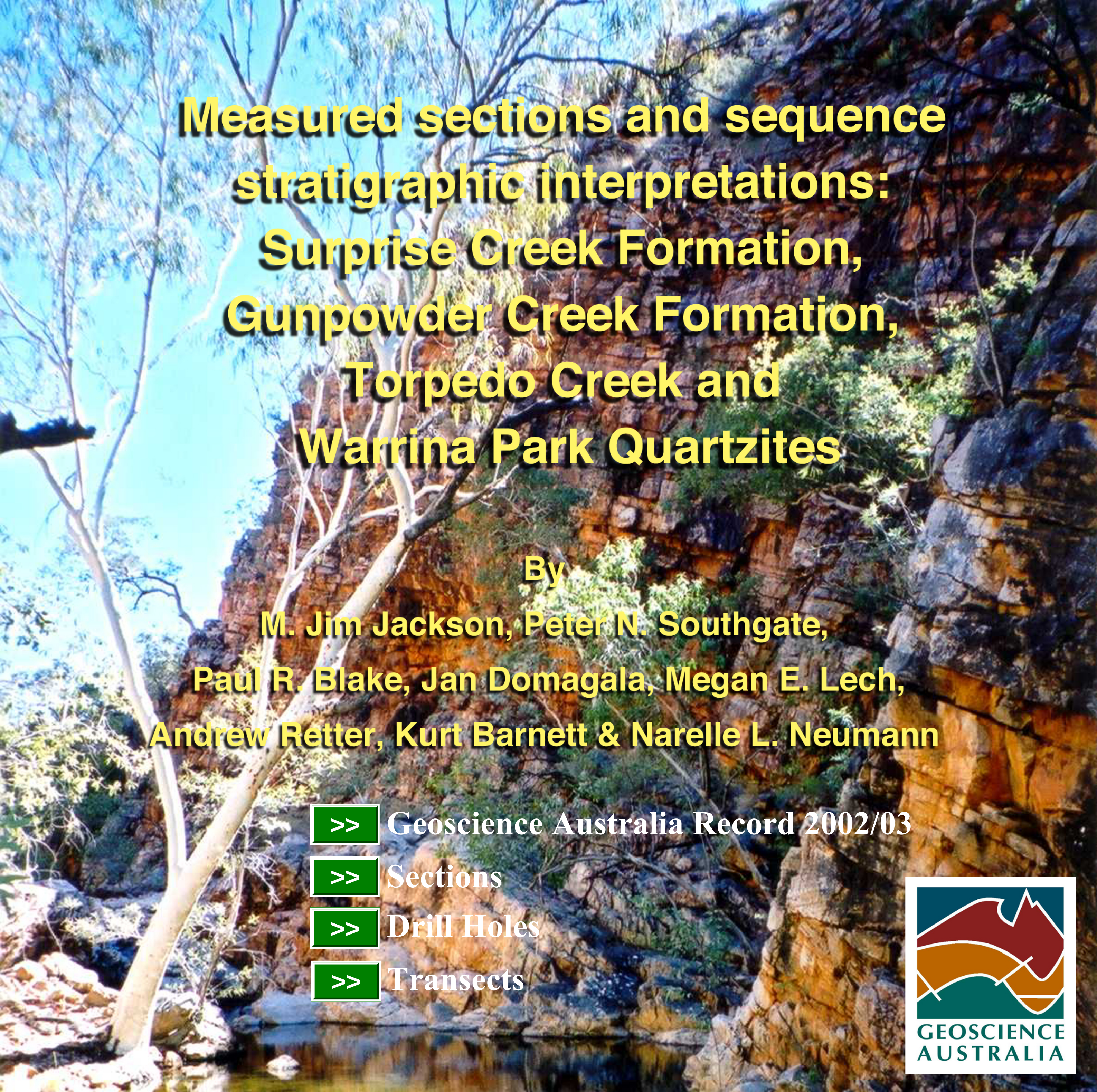

Measured sections and sequence stratigraphic interpretations: Surprise Creek Formation, Gunpowder Creek Formation, Torpedo Creek and Warrina Park Quartzites

By

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>> Sections

>> Drill Holes

>> Transects

GEOSCIENCE AUSTRALIA

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MEASURED SECTIONS AND SEQUENCE STRATIGRAPHIC INTERPRETATIONS: SURPRISE CREEK FORMATION, GUNPOWDER CREEK FORMATION, TORPEDO CREEK AND WARRINA PARK QUARTZITES.

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GEOSCIENCE AUSTRALIA

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ABSTRACT

Paleoproterozoic sedimentary rocks of northern Australia 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 public domain datasets contain 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 four single sections. These sections are subsequently combined to form twenty six composite outcrop and drill core stratigraphic sections through the Surprise Creek Formation, Warrina Park and Torpedo Creek Quartzites, lower Gunpowder Creek Formation and Moondarra Siltstone of the Calvert and Isa Superbasins. Close to twenty three thousand meters of stratigraphic/sedimentological description and interpretation are provided. Most sections contain grain size, lithology, bed thickness, sedimentary structure and gamma ray data from which facies and sequence stratigraphic surfaces are interpreted. Gamma ray data is not available for drill holes Templeton 1 and UD784. The section at Fiery Creek is generalised from the earlier work of researchers at Monash University and does not contain the detailed sedimentological information found in the rest of the logs. Eight sections contain revised interpretations from the earlier NABRE work.

Despite the absence of invertebrate fossils the sequence interpretations, in combination with SHRIMP zircon ages, 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 Geoscience Australia record and the earlier companion data releases of AGSO Records 1999/10, 1999/15 1999/19 and 2000/03 contain chronostratigraphic sequence subdivisions from which original basin shape and sediment architecture can be derived.

Lithostratigraphic miscorrelations associated with quartzite sandbodies of the Warrina Park and Torpedo Creek Quartzites, unit Prc of the Surprise Creek Formation and the lower parts of the Gunpowder Creek Formation and Moondarra Siltstone are resolved. Detailed descriptions and discussions of facies, SHRIMP Zircon ages, lithostratigraphic miscorrelations and rationale for sequence stratigraphic interpretations are provided in Jackson *et al.,* (in prep).

INTRODUCTION

This CD ROM contains outcrop and drill core stratigraphic and sedimentological data from the Surprise Creek Formation, Torpedo Creek and Warrina Park Quartzites, lower Moondarra Siltstone and lower Gunpowder Creek Formation of the Calvert and lowermost Isa Superbasins in northern Australia (Jackson et al 2000, Southgate et al 2000). Thirty four single sections are combined to subsequently form twenty six, composited outcrop and drill core stratigraphic sections. Close to twenty three thousand meters of stratigraphic/sedimentological data and interpretations are provided. The sections are formatted at a variety of scales: Single sections at a scale of 1:400 & 1:1000; composite sections at 1:2500 & 1:5000 scales.

UNIQUE_ID	SECT_LOC	FORMATION	GEOL_100K
JJ/00/01	Batson Section, Sunday Gully	Surprise Creek Formation, Warrina Park Quartzite	Prospector
JJ/00/02	Top Batson Section, Sunday Gully	Surprise Creek Formation, Warrina Park Quartzite, Moondarra Siltstone	Prospector
JJ/00/03	Gereta (upper part)	Warrina Park Quartzite, Moondarra Siltstone	Alsace
JJ/00/04	Gereta (middle part)	Surprise Creek Formation (Prb and Prc)	Alsace
JJ/00/05	Gereta (basal)	Surprise Creek Formation (Pra)	Alsace
JJ/00/06A	Gereta roadside	Surprise Creek Formation (Pra and Prb)	Alsace
JJ/00/06B	Gereta roadside	Surprise Creek Formation (Prc)	Alsace
JJ/00/07	Morella (SE)	Surprise Creek Formation (Prc)	Myally
JJ/00/08	Boomerang anticline	Surprise Creek Formation (Pra1/2/3, Prb, Prc and Prd), Warrina Park Quartzite, Moondarra Siltstone	Mt Oxide
JJ/00/09A	Gunpowder North	Lochness Formation, Surprise Creek Formation (Pra)	Mammoth Mines
JJ/00/09B	Gunpowder North	Surprise Creek Formation (Prd), Torpedo Creek Quartzite, Gunpowder Creek Formation	Mammoth Mines
JJ/00/10A	Bull Creek	Bigie Formation, Surprise creek Formation (Pra and Prb)	Alsace
JJ/00/010B	Bull Creek	Surprise Creek Formation (Prb, Prc and Prd), Warrina Park Quartzite, Moondarra Siltstone	Alsace
PS/00/01	Gunpowder South	Whitworth Quartzite, Torpedo creek Quartzite	Mammoth Mines
PS/00/02	Crocodile Waterhole North	Torpedo Creek Quartzite.	Mammoth Mines
OC/00/01	Oxide Creek area	Bigie Formation, Surprise creek Formation	Mount Oxide
OC/00/02	Oxide Creek area	Surprise Creek Formation, Warrina Park Quartzite	Mount Oxide
HT/00/01	Hidden Treasure Mine	Quilalar Formation, Bigie Formation, Fiery Creek Volcanics, Surprise Creek Formation	Alsace
HT/00/02	Hidden Treasure Mine	Surprise Creek Formation	Alsace
HT/00/03	Hidden Treasure Mine	Surprise Creek Formation, Warrina	Alsace

		Park Quartzite, Moondarra Siltstone	
LJ/00/01	Lake Julius	Quilalar Formation, Bigie Formation	Prospector
LJ/00/02	Lake Julius	Bigie Formation	Prospector
NB/00/01	North Boomerang anticline	Fiery Creek Volcanics, Surprise Creek Formation, Torpedo Creek Quartzite	Myally
BH/00/01	Barr Hole	Surprise Creek Formation, Torpedo Creek Quartzite	Mammoth Mine
BH/01/01	Barr Hole	Surprise Creek Formation, Torpedo Creek Quartzite	Mammoth Mine
MM/00/01	Mammoth Mine	Lochness Formation, Surprise Creek Formation, Torpedo Creek Quartzite	Mammoth Mine
JJ/95/01	Seymour River	Surprise Creek Formation, Fiery Creek Volcanics, Bigie Formation	Mount Oxide
Moondarra 3	Moondarra	Surprise Creek Formation, Warrina Park Quartzite	Mary Kathleen
Paroo Range	Paroo Range	Surprise Creek Formation, Warrina Park Quartzite, Moondarra Siltstone	Prospector
Crocodile Waterhole	Crocodile Waterhole	Surprise Creek Formation, Torpedo Creek Quartzite, Gunpowder Creek Formation	Mammoth Mines
Leichhardt West	Leichhardt West station	Surprise Creek Formation, Warrina Park Quartzite, Moondarra Siltstone, Breakaway Shale, Native Bee Siltstone	Prospector
Crystal Creek	Crystal Creek	Surprise Creek Formation, Warrina Park Quartzite, Moondarra Siltstone, Breakaway Shale, Native Bee Siltstone	Alsace
Fiery Creek Dome	Fiery Creek region	Surprise Creek Formation	Mount Oxide
ML/01/02	Gunpowder Magazine	Lochness Formation, Surprise Creek Formation, Torpedo Creek Quartzite	Mammoth Mines
ML/02/02	Oxide South, west of New Chidna	Surprise Creek Formation, Torpedo Creek Quartzite, Gunpowder Creek Formation	Mammoth Mines

Eight regional transects are included in the data release. Six transects have a north-south orientation, the final transect has an approximate northwest-southeast orientation (Figure 1).

- Transect 1 correlates outcrop sections along a north-south corridor from Fiery Creek Dome in the north to Crystal Creek in the south followed by a dogleg to the northwest to Crocodile Waterhole. The transect crosses the Mount Gordon Fault Zone near the Fiery Creek Dome and then passes from north to south in the Leichhardt River Fault Trough between the Mount Gordon Fault Zone and Ewen Block.
- Transect 2 is a subset of transect 1. It commences in the northern part of the Leichhardt River Fault Trough at the Boomerang North section and finishes in the south at the Crocodile Waterhole section. Transect 1 depicts sequence relationships and correlations as a panel diagram, using the base Gun Supersequence boundary as the datum. However, in Section 2 the relative vertical position of sections is varied so that systems tract geometries for Sequence 3 are optimised. This sequence contains units Prc, Prd, the Warrina Park and Torpedo Creek Quartzites. The geometries depicted in the section highlights the problems associated with the earlier lithostratigraphic correlations.
- Transect 3 correlates outcrop sections along a north-south transect from Hidden Treasure to Lake Moondarra in the Mount Isa Valley followed by a dogleg to the northwest to Paroo Range. This transect is largely restricted to the Myally Shelf and eastern Leichhardt River Fault Trough.

- Transect 4 has an approximate west-east orientation. It commences in the west at Barr Hole, crosses the Mount Gordon Fault Zone between this section and Gunpowder North/Oxide Creek sections and then continues to Gereta in the southeast, adjacent to the western flank of the Kalkadoon-Leichhardt Block. The section has been reconstructed to show systems tract geometries in the Prize Supersequence at approximately 1685 Ma.
- Transect 5 has an approximate north-south orientation. It shows the relationship between the Prize and Gun sequences. The transect commences in the north at the section Oxide South, and incorporates Barr Hole and Esperanza Waters to the south.
- Transect 6 runs south to north. Crocodile Waterhole is the southern most section followed by Investigator South, Investigator North, MM0001, UD784, Gunpowder Magazine, Gunpowder North Composite and finally Oxide Creek Composite in the north.

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

Primary observational data in the 1:400 scale section plots include:

- Lithostratigraphy at Formation and Member levels
- Gamma Ray, Lithology, Grainsize, Sedimentary Structure, Bed Thickness, Summary outcrop descriptions and Sample site locality data.

Primary observational data in the 1:1000 scale section plots include:

- Lithostratigraphy at Formation and Member levels
- Gamma Ray, Lithology, Grainsize, Sedimentary Structure, Bed Thickness, Summary outcrop descriptions and Sample site locality data.

Primary observational data in the 1:2500 composite section plots include:

- Lithostratigraphy at Formation and Member levels
- Gamma Ray, Lithology, Grainsize, Sedimentary Structure and Bed Thickness data.

Interpreted data in the 1:2500 scale composite plots includes:

- Facies summaries and Sequence stratigraphic interpretations

Primary observational data in the 1:5000 composite section plots includes:

- Gamma Ray, Lithology, and Grainsize data

Interpreted data in the 1:5000 scale composite plots is restricted to

- Sequence stratigraphic interpretations

The CD ROM also contains digital location information for the outcrop sections and drill cores. The location of measured sections and drill holes is shown in Figure 1. The chronostratigraphic Event Chart (Figure 2) summarises the sequence stratigraphic subdivision for the Calvert and Isa Superbasins. It includes several new ages for the Surprise Creek Formation and revises the earlier chart of Southgate *et al* ., (2000). Detailed descriptions of facies and stratigraphic architecture are included in Jackson et al (in prep).

Clients will notice differences between the sequence nomenclature in Domagala *et al.,* (2000) and those shown in the section plots included in this CD ROM. In 1999/2000 the dataset for the Surprise Creek Formation was limited to four sections from the Lake Moondarra region and one section to the east, at Leichhardt West. Sequence interpretations for the Prize Supersequence (Southgate *et al.,* 1999; Domagala *et al.,* 2000) were always regarded as preliminary and we were aware of stratigraphic inconsistencies in the use of the terms Warrina Park Quartzite and Torpedo Creek Quartzite. The regional dataset presented in this CD ROM has enabled resolution of the lithostratigraphic miscorrelations with consequent high-grading of the sequence picks provided in the earlier publications (see Figure 3 for summary diagram).

A subset of the stratigraphic information is found in the folder Gunpowder Workshop. This dataset contains section plots from the Oxide Creek, Gunpowder North, Bull Creek, Crocodile Waterhole and Barr Hole sections. The plots were customised for use in a field-based sequence stratigraphic basin analysis workshop on the Prize Supersequence.

DATASETS AND METHODOLOGY

Most of the stratigraphic data was collected from outcrop sections. Drill core information is restricted to two holes, UD 784 from the Mount Gordon Mine and Templeton 1 from the May Downs region made available by Western Metals and MIMEX respectively. The quality of outcrop and vehicle access provided the principal constraint in the selection of areas suitable for measuring sections. 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 in the vicinity of Gunpowder provide an understanding of the timing of relative movement along the Mount Gordon Fault Zone and associated E-W structures. Outcrop discontinuities prevented the collection of stratigraphic data in a line of continuous section. As a result most of the single sections (1:1000 scale plots) are combined to form composite sections (1:2500 and 1:5000 scale plots). The single sections were all measured within a radius of several kilometres of each other. Individual sections were spliced together at prominent marker beds (outcrop tracing of strata), 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 Jacobs Staff and Abney Level and the rocks were marked in 1.5 m intervals of true thickness. Gamma ray data was collected at 75 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.

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 and 3rd 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. Southgate *et al.,* (2000) and Domagala *et al.,* (2000) grouped rocks of the Surprise Creek Formation, Mount Isa and lower McNamara Groups into the Prize and Gun Supersequences. Sequences 1-4 in this study belong to the Prize Supersequence and are best referred to as Prize 1, Prize 2, Prize 3 and Prize 4. Incision at the Gun Supersequence boundary (Southgate *et al.,* 2000) has removed the upper parts of the Prize Supersequence. Each Supersequence name is followed by a number, which identifies the respective third order sequence. The letters 't' and 'f' refer to the type of surface, 't' denotes transgressive surface and 'F' maximum flooding surface.

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. 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-upward 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 Prize F3 and Prize 4 surfaces in the Bull Creek Section Cleaning-up trends may occasionally result from a gradual change from clastic to carbonate deposition, or a gradual decrease in anoxia (Emery & Myers, 1996).

2. A dirtying-upward gamma trend shows a progressive upward increase in gamma readings, which commonly indicates overall fining-upward successions, typically within shale-prone intervals. This trend is particularly well developed beneath the Prize F1 and Prize F2 surfaces (eg Oxide Creek and Bull Creek sections). Dirtying upward trends are common in fluvial successions, tidal channels, and estuarine fills (Emery & Myers, 1996). In shallow marine settings, dirtying-upward

trends often indicate the retreat or abandonment of a shoreline–shelf system (examples above; Emery & Myers, 1996). In deep marine settings, the dirtying-upward 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. In the Prize Supersequence these signatures are best developed in units, Pra1 and Prc of the Surprise Creek Formation, the Torpedo Creek Quartzite and Warrina Park Quartzite above the Prize 1 and Prize 3 Sequence Boundaries. 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). At the Prize 3 and Prize 4 Sequence Boundaries this switch marks a sharp basinward shift in facies belts (Jackson *et al.,* in prep). Boxcar trends are commonly found in fluvial channel sands, turbidites, aeolian sands, and occasionally within evaporites (Emery & Myers, 1996).

4. Bow or symmetrical trends consist of a cleaning-upward trend overlain by a dirtying-upward 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 lack systematic changes in either the sand or shale base-lines (Emery & Myers, 1996). Irregular trends generally represent aggradation of a shale prone or silt prone lithology, and are typical of shelfal or deep water settings (Emery & Myers, 1996). Examples of this motif are found in the relatively deep water, undulatory rhythmite and flat rhythmite facies of units Prb and Prd associated with the Prize F2 and F3 condensed sections.

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 1-10 m 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 of units Prb & Prd). 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 Type 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 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 with structurally controlled local depocentres develop (Surprise Creek Package) LST deposits typically comprise prograding and aggrading wedges of quartzite sandstone (Unit Prc and parts of the Torpedo Creek and Warrina Park Quartzites). 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 the basinward shift in facies may be recorded by a subtle change from laminite facies to tempestite facies. 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. Examples of this scenario are well developed in the Prize Supersequence e.g. (Prize 3 and 4 Sequence Boundaries associated with units Prc and parts of the Warrina Park and Torpedo Creek Quartzites).

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 (Prize 2-F2 and Prize 3-F3). 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). The switch from white quartzitic sandstones of the cyclic and spotted quartzite facies of unit Prc to tempestite and rhythmite facies of unit Prd (Sequence 3 at Oxide Creek) provides an example of progressive retreat of the shoreline and the drowning of siliciclastic provenance areas during a major marine transgression. Carbonaceous and pyritic shales in unit Prd at Oxide Creek are condensed section deposits at the top of this TST. These deposits mark the time of maximum increase in accommodation rates for the Prize Supersequence.

The highstand systems tract (HST) is the youngest and uppermost systems tract in Type 1 & 2 sequences. 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. In basinward positions, where rates of sediment supply are comparatively low, aggradational stacking patterns may occur in early highstand deposits (e.g. Prize 2 & 3 deposits above the 2F and 3F surfaces at Oxide Creek, Gereta and Hidden Treasure). In some ramp settings a succession of basinward stepping, prograding wedges can mark the terminal parts of HST deposits. These wedges of sediments are termed forced regressive wedges (Posamentier et al, 1992). The uppermost Prize 3 highstand deposits at Oxide Creek probably represent a forced regressive wedge.

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 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 (T) 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 (F) 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 maximum flooding surface occurs within the condensed section (Loutit *et al.,* 1988). The condensed section is usually identified as a shale-prone, often 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 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 order sequence boundaries on north-south structures such as the Mount Gordon Fault Zone provides additional evidence for tectonism at the 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 2) summarises the sequence nomenclature for the Calvert and Isa Superbasins in the McArthur, Murphy, Lawn Hill, Gunpowder and Mt Isa regions (Southgate *et al.,* 2000). Rocks belonging to the Surprise Creek Formation and lower McNamara Group (Torpedo Creek Quartzite and Gunpowder Creek Formation) lower Mt Isa Group (Warrina Park Quartzite and Moondarra Siltstone) are combined to form the Prize and lower parts of the Gun Supersequences, each separated by an unconformity surface.

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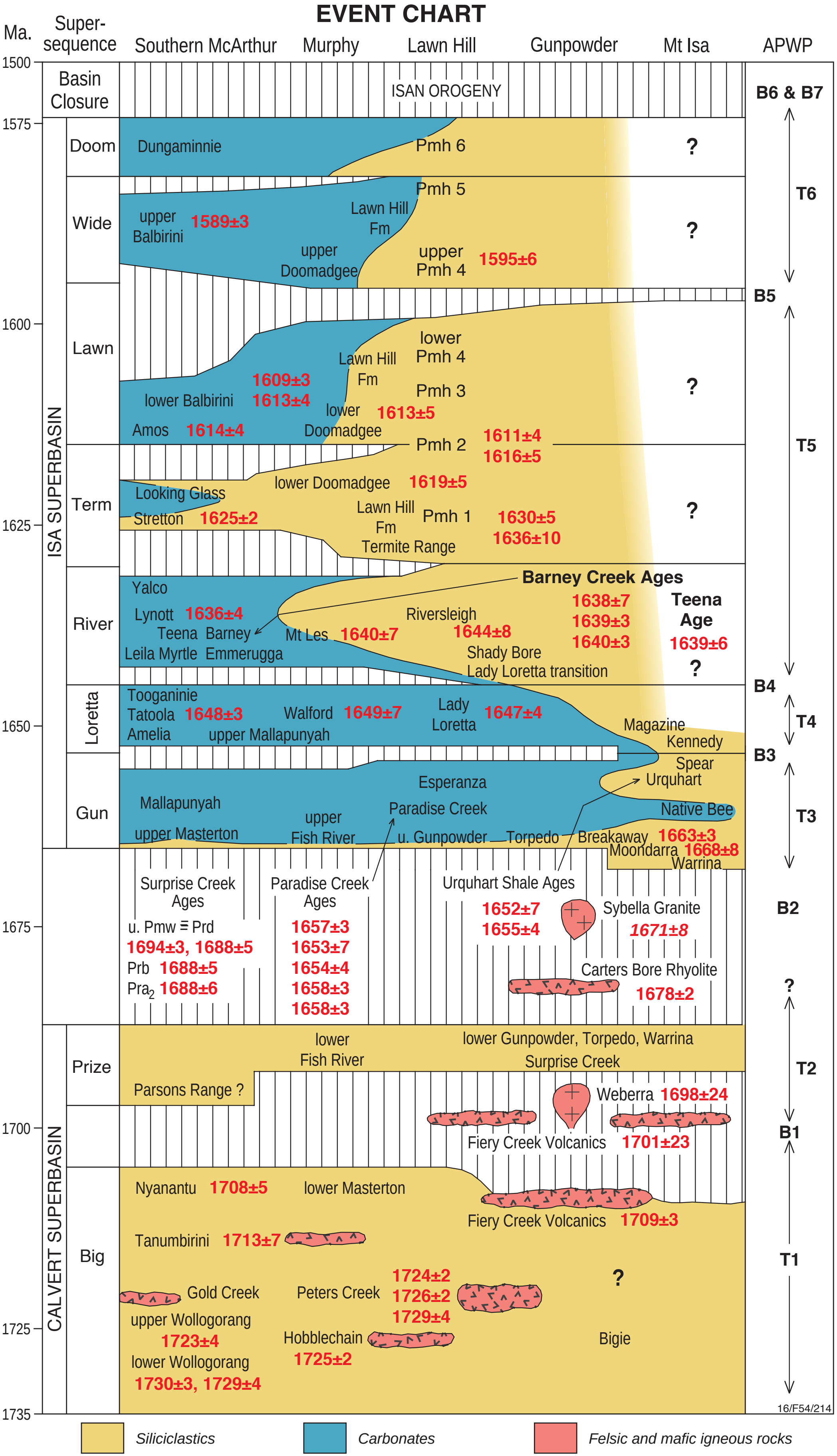
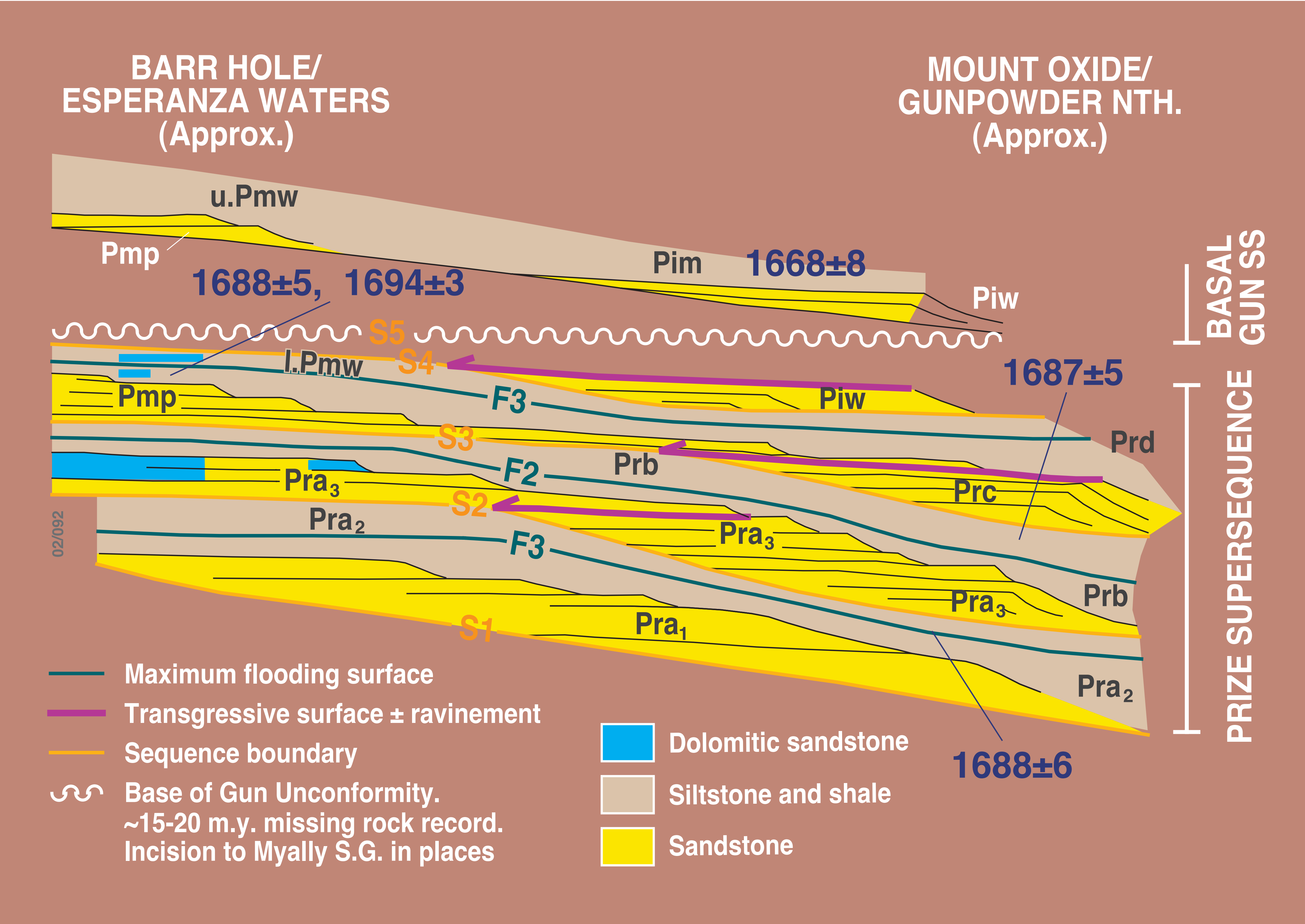
0
20
40
60 km
NABRE / AMIRA p552 GIS data : AJRetter
Drillhole location
Measured section location
Younger units
Surprise Creek Formation
Fiery Creek Volcanics
Bigie Formation
Quilalar Formation
Myally Subgroup
Haslingden Group
Basement
139 00
139 30
18 45
140 00
19 00
20 00
21 00
FIERY DOME
BOOMERANG NORTH
MORELLA
BOOMERANG SOUTH
SEYMOUR RIVER
TRANSECT 6
OXIDE CREEK
OXIDE SOUTH
TRANSECT 2
BARR HOLE
GUNPOWDER NORTH
TRANSECT 5
GUNPOWDER MAGAZINE
DD98UD784
ESPERANZA WATERS
BULL CREEK
EWAN BLOCK
DERRICK- "QUILALAR ARCH"
WHITE HILLS
HIDDEN TREASURE
TRANSECT 4
HARE CREEK
INVESTIGATOR NORTH
INVESTIGATOR SOUTH
TRANSECT 1
CROCODILE WH
CRYSTAL CREEK
GERETA
TRANSECT 3
LAKE JULIUS
SUNDAY GULLY
PAROO RANGE
LEICHHARDT WEST
MOONDARRA 3
Tempelton 1



EVENT CHART
Ma.
Super-sequence
Southern McArthur
Murphy
Lawn Hill
Gunpowder
Mt Isa
APWP
1500
1575
1600
1625
1650
1675
1700
1725
1735
Basin Closure
ISAN OROGENY
B6 & B7
ISA SUPERBASIN
Doom
Dungaminnie
Pmh 6
?
T6
Wide
upper Balbirini
1589±3
Lawn Hill Fm
Pmh 5
upper Doomadgee
upper Pmh 4
1595±6
?
B5
Lawn
lower Pmh 4
Lawn Hill Fm
1609±3
1613±4
lower Balbirini
Pmh 3
lower Doomadgee
1613±5
Amos
1614±4
?
T5
Pmh 2
1611±4
1616±5
Term
Looking Glass
lower Doomadgee
1619±5
Stretton
1625±2
Lawn Hill Fm
Pmh 1
1630±5
1636±10
Termite Range
?
River
Barney Creek Ages
Yalco
Lynott
1636±4
Teena
Barney
Leila Myrtle
Emmerugga
Mt Les
1640±7
Riversleigh
1644±8
1638±7
1639±3
1640±3
Teena Age
1639±6
Shady Bore
Lady Loretta transition
?
B4
Loretta
Tooganinie
Tatoola
1648±3
Amelia
Walford
1649±7
upper Mallapunyah
Lady Loretta
1647±4
Magazine
Kennedy
T4
B3
Gun
Mallapunyah
upper Masterton
Esperanza
Paradise Creek
upper Fish River
u. Gunpowder
Torpedo
Spear
Urquhart
Native Bee
Breakaway
1663±3
Moondarra
1668±8
Warrina
T3
Surprise Creek Ages
u. Pmw ≡ Prd
1694±3, 1688±5
Prb 1688±5
Pra2 1688±6
Paradise Creek Ages
1657±3
1653±7
1654±4
1658±3
1658±3
Urquhart Shale Ages
1652±7
1655±4
Sybella Granite
1671±8
Carters Bore Rhyolite
1678±2
B2
?
CALVERT SUPERBASIN
Prize
lower Fish River
lower Gunpowder, Torpedo, Warrina
Surprise Creek
Parsons Range ?
Weberra
1698±24
Fiery Creek Volcanics
1701±23
T2
B1
Big
Nyanantu
1708±5
lower Masterton
Fiery Creek Volcanics
1709±3
Tanumbirini
1713±7
Gold Creek
Peters Creek
1724±2
1726±2
1729±4
?
upper Wollogorang
1723±4
Hobblechain
1725±2
Bigie
lower Wollogorang
1730±3, 1729±4
T1
16/F54/214
Siliciclastics
Carbonates
Felsic and mafic igneous rocks



BARR HOLE/
ESPERANZA WATERS
(Approx.)
MOUNT OXIDE/
GUNPOWDER NTH.
(Approx.)
u.Pmw
Pmp
Pim
1668±8
Piw
1688±5, 1694±3
S5
BASAL GUN SS
l.Pmw
S4
Piw
1687±5
Pmp
F3
S3
Prd
Prb
F2
Pra3
Prc
S2
Pra2
Pra3
F3
Prb
Pra3
Pra1
S1
Pra2
PRIZE SUPERSEQUENCE
02/092
1688±6
Maximum flooding surface
Transgressive surface ± ravinement
Sequence boundary
Base of Gun Unconformity.
~15-20 m.y. missing rock record.
Incision to Myally S.G. in places
Dolomitic sandstone
Siltstone and shale
Sandstone

FIGURE CAPTIONS

Figure 1
Outcrop Geology map for the Leichhardt River Fault Trough and eastern Lawn Hill Platform showing the location of measured sections and transects featured in this CD ROM.

Figure 2
Event Chart for the Calvert and Isa Superbasins of northern Australia. This is a Revised Version of the event chart presented in Southgate *et al.,* (2000). This revised event chart includes new stratigraphic information and SHRIMP ages collected in this study and reported in Jackson et al (in prep).

Figure 3
Summary sequence stratigraphic diagram for the Prize Supersequence showing the relationships between sequences, systems tracts and lithostratigraphic units. SHRIMP zircon ages are included in the diagram.


Sections
>> Single
>> Drill Holes
>> Composite
>> Transects
>> Geoscience Australia Record 2002/03
GEOSCIENCE AUSTRALIA

Drill Holes

>> 1:1000

>> 1:2500

>> 1:5000

<< Go Back

GEOSCIENCE AUSTRALIA


Single Sections
>> 1:400
>> 1:1000
>> 1:2500
>> 1:5000
<< Go Back
GEOSCIENCE AUSTRALIA


Composite Sections
>> 1:400
>> 1:1000
>> 1:2500
>> 1:5000
<< Go Back
GEOSCIENCE
AUSTRALIA

SINGLE SECTION 1:400
ML/01/02

COMPOSITE SECTION 1:400
Oxide Creek (OC/00/01, OC/00/02, 97/OC/01, 97/OC/01, 97/OC/02, 07/OC/03)

SINGLE SECTION 1:1000
JJ/00/01
JJ/00/02
JJ/00/03
JJ/00/04
JJ/00/05
JJ/00/06A
JJ/00/06B
JJ/00/07 (Morella)
JJ/00/08 (South Boomerang)
JJ/00/09A
JJ/00/09B
JJ/00/10A
JJ/00/010B
OC/00/01
OC/00/02
HT/00/01
HT/00/02
HT/00/03
LJ/00/01
LJ/00/02
BH/01/01
MM/00/01 (Mammoth Mine)
JJ/95/01 (Seymour River)
Crocodile Waterhole
Fiery Creek Dome
ML/01/02

COMPOSITE SECTION 1:1000
Oxide South (ML/02/02a, ML/02/02c, ML/02/02d, ML/02/02e, ML/02/02e2, ML/02/02f

DRILL HOLES 1:1000
Templeton1
UD784

SINGLE SECTIONS 1:2500

JJ/00/07 (Morella)
JJ/00/08 (South Boomerang)
PS/00/01 (Investigator North)
PS/00/02 (Investigator South)
NB/00/01 (North Boomerang)
BH/00/01 (Barr Hole01)
MM/00/01 (Mammoth Mine)
JJ/95/01 (Seymour River)
Moondarra 3
Crocodile Waterhole
Fiery Creek Dome
ML/01/02

COMPOSITE SECTIONS 1:2500

Barr Hole Composite (Barr Hole, BH/00/01, BH/01/01)
Bull Creek (JJ/00/10A, JJ/00/10B)
Crystal Creek (96/CY/01, 96/CY/02, 96/CY/03, 96/CY/04)
Gereta (JJ/00/03, JJ/00/04, JJ/00/05, JJ/00/6A, JJ/00/06B)
Gunpowder North (JJ/00/01, JJ/00/02)
Hidden Treasure (HT/00/01, HT/00/02, HT/00/03)
Lake Julius (LJ/00/01, LJ/00/02)
Leichhardt West (97/LW/01, 97/LW/02, 97/LW/03, 97/LW/04, 97/LW/05, 97/LW/06, 97/LW/07, 97/LW/08)
Oxide Creek (OC/00/01, OC/00/02, 97/OC/01, 97/OC/01, 97/OC/02, 07/OC/03)
Paroo Range (96/par/01, 96/par/03, 96/par/05, 96/par/06, 96/par/07)
Sunday Gully (JJ/00/01, JJ/00/02)
Oxide South (ML/02/02a, ML/02/02c, ML/02/02d, ML/02/02e, ML/02/02e2, ML/02/02f)

DRILL HOLES 1:25000

Templeton1
UD784

SINGLE SECTIONS 1:5000

JJ/00/07 (Morella)
JJ/00/08 (South Boomerang)
PS/00/01 (Investigator North)
PS/00/02 (Investigator South)
NB/00/01 (North Boomerang)
BH/00/01 (Barr Hole01)
MM/00/01 (Mammoth Mine)
JJ/95/01 (Seymour River)
Moondarra 3
Crocodile Waterhole
Fiery Creek Dome

COMPOSITE SECTIONS 1:5000

Barr Hole Composite (Barr Hole, BH/00/01, BH/01/01)
Bull Creek (JJ/00/10A, JJ/00/10B)
Crystal Creek (96/CY/01, 96/CY/02, 96/CY/03, 96/CY/04)
Gereta (JJ/00/03, JJ/00/04, JJ/00/05, JJ/00/6A, JJ/00/06B)
Gunpowder North (JJ/00/9A, JJ/00/09B)
Hidden Treasure (HT/00/01, HT/00/02, HT/00/03)
Lake Julius (LJ/00/01, LJ/00/02)
Leichhardt West (97/LW/01, 97/LW/02, 97/LW/03, 97/LW/04, 97/LW/05, 97/LW/06, 97/LW/07, 97/LW/08)
Oxide Creek (OC/00/01, OC/00/02, 97/OC/01, 97/OC/01, 97/OC/02, 07/OC/03)
Paroo Range (96/par/01, 96/par/03, 96/par/05, 96/par/06, 96/par/07)
Sunday Gully (JJ/00/01, JJ/00/02)

DRILL HOLES 1:5000

Templeton1
UD784