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Well Logs

Cross Sections

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AGSO RECORD 1999/10

Measured Sections and Sequence Stratigraphic Interpretations: lower McNamara, Mt Isa and Fickling Groups

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Abstract

Paleoproterozoic sedimentary rocks of northern Australia (**Figure 1**), host one of the world's most important zinc repositories. Despite more than fifty years of geological investigation, including the production of 1:250,000 and 1:100,000 geological maps and the drilling of countless mineral exploration holes the public domain contains comparatively little measured section and basic sedimentological information. Because these datasets are essential for understanding sediment architecture and basin shape they from a necessary stepping stone to formulating models aimed at constraining the flow of mineralising fluids in these basins.

This data record provides the mineral exploration industry, university and government geoscientists with thirty five, composite outcrop and drill core stratigraphic sections through the lower McNamara, Fickling and Mt Isa Groups. Close to thirty one thousand meters of stratigraphic/sedimentological description and interpretation is provided. Each section contains grain size, lithology, bed thickness, sedimentary structure and gamma ray data from which facies and sequence stratigraphic surfaces are interpreted. Despite the absence of invertebrate fossils the sequence interpretations, in combination with SHRIMP zircon ages and Apparent Polar Wander Path data, permit the erection of a well-constrained chronostratigraphic framework for these Paleoproterozoic rocks. Previous lithostratigraphic subdivisions were diachronous and emphasised local stratigraphic successions rather than basin-wide correlations. The data contained in this record contains a chronostratigraphic sequence subdivision from which original basin shape and sediment architecture can be derived. The subdivision enables rocks deposited on the southern flanks of the Murphy Inlier to be more accurately correlated with sediments of similar age but markedly different facies in the Lawn Hill Platform and Leichhardt River Fault Trough to the south.

Introduction

This CD ROM contains outcrop and drill core stratigraphic and sedimentologic data from the Mt Isa, lower McNamara and Fickling Groups of the Calvert and Isa Superbasins in northern Australia (Scott et al 1999, Jackson et al 2000). Twenty one sections are from the lower McNamara Group, thirteen are from the Mt Isa Group and one is from the Fickling Group. The sections are provided as postscript **plot files** at a variety of scales (**Table 3**). All of the sections are provided at a scale of 1:1000. Sections from the Mt Isa Group are also included at 1:2000 scale. Four sections from the lower McNamara Group and one from the Fickling Group are available at 1:400 scale (**Table 1**).

Composite Section	Map Section Name	Scale		
Mt Isa Group		1:400	1:1000	1:2000
Oxide Creek	97/OC/1-3	No	Yes	Yes
Crystal Creek	96/CY/1-4	No	Yes	Yes
Paroo Range	96/PAR/1-7	No	Yes	Yes
Mt Isa	96/ISA/1-3	No	Yes	Yes
Leichhardt West	97/LW/1-8	No	Yes	Yes
Hilton	97/HI/01	No	Yes	Yes
Moondarra 1	97/BP/11	Yes	No	Yes
Moondarra 2	97/BP/13	Yes	No	Yes
Moondarra 3	97/BP/12	No	Yes	Yes
Moondarra 4	97/BP/08	Yes	No	Yes
Drill Hole H450	H450	No	Yes	No
Drill Hole Quartzite 10	Q10	No	Yes	No
Drill Hole UE 258	UE258	No	Yes	No
Composite Section	Map Section Name	Scale		
McNamara Group		1:400	1:1000	1:2000
GSQ Lawn Hill 3&4	3&4 Lawn Hill 03, Lawn Hill 04	No	Yes	No
Kamarga Dome	97/KD/1-4	No	Yes	No
WC-1	WC-1	No	Yes	No
Gregory River	97/GR/01	No	Yes	No
Mellish Park	96/MP/1-5	Yes	Yes	No
Police Creek 2	96/FC/1-6	No	Yes	No
Paradise Ck W.	96/PC/1-2	Yes	Yes	No
Paradise Creek E.	96/PC/03	No	Yes	No
Barr Hole	95/PS/1, 96/BH/2-3	Yes	Yes	No
Esperanza Waterhole	95/AW/08, 95/JJ/02	Yes	Yes	No
Mammoth North	96/CW/04	No	Yes	No
Mammoth South	96/CW/03	No	Yes	No
Crocodile Waterhole	95/AW/9-10	No	Yes	No
Anaconda AAD1	AAD1	No	Yes	No
Anaconda AASP	AASP	No	Yes	No
Judenan Creek	97/JC/1-3	No	Yes	No
Wilfred Creek	97/WC/01	No	Yes	No
Wangunda Bore	97/JJ/1-3	Yes	Yes	No
Amoco 83-5	Amoco 83-5	No	Yes	No
Thorntonia 2	97/JJ/04	No	Yes	No
Freemans Ck.NE	97/JJ/02	No	Yes	No

Table 1

Composite Section	Map section Name	Scale		
Fickling Group		1:400	1:1000	1:2000
Wire Creek	95/AW/1-4	Yes	Yes	No

Table 1 (con't)

Six regional cross sections are included in the data release (**Table 3**).

- **Transect 1** correlates outcrop sections and drill core along a north-south corridor from Kamarga Dome to Wilfred Creek. The northern three sections are located to the west of the Lady Loretta High Strain Zone. The Gregory River section occurs on the northern extension of this zone and the remaining sections occur within the north-south corridor between the Lady Loretta High Strain Zone and Mount Gordon Fault Zone.
- **Transect 2** correlates outcrop sections and drill core along a southeast oriented transect from Kamarga Dome to Oxide Creek. The section crosses the Mount Gordon Fault Zone and several NE trending structures to the west of the Mount Gordon Fault Zone.
- **Transect 3** correlates outcrop sections along an east-west transect from Paradise Creek to Crystal Creek. This section crosses the Mount Gordon Fault Zone a few kms south of Gunpowder.
- **Transect 4** depicts geometric relationships between the lower McNamara and lower Mt Isa Groups. It correlates sections between Mellish Park in the northwest and Leichhardt West in the southeast. The section commences near the Fiery Creek Fault Zone and then continues in a north-south orientation along the Mount Gordon Fault Zone prior to crossing the Redie Creek Fault Zone and heading in a southeasterly direction across the Leichhardt River Fault Trough.
- **Transect 5** is oriented in a southeast direction. It commences at Anaconda drill hole AASP1 (a few kms SE of Lady Loretta) and finishes at Leichhardt West in the Leichhardt River Fault Trough.
- **Transect 6** depicts stratigraphic architecture in the Leichhardt River Fault Trough. The section has a dominant north-south orientation. It commences at Oxide Creek in the north and terminates at Leichhardt West in the southeast. This section includes outcrop and drill ore data from the Mt Isa valley.

Each of the sections contains primary observational data and subsequent facies and sequence stratigraphic interpretations.

Primary observational data in the 1:1000 and 1:2000 scale plots includes:

- Lithostratigraphy at Group, Formation and Member levels
- Gamma Ray, Lithology, Sedimentary Structure & Bed Thickness

Interpreted data in 1:1000 and 1:2000 scale plots includes:

- Facies Summary & Sequence Stratigraphy
- Sequence boundaries and maximum flooding surfaces for second, third and fourth order sequences.

The 1:400 scale plots lack a facies summary, but include an outcrop scale description of the principal lithologies.

The CD ROM also contains digital location information for the outcrop sections, spreadsheet_sections.xls (sample of **Table 4**) and drill cores, spreadsheet_drillholes.xls (sample of **Table 5**), featured in this product and a similar CD ROM covering stratigraphic data in the upper McNamara Group (Record 1999/15). The location of measured sections and drill holes is shown in **Figure 2**. The chronostratigraphic Event Chart (**Figure 3**) summarises the sequence stratigraphic subdivision for the Calvert and Isa Superbasins (Southgate et al 2000a). One paper is included in the **appendix**. It is a copy of the paper by Krassay (1998) outlining the gamma ray technique and reproducibility of the data collected by NABRE. Detailed descriptions of facies and stratigraphic architecture are included in Bradshaw et al 2000, Domagala et al 2000, Sami et al 2000 and Southgate et al 2000a,b.

Clients will notice differences between the sequence nomenclature in Sami et al (2000) and those shown in the Geolog6 plot files. After the Sami et al (2000) paper was completed we integrated the Mt Isa Group dataset and realised that an extra third order sequence could be interpreted in the Gun Supersequence. **Table 2** shows these changes in the Gun Supersequence nomenclature.

<table>
<tr><th colspan="4">Sequence Stratigraphy</th><th colspan="2">Lithostratigraphy</th></tr>
<tr><th colspan="2">This Record</th><th colspan="2">Sami et al. 2000</th><th>McNamara Group</th><th>Mt Isa Group</th></tr>
<tr><td rowspan="5">Gun 3</td><td>Gun 3.5</td><td rowspan="5">Gun 2</td><td>Gun 2.5</td><td rowspan="5">Esperanza Formation</td><td>Spear Siltstone</td></tr>
<tr><td>Gun 3.4</td><td>Gun 2.4</td><td rowspan="4">Urquhart Shale</td></tr>
<tr><td>Gun 3.3</td><td>Gun 2.3</td></tr>
<tr><td>Gun 3.2</td><td>Gun 2.2</td></tr>
<tr><td>Gun 3.1</td><td>Gun 2.1</td></tr>
<tr><td rowspan="7">Gun 2</td><td>Gun 2.7</td><td rowspan="9">Gun 1</td><td>Gun 1.9</td><td rowspan="5">Paradise Creek Formation</td><td rowspan="2">Native Bee Siltstone</td></tr>
<tr><td>Gun 2.6</td><td>Gun 1.8</td></tr>
<tr><td>Gun 2.5</td><td>Gun 1.7</td><td rowspan="3">Breakaway Shale</td></tr>
<tr><td>Gun 2.4</td><td>Gun 1.6</td></tr>
<tr><td>Gun 2.3</td><td>Gun 1.5</td></tr>
<tr><td>Gun 2.2</td><td>Gun 1.4</td><td rowspan="4">Upper Gunpowder Creek Formation</td><td rowspan="4">Moondarra Siltstone</td></tr>
<tr><td>Gun 2.1</td><td>Gun 1.3</td></tr>
<tr><td rowspan="2">Gun 1</td><td>Gun 1.2</td><td>Gun 1.2</td></tr>
<tr><td>Gun 1.1</td><td>Gun 1.1</td></tr>
</table>

Table 2

.

Datasets and Methodology

The stratigraphic data was collected from outcrop sections and publicly available drill core. The quality of outcrop provided the principal constraint in the selection of areas suitable for measuring sections. Where-ever possible areas of poor outcrop were supplemented by drill core. As one aim of the project was to use the stratigraphic data to identify synsedimentary faults and determine stratigraphic architecture and basin shape it was necessary to collect both regional and locally detailed datasets. For example sections measured at **Barr Hole**, **Esperanza Waterhole**, **Mammoth Mines North**, **Mammoth Mines South** and **Crocodile Waterhole** provide an understanding of the timing of relative movement along the Mount Gordon Fault Zone. Outcrop discontinuities prevented the collection of stratigraphic data in a line of continuous section. As a result most of the sections are composited from a series of smaller sections measured within a radius of several kilometres of each other. Individual sections were spliced together at prominent marker beds, or by the use of overlapping gamma ray curves in conjunction with facies descriptions. Presentation of the data as composite sections is necessary for regional sequence stratigraphic analysis and correlation.

Sections were measured using a jacob staff and abney level and the rocks were marked in 1.5 m intervals of true thickness. Gamma ray data was collected at 50 cm intervals of true thickness using a hand-held Scintrex GRS 500 spectrometer that measured total gamma ray counts. A beryllium standard was used to calibrate each spectrometer. Each machine was calibrated at intervals of two to three hours. Each gamma reading was averaged over an interval of ten seconds. Where down hole wireline logs were available for drill core they were used for correlation. However, most mineral holes lacked this dataset. In these instances gamma ray data was acquired from drill core using an Exploranium GR 320 Envispec Geophysical-Environmental Gamma Ray Spectrometer with two horizontally mounted detectors. To avoid background contamination all gamma ray measurements conducted on drill core were made inside a 500kg lead shield. Krassay (1998) provides a detailed outline of the techniques used in acquiring gamma ray data and the accuracy of this method. A copy of this paper is included as **Appendix 1**.

Sedimentary facies information, including grainsize, lithology, grain composition, sedimentary structures and bed thickness were collected along each stratigraphic section on field data sheets. Grain size information was collected as a continuous curve. One of the major problems with facies-based sedimentological datasets involves a mechanism to cost effectively capture this continuous 'stream' of descriptive data in a digital form. Lithostratigraphic methodologies emphasise the description of rock bodies. However, sequence stratigraphic analyses require the identification of vertical facies trends and the stacking patterns of sedimentary cycles to determine key stratal surfaces. These features are difficult to identify from lithostratigraphic logs. The technique developed in this project, where outcrop-derived gamma ray and grainsize data are displayed as curves, complemented by lithology and facies information, enables these trends to be identified and stratal surfaces interpreted. Grainsize curves were digitised using a fax machine scanner and subsequently loaded into a customised version of Mincom's Geolog6 software application. Lithologies were generated using a series of look-up tables keyed to observations made along each section.

Sequence Stratigraphy

Nomenclature

Whereas lithostratigraphic nomenclature is purely descriptive, sequence stratigraphic classification is interpretative and therefore subject to change as additional sequences are recognised and stratigraphic precision improved. Rather than adopt an entirely new stratigraphic terminology the 2nd to 4th order sequences identified in this study are classified in the following way. Each 2nd order sequence (supersequence) is named after an abridged version of the lithostratigraphic unit that contains its maximum flooding surface. Because the most complete stratigraphic sections come from the McNamara Group, formation names from this group have been used. In this CD ROM three supersequences are recognised: the Prize, Gun and Loretta Supersequences, named after the Surprise Creek, Gunpowder Creek and Lady Loretta Formations respectively. Each Supersequence name is followed by a number, the first integer identifies a third order sequence, the number following the decimal point identifies each fourth order sequence. For example the Gun 2.3 sequence refers to the third 4th order sequence in the second 3rd order sequence of the Gun Supersequence. The letters ‘t’ and ‘f’ refer to the type of surface, ‘t’ denotes transgressive surface and ‘f’ maximum flooding surface. Qualifying text is not used to identify sequence boundaries.

Overview

This section provides an overview of the principal terms and concepts in sequence stratigraphy. The reader is advised to refer to diagrams present in the principal references quoted in this discussion, particularly figures 1-4 in Van Wagoner et al (1988) and Figure 2.9 of Emery and Myers (1996). Van Wagoner et al (1988) defined sequence stratigraphy as the study of rock relationships within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or non-deposition or their correlative conformities. Emery & Myers (1996) proposed an alternative and possibly simpler definition: sequence stratigraphy is the subdivision of sedimentary basin fills into genetic packages bounded by unconformities and their correlative conformities. It is used to provide a chronostratigraphic framework for the correlation and mapping of sedimentary facies and for stratigraphic prediction. Implicit in these definitions is the key distinction between lithostratigraphy and sequence stratigraphy. Whereas sequence stratigraphy is concerned with identifying chronostratigraphically significant surfaces that bound genetically related rock packages, lithostratigraphy is concerned with correlating similar rock bodies which are commonly diachronous and lack time significance. Lithostratigraphic correlation is most useful when the rock bodies are constrained by well-defined sequence stratigraphic boundaries.

Critical to an understanding of sequence stratigraphy is the concept of accommodation. Accommodation refers to the space available for sediment to accumulate and results from an interplay between tectonically-driven subsidence, oscillations in sea level and rates of sediment supply. It is the rate of change in accommodation and its effect on rates of sediment supply that ultimately controls the migration of sedimentary facies belts, stacking patterns of sedimentary cycles and therefore architecture of sediments filling a basin. Three scenarios are possible (see Van Wagoner et al 1988):

Accommodation rate < Rate of sediment supply - Progradational cycles.

Accommodation rate > Rate of sediment supply - Retrogradational cycles or Backstepping.

Accommodation rate = Rate of sediment supply - Aggradational cycles.

Based on the examination of stratal patterns in seismic sections, wireline logs and outcrop sections the Exxon Group (Van Wagoner et al, 1988) were able to show that cycles of progradation, retrogradation and aggradation occurred in a predictable order at a variety of scales. Furthermore, the cycles could be grouped into genetic packages (systems tracts, parasequence sets and parasequences) that combined to form a depositional sequence in which each systems tract reflected a particular stage of an accommodation cycle. Each depositional sequence is bounded by a chronostratigraphic surface termed a sequence boundary across which a basinward shift in facies may occur. Van Wagoner et al (1988) recognised Type 1 and Type 2 Sequences, each named after the character of the sequence boundary at their base. In type 1 sequences the fall in relative sea level is sufficiently large that the first topsets within the new sequence onlap clinoforms of the underlying sequence (Emery & Myers 1996). This implies a fall in relative sea level at the position of the offlap break. In type 2 sequences the fall in relative sea level occurs to landward of the offlap break so that sediments of the new sequence onlap the older topsets rather than clinoforms. Detailed discussions of the differences between these two sequences are found in Van Wagoner et al (1988, 1990) and Emery & Myers (1996). Most generalised sequence stratigraphic models are for extensional basins with a pronounced shelf break, the classic passive margin setting of many modern continental margins. In the lower McNamara, Mt Isa and Fickling Groups sequence models developed for basins with a ramp margin are more applicable (Van Wagoner et al, 1988, 1990; Handford & Loucks, 1993 Fig. 10).

Importantly, the surfaces that bound sequences and internally divide them into systems tracts and parasequences are chronostratigraphic features that cut across diachronous lithofacies boundaries. For the datasets included in this CD ROM sequence interpretations are based on the vertical stacking patterns of sedimentary facies and the interpretation of gamma ray logs derived from outcrop, drill core and downhole wireline methods. The gamma ray curves are particularly useful in sequence analysis. Whereas facies descriptions are biased by the objectives and experience of the geologist measuring the section, gamma ray data simply records the K, Th and U content of the rocks and display these data as a curve. When combined with facies descriptions the gamma ray curve enables facies trends to be recognised and aids in the identification of sedimentary cycles and their stacking patterns. The curves are particularly useful in fine grained sediments where sequence boundaries and their correlative surfaces are usually very difficult to recognise.

Well-Log Trends & Sedimentary Cycles

Regional correlations of wireline curves, and gamma ray curves in particular, are not based on identifying individual spikes. Instead, it is the broad, overall curve trends and associated lithofacies stacking patterns that allow accurate regional correlations. A wealth of literature exists on methods for interpreting sedimentary cycles in well logs (e.g. Rider, 1986; Cant 1992; Emery & Myers, 1996). Most wireline logs are interpreted through the identification of five widely recognised trends, corresponding to individual sedimentary cycles (Emery & Myers, 1996, Fig. 4.7):

1. Cleaning-up or funnel-shaped trends show an upward decrease in gamma counts, which commonly indicates an upward increase in depositional energy, upward shallowing, and upward coarsening related to progradation of a

depositional system. At a third order scale this motif is apparent between the Gun 2.3f and Gun 3.1 surfaces in the **Paradise Creek West** section. At a fourth order scale it occurs between the Gun 2.4f and Gun 2.5 as well as Gun 2.5f and Gun 2.6 surfaces of the same section. Cleaning-up trends may occasionally result from a gradual change from clastic to carbonate deposition, or a gradual decrease in anoxity (Emery & Myers, 1996).

2. A dirtying-up or bell-shaped gamma trend shows a progressive upward increase in gamma readings, which commonly indicates overall fining-upward successions, typically within shale-prone intervals. In the **Paradise Creek West** section this motif is apparent at the third order scale between the Gun 3.1 and Gun 3.2f surfaces and at the fourth order scale between the Gun 2.3 and Gun 2.3f surfaces. Dirtying up trends are common in fluvial successions, tidal channels, and estuarine fills (Emery & Myers, 1996). In shallow marine settings, dirtying-up trends often indicate the retreat or abandonment of a shoreline–shelf system (e.g. Gun 3.1 to Gun 3.2f; Emery & Myers, 1996). In deep marine settings, the dirtying-up motif may record the waning/abandonment period of submarine fan deposition (Emery & Myers, 1996).

3. Boxcar or blocky gamma-ray curve segments are sharp-based low-gamma units with internal, relatively consistent gamma readings set within a higher gamma background (e.g. The Torpedo Creek Quartzite in the **Esperanza Waterhole** section). The sharp boundaries with overlying and underlying units imply the existence of an abrupt switching from high gamma fine-grained units to low gamma coarser units (Emery & Myers, 1996). Boxcar trends are commonly found in fluvial channel sands, turbidites, aeolian sands, and occasionally within evaporites (Emery & Myers, 1996). They may also occur in sequences of vertically stacked peritidal carbonate cycles (e.g. The Gun 2.6 sequence at **Mellish Park** and **Barr Hole**).

4. Bow or symmetrical trends consist of a cleaning-up trend overlain by a dirtying-up trend of similar thickness, with no significant break between the two (Emery & Myers, 1996). A bow trend is usually the result of a waxing and waning of clastic sedimentation rate in a basinal setting, where the sediments are unconstrained by base level, such as during the progradation and retrogradation of a mud-rich submarine fan system (Emery & Myers, 1996).

5. Irregular trends have no systematic change in either the sand base-line or shale base-line, and lack the clean character of the boxcar trend (Emery & Myers, 1996). Irregular trends generally represent aggradation of a shaly or silty lithology, and are typical of shelfal or deep water settings, a lacustrine succession, or muddy alluvial overbank facies (Emery & Myers, 1996). Examples of this motif are found in the relatively deep water distal tempestite facies between the Gun 2.3f and 2.4f surfaces at **Paradise Creek West**.

Parasequences, Parasequence Sets and Systems Tracts

Parasequences form the basic building blocks (cycles) of systems tracts and sequences. Van Wagoner (1988, 1990) defined parasequences as relatively conformable successions of genetically related beds or bedsets, bounded by marine flooding surfaces and their correlative conformities. In a wave or storm dominated, shallow water, setting a siliciclastic parasequence will occur as a decameter thick coarsening upwards package where beds increase in thickness upwards, bioturbation decreases upwards and facies indicate shallowing upward trends (see examples in Van Wagoner, 1990; Emery and Myers, 1996). The best known example of a parasequence in a carbonate depositional system is the 1-10m thick, shallowing upward, succession characteristic of peritidal environments (James, 1979; Pratt, James & Cowan, 1992).

Parasequences are arranged into a succession of genetically related cycles termed parasequence sets. In a parasequence set the cycles are related by their stacking patterns to form progradational, backstepping and aggradational depositional systems. It is important to note that although a parasequence set may reflect transgression and a progressive deepening of the depositional environment, the overall deepening trend can be broken down into a series of progradational cycles or parasequences. In such a system successive parasequences typically display an increase in deeper water facies as rates of sediment supply are unable to keep up with subsidence rates. Thus successive cycles typically thin upwards until they become condensed and eventually merge in a relatively uniform package of siltstone and shale, (e.g. organic-matter rich shale facies at the top of the Gunpowder Creek Formation, unit Pmw_3 and shales near the base of the Esperanza Formation – eg. **Esperanza Waterhole**). Parasequences and parasequence sets are arranged into four depositional packages or systems tracts that together comprise a depositional sequence. The four systems tracts are:

- Lowstand Systems Tract (LST)
- Transgressive Systems Tract (TST)
- Highstand Systems Tract (HST)
- Shelf Margin Systems Tract (SMST)

The relative positions of these systems tracts within type 1 and 2 depositional sequences are shown in Figures 2-4 of Van Wagoner et al (1988). Shelf margin systems tracts are not recognised in this study and are not considered in this CD ROM. The LST is deposited during a period of relative sea level fall at the offlap break and during the subsequent period of slow relative rise. In a basin with a shelf break the lowstand can be divided into three depositional systems, the basin floor fan, slope fan and lowstand wedge or prograding complex. The submarine fans are believed to mark the period of rapid relative sea level fall; the prograding complex with its typical progradational to aggradational geometries marks the still stand and initial slow rise of relative sea level (Emery and Myers 1996).

In intracratonic settings, where pronounced shelf breaks are typically absent and ramp basins develop (e.g. Paradise Creek Formation), LST deposits typically comprise prograding wedges of sediment. Criteria for recognising the basinward shift in facies and relative fall in sea level can be quite subtle, depending on the magnitude of the fall and the position on the ramp or platform. In deeper water facies of the Paradise Creek Formation the basinward shift in facies may be recorded by a subtle change from aggradational, distal tempestites to progradational distal tempestites (e.g. Gun 2.4, **Esperanza Waterhole**). Alternatively, in more landward positions on a ramp where shallower facies occur, an abrupt influx of siliciclastic sand may provide evidence for encroachment of the shoreline and siliciclastic provenance, accompanying a fall in relative sea level e.g. (Gun 2.5, **Paradise Creek West** and **Mellish Park**).

The transgressive systems tract (TST) is the middle systems tract of a type 1 & 2 sequence. These sediments are deposited when the rate of increase in accommodation (relative sea level rise) exceeds the rate at which sediment is supplied. A backstepping set of parasequences accumulates (Gun 3.1-3.2f, **Mellish Park**). In a basinward position low rates of siliciclastic deposition facilitate the accumulation of authigenic sediments, including: laminated and bituminous carbonate mud, glauconite, phosphorites, manganese nodules and organic-matter rich shales of the condensed section. (Loutit et al, 1988 and Gun 2.2-2.3f **Barr Hole**). The switch from fine-grained siliciclastic deposits to laminated, locally phosphatic and hummocky-bedded carbonates in the Gun 2.2 sequence at Barr Hole provides an example of progressive retreat of the shoreline and the drowning of siliciclastic provenance areas during a major marine transgression. Carbonaceous shales at the top of the Gunpowder Creek Formation, Gun 2.3 sequence at **Barr Hole** are condensed section deposits at the top of this TST. These deposits mark the time of maximum increase in accommodation rates for the Gun Supersequence.

The highstand systems tract (HST) is the youngest and uppermost systems tract in a type 1 & 2 sequence. These sediments accumulate during a time of decelerating rate of relative sea level rise, enabling the rate of sediment supply to exceed the rate of accommodation. In HST deposits parasequence stacking patterns will depend upon cycle position in the HST as well as facies position on the shelf or ramp. During the early to mid parts of HST's, sites in close proximity to the siliciclastic provenance or shallow water carbonate factory will receive relatively high rates of sediment supply and a progradational set of parasequences will form. In the late or terminal parts of HST's, when accommodation rates are in significant decline shallow subtidal to supratidal facies will dominate the shallowing upward cycles. This will result in an aggradational package of parasequences as like facies belts are superposed (e.g. Gun 2.6 Sequence at **Mellish Park**). In basinward positions, where rates of sediment supply are comparatively low, aggradational stacking patterns may occur in early highstand deposits (e.g. Gun 2.3 & 2.4 sequences; **Barr Hole**, **Esperanza Waterhole**, **Paradise Creek West**). In some ramp settings a succession of basinward stepping, prograding wedges can mark the terminal parts of HST deposits. These wedges of sediments are referred to as forced regressive wedges (Posamentier et al, 1992).

Stratal Surfaces

Each of the systems tracts discussed above is bounded by a chronostratigraphic stratal surface. Three surfaces are defined:

1. Sequence Boundary
2. Transgressive Surface
3. Maximum Flooding Surface

The sequence boundary (sb) occurs at the base of the LST, or where absent at the base of the TST. Sequence boundaries are unconformities and correlative conformities associated with subaerial erosion and in some places correlative marine erosion surfaces (Van Wagoner et al., 1990). A basinward shift in lithofacies is usually found above sequence boundaries. Sequence boundaries are interpreted in well logs where evidence exists for an abrupt fall in gamma-ray counts related to a sharp lithological break. In many cases, the gamma log trend immediately beneath a sequence boundary is progradational, indicating an underlying shoaling and coarsening-up event associated with a HST. The gamma-ray trend above a sequence boundary is progradational–aggradational if a LST is present, or retrogradational if immediately overlain by a TST. Seismic sequence boundaries are identified by terminations of seismic reflectors through either onlap and/or truncation.

The transgressive surface (ts) defines the top of the LST and marks the time of initial significant marine flooding across the shelf, platform or ramp (Van Wagoner et al., 1990). Transgressive surfaces are indicated in gamma logs by a change from overall aggradation or progradation to retrogradation. In seismic profiles, the transgressive surface is identified as the major onlap surface. A marine flooding surface shows evidence of an abrupt increase in water depth, commonly accompanied by minor submarine erosion or non-deposition (Van Wagoner et al., 1990). Marine flooding surfaces are usually interpreted where gamma values suddenly increase above a cleaning-up trend.

The maximum flooding surface (mfs) marks the time of maximum rate of increase in accommodation. On seismic sections it coincides with the downlap surface which marks the switch from retrogradational trends to aggradational and progradational trends. In well logs, where higher resolution is possible, the mfs occurs within the condensed section (Loutit et al., 1988). The condensed section is usually identified as a shale-prone, organic-rich interval. Elevated gamma radiation is caused by potassium-rich clay minerals associated with the shales and anomalously high uranium and thorium contents. Some of these elements are associated with organic matter and mineralised hardgrounds containing authigenic manganese and phosphate.

Scales of Observation and Orders of Cyclicity

Because tectonic cycles of subsidence and uplift, and eustatic cycles of sea level change operate over different periods of time, sequences can be classified in terms of their order of duration (Vail et al 1977; Emery and Myers 1996). Each depositional sequence is bounded top and bottom by an unconformity surface or correlative conformity and the age differences between these surfaces provide a maximum duration for the event (tectonic or eustatic) controlling the creation or destruction of space. Van Wagoner et al (1990) Emery & Myers (1996) classify sequences into a number of orders depending on their duration. Long term cycles of continental encroachment, 1st order cycles, have a duration in excess of 50 My 2nd order cycles, or supersequences are of 5-50 My duration, 3rd order cycles are 1-5 My in duration, fourth order cycles 0.1-1 My in duration and fifth order cycles are believed to be less than 100,000 years duration. Controversy exists concerning the principal driving mechanism behind these cycles. At the larger scales (1st and 2nd order) tectonism is usually regarded as the principal driving mechanism (Emery & Myers 1996). However, Vail et al (1991) consider glacio-eustatic fluctuations as the principal driving force behind 3rd to 5th order cycles. Whereas others (e.g. Cloetingh, 1988) believe that tectonism may still be a significant driving mechanism.

In the Isa Superbasin the synchronicity of inflections on the APWP with Supersequence boundaries provides supporting evidence for tectonic events at these surfaces. Truncation beneath some third and fourth order sequence boundaries on north-south structures such as the Mount Gordon Fault Zone provides additional evidence for tectonism at this higher order scale of cyclicity.

The principal datasets for identifying stratigraphic sequences are seismic sections, wireline logs, core and outcrop. Seismic images are able to resolve strata to a minimum thickness of 25-50m, depending on the velocities of the intersected strata and acquisition parameters for the survey. Wireline logs are able to identify bed thickness' at the meter scale. Observations on drill core and outcrop sections can be made at the centimetre scale thereby providing increased resolution of stratigraphic detail. Determining the order of stratigraphic sequences requires access to the appropriate dataset. Seismic datasets are used for the identification of 1st to 3rd order sequences. Outcrop, drill core and wireline logs are necessary for the identification of 4th and 5th order sequences, and can also be used for 2nd and 3rd order cycles.

Event Chart

The event chart (**Figure 3**) summarises the sequence nomenclature for the Calvert and Isa Superbasins in the McArthur, Murphy, Lawn Hill, Gunpowder and Mt Isa regions (Southgate et al 2000a). Rocks belonging to the lower McNamara Group (Torpedo Creek Quartzite to Lady Loretta Formations) lower Fickling Group (Fish River Beds to Walford Dolomite) and the Mt Isa Group are combined to form the Prize, Gun and Loretta Supersequences, each separated by an unconformity surface. In each supersequence we identify third and fourth order sequences. Regional correlations for this stratigraphic interval are at the second to fourth order scales of precision; fifth order cycles are recognised, but are not used for correlation. Second order sequences or supersequences have a duration of approximately 10-15 Ma. 3rd order sequences (e.g. Gun 1 & Gun 2) have a duration of several million years and 4th order sequences (e.g. Gun 2.1 - 2.7 & Gun 3.1-3.5) have a duration less than 1 million years. Using this method of classification, supersequences are usually in excess of a thousand meters thick, 3rd order sequences in excess of 500m thick and fourth order sequences several tens of meters to less than 200m thick.

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Well Logs

Cross Sections

Cross Sections

Appendix 1

Outcrop and drill core gamma-ray logging integrated with sequence stratigraphy:

Examples from Proterozoic sedimentary successions of northern Australia

by

Andrew A. Krassay

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Outcrop and drill core gamma-ray logging integrated with sequence stratigraphy: examples from Proterozoic sedimentary successions of northern Australia

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Outcrop and core gamma-ray logs have been successfully used to correlate Proterozoic units in northern Australia. This paper highlights the benefits of integrating gamma-ray data and traditional sedimentology for defining large-scale depositional cycles and depositional geometry. Gamma-ray logs of outcrop and cored intervals provide excellent stratigraphic and sedimentological information for areas where conventional down-hole geophysical surveys are lacking. Both total count (scintillometer) gamma-ray profiles and spectral gamma-ray profiles enable recognition of subtle changes in lithology and sedimentary cyclicity that might have been missed during customary section measuring. Lithofacies described from measured sections and core may be characterised by their gamma-ray signatures, and the signatures may then be used as proxies for down-hole gamma-ray logs obtained from the subsurface where direct lithological information is sparse or absent. The integration of traditional lithostratigraphic descriptions with surface and subsurface gamma-ray logs results in a more robust and sophisticated stratigraphic framework than either data set can yield independently. Use of sequence stratigraphic principles enables gamma-ray log trends and their stacking patterns to be interpreted as part of larger sedimentary cycles that reflect changes in sediment supply and relative sea level. Abrupt shifts in gamma-ray values occur at important stratigraphic surfaces that define sedimentary sequences of various scales. Systematic variations in sedimentary thickness and gamma-ray stacking patterns between areas are related to changes in depositional geometry of sequences. Regional 'mapping' of stratigraphic surfaces and sequences by the correlation of vertical gamma-ray profiles and corresponding descriptive logs allows a predictive chronostratigraphic framework to be constructed for a region.

Introduction

In this paper, techniques and some initial results of outcrop and drill core gamma-ray logging of Proterozoic sedimentary successions are presented. This research has been carried out as part of AGSO's North Australian Basins Resource Evaluation (NABRE) project, a multidisciplinary project aimed at constructing an integrated stratigraphic framework for Proterozoic basins of northern Australia. The generally poor chronostratigraphic control of Proterozoic rock successions in northern Australia caused great difficulty, and ambiguity, in the early stages of the project during attempts to correlate previously defined rock units on the basis of lithostratigraphy alone. An innovative technique was needed to minimise the problem of poor chronostratigraphic control, and to enhance detailed correlation between areas. Gamma-ray logging was chosen because it is easy to use, relatively inexpensive, and results are obtained in a short time. Also, gamma-ray measurements are generally closely related to grain size, clay content, and mineralogy of sedimentary rocks, and, thus, by comparing surface gamma-ray curves with detailed descriptive logs one can readily 'ground-truth' gamma-ray readings against lithofacies. Previous studies (Loutit et al. 1990) have demonstrated the application of gamma-ray logging for correlation between outcrop and subsurface stratigraphic intervals. It was, therefore, anticipated that gamma-ray correlation between outcrops and the subsurface would be possible in northern Australian basins and that gamma-ray logs could in turn be correlated to seismic sections, using synthetic well ties (Bradshaw et al. 1996b).

Numerous accessible outcrops occur in the region studied, and a large amount of core exists from extensive base-metal exploration programs that have been conducted during the past three decades. Two different gamma-ray techniques were developed, one for outcrop and one for core. The first technique employs small, portable, hand-held gamma-ray spectrometers used as scintillometers to log outcrop measured sections (bagged samples of rock chips from percussion drill holes may also be measured using this technique). The second technique involves gamma-ray logging of cored stratigraphic intervals, using a lead-shielded, spectral gamma-ray spectrometer system which records multi-channel data.

The validity of outcrop gamma-ray logging for correlation has been proven by previous studies of sedimentary rocks of many different ages—Palaeozoic and Mesozoic units, USA (Chamberlain 1984); Carboniferous fluvio-deltaic units, Ireland (Davies & Elliott 1996); Cretaceous sandstones, Utah (Howe 1989); Namurian deltaic units, Yorkshire (Myers & Bristow 1989); Jurassic mudrocks, Dorset (Myers & Wignall 1987); Jurassic mudrocks, England, Germany and Portugal (Parkinson 1996); Pennsylvanian turbidites, Arkansas (Slatt et al. 1992). Published examples of the gamma-ray method for logging core are rare, but Lovborg et al. (1972) used this technique to analyse uranium mineralisation within a large Proterozoic igneous intrusive complex (largely syenite) in Greenland. However, Lovborg et al. (1972) did not use gamma-ray logging for correlation purposes. The two techniques above are not new, but to the author's knowledge, gamma-ray logging of drill chip samples has not been previously reported. Similarly, the combination of the techniques and their integration with sequence stratigraphy for the study of Proterozoic rocks is a new application of the technique.

When arranged into vertical profiles plotted against thickness (across strike through outcrop) or depth (down-hole along drill core) gamma-ray measurements obtained by either of the techniques above commonly show systematic vertical variations, which help to define sedimentary cycles at all scales. Individual sedimentary cycles and groups of cycles can be correlated between different localities on the basis of their gamma-ray patterns. Trends recognised on gamma-ray curves commonly correspond to changes in grain size, clay content, and mineralogy, indicative of transgressive and regressive episodes in sedimentation.

Sequence stratigraphic models define sequences on the basis of important stratigraphic surfaces (sequence boundaries, parasequence boundaries, maximum-flooding surfaces, transgressive surfaces), and these surfaces commonly exhibit distinctive gamma-ray signatures (Van Wagoner et al. 1990). Major gamma-ray peaks within the rocks studied typically relate to shale-prone parts of the section where condensed sedimentation occurred in areas of clastic starvation during maximum transgression (Loutit et al. 1988). Abrupt decreases in gamma-ray counts are associated with sharp-based lithostratigraphic units that were incised into underlying lithologies during shoaling episodes. Sequence stratigraphic interpretation based on gamma-ray curves facilitates basin-wide chronostratigraphic correlations; commonly these chronostratigraphic correlations differ from previous lithostratigraphic schemes and reveal the diachronous nature of many mapped lithostratigraphic units. The distribution of major sand-prone porous intervals (potential reservoirs and fluid conduits) and shale-prone impermeable intervals (regional seals and likely sites for mineralisation) within depositional sequences can then be predicted with greater confidence.

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Methods

Outcrop logging (portable, hand-held scintillometer)

For this type of logging, a lightweight, portable EDA (Scintrex) GRS-500 gamma-ray spectrometer is used. The instrument has a 0.124 L NaI crystal volume and is adjustable to measure gamma radiation due to total radiation or any of the other three main contributors to natural radioactivity (K, Th, U). However, the instrument cannot record data for all four channels simultaneously. For most outcrop work, only total radiation (scintillometer) measurements were made. The recording period is adjustable at 1 or 10 seconds. A 10 second count period was used throughout for this study. The instrument is calibrated at hourly intervals using a screw-on ^{133}Ba source, and adjustments may be made using both short-term and long-term gain controls.

Stratigraphic successions are first measured at true thickness in outcrop, using a Jacob's staff and Abney level, and then total radiation gamma-ray readings are recorded up-section at 0.5 m intervals. Selected stratigraphic intervals may be measured with closer sample spacing as required (e.g. thinly interbedded intervals or those with discrete tuffs or mineralised beds). The recording 'area' of the instrument approximates a half-sphere penetrating at least 30 cm into the rock (see Lovborg et al. 1971, fig. 2, their uncollimated curve), and so measurements on thin, closely spaced beds will be affected to some degree by gamma-radiation from adjacent strata. The scintillometer is allowed to stabilise for three count periods before a measurement is recorded. It is important to maintain a consistent instrument to bedding angle during measurement so that source geometry remains constant, and also to avoid rock outcrops with overhangs or bumps that might affect the amount of rock the detector 'sees'. For further discussion of these factors refer to Myers & Bristow (1989) and Parkinson (1996).

In this study no attempt was made to measure background/ cosmic radiation at each site because it was considered that absolute measurements of gamma radiation are not as important as relative changes for outcrop work (cf. Chamberlain 1984). To calculate absolute measurements one would need to continuously measure background radiation, record all four channels, subtract background from the initial readings, and apply energy calibrations. Absolute measurements are necessary only if one wishes to convert count rates into gamma-equivalent concentrations (% K, ppm U, ppm Th), and such a conversion process is complex for non-shielded field detectors (see Killeen & Carmichael 1970, Lovborg & Mose 1987). For portable detectors with small crystals and short count times conversion from counts to concentrations is likely to be relatively inaccurate. In this study gamma-ray measurements obtained by the instrument in the field are plotted as raw values in counts per second.

Drill chip logging (portable, hand-held scintillometer)

The instrument used for drill-chip logging is exactly the same as for outcrop logging. In the study area, percussion drill chips in large bags (10–20 kg) are commonly stored at the drill site. Typically, bags of chips are collected at 1 m intervals and numbered sequentially over the entire depth of a drill hole. The plastic or cloth bags do not affect gamma-radiation measurements, and so the instrument is held against the side of a bag for about 30–40 seconds and when stabilised a 10 second reading is taken. Total gamma radiation is recorded as raw values in counts per second, and background radiation is assumed to be constant over the site.

When plotted as vertical profiles, gamma-ray readings from drill chips enable a quick analysis of a single drill hole or series of holes. Potential problems with this method are related to the type of material analysed. Firstly, it is difficult to obtain much useful lithological information from sub-centimetre sized drill chips, and so it may only be possible to roughly check lithology against gamma-ray response. Secondly, one should be mindful that each sample represents a stratigraphic interval rather than a single measuring station, and so there is inherent averaging of gamma-radiation over the interval that chips are collected.

Core logging (lead-shielded, multi-channel spectrometer)

The spectrometer system used to measure gamma-radiation emitted from drill-core is far more sophisticated than that used for outcrops. When measuring drill core the volume of rock available for measurement (a stick of core) is much smaller than for outcrop work. Therefore, a spectrometer shielded from background radiation and with greater sensitivity and larger crystals is needed. Also, the geometry of cores is such that gamma-emissions occur in all directions, and a detector that surrounds the source is desirable.

In this study an Exploranium GR-320 Envispec spectrometer equipped with twin GPS-21 detectors (each with a 0.351 L NaI crystal) was used. The twin detectors are horizontally opposed and housed inside a measuring chamber surrounded by a pure lead shield, 2 cm thick (Fig. 1). Only the 'active' ends of the detectors are exposed to the measuring chamber, and the central part of the measuring chamber is shielded from the outside environment by a lead tunnel. The 'active' end of each detector points into the tunnel, which extends perpendicular to the detectors, and the 'active' ends of the detectors are separated by 16 cm across the tunnel. Sticks of core are passed manually along the tunnel into the measuring chamber on aluminium trolleys and positioned between the detectors. Once stationary, each sample is measured for a period of 1–2 minutes, depending on core diameter. The trolley is then pushed through the tunnel to the other side and retrieved. The next trolley loaded with core is positioned inside the measuring chamber, measured, and so on. Each measurement is a 256-channel spectral reading stored in memory, and blocks of readings are periodically downloaded to a PC in digital format. The spectrometer system weighs approximately 350 kg (due largely to the weight of the

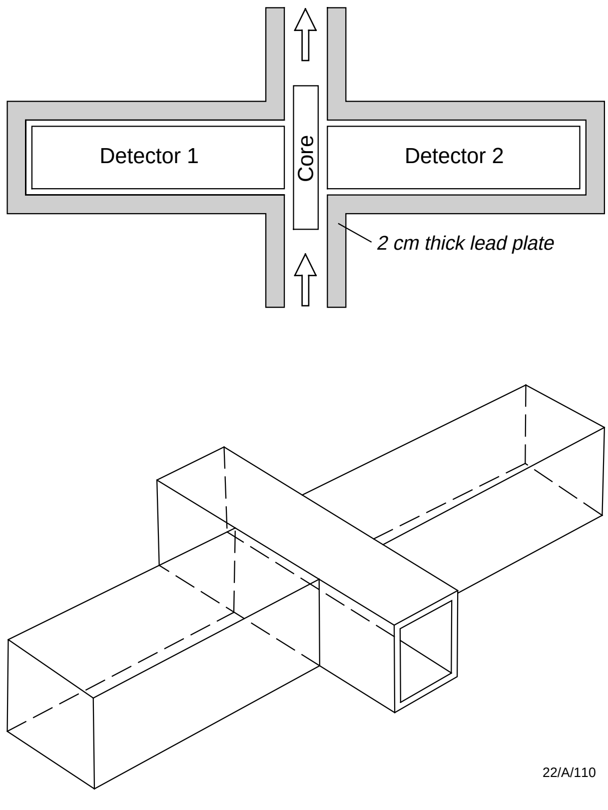

Figure 1. Plan view and 3-D sketch of lead housing and setup for core logging with GR-320 multi-channel gamma-ray spectrometer. Arrows show direction of movement of cores (loaded on trolleys) entering and leaving the measuring chamber.

lead shielding), and is mounted on a hydraulic trolley. The whole device is transported on a trayback vehicle between core repositories.

Measurements of background radiation in the chamber are made at regular intervals. Similarly, calibration standards are measured periodically with 5 minute count times at different times of the day in between measurement of normal core samples. The calibration standards are specially designed concrete cores of known radioactivity. A set of concrete calibration cores has been made for each of the standard core diameters studied, HQ (63.5 mm), NQ (47.6 mm), and BQ (36.5 mm). Each set of concrete calibration cores comprises a mixed source, a K-rich source, a U-rich source, and a Th-rich source. Importantly, the calibration cores have the same geometry and similar density to the rocks of interest. The radioactivity of the calibration cores was chosen to be close to API standard (2% K, 13 ppm U, 24 ppm Th), and of a suitable level to give good counting statistics for reasonable count periods.

Digital files for each gamma-radiation measurement are processed with software designed by Data Science Pty. Ltd. and Exploranium. Gamma-ray spectra recorded for each measurement are energy calibrated for 256 channels over 0–3 MeV, even though the GR-320 spectrometer is self-stabilised on an internal ^{137}Cs source. Count files are created after windowing counts into the four standard regions of interest (total count, K, U, and Th). Adjusted count files are then available for plotting against depth to give gamma-ray profiles.

Further processing is needed to convert count files into concentration values. Using spectral measurements obtained from the concrete calibration cores and knowing background radiation, one can calculate stripping ratios to convert individual counts for rock cores in the four channels into concentration values expressed as % K, gamma-equivalent U (ppm eU), and gamma-equivalent Th (ppm eTh).

Relationships of gamma radiation to grain size, clay content, and mineralogy

The general assumption when interpreting gamma-ray profiles is that there is a direct relationship between grain size and clay content, and that gamma-radiation correlates with clay content. Low gamma-radiation values should, therefore, indicate coarse-grained rocks, and high gamma-radiation values fine-grained rocks. Obviously, this is not true for all lithologies. Figure 2 illustrates typical gamma-ray responses of common lithologies, and readers are referred to Rider (1986, 1990) for more details.

Mineralogy can be the main contributor to natural gamma-radiation from rocks, independent of grain size or clay content. Spectral gamma-ray surveys have been specifically conducted to test the effects of particular minerals on gamma-ray response in the field. K-feldspars, micas, detrital clays, and phosphatic cements have all been shown to produce measurable gamma-ray responses within otherwise relatively homogeneous lithologies (Humphreys & Lott 1990). Similarly, heavy minerals (Th-rich) of both sand- and silt-size within sandstones are known to produce significant variations in gamma-ray response unrelated to the framework grain size or clay content of the sandstones (Davies & Elliott 1996, Myers & Bristow 1989).

Potential problems exist when simply equating gamma-ray response to grain size for lithologies that are rich in feldspar, micas, heavy minerals and, possibly, those with manganiferous or phosphatic cements (Hurst 1990). Correct interpretations of gamma-ray data require an appreciation of the mineralogy of the rocks and also rely on field analysis of lithofacies to establish the local relationship between clay content and grain size. Spectral gamma-ray logs can minimise problems in interpretation by enabling identification of anomalous gamma-radiation due to particular mineralogies.

Simple gamma-ray log trends

Despite the potential limitations discussed in the previous section, the gamma-ray technique is a powerful tool for sedimentary and stratigraphic analysis. For many lithologies, gamma-ray response can indeed be correlated with grain size after calibration with outcrop and core. In these cases, gamma-ray logs can be interpreted through the identification of three widely recognised signatures (Fig. 3) that correspond to individual sedimentary cycles:

- funnel-shaped gamma-ray curve segments with gamma counts decreasing upward, which commonly indicates a coarsening-upward succession;
- bell-shaped gamma-ray curve segments with gamma counts increasing upward, which commonly indicates an overall fining-upward succession;
- blocky gamma-ray curve segments with vertically unchanging gamma counts, which commonly indicate uniform grain size.

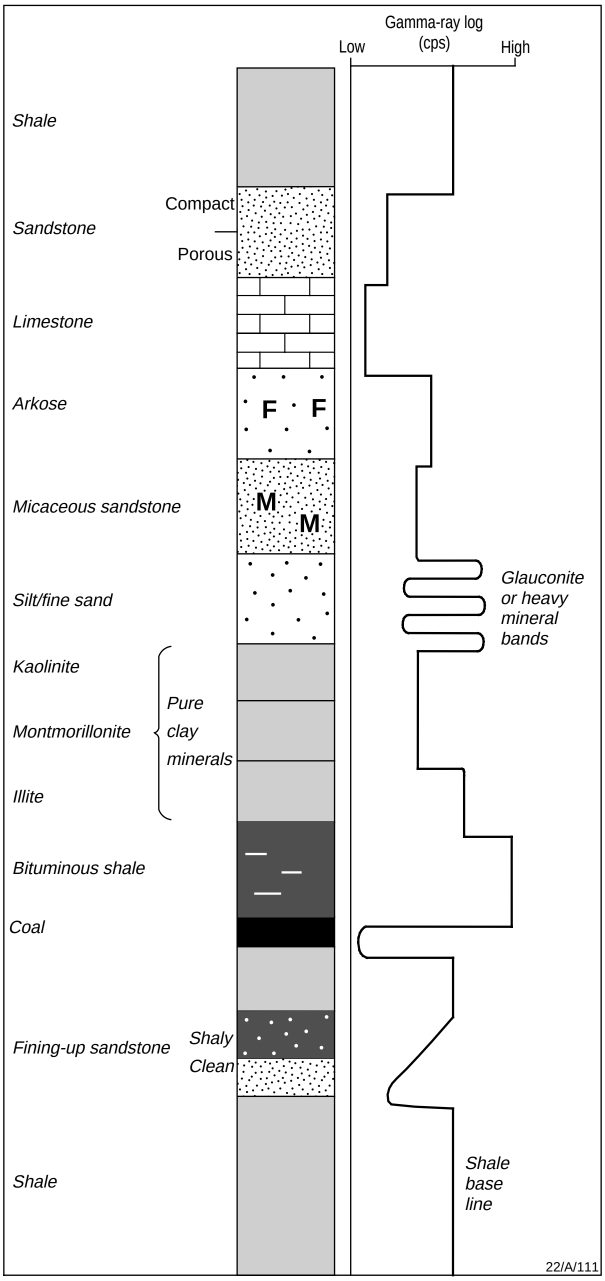

Figure 2. Typical response of gamma-ray log to common sedimentary rock types and minerals (after Rider 1986). F, feldspar; M, mica.

Sequence stratigraphic interpretation of individual gamma-ray profiles

Interpretation of gamma-ray curves is not based on identifying individual 'spikes' on the curves. Rather, it is the overall trends of the curve that are important for regional correlation. In this way, individual funnel-, bell-, or blocky-shaped segments on a gamma-ray curve become important because they commonly stack to form larger trends, which may have regional significance.

In sequence stratigraphic terms many of these individual gamma-ray segments equate to parasequences. A parasequence is 'a relatively conformable succession of genetically related beds or bedsets bounded by marine-flooding surfaces or their correlative surfaces' (Van Wagoner et al. 1990, p. 8).

Parasequences stack vertically in three main ways (Fig. 4) to form larger scale cycles (parasequence sets):

- Stacking of progressively sandier cycles, which are related to shoaling and overall regressive sedimentation. Such a stacking pattern is termed *progradational* to denote the basinward movement of a shoreline over time (Van Wagoner et al. 1990).
- Stacking of progressively more shaly cycles (though each is coarsening upward), which are related to drowning and overall transgressive sedimentation. Such a stacking pattern is termed *retrogradational* to denote the landward movement of a shoreline over time.
- Stacking of constant lithology packages, which are related to progressive building up of the sediment pile over time. Such a stacking pattern is termed *aggradational* to denote no significant movement of a shoreline over time.

Many gamma-ray logs can be quickly interpreted by identifying progradational, retrogradational, and aggradational trends. Log trends are then compared with descriptive sedimentological logs to enable interpretation of depositional environments and facies stacking patterns. Sequence boundaries and flooding surfaces can then be recognised on the basis of changes in stacking patterns on the gamma-ray logs, by the juxtaposition of lithofacies in measured section or core, and by relative or absolute values of gamma-ray lows and highs compared to the rest of the profile.

Sequence stratigraphic surfaces of differing significance typically occur within one measured section or cored interval. Gamma-ray response (events and shifts) and log trends (funnel, bell, cylinder) can be used to identify breaks in the rock record, changes in sedimentation rates, and infer changes in stratal geometry and the relative importance of sequence stratigraphic surfaces and cycles. Spectral gamma-ray curves provide additional information, which commonly helps to distinguish major sequence stratigraphic surfaces from minor ones. For example, major maximum-flooding surfaces commonly occur as large gamma-ray peaks in the upper part of major retrogradational log trends, and might correspond in outcrop to shale-prone sections enriched in organic matter due to anoxia and clastic starvation accompanying significant transgression. Uranium is commonly enriched in these fine-grained sections (largely due to adsorption onto clays). Maximum-flooding surfaces can be distinguished from minor flooding surfaces that occur at the base of small cycles by their U peaks on spectral logs, and also by the difference in Th/U ratios (Davies & Elliott 1996). In comparison, a minor flooding surface at the base of a small parasequence might only exist as a small 'kick' on the total gamma-radiation log without a pronounced retrogradational log trend, and may only be represented as a bed-scale silt or shale interval in outcrop.

Abrupt decreases in gamma-ray values on logs are commonly related to sharp lithological breaks associated with unconformities and sequence boundaries. In many cases the trend on the gamma-ray curve immediately beneath a sequence boundary is progradational, indicating coarsening-upward grain size accompanying a shoaling event that culminated in submarine or subaerial erosion. At such breaks, coarser grained, shallower water or fluvial facies commonly overlie finer grained, deeper water shaly facies. In some cases, similar facies lie immediately above and beneath a sequence boundary and there may not be an abrupt shift in the gamma-ray signal, but, typically, there is still a change in trend of the stacking pattern on the gamma-ray log.

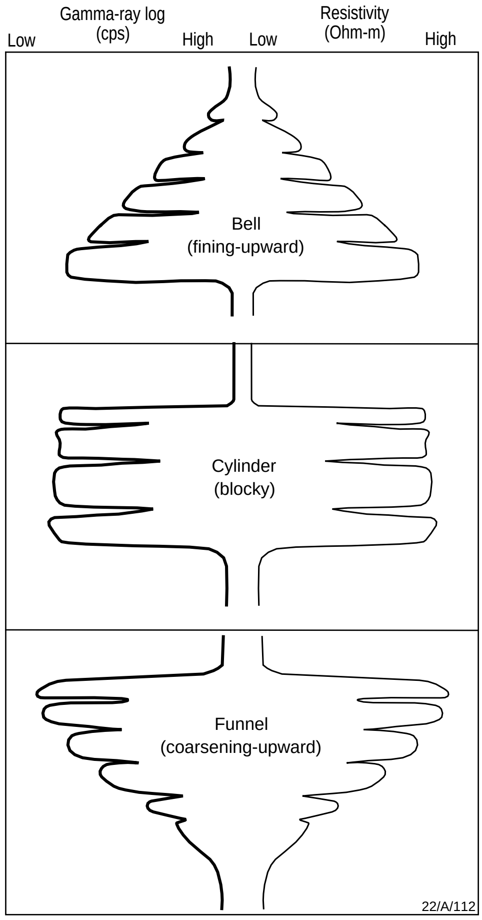

Figure 3. Three signatures commonly recognised on gamma-ray logs. The whole bell, funnel, and cylinder shapes are apparent when the gamma-ray log is paired with another log; in this case, resistivity (after Rider 1986).

Results

The following section illustrates a series of examples of gamma-ray profiles and their application to regional correlation and stratigraphic interpretation. The data represent only a very small part of the gamma-ray and measured-section database being compiled for the NABRE project. More comprehensive correlations and sequence stratigraphic analysis will follow as processing and interpretation are completed for the various stratigraphic intervals and sub-regions.

It should be stressed that interpretations presented are not solely based on gamma-ray profiles. Basic lithostratigraphic information on lithology, grain size, clay content, mineralogy, sedimentary structures, lateral continuity in outcrop, nature of sedimentary contacts, and knowledge of three-dimensional facies geometry are critical for confident correlation and sequence stratigraphic interpretation using gamma-ray profiles. Correlation based solely on gamma-ray profiles may lead to erroneous interpretations, especially when two-dimensional gamma-ray profiles are used to infer three-dimensional facies architecture (cf. Slatt et al. 1992).

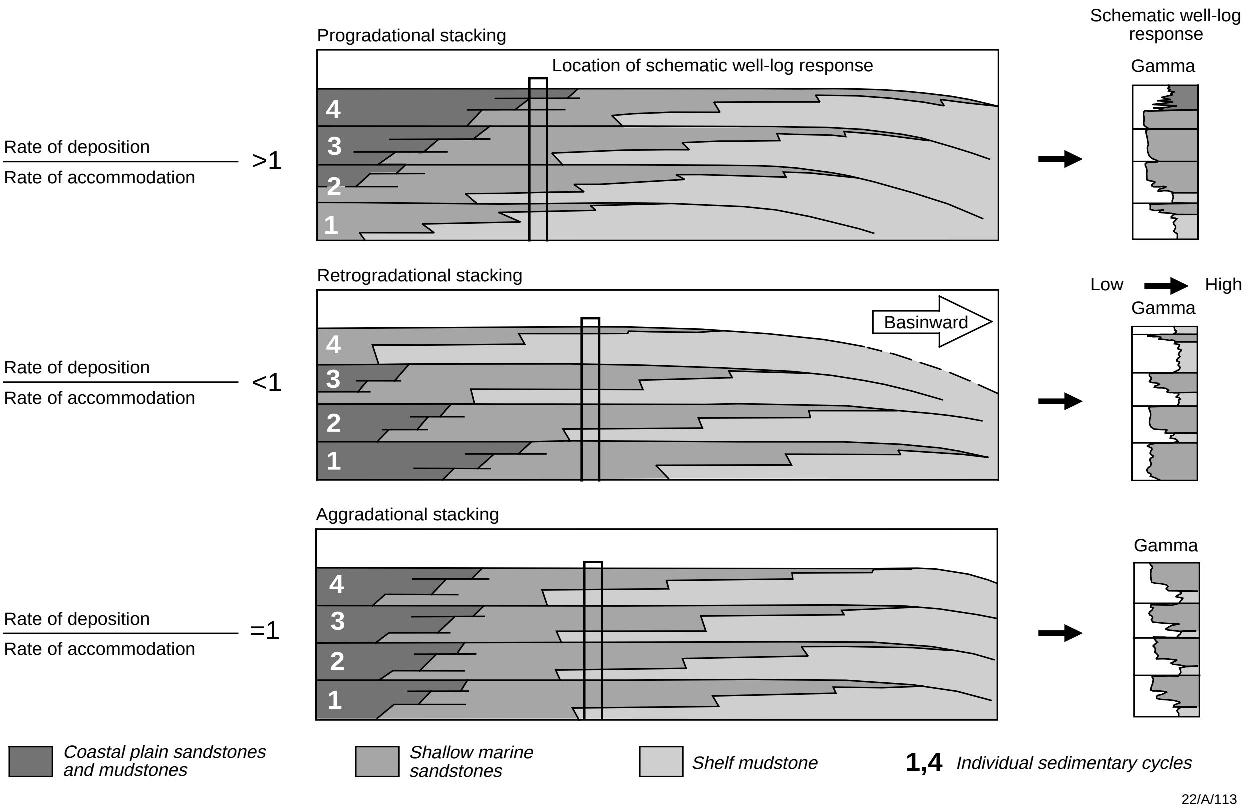

Figure 4. Schematic diagram of the three stacking patterns for individual parasequences in a sequence stratigraphic model. On the right are the gamma-ray profiles expected for wells or outcrops through each parasequence set (after Van Wagoner et al. 1990).

Outcrop gamma-ray profiles: Palaeoproterozoic Lower McNamara Group

Palaeoproterozic rocks of the Lower McNamara Group are exposed throughout the Lawn Hill Platform to the north of Mount Isa (Fig. 5). The Lower McNamara Group lies unconformably on the Kamarga Volcanics and older successions of the Myally Subgroup and also nonconformably over the Yeldham Granite (Sweet & Hutton 1982). The Torpedo Creek Quartzite at the base of the group is a fluvial to shallow marine intertidal succession and grades into interbedded siltstones, shales, and dolomitic sandy carbonates of the Gunpowder Creek Formation. A transgression in the upper Gunpowder Creek Formation culminates in a distinctive, relatively thin chert horizon (Mount Oxide Chert Member of the Paradise Creek Formation), and is overlain by thick fine-grained carbonates of the Paradise Creek Formation (Southgate et al. 1995).

There are three major sequences evident on the gamma-ray log for the lower half of the Lower McNamara Group (Fig. 6). Their boundaries are indicated by an abrupt decrease in gamma-ray values, sharp lithological contacts (sharp-based sandstones or intraclastic carbonates overlying the sequence boundary), evidence of erosion, and a change in log trend from progradational to retrogradational or aggradational.

The first major sequence (45–415 m) exhibits an aggradational trend for the lower Torpedo Creek Quartzite, a retrogradational trend up to a peak in gamma-ray values (maximum-flooding surface) within laminated siltstone of the lower Gunpowder Creek Formation at 280 m, followed by an overall progradational trend up to the sequence boundary at 415 m (Fig. 6). This sequence boundary is overlain by a ferruginous, intraclastic, sandy carbonate facies, which correlates laterally with a thicker cobble conglomerate, indicative of significant erosion at this level. The log trends for the basal sequence indicate initial high sediment supply and shallow water conditions in early Torpedo Creek Quartzite time, which resulted in a thick succession of coarse-grained, cross-bedded, quartz arenites. Gradual drowning occurred from mid Torpedo Creek Quartzite time until maximum marine transgression was reached in early Gunpowder Creek Formation time, followed by progressive shoaling as accommodation space decreased during mid–late Gunpowder Creek Formation time.

The second major sequence (415–545 m) has a lower strong retrogradational log trend, indicating rapid drowning, up to a maximum-flooding surface at 435 m, followed by progradation up to the sequence boundary at 545 m. The sequence boundary here is indicated by a sharp-based, erosional sandstone facies that corresponds to an abrupt decrease in gamma-ray values (Fig. 6). The third major sequence (base at 545 m, top not shown on Fig. 6) has a strongly retrogradational log trend up to a maximum-flooding surface at 595 m, corresponding to deepest water conditions developed in latest Gunpowder Creek Formation time. This regional maximum-flooding surface at 595 m is associated with gamma-ray values of about 550 cps for this outcrop section. However, in the Mount Oxide mine the same stratigraphic interval is better exposed and organic matter-rich shales there have higher gamma-ray values of 700 cps (Fig. 6, dashed peak).

Within these major sequences, thinner, higher-order sequences, around 50 m thick, are also evident on the gamma-ray log (Fig. 6). The Torpedo Creek Quartzite comprises several higher-order sequences marked by subtle changes in log trends, grain size, and sedimentary structures. Within these, maximum-flooding surfaces are associated with thin, recessive, silty to shaly intervals that correspond with local peaks in gamma-ray values. Minor sequence boundaries are defined by changes in log trends and subtle regional lows in gamma-ray values. These sequence boundaries are not marked by significant changes in facies or extensive erosion.

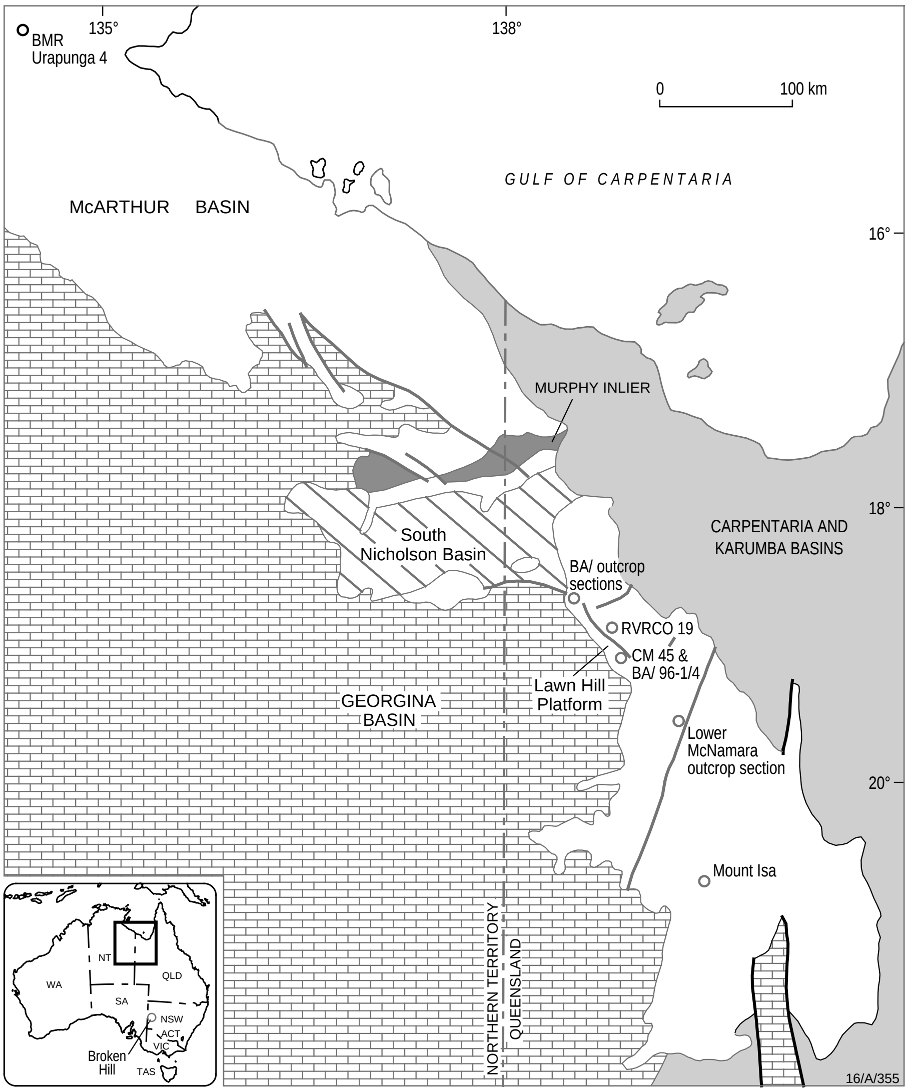

Figure 5. General location of sites in the McArthur Basin and Lawn Hill region (after Sweet & Hutton 1982).

The Gunpowder Creek Formation comprises at least seven of these higher-order sequences. The basal three sequences (~260–310 m, 310–355 m and 355–405 m) are well-defined shoaling marine cycles that stack to form the progradational part of a major sequence (Fig. 6). Each minor cycle comprises mid-shelfal, laminated to hummocky cross-stratified siltstone and very fine sandstone grading up into shallow-marine, coarser grained sandstone or intraclastic, sandy, cross-bedded dolostone (Southgate et al. 1995). Maximum-flooding surfaces occur within the fine-grained parts of the cycles, and sequence boundaries occur within or at the base of the carbonate facies. Carbonate facies between 405 and 415m represent a small erosional remnant of another minor sequence that has been truncated by the overlying major sequence boundary at 415 m (Fig. 6).

Between 415 m and 550 m, the Gunpowder Creek Formation comprises very fine to fine-grained hummocky cross-stratified and lenticular quartz sandstone interbedded with slightly micaceous ripple-laminated siltstone. Other than sandstone–siltstone bedding pairs, sedimentary cycles are very difficult to distinguish in these rocks on the basis of lithology alone. However, three minor sequences are clearly identified on the gamma-ray log over this interval (Fig. 6). The change from retrogradational to progradational log trends marks maximum-flooding surfaces, which correspond to relatively thin siltstone intervals in outcrop. Sequence boundaries at the top of progradational log trends correspond to thin, sharp-based, fine to medium-grained sandstone facies that appear similar in outcrop to sandbodies above and beneath the sequence boundary.

Above 545 m, there is a gradual change in facies, firstly, from shallow-marine, medium-grained sandstone to ripple-laminated siltstone deposited in slightly deeper water, and then, secondly, to phosphatic, stromatolitic, dolomitic siltstone and black carbonaceous shale deposited in the deepest water conditions for the area. Black carbonaceous shales and siltstones are overlain by grey, laminated to massive chert of the Mount Oxide Chert Member. Within this interval there are two minor sequences that stack in the retrogradational part of a major sequence. Above the maximum-flooding surface, at 595 m, there is a progradational log trend up to a marked fall on the gamma-ray log at the base of the Mount Oxide Chert Member.

Drill chip gamma-ray profiles: Palaeoproterozoic Riversleigh Siltstone

The Palaeoproterozic Riversleigh Siltstone (Upper McNamara Group) is generally poorly exposed on the Lawn Hill Platform and forms a recessively weathering siltstone and shale-dominated unit up to 3200 m thick (Sweet & Hutton 1982). The Riversleigh Siltstone was deposited largely in mid to outer shelf environments, but there were intermittent shoaling and deepening episodes beyond this range of environments (Andrews 1996). The Riversleigh Siltstone is considered a likely host for stratabound base-metal mineralisation, and recent exploration drilling programs have produced large amounts of drill chip and core.

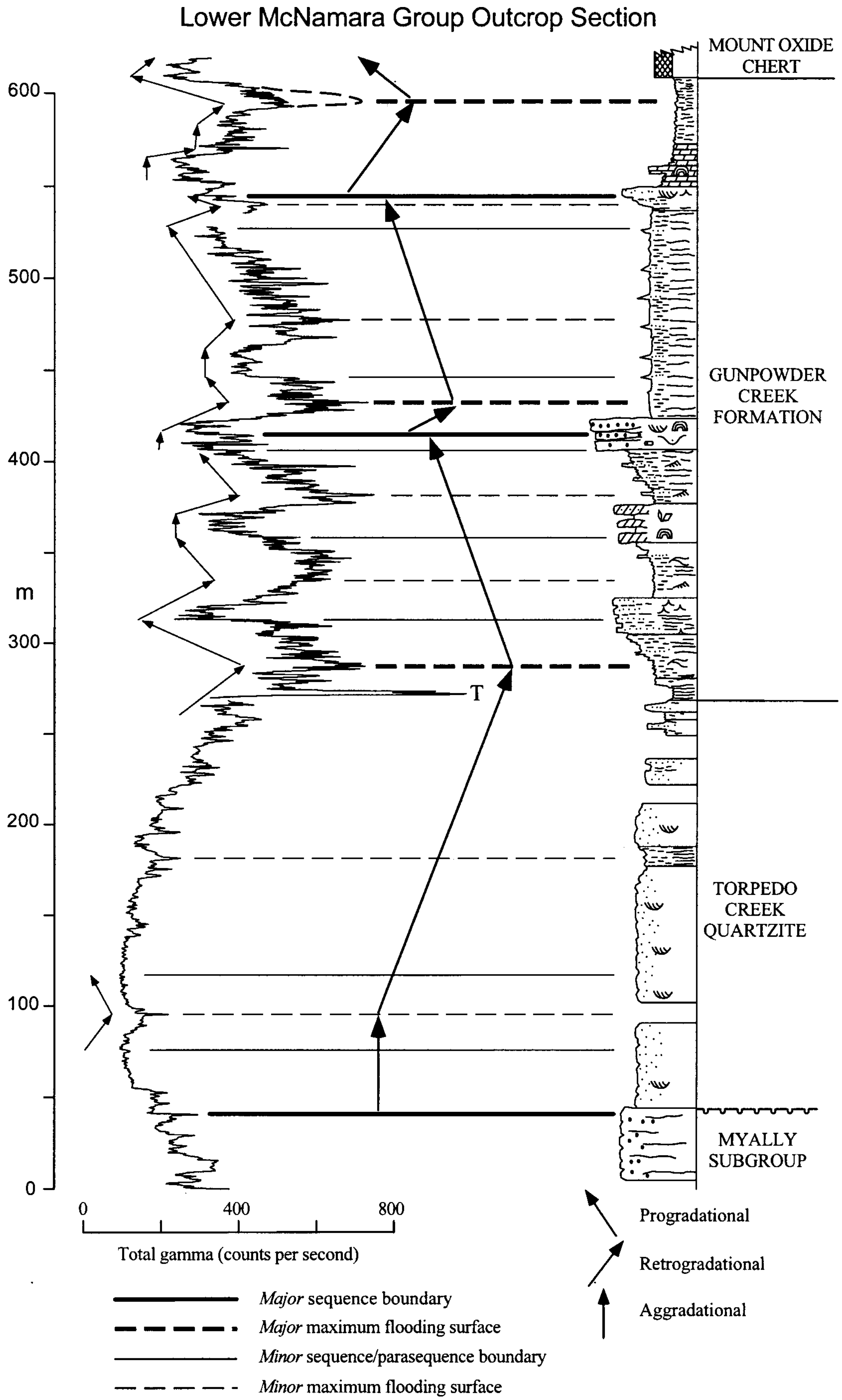

Figure 6. Composite total-emission gamma-radiation outcrop log and schematic sedimentological log for the lower half of the Lower McNamara Group (Mammoth Mines 1:100 000 sheet, northwestern Queensland). Major sequences are shown by broad arrows to the right of the gamma-ray log, minor sequences are shown by thinner arrows to the left (after Jackson et al. 1996). T, tuffaceous interval.

The sedimentary log of percussion hole RVRCO19 (see Fig. 5 for location) shows a relatively uniform sedimentary succession (Fig. 7). However, the total gamma-radiation log displays a range of 200–400 cps and distinct sedimentary cycles appear on the log. The major events interpreted on the gamma-ray log are a sequence boundary at 103 m, a generally retrogradational trend up to a maximum-flooding surface at 82 m, followed by an overall progradational trend to the top of the hole. Other events and trends are also apparent on the gamma-ray log, but the shift in gamma-ray values is not as large for these events and they represent higher-order (less significant) sedimentary cycles.

The abrupt decrease in gamma-ray values at 103 m, which marks a sequence boundary, corresponds to the upper part of a slightly coarser grained interval. The log trend above the sequence boundary is aggradational for a few metres, then changes to a retrogradational trend up to a peak in the gamma-ray log at about 82 m. This gradual increase in gamma radiation to a peak that correlates with the middle of a fine-grained interval is typical of the response of siliciclastic depositional settings to a marine transgression.

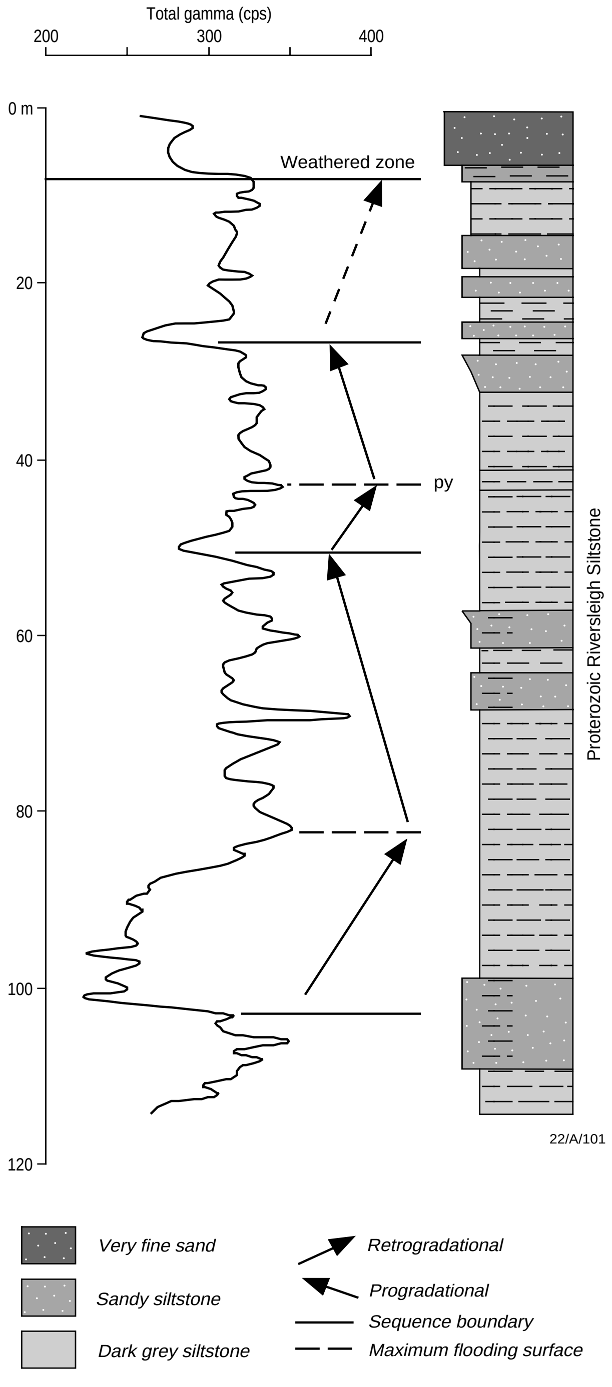

Figure 7. Total-emission gamma-radiation log measured from drill chips. Stratigraphic unit is the Riversleigh Siltstone, Upper McNamara Group (Lawn Hill 1:100 000 geological map area). Instrument count period is 10 seconds (after Krassay 1996).

Above the major maximum-flooding surface there are two minor cycles characterised by a change in log trend from retrogradational to progradational. The minor lows in the log at 50 m and 25 m are interpreted as higher-order parasequence boundaries. The minor gamma-ray peak at 45 m is probably a marine flooding surface and correlates to a fine-grained pyritic part of the section. The upper part of the log, from 25 m to 8 m, is retrogradational, suggesting another minor transgressive episode towards the top of the section.

There is a good correlation between gamma-ray response and grain size. The middle to upper parts of each progradational trend are characterised by coarser grained rocks, as would be expected with shoaling of depositional environments. The rocks surrounding the sequence boundaries are typically coarser than elsewhere (except for the parasequence boundary at 50 m). Again, this is what would be expected, because sequence boundaries represent parts of the section where there is an increased likelihood of an influx of coarser detritus derived from erosion, and there is also an overall increase in grain size accompanying the increase in the energy of depositional environments caused by shoaling. Conversely, gamma-ray peaks correlate with the finest-grained parts of the section, as would be expected for drowning of previous depositional environments where the dominant sedimentation would be clay-sized particles settling from solution.

There are parts of the log that appear problematic. For example, there is an isolated gamma-ray peak at 70 m which does not appear to correspond to an unusually fine-grained lithology. It is possible that this spike on the log is due to a thin tuff bed or cemented horizon, in which case the log response is due mostly to mineralogy rather than grain size or clay content. Closer examination of the drill chips might explain this variation.

Gamma-ray logs are potentially important for interpretation and correlation of percussion drill holes where little lithological information is available. If percussion drill chips were routinely gamma-ray logged in this fashion it is probable that individual sedimentary cycles could be more confidently correlated across a region than on the basis of lithostratigraphy alone.

Core gamma-ray profiles: Mesoproterozoic Roper Group

Spectral gamma-ray logs were obtained from cored drill hole BMR DDH Urapunga 4, which penetrates the Mesoproterozoic Roper Group in the southern McArthur Basin. From base to top, the drill hole intersects interbedded sandstone and mudstone (Corcoran Formation), a mature medium-grained quartzose sandstone (Bessie Creek Sandstone), thick organic-rich mudstone (Velkerri Formation), and interbedded siltstone and sandstone (McMinn Formation). These formations generally represent shallow marine to mid-shelf depositional environments (Jackson et al. 1987).

The gamma-ray logs for BMR DDH Urapunga 4 (Figs 8, 9) show significant shifts and events that correspond to sedimentary cycles bounded by chronostratigraphic surfaces. The entire section can be subdivided into 4 complete major sequences and one part sequence at the top (Fig. 9). Also, at least 8 minor, higher-order sequences are identified in the section.

The first major event identified on the total-emission gamma-ray log (Fig. 9) is a gamma-ray peak and maximum-flooding surface at 465 m in the Corcoran Formation. Above this surface there is a progradational log trend, indicating progressive shoaling, until an abrupt decrease in gamma-ray values occurs at the base of the Bessie Creek Sandstone. On all logs, quartz sandstones of the Bessie Creek Sandstone are clearly visible as lows, and the abrupt nature of this contact is interpreted as a

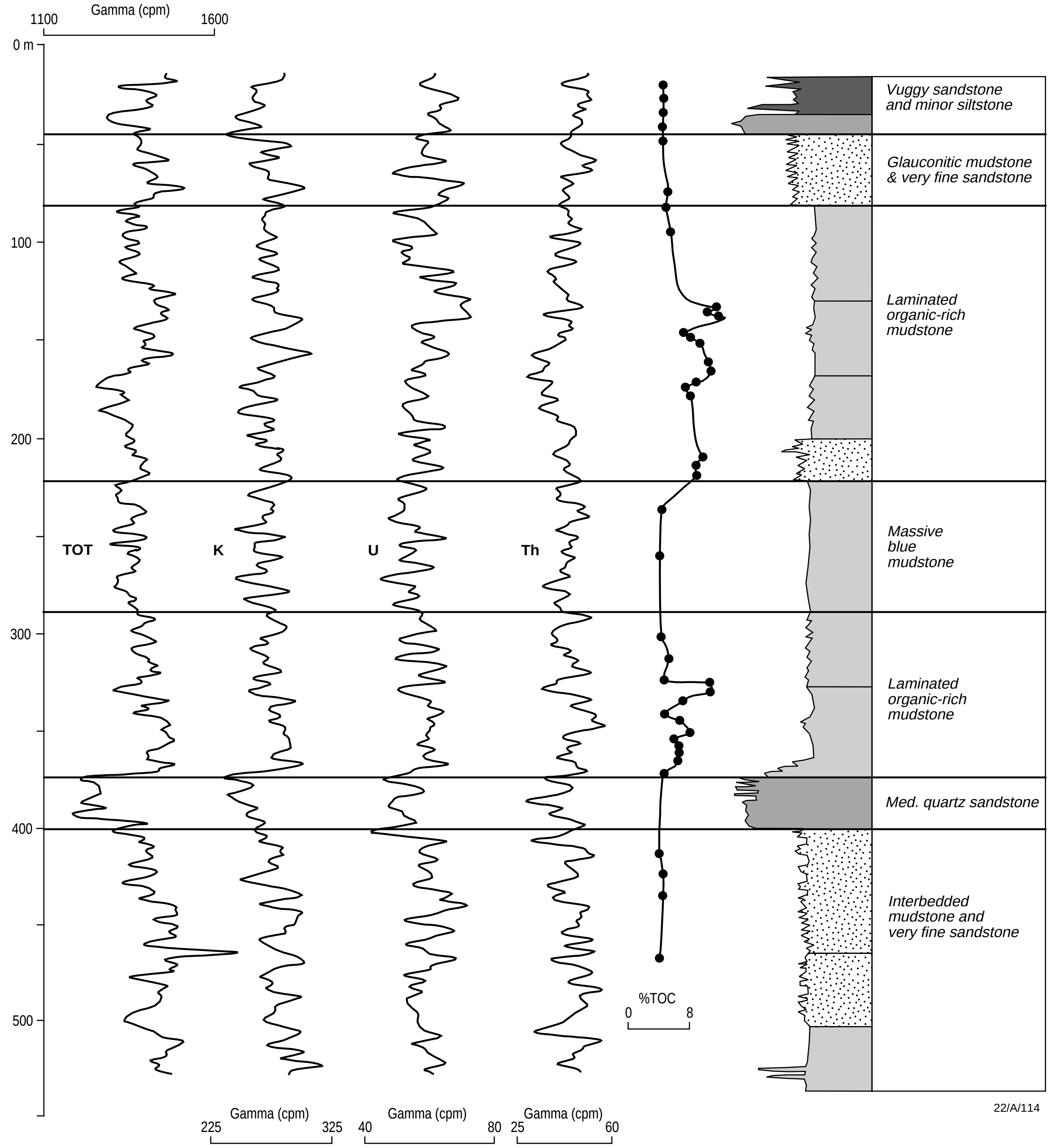

Figure 8. Spectral gamma-ray log (TOT, K, U, Th) measured from core of drill hole BMR DDH Urapunga 4 through the Roper Group in the southern McArthur Basin, Northern Territory. Instrument count period is 60 seconds. Total organic carbon (TOC) and sedimentological data are from Sweet & Jackson (1986).

sequence boundary. In the well completion report, Sweet & Jackson (1986), in fact, described sharp-based cross-bedded sets rich in mudstone intraclasts at the base of the Bessie Creek Sandstone, which attest to erosion of the underlying deeper water facies.

The pronounced retrogradational log trend at the top of the Bessie Creek Sandstone indicates rapid transgression and drowning until deepest water conditions were reached early in Velkerri Formation time. The maximum-flooding surface at about 370 m is 10 m above the base of the Velkerri Formation and correlates with a carbonaceous mudstone with elevated U log signal and high-TOC (total organic carbon) values (Fig. 8). Mudstones above the maximum-flooding surface are also highly carbonaceous and occur as highs on the total and U logs, indicating the development of a thick condensed section.

Above the maximum-flooding surface at 370 m, the logs show general progradation until the 180 m level, although there are smaller progradational–retrogradational cycles in this interval. The up-hole part of the log is dominated by two smaller aggradational–retrogradational–progradational sequences. The maximum-flooding surface at 140 m occurs within a broad gamma-ray high on the total gamma log and corresponds to peaks in the U log and TOC curve (Fig. 8). This combination of factors suggests significant transgression and anoxia in relatively deep water with the development of a condensed section in an area of clastic starvation. The maximum-flooding surface at 75 m is not as pronounced, does not involve a broad gamma-ray high on any of the logs, and does not correlate with a zone rich in organic matter, suggesting that the upper sequence involved transgression on a smaller scale. The sequence boundaries at the base of both sequences (185 m and 120 m) are illustrated on all four logs as gamma-ray lows, and on the TOC curve as low values. Another sharp-based sandstone, and sequence boundary, at 45 m is highlighted by abrupt falls in the total-emission and K gamma-ray logs. Above this sandstone there is a retrogradational log trend, indicating the beginning of another transgression.

Throughout the section the close resemblance of the U and Th logs, and the small range in Th values, suggests that there are no significant concentrations of heavy minerals or phosphatic units. However, the K log shows some interesting variations.

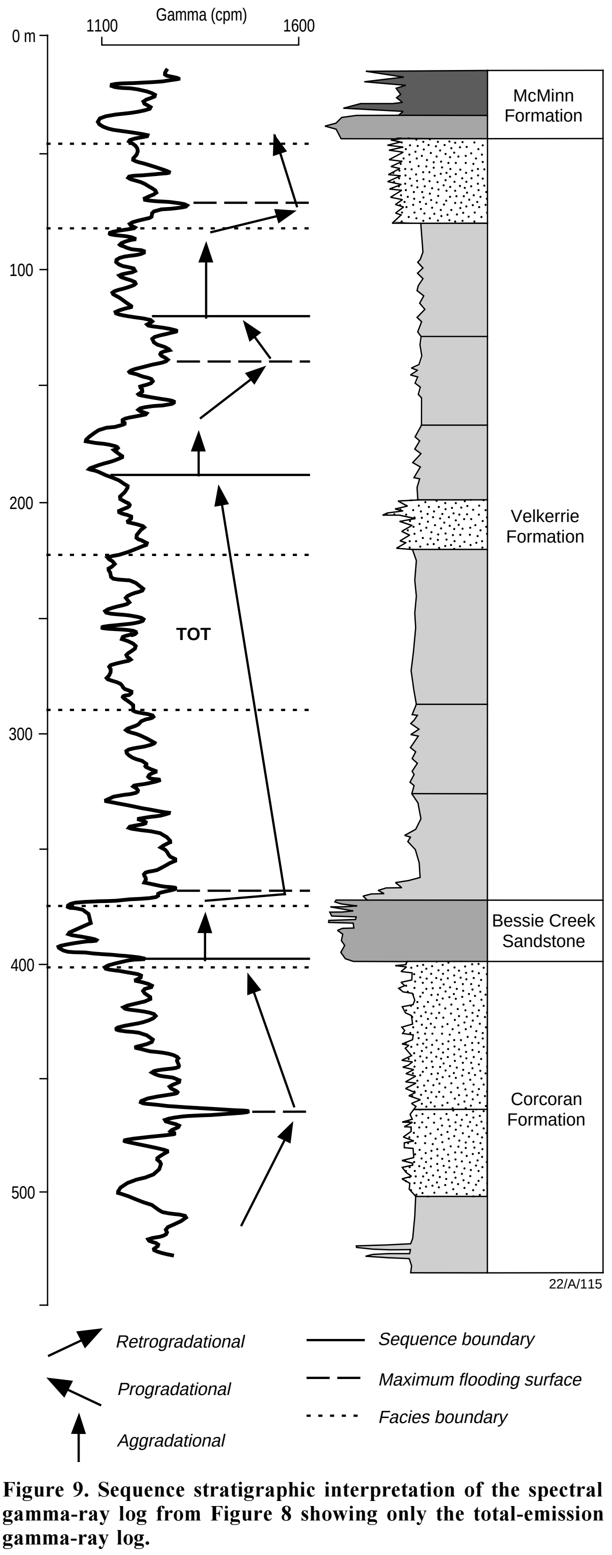

Figure 9. Sequence stratigraphic interpretation of the spectral gamma-ray log from Figure 8 showing only the total-emission gamma-ray log.

Gamma-ray peaks at about 360–370 m, 220 m, and 60–70 m on the K log occur without peaks on other logs, or where the other logs show lows. This suggests that the total gamma-radiation response of these particular intervals is not due solely to grain size. A check of the core confirms this; all three intervals contain glauconite. The high K content of the glauconite is affecting the gamma-ray logs independently of grain size. This is just one example of the advantages of using spectral gamma-ray logs in interpretation.

Recognition of common gamma-ray log trends and subsequent sequence stratigraphic interpretation in this example reveals that sequences do not all occur within the one lithostratigraphic unit, and sequence boundaries do not necessarily correspond to lithostratigraphic or lithofacies boundaries. The largest sequence in the section includes the Bessie Creek Sandstone and the lower half of the Velkerri Formation, and these formations are now genetically linked within one major sedimentary cycle. This highlights an important difference between sequence stratigraphy and lithostratigraphy. Lithostratigraphy is based on the definition of rock bodies, sequence stratigraphy is based on rock bodies bounded by chronostratigraphically significant stratigraphic surfaces. Many mapped lithostratigraphic units are diachronous, and this makes correlation based on lithostratigraphy difficult in regions where there are marked vertical and lateral facies changes.

Outcrop to subsurface gamma-ray correlation: Palaeoproterozoic Riversleigh Siltstone

This example illustrates gamma-ray correlation based on logs collected using both outcrop and conventional down-hole logging techniques. The stratigraphic interval of interest is Shady Bore Quartzite–Riversleigh Siltstone transition from a faulted outcrop on the Lawn Hill Platform (Fig. 5). In this area the Shady Bore Quartzite comprises shallow-marine quartz arenite and minor subtidal/intertidal intraclastic dolomite and dolomitic siltstone. The Riversleigh Siltstone comprises thick intervals of laminated marine siltstone and dolomitic siltstone, enclosing thinner, but significant, shallower marine sandstone intervals.

Comparison of the total-emission gamma-radiation logs for outcrop section BA/96-1/4 and adjacent drill hole CM45 (Fig. 10) reveals a close correspondence between the logs with regard to log trends and events. Significant highs and lows, representing maximum-flooding surfaces and sequence boundaries, respectively, are identified on both logs. Important events identified on the logs include a local peak in gamma-ray values, representing a maximum-flooding surface at 230 m (BA/96-1/4 and CM45), an abrupt decrease in gamma-ray values, representing a sequence boundary at 255 m (BA/96-1/4) and 250 m (CM45), and the regional peak in gamma-ray values, representing a major maximum-flooding surface (used as a datum for the logs) at 425 m. In drill core, this regional maximum-flooding surface corresponds to laminated carbonaceous siltstone and shale.

Although the logs have a good match, gamma-ray values at minima and maxima in each of the logs are not identical, and some events are slightly more prominent on one log than the other. These variations are due to a combination of factors, including the nature of the samples (unweathered samples surrounding a drillhole versus weathered outcrop at the surface), different sample geometry, different instruments, and perhaps slight lateral facies variations. In addition, the emission of gamma-rays over time is not a linear function, and there will always be small variations even if the same sample is measured repeatedly by the same instrument (cf. Rider 1986). Notwithstanding these variations, detailed correlation is possible by comparing simple outcrop gamma-ray logs with conventional down-hole log data (Fig. 10).

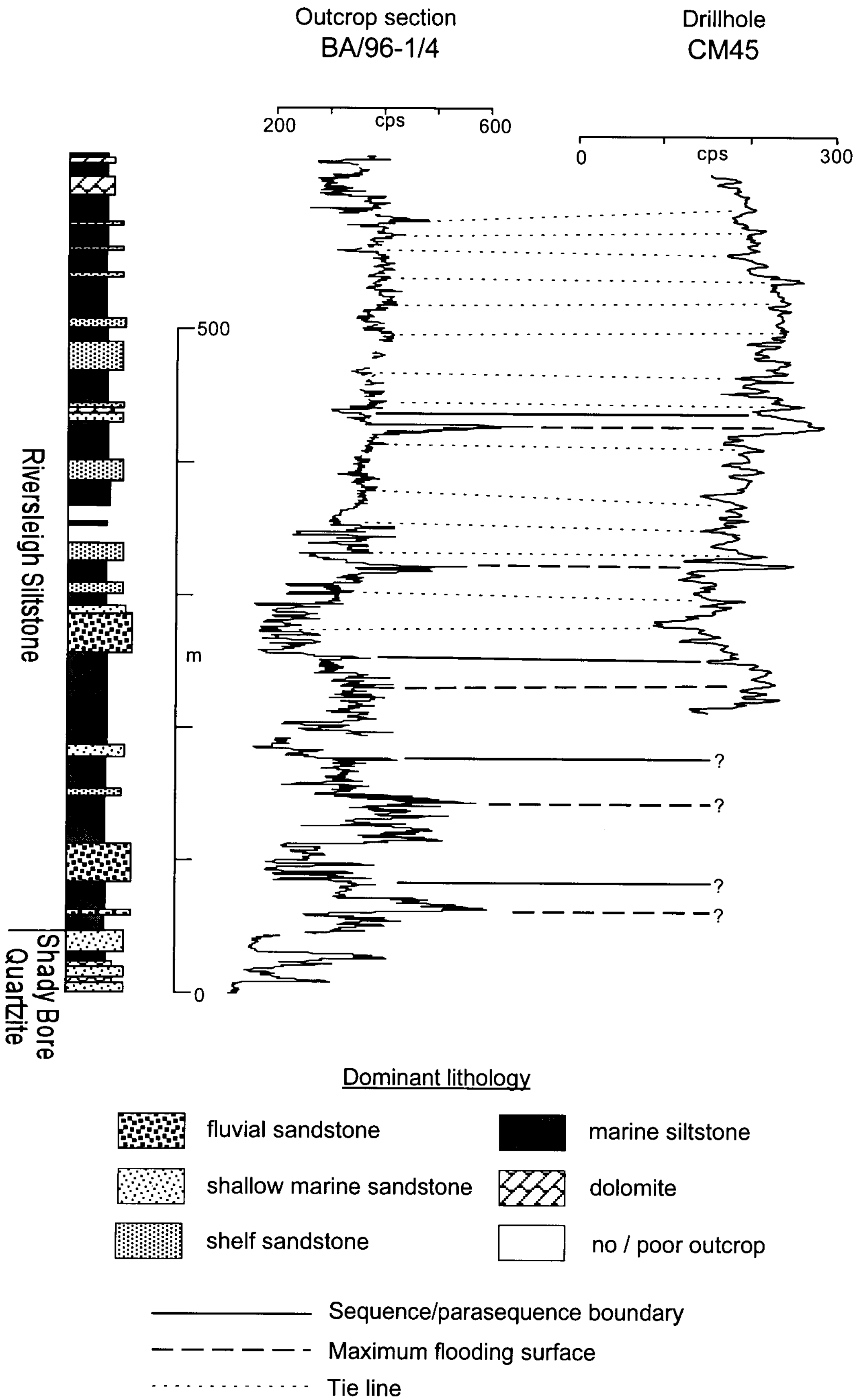

Figure 10. Outcrop to subsurface correlation based on total-emission gamma-ray logs. Outcrop section and drill hole are approximately 100 m apart in the same small fault-block. The schematic lithological column represents only the outcrop section. Instrument count period is 10 seconds. Drill-hole gamma-ray log was recorded with a conventional down-hole gamma-ray tool. The down-hole gamma-ray log has been slightly filtered, using a moving average filter (after Bradshaw et al. 1996a).

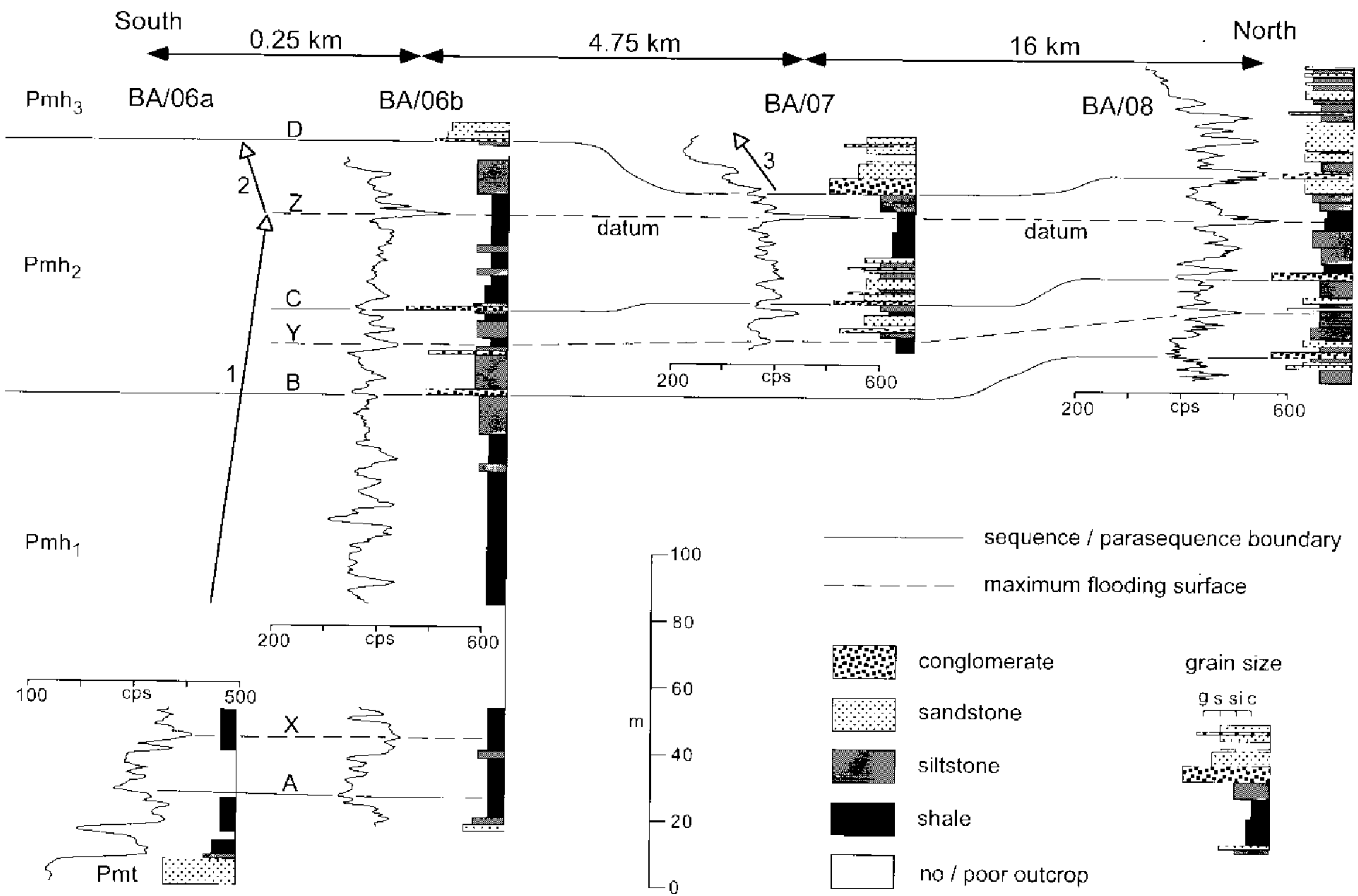

Figure 11. Schematic north–south cross-section illustrating outcrop gamma-ray logs measured along a slightly sinuous north–south-trending outcrop belt on the western portion of the Lawn Hill 1:100 000 geological map sheet in northwestern Queensland. Stratigraphic interval is the Termite Range Formation (Pmt) and Lawn Hill Formation (Pmh) of the Upper McNamara Group. Gamma-ray readings were measured every 0.5 m at true stratigraphic thickness with a count period of 10 seconds. Gamma-ray curves have been slightly filtered using a moving average filter. Grain-sizes: g, granule; s, sandstone; si, siltstone; c, claystone.

Sequence stratigraphic correlation based on outcrop gamma-ray profiles: Palaeo–Mesoproterozoic Upper McNamara Group

Gamma-ray techniques and sequence stratigraphy can be useful for correlation at the scale common in detailed basin analysis or mineral exploration. The stratigraphic interval of interest here is the upper Termite Range Formation and the lower half of the Lawn Hill Formation of the Upper McNamara Group (latest Palaeoproterozoic–earliest Mesoproterozoic). These two formations occur directly above the Riversleigh Siltstone in the same general region of the Lawn Hill Platform (Fig. 5).

The Termite Range Formation comprises thickly bedded, generally coarse-grained sandstone and minor shale up to 1300 m thick. The formation is divided into two major fining-upward sequences, and deposition occurred largely in subaqueous fan systems beneath storm wave base (Andrews 1996). The Lawn Hill Formation appears to overlie the Termite Range Formation with a sharp, conformable contact. The lower mapped member of the Lawn Hill Formation (Pmh1) consists of carbonaceous silty shale, tuffaceous shale, and rare fine-grained sandstone. The second member (Pmh2) consists almost entirely of tuffaceous siltstone, shale, and shale rip-up horizons. The third member (Pmh3) consists of fine to medium-grained quartz arenite with volcanic glass shards and shale pebble units (Andrews 1996). Rocks of all three members were deposited in a shelf environment, with shale and siltstone of Pmh1 and Pmh2 being deposited in relatively deep water beneath storm wave base. Sandstone of Pmh3 was deposited in a shallow shelfal environment dominated by storm waves (Andrews 1996).

A cross-section through part of the Upper McNamara Group (Fig. 11) reveals significant variations in relative total-emission gamma-radiation response, with values ranging from about 100 cps in coarse sandstone of the Termite Range Formation (Pmt) up to 600 cps in shale of the lower Lawn Hill Formation (Pmh2). At the broadest scale one can observe an overall retrogradational pattern (arrow 1) from the base of Pmh1 up to a gamma-ray peak in the upper part of Pmh2, followed by a slightly progradational log trend (arrow 2) towards Pmh3, then a pronounced progradational trend within Pmh3 (arrow 3). These log trends are interpreted as showing a major transgression, with prolonged deep water conditions throughout much of Pmh1–Pmh2 time, followed by shoaling and increasing energy with change in depositional environments culminating in significant erosion and incision at the base of Pmh3. However, there are numerous important sedimentary cycles superimposed upon the longer-term cyclicity.

In general, there is good correlation between gamma-ray response and grain size. Sandstone and pebble conglomerate correlate with gamma lows, and shale correlates with gamma highs. However, there are several exceptions which are due to local features of sedimentation. The base of Pmh3 is generally marked by a gamma-ray low, but the fall is not as abrupt or significant as might be expected for the change from siltstone to conglomeratic sandstone; indeed, in the case of section BA/08 the contact occurs as a gamma-log high. This is because clasts at the base of Pmh3 are derived almost entirely from underlying tuffaceous siltstone of Pmh2, and so the composition of the pebbles masks the actual grain size of the pebbles and the surrounding fine to medium-grained host sandstone.

The abrupt rise in gamma-ray log values at the contact between the Termite Range Formation and the Lawn Hill Formation at site BA/06a indicates a major change in depositional environment and a corresponding change in facies. An abrupt fall in log values (sequence boundary A) occurs about 20 m above the base of Pmh1. The gamma logs at sites BA/06a and BA/06b are almost identical and show a retrogradational trend above sequence boundary A up to a broad gamma-ray peak. This peak (maximum-flooding surface X) correlates with a thick carbonaceous shale, typical of a condensed section.

Log values remain high throughout carbonaceous shale and siltstone of Pmh1, but there are several small highs and lows, marking higher-order cycles within the shale. In the upper part of Pmh1 the log trend is progradational up to a significant gamma low that corresponds to a pebble conglomerate (sites BA/06b and BA/08). This laterally correlative horizon marks sequence boundary B and the base of Pmh2. The log trends are aggradational, then retrogradational up to maximum-flooding surface Y in the shale, followed by progradation up to a gamma low (sequence boundary C) marked by another pebble conglomerate. Above sequence boundary C, the log trends are aggradational or slightly retrogradational over 20–30 m towards a prominent gamma peak (maximum-flooding surface Z) near the top of Pmh2. This sequence stratigraphic surface is obvious on all three available gamma logs, and is used as a datum for the cross-section. The log trends are progradational above maximum-flooding surface Z, and become strongly progradational above sequence boundary D, which marks the base of Pmh3.

The lithostratigraphic succession of the upper Termite Range Formation and lower Lawn Hill Formation can thus be subdivided into at least four sequences, and it is likely that additional sequences exist in the middle to upper parts of Pmh1 (Fig. 11). Correlation of the field sections with outcrop gamma-ray profiles shows significant erosional relief on the base of Pmh3 (up to 15 m over a strike distance of <5 km). Although the facies in each measured section are similar, significant lateral facies changes do occur. Generally, facies become thinner and coarser grained to the north, and the degree of interbedding increases. By combining gamma-ray profiles with the sedimentological logs, it is possible to correlate individual cycles, even individual beds, across the region and hence achieve a much more refined geological history at a very detailed scale.

Conclusions

1. Gamma-ray log trends correspond to changes in grain size, clay content, and mineralogy. Log trends may be calibrated to particular facies patterns and depositional environments in core or outcrop. Then, stacking patterns on gamma-ray logs are interpreted as changes in depositional systems over time. On a regional scale, changes in gamma-ray stacking patterns reflect variations in the overall driving mechanisms for sedimentation in a basin (e.g. relative sea level, sediment supply, palaeogeography).
2. The hierarchy, thickness, and stacking patterns of sedimentary cycles are commonly difficult to distinguish through traditional facies descriptions of outcrops, because they involve incremental changes in rock properties. A unit with relatively little lithological contrast or expression of sedimentary cycles in the field (e.g. Riversleigh Siltstone, Fig. 7) may often be divided into a series of stacked sedimentary cycles of different orders through the use of gamma-ray logs.
3. Gamma-ray logs are relatively quick and easy to generate, and they provide excellent detail for stratigraphic correlation between outcrop sections and cored stratigraphic intervals at all scales. By correlating series of gamma-ray logs across a region, one can construct a regional stratigraphic framework, place individual ‘events’, and cycles into a regional context, and provide a test of previous lithostratigraphic correlation schemes.
4. Where conventional down-hole geophysical logs are lacking, outcrop, core and percussion drill-chip gamma-ray logs provide better regional correlation of sedimentary cycles than does lithostratigraphy alone. Thickness variations and facies geometry can be interpreted with

more confidence, which may enable more accurate, predictive assessment of source–trap–seal systems for mineralisation.

Acknowledgments

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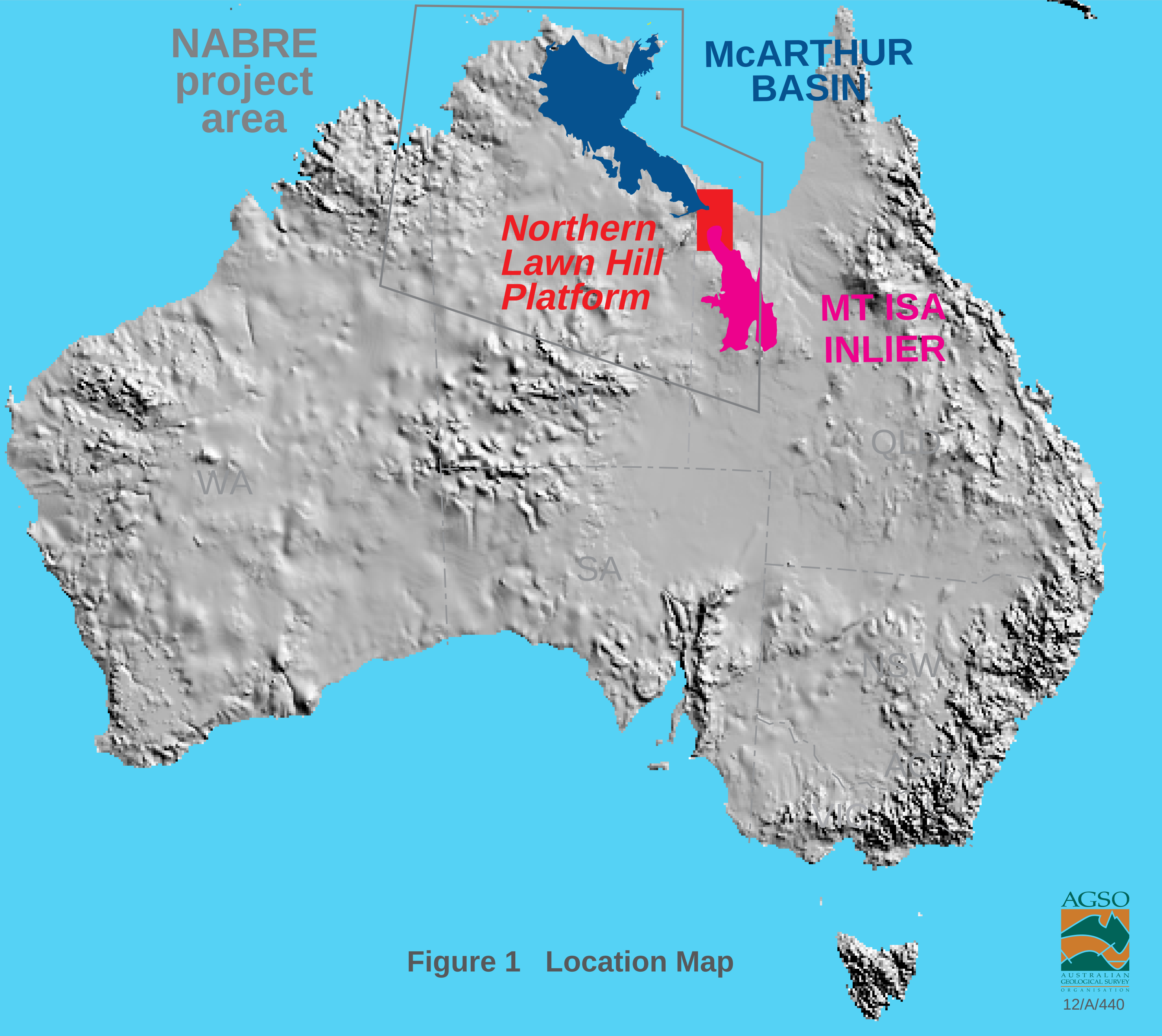

Figure 1 Location Map

SUPERSEQUENCES with location of DRILLHOLES and MEASURED SECTIONS

NABRE GIS data : AJRetter

AGSO AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

DEPARTMENT OF MINES AND ENERGY

NORTHERN TERRITORY DEPARTMENT OF MINES AND ENERGY

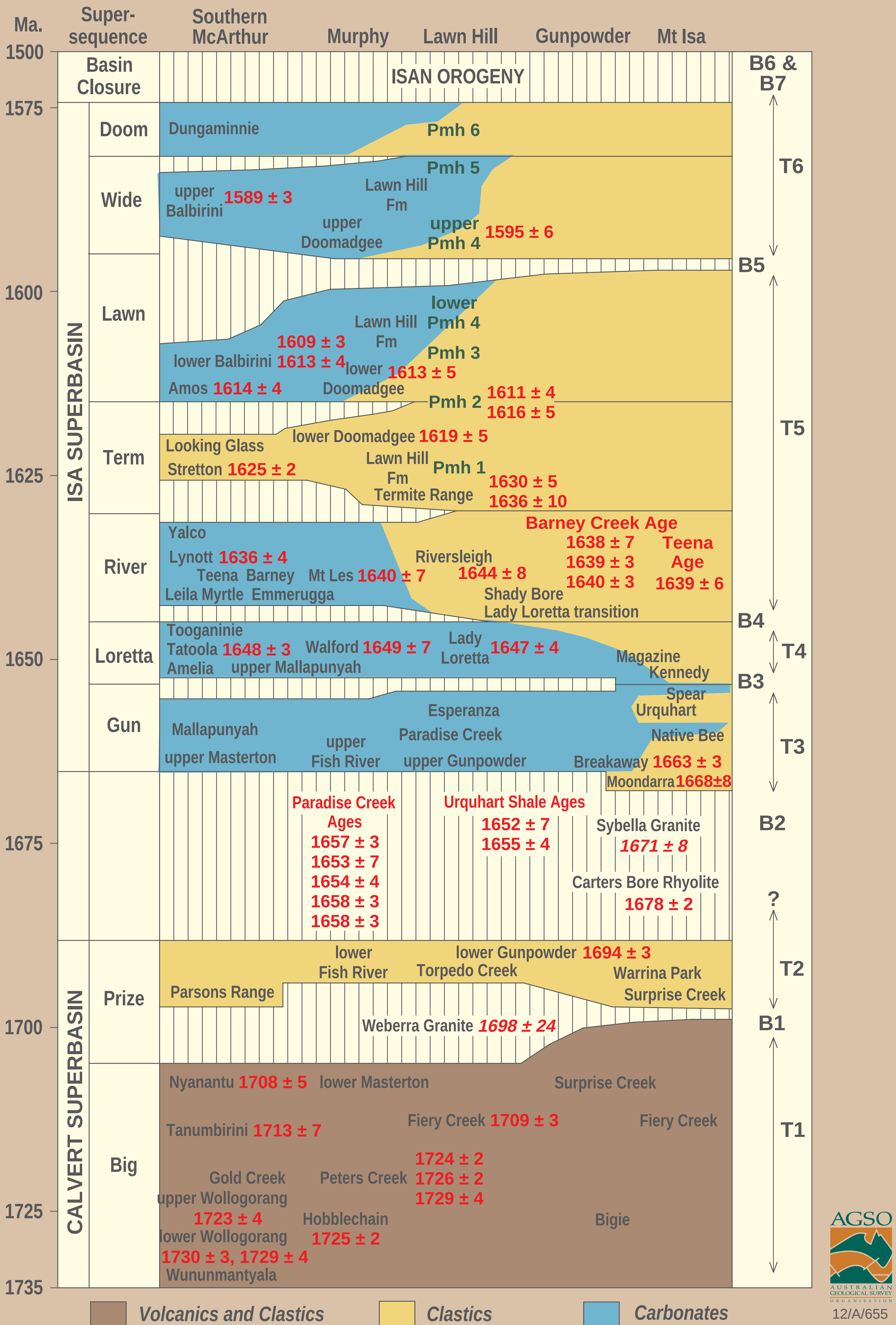

Figure 3 Basin Event Chart

Table 3 - GEOLOG FILES and POSTSCRIPT FILES FOR OUTCROP SECTIONS and DRILL HOLES

GROUP / Composite Section	Thick (m)	Files for viewing with Report AGSO 1999/10	Files for Plotting Report AGSO 1999/10		
Mt Isa		**1:1000 (or 1:2000)**	**1:400**	**1:1000**	**1:2000**
Oxide Creek	1470	Oxide Creek	No	Oxide Creek	Oxide Creek
Crystal Creek	1840	Crystal Creek	No	Crystal Creek	Crystal Creek
Paroo Range	1710	Paroo Range	No	Paroo Range	Paroo Range
Mt Isa	2230	Mt Isa	No	Mt Isa	Mt Isa
Leichhardt West	2680	Leichhardt West	No	Leichhardt West	Leichhardt West
Hilton	1325	Hilton	No	Hilton	Hilton
Moondarra 1	378	Moondarra 1 (1:2000)	Moondarra 1	No	Moondarra 1
Moondarra 2	332	Moondarra 2 (1:2000)	Moondarra 2	No	Moondarra 2
Moondarra 3	440	Moondarra 3	No	Moondarra 3	Moondarra 3
Moondarra 4	382	Moondarra 4 (1:2000)	Moondarra 4	No	Moondarra 4
Drill Hole H450	215	H 450	No	H 450	No
Drill Hole Quartzite 10	1370	Quartzite 10	No	Quartzite 10	No
Drill Hole UE 258	720	UE 258	No	UE 258	No
McNamara		**1:1000**	**1:400**	**1:1000**	**1:2000**
GSQ Lawn Hill 3&4	710	GSQ Lawn Hill 3&4	No	GSQ Lawn Hill 3&4	No
Kamarga Dome	1240	Kamarga Dome	No	Kamarga Dome	No
WC-1	440	WC-1	No	WC-1	No
Gregory River	630	Gregory River	No	Gregory River	No
Mellish Park	900	Mellish Park	Mellish Park	Mellish Park	No
Police Creek 2	1080	Police Creek 2	No	Police Creek 2	No
Paradise Creek West	850	Paradise Creek West	Paradise Creek West	Paradise Creek West	No
Paradise Creek East	530	Paradise Creek East	No	Paradise Creek East	No
Barr Hole	910	Barr Hole	Barr Hole	Barr Hole	No
Esperanza Waterhole	1180	Esperanza Waterhole	Esperanza Waterhole	Esperanza Waterhole	No
Mammoth Mines north	540	Mammoth Mines north	No	Mammoth Mines north	No
Mammoth Mines south	420	Mammoth Mines south	No	Mammoth Mines south	No
Crocodile Waterhole	410	Crocodile Waterhole	No	Crocodile Waterhole	No
Anaconda AAD1	840	Anaconda AAD1	No	Anaconda AAD1	No
Anaconda AASP	320	Anaconda AASP	No	Anaconda AASP	No
Judenan Creek	1190	Judenan Creek	No	Judenan Creek	No
Wilfred Creek	530	Wilfred Creek	No	Wilfred Creek	No
Wangunda Bore	1200	Wangunda Bore	Wangunda Bore	Wangunda Bore	No
Amoco 83-5	590	Amoco 83-5	No	Amoco 83-5	No
Thorntonia2	450	Thorntonia2	No	Thorntonia2	No
Freemans Creek NE	425	Freemans Creek NE	No	Freemans Creek NE	No
Fickling		**1:1000**	**1:400**	**1:1000**	**1:2000**
Wire Creek	765	Wire Creek	Wire Creek	Wire Creek	No

Section Number	Cross Sections
Cross Section #1	1:4000 Scale cross_section1_4000.ps GSQ Lawn Hill 3&4, Kamarga Dome, WC-1, Gregory River, Mellish Park, Police Creek 2, Paradise Creek west & east, Anaconda AASP, Anaconda AAD1, Judenan Creek, wilfred Creek
Cross Section #2	1:4000 Scale cross_section2_4000.ps GSQ Lawn Hill 3&4, Kamarga Dome, Gregory River, Mellish Park, Barr Hole, Oxide Creek
Cross Section #3	1:4000 Scale cross_section3_4000.ps Paradise Creek west & east, Esperanza Waterhole, Mammoth Mines north, Crystal Creek
Cross Section #4	1:4000 Scale cross_section4_4000.ps Mellish Park, Barr Hole, Esperanza Waters, Mammoth Mines north & south, Crocodile Waterhole, Paroo Range, Leichhardt West
Cross Section #5	1:5000 Scale cross_section5_5000.ps Anaconda AASP1, Anaconda AAD1,Judenan Creek, Wilfred Creek, Paroo Range, Moondarra 3, Mt Isa,
Cross Section #6	1:5000 Scale cross_section6_5000.ps Oxide Creek, Crystal Creek, Paroo Range, Moondarra 3, Hilton, MIM F968, MIM H450, MIM Quartzite 10, Leichhardt West

ID	UNIQUE_ID	LENGTH_(M)	ORIGNO	MEASURED_B	SECT_LOC	PROVNO.	PROVINCE	GROUPNO	GROUP	STRATNO	FORMATION	GEOL_100KM	LONG	LAT	EASTING	NORTHING	MAP_ZONE	BASE_TOP
1	95/AW/01	324.5	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6682	Fish River Formation	Hedleys Creek	138.1309	-17.78334	0195800	8031450	54	B
2	95/AW/01	324.5	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6682	Fish River Formation	Hedleys Creek	138.1402	-17.79296	0196800	8030400	54	-
3	95/AW/01	324.5	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6682	Fish River Formation	Hedleys Creek	138.1345	-17.79649	0196200	8030000	54	-
4	95/AW/01	324.5	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6682	Fish River Formation	Hedleys Creek	138.1345	-17.79784	0196200	8029850	54	-
5	95/AW/01	324.5	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6682	Fish River Formation	Hedleys Creek	138.1349	-17.79965	0196250	8029650	54	T
6	95/AW/02a	226.4	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6631	Walford Dolomite, Mount Les Siltstone	Hedleys Creek	138.1373	-17.79788	0196500	8029850	54	B
7	95/AW/02a	226.4	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6631	Walford Dolomite, Mount Les Siltstone	Hedleys Creek	138.1396	-17.80379	0196750	8029200	54	T
8	95/AW/02b	24.0	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	12886	Mount Les Siltstone	Hedleys Creek	138.1376	-17.80782	0196550	8028750	54	B
9	95/AW/02b	24.0	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	12886	Mount Les Siltstone	Hedleys Creek	138.1366	-17.81458	0196450	8028000	54	T
10	95/AW/03	124.6	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6631	Mount Les Siltstone, Doomadgee Formation	Hedleys Creek	138.1490	-17.80618	0197750	8028950	54	B
11	95/AW/03	124.6	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6631	Mount Les Siltstone, Doomadgee Formation	Hedleys Creek	138.1522	-17.81029	0198100	8028500	54	T
12	95/AW/04	130.8	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6631	Mount Les Siltstone, Doomadgee Formation	Hedleys Creek	138.1479	-17.81158	0197650	8028350	54	B
13	95/AW/04	130.8	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6631	Mount Les Siltstone, Doomadgee Formation	Hedleys Creek	138.1484	-17.81385	0197700	8028100	54	-
14	95/AW/04	130.8	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6631	Mount Les Siltstone, Doomadgee Formation	Hedleys Creek	138.1479	-17.81655	0197650	8027800	54	-
15	95/AW/04	130.8	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	6631	Mount Les Siltstone, Doomadgee Formation	Hedleys Creek	138.1502	-17.81658	0197900	8027800	54	T
16	95/AW/05	153.8	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	5619	Doomadgee Formation	Hedleys Creek	138.1420	-17.82956	0197050	8026350	54	B
17	95/AW/05	153.8	325	ATW	Wire Creek	54	Mount Isa Inlier	6631	Fickling Group	5619	Doomadgee Formation	Hedleys Creek	138.1470	-17.83730	0197600	8025500	54	T
18	95/AW/06	174.0	325	ATW	Triple T Creek	54	Mount Isa Inlier	6631	Fickling Group	6631	Peters Creek Volcanics, Fish River Formation	Hedleys Creek	138.2874	-17.78340	0212402	8031691	54	B
19	95/AW/06	174.0	325	ATW	Triple T Creek	54	Mount Isa Inlier	6631	Fickling Group	6631	Peters Creek Volcanics, Fish River Formation	Hedleys Creek	138.2783	-17.76526	0211402	8033685	54	T
20	95/AW/07	268.5	325	ATW	Esperanza Waterhole	54	Mount Isa Inlier	11575	McNamara Group	18438	Torpedo Creek Quartzite	Mammoth Mines	139.3304	-19.70180	0325000	7820650	54	B
21	95/AW/07	268.5	325	ATW	Esperanza Waterhole	54	Mount Isa Inlier	11575	McNamara Group	18438	Torpedo Creek Quartzite	Mammoth Mines	139.3351	-19.70184	0325500	7820650	54	T
22	95/AW/08	170.0	325	ATW	Esperanza Waterhole	54	Mount Isa Inlier	11575	McNamara Group	11575	Torpedo Creek Quartzite, Gunpowder Creek Formation	Mammoth Mines	139.3303	-19.70812	0325000	7819950	54	B
23	95/AW/08	170.0	325	ATW	Esperanza Waterhole	54	Mount Isa Inlier	11575	McNamara Group	11575	Torpedo Creek Quartzite, Gunpowder Creek Formation	Mammoth Mines	139.3341	-19.70770	0325400	7820000	54	T
24	95/AW/09	412.5	325	ATW	Crocodile Creek	54	Mount Isa Inlier	11575	McNamara Group	11575	Surprise Creek Formation, Torpedo Creek Quartzite, Gunpowder Creek Formation	Mammoth Mines	139.3298	-19.89196	0325150	7799600	54	B
25	95/AW/09	412.5	325	ATW	Crocodile Creek	54	Mount Isa Inlier	11575	McNamara Group	11575	Surprise Creek Formation, Torpedo Creek Quartzite, Gunpowder Creek Formation	Mammoth Mines	139.3355	-19.89427	0325750	7799350	54	T
26	95/AW/10	93.0	325	ATW	Crocodile Creek	54	Mount Isa Inlier	11575	McNamara Group	25038	Gunpowder Creek Formation	Mammoth Mines	139.3298	-19.88789	0325150	7800050	54	B
27	95/AW/10	93.0	325	ATW	Crocodile Creek	54	Mount Isa Inlier	11575	McNamara Group	25038	Gunpowder Creek Formation	Mammoth Mines	139.3341	-19.89019	0325600	7799800	54	T
28	95/AW/11	225.8	325	ATW	Barr Hole	54	Mount Isa Inlier	11575	McNamara Group	18438	Torpedo Creek Quartzite	Mammoth Mines	139.3495	-19.59763	0326900	7832200	54	B
29	95/AW/11	225.8	325	ATW	Barr Hole	54	Mount Isa Inlier	11575	McNamara Group	18438	Torpedo Creek Quartzite	Mammoth Mines	139.3515	-19.59765	0327100	7832200	54	T
30	95/AW/12	50.0	325	ATW	Barr Hole	54	Mount Isa Inlier	11575	McNamara Group	11575	Torpedo Creek Quartzite, Suprise Creek Formation	Mammoth Mines	139.3486	-19.59491	0326800	7832500	54	B
31	95/AW/12	50.0	325	ATW	Barr Hole	54	Mount Isa Inlier	11575	McNamara Group	11575	Torpedo Creek Quartzite, Suprise Creek Formation	Mammoth Mines	139.3505	-19.59493	0327000	7832500	54	T
32	95/BA/02a	22.5	324	BB & AK	Riversleigh	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8208	-19.12597	0270773	7883798	54	B
33	95/BA/02a	22.5	324	BB & AK	Riversleigh	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8169	-19.13026	0270360	7883318	54	T
34	95/BA/02b	166.5	324	BB & AK	Riversleigh	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8169	-19.13026	0270360	7883318	54	B
35	95/BA/02b	166.5	324	BB & AK	Riversleigh	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8196	-19.12858	0270642	7883507	54	T
36	95/BA/02c	73.5	324	BB & AK	Riversleigh	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8182	-19.12863	0270500	7883500	54	B
37	95/BA/02c	73.5	324	BB & AK	Riversleigh	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8142	-19.13102	0270080	7883230	54	T
38	95/BA/06a	52.5	324	BB & AK & JD	Mended Hill	54	Mount Isa Inlier	11575	McNamara Group	17975	Termite Range Formation	Lawn Hill Region	138.6175	-18.78149	0248862	7921661	54	B
39	95/BA/06a	52.5	324	BB & AK & JD	Mended Hill	54	Mount Isa Inlier	11575	McNamara Group	17975	Termite Range Formation	Lawn Hill Region	138.6157	-18.78084	0248665	7921730	54	T
40	95/BA/06b	201.0	324	BB & AK & JD	Mended Hill	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6162	-18.77802	0248713	7922043	54	B
41	95/BA/06b	201.0	324	BB & AK & JD	Mended Hill	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6113	-18.77907	0248200	7921920	54	T
42	95/BA/07	64.5	324	BB & AK & JD	Silver King	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.5859	-18.74668	0245470	7925470	54	B
43	95/BA/07	64.5	324	BB & AK & JD	Silver King	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.5868	-18.74718	0245565	7925416	54	T
44	95/BA/08	94.4	324	BB & AK & JD	Lawn Hill Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.5625	-18.60495	0242796	7941130	54	B
45	95/BA/08	94.4	324	BB & AK & JD	Lawn Hill Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.5639	-18.60316	0242940	7941330	54	T
46	95/BB/04a	38.0	324	BB & BMc	Termite Range South	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.7104	-18.90956	0258836	7907610	54	B
47	95/BB/04a	38.0	324	BB & BMc	Termite Range South	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.7083	-18.90963	0258620	7907600	54	T
48	95/BB/04b	117.0	324	BB & BMc	Termite Range South	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.7103	-18.91775	0258836	7906703	54	B
49	95/BB/04b	117.0	324	BB & BMc	Termite Range South	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.7071	-18.91819	0258500	7906650	54	-
50	95/BB/04b	117.0	324	BB & BMc	Termite Range South	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.7065	-18.91575	0258440	7906920	54	-
51	95/BB/04b	117.0	324	BB & BMc	Termite Range South	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.7043	-18.91590	0258200	7906900	54	-
52	95/BB/04b	117.0	324	BB & BMc	Termite Range South	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.7037	-18.91499	0258140	7907000	54	T
53	95/BB/04c	531.0	324	BB & BMc	Termite Range South	54	Mount Isa Inlier	11575	McNamara Group	11575	Riversleigh Siltstone, Termite Range Formation	Lawn Hill Region	138.7108	-18.92230	0258900	7906200	54	B
54	95/BB/04c	531.0	324	BB & BMc	Termite Range South	54	Mount Isa Inlier	11575	McNamara Group	11575	Riversleigh Siltstone, Termite Range Formation	Lawn Hill Region	138.7005	-18.91495	0257800	7907000	54	T
55	95/BB/05a	540.5	324	BB & BMc	Mt Caroline	54	Mount Isa Inlier	11575	McNamara Group	11575	Lady Loretta Formation, Shady Bore Quartzite	Lawn Hill Region	138.6769	-18.45451	0254653	7957946	54	B
56	95/BB/05ar	33.0	324	BB & BMc	Mt Caroline	54	Mount Isa Inlier	11575	McNamara Group	11575	Lady Loretta Formation, Shady Bore Quartzite	Lawn Hill Region	138.6737	-18.45434	0254320	7957960	54	B
57	95/BB/05a	540.5	324	BB & BMc	Mt Caroline	54	Mount Isa Inlier	11575	McNamara Group	11575	Lady Loretta Formation, Shady Bore Quartzite	Lawn Hill Region	138.6702	-18.45722	0253944	7957637	54	-
58	95/BB/05a	540.5	324	BB & BMc	Mt Caroline	54	Mount Isa Inlier	11575	McNamara Group	11575	Lady Loretta Formation, Shady Bore Quartzite	Lawn Hill Region	138.6679	-18.45572	0253700	7957800	54	T
59	95/BB/05b	164.0	324	BB & BMc	Mt Caroline	54	Mount Isa Inlier	11575	McNamara Group	17975	Termite Range Formation	Lawn Hill Region	138.6639	-18.45901	0253282	7957430	54	B
60	95/BB/05b	164.0	324	BB & BMc	Mt Caroline	54	Mount Isa Inlier	11575	McNamara Group	17975	Termite Range Formation	Lawn Hill Region	138.6617	-18.45880	0253050	7957450	54	T
61	95/BB/05c	149.0	324	BB & BMc	Mt Caroline	54	Mount Isa Inlier	11575	McNamara Group	17975	Termite Range Formation	Lawn Hill Region	138.6613	-18.45924	0253010	7957401	54	B
62	95/BB/05c	149.0	324	BB & BMc	Mt Caroline	54	Mount Isa Inlier	11575	McNamara Group	17975	Termite Range Formation	Lawn Hill Region	138.6589	-18.45696	0252750	7957650	54	T
63	95/BB/05d	160.0	324	BB & BMc	Mt Caroline	54	Mount Isa Inlier	11575	McNamara Group	17975	Termite Range Formation	Lawn Hill Region	138.6587	-18.45575	0252734	7957784	54	B
64	95/BB/05d	160.0	324	BB & BMc	Mt Caroline	54	Mount Isa Inlier	11575	McNamara Group	17975	Termite Range Formation	Lawn Hill Region	138.6570	-18.45558	0252550	7957800	54	T
65	95/BB/09c	235.5	324	BB & BMc	Upper Lawn Hill Formation	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6336	-18.90246	0250730	7908290	54	B
66	95/BB/09c	235.5	324	BB & BMc	Upper Lawn Hill Formation	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6300	-18.90530	0250360	7907970	54	T
67	95/BB/10	138.0	324	BB & BMc	Mid Lawn Hill Formation	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.5452	-18.57564	0240920	7944350	54	B
68	95/BB/10	138.0	324	BB & BMc	Mid Lawn Hill Formation	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.5470	-18.57007	0241100	7944970	54	T
69	95/BD/09a	149.0	324	BB & JD	Upper Lawn Hill Formation	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6340	-18.92663	0250812	7905614	54	B
70	95/BD/09a	149.0	324	BB & JD	Upper Lawn Hill Formation	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6330	-18.92490	250700	7905800	54	T
71	95/BD/09b	67.5	324	BB & JD	Upper Lawn Hill Formation	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6345	-18.92278	0250859	7906041	54	B
72	95/BD/09b	67.5	324	BB & JD	Upper Lawn Hill Formation	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6330	-18.92220	250700	7906100	54	T
73	95/DS/01	76.5	316	DS	Redie Creek	54	Mount Isa Inlier	11575	McNamara Group	11575	Shady Bore Quartzite, Gunpowder Creek Formation	Mammoth Mines	139.2790	-19.82092	0319750	7807410	54	B
74	95/DS/01	76.5	316	DS	Redie Creek	54	Mount Isa Inlier	11575	McNamara Group	11575	Shady Bore Quartzite, Gunpowder Creek Formation	Mammoth Mines	139.2795	-19.82056	0319800	7807450	54	T
75	95/JJ/02a	306.0	207	JJ & PS	Esperanza Waterhole	54	Mount Isa Inlier	11575	McNamara Group	25038	Gunpowder Creek Formation	Mammoth Mines	139.3331	-19.71113	0325300	7819620	54	B
76	95/JJ/02a	306.0	207	JJ & PS	Esperanza Waterhole	54	Mount Isa Inlier	11575	McNamara Group	25038	Gunpowder Creek Formation	Mammoth Mines	139.3360	-19.71134	0325600	7819600	54	T
77	95/JJ/02b	346.5	207	JJ & PS	Esperanza Waterhole	54	Mount Isa Inlier	11575	McNamara Group	14857	Paradise Creek Formation	Mammoth Mines	139.3370	-19.70954	0325700	7819800	54	B
78	95/JJ/02b	346.5	207	JJ & PS	Esperanza Waterhole	54	Mount Isa Inlier	11575	McNamara Group	14857	Paradise Creek Formation	Mammoth Mines	139.3398	-19.70776	0326000	7820000	54	T
79	95/JJ/02c	220.5	207	JJ & PS	Esperanza Waterhole	54	Mount Isa Inlier	11575	McNamara Group	6282	Esperanza Formation	Mammoth Mines	139.3409	-19.70732	0326110	7820050	54	B
80	95/JJ/02c	220.5	207	JJ & PS	Esperanza Waterhole	54	Mount Isa Inlier	11575	McNamara Group	6282	Esperanza Formation	Mammoth Mines	139.3427	-19.70598	0326300	7820200	54	T
81	95/JJ/03	114.0	207	JJ & PS	North's Camp	54	Mount Isa Inlier	11575	McNamara Group	16787	Shady Bore Quartzite	Lawn Hill Region	138.8293	-18.79000	0271200	7921000	54	B
82	95/JJ/03	114.0	207	JJ & PS	North's Camp	54	Mount Isa Inlier	11575	McNamara Group	16787	Shady Bore Quartzite	Lawn Hill Region	138.8288	-18.79180	0271150	7920800	54	T
83	95/JJ/04	137.5	207	JJ & PS	Kamarga Dome	54	Mount Isa Inlier	11575	McNamara Group	11575	Torpedo Creek Formation, Gunpowder Creek Formation	Lawn Hill Region	138.8584	-18.81300	0274300	7918500	54	B
84	95/JJ/04	137.5	207	JJ & PS	Kamarga Dome	54	Mount Isa Inlier	11575	McNamara Group	11575	Torpedo Creek Formation, Gunpowder Creek Formation	Lawn Hill Region	138.8575	-18.81020	0274200	7918800	54	T
85	95/PS/01a	554.5	106	PS & AK	Barr Hole	54	Mount Isa Inlier	11575	McNamara Group	11575	Torpedo Creek Formation, Gunpowder Creek Formation, Paradise creek Formation	Mammoth Mines	139.3509	-19.59421	0327040	7832580	54	B
86	95/PS/01a	554.5	106	PS & AK	Barr Hole	54	Mount Isa Inlier	11575	McNamara Group	11575	Torpedo Creek Formation, Gunpowder Creek Formation, Paradise creek Formation	Mammoth Mines	139.3528	-19.59594	0327240	7832390	54	-
87	95/PS/01a	554.5	106	PS & AK	Barr Hole	54	Mount Isa Inlier	11575	McNamara Group	11575	Torpedo Creek Formation, Gunpowder Creek Formation, Paradise creek Formation	Mammoth Mines	139.3524	-19.59657	0327200	7832320	54	-
88	95/PS/01a	554.5	106	PS & AK	Barr Hole	54	Mount Isa Inlier	11575	McNamara Group	11575	Torpedo Creek Formation, Gunpowder Creek Formation, Paradise creek Formation	Mammoth Mines	139.3532	-19.59748	0327280	7832220	54	T
89	95/PS/01b	61.5	106	PS & AK	Barr Hole	54	Mount Isa Inlier	11575	McNamara Group	14857	Paradise Creek Formation	Mammoth Mines	139.3519	-19.59865	0327150	7832090	54	B
90	95/PS/01b	61.5	106	PS & AK	Barr Hole	54	Mount Isa Inlier	11575	McNamara Group	14857	Paradise Creek Formation	Mammoth Mines	139.3530	-19.59929	0327260	7832020	54	-
91	95/PS/01b	61.5	106	PS & AK	Barr Hole	54	Mount Isa Inlier	11575	McNamara Group	14857	Paradise Creek Formation	Mammoth Mines	139.3539	-19.59966	0327360	7831980	54	-
92	95/PS/01b	61.5	106	PS & AK	Barr Hole	54	Mount Isa Inlier	11575	McNamara Group	14857	Paradise Creek Formation	Mammoth Mines	139.3585	-19.60440	327840	7831900	54	T
93	95/PS/05	310.8	106	PS & JJ	Mellish Park	54	Mount Isa Inlier	11575	McNamara Group	11575	Torpedo Creek Formation, Gunpowder Creek Formation, Paradise Creek Formation	Mount Oxide Region	139.2313	-19.06802	0313900	7890700	54	B
94	95/PS/05	310.8	106	PS & JJ	Mellish Park	54	Mount Isa Inlier	11575	McNamara Group	11575	Torpedo Creek Formation, Gunpowder Creek Formation, Paradise Creek Formation	Mount Oxide Region	139.2257	-19.06345	0313300	7891200	54	T
95	95/PS/06	147.0	207	PS&JJ	Tick / Fly camp	52	McArthur Basin	11512	McArthur Group	25760	Amelia Dolomite	Kilgour	135.9210	-17.06610	598000	8112900	53	B
96	95/PS/06	147.0	207	PS&JJ	Tick / Fly camp	53	McArthur Basin	11512	McArthur Group	25761	Amelia Dolomite	Kilgour	135.9247	-17.05340	598400	8114300	53	T
97	95/PS/07	330.0	207	PS&JJ	Tick / Fly camp	54	McArthur Basin	11512	McArthur Group	11512	Tatoola Sandstone, Tooganinie Formation, Amelia Dolomite	Kilgour	135.9265	-17.04795	598600	8114900	53	B
98	95/PS/07	330.0	207	PS&JJ	Tick / Fly camp	55	McArthur Basin	11512	McArthur Group	11512	Tatoola Sandstone, Tooganinie Formation, Amelia Dolomite	Kilgour	135.9396	-17.04247	600000	8115500	53	T
99	95/BM/Redie ck	217.5	310	BMc	Redie Creek	54	Mount Isa Inlier	11575	McNamara Group	10002	Lady Loretta Formation	Mammoth Mines	139.2748	-19.82608	0319320	7806834	54	B
100	95/BM/Redie ck	217.5	310	BMc	Redie Creek	54	Mount Isa Inlier	11575	McNamara Group	10002	Lady Loretta Formation	Mammoth Mines	139.2733	-19.82646	0319160	7806790	54	-
101	95/BM/Redie ck	217.5	310	BMc	Redie Creek	54	Mount Isa Inlier	11575	McNamara Group	10002	Lady Loretta Formation	Mammoth Mines	139.2765	-19.82686	0319500	7806750	54	-
102	95/BM/Redie ck	217.5	310	BMc	Redie Creek	54	Mount Isa Inlier	11575	McNamara Group	10002	Lady Loretta Formation	Mammoth Mines	139.2780	-19.82525	0319650	7806930	54	-
103	95/BM/Redie ck	217.5	310	BMc	Redie Creek	54	Mount Isa Inlier	11575	McNamara Group	10002	Lady Loretta Formation	Mammoth Mines	139.2790	-19.82525	0319753	7806930	54	-
104	95/BM/Redie ck	217.5	310	BMc	Redie Creek	54	Mount Isa Inlier	11575	McNamara Group	10002	Lady Loretta Formation	Mammoth Mines	139.2780	-19.82452	0319650	7807010	54	-
105	95/BM/Redie ck	217.5	310	BMc	Redie Creek	54	Mount Isa Inlier	11575	McNamara Group	10002	Lady Loretta Formation	Mammoth Mines	139.2790	-19.82417	0319750	7807050	54	T
106	96/AW/13	200.5	325	ATW	Hedleys Creek	54	Mount Isa Inlier	6631	Fickling Group?	6631	Fish River Formation, Walford Dolomite?	Hedleys Creek	138.1943	-17.78883	0202529	8030944	54	B
107	96/AW/13	200.5	325	ATW	Hedleys Creek	54	Mount Isa Inlier	6631	Fickling Group?	6631	Fish River Formation, Walford Dolomite?	Hedleys Creek	138.1936	-17.78033	0202444	8031884	54	T
108	96/AW/14	188.5	325	ATW	Rocky Creek	54	Mount Isa Inlier	6631	Fickling Group?	6631	Fish River Formation, Walford Dolomite?	Hedleys Creek	138.2550	-17.77778	0208954	8032263	54	B
109	96/AW/14	188.5	325	ATW	Rocky Creek	54	Mount Isa Inlier	6631	Fickling Group?	6631	Fish River Formation, Walford Dolomite?	Hedleys Creek	138.2466	-17.77028	0208048	8033081	54	T
110	96/AW/15	45.0	325	ATW	Rocky Creek South	54	Mount Isa Inlier	6631	Fickling Group?	6631	Fish River Formation, Walford Dolomite?	Hedleys Creek	138.2525	-17.77949	0208695	8032070	54	B
111	96/AW/15	45.0	325	ATW	Rocky Creek South	54	Mount Isa Inlier	6631	Fickling Group?	6631	Fish River Formation, Walford Dolomite?	Hedleys Creek	138.2554	-17.77959	0209003	8032063	54	T
112	96/AW/16	334.5	325	ATW	Gorge Creek	54	Mount Isa Inlier	6631	Fickling Group?	6631	Fish River Formation, Walford Dolomite?	Hedleys Creek	138.0274	-17.82611	0184891	8026542	54	B
113	96/AW/16	334.5	325	ATW	Gorge Creek	54	Mount Isa Inlier	6631	Fickling Group?	6631	Fish River Formation, Walford Dolomite?	Hedleys Creek	138.0385	-17.83748	0186090	8025302	54	T
114	96/AK/16	99.0	195	AK	Mt Caroline Centre South	54	Mount Isa Inlier	11575	McNamara Group	11575	Termite Range Formation, Lawn Hill Formation	Lawn Hill Region	138.7354	-18.44455	0260822	7959127	54	B
115	96/AK/16	99.0	195	AK	Mt Caroline Centre South	54	Mount Isa Inlier	11575	McNamara Group	11575	Termite Range Formation, Lawn Hill Formation	Lawn Hill Region	138.7351	-18.44559	0260793	7959012	54	T
116	96/AK/17	148.5	195	AK	Mt Caroline Centre South	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.7344	-18.44580	0260717	7958987	54	B
117	96/AK/17	148.5	195	AK	Mt Caroline Centre South	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.7351	-18.44699	0260790	7958857	54	T
118	96/AK/18	133.5	195	AK	Mt Caroline Centre South	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.7330	-18.44769	0260568	7958776	54	B
119	96/AK/18	133.5	195	AK	Mt Caroline Centre South	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.7334	-18.44861	0260613	7958675	54	T
120	96/AK/19	115.5	195	AK	Mt Caroline Centre South	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.7328	-18.44877	0260555	7958656	54	B
121	96/AK/19	115.5	195	AK	Mt Caroline Centre South	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.7340	-18.44968	0260684	7958557	54	T
122	96/AK/20	169.5	195	AK	Mt Caroline Centre South	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.7335	-18.44980	0260628	7958543	54	B
123	96/AK/20	169.5	195	AK	Mt Caroline Centre South	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.7341	-18.45125	0260693	7958383	54	T
124	96/AK/21	60.0	195	AK	Mt Caroline South West	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6704	-18.48963	0254012	7954049	54	B
125	96/AK/21	60.0	195	AK	Mt Caroline South West	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6707	-18.48936	0254047	7954079	54	T
126	96/AK/22	141.0	195	AK	Mt Caroline South West	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6687	-18.49438	0253845	7953521	54	B
127	96/AK/22	141.0	195	AK	Mt Caroline South West	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6698	-18.49546	0253957	7953402	54	T
128	96/AK/23	135.0	195	AK	Jenny Creek North	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6733	-18.49735	0254337	7953198	54	B
129	96/AK/23	135.0	195	AK	Jenny Creek North	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6767	-18.49927	0254694	7952990	54	T
130	96/AK/24	45.0	195	AK	12 Mile Tank North	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6861	-18.49421	0255682	7953563	54	B
131	96/AK/24	45.0	195	AK	12 Mile Tank North	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6862	-18.49563	0255694	7953406	54	T
132	96/AK/25	285.0	195	AK	Landing Ground North	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6604	-18.53617	0253028	7948882	54	B
133	96/AK/25	285.0	195	AK	Landing Ground North	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.6622	-18.54031	0253222	7948427	54	T
134	96/AK/26	136.5	195	AK	North Edith Ranges	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Constance Range Region	138.4908	-18.46786	0235007	7956205	54	B
135	96/AK/26	136.5	195	AK	North Edith Ranges	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Constance Range Region	138.4914	-18.46893	0235071	7956087	54	T
136	96/AK/27A	60.0	195	AK	Difficult Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.5128	-18.51417	0237406	7951110	54	B
137	96/AK/27A	60.0	195	AK	Difficult Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.5108	-18.51461	0237190	7951058	54	T
138	96/AK/27B	33.0	195	AK	Road Crossing Widallion Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.5099	-18.51304	0237100	7951230	54	B
139	96/AK/27B	33.0	195	AK	Road Crossing Widallion Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.5097	-18.51385	0237082	7951141	54	T
140	96/AK/28	300.0	195	AK	Gorge Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Constance Range Region	138.4883	-18.55602	0234886	7946440	54	B
141	96/AK/28	300.0	195	AK	Gorge Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Constance Range Region	138.4818	-18.56092	0234203	7945887	54	T
142	96/AK/29	54.0	195	AK	Gorge Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Constance Range Region	138.4884	-18.56051	0234897	7945943	54	B
143	96/AK/29	54.0	195	AK	Gorge Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Constance Range Region	138.4878	-18.56056	0234837	7945936	54	T

144	96/AK/30	169.5	195	AK	Gorge Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Constance Range Region	138.4818	-18.56092	0234203	7945887	54	B
145	96/AK/30	169.5	195	AK	Gorge Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Constance Range Region	138.4795	-18.56076	0233964	7945902	54	T
146	96/AK/31	355.5	195	AK	Widdallion Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.5016	-18.57922	0236320	7943890	54	B
147	96/AK/31	355.5	195	AK	Widdallion Creek	54	Mount Isa Inlier	11575	McNamara Group	10261	Lawn Hill Formation	Lawn Hill Region	138.4980	-18.58127	0235943	7943658	54	T
148	96/BA/01	192.0	324	BB & AK	Sweat Bee Valley	54	Mount Isa Inlier	11575	McNamara Group	24472	Shady Bore Quartzite, Riversleigh siltstone	Lawn Hill Region	138.8119	-19.07567	0269766	7889355	54	B
149	96/BA/01	192.0	324	BB & AK	Sweat Bee Valley	54	Mount Isa Inlier	11575	McNamara Group	24472	Shady Bore Quartzite, Riversleigh siltstone	Lawn Hill Region	138.8103	-19.07872	0269595	7889015	54	T
150	96/BA/02	238.0	324	BB & AK	Sweat Bee Valley	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8115	-19.07975	0269726	7888903	54	B
151	96/BA/02	238.0	324	BB & AK	Sweat Bee Valley	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8094	-19.08234	0269505	7888613	54	T
152	96/BA/03	348.0	324	BB & AK	Sweat Bee Valley	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8118	-19.08131	0269761	7888731	54	B
153	96/BA/03	348.0	324	BB & AK	Sweat Bee Valley	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8087	-19.08627	0269439	7888178	54	T
154	96/BA/04	123.0	324	BB & AK	Sweat Bee Valley	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8098	-19.08655	0269560	7888148	54	B
155	96/BA/04	123.0	324	BB & AK	Sweat Bee Valley	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8090	-19.08828	0269470	7887955	54	T
156	96/BA/05	450.0	324	BB & AK	Shady Bore Dome	54	Mount Isa Inlier	11575	McNamara Group	11575	Shady Bore Quartzite, Riversleigh siltstone	Lawn Hill Region	138.8316	-19.12955	0271910	7883416	54	B
157	96/BA/05	450.0	324	BB & AK	Shady Bore Dome	54	Mount Isa Inlier	11575	McNamara Group	11575	Shady Bore Quartzite, Riversleigh siltstone	Lawn Hill Region	138.8242	-19.13582	0271141	7882712	54	T
158	96/BA/06	87.0	324	BB & AK	Boulder Roll Valley	54	Mount Isa Inlier	11575	McNamara Group	16787	Shady Bore Quartzite	Lawn Hill Region	138.8310	-19.13380	0271856	7882945	54	B
159	96/BA/06	87.0	324	BB & AK	Boulder Roll Valley	54	Mount Isa Inlier	11575	McNamara Group	16787	Shady Bore Quartzite	Lawn Hill Region	138.8315	-19.13350	0271905	7882978	54	T
160	96/BA/07	85.5	324	BB & AK	Victor Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8316	-19.13669	0271916	7882625	54	B
161	96/BA/07	85.5	324	BB & AK	Victor Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8332	-19.13786	0272088	7882498	54	T
162	96/BA/08	229.5	324	BB & AK	Victor Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8290	-19.14057	0271649	7882192	54	B
163	96/BA/08	229.5	324	BB & AK	Victor Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8285	-19.14168	0271595	7882069	54	T
164	96/BA/09	385.0	324	BB & AK	Victor Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8241	-19.13946	0271137	7882309	54	B
165	96/BA/09	385.0	324	BB & AK	Victor Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8176	-19.14220	0270452	7881997	54	T
166	96/BA/10	202.5	324	BB & AK	Victor Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8189	-19.14466	0270595	7881726	54	B
167	96/BA/10	202.5	324	BB & AK	Victor Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8160	-19.14455	0270286	7881735	54	T
168	96/BA/11	312.0	324	BB & AK	Victor Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8159	-19.14703	0270285	7881460	54	B
169	96/BA/11	312.0	324	BB & AK	Victor Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8114	-19.14795	0269806	7881352	54	T
170	96/BA/12	220.5	324	BB & AK	Dead Horse Gully	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8196	-19.12858	0270642	7883507	54	B
171	96/BA/12	220.5	324	BB & AK	Dead Horse Gully	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8152	-19.13087	0270185	7883248	54	T
172	96/BA/13	36.0	324	BB & AK	Shady Bore Dome	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8237	-19.13300	0271078	7883024	54	B
173	96/BA/13	36.0	324	BB & AK	Shady Bore Dome	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8242	-19.13384	0271138	7882931	54	T
174	96/BA/14	250.5	324	BB & AK	The Knobs	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8235	-19.13034	0271062	7883318	54	B
175	96/BA/14	250.5	324	BB & AK	The Knobs	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.8215	-19.13508	0270849	7882790	54	T
176	96/BA/15	1428.0	195	BB & AK & JJ	Freemans Creek	54	Mount Isa Inlier	11575	McNamara Group	11575	Lady Loretta Formation, Riversleigh Siltstone, Shady Bore Quartzite	Lawn Hill Region	138.8108	-18.93790	0269459	7904607	54	B
177	96/BA/15	1428.0	195	BB & AK & JJ	Freemans Creek	54	Mount Isa Inlier	11575	McNamara Group	11575	Lady Loretta Formation, Riversleigh Siltstone, Shady Bore Quartzite	Lawn Hill Region	138.8270	-18.94040	0271170	7904351	54	T
178	96/BJ/01	380.8	324	BB & JD	Little Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.7285	-18.94496	0260798	7903715	54	B
179	96/BJ/01	380.8	324	BB & JD	Little Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.7258	-18.94629	0260510	7903565	54	T
180	96/BJ/02	552.0	324	BB & JD	North Little Creek	54	Mount Isa Inlier	11575	McNamara Group	24472	Riversleigh Siltstone	Lawn Hill Region	138.7257	-18.94236	0260500	7904000	54	B

dh_id	dh_company	nfid enti	year	tot_metres	core_size	av_azimuth	dip	core_a v_dip	core_from	core_to	easting	northing	lat_agd66	long_agd66	loc_method	on	100k_map	group	stratno	formation	member	event surface	accom_package
Amoco DDH 82/4	Amoco	n	1982	541.00							513000	8286700	-15.49694	135.12121		53	Towns	Nathan Group	26072	Balbirini Dolomite,Smythe Sandstone, Mallapunyah Formation			
Amoco DDH 82/5	Amoco	n	1982	455.50							603700	8206200	-16.22251	135.97027		53	Batten	McArthur Group	10891	Lynott Formation			
Amoco DDH 82/6	Amoco	n	1982	301.10							631900	8151700	-16.71370	136.23721		53	Glyde	McArthur Group	11512	Lynott Formation, Stretton Sandstone, Yalco Formation, Looking Glass Formation			
Amoco DDH 82/7	Amoco	n	1982	498.60							606400	8144500	-16.78007	135.99839		53	Mallapunyah	McArthur Group	11512	Lynott Formation, Stretton Sandstone, Yalco Formation, Looking Glass Formation			
Amoco DDH 83/1	Amoco	n	1983	655.00	HQ, NQ						257200	7913000	-18.86070	138.69550		54	Lawn Hill Region	McNamara Group	11512	Termite Range Formation, Riversleigh Siltstone			
Amoco DDH 83/2	Amoco	n	1983	550.00	HQ, NQ						239800	7928100	-18.72220	138.53250		54	Lawn Hill Region	McNamara Group	11512	Lawn Hill Formation, Termite Range Formation			
Amoco DDH 83/3	Amoco	n	1984	547.20	HQ, NQ						214301	7971607	-18.32618	138.29703		55	Lawn Hill Region						
Amoco DDH 83/4	Amoco	n	1983	597.60	HQ, NQ						199100	8025700	-17.83570	138.16122	7	54	Westmoreland	Fickling Group	6631	Walford Dolomite, Mount Les Siltstone, Doomadgee Formation		E,F	4, 5, 7
Amoco DDH 83/5	Amoco	n	1983	582.20	HQ, NQ						269800	7898900	-18.98948	138.81339		54	Lawn Hill Region	McNamara Group	11512	Lady Loretta Formation			
AADI 1	Anaconda	n	1976	845.00	HQ, NQ, BQ						309300	7798200	-19.90312	139.17831	co-report map	54	Mammoth Mines	McNamara Group	11512	Paradise Creek Formation, Gunpowder Creek Formation			
AARC 1	Anaconda	n	1976	900.00	NQ, BQ						315400	7803400	-19.85670	139.23710	co-report map	54	Mammoth Mines	McNamara Group	11512				
AASP 1	Anaconda	n	1976	328.50	BQ						302100	7800900	-19.87800	139.10980	co-report map	54	Mammoth Mines	McNamara Group	11512	Paradise Creek Formation, Gunpowder Creek Formation			
Amelia 33	MIM	y	1992	249.00	HQ						623600	8159400	-16.64460	136.15890		53	Glyde						
Amelia Basin 2	AO (AUST) Pty Ltd	y	1978								621137	8162610	-16.61570	136.13570	8	53	Glyde	McArthur Group	1130	Barney Creek Formation			
Amelia Basin 4	MIM	y		258.00	NQ						621700	8160100	-16.63830	136.14110	8	53	Glyde	McArthur Group	1130	Teena Dolomite, Barney Creek Formation, Reward Dolomite, Lynott Formation			
Amelia Basin 5	MIM	y		240.50	NQ						622100	8157820	-16.65890	136.14500	8	53	Glyde	McArthur Group	1130	Barney Creek Formation, Reward Dolomite, Lynott Formation			
Amelia Basin 6	MIM	y		334.00	NQ, BQ						620340	8158500	-16.65290	136.12840	8	53	Glyde	McArthur Group	1130	Barney Creek Formation, Reward Dolomite, Lynott Formation			
Argyle Creek 1	Comalco	n	1992	1680.10	R/C						224289	8010819	-17.97338	138.39671	7	54	Hedleys Creek	Fickling Group, South Nicholson Group	6631, 17123	Walford Dolomite, Mount Les Siltstone, Doomadgee Formation, Constance Sandstone		D, E, F, G, H	4, 5, 6, 7, 8,
Barney Creek 3	MIM	y	1977	352.70	NQ, BQ						615996	8182612	-16.43520	136.08650	8	53	Borroloola			Barney Creek Formation, Reward Dolomite, Lynott Formation			
BCK3	MIM	n	1976	353.00							603453	8174680	-16.50740	135.96940		53	Mallapunyah						
BMR Bauhinia Downs 3	BMR	n	1979	153.50	HQ						586800	8160400	-16.63720	135.81390	16	53	Mallapunyah	Nathan Group	923	uppermost Balbirini Dolomite			
BMR Bauhinia Downs 4	BMR	n	1979	36.50	HQ						605500	8145700	-16.76930	135.98990	16	53	Mallapunyah	Nathan Group	923	Balbirini Dolomite			
BBKD 1	WMC	y		472.30							320250	7940590	-18.61790	139.29620		54	Lawn Hill Region	McNamara Group	25038	Gunpowder Creek Formation			
BCC1DQ5869	MIM	y									309889	7811034	-19.78725	139.18525		54	Mammoth Mines	McNamara Group	10002	Lady Loretta Formation			
Beamesbrook 1	Comalco	n	1988	1394.00	R/C						333700	8014950	-17.94717	139.42973	7	54	Westmoreland	Fickling Group,Rolling Downs Group, Eulo Queen Group	6631, 16267, 6356	Doomadgee Formation, Normanton Formation, Allaru Mudstone, Toolebuc Formation, Wallumbilla Formation, Gilbert River Formation		H, I	7, 8, 9
Bing Bong 2	AO (AUST) Pty Ltd	n		442.90	NQ, BQ						603700	8253900	-15.79130	135.96820	16	53	Bing Bong	McArthur Group	11512	upper Teena Dolomite, Barney Creek Formation, Reward Dolomite, lower Lynott Formation	Coxco Dolomite Member		
CA 4	Aberfoyle	y	1983	733.00	NQ						614433	8198303	-16.29340	136.07110		53	Borroloola						5
DD95CC008	Rio Tinto	y	1995	302.90	NQ	135	60	80	83.50	302.90	253719	7920698	-18.79080	138.66350	8	54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
DD95CC009	Rio Tinto	y	1995	180.80	NQ	155	60	65	83.50	180.80	253035	7921294	-18.78530	138.65710	8	54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			
CEC10	CEC	n	1970	359.60							184570	8022000	-17.86710	138.02370	8	54	Westmoreland	Fickling Group	6631	Walford Dolomite, Mt Les Siltstone		E	4, 5
DD90LH055	CRA, Century	y	1990	394.00	HQ, NQ		90	80	0.00	394.00	247451	7930453	-18.70190	138.60530	8	54	Lawn Hill Region	McNamara Group	11575	Termite Range Formation, Thorntonia Limestone			6
DD90LH065	CRA, Century	y	1990	384.00	HQ	5	90	40	137.00	384.50	246592	7928559	-18.71890	138.59690	8	54	Lawn Hill Region	McNamara Group	11575	Lawn Hill Formation, Thorntonia Limestone			7
DD91LH210	CRA, Century	y	1991	127.00	HQ		90	70	0.00	127.00	250350	7905350	-18.92900	138.62960	22	54	Lawn Hill Region	McNamara Group	10261	Lawn Hill Formation			8
DD91LH265	CRA, Century	y	1991	589.00	HQ			50	96.60	577.50	245200	7913250	-18.85700	138.58700	8	54	Lawn Hill Region	McNamara Group	10261	Lawn Hill Formation		H	8
DD92LH376	CRA, Century	y	1992	228.00	HQ		90	70	30.00	228.00	249078	7925653	-18.74547	138.62010	8	54	Lawn Hill Region	McNamara Group	10261	Lawn Hill Formation			7
DD94LH532	CRA, Century	y	1994	279.00	HQ	360	60	40	138.30	279.00	248582	7926433	-18.73836	138.61550	8	54	Lawn Hill Region	McNamara Group	10261	Lawn Hill Formation			7
Desert Creek 1	Comalco	n	1992	2352.00	R/C						255108	8009036	-17.99317	138.68731	7	54	Westmoreland	Fickling Group, Rolling Downs Group	6631, 16267	Walford Dolomite, Mount Les Siltstone, Doomadgee Formation		E, F, G, H, I	4, 5, 6, 7, 8, 9
Egilabria 1	Comalco	n	1992	1847.00	R/C						303906	8020391	-17.89554	139.14901	7	54	Westmoreland	Fickling Group. Rolling Downs Group, South Nicholson Group	6631, 16267,	Doomadgee Formation, Constance Sandstone, Allaru Mudstone, Toolebuc Formation, Wallumbilla Formation		H, I	7, 8, 9
Emu 1	MIM	y		2096.00	NQ, BQ						617353	8186425	-16.40060	136.09900	8	53	Borroloola	McArthur Group	1130	Barney Creek Formation			
Emu 11	MIM	y	1975	759.90	NQ, BQ						613910	8186492	-16.40020	136.06680	8	53	Borroloola	McArthur Group	1130	Barney Creek Formation, Reward Dolomite, Lynott Formation			
Emu 13	MIM	y	1977	1255.00	NQ, BQ						616571	8186340	-16.40140	136.09170	8	53	Borroloola	McArthur Group	1130	Barney Creek Formation, Reward Dolomite			
Emu 9	MIM	y		709.00	NQ, BQ						615561	8186162	-16.40310	136.08220	8	53	Borroloola	McArthur Group	1130	upper Emmerugga Dolomite, Teena Dolomite, Barney Creek Formation, Reward Dolomite			
Emu 4	MIM	y			NQ, BQ						614148	8184160	-16.42120	136.06910	8	53	Borroloola	McArthur Group	1130	Barney Creek Formation			
DD95FT025	CRA	y	1995	259.70	NQ	42	55	40	84.00	259.70	264588	7918226	-18.81435	138.76620	8	54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
DD95FT029	CRA	y	1995	196.50	NQ	25	60	70	84.00	196.50	261840	7917345	-18.82199	138.74010	8	54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
GC1	Pasminco	y		90?							191820	8027500	-17.81840	138.09290		54	Westmoreland						
GC101	Pasminco	y	1995	313.30	NQ						197200	8029450	-17.80160	138.14380	8	54	Westmoreland	Fickling Group	6631	Mt Les Siltstone, Walford Dolomite		E	4, 5
GC102	Pasminco	y		300?							194700	8027650	-17.81750	138.12000		54	Westmoreland						
GC104	Pasminco	y	1995	57?	NQ						191000	8025150	-17.83950	138.08480	8	54	Westmoreland	Fickling Group	19228	Walford Dolomite			4
GC105	Pasminco	y	1995	501.20	NQ						191000	8025200	-17.83910	138.08480	8	54	Westmoreland	Fickling Group	6631	Fish River, Walford Dolomite		D	3, 4
GC41	Pasminco	y		220?							193133	8025610	-17.83570	138.10500		54	Westmoreland						
GC47	Pasminco	y	1992	312.50	NQ		90		72.00	312.50	198709	8030520	-17.79210	138.15820	8	54	Westmoreland	Fickling Group	6631	Mt Les Siltstone, Walford Dolomite		F	4, 5
GC56	Pasminco	y		155?							195219	8025617	-17.83590	138.12460		54	Westmoreland						
GC57	Pasminco	y	1993	309.10	NQ		90	80	125.85	309.10	197088	8024292	-17.84810	138.14200	8	54	Westmoreland	Fickling Group	6631	Doomadgee Formation, Mt Les Siltstone, Walford Dolomite		E, F, G	4, 5, 6, 7
GC58	Pasminco	y	1993	302.70	NQ		90		143.00	302.70	196324	8025033	-17.84130	138.13500	8	54	Westmoreland	Fickling Group	6631	Mt Les Siltstone, Walford Dolomite		E	4, 5
GC95A	Pasminco	y	1995	312.20	NQ						197100	8029320	-17.80280	138.14290	8	54	Westmoreland	Fickling Group	6631	Mt Les Siltstone, Walford Dolomite		E	4, 5
GC99A	Pasminco	y	1995	269.90	NQ				55.00	269.90	198200	8030100	-17.79590	138.15340	8	54	Westmoreland	Fickling Group	6631	Mt Les Siltstone, Walford Dolomite		E	4, 5
GCD1	ESSO	n	1981	395.00	NQ		90		6.00	389.00	197470	8025780	-17.83480	138.14590	7	54	Westmoreland	Fickling Group	6631	Doomadgee Formation, Mt Les Siltstone, Walford Dolomite		E, F, G	4, 5, 6, 7
GCD2A	ESSO	n	1981	310.00	NQ		90		0.00	310.00	188650	8021680	-17.87050	138.06210	7	54	Westmoreland	Fickling Group	6631	Doomadgee Formation, Mt Les Siltstone, Walford Dolomite		E, F, G	4, 5, 6, 7
GCD3	ESSO	n	1981	262.40	NQ		90		0.00	262.40	183240	8021020	-17.87570	138.01100	7	54	Westmoreland	Fickling Group	6631	Doomadgee Formation, Mt Les Siltstone, Walford Dolomite		E, F, G	4, 5, 6, 7
GCD4	ESSO	n	1981	387.40	HQ, NQ		90		3.00	387.40	187290	8019020	-17.89440	138.04890	7	54	Westmoreland	Fickling Group	6631	Doomadgee Formation, Mt Les Siltstone, Walford Dolomite		E, F, G	4, 5, 6, 7
Gilligans 001	CRA, Century	y	1996	273.30	HQ	230	75	50	78.00	318.20	246000	7929940	-18.70638	138.59150	8	54	Lawn Hill Region	McNamara Group	10261	Lawn Hill Formation		H	7
GRDD 1	WMC	y		472.30							320250	7940590	-18.61790	139.29622		54	Lawn Hill Region	McNamara Group	11575	Gunpowder Creek Formation, Torpedo Creek Quartzite			
H450 V1	MIM	y		334.50	HQ, NQ				59.80	334.60	340863	7705840	-20.74020	139.47160		54	Mount Isa	Mount Isa Group	12822	Magazine Shale, Kennedy Siltstone			
H19/79S	MIM	y	1992	180.00							617427	8182411	-16.43690	136.09990		53	Borroloola						
HCKD01	WMC	n	1991	594.00							210000	8030200	-17.79650	138.26460	8	54	Hedleys Creek	Fickling Group	6631	Doomadgee Formation, Mount Les Siltstone		F, G, H	5, 6, 7, 8
I20-32s	MIM	y	1990	210.00	HQ						617488	8182443	-16.43660	136.10050	8	53	Borroloola	McArthur Group	1130	Barney Creek Formation			
I22/55	MIM	y	1990	356.00	HQ						617506	8182666	-16.43460	136.10060	8	53	Borroloola	McArthur Group	1130	upper Emmerugga Dolomite, Teena Dolomite, Barney Creek Formation			
I203 ED1	MIM	y		277.00	HQ				102.70	277.00	340832	7703376	-20.76250	139.47100		54	Mount Isa						
DD95IK001	CRA Century	y	1995	187.40	NQ	115	60	59	47.60	187.40	261901	7914758	-18.84537	138.74030	8	54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
GSQ Lawn Hill 3	GSQ	n		460.00	NQ, BQ						276805	7929192	-18.71670	138.88330		54	Lawn Hill Region	McNamara Group	11575	Torpedo Creek, Gunpowder Creek, Paradise Creek			
GSQ Lawn Hill 4	GSQ	n		450.00	NQ, BQ						275069	7927326	-18.73330	138.86670		54	Lawn Hill Region	McNamara Group	11575	Paradise Creek Formation, Gunpowder Creek Formation			
Leila Yard 1	Shell (Aust) Pty Ltd	n	1981	527.00	NQ, BQ						592500	8163500	-16.60890	135.86720	16	53	Mallapunyah	McArthur Group	11512	Barney Creek Formation, Lynott Formation			
DD91LH235	Century, CRA	y	1991	261.00	NQ						246509	7916881	-18.82440	138.59460	8	54	Lawn Hill Region	McNamara Group	10261	Lawn Hill Formation		G	7
DD92LH355	CRA, Century	y	1992	237.00	NQ		90	35	81.00	237.00	252266	7932650	-18.68267	138.65120	8	54	Lawn Hill Region	McNamara Group	10261	Lawn Hill Formation			6
DD92LH375	CRA, Century	y	1992	199.00	HQ						246185	7927202	-18.73110	138.73110	8	54	Lawn Hill Region	McNamara Group	10261	Lawn Hill Formation			7
DD94LH508	CRA, Century	y	1994	258.00	HQ	354	60	75	90.00	258.00	252500	7926450	-18.73870	138.65260	8	54	Lawn Hill Region	McNamara Group	11575	Lawn Hill Formation, Thorntonia Limestone			6
DD94LH539	CRA, Century	y	1994	186.00	HQ	355	80	70	108.00	186.00	253000	7926600	-18.73740	138.65740	8	54	Lawn Hill Region	McNamara Group	11575	Lawn Hill Formation, Thorntonia Limestone			6
DD91LH102	CRA, Century	y	1991	360.00	HQ, NQ	265	60	60	41.70	360.00	246911	7927957	-18.72440	138.59980	8	54	Lawn Hill Region	McNamara Group	11575	Lawn Hill Formation, Thorntonia Limestone			8
DD91LH133	CRA, Century	y	1991	336.00	HQ	360	60	70	29.30	336.00	247150	7928002	-18.72400	138.60212		54	Lawn Hill Region	McNamara Group	11575	Lawn Hill Formation, Thorntonia Limestone		H	7, 8
DD93LH421	CRA	y	1993	407.50	HQ	220	58	55	56.60	407.50	261218	7918654	-18.81010	138.73430	8	54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
DD93LH432	CRA	y	1993	329.50	HQ	40	50	45	41.40	329.50	261063	7918371	-18.81264	138.73280	8	54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
DD94LH554	CRA, Century	y	1994	216.00	NQ, HQ	175	60	55	119.00	216.00	255500	7925550	-18.74720	138.68100	8	54	Lawn Hill Region	McNamara Group	10261	Lawn Hill Formation			6
DD94LH556	CRA Century	y	1994	276.00	HQ	175	70	60	119.00	276.00	251000	7926720	-18.73610	138.63840	8	54	Lawn Hill Region	McNamara Group	11575	Lawn Hill Formation, Thorntonia Limestone			6
LHYD 1	WMC	y		357.50							301270	7962700	-18.41650	139.11860		54	Lawn Hill Region	McNamara Group	25038	Gunpowder Creek Formation			
Lynott West 3	MIM	y	1994	396.50	HQ, NQ						610678	8185465	-16.40960	136.03650	8	53	Borroloola	McArthur Group	11512	Teena Dolomite, Barney Creek Formation, Reward Dolomite, Lynott Formation			
Lynott West 4	MIM	y	1994	344.00	HQ, NQ						604830	8185559	-16.40900	135.98180	8	53	Borroloola	McArthur Group	11512	Teena Dolomite, Barney Creek Formation, Reward Dolomite, Lynott Formation			
Lynott West 5	MIM	y	1994	375.00	HQ, NQ						607884	8186136	-16.40370	136.01030	8	53	Borroloola	McArthur Group	11512	Teena Dolomite, Barney Creek Formation, Reward Dolomite, Lynott Formation			
McA1	BHP	n	1983	451.00	NQ, BQ						565234	8205796	-16.22750	135.61040	8	53	Mount Young	McArthur Group	27398	Emmerugga Dolomite			
McA10	BHP	n	1984	365.00	HQ, NQ						602718	8174487	-16.50920	135.96250	8	53	Mount Young	McArthur Group	11512	Emmerugga Dolomite, Teena Dolomite, Barney Creek Formation			
McA3	BHP	n		456.86	NQ, BQ						595520	8288800	-15.47619	135.89046	8	53	Mount Young	McArthur Group	11512	Myrtle Shale, Tooganinie Formation, Amelia Dolomite, Mallapunyah Formation			
McA5	BHP	n	1981	495.97	NQ, BQ						618440	8249240	-15.83281	136.10603		53	Mount Young	McArthur Group	11512	Teena Dolomite, Barney Creek Formation			
McA9	BHP	n		350.00	HQ, NQ						599150	8177440	-16.48266	135.92893		53	Batten	McArthur Group	11512	Teena Dolomite, Emmerugga Dolomite	Coxco Dolomite, Mara Dolomite and Mitchell Yard Dolomite, Members		
BMR Bauhinia Downs 1	BMR	n			HQ						621000	8172000	-16.53080	136.13390	24	53	Bauhinia Downs	Tawallah Group	7486	Gold Creek Volcanics			
BMR McArthur River 2	BMR	n		399.00	HQ						597600	8167300	-16.57440	135.91490	24	53	Bauhinia Downs	McArthur Group	1130	Barney Creek Formation			
BMR Mt Young 2	BMR	n	1979	154.00	HQ						550500	8244500	-15.87800	135.46940	16	53	Mantungula	Tawallah Group	20358	Wollogorang Formation			
P142	Buka Minerals	y		332.00							297272	7812678	-19.77114	139.06504		54	Mammoth Mines	McNamara Group	10002	Lady Loretta Formation			
P148	Buka Minerals	y		269.50							296012	7811844	-19.77854	139.05293		54	Mammoth Mines	McNamara Group	10002	Lady Loretta Formation			
PDLA 64	WMC	y		610.00	NQ						299170	7815270	-19.74790	139.08340		54	Mammoth Mines						
Quartzite 010	MIM	y		1703.00	HQ, NQ				102.50	1703.00	341098	7712308	-20.68180	139.47440		54	Mount Isa	Mount Isa Group	12822	Kennedy Siltstone, Spear Siltstone, Urquhart Shale			
DD95RL010	CRA	y	1995	350.00	NQ	165	60	75	83.70	350.00	262764	7907487	-18.91113	138.74760		54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
RVCRO12	Terrasearch?	y	1995	80.00	R/C						259899	7903233	-18.94920	138.71990	2	54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
RVCRO13	Terrasearch?	y	1995	60.00	R/C						258843	7907921	-18.90680	138.71050	2	54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
RVCRO14	Terrasearch?	y	1995	80.00	R/C						258856	7907951	-18.90650	138.71060	2	54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
RVCRO19	Terrasearch?	y	1995	114.00	R/C						258813	7908135	-18.90480	138.71020	2	54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
RVD 17	Terrasearch	y		389.00	NQ						271964	7886247	-19.10400	138.83245		54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
RVD 47	Terrasearch	y		389.00	NQ						268546	7889450	-19.07470	138.80036		54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
RDV50/51	Terrasearch	y		750.00	NQ						268225	788920	-19.07627	138.79729		54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			
RVD 5	Terrasearch	y		227.00	NQ						268672	7889275	-19.07627	138.80154		54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			5
Stone Axe 13D	MIM	y	1996?	462.00	HQ, NQ				80.10	462.00	345759	7729309	-20.52870	139.52870		54	Mary Kathleen	Mount Isa Group	12822	Breakaway Shale, Moondarra Siltstone, Warrina Park Quartzite, Surprise Creek Formation			
Stony Creek 3	MIM	y	1996?	352.00	BQ				74.50	352.00	347397	7711503	-20.68960	139.53480		54	Mary Kathleen	Mount Isa Group	12822	Moondarra Siltstone, Warrina Park Quartzite, Surprise Creek Formation			
UE 258	MIM	y	1996?	814.80	NQ, BQ				96.00	814.80	342343	7693862	-20.84860	139.48470		54	Mount Isa	Mount Isa Group	12822	Native Bee Siltstone, Breakaway Shale, Moondarra Siltstone			
BMR Urapunga 1	BMR	n	1983	269.00	HQ						374100	8433500	-14.16687	133.83339	16	53	Flying Fox	Roper Group	11034	Mainoru Formation			
BMR Urapunga 3	BMR	n	1983	94.00	HQ						364900	8379600	-14.65366	133.74543	16	53	Moroak	Roper Group	16319	Corcoran Formation			
BMR Urapunga 2	BMR	n	1983	211.00	HQ						352100	8351000	-14.91150	133.62497	16	53	Moroak						
BMR Urapunga 4	BMR	n	1984	530.00	HQ, NQ						423700	8374200	-14.70479	134.29126	16	53	Chapman	Roper Group	16319	Corcoran Formation, McMinn Formation			
BMR Urapunga 5	BMR	n	1984	604.00	HQ, NQ						437300	8373400	-14.71237	134.41757	16	53	Chapman	Roper Group	11034	Mainoru Formation	Hodgson Sandstone Member		
BMR Urapunga 6	BMR	n	1984	422.50	HQ, NQ						449900	8370200	-14.74157	134.53455	16	53	Urapunga	Roper Group	16319	Limmen Sandstone, Mainoru formation			
WC 1	CRA	n		437.50	HQ, NQ, BQ						272650	7917030	-18.82606	138.84255		54	Lawn Hill Region	McNamara Group	11575	Kamarga Volcanics, Torpedo Quartzite, Gunpowder Creek Formation			
Wearyan 1	CEC	n	1982	843.30	NQ, BQ						656322	8139821	-16.81960	136.46710	16	53	Bauhinia Downs	McArthur Group	11512	Masterton Sandstone, Mallapunyah formation, Amelia Dolomite, Tatoola Sandstone			
WFDD17	WMC	n	1991	642.00							208700	8030100	-17.79730	138.25230	8	54	Hedleys Creek	Fickling Group	6631	Walford Dolomite, Mount Les Siltstone, Doomadgee formation		E, F, G, H	4, 5, 6, 7, 8
WFDD39	WMC	n	1991	296.80							210891	8030650	-17.79260	138.27300	8	54	Hedleys Creek	Fickling Group	6631	Walford Dolomite, Mount Les Siltstone, Doomadgee formation		E, F, G	4, 5, 6, 7
WFDD47	WMC	n	1991	328.00							210850	8030600	-17.79300	138.27260	8	54	Hedleys Creek	Fickling Group	6631	Walford Dolomite, Mount Les Siltstone, Doomadgee formation		E, F	4, 5, 6
WFDD59	WMC	n	1991	602.00							210000	8030400	-17.79470	138.26460	8	54	Hedleys Creek	Fickling Group	6631	Mount Les Siltstone, Doomadgee Formation, Walford Dolomite		E, F, G, H	4, 5, 6, 7, 8
WFDD74	WMC	n	1991	351.00			90	80	28.00	351.00	215250	8031578	-17.78480	138.31420	8	54	Hedleys Creek	Fickling Group	6631	Walford Dolomite, Mount Les Siltstone		E	4, 5
PDCM000009	Aberfoyle	y		249.50	NQ			60	138.00	249.50	290953	7882880	-19.13644	139.01250		54	Mount Oxide						
PDCM000017	Aberfoyle	y		501.40	NQ			70	120.00	501.40	304136	7820512	-19.70108	139.13136		54	Mammoth Mines						
PDCM000024	Aberfoyle	y		170.50	NQ			66	54.00	170.50	289630	7930106	-18.70974	139.00500		54	Gregory Downs						
PDCM000026	Aberfoyle	y		288.20	NQ			69	73.00	288.20	297291	7924916	-18.75738	139.07709		54	Gregory Downs						
PDCM000035	Aberfoyle	y		349.00	NQ			84	114.00	349.00	298750	7827000	-19.64194	139.08069		54	Mammoth Mines						
PDCM000045	Aberfoyle	y		501.50	NQ			67	72.00	300.00	269500	7888800	-19.08065	138.80935		54	Lawn Hill Region	McNamara Group	24472	Riversleigh Siltstone			
QLG 5001	Aquitaine	n	1983	282.80	NQ		90		99.37	282.80	196000	8024380	-17.84719	138.13181	7	54	Westmoreland	Fickling Group	6631	Doomadgee Formation, Mt Les Siltstone, Walford Dolomite		E, F, G	4, 5, 7

dh_id	dh_company	nfidenti	year	tot_metres	core_size	av_azimuth	dip	core_av_dip	core_from	core_to	easting	northing	lat_agd66	long_agd66	loc_method	on	100k_map	group	stratno	formation	member	event surface	accom_package
QLG 5002	Aquitaine	n	1983	261.80	NQ		90		135.00	261.80	192580	8022860	-17.86040	138.09930	7	54	Westmoreland	Fickling Group	6631	Doomadgee Formation, Mt Les Siltstone, Walford Dolomite		E, F, G	4, 5, 7
Burketown 1	MiU East Oil	n	1964	975.00	?		90		100.00	975.00	345237	8002336	-18.06200	139.53770	7	54	Wernadinga	McNamarra Group, Eulo Queen Group, Rolling Downs Group	11575, 6356,	Normanton Formation, Allaru Mudstone, Toolebuc Formation, Wullumbilla Formation, Gilbert River Formation			
Armraynald 1	Comalco	n	1988	638.00	R/C		90				368720	7994550	-18.13391	139.75905	7	54	Wernadinga	McNamarra Group, Eulo Queen Group, Rolling Downs Group	11575, 6356,	Normanton Formation, Allaru Mudstone, Toolebuc Formation, Wullumbilla Formation, Gilbert River Formation			
GRQ 81-2	Amoco	n	1981	417.50	NQ, BQ		90		206.00	417.50	298200	8040450	-17.71380	139.09710	7	54	Westmoreland	Rolling Downs Group	16269	Normanton Formation, Allaru Mudstone, Toolebuc Formation, Wullumbilla Formation			
F968	MIM	n		535.00							341350	7710600	-20.69729	139.47667		54	Mount Isa	Mount Isa Group	19001	Urquhart Shale			

location method

LOCMETHNO	LOCMETHOD	Acurracy (m)	Preferences
0	unknown		
1	GPS observation (WGS84 - World Geodetic System 1984)	100	
2	GPS observation (AGD66 - Australian Geodetic Datum 1966)	100	
3	GPS observation (AGD84 - Australian Geodetic Datum 1984)	100	
4	GPS observation (GDA94 - Geocentric Datum Australian 1994)	100	
5	astronomical observation		
6	surveyed from ground control		
7	published report		
8	unpublished report		
10	non-standard topographic map		
11	1:25 000 topographic map	25	
12	1:50 000 topographic map	50	
13	1:100 000 topographic map (AMG66)	100	
14	1:250 000 topographic map	250	
15	1:500 000 topographic map	500	
16	1:1 000 000 topographic map	1000	
20	non-standard geological map		
21	1:25 000 geological map	25	
22	1:50 000 geological map	50	
23	1:100 000 geological map (AMG66)	100	
24	1:250 000 geological map	250	
25	1:500 000 geological map	500	
26	1:1 000 000 geological map	1000	
30	Differential GPS - Survey quality (WGS84)	1	

GROUP	strat number
Rolling Downs Group	16267
Fickling Group	6631
South Nicholson Group	17123
Eulo Queen Group	6356
McArthur Group	11512
McNamara Group	11575
Mount Isa Group	12822
Nathan Group	26072
Roper Group	16319
Tawallah Group	17902

Drilldb.xls Well Name and Zone

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A82-05	53
A82-06	53
A82-07	53
A83-01	54
A83-02	54
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A83-05	54
AADI 1	54
AARC 1	54
AASP 1	54
Amelia 33	53
Amelia Basin 2	53
Amelia Basin 4	53
Amelia Basin 5	53
Amelia Basin 6	53
Argyle Creek 1	53
Barney 3	53
BCK3	53
Bauhinia 3	53
Bauhinia 4	53
BBKD 1	54
BCC1DQ5869	54
Beamesbrook 1	54
Bing Bong 2	53
CA 4	53
DD95CC008	54
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CEC10	54
DD90LH055	54
DD90LH065	54
DD91LH210	54
DD91LH265	54
DD92LH376	54
DD94LH532	54
Desert Creek 1	54
Egilabria 1	54
Emu 1	53
Emu 11	53
Emu 13	53
Emu 9	53
Emu 4	53
DD95FT025	54
DD95FT029	54
GC1	54
GC101	54
GC102	54
GC104	54
GC105	54
GC41	54
GC47	54
GC56	54
GC57	54
GC58	54
GC95A	54
GC99A	54
GCD1	54
GCD2A	54
GCD3	54
GCD4	54
Gilligans 001	54
GRDD 1	54
H450 V1	53
H19/79S	53
HCKD01	54
I20-32s	53
I22/55	53
I203 ED1	54
DD95IK001	54
Lawn Hill 03	54
Lawn Hill 04	54
Leila Yard 1	53
DD91LH235	54
DD92LH355	54
DD92LH375	54
DD94LH508	54
DD94LH539	54
DD91LH102	54
DD91LH133	54
DD93LH421	54
DD93LH432	54
DD94LH554	54
DD94LH556	54
LHYD 1	54
Lynott West 3	53
Lynott West 4	53
Lynott West 5	53
McA1	53
McA10	53
McA3	53
McA5	53
McA9	53
BMR Bauhinia Downs 1	53
BMR McArthur River 2	53
BMR Mt Young 2	53
P142	54
P148	54
PDLA 64	54
Quartzite 010	54
DD95RL010	54
RVCRO12	54
RVCRO13	54
RVCRO14	54
RVCRO19	54
RVD 17	54
RVD 47	54
RVD 5	54
Stone Axe 13D	54
Stony Creek 3	54
UE 258	54
Urapunga 1	53
Urapunga 2	53
Urapunga 3	53
Urapunga 4	53
Urapunga 5	53
Urapunga 6	53
Wearyan 1	53
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WFDD47	54
WFDD59	54
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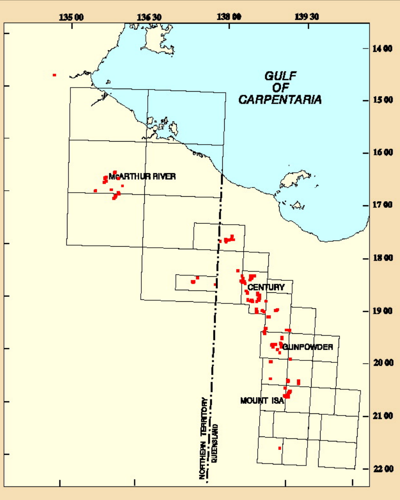
GRQ 81-2	54



Barr Hole

95PS-01A, 95PS-01B/95BH-01, 96BH-02B, 96BH-02A, 96BH-03

SCALE 1:1000

Easting: 327040

Northing: 7832580

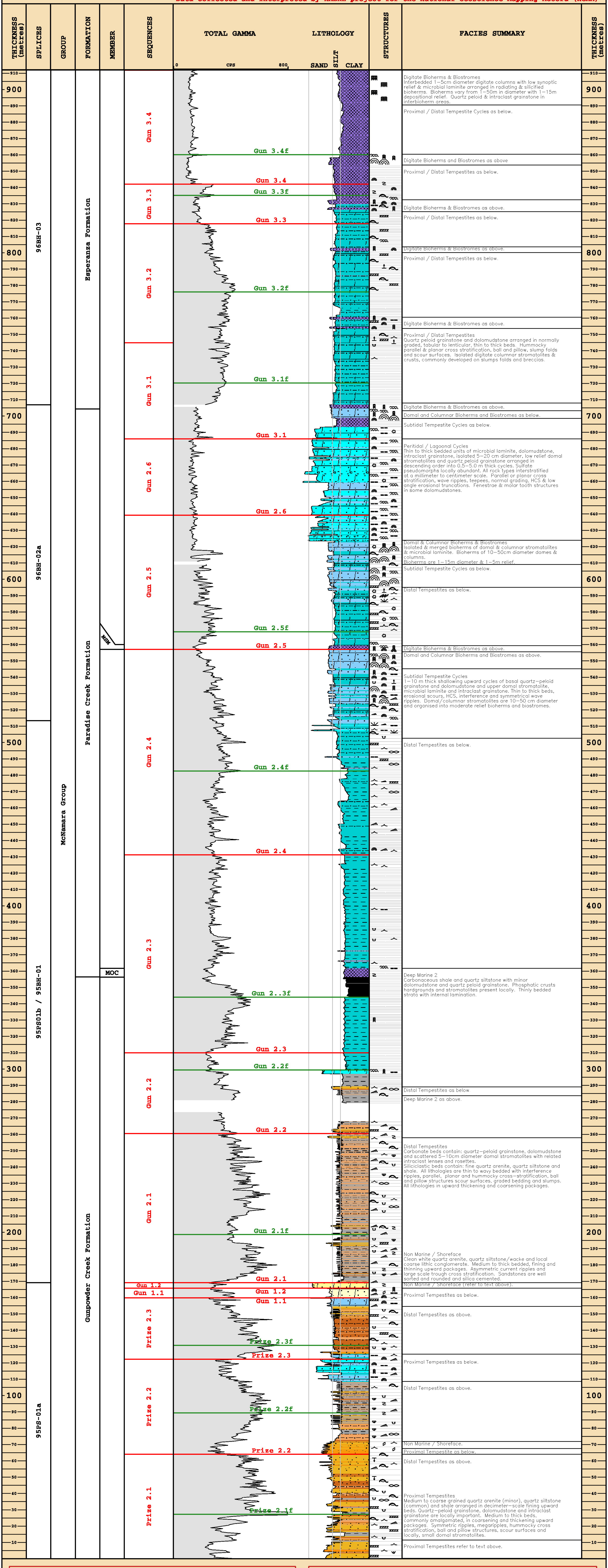
Data type: Measured Section

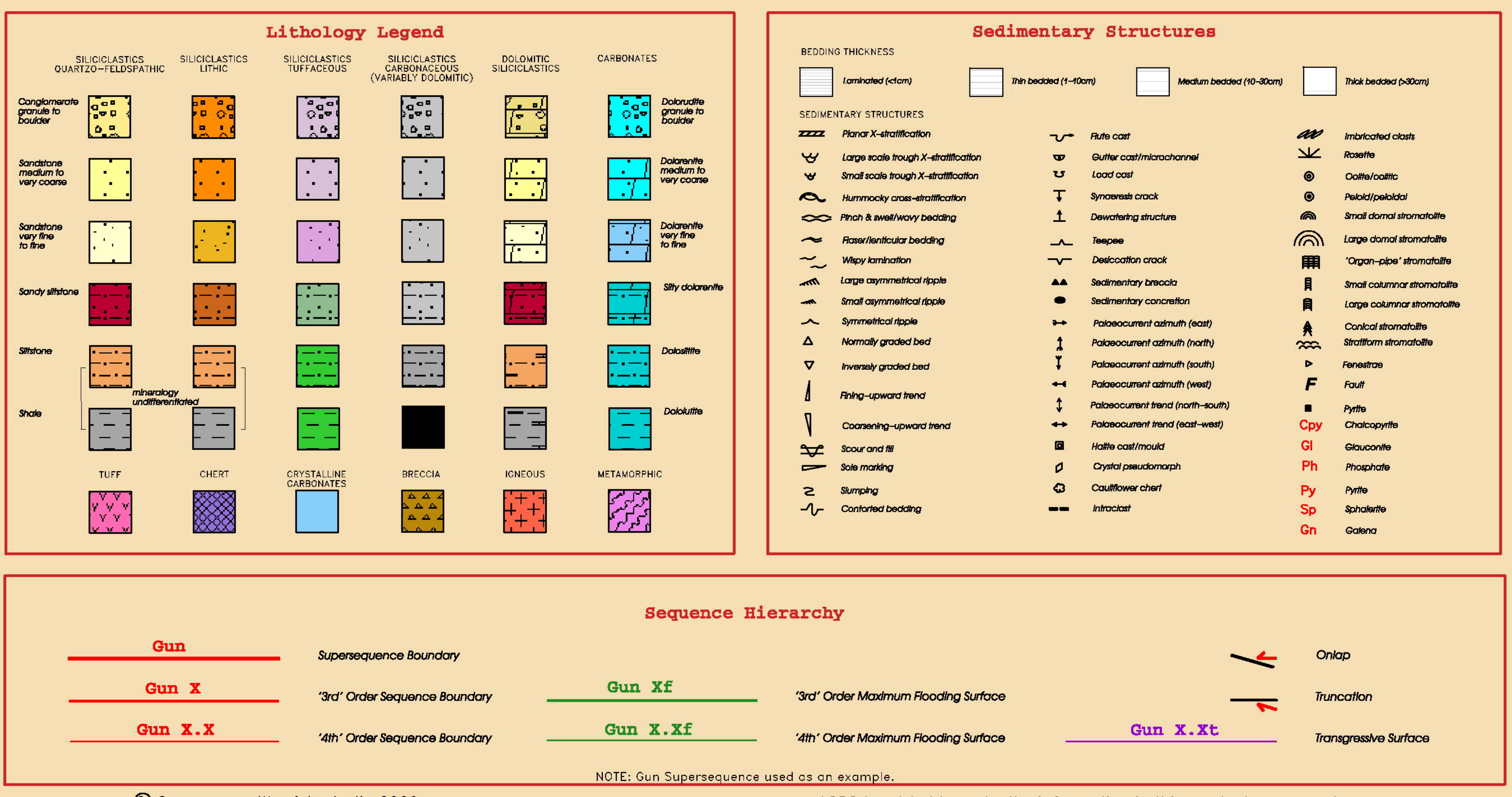
Map sheet: Mammoth Mines

Geology: A Krassay, T Sami & P Southgate

Geolog compilation: K Barnett, U Rokvic, I Zeilinger

Data collected and interpreted by NABRE project for the National Geoscience Mapping Accord (NGMA)





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Phone 02–62499519, Facsimile 02–62499982

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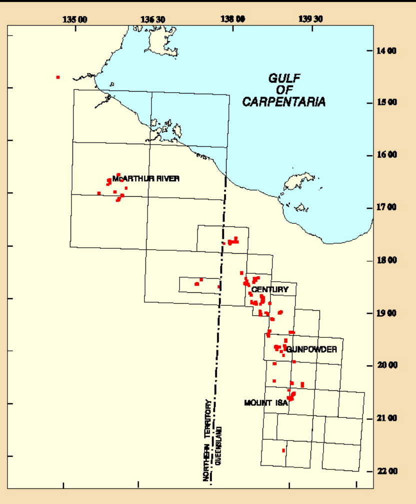

Esperanza Waterhole

95JJ-02A, 95JJ-02B, 95JJ-02C

SCALE 1:1000

Easting: 325300

Northing: 7819620

Data type: Measured Section

Map sheet: Mammoth Mines

Geology: J Jackson, T Sami & P Southgate

Geolog compilation: K Barnett, U Rokvic, I Zeilinger

Data collected and interpreted by NABRE project for the National Geoscience Mapping Accord (NGMA)

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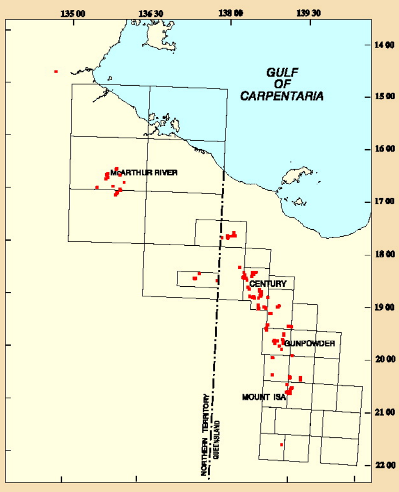
Phone 02–62499519, Facsimile 02–62499982

Date: 23–Feb–2000 10:12:12



Mammoth Mines North

96CW-04A, 96CW-04B

SCALE 1:1000

Easting: 327147

Northing: 7817811

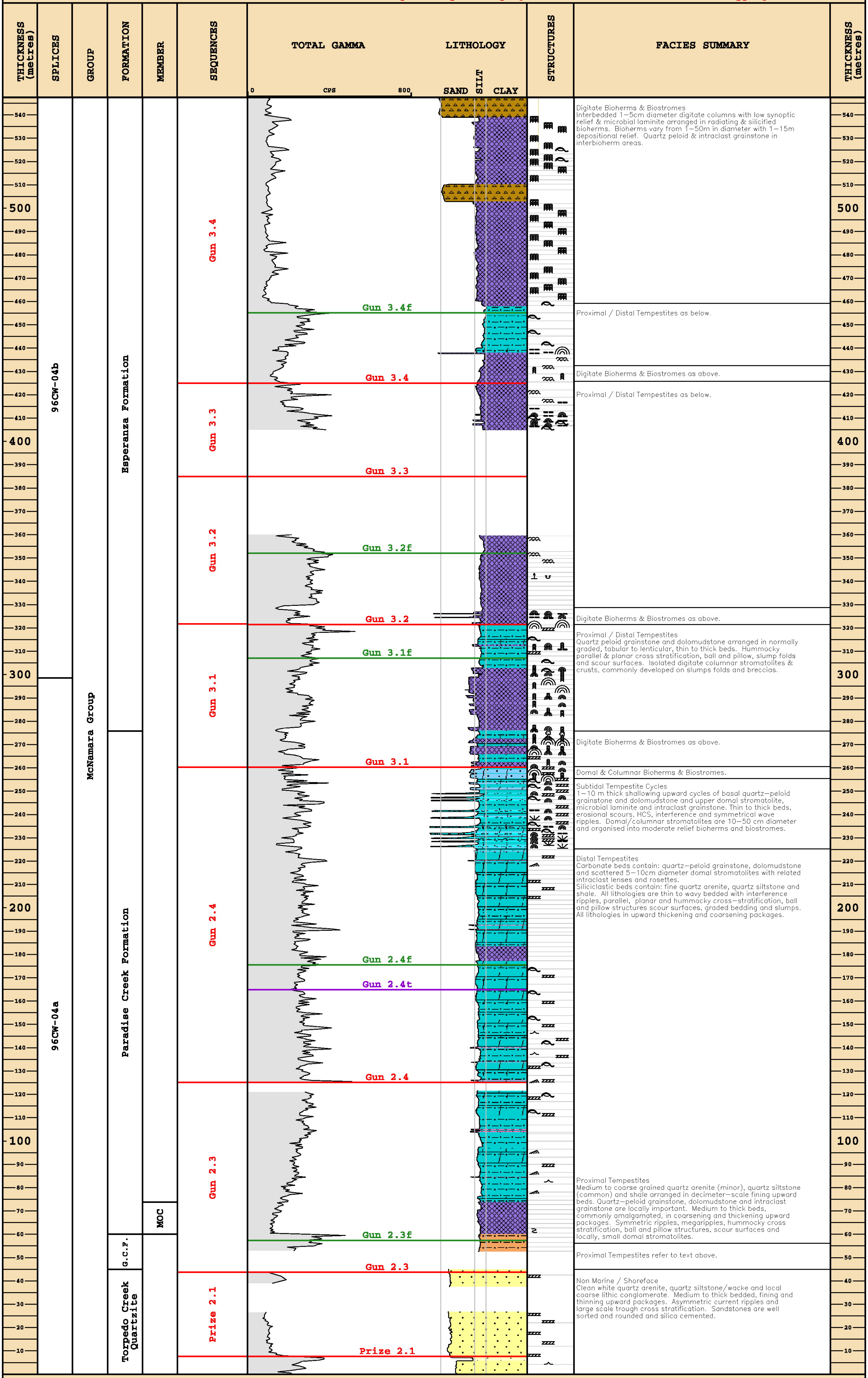
Data type: Measured Section

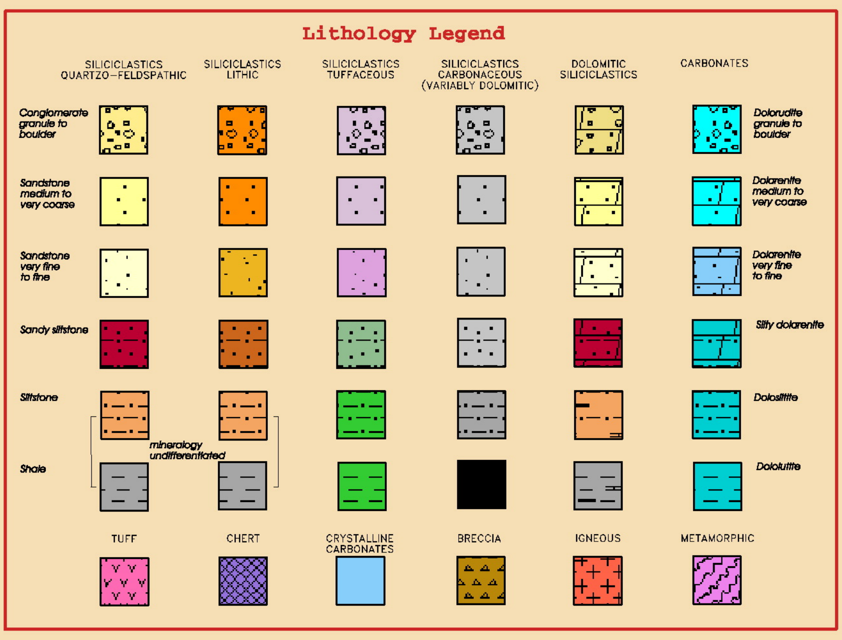
Map sheet: Mammoth Mines

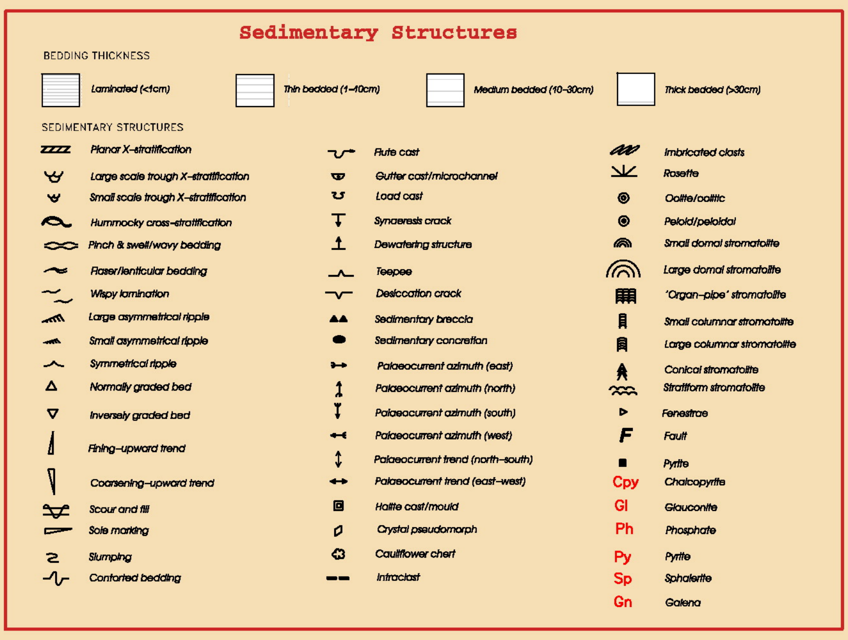
Geology: T Sami & P Southgate

Geolog compilation: K Barnett, U Rokvic, I Zeilinger

Data collected and interpreted by NABRE project for the National Geoscience Mapping Accord (NGMA)







Sequence Hierarchy

Gun	Supersequence Boundary				Onlap
Gun X	'3rd' Order Sequence Boundary	Gun Xf	'3rd' Order Maximum Flooding Surface		Truncation
Gun X.X	'4th' Order Sequence Boundary	Gun X.Xf	'4th' Order Maximum Flooding Surface	Gun X.Xt	Transgressive Surface

NOTE: Gun Supersequence used as an example.

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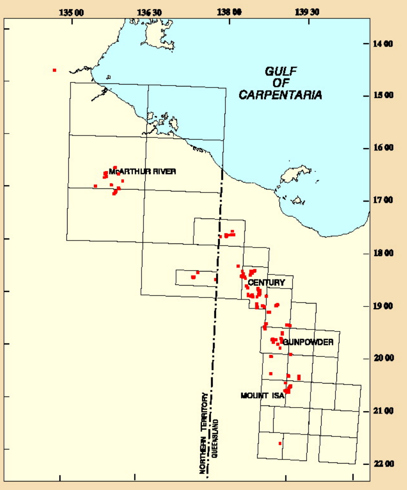
Date: 17–Feb–2000 12:20:00



Mammoth Mines South

96CW-03

SCALE 1:1000

Easting: 326880

Northing: 7812450

Data type: Measured Section

Map sheet: Mammoth Mines

Geology: T Sami & P Southgate

Geolog compilation: K Barnett, U Rokvic, I Zeilinger

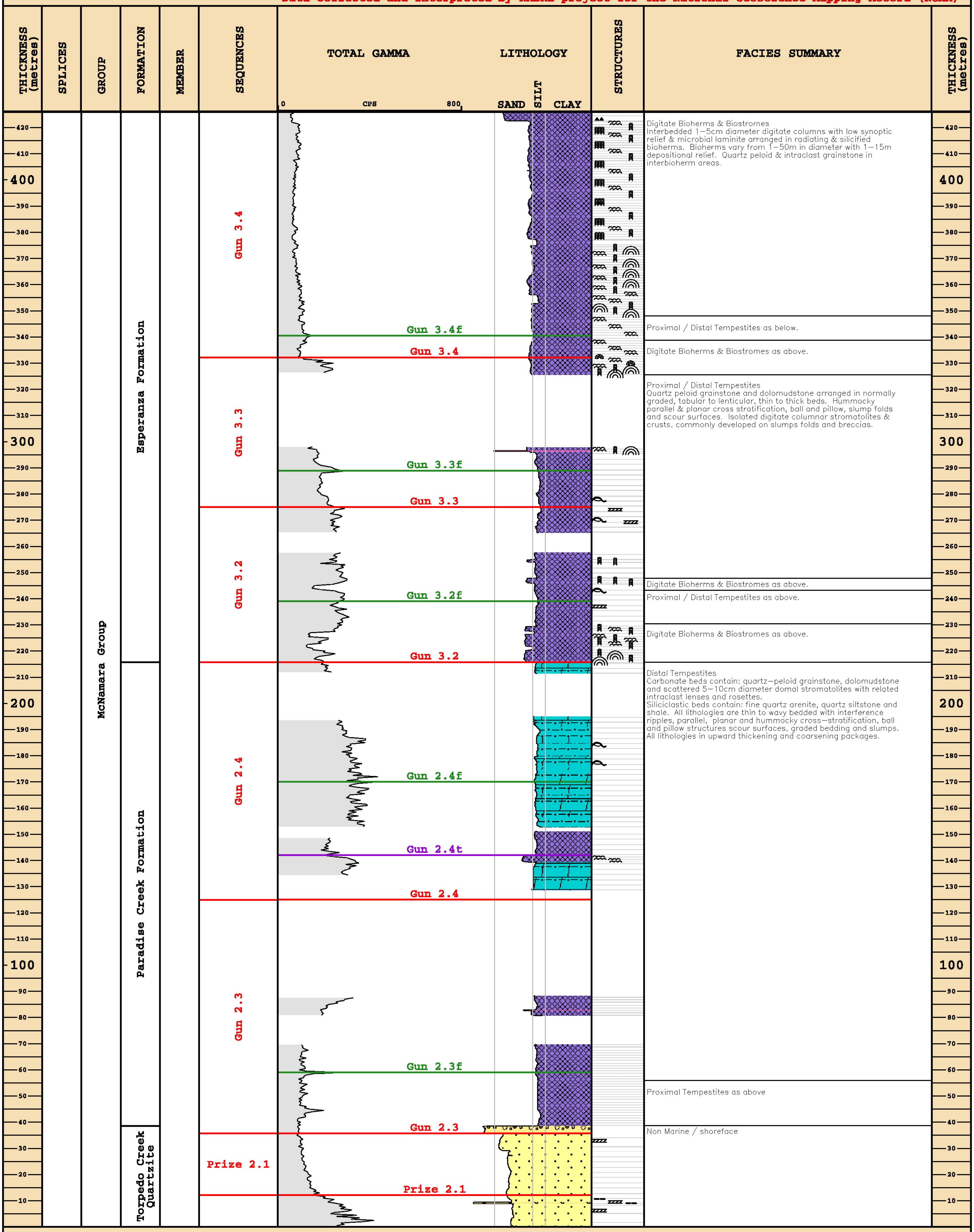
AUSTRALIA

DEPARTMENT OF MINES AND ENERGY

NORTHERN TERRITORY · DEPARTMENT OF MINES AND ENERGY

AGSO · AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Data collected and interpreted by NABRE project for the National Geoscience Mapping Accord (NGMA)



Lithology Legend

SILICICLASTICS QUARTZO–FELDSPATHIC · SILICICLASTICS LITHIC · SILICICLASTICS TUFFACEOUS · SILICICLASTICS CARBONACEOUS (VARIABLY DOLOMITIC) · DOLOMITIC SILICICLASTICS · CARBONATES

- Conglomerate granule to boulder — Dolorudite granule to boulder
- Sandstone medium to very coarse — Dolarenite medium to very coarse
- Sandstone very fine to fine — Dolarenite very fine to fine
- Sandy siltstone — Silty dolarenite
- Siltstone — Dolosiltite
- Shale — Dololutite
- mineralogy undifferentiated

TUFF · CHERT · CRYSTALLINE CARBONATES · BRECCIA · IGNEOUS · METAMORPHIC

Sedimentary Structures

BEDDING THICKNESS

- Laminated (<1cm)
- Thin bedded (1–10cm)
- Medium bedded (10–30cm)
- Thick bedded (>30cm)

SEDIMENTARY STRUCTURES

- Planar X–stratification
- Large scale trough X–stratification
- Small scale trough X–stratification
- Hummocky cross–stratification
- Pinch & swell/wavy bedding
- Flaser/lenticular bedding
- Wispy lamination
- Large asymmetrical ripple
- Small asymmetrical ripple
- Symmetrical ripple
- Normally graded bed
- Inversely graded bed
- Fining–upward trend
- Coarsening–upward trend
- Scour and fill
- Sole marking
- Slumping
- Contorted bedding
- Flute cast
- Gutter cast/microchannel
- Load cast
- Synaeresis crack
- Dewatering structure
- Teepee
- Desiccation crack
- Sedimentary breccia
- Sedimentary concretion
- Palaeocurrent azimuth (east)
- Palaeocurrent azimuth (north)
- Palaeocurrent azimuth (south)
- Palaeocurrent azimuth (west)
- Palaeocurrent trend (north–south)
- Palaeocurrent trend (east–west)
- Halite cast/mould
- Crystal pseudomorph
- Cauliflower chert
- Intraclast
- Imbricated clasts
- Rosette
- Oolite/oolitic
- Peloid/peloidal
- Small domal stromatolite
- Large domal stromatolite
- 'Organ–pipe' stromatolite
- Small columnar stromatolite
- Large columnar stromatolite
- Conical stromatolite
- Stratiform stromatolite
- Fenestrae
- F Fault
- Pyrite
- Cpy Chalcopyrite
- Gl Glauconite
- Ph Phosphate
- Py Pyrite
- Sp Sphalerite
- Gn Galena

Sequence Hierarchy

Gun	Supersequence Boundary				Onlap
Gun X	'3rd' Order Sequence Boundary	Gun Xf	'3rd' Order Maximum Flooding Surface		Truncation
Gun X.X	'4th' Order Sequence Boundary	Gun X.Xf	'4th' Order Maximum Flooding Surface	Gun X.Xt	Transgressive Surface

NOTE: Gun Supersequence used as an example.

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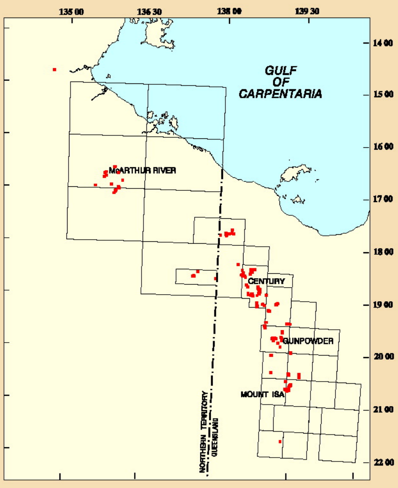
Date: 17–Feb–2000 12:20:00



Crocodile Waterhole

95AW-09

SCALE 1:1000

Easting: 325150

Northing: 7799600

Data type: Measured Section

Map sheet: Mammoth Mines

Geology: T Sami, P Southgate & A Wells

Geolog compilation: K Barnett, U Rokvic, I Zeilinger

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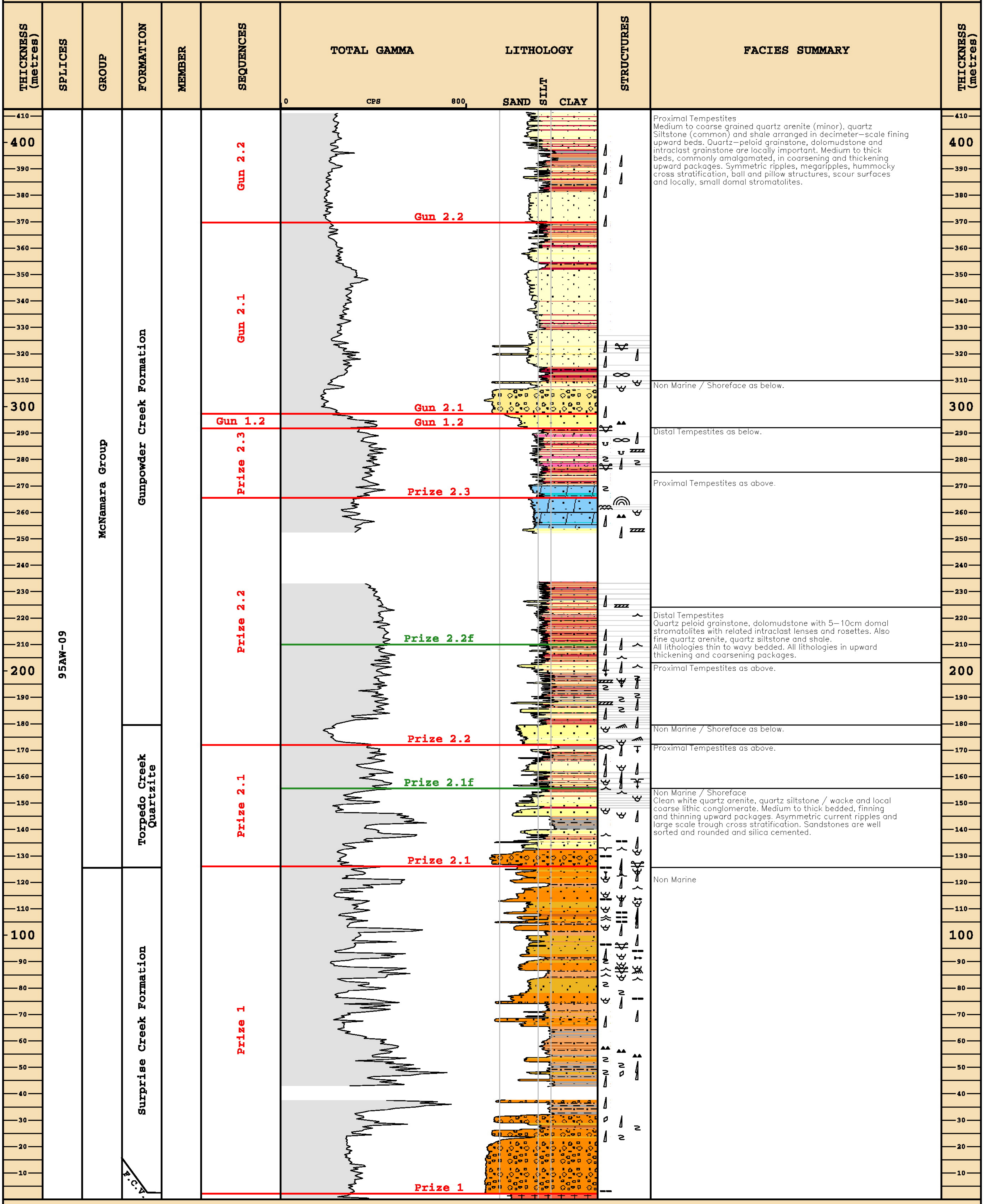
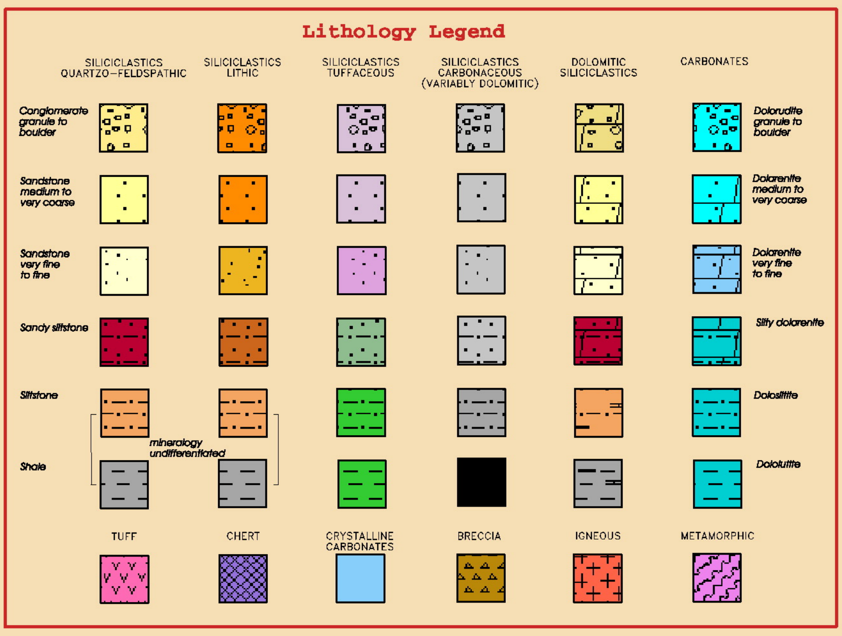
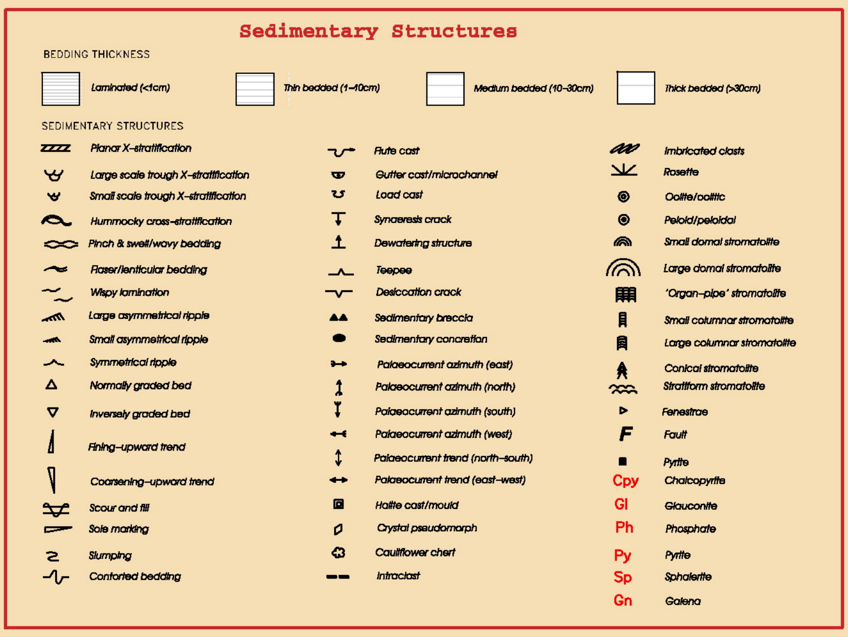


Lithology Legend



Sedimentary Structures



Sequence Hierarchy

Line	Meaning	Line	Meaning	Line	Meaning
Gun	Supersequence Boundary				Onlap
Gun X	'3rd' Order Sequence Boundary	Gun Xf	'3rd' Order Maximum Flooding Surface		Truncation
Gun X.X	'4th' Order Sequence Boundary	Gun X.Xf	'4th' Order Maximum Flooding Surface	Gun X.Xt	Transgressive Surface

NOTE: Gun Supersequence used as an example.

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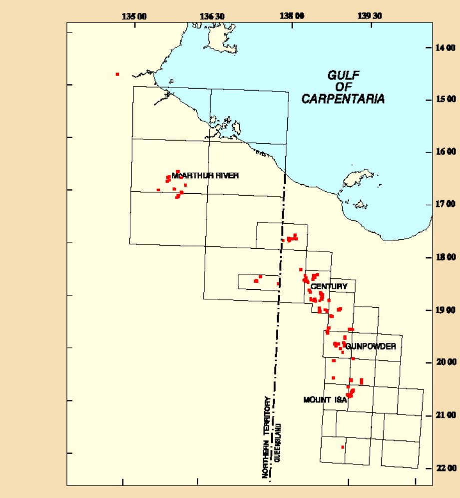
Date: 06–Mar–2000 12:26:17



Paradise Creek West

96PC-01, 96PC-01A, 96PC-02A, 96PC-02B, 96PC-02C

SCALE 1:1000

Easting: 309693

Northing: 7811580

Data type: Measured Section

Map sheet: Mammoth Mines

Geology: T Sami & P Southgate

Geolog compilation: K Barnett, U Rokvic, I Zeilinger

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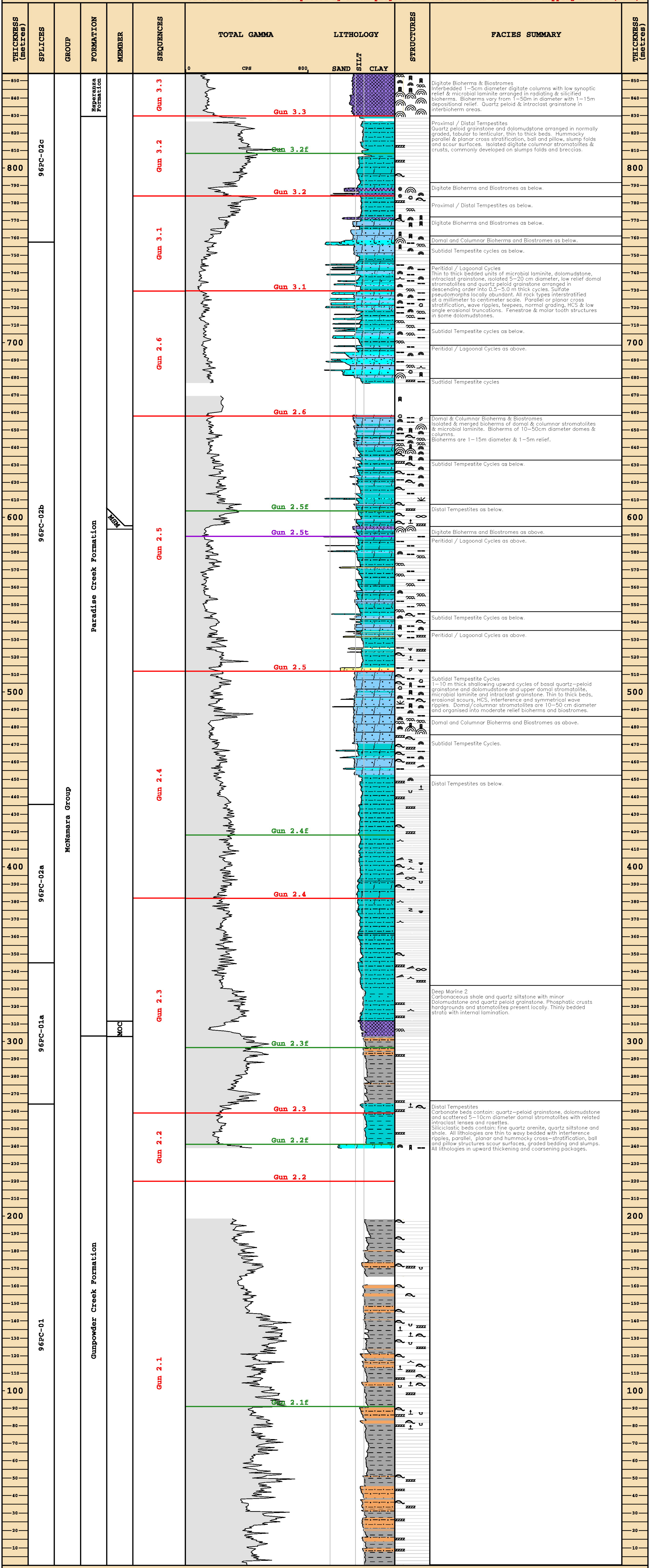

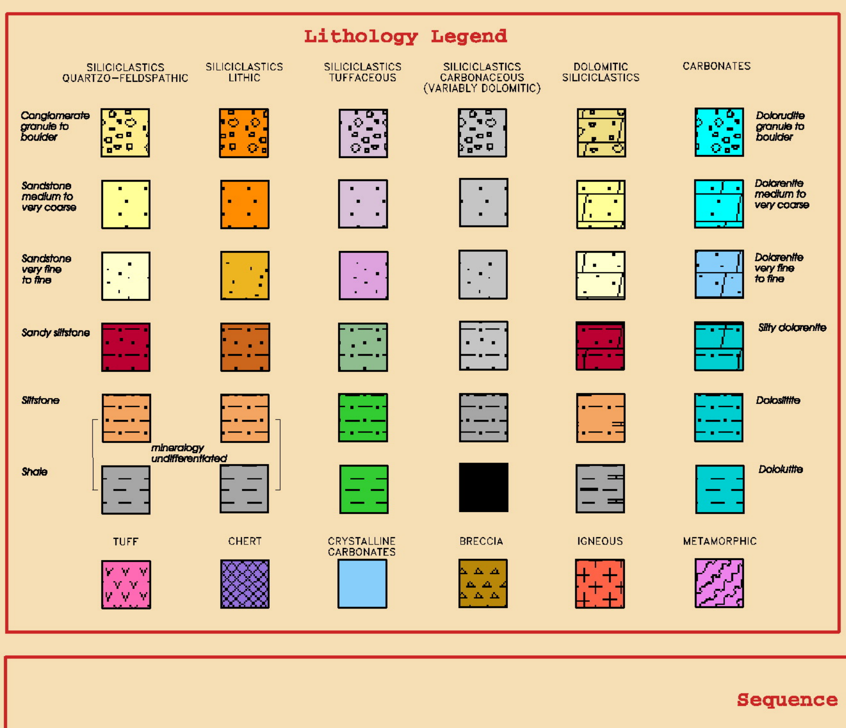

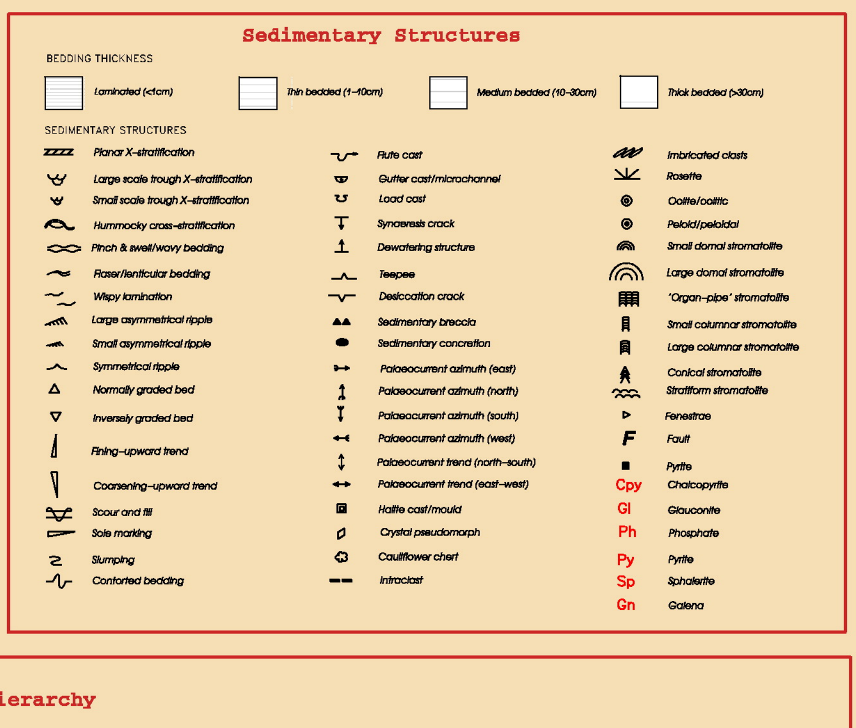

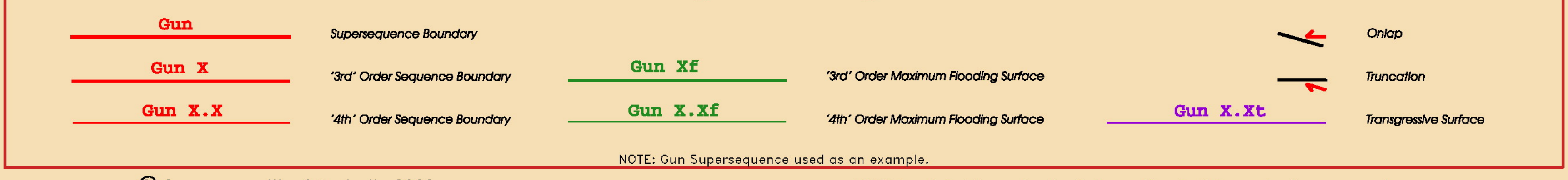

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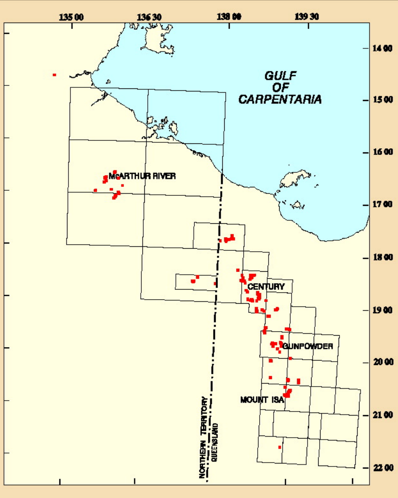

Mellish Park

95PS-05A, 95PS-05B, 96MP-01A, 96MP-01B, 96MP-02B, 96MP-02A, 96MP-03

SCALE 1:1000

Easting: 313900

Northing: 7890700

Data type: Measured section

Map sheet: Mount Oxide

Geology: T Sami, J Jackson and P Southgate

Geolog compilation: K Barnett, U Rokvic, I Zeilinger

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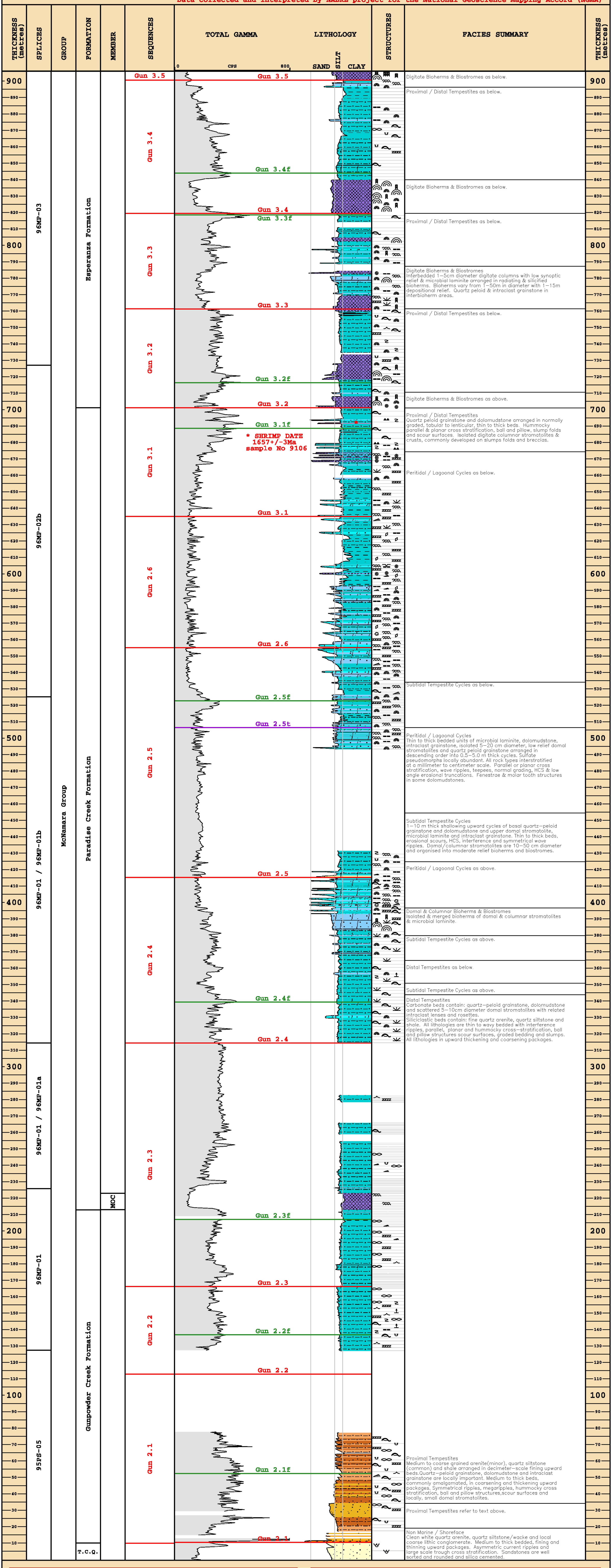

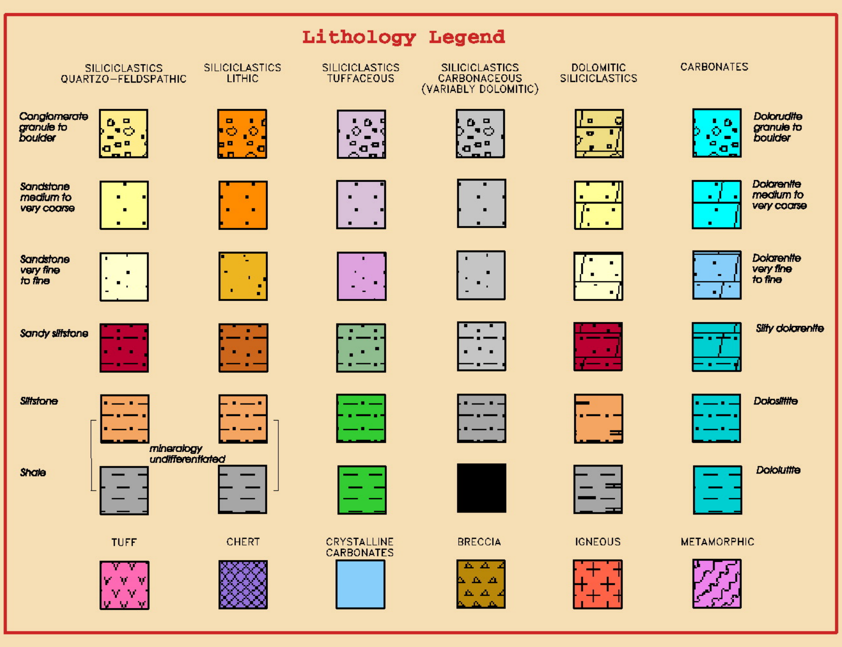

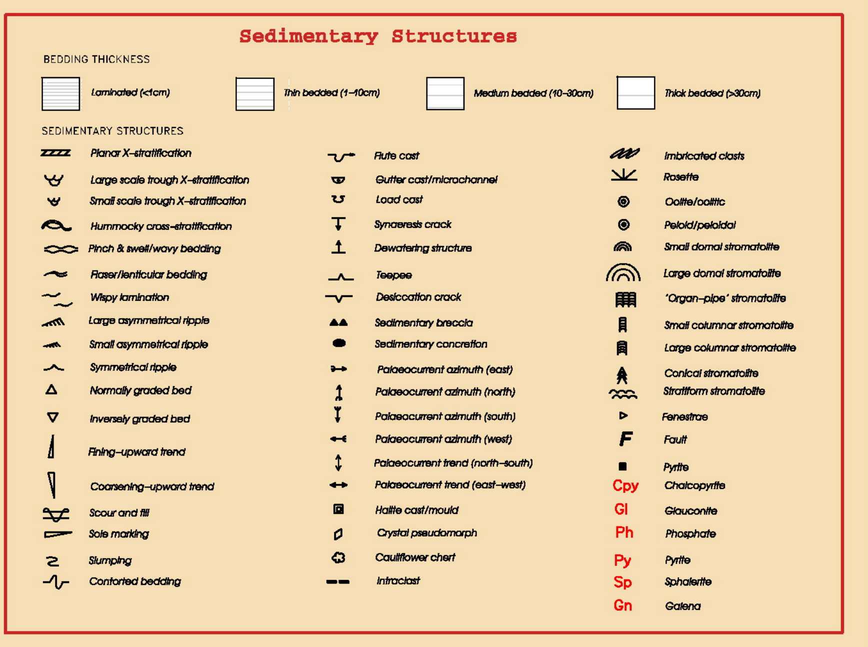

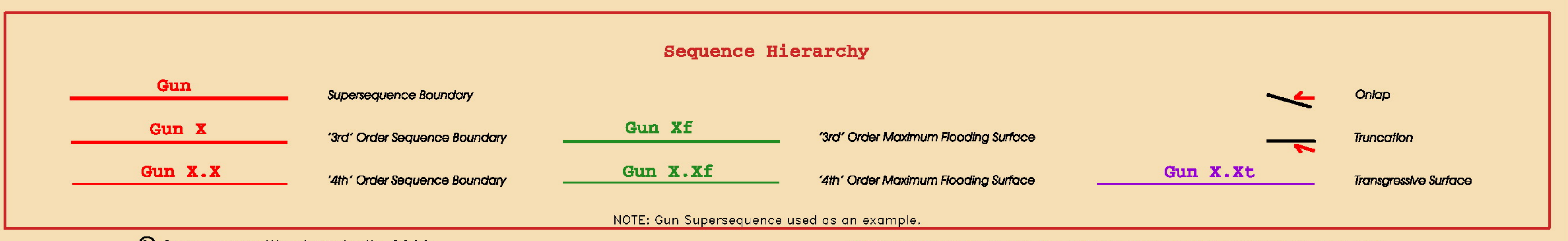

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Date: 17–Mar–2000 12:04:45