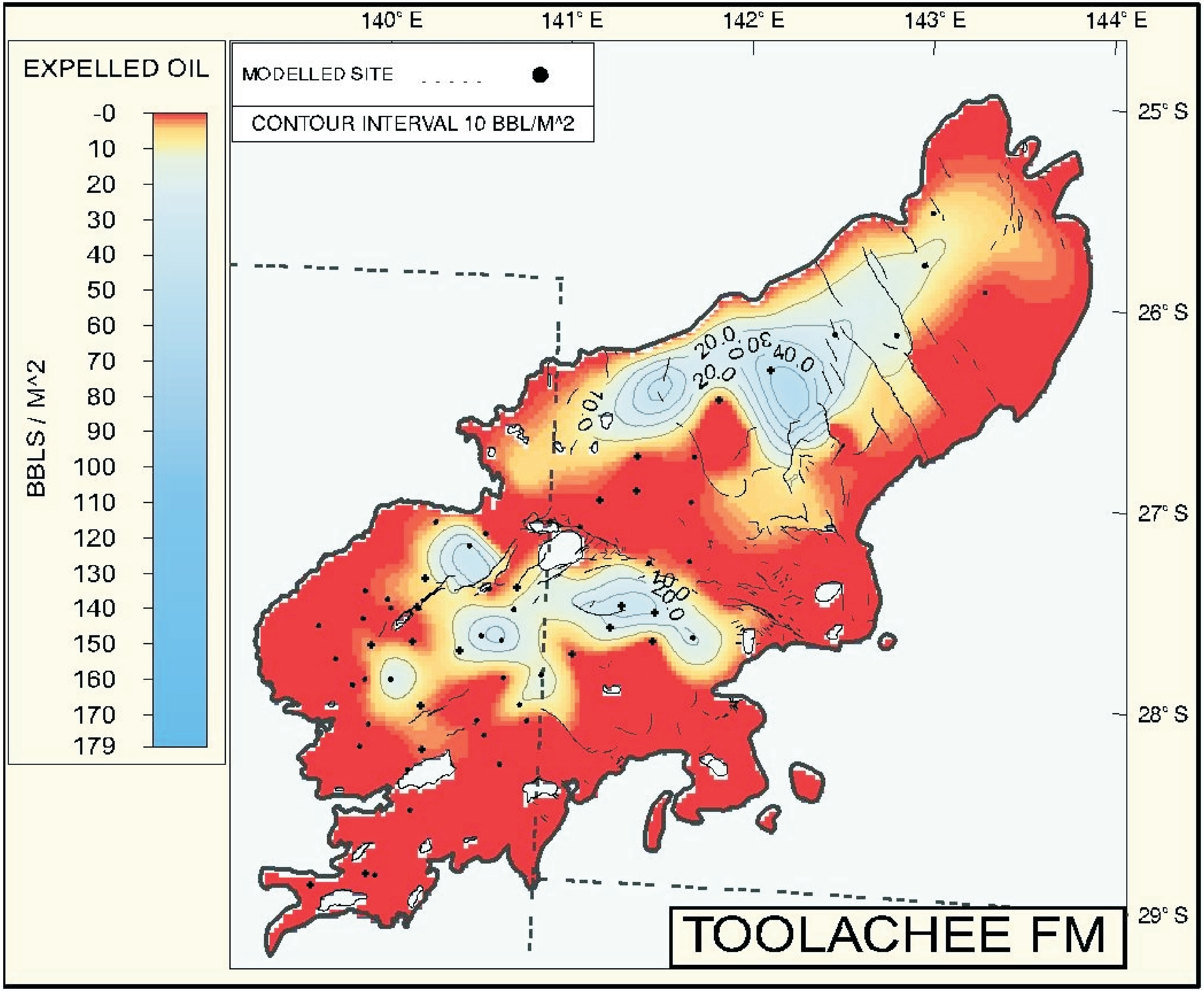


Figure 85: Oil expulsion – top Toolachee Formation (from Deighton & others, in preparation)

GO BACK
OPEN REPORT

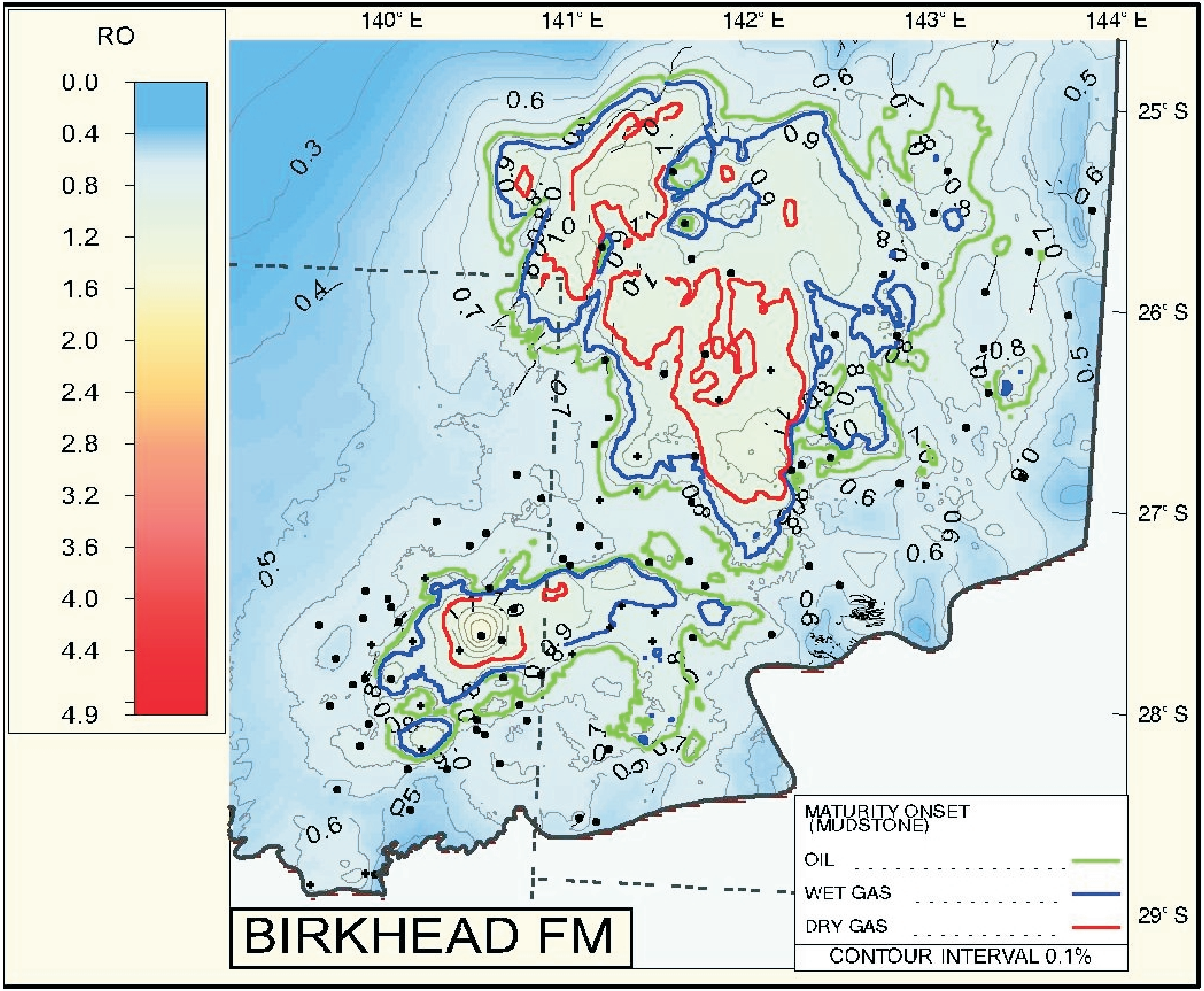


Figure 86: Maturity distribution – Birkhead Formation (from Deighton & others, in preparation)

GO BACK

OPEN REPORT

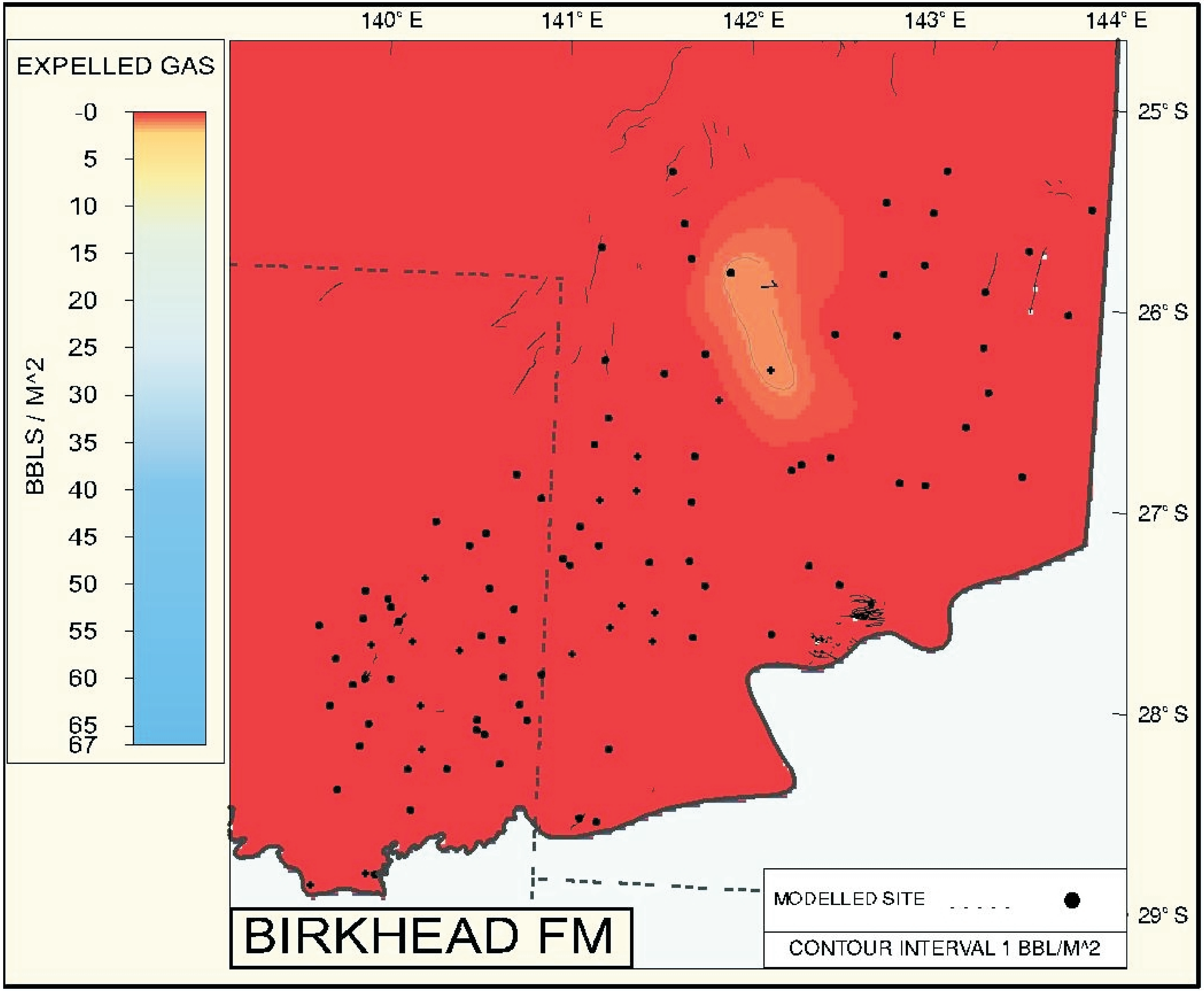


Figure 87: Gas expulsion – Birkhead Formation (from Deighton & others, in preparation)

GO BACK

OPEN REPORT

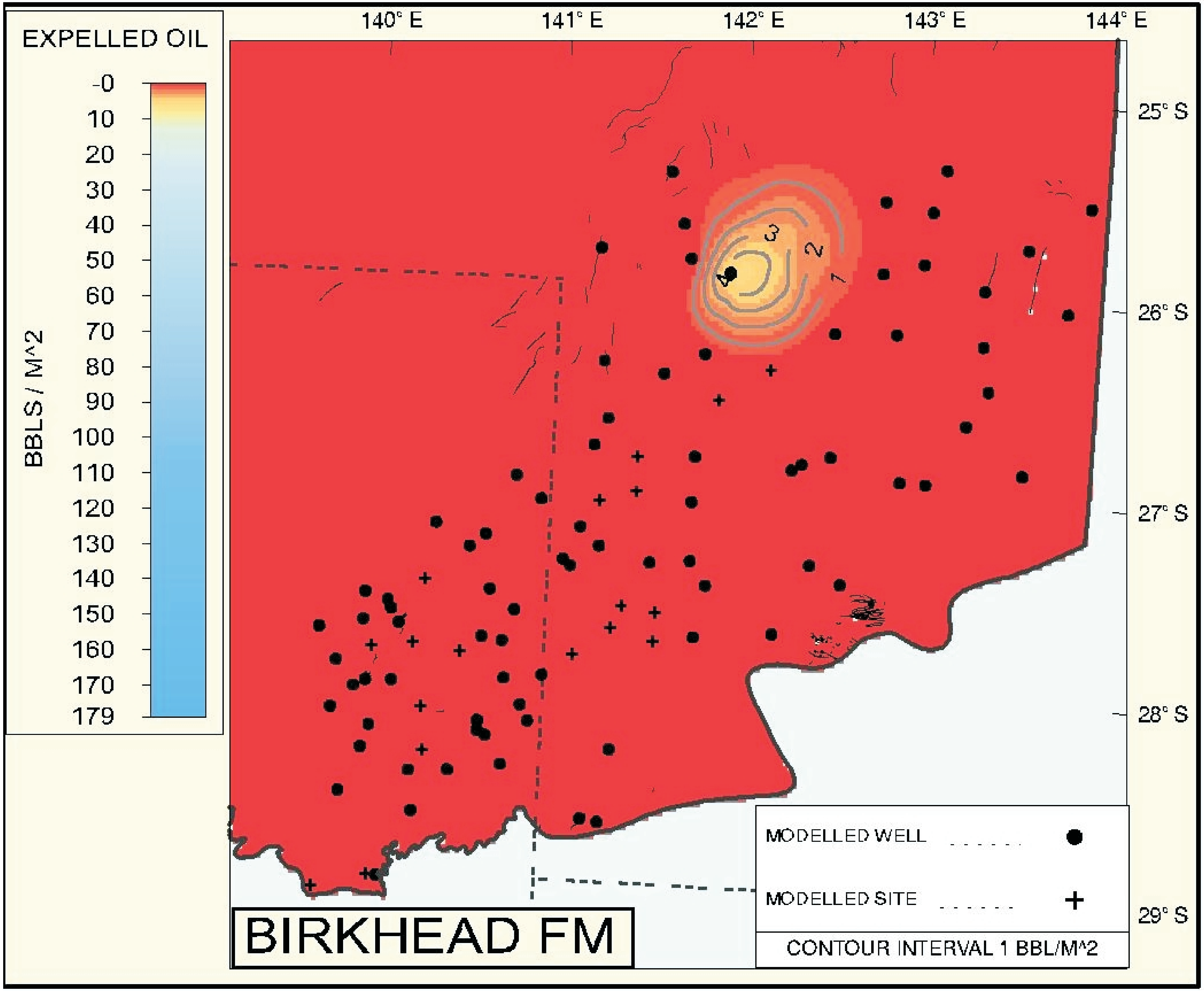


Figure 88: Oil expulsion – Birkhead Formation (from Deighton & others, in preparation)

GO BACK

OPEN REPORT

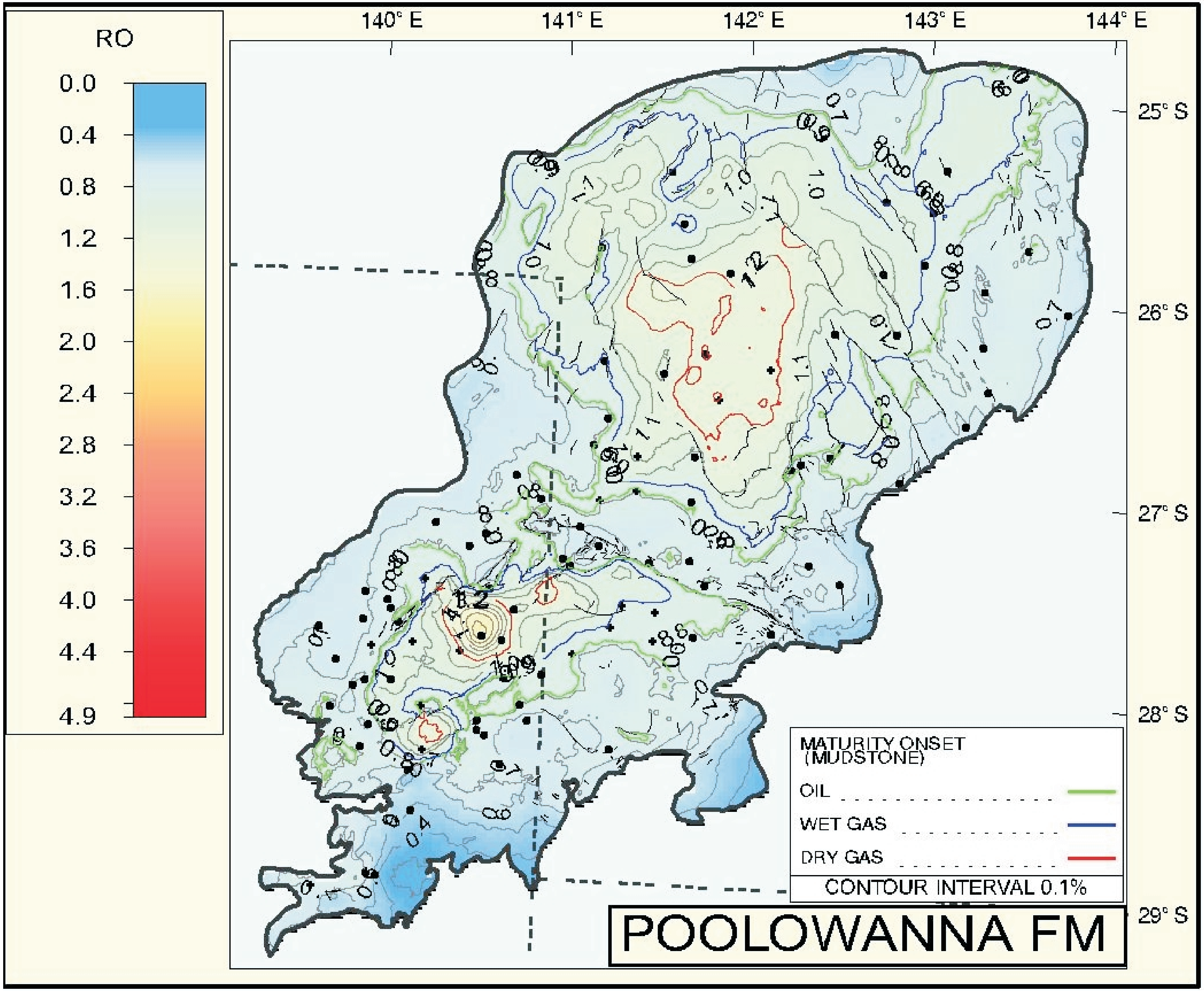


Figure 89: Maturity distribution – Poolowanna Formation (from Deighton & others, in preparation)

GO BACK

OPEN REPORT

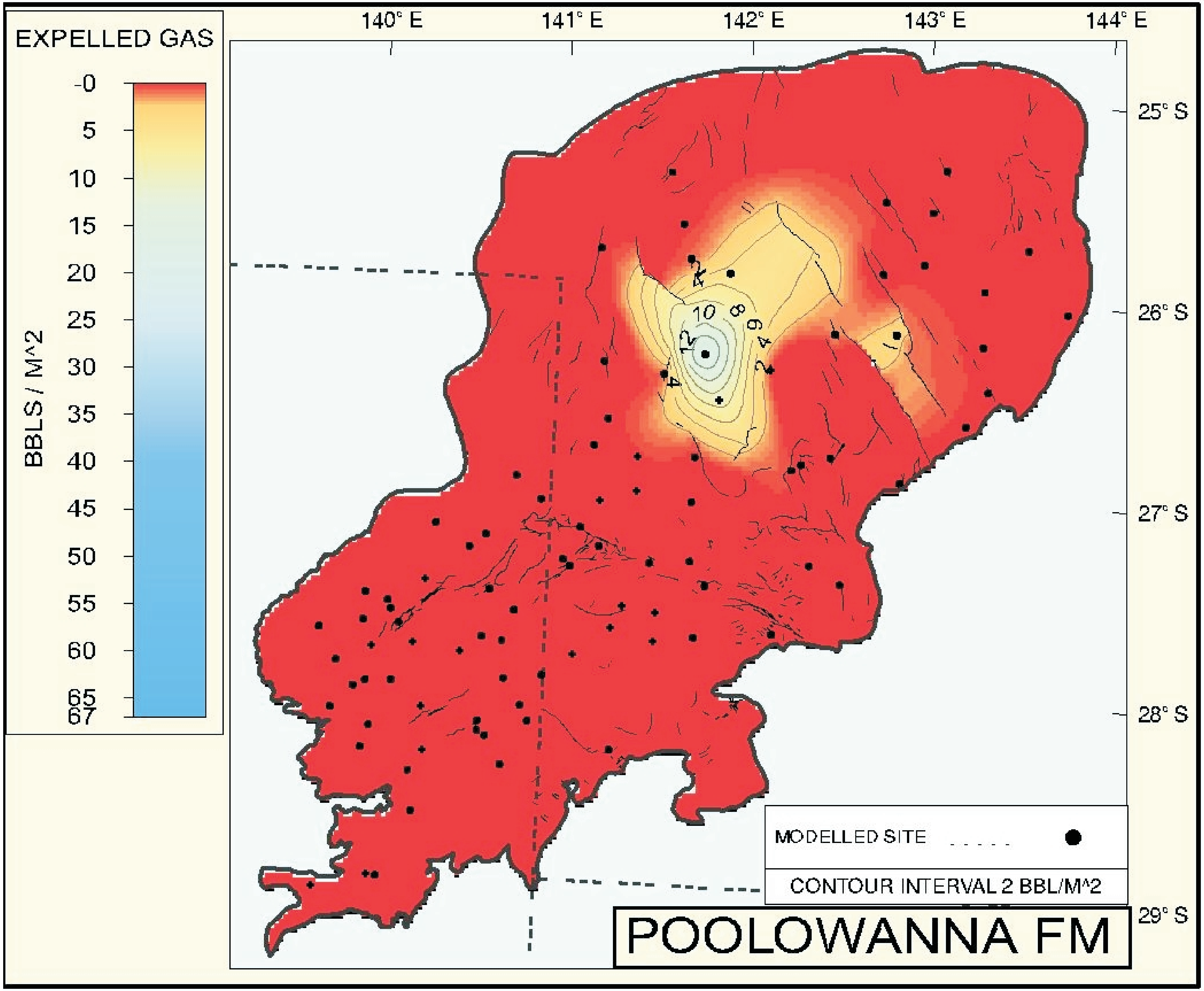


Figure 90: Gas expulsion – Poolowanna Formation (from Deighton & others, in preparation)

GO BACK

OPEN REPORT

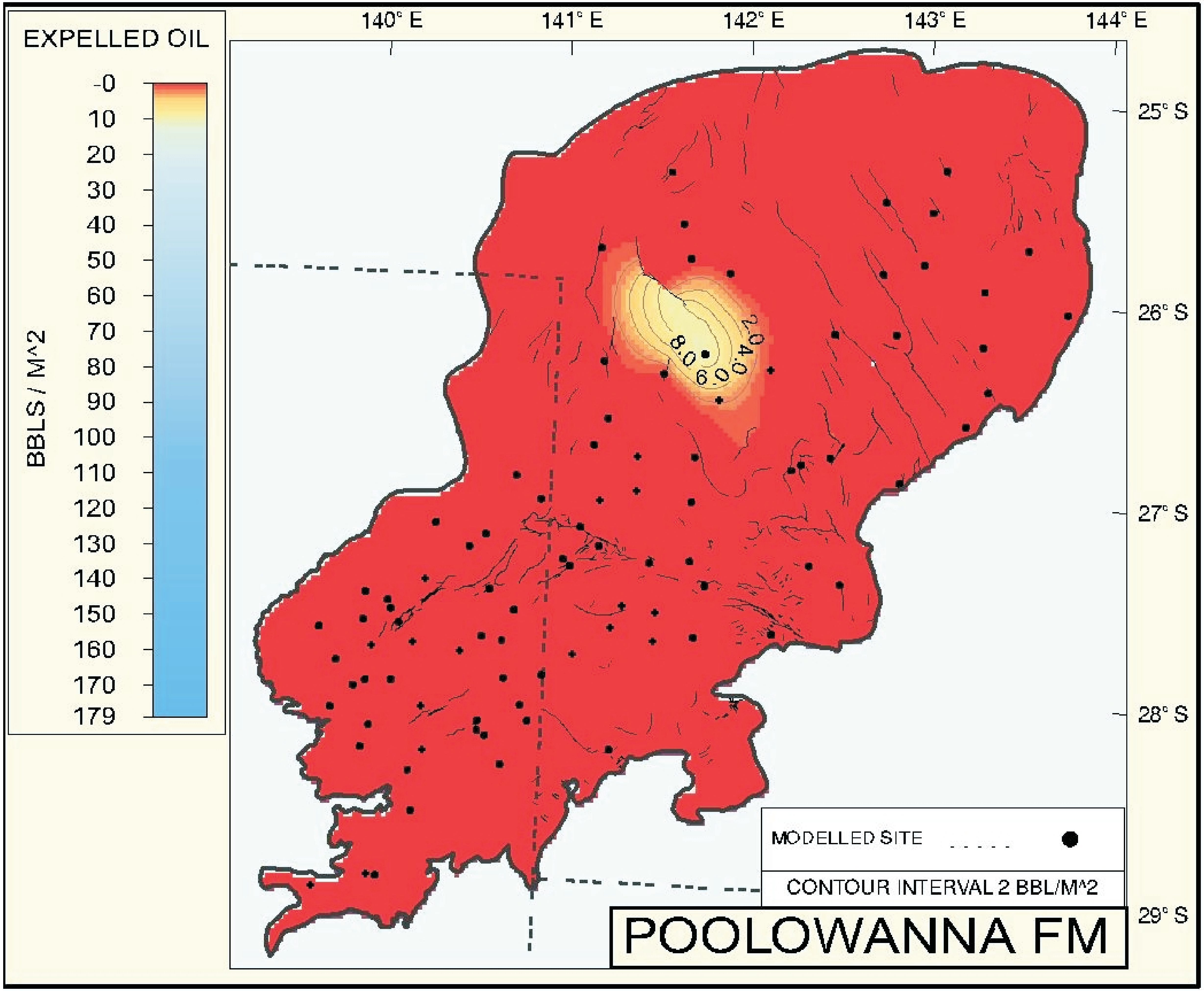


Figure 91: Oil expulsion – Poolowanna Formation (from Deighton & others, in preparation)

GO BACK

OPEN REPORT

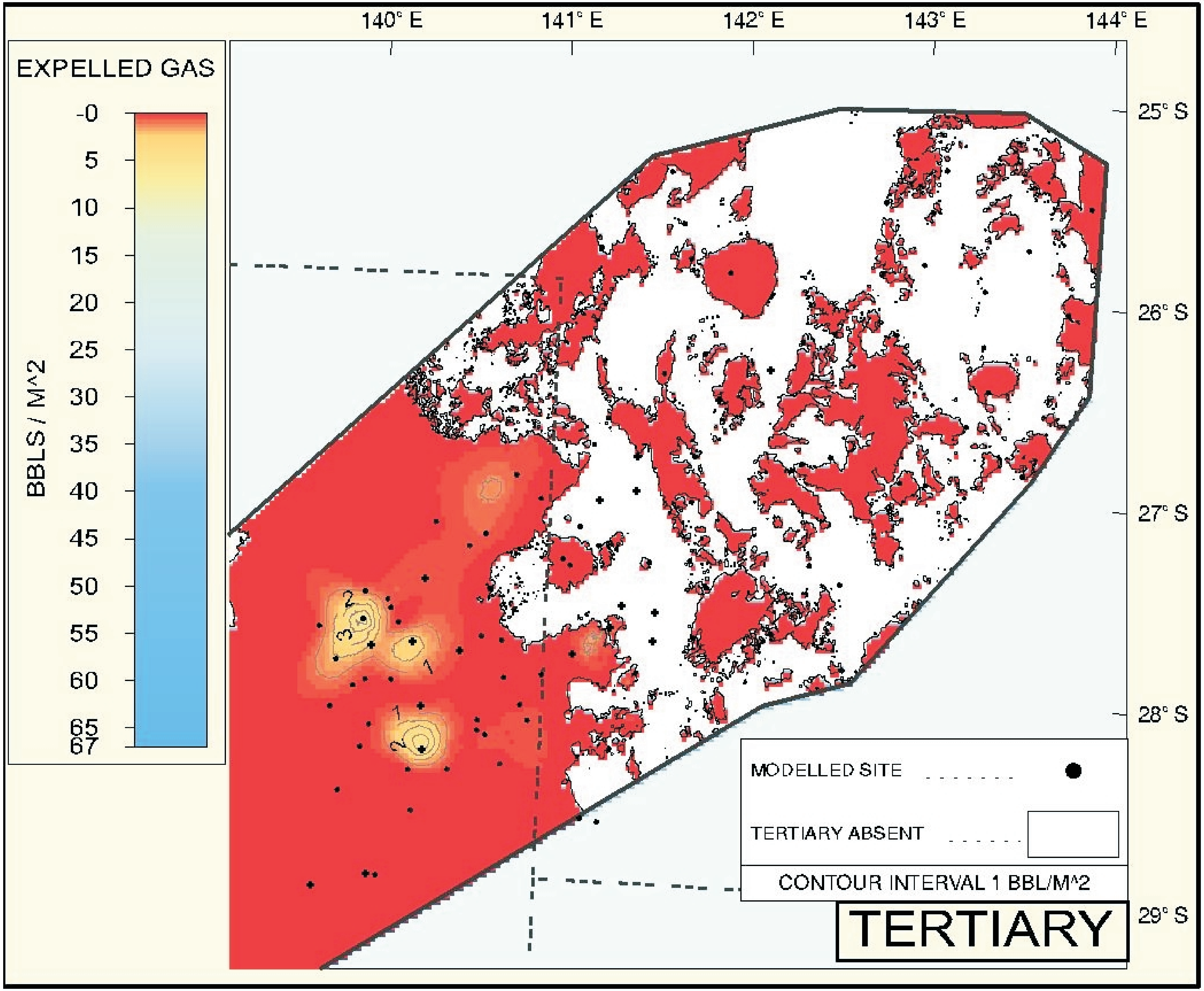


Figure 92: Gas expulsion during Cainozoic (from Deighton & others, in preparation)

GO BACK
OPEN REPORT

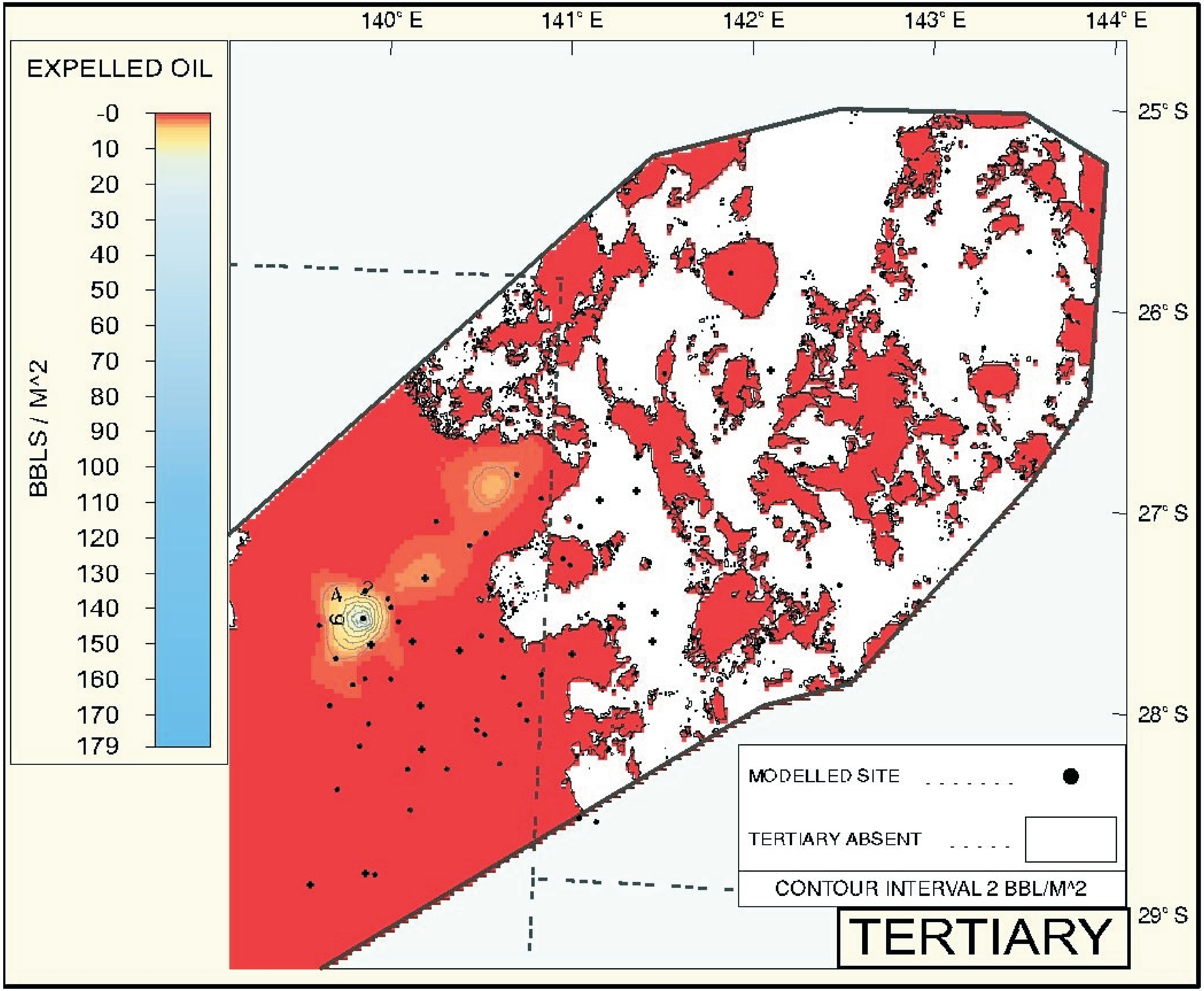


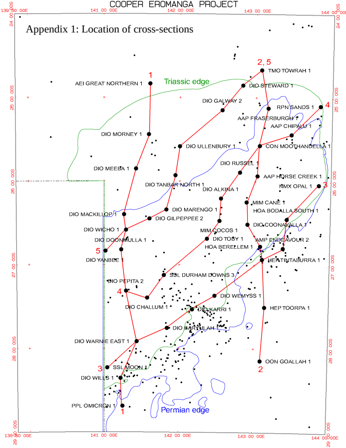
Figure 93: Oil expulsion during Cainozoic (from Deighton & others, in preparation)

GO BACK

OPEN REPORT

COOPER EROMANGA PROJECT

Appendix 1: Location of cross-sections



BACK TO REPORT

1:5000000

0 20 40 60 80 100
KILOMETRES

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
AUSTRALIAN NATIONAL SPHEROID
CENTRAL MERIDIAN 141 00 00E

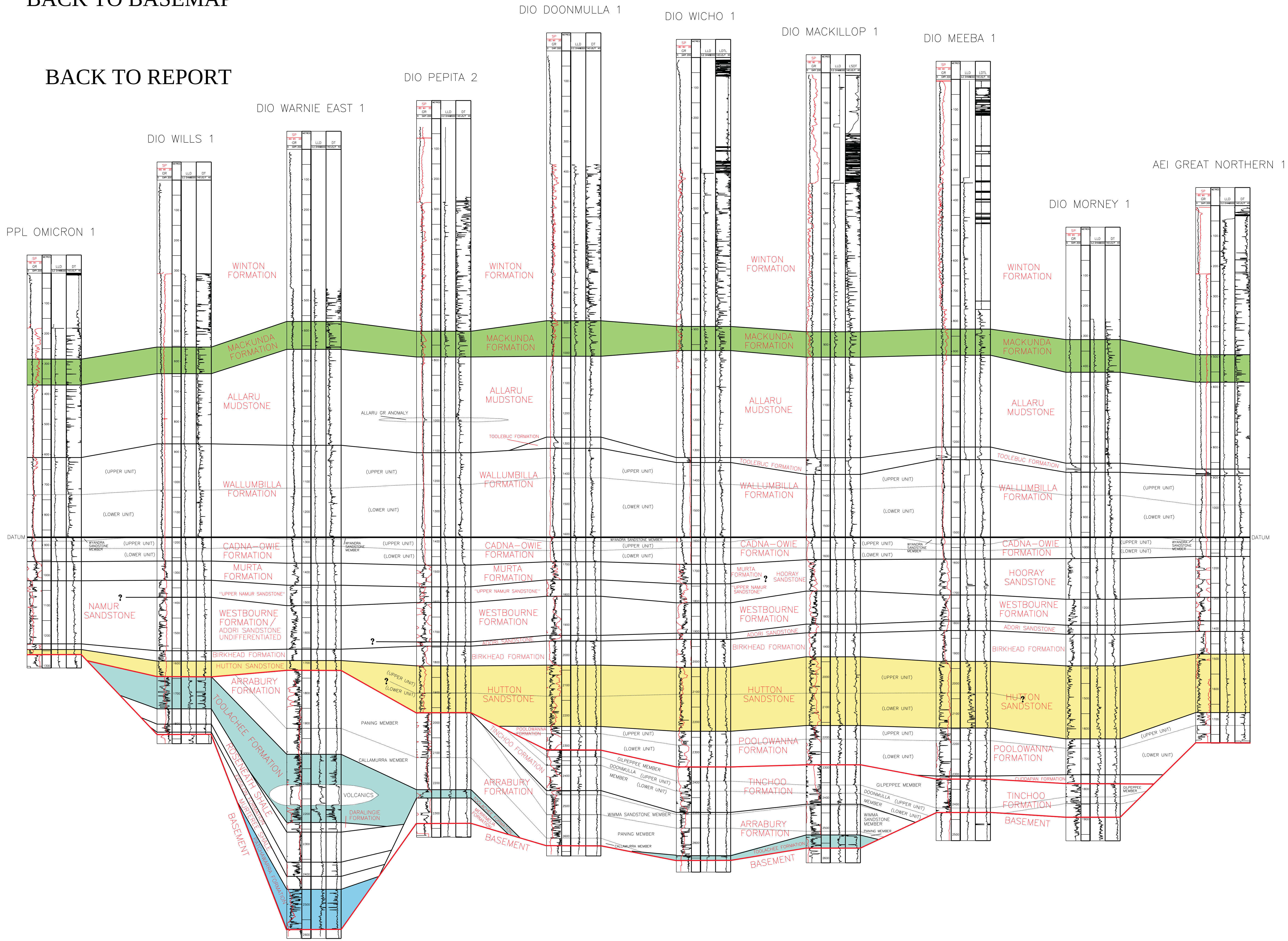
Lithostratigraphic
Section Lines 1 to 5

Click on line number to open section line

BACK TO BASEMAP

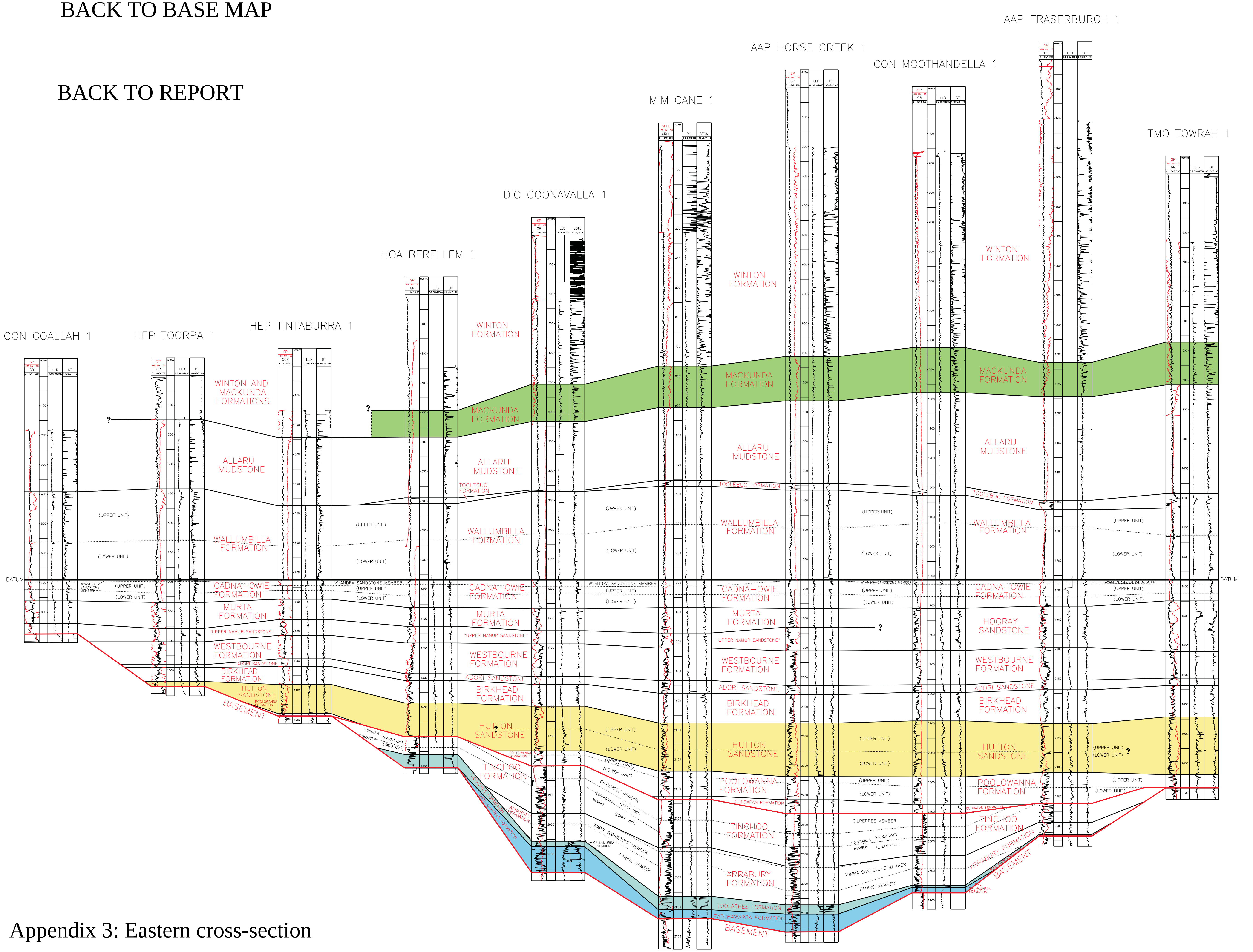
BACK TO REPORT

Appendix 2: Western cross-section



BACK TO BASE MAP

BACK TO REPORT

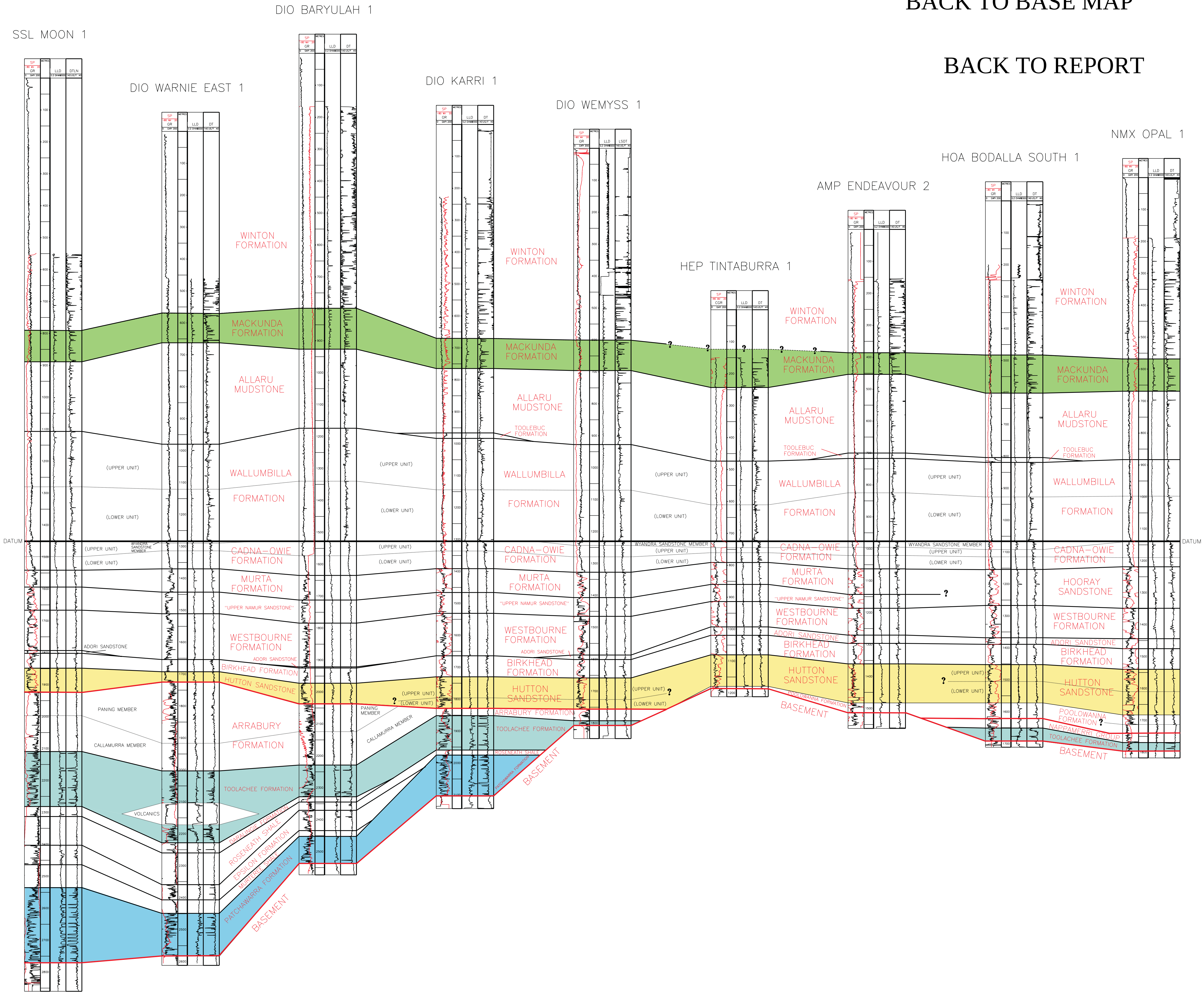


Appendix 3: Eastern cross-section

Appendix 4: Southern cross-section

BACK TO BASE MAP

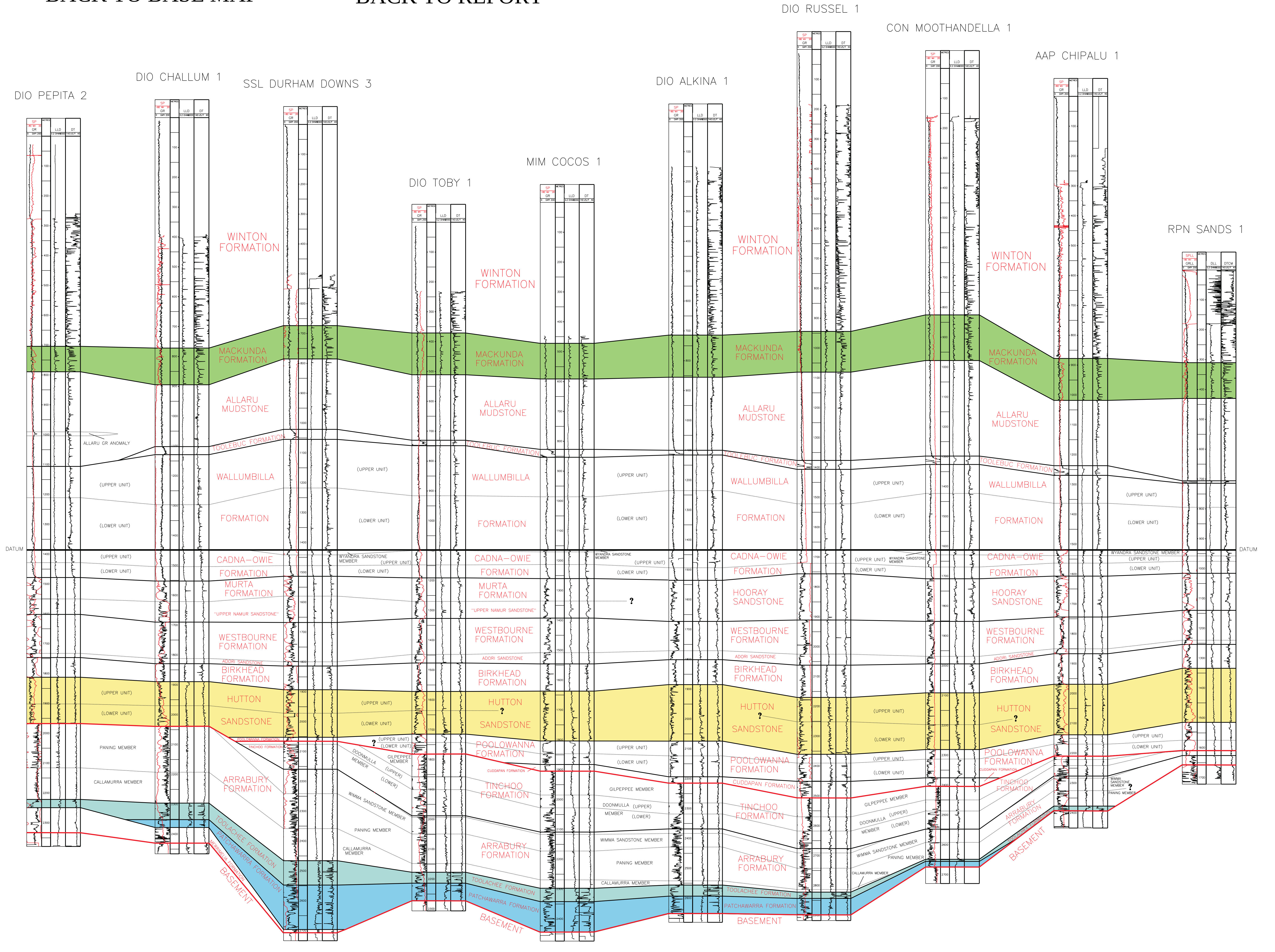
BACK TO REPORT



Appendix 5: Middle cross-section

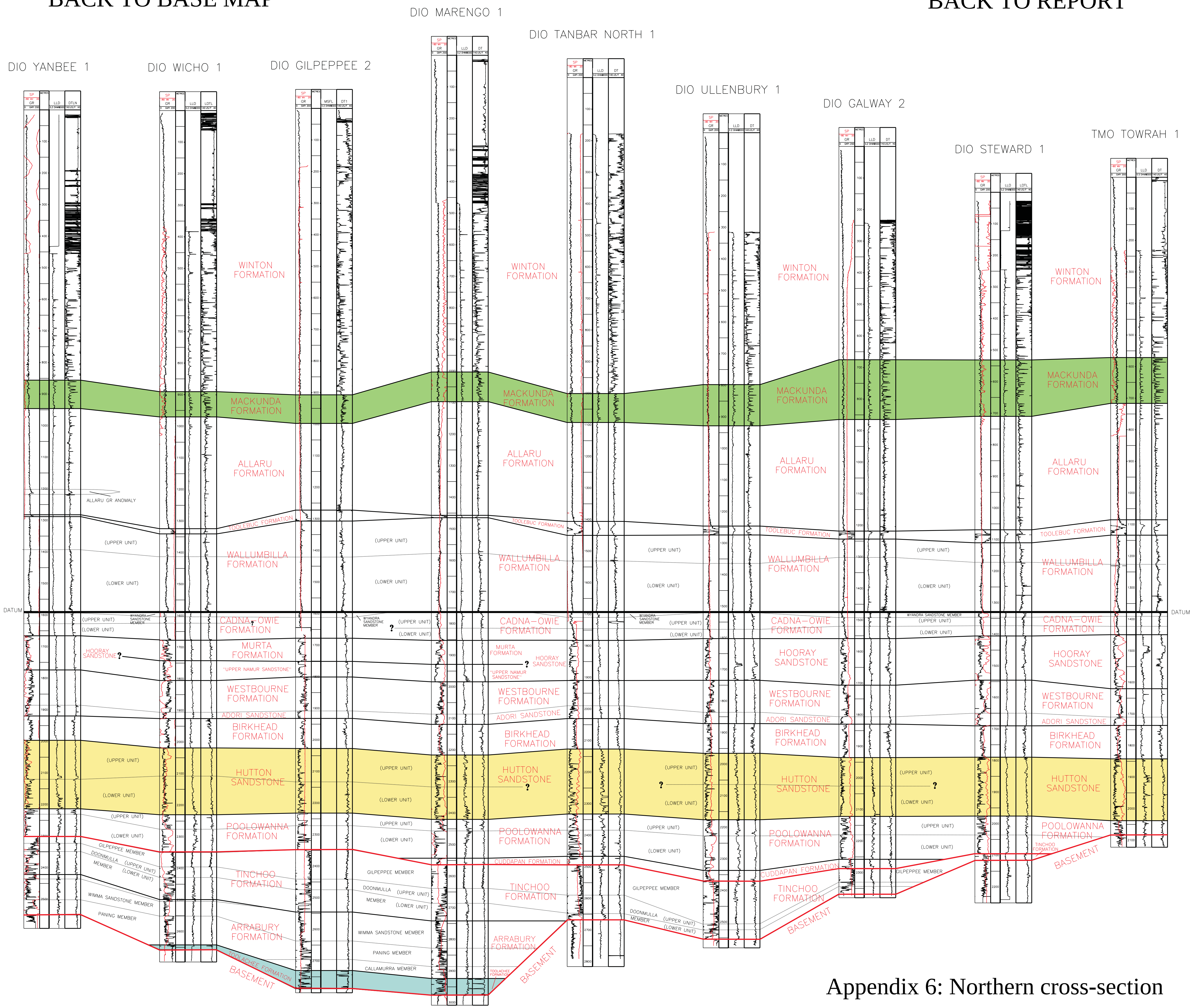
BACK TO BASE MAP

BACK TO REPORT



BACK TO BASE MAP

BACK TO REPORT



Appendix 6: Northern cross-section