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Integrated Basin Analysis of the Isa Superbasin using Seismic, Well-log and Geopotential Data:

An Evaluation of the Economic Potential of the Northern Lawn Hill Platform

edited by
B.E. Bradshaw and D.L. Scott

AGSO Record 1999/19

The North Australian Basins Resource Evaluation was a multidisciplinary project.

Its aim was to provide the mineral exploration industry with a predictive chronostratigraphic basin framework in northern Australia.

The project was a collaborative venture of the Commonwealth, Queensland and Northern Territory Governments, funded under the National Geoscience Mapping Accord.

Industry collaboration provided access to confidential drill core and regional geophysical datasets.

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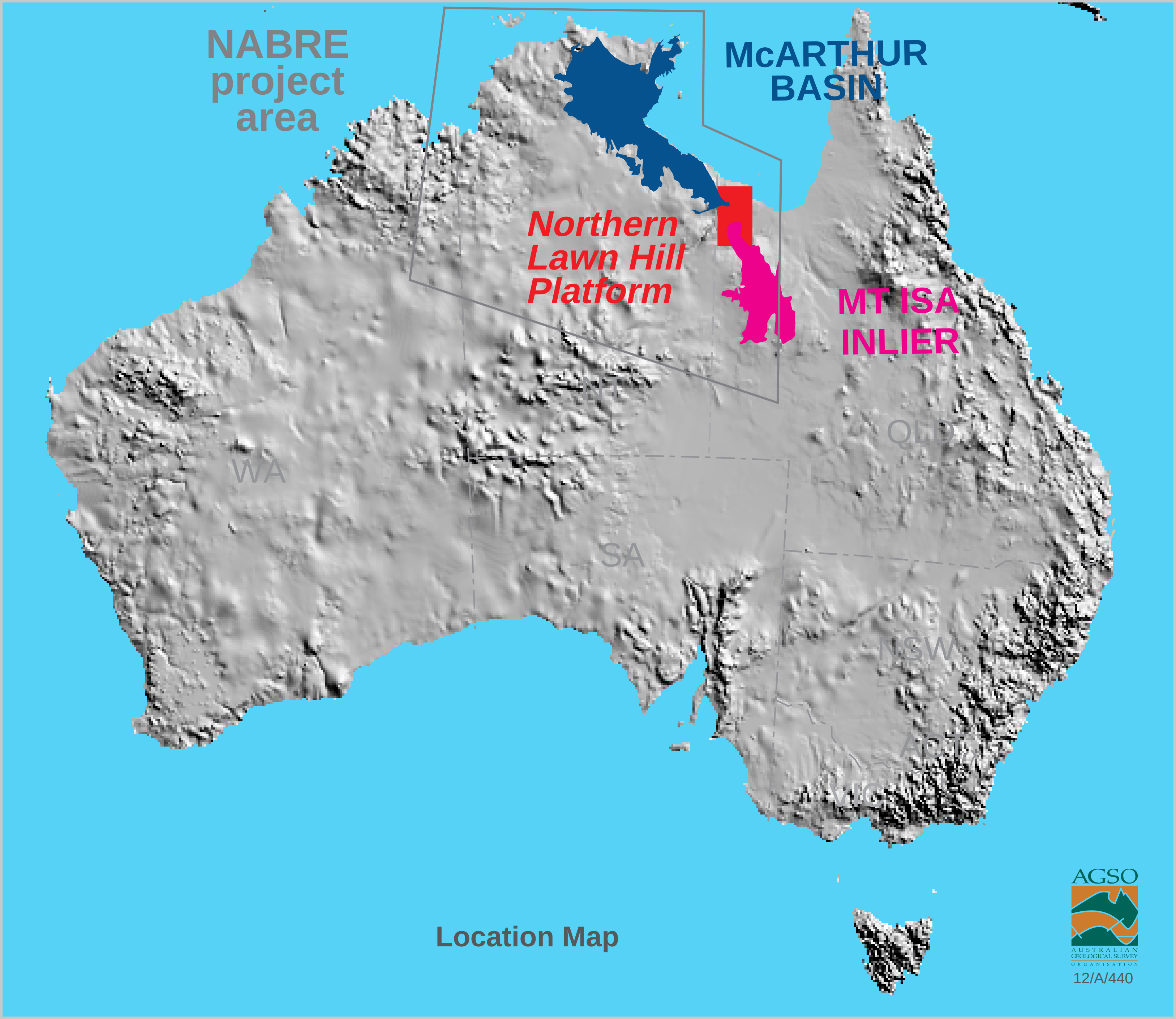
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area
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MT ISA
INLIER
WA
SA
QLD
NSW
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VIC
Location Map
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List of Contents

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CHAPTER 1

Introduction, Background and Regional Geology

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Chapter 1

INTRODUCTION, BACKGROUND and REGIONAL GEOLOGY

1.1. Integrated Seismic, Well log, and Geopotential Database of the Northern Lawn Hill Platform

(B.E. Bradshaw, D.L. Scott, A.A. Krassay, and J. Leven)

NABRE (North Australia Basin Resource Evaluation) is a multidisciplinary National Geoscience Mapping Accord (NGMA) project. The north Australian Carpentaria–Cloncurry mineral belt is endowed with several world-class Proterozoic sediment-hosted lead–zinc–silver, copper, and gold deposits. Current mineral exploration models are based largely on interpretations of near-surface strata made from geological maps, geochemical databases, and potential-field data sets. A growing interest now exists in predicting the occurrence of potential exploration targets in areas within 500m of subsurface cover. Traditional exploration strategies are unable to accurately predict such subsurface targets. Instead, a multidisciplinary regional basin analysis is required using seismic and geopotential data, outcrop, drill core, and wireline logs. Modern basin analysis techniques from the petroleum exploration industry are particularly useful in evaluating the structural and sequence stratigraphic framework of basins containing sediment-hosted ore bodies. As well as documenting the structural and stratigraphic evolution of the northern Lawn Hill Platform in the Isa Superbasin, this report provides an example of how integrated basin analysis techniques can be used to identify mineral plays beneath shallow cover.

Seismic reflection profiles provide important details on the continuity of stratal surfaces, geometry and stacking patterns of sedimentary sequences, burial history of strata, potential fluid-flow pathways, and the structural controls on basin evolution. The seismic database used in this record is a 2-D grid along the southern flanks of the Murphy Inlier (**Fig. 1.1.1**). Between 1986 and 1991 Comalco Aluminium Ltd acquired approximately 1000km of reflection seismic profiles that image well preserved parts of the Isa Superbasin away from deformed areas to the south and east. The seismic data grid straddles the boundary of the 1:250 000 Westmoreland *(Grimes and Sweet, 1979)* and Lawn Hill *(GSQ, 1983)* map sheets, which comprise the study area for this report. Rationale behind Comalco's exploration program is described by *McConachie et al. (1993)*.

Digital copies of the original final stack Comalco seismic lines were obtained from the Geological Survey of Queensland (GSQ) and migrated by Jim Leven, AGSO. Dipping reflections on unmigrated (or stack) seismic sections are plotted downdip from and with a lower dip than their true reflection position or depth point *(Dobrin and Savit, 1988)*. The migration process attempts to reposition reflected energy of dipping events to its true subsurface location. However, a limitation of 2-D seismic migration is that it assumes true dip within the plane of the seismic section, and is therefore only completely successful on true “dip lines”. A true dip line is correctly migrated whereas a strike line is not migrated at all and oblique lines are only partially successfully migrated. Intersections of dip and strike lines therefore commonly mistie, but do so in a systematic manner.

In the reprocessed Comalco data set, migration misties are generally insignificant (‹25 msec). However, migration misties of up to 125msec occur at some intersections with steeply dipping events (**Fig. 1.1.2**, **Table 1.1.1**). Algorithms for producing digital isochron and time structure maps generally cannot tolerate misties of this magnitude. To overcome this, isochron maps in this report were created using forced tied interpretations. However, the archive series (**Preliminary Edition Data Release**) and illustrated seismic sections show the correct reflection positions of sequence boundaries.

Additionally, a post migration coherency filter was applied to the seismic data to enhance coherent events and remove unwanted noise. The application of this filter destroys true amplitude information. Therefore, care must be exercised in interpreting the relative amplitudes of the reflection events in the migrated sections. The effect of enhancing coherence between peaks from one seismic trace with its neighbour can lead to the appearance of reflection continuity where in reality a minor offset may exist (see discussion of late stage fracturing in **Chapter 3**). Another effect is the apparent merging of reflection terminations into the reflection above or below. The identification of reflection terminations and their relationship with adjacent reflections is key to defining the sequence stratigraphy (see **Preliminary Edition Data Release** for summary on interpretation methodology). The determination of which branch of a merger is often dependent on the ability of interpreted horizons to tie at intersections throughout the grid.

Table 1.1.1 Comalco seismic grid mistie table.

STRIKE LINE *tied to*	**DIP LINE *misties at***	**SUPERSEQUENCE LEVEL**
89BN-03	89BN-06	Loretta to Big
91BN-03	91BN-08	Gun to Big
91BN-03	91BN-09	Loretta to Big
91BN-41	91BN-06	Gun to Big
91BN-41	91BN-07	River to Big
91BN-41	91BN-46	River to Big
91BN-41	91BN-47	Loretta to Big
91BN-43	91BN-08	River to Big
91BN-43	91BN-47	River to Big
91BN-50	91BN-52	Loretta to Big
91BN-51	91BN-52	Gun to Big
91BN-54	91BN-53	Gun to Big

Four petroleum wells drilled by Comalco (**Argyle Creek_1**, **Desert Creek_1**, **Egilabria_1**, and **Beamesbrook_1**) within the seismic grid provide the most complete well log data sets through Proterozoic strata. Each well contains spontaneous potential, bulk density, neutron porosity, gamma ray, sonic velocity, resistivity, and ditch gas curves. Detailed lithological descriptions are provided with original percentage estimates of each lithology. Most wells also contain check shot velocity surveys (except Beamesbrook_1), synthetic seismograms, deviation surveys, and broad sampling of TOC and base metal values. Well completion and VSP reports for the four Comalco wells *(Dunster et al., 1989, 1993 [a,b,c])* are readily available through the GSQ.

There has been extensive drilling by several companies along the flanks of the southern Murphy Inlier in the last few decades. However, most of the well completion records contain lithofacies data with no accompanying wireline logs. In this record, only wells with gamma curves accompanying lithological descriptions are used to interpret and correlate sequence boundaries. These include 6 holes from the Walford Creek Prospect (Western Mining Corporation), and three holes from the Gorge Creek Prospect (Elf Aquitaine QLG_5001, QLG_5002, and Amoco 83_4). In most completion reports, qualitative descriptions of major and minor lithologies are provided. We have subsequently estimated a percentage of each lithology to produce lithological striplogs to accompany the gamma logs.

Gamma-ray curves from outcrop sections were obtained using a hand held spectrometer (Scintrex GRS-500). Natural radioactivity readings were taken over 10-second periods at 0.5m intervals of true thickness. Gamma ray curves permit correlation into subsurface datasets. Similar techniques have been used on Phanerozoic strata, but this is the first time this technique has been used extensively on Proterozoic stratigraphy. The use of the methodology has also been rare in the analysis of mineral systems. Detailed lithological descriptions were obtained simultaneously to accompany the gamma logs. Composite sections for the Upper McNamara, lower McNamara, and Fickling Groups were subsequently compiled using GEOLOG© software distributed by Mincom®.

Palaeomagnetism and Super High Resolution Ion Microprobe (SHRIMP) analyses on zircons provide independent age constraints. Apparent Polar Wander Path (APWP) data were originally collected from the McArthur Basin in the late 1970’s *(Idnurm et al. 1995)*. In this study, additional poles from the Lawn Hill region help constrain the chronostratigraphic correlations. Rocks of the Isa Superbasin also contain numerous, zircon-rich, tuffs and redeposited tuffaceous beds, typically found in deeper water facies in areas of relative low sedimentation. Many have undergone K-feldspar metasomatism so that gamma ray data assists with their detection. Zircons from these beds provide precise and/or maximum depositional ages and assist with determining the order of sequence boundaries.

Regional gravity and magnetic data for the two 1:250 000 map sheet areas (17°00S-19°00S, 138°00E-139°30) were extracted from the AGSO national data sets *(Murray, 1997; Tarlowski et al., 1996, 1997)*. The gravity data were extracted at a resolution of 2500m grid cell size (gcs). The data were then regridded to 400m gcs using the minimum curvature technique. Image enhancement included applying the HSV colour model *(Milligan, et al 1992)*, a sun azimuth of 315°, elevation 45° and a vertical exaggeration of *100 (Horn,* *1981)*. The magnetic data were extracted at a resolution of 400m gcs and enhanced in the same way as the gravity data except that a vertical exaggeration of 20 was applied. Depth to magnetic source was computed using the Phillips Deconvolution Method *(Phillips, 1995)*. Depths were calculated from 1600m-spaced extracted N-S profiles and regridded to 400m gcs using the minimum curvature technique.

1.2. Tectonostratigraphic Overview of the Isa Superbasin

(P.N. Southgate, B.E. Bradshaw, D.L. Scott, J. Domagala, M. Idnurm, M.J. Jackson, A.A. Krassay, J.F. Lindsay, R.W. Page, T.T. Sami, and A.T. Wells)

The Comalco seismic grid provides subsurface data on the geometry and tectonic history of intracratonic basins of the northern Lawn Hill Platform (**Fig. 1.2.1**). This region forms the northern extension of a broad N-S belt of Proterozoic outcrop termed the "Mount Isa Inlier" (**Fig. 1.2.2**; *Blake, 1987*). Its northern boundary abuts the Murphy Inlier, across which the outcrop belt extends to the NW into the Wearyan Shelf and McArthur *Basin (Jackson et al., 1987)*. Intracratonic basin development was initiated at around 1900Ma when many of the cratonic elements of the present-day Australian continent show evidence for widespread extension *(Myers, et al., 1996; Etheridge et al., 1987; Etheridge and Wall, 1994)*. Subsequent deformation during the Barramundi Orogeny at c.1870Ma established metamorphic basement for the region. At its northern extent the seismic grid impinges on the Murphy Inlier (**Fig. 1.2.1**). From here it extends approximately 50kms to the south and terminates to the north of the main belt of Palaeoproterozoic outcrop of the Lawn Hill Platform. Throughout most of the seismic grid Palaeoproterozoic outcrop is buried beneath a variably thick Phanerozoic cover.

Post-Barramundi Orogeny rocks were divided by *Blake (1987)* into three "cover sequences" separated by regionally evident angular unconformities. The cover sequence terminology is widely used but we feel it is misleading because strata within at least the two younger cover sequences also contain evidence of multiple tectonic events. South of the study area, in the eastern part of the Mount Isa terrain, *O'Dea et al. (1997)* support a single episode of rifting, the Leichhardt Rift, which corresponds to *Blake's (1987)* "cover sequence 2". The stratigraphy includes a 6-8km package of continental flood basalts (Eastern Creek Volcanics) lacking associated felsics *(Bain et al., 1992)*, and several kilometres of carbonate and siliciclastic sediments (**Fig. 1.2.3**). *Eriksson et al. (1993)* provide convincing evidence for a number of rift-sag events within this stratigraphic interval, inferring a series of stacked basins or basin phases within "cover sequence 2". Likewise, NABRE studies *(Scott and Bradshaw, 1997; Scott et al., 1998[a])* and fieldwork to the south *(O'Dea et al., 1997; Betts and Lister, 1997; Betts, 1998)* demonstrate that "cover sequence 3" incorporates at least three major tectonic events.

McConachie et al. (1993) published an interpretation of the Comalco seismic data and proposed the term "Mount Isa Basin" for Palaeo- and Mesoproterozoic strata included in “cover sequence 3” of *Blake (1987)* and the overlying South Nicholson Group. In their interpretation the Upper McNamara to South Nicholson Groups represent a progressively developing foreland basin (**Fig. 1.2.4**). Beneath the interpreted foreland basin occurs a thin "passive margin" package (lower McNamara Group) and a basal "rift" package (Peters Creek Volcanics). As discussed below, the term "Mount Isa Basin" is considered inappropriate for the Palaeoproterozoic and genetically unrelated Mesoproterozoic basins interpreted in this study.

The NABRE interpretation (**Fig. 1.2.5**) does not include tectonic activity and stratigraphic growth in the "rift" package of *McConachie et al. (1993)*. Instead, a major tectonic event and accompanying volcanism beneath the “acoustic basement” reflection is interpreted (**Figs. 1.2.5** and **1.2.6**). This study provides evidence for a series of stacked sedimentary basins within the Palaeoproterozoic, some bounded by major angular unconformities (**Fig. 1.2.5**). Both our sequence stratigraphic and structural interpretations (**Chapters 2** and **3**) of the Palaeoproterozoic package support a tectonic evolution marked by transtensional to extensional and inversion structural events, that punctuated periods of regional subsidence. Finally, outcrop relationships, seismic data, and geochronological ages provide ample evidence that the Palaeoproterozoic and Mesoproterozoic successions are neither spatially nor temporally linked.

A growing body of evidence suggests that sediment accumulation in Palaeoproterozoic Isa Superbasin of northern Australia was punctuated by numerous regional tectonic events. These events produced significant changes in rates of accommodation and sediment supply, leading to the development of angular unconformities and correlative conformities. Previous interpretations regarded this period of basin evolution as a sag phase *(O’Dea et al. 1997, Betts et al. 1996)*. The identification of numerous tectonic events in the Palaeo- and Mesoproterozoic successions of northern Australia renders the Superbasin terminology of *Walter et al. (1992, 1995)* an appropriate description of this series of stacked sedimentary basins. The term Isa Superbasin is used to describe those Palaeoproterozoic rocks formerly included in “cover sequence 3” (**Fig. 1.2.3**).

In this interpretation, the Isa Superbasin is subdivided into nine supersequences or basin phases as defined by *Duval et al., (1992)*. Each 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 publication, the broad packaging of seismic sequences is described at the supersequence level (eg the Gun Supersequence). The resolution of seismic sequences is generally only to the third-order scale and described by adding a single digit number after the supersequence (eg the Gun 2 sequence). Well logs and outcrop sections allow a detailed fourth-order interpretation of sequences which are described by adding a second digit, such that the Gun 2.3 refers to the third, fourth order sequence in the second, third order sequence of the Gun Supersequence.

Rocks of the Isa Superbasin span an interval of approximately 150Ma, and include a number of lithostratigraphic groups and formations as well as igneous units (**Fig. 1.2.3**). These rocks, and their metamorphosed equivalents in the eastern succession host major zinc-lead-silver deposits in northern Australia. A regional thermal and structural event produced felsic and mafic volcanics and associated volcaniclastic sedimentation between 1700-1730Ma. This event created a basement template or architecture that influenced the geometry of subsequent supersequences in the Isa Superbasin. Sedimentation ceased in response to regional uplift, widespread shortening, and metamorphism during the Isan Orogeny between 1575 and 1500Ma. *(Blake 1987, O'Dea et al., 1997)*. Isa Superbasin sediments attain a maximum cumulative thickness of approximately 15kms. However, they are locally much thinner with approximately 1.5kms preserved along the southern flanks of the Murphy Inlier where reactivated basement faults and local igneous activity resulted in repeated incision and reduced rates of accommodation (**Figs. 1.2.3** and **1.2.5**).

The seismic grid images a reflective package of sediments corresponding to Palaeoproterozoic units ranging in age from c.1710Ma to c.1585Ma *(Page and Sweet, 1998; Page et al., in press)*. In outcrop, this succession is represented by the lithostratigraphic upper Peters Creek Volcanics to Doomadgee Formation. The reflective package comprises a southward-thickening megawedge (**Fig. 1.2.5**). The northern limit of the megawedge crops out on the southern edge of the Murphy Inlier as a 1.1km thick package corresponding to the Fickling Group. Fifty kilometres to the south at the southern limit of the seismic grid the wedge has thickened to approximately 10km and corresponds to the McNamara Group.

The initial interpretation of this seismic grid recognised three major seismic packages *(McConachie et al., 1993). Scott and Bradshaw (1997)* and *Scott et al. (1998[a])* subsequently identified 6 major onlap and/or truncation surfaces that each represented a major basin event (PM0, PM1, LM1, RV1, TL1, and WD1). In this publication, these seismic surfaces are integrated with the basin events identified in outcrop sections and wells to develop the basin event chart shown in **Fig. 1.2.7**. As a result of this integrated analysis nine supersequences are now defined within the megawedge *(Southgate et al., in press[a];* **Fig. 1.2.7***)*. In the southern McArthur and Murphy Inlier regions, reduced accommodation rates resulted in regionally significant incision surfaces at each of the supersequence boundaries. On seismic sections, second order supersequence boundaries, which display significant incision, coincide with areas of local fault reactivation, tilting or inversion, indicating that these boundaries are tectonically enhanced. Increased accommodation rates in the Lawn Hill to Mount Isa regions produced regionally correlative surfaces in the upper six supersequences. Each supersequence is approximately 10-20My duration and between one to three thousand meters thick (**Fig. 1.2.7**). In each supersequence, lowstand or transgressive deposits overlie the basal unconformity. Transgressive deposits display backstepping, progressively deepening facies architecture indicative of increasing accommodation rates. This retrogradational trend is reversed at the second order maximum flooding surface above which sequences show progressive shallowing and gradually declining accommodation rates. Incision also occurs on some third and fourth order sequence boundaries in the upper parts of supersequence highstands.

Of the datasets used in the NABRE study, the seismic data is the most critical for determining large-scale structural and stratigraphic features. Once significant stratal surfaces (seismic reflections) are tied to outcrop or drill core it enables the timing and geometric significance of regional basin events to be identified and mapped. Poor outcrop usually prevents the lateral tracing of erosion surfaces identified in the field so that it is difficult to assess their regional significance. Seismic data provides an image of the amount of truncation on these surfaces, assisting with an understanding of their magnitude and regional significance. Four petroleum exploration wells and a mineral exploration hole in the Walford Creek Prospect intersect the seismic grid. These holes are combined with the forty six kilometres of outcrop and ten kilometres of drill core stratigraphic data from the remaining parts of the McNamara, Mount Isa, Fickling, McArthur, and Nathan Groups to underpin correlations used in the seismic interpretations and summarised in the Event Chart (**Fig. 1.2.7**).

U-Pb SHRIMP zircon age determinations provide an absolute age for depositional packages and some of the stratal surfaces identified on the seismic profiles. Samples were collected along outcrop sections and from drill core. Euhedral zircons are most common in redeposited tuffaceous beds, usually preserved in deeper water facies in areas of relative sediment starvation. The gamma ray tool assisted in the identification of many tuffaceous beds. Previous Apparent Polar Wander Path (APWP) data from the McArthur Basin *(Idnurm et al., 1995)* have been augmented by new palaeomagnetic poles from the McArthur and Lawn Hill regions. *Page and Sweet (1998)* provide a detailed account of the SHRIMP zircon dataset used to provide absolute age constraints. *Idnurm (in press)* outlines the new palaeomagnetic results incorporated in this synthesis.

Loutit et al. (1994) proposed that prominent inflections and bends in the Proterozoic APWP for Australia may be the product of interplate tectonic events, leading to intraplate deformation which ultimately controlled sedimentary basin evolution, ore fluid production, and the timing of mineralisation. In the Isa Superbasin chronostratigraphic chart (**Fig. 1.2.7**) accommodation history, igneous activity, and the flow of mineralising fluids can all be interpreted to relate to events suggested by bends on the APWP. In the interval 1730-1580Ma five major bends are suggested by determined poles (**Fig. 1.2.8**). Integration of stratigraphic, SHRIMP zircon, and APWP datasets (**Fig. 1.2.7**) indicates that each of these bends broadly coincides with the inception of a supersequence in the Isa Superbasin.

Deposition of the fluvial to shallow marine South Nicholson Group (c. 1480Ma) began some 100My after the McNamara Group was deposited. The two groups are separated by a marked unconformity. The Mesoproterozoic

South Nicholson Group outcrops in the western and northwestern portions of the seismic grid (**Fig. 1.2.1**). The Proterozoic packages are overlain by an eastward thickening sequence of Mesozoic Carpentaria Basin cover. Palaeo- and Mesoproterozoic sedimentary rocks of the Isa Superbasin and South Nicholson Group are mostly interpreted to be of marine origin. Evidence for rocks with an oceanic crustal affinity in the Mount Isa Inlier remains controversial *(cf Ellis and Wyborn, 1984; Taylor, 1997; Wyborn et al., 1988)*. Since at least 1900Ma most evidence supports an underlying continental lithosphere subjected to major marine incursions, rather than the creation of new oceanic basins.

The remaining parts of this introductory section provide regional overviews of the stratigraphic successions imaged in the seismic grid. These overviews are based on outcropping successions of the Lawn Hill Platform and Leichhardt River Fault Trough to the south, and along the Murphy Inlier in the north.

1.3. Isa Superbasin

Mount Isa and Lower McNamara Groups

(P.N. Southgate, M.J. Jackson, T.T. Sami, J. Domagala,
A.A. Krassay, and B.M. McConachie)

1.3.1. Introduction

Rocks comprising the lower parts of the Isa Superbasin *(Scott et al., 1998[a])* crop out in the Leichhardt River Fault Trough (Fiery Creek Volcanics, Bigie and Surprise Creek Formations, and Mount Isa Group) and on the Lawn Hill Platform (Fiery Creek Volcanics, Surprise Creek Formation, and lower McNamara Group). Lithostratigraphic mapping by *Sweet and Hutton (1982)* and *Hutton and Wilson (1984, 1985)* on the Lawn Hill Platform subdivided the lower McNamara Group into five formations: Torpedo Creek Quartzite, Gunpowder Creek, Paradise Creek, Esperanza, and Lady Loretta Formations. In the Leichhardt River Fault Trough the time equivalent Mount Isa Group comprises the Warrina Park Quartzite, Moondarra Siltstone, Breakaway and Urquhart Shales, Spear and Kennedy Siltstones, and Magazine Shale *(Derrick et al., 1976)*. Siliciclastics of the Surprise Creek Formation unconformably underlie both groups *(Derrick et al., 1980)*. Outcrop composite sections through the lower McNamara Group (Torpedo Creek Quartzite to Lady Loretta Formation) attain a maximum cumulative thickness of 2500m with an additional 200-300m likely in intervals of poor outcrop. Rocks of the Surprise Creek Formation and Mount Isa Group attain maximum measured thicknesses of 800m and 3400m respectively. The Mount Gordon Fault Zone separates the Lawn Hill Platform successions from those of the Leichhardt River Fault Trough. Fine grained siliciclastic sediments dominate the Leichhardt River Fault Trough. Although carbonate rocks dominate the Lawn Hill Platform, siliciclastics occur in the lower parts of the stratigraphy and in the Lady Loretta Formation and are common in southern regions. Depositional environments vary from inner-ramp peritidal carbonate complexes of the Lawn Hill Platform to outer-ramp and basinal siliciclastic deposits of the Leichhardt River Fault Trough. These strata accumulated during the initial 85My of the Isa Superbasin. A hitherto unrecognised unconformity surface with up to 25My of missing rock record occurs within the lower Mount Isa and McNamara Groups.

In the chronostratigraphic framework constructed as part of the NABRE project (**Fig. 1.2.7**), lower McNamara Group strata are divided into four supersequences: the Big, Prize, Gun, and Loretta Supersequences (**Fig. 1.3.1**). NABRE has only undertaken reconnaissance fieldwork in the Big Supersequence and it is not considered in this section. The Surprise Creek Formation, Warrina Park and Torpedo Creek Quartzites, and lower Gunpowder Creek Formation are combined to form the Prize Supersequence (**Fig. 1.2.7**). The Gun Supersequence boundary occurs within the Gunpowder Creek Formation and at the base of the Moondarra Siltstone. Gun Supersequence strata include the mid-lower Gunpowder Creek to Esperanza Formations of the Lawn Hill Platform, and Moondarra Siltstone to lower Kennedy Siltstone in the Leichhardt River Fault Trough. The Loretta Supersequence comprises the upper Kennedy Siltstone and Magazine Shale as well as the Lady Loretta Formation (**Fig. 1.2.7**). Each supersequence is divided into a series of third- and fourth-order sequences. This high-resolution sequence stratigraphy is based mainly on the analysis of numerous composite stratigraphic sections, drill holes, and gamma-ray curves *(Southgate et al., 1999; Krassay et al., 1999).* Outcrop sections and drillholes were integrated with seismic sections to help resolve the scale of sequences.

1.3.2. Prize Supersequence

The accommodation history of the Prize Supersequence is summarised in the composite outcrop sections from Barr Hole and Leichhardt West (**Figs. 1.3.1** and **1.3.2**) from either side of the Leichhardt River Fault Trough (**Fig. 1.2.2**). The Prize Supersequence can be divided into two third order sequences (Prize 1 and 2). A tectonically enhanced sequence boundary at the base of the Warrina Park and Torpedo Creek Quartzites separates Prize sequences 1 and 2. SHRIMP zircon ages are not available for the Surprise Creek Formation. However, euhedral zircons in pink, redeposited tuffaceous beds from the lower Gunpowder Formation at Esperanza Waterhole provide a depositional age of 1694±3Ma for the upper third order sequence.

The gamma ray curve for Leichhardt West displays a lower, dirtying upward or bell-shaped motif, as siltstone and shale gradually replace sandstone (**Fig. 1.3.2**). This gamma ray pattern is followed by an irregular trend characteristic of aggradational facies. At Leichhardt West sandstones and quartzites at the base of the Surprise Creek Formation accumulated in shoreline depositional systems and pass vertically into deeper water, very fine grained sandstone, siltstone, and shale. The deepest water facies are found between 400-500m above the base of the section. These shales, black and pyritic when fresh, mark the condensed section and record the time of maximum accommodation and minimum sediment supply for this supersequence. At Leichhardt West the transgressive suite of facies is followed by an aggradational package of laminated and thinly interbedded fine-grained sandstone, siltstone, and shale. The sandstone near 500m marks a fourth order sequence boundary. At Leichhardt West, the Gun Supersequence boundary truncates the remaining parts of the Prize Supersequence. Throughout the Leichhardt River Fault Trough the basal Gun Supersequence boundary has incised, and in places completely removed, the Warrina Park Quartzite so that rocks of the Moondarra Siltstone in places directly overlie the Surprise Creek Formation.

The section at Barr Hole preserves the most complete record of sediments in the upper Prize Supersequence. Along the Mount Gordon Fault Zone, rocks of the Warrina Park and Torpedo Creek Quartzites onlap sediments of the Myally Subgroup along an angular unconformity. Elsewhere the sequence boundary at the base of the Warrina Park and Torpedo Creek Quartzites is generally conformable with the underlying successions. At Barr Hole and Esperanza Waterhole, the gamma ray curve displays an initial bell-shaped transgressive motif as non-marine and shoreface sandstones grade into proximal and distal tempestite facies. Three higher order cycles are preserved in Prize 2 (**Fig. 1.3.1**), the upper two contain stromatolitic carbonates and siliciclastics *(Sami et al., in press)*.

1.3.3. Gun Supersequence

Three third order sequences are recognised in the Gun Supersequence. All three sequences are present in the Leichhardt River Fault Trough (**Fig. 1.3.2**) and on the Lawn Hill Platform south of the Redie Creek Fault Zone. North of the Redie Creek Fault Zone the lower sequence (Gun 1) is absent due to onlap. The Gun Supersequence boundary both parallels and transgresses lithostratigraphic units. Extrusion of the Carters Bore Rhyolite at 1678±2Ma (U-Pb SHRIMP age; *Page and Sweet, 1998*) and intrusion of the Sybella Batholith at 1671±8Ma(U-Pb age*; Connors and Page 1995*) provides an absolute age for tectonism and probable uplift responsible for the regional incision of Prize sediments at the Gun Supersequence boundary (**Figs. 1.3.1** and **1.3.2**). U-Pb SHRIMP zircon ages from detrital zircons in the Moondarra Siltstone (1668Ma) provides a maximum age for this formation and is consistent with depositional ages of euhedral zircons in the Breakaway Shale (1663±3Ma); the lower Paradise Creek Formation (1658±3Ma, 1658±3Ma, 1654±4Ma, and 1653±7Ma); and the upper Paradise Creek Formation (1657±3Ma). Collectively, these ages and the 1694±3Ma date from the lower Gunpowder Creek Formation indicate that approximately 20-25My of rock record is missing on the unconformity at the base of the Gun Supersequence.

In the Leichhardt River Fault Trough, siliciclastic sediments dominate the Gun Supersequence transgressive deposits (**Fig. 1.3.2**). Here, high rates of sediment supply and subsidence led to the accumulation of 1000m of siltstone and shale (Moondarra Siltstone and lower Breakaway Shale). The Supersequence highstand deposits are characterised by a lower, irregular gamma trend that is indicative of aggradation, followed by a funnel-shaped motif interpreted to represent progradation. At Leichhardt West, fine to medium grained and cross-bedded sandstones overlie the sequence boundary at the base of Gun 2. These deposits mark an abrupt basinward shift in facies and are interpreted to result from the tectonic event responsible for subsidence of the Lawn Hill Platform north of the Redie Creek Fault Zone.

Initial transgression north of the Redie Creek Fault Zone (Gun 2) inundated the Lawn Hill Platform. In the Lawn Hill and Gunpowder regions, siliciclastic very fine sandstones and siltstones (proximal and distal tempestites) fine upward into shale, rhythmically laminated and locally phosphatic dolomudstone, and eventually carbonaceous shale (*Sami et al., in press*, **Fig. 1.3.1**). The transition from siliciclastic deposits, to chemical sediments dominated by carbonates, but also containing authigenic components, reflects gradual onlap, eventual drowning of the siliciclastic provenance, and declining sedimentation rates. Carbonaceous shales of the uppermost Gunpowder Creek Formation (**Fig. 1.3.1**) and fissile shales of the Breakaway Shale characterise the condensed section of the supersequence.

Sediments of the overlying supersequence highstand deposits (Gun 2.3f-3.5) accumulated on a broad SE-ESE facing ramp that stretched from the Murphy Inlier in the northwest to the Kalkadoon-Leichhardt Belt in the southeast. Across this ramp, a northern and western inner clastic facies belt of fluvial and coastal facies (upper Fish River Formation) passed laterally to the south and east into peritidal and then inner to outer ramp carbonate facies (Paradise Creek and Esperanza Formations) and eventually deeper water, fine-grained siliciclastics and carbonates of the Native Bee Siltstone, Urquhart Shale, Spear and lower Kennedy Siltstones. At Leichhardt West and Barr Hole (**Figs. 1.3.1** and **1.3.2**) early supersequence highstand deposits are characterised by a gamma ray curve that displays an irregular trend indicative of aggradation. Rhythmically laminated siltstones and shales deposited beneath storm wave base and distal tempestite facies characterise these deep water deposits *(Sami et al., in press)*. A cleaning-upward, funnel-shaped gamma motif characterises highstand deposits of the Gun 2 sequence and provides evidence for progradation and the accumulation of successively shallower water depositional systems culminating in emergence at Barr Hole. At Leichhardt West mixed carbonates and siliciclastics deposited beneath storm wave-base accumulated in this area of high subsidence rates (**Fig. 1.3.2**).

Sedimentation in the Gun 3 sequence commenced with a transgressive suite of deposits near the base of the Esperanza Formation and Urquhart Shale, and culminated in the accumulation of rhythmically laminated shales beneath storm wave base (**Fig. 1.3.1**). In the Esperanza Formation, a progradational package of laminated and slump-bedded dolosiltstones and silicified digitate bioherms characterise the highstand deposits that eventually culminated in the accretion of 'organ-pipe' silicified columnar stromatolites (*Sami et al. in press;* **Fig. 1.3.1**). In the Leichhardt River Fault Trough, high accommodation rates provided space for the accumulation of rhythmically laminated shale, dolomitic siltstone, and very fine and variably dolomitic sandstone of the Urquhart Shale, Spear and lower Kennedy siltstones *(Domagala et al., in press)*.

Poor outcrop renders correlations between the Lawn Hill and Mount Isa regions in the upper parts of this third order highstand equivocal. Halite pseudomorphs and stromatolites in the Kennedy Siltstone *(Neudert and Russell, 1981)* provide evidence for initial shallow water environments at Mount Isa and possible closure of the Gun Supersequence. U-Pb SHRIMP zircon ages of 1652±7Ma, and 1655±4Ma from the upper Urquhart Shale infer correlation with the upper Esperanza Formation. Possible correlations between the Mount Isa and McNamara Groups are discussed in *Southgate et al. (in press[b])*.

1.3.4. Loretta Supersequence

Poor outcrop near the base of the Lady Loretta Formation and Kennedy Siltstone inhibits an unequivocal understanding of this supersequence and its lower bounding surface. South of Kamarga Dome, the Lawn Hill and Mount Oxide 1:100,000 sheets identify a ferruginized and silicified breccia at the base of the Lady Loretta Formation. *Sweet and Hutton (1982)* suggested a Tertiary origin for the breccia. *Dunster (1998)* interprets this, and other silicified and ferruginized breccias in the Esperanza and Paradise Creek Formations, as related to prolonged periods of near surface weathering. Exploratory drilling by Amax *(Nutter, 1976)* concluded that the breccia developed as a weathering product of a pyritic shale and siltstone unit. In areas of low relief and poor outcrop *Dunster (1998)* has shown that silicified breccias related to near surface weathering mantle the current surface and transgress lithostratigraphic units. However, at the base of the Lady Loretta Formation areas of good outcrop demonstrate that the breccia is conformable with the regional dip, suggesting a Palaeoproterozoic origin. Where these 'in-situ' outcrops occur, the brecciated rocks are variably ferruginized and silicified so that it is difficult to identify primary lithologies. To resolve the origin of this unit a stratigraphic drilling program by the GSQ aimed to penetrate the brecciated unit at depth. However, GSQ holes Lawn Hill 1 and 2 were abandoned before reaching their targets *(Hutton 1983)*. Seismic sections on the southern flank of the Murphy Inlier (this volume) suggest that this breccia may be related to an unconformity surface and regional truncation.

The most complete section for the Loretta Supersequence occurs on the southern flanks of the Kamarga Dome (**Fig. 1.3.1**). In outcrop this supersequence is divided into two third order sequences (Loretta 1 and 2). Loretta 1 is based on seismic interpretations and the inferred stratigraphic position of the basal breccia, while Loretta 2 crops out near Kamarga Dome (**Fig. 1.3.1**). An interval of uncertain thickness separates the basal breccia from the first outcrops of cherty stromatolitic dolostone. Near Kamarga Dome, an aggradational gamma ray motif characterises the cyclic, subtidal and peritidal, inner-ramp tempestite carbonates of the Loretta Supersequence. In the lower parts of this section, conophytic subtidal carbonates indicate a deepening upward cycle into a 30m thick shale, that subsequently shallows upward into subtidal carbonate facies. Similar subtidal conophytic facies occur on either side of an interval of no outcrop between

1625m and 1750m **(Fig. 1.3.1**). In areas of good outcrop, conophytic stromatolites are found in comparatively 'deep water' subtidal, inner ramp settings and are generally associated with transgressive packages. Their proximity to this interval of no outcrop may provide indirect evidence for a shale package in this recessive unit. Carbonate cycles between 1750m and 2000m generally have siliciclastic siltstones and shales at their base. These cycles are thicker than those in the overlying parts of the Loretta Supersequence and display deeper water facies at their base. Collectively these observations are consistent with the deepest water conditions occurring in the lower parts of Loretta 2 and support the interpretation of a shale in this interval of no outcrop. Correlations to wireline logs from holes intersecting the seismic grid to the north suggest that this interval of no outcrop probably equates to pyritic shales in the transgressive systems tract of the Loretta Supersequence. The remaining parts of the supersequence highstand comprises a succession of fourth order sequences each characterised by progressively shallower water subtidal and peritidal carbonate cycles. Coarse to fine quartz grains are increasingly common toward the top of the supersequence and provide evidence for an encroaching siliciclastic provenance.

1.4. Isa Superbasin – The Upper McNamara Group

(A.A. Krassay, B.E. Bradshaw, J. Domagala, B.M. McConachie, D.L. Scott and M.J. Jackson)

1.4.1. Introduction

The upper McNamara Group contains up to 7000m of marginal to deep marine clastic sediments deposited within the final 50 to 60my of the Isa Superbasin's evolution. The thickest accumulation of upper McNamara Group strata occurs in the Lawn Hill region. Sediments thin to the north and west (where they are also concealed by younger strata) and are not preserved to the south and east *(Andrews, 1996)*. Lithostratigraphic mapping by *Sweet and Hutton (1982)* subdivided the upper McNamara Group into four formations: Shady Bore Quartzite, Riversleigh Siltstone, Termite Range Formation, and Lawn Hill Formation. Subsequent mapping and section logging by *Andrews (1996, 1998)* has recognised additional informal members within these four formations (**Fig. 1.4.1**).

In the chronostratigraphic framework constructed as part of the NABRE project, Upper McNamara Group strata are divided into 5 supersequences: the River Supersequence, Term Supersequence, Lawn Supersequence, Wide Supersequence, and Doom Supersequence (**Fig 1.2.7**). Details of the sequence stratigraphy of the upper McNamara Group are summarised in **Figs. 1.4.2, 1.4.3** and **1.4.4**. The uppermost Lady Loretta Formation, Shady Bore Quartzite, and Riversleigh Siltstone are combined to form the River Supersequence (**Fig. 1.4.2**). The Term Supersequence represents strata from the base of the Termite Range Formation to the base of the Bulmung

Sandstone (H3) member of the Lawn Hill Formation (**Fig. 1.4.3**). The remaining three supersequences all occur within the Lawn Hill Formation. The Lawn Supersequence extends from the base of H3 to the base of H4s members. The Wide Supersequence includes the interval between the base of H4s and upper Widdallion Sandstone (H5) members. The Doom Supersequence extends from the uppermost Widdallion Sandstone through the H6 member of the Lawn Hill Formation (**Fig. 1.4.4**). Each supersequence is in turn divided into a series of third- and fourth-order sequences. This high-resolution sequence stratigraphy is based mainly on analysis of numerous stratigraphic sections, drill holes, and gamma-ray curves measured during the NABRE 1995-1997 field seasons. All of the outcrop and drill core sections that comprise the composites are from the Lawn Hill Platform (**Fig. 1.2.2**). Outcrop sections and drillholes were integrated with the seismic data to help resolve the hierarchy of sequences.

Integrated seismic, outcrop, and well log studies show this clastic-dominated part of the Isa Superbasin as characterised by two broad periods of extension and subsequent thermal relaxation. The River Supersequence represents the first major extensional event, with the Term and Lawn Supersequences representing subsequent sag phases. A second extensional episode occurred during deposition of the Wide Supersequence, while the overlying Doom Supersequence was deposited during a subsequent sag phase. Recent models for the sequence stratigraphy and contemporaneous depositional systems of rift-sag basins *(cf Prosser, 1993; Ravnas and Steel, 1998)* are useful in providing a better understanding of tectonostratigraphic cycles within upper McNamara Group strata.

1.4.2. River Supersequence

The River Supersequence is divided into 8 third-order sequences: the oldest is in the uppermost Lady Loretta Formation; one within the Shady Bore Quartzite; one comprising the upper Shady Bore Quartzite and basal Riversleigh Siltstone; and the remaining 5 from the Riversleigh Siltstone (**Fig. 1.4.2**). Thickness and facies of the River Supersequence vary markedly across the Termite Range Fault and several SW-NE faults that bound individual fault controlled sub-basins (**Fig. 1.7.7**; *Andrews, 1996; Krassay et al., 1997a, 1998*). The River Supersequence is up to 3300m thick in local depocenters within the south-central Lawn Hill region, and thins northwards to a minimum of 500m at Mount Caroline. The River Supersequence subsequently thickens north of Mount Caroline (in the Comalco seismic grid), possibly across the WSW-ENE trending Elizabeth Creek Fault zone, and across several E-W trending fault zones (**Figs. 2.1.2, 2.1.3, 2.1.4, 2.1.5, 2.1.6** and **2.6.2**; *Bradshaw and Scott, 1997; Scott et al., 1998[a]*).

The River Supersequence boundary separates subtidal carbonate platform facies of the Loretta Supersequence from deeper water, inner to outer ramp siltstones and shales of the River Supersequence. The supersequence boundary occurs near the base of the informally defined Lady Loretta transition beds *(Southgate et al., in press[a])*. Around the Kamarga Dome region, erosion at the River 1 sequence boundary has removed up to 14m of the underlying Loretta Supersequence. Further south this surface separates thick lower carbonate-dominated facies from upper, deep water, mixed siliciclastic-carbonate facies.

Overall trends in the accommodation and sedimentation history of the River Supersequence indicate a period of significant syndepositional fault activity associated with regional extensional tectonics. Northward onlapping transgressive systems tracts are prominent features within the River Supersequence. Preliminary interpretations of the Comalco seismic grid to the north also show northward onlapping wedges as the characteristic seismic geometry for the River Supersequence *(Scott et al., 1998[a])*. Rift sequence models of *Prosser (1993)* and *Ravnas and Steel (1998)* are used to divide the River Supersequence into three main accommodation phases:

1. Early rift phase conditions characterised by low accommodation and deposition of fluvial to coastal quartz sandstones and carbonates in northward thinning wedges during the River 1 and 2 sequences;

2. Rift climax conditions characterised by syndepositional growth faulting and rapid subsidence/transgression into deep marine, anoxic half-graben basins during the deposition of thick siltstones and locally thick lowstand sandstones in the River 3-6 sequences; and

3. Late rift stage conditions with decreased syndepositional growth faulting and increasing basin margin instability during the deposition of the turbidite sandstone-dominated River 7-8 sequences.

1.4.3. Term Supersequence

The Term Supersequence represents a change in the tectonostratigraphic style of the Isa Superbasin *(Andrews, 1996; Domagala et al., 1997)*. The Term Supersequence boundary is abrupt and erosional *(Andrews, 1998)*. *Andrews (1996)* proposes that basinal fault activity to the west of the Lawn Hill region accounts for the rapid deposition and major shift in sediment provenance from south to west associated with the onset of the Term Supersequence. The Term Supersequence is divided into 6 sequences: one within the Termite Range Formation; one including the upper Termite Range Formation and lower Lawn Hill Formation; three within the Pmh1 (H1s and H1r) member of the Lawn Hill Formation; and one within the Pmh2 (H2) member of the Lawn Hill Formation (**Fig. 1.4.3**). The Term Supersequence can be divided into three main tectonostratigraphic phases:

1. a possible post-rift stage *(cf Prosser, 1993; Ravnas and Steel, 1998)* from the underlying River rift event during the deposition of laterally continuous, high concentration debris flow sandstones in Term sequences 1 and 2;

2. a sag phase characterised by the rapid subsidence/transgression into deep marine carbonaceous shales and siltstones which thicken dramatically across the NW-SE trending Termite Range Fault in Term sequences 3 and 4; and

3. a tectonically controlled regression resulting in a shoaling- and coarsening-up cycles into the tuffaceous sandstones and siltstones of the laterally continuous Term 6 sequence during a period of syndepositional volcanic activity *(Andrews, 1998)*.

1.4.4. Lawn Supersequence

The Lawn Supersequence represents one of the thinnest units within the Isa Superbasin (~950m deposited in ~15my). Unlike the underlying River and Term Supersequences, no evidence currently exists for significant lateral thickness variations in the Lawn Supersequence. The Lawn Supersequence boundary is a sharp erosional surface *(Krassay et al., 1997b)*. Four third-order sequences are recognised: Lawn 1 in the Bulmung sandstone (H3) member, and Lawn 2-4 in the Pmh4 (H4r) member of the Lawn Hill Formation (**Fig. 1.4.4**). Two main tectonostratigraphic phases are also recognised in the Lawn Supersequence:

1. initial low accommodation conditions associated with a major basinward shift in facies to the shallow marine Bulmung Sandstone in the lowstand systems tract of Lawn 1; and

2. rapid subsidence/transgression into deep marine carbonaceous shales in the upper Lawn 1 sequence, and continued deepening and increasing sediment starvation through Lawn sequences 2-4.

1.4.5. Wide Supersequence

The Wide Supersequence records a significant change in tectonostratigraphic styles in the Isa Superbasin. Unlike the underlying River, Term, and Lawn Supersequences, the Wide Supersequence shows subtle, overall coarsening-upward from a basal siltstone (H4s) member to the Widdallion Sandstone (H5) member. The basal contact of the Wide Supersequence (Wide 1) is abrupt and represents a major tectonic basin event surface *(Krassay et al., 1997b; Andrews, 1996)*. Dolomitic siltstone facies occur above the Wide Supersequence boundary, while carbonaceous shale and silty shale facies occur beneath. Three third-order sequences are recognised within the supersequence: Wide 1 and 2 in the H4s member, and Wide 3 in the Widdallion Sandstone member (**Fig. 1.4.4**). Two main tectonostratigraphic phases are suggested for the Wide Supersequence:

1. an early rift phase *(cf Prosser, 1993; Ravnas and Steel, 1998)* characterised by sediment-underfilled half-graben and occasional growth of the Wide 1 and 2 sequences across

wrench fault systems into local sub-basins (Elizabeth Creek and Century sub-basins, *Bradshaw et al., 1998*); and,

2. a rift climax *phase (cf Prosser, 1993; Ravnas and Steel, 1998)* with the deposition of extensive turbidite sandstones and common growth of Wide 3 strata across wrench fault systems.

1.4.6. Doom Supersequence

Strata from the Doom Supersequence are generally poorly preserved beneath the South Nicholson unconformity. Much of our understanding for this final phase of the Isa Superbasin is based on evidence presented by *Bradshaw et al. (1998)* in the northwestern part of the Comalco seismic grid. This seismic and well log data suggests that the Doom Supersequence is characterised by a period of relatively uniform subsidence rates across the basin with no growth of strata. Incision at the Doom Supersequence boundary is not evident, although it is marked by an increase in sand content, a change in gamma-ray log signals to higher values, and a change in mineralogy to feldspar-rich facies *(Krassay et al., 1997b)*. A marked unconformity is present in correlative Nathan Group strata from the McArthur River region *(Jackson et al., in press[b])*. Five third-order sequences are recognised in the Doom Supersequence: one from the upper-most Widdallion Sandstone (H5) member; two from the H6 siltstone member; and two from an as yet undefined sandstone member (**Fig. 1.4.4**). Three main tectonostratigraphic phases are suggested for the Doom Supersequence:

1. a possible post-rift *phase (cf Prosser, 1993; Ravnas and Steel, 1998)* from the underlying Wide extensional event resulting in the deposition of a high concentration, debris flow sandstone in Doom 1;

2. a sag phase resulting in gradual transgression and sediment starvation in Doom sequences 2 and 3; and

3. initiation of the Isan Orogeny resulting in rapid shallowing and coarsening up into inner ramp and fluvial sandstones in Doom sequences 4 and 5.

Doom 3 is the youngest preserved sequence from the Upper McNamara Group in outcrop sections of the Lawn Hill Platform. Significant incision occurs at the base of the South Nicholson Group (**Fig. 1.7.1**) which suggests that younger strata were deposited in the Isa Superbasin and subsequently removed by erosion. Current outcrop trends and SHRIMP zircon dates within a basal conglomerate from the South Nicholson Group *(Page, 1997)* suggest that sedimentation within the Isa Superbasin ceased at about 1585Ma. This coincides with the first evidence of metamorphism in the Eastern Fold Belt *(Page and Sun, 1998)* at 1584Ma. Initiation of the Isan Orogeny therefore appears to have had the effect of reduced accommodation and clastic deposition within the Isa Superbasin, and eventually deformed and eroded the original basin geometry.

1.5 Southern Murphy Inlier: Peters Creek Volcanics

(D.L. Scott, M.J. Jackson and D. Rawlings)

The Murphy Inlier (**Fig. 1.2.1**) has long been recognised as a significant basement ridge *(*eg *Roberts, et al., 1963; Plumb and Derrick, 1975; Sweet et al., 1981; Ahmad and Wygralak, 1989)*. However, the basement complex is still poorly understood due to the highly weathered nature of outcrops and a lack of focussed studies. The Inlier is cored by the isoclinally folded Murphy Metamorphics (>1900Ma) comprising metasediments and metavolcanics thought to have been deposited in a "geosyncline". A variety of dates for the rocks of the Inlier can be found in AGSO's national database, OZCHRON. The Cliffdale Volcanics (c. 1850-1770Ma), a 4000m thick pile of coarse, poorly sorted dacitic and rhyolitic ignimbrite and flow-banded alkali rhyolite with minor tuff, unconformably overlie the metamorphics. Both units appear to be intruded by the Nicholson Granite Complex that exhibits many petrological and geochemical similarities to the Cliffdale Volcanics and a 50-60my range of isotopic ages (c.1860-1705Ma). It is likely that the intrusives are at least in part co-magmatic with the volcanics *(Grimes and Sweet, 1979)*. These older Murphy Inlier rocks are overlain by the Peters Creek Volcanics that include interbedded sedimentary units.

The E-W outcrop belt of the Murphy Inlier, on the western side of the Westmoreland sheet (**Fig. 1.2.2**), is associated with prominent E-W trending long wavelength magnetic and gravity anomalies. The anomalies extend across the sheet to the east, and in the case of Bouguer gravity, also to the northeast (**Fig. 1.5.1**). These broad belts of geophysical highs are interpreted to be the expression of the Cliffdale Volcanics and Nicholson Granite Complex. The long wavelength geophysical anomalies are marked by a shorter wavelength high which steps en echelon to the NE, suggesting deep basement trends of EW and NNE.

The mottled belt of short wavelength, high frequency magnetic anomalies corresponds to the basal unit of the Peters Creek Volcanics, the Buddawadda Basalt member (BB on **Fig. 1.5.1a**). The Peters Creek Volcanics are separated from the "basement" granites and acid volcanics of the inlier by the Wire Creek Sandstone (~70m thick) which overlies a pronounced unconformity on basement. The Wire Creek Sandstone is a coarse, coarsely graded, conglomeratic alluvial fan and braided stream deposit *(Sweet, et al., 1981)*. The Peters Creek Volcanics appear to overlie the Wire Creek sandstone concordantly (although some time break is assumed) and comprise a bimodal volcanic and intrusive suite with intercalated sediments (eg Ptp_{1s}, Ptp_3, **Fig. 1.5.2**).

There are several correlations of the Peters Creek Volcanics to other igneous units of the region. Correlatives include the Seigal Volcanics, the Settlement Creek Volcanics, the Gold Creek Volcanics through to upper Tawallah Group felsic units (eg Hobblechain Rhyolite and Packsaddle Microgranite) to the west and north and the Kamarga Volcanics, the Eastern Creek Volcanics, the Mitchiebo Volcanics, the Fiery Creek Volcanics, the Top Rocky and Carters Bore Rhyolite and the Sybella Granite to the south *(Plumb and Sweet, 1974; Grimes and Sweet, 1979; Sweet et al., 1981; Hutton and Sweet, 1982; Sweet and Hutton, 1982; Ahmad and Wygralak, 1989; Plumb et al., 1990)*. These correlations were based primarily on regional mapping and limited geochronology. Most of the igneous units in the region have been highly altered and thus the early geochronological data is difficult to reconcile with some of the known geological relationships.

More recent U-Pb SHRIMP zircon ages from many of the units have begun to clarify the magmatic history of the region *(Page, 1988; Page et al., 1997; Page, 1997; Page and Sweet, 1998)*. Likewise, continuing palaeomagnetic studies serve to constrain correlations and ages of the igneous units *(Idnurm et al., 1995; Idnurm, 1997; M. Idnurm, AGSO, unpubl. data)*. In addition, recent field work by the NABRE team on the Murphy Inlier (helicopter support by Rio Tinto Zinc) and analysis of available geochronology, geochemistry, and palaeomagnetic data has further refined our understanding of the Peters Creek Volcanics *(Jackson et al., 1998; Scott et al., 1998[b]; Mackenzie, unpubl.)*. The details of these investigations are presented in *Idnurm, in press, Jackson et al., in press[a], Page et al., in press* and *Scott et al., in press*. However, it is useful to provide a synopsis of some of the key results in relation to the development of the basement story underlying the northern Lawn Hill Platform, and the interpretation of the limited seismic data that constrain it.

Fig. 1.5.2 summarises the changes in the geological relationships documented in recent outcrop investigations. Rather than a broadly conformable, coeval pile of bimodal igneous units with scattered sedimentary lenses, it is now recognised that the Peters Creek Volcanics package records a long, complex history of multiple magmatic and sedimentation events. The extrusive basal Buddawadda Basalt (Ptp_1) is clearly geochemically and palaeomagnetically distinct from the mafic sills, Ptp_{1i}, that intrude it (**Figs. 1.5.3** and **1.5.4**). Outcrop relationships verify that the mafic units recently sampled for determination of the palaeomagnetic pole and which have previously been mapped as the upper portion of Ptp_1 above the sandstone “lense”, Ptp_{1s} , are in fact intrusive dolerites *(Jackson et al., in press[a])*. The poles from these dolerites are clearly better grouped with the upper Peters Creek Volcanics and Fiery Creek Volcanic poles than with those determined from older units *(M. Idnurm, pers. comm.)*.

The sandstone unit, Ptp_{1s}, is not a coeval part of the Buddawadda Basalt flows, but disconformably overlies them and is also intruded by mafic sills. Ptp_{1s} is probably a correlative of the Wunnumuntyala Sandstone to the northwest *(Jackson et al., 1998)*. The rhyolitic to dacitic members Ptp_2 , Ptp_5, and Ptp_7 are all demonstrably intrusive or highly viscous extrusives and probably include several sheets of various ages within any given member. The various sedimentary rocks in the Ptp_1- Ptp_3 interval (shown as Wunn, SCV and L. Woll on right hand column of **Fig. 1.5.2**) are postulated to have originally been a concordant and coherent sedimentary package. Unit Ptp_3 has been definitively correlated to a Tawallah Group unit, the Wollogorang Formation *(Jackson et al., 1998)*, as first proposed by *Grimes and Sweet (1979)*. Recently dated samples from the Wollogorang Formation (from north of the Inlier) indicate a major break within the formation *(Jackson et al., 1997)*. We suggest this break is probably the result of uplift associated with the early phases of Peters Creek Volcanic felsic intrusive activity. Unit Ptp_4 is a thin extrusive mafic lava that directly overlies the carbonate unit Ptp_3. It is now believed that this unit marks the base of the Isa Superbasin on the Inlier, whereas the underlying carbonate belongs to the Leichhardt Superbasin; thus, the boundary between these units represents a major unconformity. Ptp_4 is separated from Ptp_6 that is characterised by peperitic units and fine-grained sediments, by an additional felsic intrusive unit Ptp_5.

The interpretations of seismic data where it impinges on the Murphy Inlier also helps to constrain interpretations of the Peters Creek Volcanics. **Fig. 1.5.5** provides interpretations of the limited seismic data over the Murphy Inlier and elucidates some of the various possible relationships. The outcrop relationships and thicknesses guided the interpretation of the seismic data. On the basis of the disconformity between the lower Ptp_1 mafic rocks and the sandstone unit, Ptp_{1s}, together with new correlations of the Seigal volcanics in the northwest with the Eastern Creek Volcanics to the south, the Buddawadda Basalt is now considered to be significantly older than the rest of the Peters Creek Volcanics and forms part of the Leichhardt Superbasin. Both the Seigal and Eastern Creek Volcanics have thick sedimentary successions between them and the next magmatic event that also belong to the Leichhardt Superbasin. On the Murphy Inlier, the Leichhardt Superbasin sedimentary package is extremely thinned by erosion, and is represented only by remnants of Ptp_{1s} and Ptp_3. The Leichhardt Superbasin succession was subsequently intruded and overlain by the igneous units Ptp_2- Ptp_7. These members are interpreted to be a part of the Big Supersequence within the Isa Superbasin. The upper Peters Creek Volcanics are thickest in the north, thinning to the south as a result of both pinching out of the intrusive felsic members and erosion by the overlying Prize Supersequence (**Fig. 1.5.5**).

In the east, where the Peters Creek Volcanics are covered by Mesozoic Carpentaria Basin sediments, the seismic data, combined with geopotential data interpretations and modelling, provide the only constraints on the Peters Creek Volcanics. Interpretations of the highly complex Big Supersequence (of which the upper Peters Creek units are a part) are less confident away from the outcrop belt. However, interpretations provided in the archive (eg line 91bn-26 and adjacent lines) and discussions of the transition between the Leichhardt and Isa Superbasins (**Chapters 2** and **3**) provide insights into the subsurface character, distribution, and geometry of the Peters Creek Volcanics.

The strong geochemical similarities between the upper Peters Creek and the Fiery Creek Volcanics (**Fig. 1.5.3**) suggest that they are genetically linked *(McKenzie, unpubl.)*. Palaeomagnetic data (**Fig. 1.5.4**) also supports the correlation *(Idnurm, in press)*. However, recent U-Pb SHRIMP dates from the upper Peters Creek Volcanics are 10-20my older than the single U-Pb SHRIMP date for the Fiery Creek Volcanics (**Fig. 1.5.4**). The date from the Fiery Creek Volcanics is thought to be derived from a very late stage intrusive unit. No dates from the postulated latest preserved stage of felsic intrusion in the Peters Creek Volcanic succession (**Fig. 1.5.2**) have yet been obtained, nor is it known how much additional material may have been eroded from above the youngest dated member. Additional dating of both volcanic successions and focussed mapping will be required to clarify this enigmatic correlation.

Correlation of the stratigraphy interpreted from the southernmost seismic data to outcrop investigations to the south *(Bradshaw et al., 1996; Bradshaw and Scott, 1997; Scott et al., 1998[a];* **Chapter 5** this Record) suggests that the Fiery Creek Volcanics should underlie the reflective seismic megawedge (eg **Fig. 1.2.5**). The impedance contrast between a siliciclastic unit and a basic volcanic unit would be expected to be high and thus a likely possibility for "acoustic basement" (ie the Prize Supersequence boundary). In contrast to the lack of seismic character seen below Prize in the south, the upper Peters Creek Volcanics in the north are a thick, highly reflective package with ample internal geometry (cf the north and south ends of the Argyle Creek and Desert Creek composites, **Figs. 2.2.1** and **2.2.2**). The differences in seismic character between the Peters Creek in the north and the Fiery Creek Volcanics in the south may be attributed to several factors. Firstly, the thickness (~10km) of basin fill above the Prize Supersequence boundary in the south depletes the amount of energy reaching this level and may help to explain the lack of seismic character below it. Whereas in the north, the Peters Creek Volcanics are virtually at the surface. Secondly, as we now understand the intrusive and viscous nature of the felsic units of the Peters Creek Volcanics, they have been interpreted to pinchout not far from their outcrop, and cannot reasonably be extended the 50+km to the southern extent of seismic data coverage.

In conclusion, the Murphy Inlier has clearly been the locus for repeated magmatic events and significant isostatic adjustment for ~200my of Proterozoic history. The inference is that it has also been the location of deep earth processes from at least c.1850Ma until the end of deposition of the Isa Superbasin (c.1585Ma). If the early interpretation of a "geosynclinal" environment for the sedimentary precursors of the Murphy Metamorphics is correct, it is possible that it marks the location of an early Proterozoic subduction zone which may have evolved from an Archaean collision belt. These types of processes are commonly associated with anomalies in the tectosphere *(Jordan, 1988)*, which are long-lived and which tend to focus tectonic stresses. These concepts will be more fully developed in future work *(eg Scott et al., in press)*. Details of the Inlier's relationship to sedimentation (ie as a margin or transgressed) during the deposition of the Isa Superbasin are provided in **Chapter 2**.

1.6. Attenuated Sequence Stratigraphy of the Isa Superbasin: The Fickling Group, Southern Murphy Inlier

(J.F. Lindsay, B.E. Bradshaw, A.A. Krassay, and A.T. Wells)

1.6.1. Introduction

The Fickling Group onlaps the Murphy Inlier along the northwestern margin of the Isa Superbasin and consists of four lithostratigraphic formations: the Fish River Formation, Walford Dolomite, Mount Les Siltstone, and Doomadgee Formation. The succession is very thin (less than 1km, *Sweet et al., 1981*) with pronounced erosional surfaces separating major basin phases. In contrast, the McNamara Group, its correlative to the south, contains nine formations and is over 8500m thick *(McConachie and Dunster, 1998; this study)*. The Fickling Group strata represent the Prize through Doom Supersequences (the older Big Supersequence is present in the underlying Peters Creek Volcanic, **Section 1.5**) despite the dramatic attenuation of Isa Superbasin strata *(Lindsay and Wells, 1997)*. Consequently, the Fickling Group provides an important record of the accommodation history in a margin setting during the evolution of the Isa Superbasin. Sequence stratigraphy of outcrop and drillhole sections through the Fickling Group (**Figs. 1.1.1** and **1.6.1**) are used to determine which sequences are present in the four formations of the Fickling Group. These results are integrated with sequence stratigraphic interpretations of the Comalco seismic data and well logs (**Chapter 5**) to determine the overall basin fill history for the Isa Superbasin in the northern Lawn Hill Platform.

Major structural elements on the Murphy Inlier include the W-E trending Fish River Fault, the WSW-ENE trending Nicholson River Fault, and the NW-SE trending Calvert Fault (**Fig. 1.6.2**). The Fish River Fault is a conspicuous structural element that defines the northern margin of the Lawn Hill Platform *(Rowley, 1983). Sweet et al. (1981)* attribute its initial development to doming during the intrusion of early phases of the South Nicholson Granite Complex, although older rocks outcrop. The Fish River Fault is heavily silicified and is a prominent 20 to 30m high erosional ridge along much of its outcrop length. Normal fault movement uplifted the northern block by 500m to 1000m *(Sweet et al., 1981)*. Extensive sedimentary talus breccias within the Mount Les Siltstone are evidence for synsedimentary growth on the Fish River Fault. *Rohrlach et al. (1998)* propose that the Nicholson River and Fish River Faults define the Hedley's Half-graben. They propose that the half graben contains a wedge of Fickling Group strata that thickens to the south into the bounding Nicholson River Fault. Seismic interpretations in this study indicate that the Nicholson River Fault was a major growth fault during deposition of the River

Supersequence. The Fish River Fault was a minor antithetic growth fault during this time (**Chapters 2** and **3**).

A later phase of deformation, which affected both basement and cover rocks, is evident as a series of NW-SE trending faults dominated by the Calvert Fault *(Rowley, 1983)*. The vertically dipping Calvert Fault can be traced for more than 200km as a zone of intense silicification up to 100m wide *(Ahmad and Wygralak, 1989)*. Seven kilometres of strike-slip and 750m of normal movement have been documented *(Roberts et al., 1963)*. *Sweet et al. (1981)* suggest that the major horizontal movement occurred before the cover rocks were deposited and that later movements were restricted to minor vertical adjustments. WNW trending structures (including the Calvert Fault) were active sporadically during accumulation of the Peters Creek Volcanics and overlying Fickling Group *(Rohrlach et al., 1998;* **Chapter 3***)*. Although several stages of movement probably occurred along major NE and NW trending faults which affected both basement and cover rocks, the lack of significant displacement of the South Nicholson Group, especially on the Calvert Fault, indicates that most movement had ceased by ~1500Ma.

1.6.2. Prize Supersequence (Lower Fish River Formation)

In outcrop, the Fish River Formation appears to be a relatively homogeneous lithological unit. However, gamma-log and facies analysis shows that it consists of two major depositional packages separated by a well defined sequence boundary *(Lindsay and Wells, 1997;* **Figs. 1.6.1** and **1.6.3***)*. The two packages have been correlated with the Prize and Gun Supersequences (**Chapter 5**).

The lower Fish River Formation (Prize Supersequence) lies on a marked unconformity cut into and containing clasts of Peters Creek Volcanics and the Nicholson Granite Complex *(Lindsay and Wells, 1997)*. This prominent sequence boundary overlies progressively older units indicating increased uplift and erosion in the west *(***Fig. 1.6.3***; Sweet et al., 1981)*. Lithologically, the Prize Supersequence includes the sandstones and conglomerates of the Pff_1 member which grade into siltstones of member Pff_2 of the Fish River Formation. The Prize Supersequence is interpreted as consisting of one third-order sequence, the Prize 2 sequence, on the southern Murphy Inlier. Integrated gamma and lithology analyses indicate that a thick transgressive systems tract, with thin, local lowstand and highstand systems tracts dominates the Prize 2 sequence.

The lower 50m of the Prize 2 sequence consists of a thin lowstand systems tract deposit of fluvial conglomerates and peritidal, coarse conglomeratic sandstones containing clasts of the underlying Peters Creek Volcanics. Angular clasts of rhyodacite up to 30cm in diameter are abundant in the basal conglomerates and partially fill channels that incise up to 10m into the underlying volcanics. The abundance of locally sourced high volcanic K-feldspar material in the conglomerates produces the anomalously strong gamma-ray response at the base of the sequence.

The transgressive systems tract generally consists of fining-up peritidal-subtidal parasequences at the base, that retrograde into coarsening-upward, inner ramp-upper shoreface parasequences towards a maximum flooding surface. Fining-upward parasequences grade from conglomeratic, coarse grained, trough cross-bedded peritidal sandstones at the base to medium grained, trough to planar cross-bedded, wave rippled subtidal sandstones at the top of each parasequence. Coarsening-up parasequences generally begin with laminated marine (inner ramp to lower shoreface) siltstones and shales at the base and coarsen up into fine to medium grained, hummocky to trough cross-bedded, upper shoreface to peritidal sandstones. Stromatolites appear on prominent hardgrounds associated with the condensed interval at the top of the transgressive systems tract.

A thin highstand systems tract is present in some locations where it consists of regularly laminated, inner ramp shales and siltstones with occasional red-brown to purple, fine-grained sandstones. The shales of the highstand systems tract are generally poorly exposed, but form a shallowing-upward succession truncated by a major erosion surface (Gun Supersequence boundary) where observed. The upper part of the highstand tract has been removed locally by erosion. Further east, most of the highstand systems tract has been eroded (**Fig. 1.6.3**).

1.6.3. Gun Supersequence (Upper Fish River Formation)

The upper Fish River Formation is correlated with the Gun 2 sequence. The break between the Gun and Prize Supersequences is sharply defined by gamma logs that shows an abrupt drop in values across the boundary (**Fig. 1.6.1**). The base Gun Supersequence boundary is a major erosion surface that truncates the lower Prize Supersequence (**Fig. 1.6.3**). Overlying the intra-Fish River unconformity is a distinct boulder conglomerate containing silicified clasts (locally more than 1m in diameter) derived from the lower Fish River Formation. The silicified nature of the clasts indicates a major time break between the Prize and Gun Supersequences *(Lindsay and Wells, 1997)*, which is correlated to the 25My gap within the Gunpowder Formation of the Lower McNamara Group (**Sections 1.2** and **1.3**). This conglomerate and associated coarse-grained sandstones are interpreted to represent lowstand fluvial to peritidal depositional systems *(Lindsay and Wells, 1997)*.

The overlying transgressive systems tract is associated with aggrading, medium-grained, trough cross-bedded to wave rippled, upper shoreface to peritidal sandstones of member Pff_3. The Gun Supersequence terminates relatively abruptly against either a major erosional surface, or locally, against the Fish River Fault *(Lindsay and Wells, 1997)*. Seismic data also shows major truncation of the Gun Supersequence by the overlying Loretta Supersequence boundary which results in only the lower part of Gun 2 preserved to the east (**Fig. 1.6.3**).

1.6.4. Loretta Supersequence (Walford Dolomite)

The Loretta Supersequence thins rapidly from the Lawn Hill Platform to the southern flanks of the Murphy Inlier. Seismic data shows this thinning is due to truncation by the overlying River Supersequence boundary (**Chapter 2**). Along the Murphy Inlier the Walford Dolomite is the sole lithostratigraphic unit of this supersequence. Previously, the basal contact of the Walford Dolomite was described as sharp, but apparently conformable *(Sweet et al., 1981; McConachie and Dunster, 1998)*. However, *Lindsay and Wells (1997)* have identified an erosional, angular unconformity beneath the Walford Dolomite in field sections. Seismic data confirms the presence of a south dipping angular unconformity beneath the Loretta Supersequence (**Chapter 2**). Recent SHRIMP zircon dates from tuffaceous shales in the Walford Dolomite indicate an age of 1649±7Ma *(Page et al., in press)* confirm correlation to the Lady Loretta Formation in the lower McNamara Group (1647±4Ma) and placement of this unit in the Loretta Supersequence (**Fig. 1.2.7**).

The Walford Dolomite Formation is poorly exposed and is generally only represented in outcrop by weathered remnants of silicified dolomite or chert. However, drill hole data from the Walford Creek and Gorge Creek Prospect areas provide sequence stratigraphic data for the Walford Dolomite. The Walford Dolomite generally consists of dolostone with minor interbeds of dark green shale and siltstone (5 to 10cm thick). Regional variations occur in lithofacies from the western to eastern outcrop belts (**Fig. 1.6.4**). The oldest Loretta Supersequence strata occur to the east in the Walford Creek Prospect area. The basal (Pfw_b) Walford Dolomite of *Sweet and Slater (1975)* forms a distinct clastic-rich fourth-order transgressive-regressive cycle in the Loretta 2.2 sequence. The base of the Loretta 2.2 sequence comprises subtidal to peritidal carbonates that grade into inner ramp siltstones to form a transgressive systems tract. Intertidal-peritidal carbonates subsequently prograde over the siltstones as part of a highstand systems tract. The highstand systems tract contains a distinct stromatolitic dolomite unit. The stromatolites form thin columns up to 1cm across (the “lower collenia marker bed” of *Taylor, 1970*) in contrast to the more common bulbous form that characterises the Walford Dolomite *(Rowley, 1983)*. The Loretta 2.2 sequence is the only remnant of the Loretta Supersequence in the east. The River Supersequence boundary truncates and removes all younger sequences (**Fig. 1.6.4**).

Further west in the Gorge Creek Prospect area, the Walford Dolomite contains a younger and thicker aggradational package of subtidal to peritidal dolostones. The dolostones are largely stromatolitic or microbial laminites with fewer packstone to wackestone beds and black or green shales. Halite casts occur at the base of some cycles. The lower part of the formation is more oolitic and glauconitic, whilst the upper part contains a higher proportion of dololutite and dolarenite *(Taylor, 1970)*. The facies define 50 to 100m thick, shallowing-upward parasequences that were deposited in a subtidal to peritidal ramp setting. A single elevated phosphorus value (1300 ppm) suggests that phosphatic hardgrounds are present in the Walford Dolomite.

The similar aggradational nature of the western Walford Dolomite is correlated with the third order highstand systems tract from the Loretta 2 sequence on the Lawn Hill Platform. Due to the aggradational nature of the depositional setting, fourth-order sequence boundaries within the formation are not well defined, although the gamma log suggests subtle stacking patterns of sequences or parasequences *(***Fig. 1.6.4***; Lindsay and Wells, 1997; Lindsay and Brasier, in press)*.

The dramatic change in thickness of the Walford Dolomite from a thin basal sequence (Loretta 2.2) in the east to the entire sequence to the west suggests a significant change in the accommodation history of the two regions. Seismic data shows that much of the Loretta Supersequence was eroded by uplift of a south dipping block that formed during the deposition of the River Supersequence. The thicker section in the west was probably preserved because it was deposited on basement that was subsiding during the same deformation event.

The Walford Dolomite was deposited in a platform or ramp setting as a series of thin subtidal to peritidal cycles within fourth-order sequences or parasequences *(Lindsay and Wells, 1997; Lindsay and Brasier, in press)*. The primary fabrics of the carbonates, especially the major platform carbonate units, are well preserved and suggests that diagenesis, including dolomitization and silicification, occurred soon after deposition *(cf., Veizer et al., 1992; Lindsay and Brasier, in press)*. The silicified dolomite locally transgresses the stratigraphy, although generally it is confined to one stratigraphic level near the top of the Walford Dolomite *(Rowley, 1983; Lesh, 1980)*. This diagenetic pattern suggests that the more massive carbonates were sealed to the passage of fluids during early diagenesis. Silicification, although widespread, is best developed east of the Calvert Fault *(Rowley, 1983)* and suggests that it was a major conduit for alteration fluids, possibly during the initial period of northerly uplift at the beginning of the River Supersequence.

1.6.5. River Supersequence (Mount Les Siltstone and Lower Doomadgee Formation)

The River Supersequence is represented by three third-order sequences, River 5, 6, and 7, along the southern flanks of the Murphy Inlier (**Fig. 1.6.1**). The lithostratigraphic formations associated with the River Supersequence vary from the western to eastern ends of the Murphy Inlier owing to a lateral facies change within the River 7 sequence (**Fig. 1.6.4**). In the western outcrop belt around the Gorge Creek Prospect area, the River Supersequence corresponds to the Mount Les Siltstone and the Pfd_{1-2} members of the Doomadgee Formation as defined by *Sweet et al. (1981)*. To the east in the Walford Creek Prospect area, the River Supersequence corresponds to the five informal lithofacies members of the Mount Les Siltstone as defined by *Rohrlach et al. (1998; their Fig. 4)*. Previously, the sequence boundary at the base of the River Supersequence (contact with underlying Walford Dolomite) was believed to be conformable and possibly gradational *(Sweet et al., 1981; McConachie and Dunster, 1998)*. However, the River Supersequence boundary is now known to be a sharply defined erosional surface both near the Murphy Inlier *(Lindsay and Wells, 1997)* and also further south in the Lawn Hill region *(Krassay et al., 1997a)*. Seismic data shows a regional, southerly inclined truncation surface at the base of the River Supersequence (**Chapter 2**). The River Supersequence boundary is immediately overlain by a thin conglomeratic lag consisting in part of centimetre-sized clasts of silicified, stromatolitic Walford Dolomite suggesting that the surface represents a significant unconformity *(Lindsay and Wells, 1997)*.

Each of the three River sequences contain well defined transgressive and highstand systems tracts, with significant lowstand systems tracts also present in River 5 and 7 (**Figs. 1.6.1** and **1.6.4**). Prominent syngenetic pyrite beds are often associated with carbonaceous shale intervals *(TOC values 1.6-3 %; Dorrins et al., 1993)* within condensed sections of the River sequences. Pyrite beds contain a range of complex, concretionary, filamentous, open framework, and stromatolitic textures and display abundant evidence of soft-sediment deformation *(Rohrlach et al., 1998)*. The River sequences are interpreted as forming beneath storm wave base in an inner to outer ramp depositional environment, although the River 7 sequence shows evidence for local shallow marine and possibly fluvial conditions *(Lindsay and Wells, 1997)*. An allochthonous talus breccia member containing scarp derived blocks of Walford Dolomite occurs adjacent to the Fish River Fault and provides evidence for syndepositional growth faulting during deposition of the River Supersequence *(Rohrlach et al., 1998)*. The talus breccia member extends several hundred metres basinward where it grades into matrix supported debris-flow breccias within the Mount Les Siltstone *(Rohrlach et al., 1998)*. Talus breccias appear to have formed in a submarine scarp and hydrothermal mound setting within deep water aerobic to anaerobic conditions. The facies was controlled by adjacent growth faulting (*Rohrlach et al., 1998)*. A SHRIMP zircon age of 1640±7Ma *(Page and Sweet, 1998)* allows correlation of the Mount Les Siltstone to the Riversleigh Siltstone, which, higher in the section, has produced a SHRIMP age of 1644±8Ma *(Page, pers comm.)*.

The River 5 sequence occurs within the informal $Pff_{1\text{-}3}$ members of the Mount Les Siltstone as defined by *Rohrlach et al. (1998)*. A lowstand systems tract is interpreted at the base of River 5 in the basal siltstone (Pff_1) member. The River 5 lowstand is characterised by a progradational gamma motif that corresponds to rhythmically interbedded dolomitic sandstones and siltstones. *Rohrlach et al. (1998)* interpret the Pff_1 member as a package of mixed clastic and carbonate turbidites with some storm reworking near the base. An overlying transgressive systems tract is defined by a retrogradational gamma motif associated with the lower black shale (Pff_2) member. The number 3 pyrite lens from the Walford Creek Prospect *(Rohrlach et al.,1998, their Fig. 6)* occurs within the River 5 transgressive systems tract, usually immediately below the maximum flooding surface (**Fig. 1.6.4**). The River 5 transgression was a tectonically active period of deep water, anaerobic deposition of carbonaceous, dolomitic, and pyritic silty-shales, and submarine flows of scarp derived talus breccias and sulphide mound debris *(Rohrlach et al.,* *1998)*. River 5 ends with the marked onset of a highstand systems tract characterised by an aggradational gamma package associated with the lower three-quarters of the green siltstone (Pff_3) member of the Mount Les Siltstone. The low gamma values which characterise the River 5 highstand result from the dolomitic siltstones and dolomitic sandstones associated with this member, the latter representing distal portions of a talus breccia member located along the Fish River Fault *(Rohrlach et al., 1998)*. Numerous interbeds of volcanic shales (tuffs) result in high gamma spikes within the overall blocky gamma motif of the highstand. The River 5 highstand was a tectonically active phase of deposition characterised by deposition of volcanic shales and mass flows of debris scarps and fine grained carbonates derived from an active basin margin *(Rohrlach et al., 1998)*.

River 6 corresponds to the upper part of the Pff_3 member and the entire Pff_4 member as informally defined by *Rohrlach et al. (1998)*. The River 6 sequence boundary is generally found at the base of a thin dolarenite or dolarudite bed. In most areas, the River 6 sequence is dominated by a thick transgressive systems tract in which the Pff_3 green siltstone member floods into the Pff_4 upper black shale member of the Mount Les Siltstone. A thin lowstand dolarenite is evident in WFDD74, and thin highstand systems siltstones are also present in most wells and outcrop sections. Thick pyrite beds from the number 1 and 2 pyrite lenses occur within carbonaceous shales at the top of the River 6 sequence boundary. *Rohrlach et al. (1998)* interpret the upper black shale member as deposited below storm wave base in anaerobic conditions. The presence of abundant soft sediment deformation and submarine mass flow scarp-derived talus breccias and sulphide mound debris *(Rohrlach et al., 1998)* indicates the River 6 sequence was a period of rapid subsidence driven by syndepositional fault activity.

River 7 is the most variable of the three sequences on the southern flanks of the Murphy Inlier. On the eastern Murphy Inlier around the Walford Creek Prospect, the River 7 sequence shows a simple retrogradational-progradational gamma log motif (**Figs. 1.6.1** and **1.6.4**) that corresponds with the $Pffl_5$ member of the Mount Les Siltstone as informally defined by *Rohrlach et al. (1998)*. Here in the eastern outcrop belt, the River 7 sequence begins with a thin lowstand sandstone and an associated blocky gamma log trend. A relatively thick transgressive systems tract is then evident from the strongly retrogradational gamma log trend and associated fining up lithofacies from sandstones and siltstones to carbonaceous shales. *Rohrlach et al. (1998)* note that the $Pffl_5$ member was initially deposited below storm wave base and has no associated pyrite lenses at the top of the transgressive systems tract. The River 7 sequence ends at the Walford Creek Prospect with a marked highstand systems tract as indicated by a progradational gamma log trend and associated coarsening up from the carbonaceous shales into dolomitic siltstones and sandstones. The upper part of the $Pffl_5$ member associated with the River 7 highstand was deposited above storm wave base as indicated by the abundance of scouring and dewatering structures *(Rohrlach et al., 1998)*.

Further west in the Gorge Creek Prospect area, the River 7 sequence shows a marked lateral facies change, particularly within the lowstand systems tract (**Fig. 1.6.4**). Here, the lowstand is much thicker and characterised by a fluvial-shallow marine, trough cross-bedded conglomeratic sandstone. The River 7 lowstand and early transgressive systems tract in this western outcrop belt corresponds to the Pfd_1 member of the Doomadgee Formation as originally defined and mapped by *Sweet and Slater (1975)* and *Sweet et al. (1981)*. A major unconformity appears to be present at the base of River 7 in this region *(Rowley, 1983; Lindsay and Wells, 1997)*. The lowstand deposit consists of a basal conglomerate unit of variable thickness (1-5m), containing clasts, pebbles, and cobbles of silicified Walford Dolomite and Mount Les Siltstone and orthoquartzites of unknown origin *(Rowley, 1983; Lindsay and Wells, 1987)*. In the west, the base of the River 7 transgressive systems tract is a shallow marine oolitic sandstone that deepens upward into a deep marine carbonaceous siltstone and shale. Gamma logs show a similar retrogradational trend in the River 7 transgressive systems tract in the western and eastern outcrop belts. The overlying highstand systems tract is also very similar in the west and east, showing a progradational package of oolitic shallow marine sandstones.

The carbonaceous siltstone/ shales and overlying shallow marine sandstones from the River 7 transgressive and highstand systems tracts are mapped in the western area as the $Pffd_2$ member of the Doomadgee Formation *(Sweet and Slater, 1975; Sweet et al., 1981)*. However, the cross-section in **Fig. 1.6.4** shows there is very little difference in the gamma and lithology trends between western and eastern regions; ie the Pfd_2 member in the west is essentially the same as the informal Pff_5 member of *Rohrlach et al. (1998)* from the east. This contrast in the placement of River 7 is due to the thickening of the lowstand systems tract into a prominent lowstand fluvial-coastal conglomeratic sandstone unit in western areas. However, gamma log trends from the overlying transgressive and highstand systems tract, and subsequent Term Supersequence boundary clearly show these Doomadgee strata belong to the River 7 sequence and highlights the dangers of correlating lithostratigraphic units without a sequence stratigraphic framework. The change in lithofacies of the lowstand systems tract seems to occur in the vicinity of the Calvert Fault. It is possibly that the lateral facies change is associated with tectonic activity along the Calvert Fault at River 7 time, the western Inlier representing an uplifted area characterised by footwall incision and incised valley fill. To avoid confusion in lithofacies nomenclature, we propose referring to the Rohrlach et al. informal scheme as the eastern Mount Les Siltstone/Doomadgee Formation members, and the *Sweet et al. (1981)* scheme as the western Mount Les Siltstone/Doomadgee Formation members.

1.6.6. Term Supersequence (Doomadgee Formation)

The Term Supersequence boundary is a regional truncation surface that eroded all of the underlying River 8 sequence. Overlying this unconformity in the Walford Creek Prospect area, a coarse grained intraclast dolarenite which forms the lowstand systems tract of Term 4 (**Fig. 1.6.1**). *Rohrlach et al. (1998)* interpret this basal carbonate as the eastern Pfd_1 member from the base of the Doomadgee Formation. Further west, a basal carbonate is also present at Elf Aquitaine 5002 and Amoco 83-4, while a coarse to fine grained dolomitic sandstone is present at Elf Aquitaine 5001 and the AW 1-5 composite section (**Fig. 1.6.4**). The composite field section through the lowstand dolomitic sandstones shows the presence of numerous desiccation cracks. In both areas, the basal lowstand carbonate/sandstone is overlain by a relatively heterolithic section of interbedded laminated very fine grained dolomitic sandstones, siltstones, and shales. Retrogradational gamma logs show that this section deepened into an inner ramp environment to form the transgressive systems tract of Term 4. Overlying strata are broadly aggradational to slightly progradational and interpreted as the highstand systems tract of Term 4. The Term 5 sequence boundary occurs as a thin package at the top of the Term Supersequence and is marked by a coarse dolomitic sandstone. Strata above the Term 4 lowstand are identified by *Rohrlach et al. (1988)* as the eastern Pfd_2 member in the Walford Creek region. In western regions, the basal dolarenite/dolomitic sandstone and overlying interbedded dolomitic sandstones, siltstones and shales are all placed in the Pfd_3 member from the upper Doomadgee Formation *(Sweet et al., 1981; Rowley, 1983)*. This relationship highlights the inherent problems in attempting to correlate lithostratigraphic units along the Murphy Inlier. The sequence stratigraphic framework we have presented will help to alleviate future problems in the correlation of synchronous depositional systems within the Fickling Group.

1.6.7. Lawn, Wide and Doom Supersequences (Upper Doomadgee Formation)

The Lawn, Wide, and Doom Supersequences are generally poorly preserved on the Murphy Inlier due to post depositional erosion by the South Nicholson Group. No record of these supersequences exists in well logs from western areas, but correlative strata are present in some of the Walford Creek Prospect holes to the east (**Figs. 1.6.1** and **1.6.4**). The Lawn Supersequence is represented by only one third-order sequence, the Lawn 1 sequence, which corresponds to the uppermost eastern Pfd_3 member of the Doomadgee Formation. Only the lowstand and transgressive systems tracts of Lawn 1 are preserved in the eastern outcrop belt. Seismic data shows that the highstand systems tract and younger Lawn 2-4 sequences have been truncated by the Wide Supersequence boundary (**Chapters 2** and **5**). An aggradational very fine sandstone and siltstone that was deposited in an inner ramp to shoreface environment represent the Lawn 1 lowstand. An overlying transgressive systems tract is indicated by a retrogradational gamma trend corresponding to a fining up from the sandstones and siltstones into deep marine siltstones and shales. SHRIMP zircon dates from tuffaceous siltstones within this sandstone unit (1613±5Ma) confirm that it correlates with the Bulmung Sandstone (1611±5Ma).

The Wide Supersequence is marked by a fall in gamma values that corresponds to a major basinward shift in lithofacies (**Fig. 1.6.1**). The Wide Supersequence boundary is a major truncation surface that removes the Lawn 2-4 sequences. The Wide 1 sequence occurs above the truncation surface and is characterised by a slightly retrogradational package of fine grained dolomitic sandstones. These dolomitic sandstones of Wide 1 represent a proximal transgressive systems tract deposited in a coastal - shoreface environment. The Wide 2 sequence is missing in the Fickling Group, but seismic data shows it onlaps onto Wide 1 south of the Murphy Inlier. The Wide 3 sequence boundary is indicated at the top of drill holes by a high-gamma sandstone, similar to the high-gamma Widdallion Sandstone found in Wide 3 on the Lawn Hill Platform (**Section 1.4**). Carbonaceous siltstones and shales overly this high-gamma sandstone and probably represent the transgressive systems tract of Wide 3. Although a progradational gamma trend is indicated in the well data, this is likely to be a signature generated by weathering in the regolith zone rather than a primary sedimentary signature. The Doom Supersequence may occur above Wide 3 in drill hole WFDD17, but would lie in the zone of regolith weathering and thus be impossible to confirm. Strata from the Wide and Doom Supersequence correspond to the eastern Pfd_3 member of the Doomadgee Formation.

1.7. The South Nicholson and Roper Groups: Evidence for the early Mesoproterozoic Roper Superbasin

(M.J. Jackson, I.P. Sweet, R.W. Page, and B.E. Bradshaw)

1.7.1. Introduction

The Mesoproterozoic South Nicholson and Roper Groups have long been interpreted as representing separate epicontinental basin entities to the underlying Palaeoproterozoic McNamara and McArthur Group strata respectively *(Sweet et al. 1981; Sweet and Hutton, 1982; Sweet, 1984; Jackson et al., 1987)*. The Roper and South Nicholson Groups have also been broadly correlated *(eg Dunn et al., 1966; Plumb et al., 1981; Jackson et al., 1987)* because of the similarity of lithofacies.

Rb-Sr illite age dating of the Roper Group at 1429±31Ma *(Kralik, 1982)* compared with ages of around 1640Ma from the Mount Isa and McNamara Groups, indicated that there could be a significant time break between these Mesoproterozoic and Palaeoproterozoic successions. However, *McConachie et al. (1993)* and *McConachie and Dunster (1998)* interpret a conformable relationship between the South Nicholson Group and the McNamara Group throughout the Comalco seismic grid in the Lawn Hill area, despite clear evidence of an unconformity 5km south of the seismic grid (**Fig. 1.7.1**). These authors proposed a foreland continuum model to explain their apparent conformable relationship in the seismic grid. In their basin model, commencement of the Isan Orogeny is placed at the base of the upper McNamara Group (~1640Ma). The foldbelt and associated foreland basin are inferred to subsequently propagate northwards, culminating in deposition of the late orogenic “fluvial” South Nicholson Group.

In this section, we present our preference for an epicontinental South Nicholson-Roper superbasin, herein named the *Roper Superbasin*, separate from the underlying Isa Superbasin *(Jackson et al., in press[a])*. This view is based on a review of previous regional information, new isotopic dating, and recent insights from the NABRE project.

1.7.2. Seismic Character of the South Nicholson Group

Most of the evidence presented by *McConachie et al. (1993)* and *McConachie and Dunster (1998)* for a foreland continuum model between the McNamara Group and South Nicholson Group comes from their interpretation of the Comalco seismic lines and associated wells. Over most of the seismic grid, South Nicholson Group equivalent rocks form a relatively thin package close to the seismic datum (mean sea level). The original Comalco interpretations were made on paper sections with little vertical exaggeration, which led to relatively poor imaging of the base of the South Nicholson Group. Only in the east around the Egilabria well is the South Nicholson Group thick enough to produce useful reflections on paper copies of the seismic sections. According to *McConachie and Dunster (1998)* information from Egilabria_1 and relationships on surrounding seismic sections show a conformable and interdigitating relationship between the South Nicholson and McNamara Groups.

Reinterpretation of the stratigraphic relations of the South Nicholson Group *(Bradshaw et al., 1998)*, using digitally enhanced seismic sections, shows that the group lies with subtle to marked angular unconformity on the underlying Isa Superbasin in most parts of the Comalco grid (**Fig. 1.7.2**). Correlation of strata across the four Comalco wells shows at least 1000m of erosion from the upper part of the Isa Superbasin in the area between Egilabria_1, in the east, to Argyle Creek_1, in the west (**Fig. 1.7.3**). Integrated well log and seismic interpretation thus supports the presence of a regional angular unconformity, which we will argue represents a major basin phase boundary at the base of the South Nicholson Group. In some isolated areas such as at Egilabria_1, the South Nicholson Group is locally concordant on older strata, but laterally these same strata also exhibit significant angular relationships (**Fig. 1.7.4**). The Comalco seismic grid is east of the main South Nicholson Group outcrop belt (**Fig. 1.1.1**). Isolated depocentres with up to 650m of strata occur in synclines to the east, and up to 300m of strata is preserved within incised valleys around Argyle Creek_1. However, in most parts of the seismic grid the South Nicholson Group thins through onlap and truncation to <100m (**Fig. 1.7.5**). In western areas the basal part of the Group is generally characterised by semi-transparent, semi-continuous to chaotic reflections, while in eastern areas reflections are moderate to high amplitude, parallel to clinoformal. These seismic characteristics are consistent with the presence of fluvial and shallow marine sequences in this part of the section.

1.7.3. Stratigraphic Architecture of the South Nicholson Group

The following information is based largely on a review of previously published information from regional mapping surveys carried out during the 1960-70s *(Smith and Roberts, 1963; Roberts et al., 1963; Sweet et al., 1981; Sweet, 1984; Ahmad and Wygralak, 1989)*, supplemented with unpublished material and our recent observations.

The South Nicholson Group is preserved over an area of about 20 000km^2 in far northwest Queensland and the adjacent Northern Territory. Outcrops of the group cover the western half of the Comalco seismic grid area and extend to the west, south-west, and south of the grid (**Fig. 1.1.1**). The two composite sections on the right hand side of **Fig. 1.7.6** show the main characteristics of the Group in two areas:

- Near the seismic grid (Seigal-Hedleys-Bowthorn column), which is at the northeast end of the outcrop belt and is based on information in *Sweet et al. (1981)*;

- In the south-central part of the outcrop belt (Carrara Range Region) which is based on information in *Sweet (1984*). The South Nicholson Group consists dominantly of quartz sandstone units interstratified with units of siltstone and shale. The lower half of the group is dominated by cross-stratified, medium to coarse grained quartz sandstone deposited in fluvial and shallow marine environments. The upper half is dominated by finer grained lithologies, including very fine-grained glauconitic sandstone, siltstone, and shale, deposited in mostly deeper marine environments *(Sweet et al., 1981)*.

In the most recently published maps from the north of the region (Seigal and Hedleys Creek 1:100 000 maps), the various siltstone units in the lower part of the South Nicholson Group (Pandanus, Wallis, and Bowthorn Members) are laterally extensive and can be mapped on a scale of at least tens of kilometres *(Sweet et al., 1981, their Fig. 3)*. We have not carried out detailed sequence stratigraphic studies on this part of the succession. However, based on the vertical stacking patterns of rock types it is reasonable to propose that these shale intervals represent regional flooding episodes and are broadly correlative with the transgressive-regressive shale-sandstone units in the Roper Group (Roper River column in **Fig. 1.7.6**). The two South Nicholson columns and the more complete Roper River column on **Fig. 1.7.6** all show:

- A gradual upward increase in shale content probably related to overall gradual transgression;

- A similar number of shale/sand units of variable but comparable thickness; and,

- Identical shallow-water oolitic ironstones - the Train Range Ironstone Member (South Nicholson Group) and the Sherwin Ironstone Member (Roper Group) at similar stratigraphic positions.

The geometry of the South Nicholson Group is generally not well known. However, regional variations appear to be very gradual based on the following observations. In the north (SEIGAL) the South Nicholson Group is around 650m thick, whereas in the northeast, in HEDLEYS CREEK, it reaches about 1300m. In the far west (western Mount Drummond 1:250 000 sheet area) it is over 2000m thick. Across the Comalco grid (ie at the eastern most extent of the South Nicholson Group) its thickness is highly variable, ranging from 0-650m thick (**Fig. 1.7.6**). From this information, we suggest that there is a broad regional trend of gradual thickening to the south and/or southwest (**Fig. 1.7.7**): similar to that seen in the Roper Group (**Section 1.7.4**). On a more local scale, *Sweet et al. (1981, p 21)* interpreted the northwesterly thinning of the basal member of the Constance Sandstone (Psa_1) in SEIGAL and HEDLEYS CREEK as due to onlap of the base of the Group onto the Murphy Inlier. This observation is consistent with seismic interpretations and implies that the basement block had positive relief during the early stages of deposition of the South Nicholson Group. The gradual south- to southwest-thickening wedge that characterises the South Nicholson Group contrasts markedly with the stratigraphic architecture of the underlying McNamara Group in the Isa Superbasin. In particular, the River, Term, and Wide Supersequences show rapid thickness and lithofacies variations across regional fault systems (eg Termite Range Fault, Elizabeth Creek Fault), while the Lawn and Doom Supersequences tend to maintain relatively tabular architectures (**Fig. 1.7.7**). These contrasting stratigraphic architectures suggest different basin settings for the South Nicholson Group and Isa Superbasin.

According to *Sweet et al. (1981)*, the sandstone and siltstone-shale units forming the South Nicholson Group are conformable with each other. However, as noted earlier, the basal contact of the South Nicholson Group is disconformable to unconformable on the underlying, more tightly folded, Lawn Hill Platform succession. In SEIGAL the South Nicholson Group overlies, with angular unconformity, all units of the Fickling Group. Likewise, in the Carrara Range region, *Sweet (1984)* describes the Constance Sandstone as overlying the Lawn Hill Formation with angular unconformity in most areas, except in the northwest of the area where it is locally disconformable.

The prominent regional angular unconformity at the base of the South Nicholson Group is also clearly portrayed on the 1:500 000 scale Mount Isa Inlier and Environs geological map along longitude 138°30’. In this location, west-trending fold axes in tightly folded McNamara Group are sharply truncated by gently-dipping South Nicholson Group (see also **Fig. 1.7.1**).

1.7.4. Age of the South Nicholson Group

An important aspect of the sequence stratigraphic studies undertaken in the NABRE project in 1996-97 was to assess the relative importance of the major surfaces identified during stratigraphic section measuring. One way to measure the time gap a surface represents is by sampling and dating tuffs beds above and below each surface. We attempted to do this for the surface at the base of the South Nicholson Group. The youngest tuff bed dated in the Isa Superbasin, from the H4s siltstone member of the Lawn Hill Formation, dates the base of the Wide Supersequence at 1595±6Ma *(Page and Sweet, 1998)*. *Bradshaw et al. (1998)* document at least another 1500m of strata above the H4s siltstone at the Egilabria_1 well.

A sample for dating was collected from a pebbly, coarse-grained, feldspathic sandstone from the Constance Sandstone, immediately above the surface forming the base of the South Nicholson Group (at NABRE site BJD/09B, sample 9577.9077, west of Little Creek in the Lawn Hill region). This sample yielded an age of 1591±10Ma, which is considered to be the age of detrital grains sourced from the underlying Lawn Hill Formation and not the depositional age of the base of the South Nicholson Group for following reasons:

- The zircon grains from this feldspathic sandstone consist of euhedral to subhedral, to variably rounded morphologies that suggest a complex provenance history. Only the more pristine euhedral types were analysed in the SHRIMP session, as the aim was to determine the sediment's most realistic (maximum) depositional age. Almost all of the 28 data points (**Table 1.7.1**) are concordant to sub-concordant. Grains 17.1 and 22.1 have 26% Pb loss, but they still fit within the main age population. Analyses of grains 128.1 and 124.1 reflect earlier sedimentary sources at 1822Ma and 1691Ma, respectively. However, the rest of the data (26 of the 28 analyses) define a single $^{207}Pb/^{206}Pb$ age distribution (χ^2 1.08) at 1591±10Ma. This is a maximum depositional age for the unit. The similarity of age to the youngest dated (H4s) member of the Lawn Hill Formation, and the unusual and comparably high Th/U in the zircons (similar to member H4s zircons) strongly suggest that this zircon detritus was derived from the upper part of the Lawn Hill Formation.

- If this SHRIMP date is interpreted as the age for initiation of South Nicholson Group sedimentation, then an additional 1500m of strata would have to have been deposited above H4s within a 6-10Ma period. A major episode of folding and at least 5500m of erosion then followed the period of rapid sedimentation. This scenario seems very unlikely, especially as it allows only a few million years for a major orogenic event to take place.

- The base of the South Nicholson Group in this area contains abundant reworked material, ranging from cobbles to granules, from the underlying Lawn Hill Formation. The underlying Pmh_6 member contains beds of green, possibly tuffaceous siltstone. It is therefore likely that sediments sampled for SHRIMP dating include reworked Pmh_6 tuffs and that the SHRIMP date is actually the age for deposition of the Doom Supersequence.

Table 1.7.1. Summary of U-Pb zircon SHRIMP results for metasediments from the Mullera Formation, South Nicholson Group

Sample No.	*Lithology*	*Drill hole*	*Sample depth*[1]	**Zircon ages (Ma)**[2]
9677.9137	Grey green carbonaceous siltstone	DDA 127	260-265	1740, 1780-1800, 1850-1870
9677.9140	Grey carbonaceous siltstone	DDA 127	1109-1120	1680, 1770, 1820, 1880
9677.9141	Grey carbonaceous shale	DDA 149	60-69	1680, 1780, 1850-1900, 2260
9677.9142	High γ-ray response carbonaceous shale	DDA 151	63-69	~1670, ~1750, ~1860
9677.9144	Pyritic grey shale	DDA 172	369-404	1570, 1680, 1780, 1840
9677.9145	Pyritic grey shale	DDA 172	453-463	1675, 1780, 1850
9577.9088	Pale green tuffaceous clay	McA 15[3]	166.23-166.37	1493 ± 4Ma
9577.9119	Pale green tuffaceous clay	Broughton No. 1[4]	251.65-251.85	1492 ± 4Ma

1. Depths for the DDA-series holes are in feet; those for McA 15 and Broughton 1 are in metres
2. Ages for the material from the DDA-series holes are provenance ages; those for McA 15 and Broughton 1 are interpreted as depositional ages
3. Located on the Mount Young 1:250 000 sheet area, at Lat. 15°56´S, 135°31´E
4. Located on the Urapunga 1:250 000 sheet area, at Lat. 14°22´S, 133°37´E

Six feldspathic (possibly tuffaceous) siltstone and shale samples from the Mullera Formation, higher in the South Nicholson Group, were also selected for zircon separation and SHRIMP analysis in order to provide constraints on the depositional age or maximum depositional age. The samples, each of 0.5 to 0.8 kg, were obtained from cores of BHP holes in the Constance Range iron deposits *(Harms, 1965)*. They provided abundant rounded to sub-euhedral zircon grains, which yielded the SHRIMP U-Pb zircon ages summarised in **Table 1.7.1**.

In general, the most pristine, euhedral zircons were targeted as a means of defining the most realistic maximum depositional ages for the sediments. Despite the fact that there was no predictable correlation between zircon morphology and U-Pb age, some very consistent patterns emerge from the data. In all but one sample, there is a strong provenance component at about 1680Ma (**Fig. 1.7.8**). This is the dominant detrital zircon population in four of the six samples, and probably corresponds to source terrain(s) of lower McNamara Group–Carters Bore Rhyolite–Sybella Granite age. It is clearly a reliable maximum age for the Mullera Formation.

The 1770-1780Ma detrital suite is evident in all samples (although it is unclear for sample 9677.9142, as only a few grains were analysed), and this age group matches well known magmatic terrains, eg. the Haslingden Group in the Mount Isa Inlier. The third major provenance source, corresponding in age to Barramundi Orogeny rocks, is reflected in the 1850-1880Ma zircon detrital ages. The distribution of the various provenance ages is highlighted in the histogram plot in **Fig. 1.7.8**.

In sample 9677.9144, one mildly abraded euhedral zircon (grain 510.1) has a distinctively high Th/U ration (1.25) and a much younger age of 1569±19Ma (1σ). This analysis has low common Pb, unlike the high common Pb, 1547±49Ma age for analysis 313.1, sample 9677.9137. This detrital zircon age of 1569±19Ma therefore provides the youngest maximum age for these sediments, and is consistent with other evidence for the broad correlation of the South Nicholson Group with the Roper Group (see below).

Recent isotopic dating, and regional lithostratigraphic correlations between the South Nicholson Group and the Roper Group, and similar studies of the Nathan Group and the upper McNamara Group, suggest that the time gap represented by the unconformity at the base of the South Nicholson Group represents about 80-100 My.

1.7.5. Regional Correlative - the Roper Group

Like the South Nicholson Group, the Roper Group consists predominantly of alternating formations of clean quartz sandstone and shale. These units are internally concordant and conformable and show remarkable lateral consistency and continuity over at least 145 000km^2 of the Northern Territory *(Abbott and Sweet, in press)*. The Roper Group is gently folded and sits unconformably on older, more tightly folded and faulted carbonate-rich successions — the McArthur and Nathan Groups. Regional thickness changes for the main lithostratigraphic subdivisions of the Roper Group, between Borroloola and the Roper River area, are shown in **Fig. 1.7.9** *(*modified after *Jackson and Raiswell, 1991, Fig. 2)*. The Roper Group thickens gradually to the west/southwest: it is around 1400m thick in the Abner Range area (17°S, 136°E) and 2000m thick in the Roper River area (15°S, 135°E). Based largely on geophysical studies, *Plumb and Wellman (1987)* suggest that the Roper Group continues to thicken to the southwest to about 5000m in the Beetaloo Sub-basin (17°S, 134°E). This has been confirmed by petroleum drilling in the sub-basin *(Lanigan et al., 1994)*.

The two simplified representative columns through the Roper Group shown on the left in **Fig. 1.7.6** are from the best exposed sections in the Abner Range and Roper River areas *(Sweet and Jackson, 1986; Jackson et al., 1988)*. In the most complete section at Roper River the Group consists of about 15 alternating units of quartz sandstone and siltstone-shale, most of which have been formally described as formations or members of the Group. As with the South Nicholson Group, finer grained units are dominant in the upper half of the section. However, coarser grained oolitic ironstones occur in the middle of the McMinn Formation. In general, individual sandstone formations are around 50m thick and show many features characteristic of deposition in high energy current- and wave-affected shallow marine environments. These sandstones thicken gradually to the south and west and average 250m thick in the AMOCO Broadmere Well (**Fig. 1.7.9**). In the Roper River section the siltstone-shale formations are generally thicker than their enclosing coarser grained clastics. They are commonly 200-300m thick and show evidence of deposition in lower energy, inner to outer shelf environments *(Jackson et al.,* *1988; Jackson and Raiswell, 1991)*. These finer grained facies represent broad marine flooding episodes. Unlike the coarse-grained facies, the fine-grained transgressive units do not show apparent thickening into the Broadmere area. The thickness variations in the coarser clastics are therefore probably best interpreted as due to increased clastic input from source areas to the south and/or west (from the direction of the Tennant Creek region, or from farther south; *Abbott and Sweet, in press*).

In all parts of the McArthur Basin the Roper Group is separated from the underlying Palaeoproterozoic rocks by a disconformity or unconformity *(Jackson et. al., 1987; Pietsch et. al., 1991; Haines et al., 1993)*. In the Abner Range area the basal unit of the Roper Group is the Limmen Sandstone, a fine to medium grained quartz sandstone commonly with pebbles of chertified carbonates at the base. Around the northern end of the range it sits on different stratigraphic levels of the Dungaminnie Formation, indicating a slight angular unconformity between the Roper Group and the underlying Nathan Group. Farther west and northwest a thin siltstone-mudstone unit, the Mantungula Formation, beneath the Limmen Sandstone, marks the base of the Roper Group. The following stratigraphic relations along the western margin of the Batten Fault Zone (as portrayed on Bauhinia Downs and Mount Young 1:250,000 geological maps), indicate a pronounced regional unconformity:

- At the northern end of this outcrop belt, in the Eastern Creek area (16°S, 135.5°E), the Roper Group sits on the Nathan Group (depositional age of about 1590Ma).

- 40km to the south it has cut down to sit on cherty carbonate units from the middle of the Batten Subgroup (depositional age of about 1640Ma).

- At Yah Yah (17°S, 135.4°E), at the southern end of the outcrop belt, it has eroded down as low as the Tatoola Sandstone (depositional age of about 1650Ma) which is near the base of the McArthur Group.

- Farther north, in the Mount Marumba and northwestern Urapunga sheet areas in southern Arnhem Land, the Mount Rigg Group, an equivalent of the Nathan Group, is overlain disconformably and with subtle angular unconformity by the Roper Group. At least 500 m, and possibly up to 1000m, of Mount Rigg Group appears to have been eroded and a regolith surface developed, before the basal Roper Group (Limmen Sandstone) was laid down (*Sweet et al., 1999*).

These regional trends indicate deposition and lithification of more than 2000m of section, (representing about 40Ma), followed by deformation and extensive erosion, before deposition of the succeeding Roper Group. The erosion in the McArthur region of about 2000m of section from north to south over a distance of about 120kmis comparable to the 1000m of erosion from east to west within a distance of about 80kmin the area of the Comalco wells (**Fig. 1.7.3**).

1.7.6. Age of the Roper Group

Prior to the NABRE study the best estimate for the depositional age of the Roper Group was about 1430Ma *(Jackson et al., 1988)*. This was based on:

- a minimum age of approximately 1280Ma from K-Ar dating of dolerite sills that intrude the upper part of the group *(McDougall et al., 1965)*, and
- a Rb-Sr age of 1390±20Ma from glauconite grains from near the base of the group *(McDougall et al., op cit)*; and
- a Rb-Sr date of 1429±31Ma for diagenetic illite from near the top of the group (*Kralik, 1982*).

As part of the NABRE project, samples of green claystone (suspected as being tuffs) were collected from dark grey, laminated, low-energy (deep water) shales from the lower part of the Mainoru Formation, in order to assess the age of the lower Roper Group. Samples were obtained from two drill holes — BHP's McA 15 and Pacific Oil and Gas Broughton 1 (**Table 1.7.1**). Zircons recovered from these thin tuff beds are generally pale brown, squat euhedral crystals, although the Broughton 1 sample yielded additional long slender grains. Minor bleb-like inclusions and cracked altered cores are also evident in some grains.

The SHRIMP U-Pb data for these rocks were acquired in two separate sessions. Zircons from the McA 15 tuff have relatively low U content, generally between 60-130 ppm. The data are generally concordant (except for grain 10.1 that has 15% recent Pb loss) and 56 of the 57 analyses (deleting aberrantly young analysis 17.1) define a cluster in $^{207}Pb/^{206}Pb$ corresponding to the zircon suite's igneous crystallisation age of 1493±4Ma (χ^2 1.27). The zircon population from the Broughton 1 sample has higher U (generally 60-220 ppm), but the data are as concordant as those from the McA 15 tuff. Data from the separate Broughton 1 analytical sessions are in close agreement, and 46 of the 49 analyses (deleting 103.2, 113.1, and 106.1) provide a zircon crystallisation age of 1492±4Ma (χ^2 1.37).

The two Mainoru Formation ages are in excellent agreement with each other. Strictly they are maximum ages for the deposition of these tuffaceous sediments, but the coherence of the results and the lack of any clearly older detrital zircons suggest that these ages record the zircon igneous crystallisation more or less synchronous with the depositional event. Stratigraphically the samples occur within a major highstand cycle in the lower Roper *group (Abbott and Sweet, in press)*, and indicate that deposition of the Roper Group most probably commenced at about 1500Ma. In drill hole BMR Bauhinia Downs 3, at the northern end of the Abner Range, euhedral zircon crystals with pristine igneous character have been extracted from a green claystone sample from within a laminated black shale sequence in the upper part of the Balbirini Dolomite, near the top of the Nathan Group. These zircons have recently yielded a Shrimp U-Pb age of 1589±3Ma *(Jackson et al., in press[b])*. Consequently, the unconformity at the base of the Roper Group, and by correlation that at the base of the South Nicholson Group, represents a time break of some 80-90 million years.

Page and Sun (1998) have interpreted an isotopic age of about 1584±17Ma (from the Eastern Fold Belt of the Mount Isa Inlier) as the first evidence for metamorphism associated with the Isan Orogeny. Thus, the 80-90Ma time break between the latest known deposition in the Isa Superbasin and the initial deposition in the Roper Superbasin is most likely to represent the period of regional deformation and erosion associated with the Isan Orogeny.

1.7.7. Summary

As noted by *Dunn et al. (1966)*, the Roper and South Nicholson Groups are lithologically very similar. In the most complete sections, both groups comprise about 15 units (tens to hundreds of metres thick) of either sandstone or siltstone-shale. The clastic lithofacies of the Roper and South Nicholson Groups are very different from the mixed carbonate-clastic lithofacies that characterise the underlying McArthur, McNamara and Fickling Groups.

The broad, gradual, regional thickness variations in the Roper and South Nicholson Groups are very different from the rapid lateral thickness changes documented in the fault controlled sub-basins operating during upper McNamara and McArthur/Nathan Group times. There is a marked stratigraphic break between the Roper Group and underlying Nathan-McArthur Groups, and also between the South Nicholson Group and the McNamara/Fickling Groups. At some localities this is a subtle disconformity, but in most areas it is an obvious angular unconformity.

Shrimp U-Pb zircon dating of tuffs from the uppermost units in the upper McNamara and Nathan Groups indicate depositional ages around 1590Ma. There are no reliable isotopic depositional ages from the South Nicholson Group, but the depositional age for tuffs in the lower Roper Group is around 1490Ma. This indicates a major stratigraphic break (approaching 100Ma) between the older mixed carbonate-clastic successions and the younger dominantly clastic packages. This break probably equates with the Isan Orogeny. We consider that the Roper and South Nicholson clastic successions were deposited in very different tectonic and basinal settings than those proposed for the underlying McArthur-Nathan and McNamara-Fickling Groups. Given the ~100Ma timebreak, they cannot represent a foreland basin to the Isan Orogeny.

This interpretation is markedly different from the foreland basin model presented in *McConachie et al. (1993)* and *McConachie and Dunster (1998)* who prefer a much closer genetic link and continuity of sedimentation between the two groups. We consider the major episode of sandstone-mudstone deposition recorded in the Roper and South Nicholson Groups, and their distinctly different tectonic setting from the underlying successions, warrants recognition of a separate superbasin *(Jackson et al, in press[a])*.

List of figures

magnetic sources computed using the Phillips Deconvolution Method; C) Bouguer Gravity image.

1.5.2 Stratigraphic columns elucidating the changes to the traditional understanding of the Peters Creek Volcanics on the left resulting from integration of recent regional U-Pb SHRIMP geochronology, palaeomagnetic and field investigations focussed on the Murphy Inlier with existing geochemical and geological data.

1.5.3 'Spider' diagram of relative element abundances of the Seigal, Fiery Creek and Peters Creek Volcanics. The Buddawadda Basalt member of the Peters Creek is shown separately from members 2-7. Note the affinity between the Buddawadda Basalt and the Seigal Volcanics and their differences to the upper Peters Creek and Fiery Creek Volcanics that also show strong geochemical affinity.

1.5.4 Comparison of historical and recent NABRE geochronological, geochemical, palaeomagnetic, and geological data for the igneous units from the north and south outcrop belts around the seismic grid. Geochemical data are grouped (G1 to G3) by compositional affinities (Mackenzie, unpubl.). Palaeomagnetic poles are labelled with a relative age (1>2, a>b>c) as determined by their positions on the apparent polar-wander path (APWP). P(op) = overprint, no primary pole is available; the P2c pole of the FCV appears to be younger than the $Ptp_{5\text{-}7}$ P2b pole; the sample was obtained from a section where no Quilalar Formation or felsic FCV are preserved. Geochronological data are obtained from U-Pb SHRIMP analysis of samples from the indicated units, except for Ptp_3, which is estimated from ages obtained from correlative lower Wollogorang Formation. uncon = unconformity established by recent field work. X = major component or mode of emplacement; x = minor component or mode of emplacement.

1.5.5 Geological interpretations of the seismic data (Figs. 2.2.1 and 2.2.2) that image the Murphy Inlier. To view the regional context of these interpretations the reader is referred to the regional composite profiles provided in Figs. 2.1.2 and 2.1.3. Schematic interpretations of the relationship of the Murphy Inlier and the Peters Creek Volcanics to the Isa Superbasin are found in Figs. 1.2.3, 1.2.5 and 1.2.8.

1.6.1 Sequence stratigraphy of the Fickling Group, eastern Murphy Inlier, based on analysis of composite gamma curve and lithofacies trends.

1.6.2 Map of the Murphy Inlier and Fickling Group showing major faults, outcrop section locations and mineral prospect areas referred to in the text.

1.6.3 Cross-section of outcrop logs of the Prize and Gun Supersequences (Fish River Formation) along the Murphy Inlier.

1.6.4 Cross-section of the Loretta through Doom Supersequences along the Murphy Inlier.

1.7.1 Aerial photo interpretation of the angular unconformity at the base of the South Nicholson Group or Basin, 10kmsouth of Elizabeth Creek.

1.7.2 Seismic geometry of the South Nicholson Group (SNB) overlying the Isa Superbasin in northwestern Lawn Hill Platform. The base of the South Nicholson Group is erosional, and most of the Doom Supersequence has been removed.

1.7.3 Evidence for extensive erosion of Isa Superbasin beneath the South Nicholson Group in Comalco well log data.

1.7.4 Seismic example of locally conformable relationship between South Nicholson Group (SNB) and Isa Superbasin. This relationship suggests deposition of the SNB commenced before deformation caused topography was fully peneplaned.

1.7.5 Isochron map of South Nicholson Group (Basin) within the Comalco grid.

1.7.6 Representative lithostratigraphic sections through the Roper Group in the southern part of the McArthur Basin and the northern part of the Lawn Hill Platform.

1.7.7 Inferred geometry of the South Nicholson Basin compared to older fault-controlled sub-basin geometries within the Isa Superbasin.

1.7.8 Histogram plots showing ages of provenance terranes revealed by SHRIMP analysis of samples from the Mullera Formation, South Nicholson Group.

1.7.9 Thickness variations of main units within the Roper Group (correlated to the South Nicholson Group) to the northwest of the Murphy Inlier.

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CHAPTER 2

Seismic Sequence Stratigraphy

and

Basin Evolution

AGSO Record 1999/19

AGSO
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Chapter 2

SEISMIC SEQUENCE STRATIGRAPHY
and
BASIN EVOLUTION

(D.L. Scott and B.E. Bradshaw)

2.1. Introduction

This chapter outlines the gross geometry and basin-fill history of the Isa Superbasin. A series of five regional cross-sections are used to elucidate the geometry of the Isa Superbasin (**Figs. 2.1.1**, **2.1.2**, **2.1.3**, **2.1.4**, **2.1.5** and **2.1.6**). These cross-sections are representative of the seismic data which are available for the northern Lawn Hill Platform. Cross-sections are composites (ie jump-correlation) of individual seismic sections (**Fig. 2.1.1**). Composites were designed to relate to constraining wells and drillholes. Isochron maps depicting two-way travel-time (msec) contours provide a plan-view of the geometry of sedimentary packages defined by seismic surfaces (eg **Fig. 2.1.7**). **Table 2.1** provides information on how to convert these msec values into approximate metre thicknesses for each supersequence. Flattened seismic lines (see individual examples throughout this chapter) help visualise the basin-fill history of the Isa Superbasin in the northern Lawn Hill Platform area.

Seismic reflection profiles provide important details regarding the stacking patterns, internal and lateral geometry, and structural controls on the Isa Superbasin within the northern Lawn Hill Platform. Geopotential modelling (**Chapter 3**) is used to determine the probable geometry of basins beneath the seismic penetration. Insights into basin events are particularly enhanced in this area due to the preservation of the original depositional geometry of most seismic sequences and only minor post-depositional deformation (eg **Fig. 2.1.2**). Outcrop exposures south of the seismic grid (ie south of the Elizabeth Creek Fault) are, by comparison, highly deformed due to extensive folding and faulting during the Isan Orogeny (eg **Fig. 2.1.6**).

Seismic profiles are divided into genetically related packages by first identifying gross reflection patterns. These gross packages are then broken down into seismic sequences on the basis of reflection termination patterns. The main reflection termination types outlined by *Vail (1987)* are onlap, downlap, truncation, toplap, and apparent truncation (**Fig. 2.1.8**). Sequence boundaries are characterised by regional onlap and/or truncation surfaces (see **Appendix** for details on sequence stratigraphy nomenclature and techniques). The hierarchy of seismic boundaries as sequence (3rd-order) versus supersequence (2nd-order or basin event) boundaries generally depends on the degree of regional truncation and onlap. In this study supersequence boundaries are mainly defined where one or more seismic sequence(s) onlaps onto or is truncated by another. The interpretation of seismic sequences is constrained by analysis of well logs, borehole geology, and outcrop sections within and adjacent to the seismic lines. Well-log and outcrop interpretations allow a higher resolution breakdown of the geometry of seismic sequences. Details of the integration of well-log, outcrop, and seismic sequence stratigraphy are presented in **Chapter 5**.

The total reflective package imaged in the Comalco seismic grid corresponds to lithostratigraphic Palaeoproterozoic units ranging in age from c.1710Ma to c.1585Ma *(Page and Sweet, 1998; Page, 1997; Page, pers. comm.)*. The gross geometry of this reflective package is a south-thickening megawedge (**Figs. 2.1.2, 2.1.3, 2.1.4, 2.1.5, 2.1.6** and **2.1.7**). The northern limit of the megawedge is approximately 900m thick and corresponds to the Fickling Group that outcrops on the southern flank of the Murphy Inlier. At the southern limit of the seismic grid the megawedge thickens to at least 10km over a distance of ~50km and corresponds to outcrops of the McNamara Group. Within the seismic grid there are 6 major onlap and/or truncation surfaces that correlate to major basin events. *Scott and Bradshaw (1997), Bradshaw et al. (1998)* and *Scott et al. (1998)* originally named these seismic surfaces as PM0, PM1, LM1, RV1, TL1 and WD1. Preliminary seismic interpretations have since been integrated with basin events identified in outcrop sections and wells to develop the NABRE basin event chart (**Fig. 1.2.7**, **Section 1.2**). The seismic megawedge is now divided into the nine supersequences defined by NABRE's integrated basin analysis (**Table 2.2**). In subsequent discussions of the seismic interpretations the current NABRE supersequence terminology is used to name seismic units.

Table 2.1. Average velocities and conversion factors for determining isopach values from isochron maps (multiply the conversion factor by the mapped isochron value to obtain an approximate thickness in metres).

Supersequence	Ave. Velocity (m/s)	Conversion Factor
Isa Superbasin	5500	x2.75
Big	5500	x2.75
Prize	5500	x2.75
Gun	5500	x2.75
Loretta	5500	x2.75
River	4500	x2.25
Term	4500	x2.25
Lawn	4500	x2.25
Wide	4500	x2.25
Doom	4500	x2.25
Roper Superbasin	4500	x2.25
Carpentaria Basin	2500	x1.25

Table 2.2. Nomenclature for seismic surfaces and corresponding supersequence boundaries.

Preliminary Seismic Surface *Scott and Bradshaw (1997)*	**Supersequence Boundary** *This Study*
WD4	Doom
WD1	Wide
TL5	Lawn
TL1	Term
RV1	River
LM1	Loretta
PM2	Gun
PM1	Prize
PM0	Big

2.2. Big Supersequence

The Big Supersequence was deposited during the first Isa Superbasin basin phase. It correlates with the fluvial Bigie Formation and includes the Fiery Creek and upper Peters Creek Volcanics. The Big Supersequence is poorly constrained by seismic data and mostly lies beneath acoustic basement. Some constraints are possible through correlations to outcrops on the southern flanks of the Murphy Inlier, borehole logs on line 91BN-31, and from results of the geopotential models. The Big Supersequence is usually only well imaged at the northern ends of seismic lines where the megawedge thins (**Figs. 2.2.1, 2.2.2, 2.2.3** and **2.2.4**). In these northern areas, the Big Supersequence comprises the upper Peters Creek Volcanics and rare sedimentary packages (**Fig. 1.5.5**). An interpretation for the Big Supersequence boundary is presented on most seismic profiles based primarily on the basement template developed from geophysical data, although this interpretation is highly speculative (**Chapter 3**).

The Big Supersequence boundary represents a major regional unconformity between the Isa Superbasin and the Leichhardt Superbasin. The unconformity erodes through different amounts of the underlying Leichhardt Superbasin strata and overlies the succession with variable angularity in outcrop to the south. Also notable in outcrop is that strata of the Prize Supersequence with no intervening Big Supersequence sometimes overlie the Leichhardt Superbasin. The seismic data provide evidence that this is also true in the northern Lawn Hill Platform.

Reflective packages attributed to the Big Supersequence on data in the western study area are interpreted to overlie high amplitude continuous parallel reflections at depth of the Eastern Creek Volcanics and Buddawadda Basalt of the Leichhardt Superbasin (**Figs. 1.5.5**, **2.2.1** and **2.2.2**). Away from the Murphy Inlier, less distinct reflections below acoustic basement are generally concordant. In these western areas the underlying Leichhardt Superbasin strata dip to the south and appear to terminate against a low angle truncation surface (**Figs. 2.2.1** and **2.2.2**). In the east, the Big Supersequence boundary forms a major angular unconformity above Leichhardt Super Basin strata that dip steeply northwards (**Figs. 2.2.3** and **2.2.4**). This change in the nature of the Big Supersequence boundary from west to east is interpreted as resulting from a change in basement half graben polarity (**Chapter 3**). In most areas, there is no significant onlap against the Big Supersequence boundary except where interpreted syndepositional growth onlaps and appears to incise channels into tilt blocks (**Fig. 2.2.3**). These fluvial packages are correlated to the Bigie Formation that underlies the mafic Fiery Creek Volcanics (eg at Seymour River and Police Creek on the Mount Oxide 1:100,000 map sheet).

A high amplitude doublet ("acoustic basement") occurs at the top of the Big Supersequence that may be the expression of the subsequent mafic extrusive and/or high level intrusive Fiery Creek Volcanics (**Fig. 2.2.4**). Interpretation of seismic data suggest that the Big Supersequence was deposited onto a major truncation surface, associated with half graben defined by north and south dipping growth faults and interrupted by local magmatically induced topography.

The Big Supersequence isochron map depicts irregular thicknesses (**Fig. 2.2.5**). The Big Supersequence generally thickens to the northern end of seismic lines reaching a maximum of about 2400m (~870msec) in the northeast. The supersequence thins to about 1500m (~545msec) on the southern Murphy Inlier through the doming of strata, pinching out of intrusive magmatic layers, and truncation. On the southeastern end of the Beamesbrook composite the Big Supersequence appears to be completely truncated by the overlying Prize Supersequence boundary (**Fig. 2.1.6**). The Big Supersequence appears to thicken to 1000m locally near northeast and southerly dipping growth faults (**Figs. 2.1.4** and **2.1.5**).

In general, the Big Supersequence is characterised by packages of semi-continuous, low to moderate amplitude, parallel to channelised reflections (**Fig. 2.2.3**), or packages of chaotic, mounded, low amplitude to semi-transparent facies (**Figs. 2.2.1**, **2.2.2** and **2.2.4**). These seismic facies are consistent with the presence of igneous and interbedded clastic lithologies. The chaotic, mounded, and transparent facies generally form a broad domal geometry (the Peters Creek dome) at the northern ends of eastern lines (**Figs. 2.2.1** and **2.2.2**). Overlying reflections from the Prize and Big Supersequences show clear onlap onto the truncated dome surface. The seismic geometry is interpreted as indicative of doming by the late stage Big Supersequence (c.1720Ma-1710Ma) felsic intrusions with subsequent, or possibly contemporaneous, onlap by overlying sequences. Outcrop and map relationships in the Murphy Inlier support late stage doming in the Peters Creek Volcanics pile. We interpret the Big Supersequence to represent a 1500-2400m thick interval of volcanics, volcaniclastics, and siliciclastics (Fiery Creek Volcanics and Bigie Formation). Although poorly constrained in the seismic data, this supersequence records a period of major tectonism and magmatism in the initial stages of the Isa Superbasin *(Betts et al., 1996; Scott et al., 1996; O'Dea et al., 1997; O'Dea and Lister, 1997)*.

2.3. Prize Supersequence

The basal unit of the megawedge is a distinct reflective seismic package, formerly termed the PM package by *Scott and Bradshaw (1997)*, *Bradshaw et al. (1998)* and *Scott et al. (1998)*. The PM package is now split into the Prize and Gun Supersequences (**Table 2.2**). The Prize Supersequence was deposited during a period of fluvial to shallow marine clastic sedimentation that includes the Surprise Creek, Torpedo Creek, and lower Gunpowder Creek (1694±3Ma) Formations (south of the seismic grid) and the lower Fish River Formation (southern Murphy Inlier, Pff_1-Pff_2; **Section 1.6**). The Prize Supersequence is very well imaged on all seismic sections, although constraints on lithologies associated with the supersequence are limited to outcrop sections from the southern Murphy Inlier at the northern ends of some seismic lines (**Figs. 2.1.2** and **2.1.3**).

The Prize Supersequence boundary is a significant unconformity that is recognised throughout the seismic data. On the two western composite sections, the Prize Supersequence boundary truncates the underlying Big Supersequence and onlaps onto the Peters Creek Volcanics (**Figs. 2.2.1** and **2.2.2**). Prize is also a major truncation surface on the Beamesbrook composite section where the underlying Big Supersequence has been totally removed by erosion (eg **Fig. 2.1.6**). Lines south of the Peters Creek dome show the Prize Supersequence as disconformable to conformable with underlying Big Supersequence strata. Very little truncation or onlap is evident (**Figs. 2.2.4** and **2.3.1**). Seismic interpretations suggest that throughout most of the grid the Prize Supersequence was deposited over a relatively low relief substrate, although the underlying Peters Creek Volcanics formed a topographic high on the southern flanks of the Murphy Inlier.

The Prize Supersequence has a distinctly uniform thickness across most of the seismic grid of 500-700m (180-255msec; **Fig. 2.3.2**). Seismic data show a gradual thickening up to 1000m (375msec) to the southeast, and thinning northwards before being totally truncated by the Loretta sequence boundary (**Fig. 2.2.4**) or the base sequence boundary of the Carpentaria Basin (**Figs. 2.1.5** and **2.1.6**). The Prize Supersequence thins fairly rapidly in northwestern areas to 0-150m (0-55msec) through onlap against the Peters Creek Volcanics and minor truncation beneath the Gun Supersequence (**Figs. 2.1.2** and **2.1.3**).

The Prize Supersequence is generally characterised by moderate amplitude, continuous, parallel seismic reflections (**Fig. 2.3.1**). This dominant topset or "train-track" geometry is interpreted to reflect fluvial to shallow marine depositional conditions. Channellised facies associated with fluvial systems commonly disrupt the continuous reflections, particularly toward the base of Prize (**Fig. 2.3.3**). A semi-transparent onlapping seismic package occurs on the southern flanks of the Murphy Inlier (**Figs. 2.2.1** and **2.2.2**). This semi-transparent facies is interpreted as a more proximal conglomeratic sandstone unit as found in the lower Fish River Formation (**Section 1.6**). Overall, the Prize Supersequence is interpreted from the seismic grid as a northerly continuation of the clastic ramp interpreted by *Sami et al. (1997)* in Prize age strata on the southern Lawn Hill Platform (**Section 1.3**). Further north, strata from the Prize Supersequence attenuate as they transgress onto the Murphy Inlier.

2.4. Gun Supersequence

The upper two-thirds of the PM seismic package *(Scott and Bradshaw, 1997)* correlates to the Gun Supersequence. In outcrop to the south of the seismic grid, the Gun Supersequence boundary is a subtle unconformable surface within the Gunpowder Formation, but shows locally incision into underlying Prize Supersequence strata (**Section 1.3**). However, SHRIMP dating of zircons from samples within the formation indicate that a major depositional hiatus (up to 25My) is present at the Gun Supersequence boundary. Facies of the Gun Supersequence range from fluvial to shallow marine sandstones of the upper Fish River Formation (Pff_3) in the north, to deep marine siltstones of the upper Gunpowder Creek Formation and platform carbonates of the Paradise Creek (1654±3Ma, 1659±3Ma) and Esperanza (1657±3Ma) Formations in the southeast.

The Prize and Gun Supersequences generally appear relatively conformable throughout the seismic grid (eg **Fig. 2.3.1**). However, significant truncation can occur locally. At the southern end of the Argyle Creek seismic composite an incised valley up to 7.5km wide occurs at the base of the Gun Supersequence and removes about 150m of the Prize Supersequence **(Fig. 2.3.3**). At the northern end of the Argyle Creek and Desert Creek composite lines the Gun Supersequence boundary truncates about 150-250m of the Prize Supersequence (**Figs. 2.2.1** and **2.2.2**). An onlap surface at or just above the Gun Supersequence boundary is also apparent. There are several onlap and toplap surfaces within the Gun Supersequence (**Figs. 2.3.1** and **2.3.3**). Most of these surfaces are inferred to represent minor (4th-order) sequence boundaries and are not interpreted and tied throughout the seismic grid. However, an important fourth-, possibly third-order sequence boundary, Gun 2.5, has been interpreted and tied throughout the grid. The Gun 2.5 sequence boundary is either a significant onlap and/or toplap surface **(Figs. 2.3.1** and **2.3.3**).

The Gun Supersequence shows a progressive thinning from a maximum of 1700m (620msec) in the southeast to 0-100m (0-35msec) in the north **(Fig. 2.4.1**). Much of this thinning is due to major truncation by the overlying Loretta Supersequence boundary (**Figs. 2.1.2** to **2.1.6** and **2.2.4**). Some northward thinning also occurs due to onlap of strata onto the underlying Prize and Big Supersequences (**Figs. 2.2.1** and **2.2.2**). Erosion of the Gun Supersequence masks its original depositional thickness trends, although this truncation seems to occur north of about the 450ms (~1200m) isochron. The southeasterly thickening of the Gun Supersequence would therefore appear to be an original depositional trend, similar to that of the underlying Prize Supersequence.

The Gun Supersequence is generally characterised by moderate to high amplitude, continuous to semi-continuous, parallel to clinoformal seismic facies (**Figs. 2.3.1** and **2.3.3**). The Gun Supersequence is distinguished from the underlying Prize Supersequence by its slightly higher reflectivity and clinoformal geometry. The high reflectivity is interpreted as interbedded carbonates and locally derived clastics. Reflectivity of the Gun Supersequence tends to be lower on the southern margins of the Murphy Inlier (**Figs. 2.2.1** and **2.2.2**), and is attributed to the increase of clastic input of fluvial to shallow marine sandstones of the upper Fish River Formation. Clinoforms are particularly well developed above the Gun 2.5 sequence boundary (**Figs. 2.3.1** and **2.3.3**). These clinoforms are low angle features that prograde toward the southeast. Seismic reflections commonly onlap to the northwest, particularly near the base of the Gun Supersequence. The Gun Supersequence is interpreted from the seismic grid to represent the northern margin of the southeasterly prograding carbonate platform described by *Sami et al. (1997)* on the Lawn Hill Platform (**Section 1.3**).

2.5. Loretta Supersequence

The Loretta Supersequence is the oldest seismic package constrained by drill hole data. The **Desert Creek_1** and **Argyle Creek_1** wells penetrate the Loretta Supersequence and show it consists of oolitic crystalline dolomites and dolarenites, with minor interbeds of sandy dolomite, siltstone, and carbonaceous shale. The Loretta Supersequence is also penetrated by the WFDD74 drill hole (WMC) from the Walford Creek Prospect. Correlation of the Walford Creek drillhole to seismic data indicates this interval is the Walford Dolomite from the Fickling Group (**Chapter 1.6**). SHRIMP zircon ages of the Walford Dolomite and the Lady Loretta Formation on the northern Lawn Hill Platform (1649±7Ma vs. 1647±4Ma, respectively) confirm the correlation regionally. The seismic grid details the transition from the sub-tidal to peritidal platform carbonates of the Walford Dolomite in the north to the subtidal platform carbonates of the Lady Loretta Formation further south.

The Loretta Supersequence boundary is a regional, low angle unconformity at the northern ends of all seismic lines (**Figs. 2.1.2**, **2.1.3**, **2.1.4**, **2.1.5**, **2.1.6** and **2.2.4**). On most northern seismic lines, the Loretta Supersequence boundary erodes the underlying Gun Supersequence, whereas the Central seismic composite section shows the Loretta Supersequence erodes both the Gun and Prize Supersequences (**Figs. 2.1.4** and **2.2.4**). Reflections within Loretta Supersequence are generally flat-lying implying a significant peneplain was achieved. Several seismic lines show a northerly onlapping wedge at the base of the supersequence (**Figs. 2.5.1**). This wedge may correlate to transgressive siltstones/shales and breccias at the base of the Lady Loretta Formation. The geometry of the Loretta Supersequence suggests a regional south-dipping monocline was formed and eroded after deposition of Gun strata, with the eroded debris possibly deposited as the basal breccia facies of the Lady Loretta Formation (**Section 1.3**). The eroded monocline was subsequently transgressed in the south and covered by the main carbonate platform.

The Loretta Supersequence shows a progressive thinning from 1400m (510msec) in the south/southeast to 0-150m (0-55msec) in the north (**Fig. 2.5.2**). Most of this thinning is due to major truncation by the overlying River Supersequence boundary (**Figs. 2.1.2, 2.1.3, 2.1.4, 2.1.5** and **2.1.6** and **2.5.1**). Minor thinning to the north also occurs due to onlap within the basal wedge (**Fig. 2.5.1**). Estimates of the original depositional thickness trends are speculative due to the erosion by the River Supersequence boundary. The basal wedge appears thickest at the southern end of the eastern grid and is poorly developed in the west. Overall the isochron map of this supersequence (**Fig. 2.5.2**) indicates thickening of the supersequence to the southeast.

The Loretta Supersequence is generally characterised by low amplitude, continuous, parallel reflections (**Figs. 2.5.1**). The Loretta package is characterised on seismic sections by its semi-transparent appearance generated by the low amplitude of reflections. The low reflectivity of Loretta is interpreted to reflect the presence of relatively massive carbonate beds with few siliciclastic interbeds. Some important variations to the dominant facies include a distinct high amplitude reflection doublet at the base of the supersequence as the southern basal wedge pinches out to the north (**Fig. 2.5.1**). The high reflectivity of this doublet may be due to the presence of either siltstones/shales or breccias in the basal wedge. One line also shows the continuous parallel seismic facies changing laterally to a more chaotic and transparent seismic facies (**Fig. 2.5.3**). On the Argyle Creek composite line (**Fig. 2.1.2**), the semi-transparent chaotic facies appears to overlie a more reflective, continuous parallel facies to the south. Our interpretation is that the semi-transparent facies represents a proximal platform carbonate (the Walford Dolomite) that has prograded over a slightly deeper platform carbonate succession (ie the Lady Loretta Formation). The chaotic nature of reflections is interpreted to result from the presence of incompetent evaporite beds that, in this location, have experienced minor ductile deformation and disrupted the surrounding coherent carbonate beds. The Loretta Supersequence is interpreted in the seismic grid to represent a transitional platform carbonate package formed after a major regional tectonic tilting event.

2.6. River Supersequence

The River Supersequence is well constrained by wells, drillholes and outcrop sections. Both the **Desert Creek_1** and **Argyle Creek_1** wells penetrate the River Supersequence and show it to be dominated by siltstones and shales, with minor dolomitic limestones and fine grained sandstones. Drillholes from the Walford Creek prospect on the southern Murphy Inlier also penetrate the northern margin of the River Supersequence where carbonaceous shale intervals host sub-economic zinc mineralisation. SHRIMP ages from zircons allow the chronostratigraphic correlation of the deep marine Mount Les

Siltstone (1640±7Ma) that outcrops on the southeastern Murphy Inlier to the deep marine Riversleigh Siltstone (1644±8Ma) on the Lawn Hill Platform. The River Supersequence is associated with a major hairpin in the Apparent Polar Wander Path (**Fig. 1.2.8**) and numerous growth faults in the Riversleigh Siltstone, Mount Les Siltstone and Barney Creek Formation. The seismic data allows insights into the nature of this deformation and associated zinc mineralisation.

The River Supersequence boundary represents a major regional truncation surface at the northern end of all seismic lines (**Figs. 2.1.2, 2.1.3, 2.1.4, 2.1.5, 2.1.6** and **2.5.1**). The River Supersequence boundary has eroded most of the underlying southerly dipping Loretta Supersequence in the north (**Figs. 2.5.1** and **2.6.1**). Strata from the River Supersequence onlaps onto the Loretta Supersequence south of the main truncation surface (**Figs. 2.1.2, 2.1.3** and **2.1.4**). This relationship suggests a broad tilt block geometry in which the northern updip section was truncated as the southern downdip section subsided and was infilled.

The River Supersequence thins irregularly northwards from ~2300m (1020msec) in the south to 50-300m (20-135msec) in the north (**Fig. 2.6.2**). The northward thinning of River is mainly through onlap of reflections at the base and within the supersequence (~1700m). Some thinning also occurs due to truncation by the overlying Term Supersequence (~300m) (**Fig. 2.6.1**). An important feature of the River Supersequence is local thickening up to 500m within the hangingwalls of east to northeast trending growth faults (**Figs. 2.6.1** and **2.6.3**). Syndepositional growth of the River Supersequence is particularly well developed in the west as shown on the Argyle Creek and Desert Creek composite lines (**Figs. 2.1.2** and **2.1.3**). Further east significant growth of the River Supersequence occurs mainly to the south against the interpreted extension of the Elizabeth Creek Fault (**Figs. 2.1.4** and **2.1.5**). On the Beamesbrook composite line syntectonic growth of the River Supersequence is absent (**Fig. 2.1.6**). However, folding of River Supersequence strata on the southern ends of seismic lines may obscure growth wedges. Growth faults and associated south to southeast thickening tectonic wedges of the River Supersequence are the most prominent depositional features indicating extension within the Isa Superbasin megawedge.

The River Supersequence is generally characterised by moderate-high amplitude, continuous, parallel reflections within northwest onlapping wedges (**Figs. 2.6.1** and **2.6.3**). The supersequence is distinguished from surrounding seismic packages by its higher reflectivity, onlapping wedge geometry, and clear syndepositional growth fault features. The high reflectivity is inconsistent with the relatively homogenous siltstone lithology described in well cuttings and probably results from contrasting coarser versus finer grained siltstones, or the presence of dolomitic and pyritic intervals. The River Supersequence, where penetrated by wells, represents attenuated sedimentation on the thin shoaling ends of tilt blocks. More details regarding thickness variations in the River Supersequence are provided in **Chapter 5**.

Within the River Supersequence at least four higher order (3rd-order) sequences are recognised. These higher order sequences (River 5, 6, 7 and 8) are correlated to the upper Riversleigh Siltstone (R2s-R4s) based on the interpretation and correlation of gamma logs from wells, drillholes and outcrop sections (**Chapter 5**). River 5 is the basal onlapping sequence and is only well preserved at the southern end of seismic lines (**Fig. 2.1.2**). River 6 forms a prominent wedge which onlaps onto River 5 at the southern end of most lines, particularly the Desert Creek seismic composite (**Figs. 2.1.3** and **2.6.3**). A prominent onlap surface is present above River 6 and defines the River 7 sequence boundary (**Fig. 2.6.3**). The River 7 surface often truncates and incises channels into River 6 north of the main onlapping wedge (**Fig. 2.6.4**). These channels are interpreted to represent local erosion of the shoaling side of tilt blocks. Channel fill strata are usually high amplitude and contain some southerly prograding clinoforms. Occasional southerly prograding clinoforms are also present within the main River 7 wedge (**Fig. 2.6.3**).

River 8 is poorly preserved due to truncation by the overlying Term Supersequence. However, a northerly onlapping wedge appears to be present in River 8 at the southern end of the Argyle Creek seismic composite (**Figs. 2.1.2** and **2.7.2**). Southerly prograding clinoforms are commonly observed in River 8 on updip ends of tiltblocks. The River Supersequence is interpreted from the seismic grid as representing a period of regional extensional tectonics and syndepositional growth faulting that coincided with the beginning of clastic-dominated sedimentation in the upper McNamara Group.

2.7. Term Supersequence

Much of the southward thickening of the Isa Superbasin megawedge consists of the distinct wedge shaped TL seismic package *(Scott and Bradshaw, 1997)*. The TL seismic package is now divided into the lower Term and upper Lawn Supersequences. Only the upper two thirds of the Term Supersequence is penetrated by the Desert Creek_1 and Argyle Creek_1 wells. Lithologies represented in the wells are characterised by siltstones, with minor sandstones and shales. Only the upper part of the Term Supersequence is present on the southeastern Murphy Inlier where shallow coastal dolarenites and deeper marine sandstones and siltstones are present in the eastern Pfd_{1-2} members of the Doomadgee Formation (**Section 1.6**). In outcrop sections in the southern Lawn Hill Platform, the Term Supersequence begins with a basal turbiditic and hemipelagic submarine fan system, the Termite Range Formation (1636±10Ma, 1630±5Ma). The basal turbidites deepen and fine into lower-energy, deep-water deposits characterised by thick, laminated, carbonaceous black shales and siltstones with abundant concretions from the lower (Pmh_1 and Pmh_2) members of the Lawn Hill Formation. Seismic data documents the causes of the extreme thinning of the Term Supersequence from south to north.

The Term Supersequence boundary is a major onlap surface and a minor truncation surface (**Figs. 2.6.1** and **2.7.2**). Most Term sequences pinchout through onlap against the southerly dipping River Supersequence (**Figs. 2.1.2** to **2.1.4**). The Term Supersequence boundary usually erodes the underlying River 8 sequence at the northern ends of seismic lines (**Figs. 2.1.2** to **2.1.4**). Overall the Term Supersequence boundary seems to document a period of broad regional transgression above a southwesterly downwarped surface with some emergence and truncation occurring in the north.

The Term Supersequence blankets most of the seismic grid with a northward thinning cover of between 800-150m (355-65msec; **Fig. 2.7.1**). In the western areas, the Term Supersequence shows a significant southwesterly thickening up to a maximum of 2500m (110msec) on the Argyle Creek seismic composite. The overall north to northeast thinning of the Term Supersequence is due to the onlapping of strata against the supersequence boundary and contrasts sharply with most older supersequences which all tend to thin toward the northwest. Syndepositional faults are not apparent in the seismic data.

The Term Supersequence is characterised by low to high amplitude, continuous to semi-continuous, parallel to clinoformal and chaotic reflections (**Figs. 2.7.2**, **2.7.3** and **2.7.4**). Within the Term Supersequence five 3rd-order sequences are recognised which can be confidently correlated to sequences identified in outcrop on the Lawn Hill Platform (Term 1-5). All five sequences show evidence for mounded fan and chaotic (channellised) reflections toward the southern ends of the Argyle Creek and Desert Creek seismic composites (**Figs. 2.7.2**, **2.7.3** and **2.7.4**). A distinct high amplitude reflection doublet occurs at the base of the supersequence north and northeast of the main Term depocenter (**Fig. 2.7.4**). This basal doublet correlates to the upper part of the Term 2 sequence and corresponds to carbonaceous (Pmh_1 equivalent) siltstones in **Argyle Creek_1** and **Desert Creek_1** wells **(Chapter 4)**. The basal doublet may represent a 2nd-order condensed section from the Term Supersequence equivalent to the concretionary horizons in Pmh_1 member shales *(Krassay et al., in press)*. Overlying sequences also tend to be characterised by parallel and continuous reflection configurations away from the main Term depocenter (**Fig. 2.6.1**). The Term Supersequence is interpreted in the seismic grid to represent a period of broad regional subsidence and transgression of deep marine sandstones and siltstones/shales.

2.8. Lawn Supersequence

The upper portion of the TL package is assigned to the Lawn Supersequence. The entire Lawn Supersequence is penetrated by the **Desert Creek_1** and **Argyle Creek_1** wells. **Beamesbrook_1** and **Egilabria_1** wells penetrate the upper portion of the Lawn Supersequence, while several Walford Creek drillholes penetrate the lower part. Lithologies represented in the wells are silicified (tuffaceous?) sandstones at the base of the Lawn Supersequence which rapidly fine up into carbonaceous siltstones/shales. These lithologies are very similar to those found in outcrop sections to the south of the seismic grid where the tuffaceous shallow marine Bulmung Sandstone (1611±4Ma) fines upward into the carbonaceous siltstones and shales of the "H4r member". Similar tuffaceous shallow marine sandstones also occur in the upper part of the eastern Pfd_2 member of the Doomadgee Formation (1613±4Ma). Seismic data image the continuity of lithologies from the southern Lawn Hill Platform through to the Comalco wells and the southern Murphy Inlier.

The Lawn Supersequence boundary is relatively conformable through most of the seismic grid. Truncation of the underlying Term Supersequence is minor and very localised (**Figs. 2.7.3** and **2.7.4**). Onlap onto the Lawn Supersequence boundary is also rare and tends to be local rather than regional (**Fig. 2.8.1**). This lack of regional onlap against Lawn is consistent with the continuation of the Bulmung Sandstone from the Lawn Hill Platform to the southern Murphy Inlier and suggests it forms a fairly continuous basal sheet throughout the region. Criteria for definition of Lawn as a supersequence are based on considerations of the changing accommodation rates in sequences above and below, and associated changes in volcanic activity and geometry of the TL package (ie prominent wedge below the sheet-like geometry of the Lawn as seen in **Figure 2.8.2**).

The Lawn Supersequence thins to the north and northeast from ~900-50m (400-20msec; **Fig. 2.8.3**). Most of the northward thinning is due to erosional truncation by the overlying Wide Supersequence (**Figs. 2.1.2** and **2.1.3**). Local irregularities in the isochron trends are also due to erosional truncation by the Wide Supersequence over positive flower structures generated during the Wide Event (**Chapter 3**; **Fig. 2.1.4**). The northeast thinning of Lawn appears to be an original depositional feature resulting from internal onlap of strata within the upper carbonaceous shale sequences (**Fig. 2.8.1**). Regional thickness trends suggest that the Lawn Supersequence originally formed a relatively continuous blanket across the region that thinned gradually to the northeast.

The Lawn Supersequence is generally characterised by variable (low to high) amplitude, parallel, continuous reflections (**Figs. 2.8.1** and **2.8.2**). Four higher order (3rd-order) sequences are recognised within the Lawn Supersequence and correlate to sequences identified in outcrop on the Lawn Hill Platform (Lawn 1, Lawn 2, Lawn 3 and Lawn 4). Prominent onlap surfaces are often present in the carbonaceous siltstone-dominated Lawn 3 and carbonaceous shale-dominated Lawn 4 sequences (**Figs. 2.8.1** and **2.8.2**). In the Desert Creek seismic composite, the second sequence (Lawn 2) stands out as the most reflective (**Fig. 2.8.2**). As Lawn 2 occurs at the transition from the Bulmung Sandstone into the carbonaceous "H4r member" siltstones and shales, the high reflectivity may result from interbedding of these three lithologies. On the Egilabria composite the carbonaceous shale-dominated Lawn 4 sequence is the most reflective, possibly due to the presence of interbedded dolomitic beds or sulphate mineralisation in the carbonaceous shales *(Bradshaw et al., 1998;* **Fig. 2.8.1***)*. Although topset reflections dominate the Lawn Supersequence, occasional clinoform reflections are present (**Fig. 2.8.2**). All four sequences are present on the southern ends of the Argyle Creek and Desert Creek composite lines; while at the northern ends of these composites the upper three sequences are eroded by the overlying Wide Supersequence boundary (**Figs. 2.1.2** and **2.1.3**). Only the Lawn 1 sequence is present on the southern Murphy Inlier. Well logs at **Egilabria_1** and **Beamesbrook_1** show that the upper Lawn 4 sequence is present (**Chapter 4**), but it is uncertain which of the underlying sequences are present due to a lack of well log control. The Lawn Supersequence is interpreted in the seismic grid to represent a period of relatively continuous sedimentation and accommodation rates throughout the region.

2.9. Wide Supersequence

The uppermost Isa Superbasin seismic package is the WD package. The WD seismic package is now divided into the lower Wide and upper Doom Supersequences. All four Comalco wells penetrate strata from the Wide Supersequence. Well data show the base of Wide is usually dolomitic limestones and siltstones while the upper part is arkosic sandstones that change laterally into siltstones. These lithologies are similar to correlative strata from outcrop sections on the Lawn Hill Platform where the Wide is represented by dolomitic siltstones of “member H4s” (1595±6Ma) and the overlying deep marine Widdallion Sandstone member. The basal “H4s member” hosts the world-class Pb-Zn Century deposit. Strata from the Wide Supersequence are occasionally preserved in the eastern Pfd_3 member of the Doomadgee Formation in the form of fluvial/coastal sandstones. Seismic data provide insights into the tectonic and depositional systems associated with mineral systems from the Wide Supersequence.

The Wide Supersequence boundary is a major basin event boundary. In most areas, the Wide Supersequence boundary increasingly truncates the underlying Lawn 2, 3 and 4 sequences to the north (**Figs. 2.1.2** and **2.1.3**). Occasionally, the Wide Supersequence boundary erodes folded Lawn Supersequence strata over positive flower structures (**Fig. 2.1.4**). The Wide Supersequence boundary also forms a major onlap surface in the southeastern part of the seismic grid (**Figs. 2.9.1** and **2.9.2**). These observations suggest the Wide Supersequence was initiated by a period of regional strike-slip deformation with accompanying zones of both transtension and transpression.

The Wide Supersequence thins gradually from ~1200m (535msec) in the southeast to ~50m (20msec) in the north (**Fig. 2.9.3**). The north to northeast thinning is mainly through onlap at the base and within the supersequence. An important feature of the Wide Supersequence is its local thickening by up to 150m within small graben that are associated with west-northwest wrench or strike-slip faults and northeast trending fault splays which accommodate most of the growth (**Fig. 2.9.4**). Syndepositional growth of the Wide Supersequence is particularly well developed on the Desert Creek composite line (**Fig. 2.1.3**). Major growth of Wide strata may also occur across the Elizabeth Creek Fault in the southeastern grid region where a potential Century equivalent mineral prospect has been proposed *(Bradshaw et al., 1998;* **Chapter 6***)*.

The Wide Supersequence is generally characterised by a basal high amplitude reflection doublet or triplet overlain by a moderate amplitude, continuous to semi-continuous, parallel to chaotic northerly onlapping reflections (**Figs. 2.9.1**, **2.9.4** and **2.9.5**). The basal high amplitude, continuous, and regionally parallel reflections correlate to dolomitic limestone and siltstone lithologies in the four Comalco wells. The basal reflection doublets/triplets are divided into the Wide 1 and Wide 2 sequences. In the southeast, Wide 1 and Wide 2 both form prominent northerly onlapping wedges in the hanging wall of the Elizabeth Creek Fault (**Fig. 2.9.2**). Elsewhere, minor growth of these sequences is commonly observed (**Figs. 2.9.4** and **2.9.5**). In the northeast, Wide 2 pinches out between the Wide 1 and Wide 3 sequences. Wide 3 forms the upper less reflective northward onlapping wedges that correlate to the arkosic sandstone (Widdallion Sandstone) in the Comalco wells. Although northerly onlapping reflections are the most common reflection geometry, channels and southward prograding clinoforms are also evident which are interpreted as submarine canyons and channel levee complexes generated by turbidity flows (**Figs. 2.9.1**, **2.9.4** and **2.9.5**). The Wide 3 sequence shows the most significant growth across wrench fault systems (**Fig. 2.9.4**). The Wide Supersequence is interpreted as representing a period of significant strike-slip tectonics and wrench fault activity.

2.10. Doom Supersequence

The upper portion of the WD package, the Doom Supersequence, was deposited during the final basin phase in the evolution of the Isa Superbasin. The Doom Supersequence is generally poorly preserved in outcrop throughout the Mount Isa region, except at the **Egilabria_1** well where the entire supersequence appears to be preserved. Lithologies at **Egilabria_1** are basal (high-gamma) deep marine sandstones that fine into deep marine siltstones and carbonates, before shoaling rapidly to shallow marine to fluvial sandstones (**Chapter 4**). Similar lithologies are preserved in the southern Lawn Hill Platform where (high-gamma) deep marine sandstones of the upper Widdallion Sandstone fine upward into deep marine siltstones of the Pmh_6 member of the Lawn Hill Formation. The Doom Supersequence is either absent or highly weathered on the southern Murphy Inlier. Seismic data image the original continuity of strata in the Doom Supersequence and suggest the cause of its poor preservation throughout the Isa Superbasin as outlined below.

The Doom Supersequence boundary is relatively conformable throughout most of the seismic grid. Truncation of the underlying Wide 3 sequence possibly occurs at the ends of the Desert Creek and Central seismic composites (**Figs. 2.1.3** and **2.1.4**). However, on most lines there is no truncation or onlap apparent on the Doom Supersequence boundary (**Figs. 2.9.1** and **2.9.5**). As with the Lawn Supersequence, criteria for definition of Doom as a supersequence are based on consideration of changing tectonic styles, sediment provinces, the broad geometry of each and a prominent continuous reflection doublet at its base. In particular, Doom Supersequence has a sheet-like topset geometry and lacks the syndepositional growth of the Wide Supersequence.

The Doom Supersequence shows irregular thicknesses (**Fig. 2.10.1**). Throughout most of the seismic grid the Doom Supersequence is preserved as a ~600m (265msec) cap to the Isa Superbasin. However, in the east around the Egilabria_1 well, the Doom Supersequence locally thickens to ~1050m (465msec). Seismic data clearly show that the erratic trends in thickness of Doom Supersequence strata are due to erosional truncation during the Isan Orogeny prior to deposition of the South Nicholson Group (**Figs. 2.1.2** to **2.1.6**). Local preservation of Doom strata around the Egilabria_1 well was due to its deposition into remnant topography of a regional syncline in this region (**Fig. 2.1.5**). The Doom Supersequence is interpreted to have originally formed a sediment cover of relatively uniform thickness extending from the Lawn Hill Platform to the southern Murphy Inlier and possibly into the McArthur River area.

The Doom Supersequence displays a wide range of seismic facies. The basal sequence (Doom 1) is characterised by a distinct pair of very high amplitude, low frequency reflections at its base (**Figs. 2.9.1** and **2.9.5**). Within these reflections, small scale southward dipping clinoforms are sometimes present (**Fig. 2.9.1**). This highly reflective base to Doom 1 correlates to high-gamma ray emitting sandstones and siltstones in the **Egilabria_1** and **Beamesbrook_1** wells (**Chapter 4**). Above the basal reflections, lower amplitude, discontinuous to chaotic seismic reflections that display shingled and channelled configurations are characteristic (**Figs. 2.9.1** and **2.9.5**). This basal package is interpreted to represent a regional scale debris flow at its base with overlying channel-levee complexes.

Above the basal package, the remaining sequences are characterised by continuous, moderate amplitude, planar reflections, although these sequences are erratically preserved due to the erosion by the much younger South Nicholson Group (**Fig. 2.9.1**). Clinoformal, onlapping, and topset internal configurations are also evident. Most clinoforms in the package prograde northward indicating a major change in sediment transport trends compared to underlying sequences throughout the Isa Superbasin. The base of the uppermost sequence incises up to 30m into the underlying sequence. Current geochronological data suggest that deposition of the upper Doom Supersequence continued to c.1585Ma. The Doom Supersequence records a progressive decrease in accommodation space and change in provenance probably associated with onset of the Isan Orogeny *(Blake, 1987; Stewart and Blake, 1992)*. Details of subsequent deposition within the South Nicholson Group are covered in **Section 1.7**.

2.11. Basin Evolution

Integration of the COMALCO seismic data with other datasets has led to significant revisions of the previously proposed tectonostratigraphic history of the northern Lawn Hill Platform. Topset (relatively parallel and continuous) seismic reflections dominate, while offlapping (clinoformal) reflections, a characteristic feature of passive shelf margins, are rare and where present are low gradient features. Basins dominated by thick topset deposits are generally interpreted to be intracontinental ramp margins and foreland basins *(Emery and Myers, 1996)*. However, the foreland basin setting proposed by *McConachie et al. (1993)* is considered unlikely due to the lack of evidence for a pre-Isan Orogeny thrust belt and the lack of substantial northward prograding shallow- to non-marine sediments except at the very top of the Palaeoproterozoic Isa Superbasin megawedge. The sequence stratigraphy outlined in this study are more consistent with a ramp margin model *(Van Wagoner et al., 1990)* than with models of passive shelf break margins *(Vail, 1987)* or foreland basins *(Dorobek and Ross, 1995;* **Fig. 2.1.8***)*.

The geometry and geology of the Isa Superbasin compiled by the NABRE project support the evolution in a wholly intracratonic ramp margin setting. Within this intracontinental basin setting, a series of structural events are recorded by basin phases that identify fluctuating accommodation space and changing basin geometry. A reconstruction of these Palaeoproterozoic basin phases within the Lawn Hill Platform is presented in **Fig. 1.2.6**. The reconstruction is based on seismic sections flattened on key sequences, and is integrated with gamma-ray and sedimentological logs of outcrops and wells, U-Pb zircon (SHRIMP) geochronology of tuff beds in the sedimentary pile and underlying igneous units, and consideration of the Apparent Polar Wander Path constructed for the region.

The Big Supersequence records a period of major tectonism and magmatism in the initial stages of the Isa Superbasin. Underlying strata from the Leichhardt Superbasin were deformed and significantly eroded at the onset of the Isa Superbasin. In many areas, truncation of Leichhardt Superbasin strata generated a relatively flat peneplain, followed by regional extension causing block tilting and footwall uplift. The resulting half-graben possibly infilled with fluvial conglomerates and mafic volcanics before being intruded by felsic igneous rocks. In some areas, particularly around the Murphy Inlier, truncation of Leichhardt Superbasin strata was associated with updoming during igneous activity associated with the younger Peters Creek Volcanics. Felsic igneous activity continued for a documented period of at least 20My.

The Prize Supersequence formed during a period of thermal relaxation and relative tectonic quiescence, although local felsic magmatic activity continued to disturb topography locally. No evidence exists in the PM package for the “rift phase” described by *McConachie et al. (1993)*. Instead, the current mapping shows that the Prize Supersequence is a tabular, planar unit with no syndepositional growth faults or tectonic wedges. The Prize Supersequence formed in a clastic ramp margin setting resulting in the deposition of the siliciclastic Surprise Creek, Torpedo Creek and lower Gunpowder Creek Formations. These fluvial to shallow marine sandstones and siltstones gradually thin to the northwest to the fluvial to shallow marine sandstones of the lower Fish River Formation. Prize Supersequence strata thin more rapidly near the Murphy Inlier due to local doming presumably driven by thermal anomalies.

A major 25My depositional hiatus separates the Gun and Prize Supersequences in most areas south and north of the seismic grid (**Sections 1.3** and **1.6**). Evidence for a major regional unconformity is generally lacking at this time throughout most of the seismic grid. Local incision surfaces of the scale observed in outcrop are occasionally present, particularly at the northern ends of lines where the Gun Supersequence truncates the underlying Prize and Big Supersequences over the southern Murphy Inlier. These observations from seismic data may indicate that the depositional hiatus was associated with decreased accommodation driven by igneous intrusions on the Murphy Inlier and throughout the Lawn Hill Platform (eg the Sybella Granite).

Interpretations of the seismic data indicate that the Gun Supersequence was deposited on a gradually northwest thinning ramp margin. As the lower part of the Gun Supersequence prograded to the southeast, sediments changed laterally from fluvial to shallow marine sandstones of the upper Fish River Formation to the marine siltstones in the upper Gunpowder Creek Formation. Middle to inner platform carbonates of the Paradise Creek and Esperanza Formations probably originally continued across the Murphy Inlier into the continental red beds of the Mallapunyah Formation (McArthur Group) prior to their truncation by the Loretta Supersequence.

The Loretta Supersequence represents a transitional platform carbonate package formed after a regional tilting event. During a period of possible monoclinal folding and low angle truncation of the underlying Isa Superbasin supersequences in the north, a basal breccia and transgressive siltstone/shale sequence was deposited in southeastern regions. The cause of this monoclinal folding is uncertain but may be related to thermal anomalies generated by igneous activity beneath the Murphy Inlier or by isostatic adjustment of depleted lower crust and upper mantle. A carbonate platform subsequently built up and gradually prograded south, possibly southeast over the eroded monocline as accommodation rates increased. The transition from proximal Walford Dolomite strata to more distal Lady Loretta Formation strata would probably occur in the seismic grid at about the southern margin of the monocline where subsidence rates would be higher. The planar geometry of the Loretta Supersequence suggests that its carbonate platform also extended across the Murphy Inlier into the shallow water carbonates/clastics of the Amelia Dolomite, Tatoola Sandstone, and Tooganinie Formation (McArthur Group).

The River Supersequence represents a period of regional extensional tectonics and syndepositional growth faulting. Thick northerly onlapping wedges are consistently observed within four third-order sequences from the Argyle Creek seismic composite in the west to the Egilabria seismic composite in the east. The northerly pinchout of these wedges often coincides with erosion of underlying sequences on the shoaling sides of tilt blocks. Older sequences are present south of the seismic grid and presumably pinchout through regional onlap (**Section 1.4**). The geometry and sequence stratigraphy of the River Supersequence indicates a period dominated by regional transgression and high subsidence rates as extensional half-graben were episodically generated across the seismic grid. The broad northward thinning geometry of the River Supersequence requires that the Murphy Inlier was emergent and acted as a basin margin during most of the period of deposition. Intrabasinal highs such as the Murphy Inlier may have been important in compartmentalising River sub-basins and generating anoxic water columns that led to precipitation of metals due to reduction by organic matter. The tectonic activity recorded during the River Supersequence coincides with an end to the carbonate platform-dominated sedimentation of the lower McNamara Group and the beginning of clastic-dominated sedimentation in the upper McNamara Group. Development of the River Supersequence coincides with a major hairpin in the APWP (**Fig. 1.2.8**).

The Term Supersequence is interpreted in the seismic grid to represent a period of broad regional subsidence. Subsidence rates were particularly high in the southwest where Term Supersequence strata thicken rapidly. The thickening of Term strata to the southwest is associated with a change from continuous parallel seismic reflections to a channellised and mounded fan geometry. This change in reflection configurations to the southeast suggests thickening of strata was associated with an area of basin margin instability. The lack of evidence in seismic data for any syndepositional fault activity indicates this basin margin instability was associated with episodic flexure. However, outcrop data on the Lawn Hill Platform suggest that local syndepositional faulting may have occurred south of the seismic grid *(Krassay et al., in press)*. The geometry of the Term Supersequence indicates that the Murphy Inlier continued to be emergent during deposition of each sequence. Additional evidence for emergence to the north is also found in the presence of desiccation cracks in shallow water sandstones at the base of the eastern Doomadgee Formation (ie Term 4 sequence) which correlate to “H1s member” submarine fan sandstones on the Lawn Hill Platform (**Chapter 5**).

The Lawn Supersequence is interpreted in the seismic grid to represent a period of relatively continuous sedimentation and accommodation rates throughout the region. A shallow marine tuffaceous sandstone (the Bulmung Sandstone) was initially deposited as an extensive blanket from the northern Lawn Hill Platform to the southern Murphy Inlier following a brief period of emergence possibly initiated by regional volcanism. Carbonaceous siltstone- and shale-dominated sequences above the basal sandstone sequence indicate a period of broad regional subsidence and transgression. The apparent broad thinning of Lawn to the northeast suggests that this regional transgression was directed toward the Murphy Inlier. The Lawn Supersequence was probably the first supersequence to completely transgress the Murphy Inlier following its emergence during Term and River Supersequence times. During the transgression the Lawn Supersequence extended into the shallow marine carbonates/clastics of the Amos Formation and lower Balbirini Dolomite in the McArthur River region *(Jackson and Southgate, in press)*. Strata from the Lawn Supersequence were subsequently folded and truncated during a period of strike-slip deformation at the beginning of the Wide Supersequence.

The Wide Supersequence is interpreted as representing a period of significant strike-slip tectonics and wrench fault activity. Wrench tectonics appear to be associated with a far-field tectonic event, possibly the earliest stages of the Isan Orogeny. The geometry and sequence stratigraphy of the Wide Supersequence indicates that this was a period of broad regional transgression and locally high subsidence rates during which the “H4s member” siltstones and the Widdallion Sandstone thinned and thickened northwards across local sub-basins. The thinning of Wide sequences toward the Murphy Inlier suggests that this was again an intrabasinal high. Evidence of syndepositional growth and basin margin instability (debris flows) is consistently observed in the upper Wide 3 sequence (Widdallion Sandstone equivalent). Significant growth of the Wide 1 and 2 sequences (H4s equivalent) is also seen locally in southeastern seismic profiles. Local growth of the basal Wide sequences appears to be important in generating the carbonaceous shales which host Century style Pb-Zn mineralisation *(Bradshaw et al., 1998;* **Chapter 6***)*.

The Doom Supersequence originally formed a continuous sedimentary cover that would have extended across the Murphy Inlier into the shallow marine clastics/carbonates of the Dungaminnie Formation in the McArthur River region *(Jackson and Southgate, in press)*. Basal submarine debris flow sandstones from the upper Widdallion Sandstone record a period of initial basin margin instability. Subsequent fining up into deep marine siltstones and carbonates indicates a period of either increasing accommodation space and/or changing sediment provenance. A final phase of rapid shallowing and coarsening up into shallow marine and fluvial sandstones followed by regional deformation and erosion marks an end to deposition of the Isa Superbasin and regional onset of the Isan Orogeny.

Throughout the history of the Isa Superbasin, accommodation for sedimentation has fluctuated significantly. The granitic cores of the Murphy Inlier and the Kamarga dome pre-date both the Leichhardt Superbasin and Isa Superbasin attesting to the continental character of the lithosphere of the northern Lawn Hill Platform. Geodynamical mechanisms for the subsidence and uplift fluctuations are speculative. The voluminous mafic event of the underlying Leichhardt Superbasin suggests major lower crustal and/or mantle disturbance. Although poorly constrained, the age of this event predates the deposition of the Isa Superbasin by ~50-60my *(Jackson et al., 1998)*.

In the Lawn Hill Platform, evidence for significant extension is limited, although the Big Supersequence at the base of the Isa Superbasin is interpreted to be associated with a major extensional event based on geophysical data (**Chapter 3**). Widespread bimodal volcanism is also documented during the Big Supersequence. Extensional geometries occur in the River Supersequence at 1640Ma, but fault offsets are on the order of 100's of meters and only minimal block rotation and tilting occurred. Wide (~1595Ma) Supersequence geometries are consistent with a wrench and/or strike-slip deformation event and may reflect the initiation of orogenic processes. No major volcanism is associated with either the River or Wide Supersequences.

Periods of increased production of volcaniclastic tuffaceous sediments have allowed geochronological interpretations of the sequences of the Isa Superbasin. The timing of production of widespread magmatism and subsequent periodicity of the occurrence of the volcaniclastic sediments in the Lawn Hill Platform area show a remarkable similarity to fluctuations in melt production predicted by numerical modelling of plume-lithosphere interactions *(eg Manglik and Christensen, 1997)*. Further, recent modelling of thermal effects of intracontinental magmatism *(Gvirtzman and Garfunkel, 1997)* predicts that emplacement of deep seated intrusions can cause significant fluctuations in uplift and subsidence and associated accommodation space for overlying basins.

Available outcrop evidence supports both an extrusive and intrusive genesis for much of the igneous activity associated with the Big Supersequence. The deep intrusion mechanism suggested by *Gvirtzman and Garfunkel (1997)*, possibly associated with an earlier plume active during the Leichhardt Superbasin, is proposed as a likely explanation that accounts for the initiation of and fluctuations in accommodation space within the Isa Superbasin *(Scott et al., in press)*.

List of figures

2.2.1 Seismic sequence stratigraphy of Big, Prize and Gun Supersequences over the Peters Creek magmatic dome, line 91BN-30 (unflattened). LSB = Leichhardt Superbasin. M1-M5 relate to magmatic members of the Peters Creek Volcanics. This section comprises the northern end of the Argyle Creek composite Line (Fig. 2.1.2).

2.2.2 Seismic sequence stratigraphy of Big, Prize and Gun Supersequences over the Peters Creek magmatic dome, line 91BN-31 (flattened on Loretta). LSB = Leichhardt Superbasin. M1-M5 relate to magmatic members of the Peters Creek Volcanics. This section comprises the northern end of the Desert Creek composite Line (Fig. 2.1.3).

2.2.3 Onlap and incision of the Big Supersequence, showing angular unconformity with reflection interpreted as the Eastern Creek Volcanics (ECV) of the Leichhardt Superbasin, Line 91BN-41 (unflattened).

2.2.4 Seismic sequence stratigraphy of Big, Prize, Gun and Loretta Supersequences truncating Leichhardt Superbasin reflections, Line91BN-26 (flattened on Loretta).

2.2.5 Isochron map of the Big Supersequence, showing distinct lateral thickness changes.

2.3.1 Seismic sequence stratigraphy of the Prize and Gun Supersequences, Line 91BN-08 (unflattened).

2.3.2 Isochron map of the Prize Supersequence, showing a broad ramp geometry.

2.3.3 Seismic sequence stratigraphy of the Prize and Gun Supersequences, Line 90BN-19 (unflattened). This section is part of the Argyle composite line (Fig. 2.1.2).

2.4.1 Isochron map of the Gun Supersequence, showing a regional ramp geometry.

2.5.1 Seismic sequence stratigraphy of the Loretta Supersequence, Line 91BN-07 (flattened on River). This section is part of the Desert Creek composite (Fig. 2.1.3).

2.5.2 Isochron map of the Loretta Supersequence, showing nearly tabular geometry of the seismic grid.

2.5.3 Seismic sequence stratigraphy of the Loretta Supersequence showing progradation of deformed evaporites over deeper marine carbonates, Lines 90BN-23, 20 and 19 (flattened on River). This figure is part of the Argyle Creek composite (Fig. 2.1.2).

2.9.5 Seismic sequence stratigraphy of the Wide and Doom Supersequences, Line 91BN-09 (flattened on Doom 2).

2.10.1 Isochron map of the Doom Supersequence.

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CHAPTER 3

Structural Framework

Chapter 3

STRUCTURAL FRAMEWORK

(D.L. Scott and C.Z. Tarlowski)

3.1. Introduction

The part of the northern Lawn Hill Platform covered by the seismic grid (**Fig. 1.1.1**) is mostly concealed by Cainozoic colluvium. Thus the structural aspects of the Palaeoproterozoic rocks of the Isa Superbasin in this area are largely unknown. Immediately north and west of the seismic grid, Mesoproterozoic Roper Superbasin strata gently undulate from horizontal and form an angular unconformity with older Palaeoproterozoic Isa Superbasin strata which dip gently southwards. To the south of the Elizabeth Creek Fault Zone (**Fig. 3.1.1**), Palaeoproterozoic strata are extensively and tightly folded (eg Mount Caroline and Ploughed Mountain anticlines) and variously translated by regionally extensive, linear faults that mostly trend W to NW (eg Calvert, Termite Range, and Little Range faults). A previous interpretation of the seismic data by *McConachie et al. (1993)* focussed on the petroleum potential of the region in light of their proposed foreland basin model. Although a series of seismic profiles displaying major interpreted fault systems were presented by *McConachie et al. (1993)*, no structural maps were published. The structural synopsis of the northern Lawn Hill Platform provided by *McConachie et al. (1993)*, which they termed the Bowthorn Block in their work, follows:

> "...[it is] *relatively undeformed however it contains a series of reverse faults trending east-west which are interpreted from seismic data to be down-to-the-north normal faults that have been reactivated as thrusts*."

A sequence stratigraphic analysis of the seismic data was provided by *McConachie et al. (1993)*, *McConachie and Dunster (1996, 1998)*, and *Dunster and McConachie (1998)*, that recognised *"more than 15 unconformities*" which they grouped into three main phases (**Fig. 1.2.4**): a basal syn-rift phase correlating to our PM package (Prize and Gun Supersequences), a thin passive margin phase correlating to our LM package (Loretta Supersequence), and a peripheral foreland basin phase correlating to our RV through South Nicholson Group packages (River through Doom Supersequences plus the South Nicholson Group reflection packages). Thus, all faults presented on profiles were syn-rift normal faults related to the Peters Creek Volcanics, which were overturned or re-activated during the foreland basin phase. In this scenario, the Elizabeth Creek Fault was a major syn-rift fault during the emplacement and deposition of the Peters Creek Volcanic succession, and became the "frontal thrust" in the foreland phase which includes both the Palaeoproterozoic and Mesoproterozoic packages.

Concurrently, preliminary summaries of the NABRE interpretation of the seismic data were put forward at workshops and conferences *(Bradshaw et al., 1996; Scott and Bradshaw, 1997)* and subsequently presented more formally in the literature *(eg Bradshaw et al., 1998[a,b]; Scott, et al., 1998[a,b])*. Geophysical investigations into depth to magnetic source and profile modelling around the seismic grid were presented in *Tarlowski and Scott (1997)*, and *Leven et al. (1997)*, respectively. A synopsis of the ongoing basement investigations was presented in *Scott et al. (1998[c])*. We present herein the final interpretation of the NABRE structural analysis of the Comalco seismic grid.

Although the reflections identified by *McConachie et al. (1993)* as unconformities are also recognised as sequence boundaries in our interpretation, a very different interpretation of the structural history of the area is postulated on the basis of:

- The positions and correlation of surfaces across fault zones;
- Their correlation to outcrop and drillhole lithostratigraphic units to the north and south;
- Detailed integration with new geochronological and palaeomagnetic data, and finally;
- Rigorous matching of horizons at profile intersections to assess the volumetric or three-dimensional sense of sedimentary packages to identify syn-tectonic sedimentary growth.

Details of the differences between the final NABRE tectonostratigraphic framework and previous work are outlined in **Chapters 2**, and the evidence for correlation and extrapolation to outcrop sections and drillhole data are detailed in **Chapter 5**.

The primary difference in stratigraphic interpretations relates to the correlation and extrapolation of the Peters Creek Volcanic succession *(Bradshaw et al., 1998[a]; Scott et al., 1998[a,b,c])*. **Section 1.5** outlines advances made in understanding the nature and timing of the Peters Creek Volcanic succession (*Jackson et al., in press*). **Sections 2.2** to **2.4** describe the geometry of the grid-wide reflective package (Prize and Gun Supersequences) ascribed by *McConachie et al. (1993)* to the Peters Creek Volcanics or rift phase. The final NABRE seismic interpretation presented in **Chapter 2** shows no evidence within this reflective package of a basal rift. The Prize and Gun Supersequences are exceptionally tabular and reflective, with no evidence of diverging reflections into faults or the chaotic and transparent zones expected from a volcanic, intrusive, and volcaniclastic succession. Understanding depositional geometry and facies distribution is essential to the development of an accurate structural interpretation. Further, correlation of the Peters Creek Volcanics that outcrop at the northwest extent of the seismic grid (**Fig. 1.5.5**) to the seismic data suggests that they are not the equivalents to this tabular package.

Instead, a sub-acoustic basement 'rift package' (the Big Supersequence) is postulated and tested against observed geophysical data *(Tarlowski and Scott, 1997; Scott, et al., 1998[b,c];* **Section 3.2***)*. This tectonic/thermal event marks the beginning of the Isa Superbasin and establishes the basement template upon which the remaining supersequences are deposited. Our investigations in the northern Lawn Hill Platform identify four distinct periods of deformation within the Isa Superbasin beginning with the tectonic event at c. 1730-1725Ma which initiated processes that provided the long term accommodation for the Isa Superbasin sequences (~1720-1585Ma). Discerning basin and depositional geometry using the sequence stratigraphic approach through time has been the key to our refinement and definition of the two following structural events just prior to c.1640Ma and 1595Ma. Deposition of the Isa Superbasin ended with the initiation of the Isan Orogeny at c. 1575Ma. The orogeny has been described as a multi-phase compressive event (*Blake, 1987* and references therein). We suggest on stratigraphic and structural evidence that the c.1595Ma event may be the initiation of the long-lived orogenic process. The four deformation events overprint the basement, which probably was dominated by E-W and N-S 'Barramundi' trends.

3.2. The Basement

The nature of 'basement' in the northern Lawn Hill Platform is difficult to define. In the following discussion, basement is defined as everything older than the Isa Superbasin, which we believe began with widespread extension, block rotation, and bimodal volcanism. The evolution of this tectonically active period is a matter of great controversy in the current literature (*Jackson et al., in press*).

The core of the Murphy Inlier comprises the Murphy Metamorphics (>1900Ma) plus the Cliffdale Volcanics (c.1850-1770Ma) and Nicholson Granite Complex (c.1860-1705Ma). The core of the Kamarga Dome in the south is the Yeldham Granite (c.1820Ma). It is inferred that the thick sequences of the Leichhardt Superbasin which outcrop to the south and northwest also occur in the subsurface and overly these older basement inliers. Without detailed field relationships, inferences on the nature of the basement must be based on geophysical data.

A preliminary attempt to define crustal elements within the NABRE area of approximately 1.3 million km^2 has incorporated domain, fabric, lineament and fault system interpretation of geopotential data *(Tarlowski and Scott, 1997; Scott et al., 1998[a])* and is more fully developed in *Tarlowski and Scott (1999)*. The regional analyses suggest that overprinting of at least two temporally separate, large scale (eg the East African Rift system) interconnected basin systems are required to explain the geophysical signature of the lithosphere. Regional broadly N-S and E-W geophysical trends are evident and are ascribed to the event which affected most of the cratonic elements of Australia somewhere between 1900Ma and 1800Ma, the "Barramundi Event" *(Etheridge and Wall, 1994)*. However, *Tarlowski and Scott (1999)* suggest that this event may have occurred later and was associated with the underlying Leichhardt Superbasin. A second, predominant NW-SE grain affects most of the north Australian Cratonic element *(Meyers et al., 1996)* and appears to offset the N and E trends. Compartmentalisation and segmentation of the NW-SE trends by NE-SW features is common in most northern Australian regions. *Tarlowski and Scott (1999)* ascribe these features to the development of the Isa Superbasin. The NW geophysical lineaments broadly correspond to many exposed regional structures. Similar trends of exposed faults in the northern Lawn Hill Platform occur but are rarely coincident with geophysical lineaments or steep gradients (eg the Calvert and Termite Range Fault, **Fig. 3.1.1**).

Geopotential data from the study area (**Fig. 1.5.1**) were analysed to determine the effects of the larger scale template on subsequent basin evolution in the northern Lawn Hill Platform. The broad long-wavelength geophysical anomalies which extend across the entire study area, just north of 18° 00’ S, are the main characteristic within the study area that we ascribe to the regional E-W and N-S trends. It is probable that outcropping E-W structures (eg the Fish River, Elizabeth Creek, and Little Range Faults; **Fig. 3.1.1**) are the modern expression of the influence of this very early and fundamental grain on later deformation. Within the broad, long wavelength gravity and magnetic highs, shorter wavelength E-W anomalies step en echelon to the northeast. A meridional boundary may be interpreted in the study area approximately along ~139°45’ E that separates distinctive geophysical domains to the east and west.

The ellipsoidal magnetic and gravity low just southwest of 18°30’ S, 139°00’ E corresponds to the Kamarga Dome which is cored by the Yeldham Granite. The geophysical expression of the granite highlights the ambiguity of interpreting the geophysical data (**Fig. 3.2.1**), particularly when contrasted with the anomalies that the presumed coeval Murphy Inlier basement produces. Whilst the outcrop pattern of the dome is typically circular, the gravity expression is a dumbbell shaped low under the western half, and a high under the eastern half. The magnetic low usually attributed to the Kamarga Dome is offset to the north, probably due to the overprinting of the Kamarga Volcanics in the south and east. The contribution of the shallow Kamarga Volcanics is responsible for the long wavelength, shallow depth to magnetic source pattern around the dome (**Fig.**

1.5.1b). The magnetic and gravity lows in the far southwest of the study area probably correspond to another buried felsic system, perhaps draped with a magnetic unit, of unknown age.

Moderate to high frequency magnetic anomalies correspond to outcropping or near surface mafic Eastern Creek and Kamarga Volcanics in the SE corner and correlative *(Page and Sweet, 1998)* Seigal Volcanics in the NW corner. These two volcanic packages are considered to be time equivalents of the Buddawaddah Basalt *(***Section 1.5***; Jackson et al., in press)* whose outcrop belt can be correlated to a belt of mottled, high frequency magnetic anomalies (cf **Figs. 1.5.1** and **3.2.1**). Combined, the distribution of these magnetic units as interpreted from the geophysical data provide us with the best indication of the geometry of the Leichhardt Superbasin underlying the Isa Superbasin in the northern Lawn Hill Platform. That is, gently dipping sheet-like mafic units near surface in the southeast and northwest corners and tilted, deeply buried magnetic bodies within the central zone.

A steep NW-SE gravity gradient, interrupted by the Murphy Inlier anomaly, separates a generally low gravity signature in the southwest from a region characterised by gravity highs in the northeast. The regional NW-SE gravity gradient is not evident in the magnetic data. However, crossing the southwest quadrant of the study area there is a strong magnetic gradient of similar trend, bending to a more E-W trend to the west. These steep magnetic anomalies are sub-parallel to, but not coincident with, the outcropping Termite Range and Little Range Faults (**Fig. 3.1.1**). The NW-SE magnetic gradient is sub-parallel to, but steepest to the southwest of the outcropping Termite Range Fault. Significant stratigraphic thickness changes within some of the Isa Superbasin supersequences have been documented across this fault *(Andrews, 1996)*. The bend to an E-W trend is sub-parallel to, but offset to the north of the Little Range Fault. The non-coincident relationship of the geophysical gradients with the outcropping structures suggests that a later-stage deformation utilised some more fundamental structure at depth. That neither magnetic gradient has a gravity expression suggests that these boundaries are not manifest in the lower crust or mantle.

Depth contours of the base of the reflective package in the seismic data generally follow contours of the magnetic image with the proviso that depth contours do not deepen sufficiently to account for the large magnetic low extending southeast from 18°00' S, 139°00' E (cf **Figs. 3.2.2** and **1.5.1b**). As discussed in **Section 1.5**, the Peters Creek Volcanics are now thought to represent two distinct magmatic events associated with the Leichhardt Superbasin and Isa Superbasin and separated by a significant hiatus *(Jackson et al., in press)*. A variety of preliminary models were constructed and tested against observed geophysical data without the constraints of a completed seismic data interpretation *(Leven et al., 1997)*. Refining these initial results, modelling for this study used the interpretations of relevant seismic data to constrain the geometry (ie depth and dip of igneous units) of the geological models south of the Murphy Inlier. The relationship between the igneous units is also constrained by assigning reasonable physical properties *(*eg *Hone et al., 1987)* and by using thicknesses and positions from outcrop and seismic data interpretations. Two key profiles extracted from the gridded image data along the 138°30' E and 139°00' E meridians highlight the results of this investigation (**Figs. 3.2.3** and **3.2.4**).

The observed data of both profiles require additional magnetic bodies below the thin volcanic unit interpreted to exist at acoustic basement depths (ie the Fiery Creek Volcanics). It is inferred that the additional magnetic bodies are the tholeitic volcanics of the Leichhardt Superbasin (ie Seigal, Eastern Creek and Kamarga Volcanics, and the Buddawadda Basalt member of the Peters Creek Volcanics). The geological models suggest that the two igneous events are separated by a major extensional event under the northern Lawn Hill Platform. The extensional event produced a marked angular unconformity between the two packages in the east, while maintaining an apparently conformable relationship in the west. Strong discordant reflections below acoustic basement (eg **Fig. 2.1.4**) in the east are consistent with the depths and thicknesses of the older igneous units displayed in the eastern geopotential model (**Fig. 3.2.4**). The western geopotential model (**Fig. 3.2.3**) is constrained by a new understanding of the Peters Creek Volcanic (cf with **Fig. 1.5.5**, the northern end of **Fig. 2.1.3**, and southern end of **Fig. 2.1.2**), and a good match between acoustic and magnetic basement in the south *(Tarlowski and Scott, 1997)*.

The profile models require a polarity switch in the extensional basement system (**Fig. 3.2.1**; *Scott et al., 1998[b], and in press*). The modelling suggests that acoustic basement in the east is the top of the younger Isa Superbasin mafic igneous unit, which makes only a small contribution to the magnetic signal. However, in the west the data do not constrain which unit underlies the megawedge of high seismic reflectivity, although where reflections are discernible below acoustic basement they are mostly sub-parallel to the megawedge. Thus, acoustic basement may alternate between the top of the older Leichhardt Superbasin unit and the younger unit along the profile. The geophysical data require a magnetic unit of greater thickness than what can be plausibly assigned to the Fiery Creek Volcanics. The model is consistent with correlations of seismic interpretations and NABRE outcrop data to the south and with geochronological data. The models also explain the lack of upper Leichhardt Superbasin strata in the west as determined from outcrop investigations on the Murphy Inlier *(Jackson et al., in press)*. The upper Leichhardt Superbasin strata would have been largely eroded from the shoaling side of the interpreted southward dipping half-graben. These models are consistent with outcrop and uphole geological information in the north and offer a better explanation of the geometries of later reactivations as discussed below.

The basement template of the northern Lawn Hill Platform comprises an overprinting by the extensional event which is coeval with or just pre-dates the younger Isa Superbasin mafic unit on the older N-S and E-W trends of the Murphy Inlier. The extension is interpreted to have been accommodated by east to southeast trending normal faults linked to north to northeast trending transverse faults (**Fig. 3.2.1**). Igneous activity recorded in the Murphy Inlier outcrop belt suggests the event had begun at ~1730Ma, and detrital zircons from the Fish River Formation suggest it may have continued to as late as ~1718Ma. The extension is accommodated by the southward facing normal fault(s) in the northeast and by northward facing extensional structure(s) to the SSW. The Little Range Fault may be a modern expression of reactivation of this deep, bounding structure (**Fig. 3.1.1**). The polarity reversal zone comprises a complex, transverse ramp which is probably localised by the influence of an earlier N-S Barramundi trend. The basement template geometry explains the pronounced angular unconformity between the Isa and Leichhardt Superbasins in the eastern profile that correlates in time with a conformable relationship in the west.

The relationship between the Superbasins in outcrop to the south is also one of both angular unconformity and conformity. The structures controlling the depositional geometries of the basal Isa Superbasin in outcrops to the south trend northeasterly and northwesterly according to several authors *(Betts et al., 1996; Scott et al., 1996; Betts, 1997; Betts and Lister, 1997; O'Dea et al., 1997; O'Dea and Lister, 1997)*. The difference in geometry between our interpretation and others may relate to timing (ie temporally distinct episodes) or to location with most of the studies in the south focussed on the west and northwest flanks of an active area of doming (the northwest trending Fiery Creek Dome and Weberra Granite belt). Regionally, the specific unit forming the overlying strata of the angular unconformity between the Isa Superbasin and Leichhardt Superbasin varies significantly from the clastic Bigie Formation underlying the Fiery Creek Volcanics to the Torpedo Creek Formation (Big to Gun Supersequences) at the base of the McNamara Group (**Fig. 1.2.3**). Thus, this tectonic event directly controlled regional topography and depositional geometries for at least 30My. The following discussion outlines how this tectonic event and the resulting basement template continued to influence depositional and structural geometries of the subsequent Palaeoproterozoic basin phases in the northern Lawn Hill Platform.

3.3. Deformation Events

The extensional geometry of the ***~1730Ma Big Event*** is mainly constrained through interpretations of geopotential data as discussed in the previous section. The Big Supersequence is only well imaged near that portion which is part of the Peters Creek Volcanics (**Section 1.5**). Elsewhere it exists below the Prize Supersequence, whose base is generally acoustic basement. However, the sub-acoustic basement does have local reflectivity and the seismic data has been interpreted on the basis of the model derived from analysis of the magnetic and gravity data. We have postulated steep north to northeast trending transverse structures connected by east to southeast trending normal bounding faults **(Fig. 3.2.1**). A polarity reversal of major bounding faults bisects the northern Lawn Hill Platform, with northward-deepening half grabens in the east and southward-deepening half grabens in the west (**Figs. 3.2.1** and **3.2.2**). The Big Event geometry appears to have largely overprinted the earlier more northerly and easterly basement fabrics although its geometry may have been influenced by the pre-existing heterogeneities in the northern Lawn Hill Platform.

Although there is a high level of speculation in the interpretation of the seismic data due to the lack of consistent reflections below the Supersequence, **Fig. 2.2.3** shows a good example of where coherent reflections do exist (most of the archive seismic lines have some indication of our interpretation of the Big Supersequence). As discussed in **Section 2.2**, the internal geometry of reflections and the interpreted wedge shape of the Big Supersequence (away from the Murphy Inlier igneous succession) against an interpreted growth fault are consistent with the understanding of these units in the south and support a period of extensional tectonism and syntectonic deposition. In the north, the refined understanding of the Peters Creek Volcanics allows some confidence in the interpretation of the seismic data.

The grid-wide, very tabular geometry of the Prize, Gun, and Loretta Supersequences argues that these strata were deposited in a period of relative tectonic quiescence. Documented incision between the Prize and Gun Supersequences (eg **Fig. 2.3.3**) and the low-angle unconformity between the combined Prize/Gun package and the Loretta Supersequence indicates that changes in accommodation occurred. As discussed in **Section 2.5**, there is some evidence of the Loretta Supersequence basal doublet diverging into a wedge to the south. This wedge is limited to the southernmost extent of seismic data coverage. A possible explanation of this localised and subtle wedge is that it results from a monocline or significant break in slope. This would be consistent with the apparent conformity of the Loretta Supersequence with the lower packages in the south combined with a low-angle unconformity in the north. It is also possible that some initial small-scale extension was starting to affect the Isa Superbasin during deposition of the Loretta Supersequence (see below).

The stratigraphic geometry of the overlying River Supersequence is significantly different and records the effects of the next significant deformation event at ***~1640Ma, the River Event***. All of the interpreted normal faults of the River Event within the seismic grid are downthrown in a northerly direction (**Fig. 3.3.1**). However, the strike of individual fault segments is variable and most orientations show some sedimentary growth into them. The time-structure map at the River Supersequence horizon (**Fig. 3.3.2**) exhibits an overall E-W to NE/SW orientation of contours. Profiles with NW-SE azimuths generally show the maximum growth and wedge geometries of the River Supersequence into generally simple, listric normal faults (**Fig. 3.3.3**; see also line 91bn-19). These listric faults are always combined with distinct onlapping and diverging reflection characteristics that define the extent of tilt blocks (see line 91bn-29). Correlation of fault picks between adjacent profiles in the Argyle Creek sub-grid suggest that these fault segments trend mostly northeast. In other instances, the structures required to offset stratigraphic thickness changes must be steep and northwest trending to honour line ties (**Fig. 3.3.4**, see also lines 91bn-03 and 91bn-12). Many lines require both fault types to obtain a sensible stratigraphic interpretation (**Fig. 3.3.4**; see also lines 91-bn-42 and 91bn-10). Another common structural style constrained by detailed stratigraphic interpretation is a continuous inward facing structure along a single profile (**Fig. 3.3.5**).

This linked system of variable fault orientations produces local depocentres within tilt blocks. The geometry of River Event structures is influenced by the underlying basement template. Transverse structures in extensional systems are commonly better developed on the deepening side of half grabens and particularly at normal fault polarity reversals. Thus, basement heterogeneities are likely to differ depending on whether or not subsequent successions overly the shoaling or deepening side of half grabens. In the west, faults of River Supersequence age occur on the shoaling, hinge side of the underlying Big Event. In the far west, River Event fault segments are strongly northwest and northeast trending and splay away from interpreted basement structures. The River Event segments become more coincident with underlying Big Event structures toward the center of the seismic grid and towards the polarity switching basement structure (**Fig. 3.3.6**).

In the east, the Big Event may have better developed transverse structures, producing deep heterogeneities. Thus, the subsequent structures are interpreted to have northwest and northeast trends, with depocentres well-developed above intersections of the Big Event structures. In this eastern area, River Event structures appear less segmented and to have greater offset and stratigraphic growth than in the west. However, this may be a bias introduced by the more widely spaced data. Regardless of orientation of bounding faults, growth of River Supersequence stratigraphy in local depocentres occurs into both 'normal' and 'transverse' faults. Thus, the fairly well constrained east trending zone of en echelon River Event structures may reflect a regional, north-south directed extension. This would be consistent with geometries and kinematic indicators recorded for extensional structures of a similar age in the McArthur Basin along the Emu Fault *(Hinman, 1995, 1996; Neudert and McGeough, 1996)*.

There is evidence in the internal seismic stratigraphic geometries of the River Supersequence that growth occurs in two distinct pulses. This is reflected by evidence of a differently oriented River Event structure in the southern end of the Desert Creek sub grid (at about 18°30' S, 139°15' E, **Fig. 3.3.1**). Analysis of outcrop facies and geometries of measured gamma logged sections within the River Supersequence to the south provides further evidence of multiple periods of stratigraphic growth across east to northeast trending faults *(Krassay et al., in press)*. On plan maps, outcrop faults can clearly be assigned to the two distinct orientations recognised in the seismic data. This subdivision has significant bearing on which level of the River Supersequence may be an appropriate host rock for mineralising fluids.

On several lines, some evidence of tectonic growth in the Loretta Supersequence may push the initiation of the River Event back to ~1650Ma (eg lines 89bn-06, 90bn-06, 90bn-01). Growth is minor (<50m), onlap geometries are present (eg line 91bn-19) but uncommon and poorly developed, and we were unable to successfully demonstrate a tectonic event consistently throughout the grid at this earlier time. Further, evidence of erosion of the Loretta Supersequence by the River Supersequence on upthrown tilt blocks (eg line 91bn-09) suggests that the primary extension attributable to this event started after the deposition of the Loretta Supersequence.

There is too little constraint on the exact geometries of the Big Event structures to elucidate the connection in profile of the River Event structures with them. However, a line drawing of the interpretation of profile 90bn-10 (**Fig. 3.3.7**) highlights the variety of possible interactions and the distinct soling of the younger system into the Big Supersequence (see also lines 91bn-09, 91bn-27, 91bn-08, and 91bn-07). The interpretation in **Fig. 3.3.7** also suggests a possible association of compartmentalisation between both episodes of deformation.

Both well log and seismic data constrain the facies and geometry of the next deformation event at ***~1595Ma, the Wide Event***. This event overprints and interacts with both of the previous deformations. The primary trend of the Wide Event in the northern Lawn Hill Platform is W to NW (**Fig. 3.3.8**). Locally, angular truncation geometries and incision at the base of the Wide Supersequence suggest gentle folding prior to or contemporaneous with deposition of the growth packages (see lines 91bn-45, 91bn-07, 91bn-49, and 91bn-19). Syn-tectonic stratigraphic growth is documented in the Wide Supersequence internal geometry (see **Section 2.9**). The WNW trending structures are frequently steep and rooted in River Event structures (see center of **Fig. 3.3.7** and line 91bn-06). Northeast trending splay structures are also evident. These structures most commonly sole into the River Supersequence (eg **Figs. 3.3.3, 3.3.4** and **3.3.7**). Sharp changes in thickness across all of the structures document syn-tectonic growth of the Wide Supersequence. Thickest development is usually contained within small grabens formed by northeast trending splays. Growth is most commonly limited to a few tens of meters, but can exceed a hundred meters in some localities (**Fig. 3.3.9**). The depositional and fault geometries suggest wrench motion on steep WNW strike slip faults with primary normal movement on both northwest and southeast dipping northeast trending splays. Reverse motion on the NE splays is not uncommon (eg line

91bn-19). Both negative and positive flower structures can be interpreted. Antithetic splays, that is SE dipping, are required in some instances. There are probably numerous other faults of this nature that have not been interpreted due the difficulty of distinguishing them from later deformation(s) (eg **Fig. 2.1.4**; see also lines 91bn-51, 91bn-08, and 91bn-07). As an example, the east facing Wide Event structure on **Fig. 3.3.7** at about the line tie with 91bn-08 cannot be connected as a soling fault all the way to the next Wide structure to the east because of line ties. Thus, it probably roots in the River structure and has an accompanying antithetic.

The distribution of the Wide Event age fault system appears to be significantly influenced by the underlying structures. The strike-slip system appears to 'jog' consistently over offsets in the River Event system, so grabens and horsts tend to be best developed there. There are examples of Wide Event structures that developed away from River Event structures (eg lines 91bn-44 and 91bn-06), and they have also offset earlier structures. Thus, the apparent complexity of the Wide Event fault network was increased over the same intersections in the Big Event trends, developing classical 'flower structures' (eg line 91bn-09). Where they were rooted into the transverse River Event structures, there was probably a higher potential for tapping deep fluids. Conversely, the NE-trending splays frequently sole out into the River or, less frequently, the Loretta packages, and so are considered to have been less likely to tap deep fluids. However, they may have been appropriate conduits at the time of dilation for both organic-rich fluids and metal-rich brines trapped temporarily in deeper sequences.

Due to loss of section by erosion by the overlying South Nicholson Group, it is not always possible to distinguish between the Wide Event structures and a later ENE and WNW conjugate joint set (**Fig. 3.3.10**) of the ***~1575Ma Doom Event***. Because of this ambiguity, it is usually not possible to determine whether individual steepened, overturned, or offset River Event structures were modified by the Wide Event or the later Doom Event (**Fig. 3.3.11**; see also lines 91bn-47 and 91bn-10). The conjugate joints dominate a distinct pulse of deformation occurring after the deposition of the Doom Supersequence (<1585Ma) and before deposition of the South Nicholson Basin (SNB, **Fig. 3.3.10**).

The joint pattern of Doom Event faults suggests regional N-S compression, probably from the initial stages of the Isan Orogeny (**Fig. 3.1.1**). Other joint orientations are interpreted, but are less pervasive. Deep erosion of the upper Isa Superbasin succession by the South Nicholson Group and insufficient density of seismic profiles makes deconvolving multiple sets due to the multiple deformations associated with this orogeny impossible. Both normal and reverse motions on Doom Event structures are evident (eg lines 90bn-12, 90bn-17, 91bn-06, 91bn-20). Very large normal offsets are also recorded (eg lines 91bn-11, 91bn-19, 91bn-54). The large offsets seem to be associated with the Calvert Fault (**Fig. 3.1.1**), suggesting that this structure may be of this age.

The marked increase in density of joints over older structural systems suggest that joint orientation variability may be due to reactivation. Indeed, structures interpreted for this deformation are only indicative, as interpreting them wherever reflector discontinuity is present would completely obscure the data. In some instances, joints appear to offset the entire Isa Superbasin 'mega-wedge' and clearly offset earlier fault systems (**Figs. 3.3.4** and **3.3.7**). However, it is also common for 'late stage' fracturing to reactivate at least segments of earlier structures (eg lines 91bn-19, 91bn-54, and 91bn-05) or to be rooted in them (eg line 91bn-11). As pre-existing structures are variously aligned, the complexity of the fracture system associated with them is increased. These late-stage structures are thought to be the main conduits for the metalliferous brines that resulted in the Century ore body *(Broadbent et al., 1996*).

Other deformation features of the Doom Event are shown in **Figure 3.3.12**. On this northeast trending profile, a broad synform of the entire megawedge is apparent. Stratigraphic growth of both the River and Wide supersequences is possible to the southwest of the Beamesbrook well in the disturbed axis of the synform. However, the relatively poor data quality and lack of suitable tie lines make interpretation of structures of these ages speculative. The axis of the synform is also unconstrained but must trend N-NW, which suggests an overall N to NE directed compression.

3.4. Structural Synthesis

This study has discerned distinct periods of intense deformation whose timing is constrained by dating of relevant stratigraphy. Active deformation appears to have affected sedimentation in the northern Lawn Hill Platform at c.1730Ma, c.1640Ma, c.1595Ma, and post c.1580Ma, referred to herein as the Big, River, Wide, and Doom Events, respectively. There is evidence that each of the deformations was episodic. The progressive overprinting of these events has resulted in a variety of interconnected, complex fault systems (**Fig. 3.3.6**).

Extensional fault geometries of the ~1730Ma Big Event are not well constrained by the seismic data. However, interpretation of geopotential data constrains tilting of basement blocks and suggests steep north to northeast trending transverse structures which connect ESE-SE normal bounding faults (**Fig. 3.2.2**). Recent mapping around the Fiery Creek Dome, just south of the study area, records similarly trending structures for this event, although there normal fault movement seems to occur primarily on the NE structures *(Betts et al., 1996; Scott, et al., 1996; Betts and Lister, 1997; Betts, 1997;)*. As discussed above, SHRIMP ages from Peters Creek Volcanics on the Murphy Inlier in the north and Fiery Creek Volcanics in the south suggest that felsic igneous activity related to the Big Event continued from c.1729Ma-1709Ma. The long-lived magmatism requires a major thermal event. The collapse of this thermal event and significant regional deformation that accompanied it set up the large scale accommodation cycle of the Isa Superbasin.

O'Dea et al. (1997) record three angular unconformities (Myally, Bigie, and Surprise Creek) which span from the upper Leichhardt Superbasin through the Prize Supersequence of the Isa Superbasin. We believe the unconformities comprise the same regional event characterised by pulsing and localised magma production. A polarity reversal of the major bounding faults of the Big Event bisects the northern Lawn Hill Platform, with a northward deepening half graben in the east and a southward deepening half graben in the west. The separating transverse structural zone extends from the Murphy Inlier to at least the area of the Century deposit (**Fig. 3.3.6**). Similar trending structures which segment the east to southeast bounding faults are interpreted throughout the northern Lawn Hill Platform. The Big Event strongly overprints the more E-W and N-S geophysical trends of the older Murphy Inlier, although Big Event geometries in the northern Lawn Hill Platform may have been influenced by these ancient crustal heterogeneities.

Two interconnected fault systems occur in the extensional fault geometries of the ~1640Ma River Event (**Fig. 3.3.1**):

- WNW-NW 'transfer faults' associated with NE normal faults and

- ~N-S offsets associated with ESE normal faults.

The geometry of River structures imaged by the seismic data are influenced by the underlying basement template. In the west, the River faults occur on the shoaling, hinge side of the underlying Big Event half-graben where the NE transverse structures are poorly developed. There the ESE River structures dominate and probably reflect the geometry of the earlier "Barramundi Event" which gives the Murphy Inlier its dominant E-W trend. The River Supersequence, host rocks of the McArthur River Mine to the northwest, also thicken in sub-basins bounded by ESE structures and a long-lived, pre-existing N-NNW structure, the Emu Fault *(Hinman, 1995, 1996; Neudert* and *McGeough, 1996)*.

In the east, where the Big Event produced stronger heterogeneities, the River structures appear to assume the NW and NE trends of the Big Event. The eastern River structures are less segmented and have larger offsets. Seismic data suggests growth into both trends. Stratal geometries exposed in outcrops south of the Century deposit also document growth of the River Supersequence into NE and NW trending faults *(Andrews, 1996; Krassay et al., 1997[a,b] and in press)* implying oblique slip on both fault trends. River Supersequence depocenters appear to have been localised over and migrated across structures of the Big Event in the northern Lawn Hill Platform area. This suggests some form of reactivation of or influence by the older structures.

Sub-basin growth geometries are similar throughout the region showing thickening of a few 100's of meters over distances of ~10 km in both seismic and outcrop data (**Fig. 2.6.1**). Regional extension was likely to have been approximately N-S during this event given the variety of fault geometries which produced stratal growth. Sequences within the River Supersequence record consistent patterns of onlap and truncations which are interpreted to represent episodic movement on the faults and a probable inversion event within the package. The palaeomagnetic data derived from correlatives of the River Supersequence in the McArthur Basin to the northwest define a sharp hairpin bend in the Apparent Polar Wander Path *(*Fig. 1.2.8*; Idnurm et al., 1995; Idnurm, 1997*). There is no evidence of extensive magmatism and scant evidence of tuffaceous sediments within the River Supersequence. Thus, the River Event deformation probably reflects an intracontinental response to a farfield plate re-organisation.

The fault geometries of the ~1595Ma Wide Event are consistent with ESE wrench motion on steep west-northwest strike-slip faults and northwest and southeast dipping NE splays (**Fig. 3.3.8**). Both negative and positive flower structures occur. Growth of the Wide Supersequence is usually contained within wrench graben formed by southeast and northwest dipping NE splays. However, growth of the Wide Supersequence also occurs into WNW structures close to NE splays, especially where antithetic NE splays are not well developed. The Wide structures were largely influenced by the underlying River Event structures and thus also show more complexity over the Big Event trends. That is, WNW strike-slip trends are more continuous than NE trends and appear to have 'nucleated' at major River Event transverse offsets. WNW strike slip faults 'bend' at transverse (NW and NNW) structures of the River system, so flower structures develop here. Better developed NE splays are also spatially correlated to the larger offsets in the River system. NE splays frequently sole out into the River Supersequence or, less frequently, into the Loretta Supersequence. Growth in the wrench graben was restricted to 50-100m and the grabens are usually only 1-2 kilometres wide. The Wide Event also shows evidence of episodic fault movement. In particular localities, only the lower sequence shows clear thickness changes (**Fig. 2.9.5**). In many areas, the upper Wide 3 sequence shows the main tectonic growth geometry (**Fig. 2.9.4**). In yet others, a combination of the two episodes account for the total growth package.

The Wide Event appears to have been less prevalent in the east over the deep Big Event half graben, but this may reflect a bias introduced by the wide spacing of data. The data require some local tectonic stratal growth in the Wide Supersequence (eg **Fig. 2.9.2**), but lateral extent and geometry of the thickened package are poorly constrained. Primary structures that controlled the anomalous growth are predicted to lie beyond the seismic coverage area (**Figs. 3.3.8** and **3.3.9**).

A deformation that produced ENE and WNW conjugate joint sets suggests regional N-S compression. The joint sets pervade the Isa Superbasin but do not affect the overlying South Nicholson Group (**Fig. 3.3.10**). Thus, this compressive phase commenced sometime after the deposition of the Doom Supersequence and prior to the deposition of the South Nicholson Group (~1585Ma to ~1500Ma). The trends of these late-stage faults are not always consistent. In some cases, this is because of clear reactivation of earlier structures. An alternative interpretation is multiple phases of Doom Event deformation, but it is not possible to deconvolve multiple events due to the deep incision by the overlying South Nicholson Group. The Doom Event(s) probably record the various stages of the Isan Orogeny (~1580Ma-1500Ma) in the northern Lawn Hill Platform. The density of joints shows a marked incrased over structures of the older structural events. In some instances, joints appear to offset the entire megawedge and can be seen to offset earlier River and Wide Event faults. In other instances, joints clearly reactivated older structures (**Fig. 3.3.7**). Older structures are variously aligned thus increasing the complexity of the fracture system in these locations.

The effect of the Isan Orogeny on the northern Lawn Hill Platform is recorded in the stratigraphic response by steady decrease of accommodation for sedimentation through the upper Doom Supersequence, as discussed above. It was probably not a coincidence that this trend immediately follows the wrench style Wide Event which was characterised by both transpressive and transtensional periods. Stratigraphic evidence suggests that the Wide Event marks the start of the long-lived Isan Orogeny. However, the area covered by the seismic data did not experience the intense folding and metamorphism that is recorded in outcrop to the south. Strain was effectively accommodated by gentle folding and jointing north of the outcropping Elizabeth Creek Fault Zone that extends across the entire region just south of the seismic grid. Onlap terminations within synforms at the base of the much younger South Nicholson Group, suggest that remnant topography created in the Isan Orogeny had not been peneplaned (eg line 89bn-07). The seismic data image several sequences within the South Nicholson Group, but insufficient data exists to successfully describe the tectonostratigraphic history of this basin phase due to later erosion by the Phanerozoic Carpentaria Basin.

3.5. Evolution of Fault Systems

Fig. 3.5.1 shows a schematic image of fault interactions obtained from seismic interpretations in **Fig. 3.5.2**. The image provides a simple example of the many ways the variously aged deformations can interact when each successive deformation phase was focussed on older structures. Only the largest scale late-stage (<1580Ma) conjugate set is shown. As documented by many examples presented herein and in the archive seismic line interpretations, the variety of possible interconnectivity range from fault segments soling into various supersequences to being rooted all the way to a basement structure. The data reveal that the fault zones are pervasively jointed down to scales of seismic resolution and probably even smaller. Multiple variations of fault connectivity are possible when considering a prospect-sized system. Establishing which element of which deformation and the nature of adjacent lithofacies will be crucial to establishing fluid flow pathways. However, the northern Lawn Hill Platform has a high potential to have all the structural elements combined. This type of location also has high potential to produce the suitable host facies and appropriate 'plumbing' considered crucial to high prospectivity. In some areas, late-stage compressional deformation has unroofed the system, bringing the potential mineralised zone to depths that allow economic exploration. As this compressive event was less severe in the northern Lawn Hill Platform than areas further south and east, the study area may not have experienced the later erosional loss of mineralised strata known to have occurred in some localities *(eg Broadbent et al., 1996)*.

The development of structurally controlled lithofacies required for hosting mineral precipitation seems to be best developed over the basement structure intersections. In being localised here, fault interconnectivity provides conduits to a number of possible sources for brines to acquire metals (eg. from both the Fiery Creek Volcanics and the deeper Eastern Creek Volcanics). The number of possible sources for metalliferous brines is increased in areas where thick preserved Leichhardt Superbasin succession increases the potential for deep acquifers to have been tapped which may already hold metalliferous brines from previous fluid flow events. The development of metalliferous brines will be dependent on the timing of fluid events relative to the depths of source lithofacies.

Viewed more regionally, the depth to magnetic source image provides a view of where thick sedimentary piles may exist (**Fig. 1.5.1**). A 'deep' under the eastern half of the seismic grid is evident. Interestingly, the series of smaller 'deeps' that are depicted along a NW axis in the SW corner of the image are more likely to be related to movement during the River Event *(Krassay et al., in press; pers. comm.)* which is consistent with the geometries interpreted for this event under the seismic grid. This image records the current geological configuration of magnetic material and incorporates all of the structural events discussed above. The ability of the seismic data to deconvolve the timing of the various deformation events adds greatly to interpretation of the geophysical data on its own in the search for areas of potential mineralisation.

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CHAPTER 4

Well Log

Sequence Stratigraphy

AGSO Record 1999/19

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Chapter 4

WELL LOG SEQUENCE STRATIGRAPHY

(A.A. Krassay and B.E. Bradshaw)

4.1. Introduction

Between 1986 and 1991 Comalco Aluminium Ltd conducted seismic surveys and drilled four deep petroleum exploration wells in the area immediately south of the Murphy Inlier on ATP 423P (see *Bradshaw et al., 1998* for more details). These four wells (**Desert Creek_1**, **Egilabria_1**, **Argyle Creek_1** and **Beamesbrook_1**) provide the most complete well-based stratigraphic sections through Isa Superbasin strata in the northern Lawn Hill Platform.

Stratigraphic data provided by the four wells are particularly useful as they help constrain the ages and depositional systems associated with seismic sequences. The wells contain full suites of modern downhole electric logs and descriptions of lithologies from well cuttings. In this Chapter, we present interpretations of the gamma-ray, sonic velocity, and lithology logs at a small scale (1:15 000). However, larger scale (1:2000) strip logs which include resistivity curves, and a 1:5000 scale well log cross-section are available in the accompanying **Preliminary Edition Data Release** *(Bradshaw and Scott, 1999)*. Integrated analysis of well logs and lithological logs allows a high-resolution interpretation of sequences. Consequently, sequences are named at a fourth-order scale (ie Sequence x.x; **Section 1.2**). Together, Desert Creek_1 (**Fig. 4.1**) and Egilabria_1 (**Fig. 4.2**) provide a complete coverage of strata associated with the Loretta through Doom Supersequences. Desert Creek_1 contains the best preserved section of the lower Supersequences (Loretta through Lawn, total thickness of 1786m), whilst Egilabria_1 contains the greatest preserved thickness (1146m) of the Wide and Doom Supersequences (**Table 4.1**). Reference is also made to well-log trends at Argyle Creek_1 (**Fig. 4.3**) and Beamesbrook_1 (**Fig. 4.4**) to provide additional insight into the sequence stratigraphy.

Table 4.1 Preserved thickness of Isa Superbasin Supersequences in Comalco wells.

Supersequence	Desert Creek_1	Egilabria_1	Argyle Creek_1	Beamesbrook_1
Loretta	82m	---	185m	---
River	589m	---	345m	---
Term	626m	---	470m	---
Lawn	489m	205m	319m	185m
Wide	287m	300m	83m	431m
Doom	134m	846m	---	198m

4.2. Stratigraphic Nomenclature

Well log sequences are interpreted and named using the chronostratigraphically-based framework and sequence stratigraphic terminology proposed by the NABRE Project to correlate rocks across the Isa Superbasin (**Section 1.2**). This sequence stratigraphic nomenclature scheme is significantly different to published lithostratigraphic schemes. We include references to previous lithostratigraphic schemes to provide a link between our new terminology and formally defined lithostratigraphic units from previously published reports and maps. The Comalco wells were drilled about halfway between outcrops of McNamara Group strata on the Lawn Hill Platform, and Fickling Group strata on the southern flanks of the Murphy Inlier. As most supersequences in the Isa Superbasin thin to the north toward the Murphy Inlier (**Chapter 2**), the wells usually intersect fewer stratigraphic units than are found in the McNamara Group, and more stratigraphic units than occur within the outcropping Fickling Group. We therefore refer to the lithostratigraphic units from the McNamara Group when describing well log lithofacies.

For Upper McNamara Group rocks and their equivalents, there are two important lithostratigraphic classification schemes (**Fig. 1.4.1**):

- the formal lithostratigraphic subdivisions of Sweet and Hutton (1982) based on BMR mapping programmes of the late 1970s and early 1980s;

- informal lithostratigraphic subdivisions documented by Andrews (1998) based on detailed mapping surrounding the Century mine lease on the Lawn Hill 1:100,000 map sheet.

We refer to *Andrews' (1998)* informal subdivisions in inverted commas (eg “member H1s”), and *Sweet and Hutton's (1982)* subdivisions as formally defined (eg Lawn Hill Formation, Bulmung Sandstone Member, Pmh3 interval).

4.3. Loretta Supersequence

Rocks of the Loretta Supersequence were only intersected near the base of Desert Creek_1 (82m thick) and Argyle Creek_1 (185m thick). Loretta sequences are identified and correlated mainly on the basis of seismic interpretations and ties to the outcrop belt to the south. In Desert Creek_1, oolitic dolomitic limestone facies *(Dunster et al., 1993[a])* at the base of the well are interpreted as belonging to a transgressive systems tract of the Loretta 2.3 sequence (**Fig. 4.1**). In Argyle Creek_1, interbedded carbonates and siliciclastics are interpreted as belonging to the Loretta 2.1 and 2.2 sequences (**Fig. 4.3**). The sequences at Argyle Creek_1 exhibit highly variable log values (probably due to interbedding), but the stacking patterns allow conventional sequence stratigraphic interpretations.

In the case of the only fully intersected Loretta sequence (Loretta 2.2 in Argyle Creek_1), a thick transgressive systems tract with an overall retrogradational gamma-ray log trend occurs immediately above sequence boundary Loretta 2.2. The spiky log signals throughout the transgressive systems tract are most likely the result of interbedded carbonate and fine-grained siliciclastics. In both wells the top of the Loretta Supersequence is marked by an abrupt change in facies (up to 100% siliciclastics), and major shifts in log signals.

4.4. River Supersequence

The Comalco wells intersect only part of the River Supersequence. Integrated outcrop and seismic interpretations reveal that the oldest River sequences (River 1.1 - 4.1) are missing through onlap at the position of the Comalco wells. Rocks missing through onlap include the upper part of the Lady Loretta Formation, the entire Shady Bore Quartzite, and the lower half of the Riversleigh Siltstone encompassing “members R1-R2r”. Therefore, the first sequence boundary (River 1.1) of the River Supersequence identified in Desert Creek_1 actually represents the amalgamation of sequence boundaries River 1.1, 2.1, 3.1, 4.1, and 5.1.

4.4.1. Sequence River 5.1

Above the amalgamated sequence boundary there is a coarser interval with a generally progradational gamma-ray log. This interval is interpreted as sandy and silty lowstand deposits equivalent to “member R2s” in outcrop. At 2235m in Desert Creek_1 the logs change and the facies become much finer-grained (**Fig. 4.1**). The gamma-ray low at this point is due to the presence of dolomitic limestone. This point is interpreted as the transgressive surface (River 5.1t). Transgressive systems tract deposits above this surface have a retrogradational log trend up to the maximum flooding surface (River 5.1f) at 2217m in Desert Creek_1. Overlying highstand systems tract siltstones exhibit a progradational log trend.

4.4.2. Sequence River 6.1

This sequence is missing through onlap onto River 7.1 at Argyle Creek_1. However, at Desert Creek_1 it comprises a very thick interval of carbonaceous siltstone and shale. An inflection point on the gamma-ray, sonic, and resistivity logs, and a change in facies from siltstone to carbonaceous silty shale (**Fig. 4.1**) marks the base of the sequence (sequence boundary River 6.1). Above sequence boundary River 6.1 is a very thick transgressive systems tract with an overall retrogradational log pattern, although there are several gamma-ray high zones. The maximum flooding surface (River 6.1f) occurs within a thin zone of highly carbonaceous shale at 2060m surrounded by finely crystalline dolomitic limestone *(Dunster et al., 1993[a])*. The dolomitic limestone is dark grey in colour, interlaminated with siltstone, and lacks any indications of a shallow-marine origin (ie oolites). We interpret these carbonates as a condensed section deposited during a time of low clastic input at a maximum in relative sea level. Overlying highstand systems tract facies are similar to those of the transgressive systems tract, but have a subtly progradational log trend (**Fig. 4.1**).

4.4.3. Sequence River 7.1

Sequence boundary River 7.1 is marked by an abrupt fall in gamma-ray values, a peak in sonic velocities, and an inflection point on the resistivity log. At Desert Creek_1, rocks above the sequence boundary are carbonaceous siltstones with a strongly progradational log trend. On seismic sections this interval exhibits complex channelised geometries, and this part of the sequence is interpreted as a lowstand systems tract. At 1955m in Desert Creek_1, there is an obvious change to a retrogradational log trend (**Fig. 4.1**). This inflection point is interpreted as the transgressive surface (River 7.1t). Transgressive systems tract carbonaceous siltstones exhibit a strongly retrogradational gamma-ray trend up to the maximum flooding surface (River 7.1f) at 1893m. Siltstones from this interval have high organic contents (TOC 3.1%, *Dunster et al., 1993[a]*) indicative of condensed sedimentation in a quiet, sediment-starved, relatively deep water setting. Above the maximum flooding surface is a thick highstand systems tract composed of carbonaceous siltstones with a strongly progradational log trend (**Fig. 4.1**). Fine-grained units of both the transgressive systems tract and highstand systems tract correspond to poorly-exposed “member R3r” in outcrop.

4.4.4. Sequence River 8.1

At 1815m in Desert Creek_1, there is a sharp decrease in gamma-ray values interpreted as sequence boundary River 8.1 (**Fig. 4.1**). This sequence boundary is more obvious in **Argyle Creek_1** (at 1280m) where a large decrease in gamma-ray values is coincident with a significant increase in sand content. Sandstone-dominated facies above sequence boundary River 8.1 in Argyle Creek_1 are interpreted as lowstand units equivalent to “member R3c” mixed sandstone and carbonate facies. However, such obvious lowstand deposits are not preserved at **Desert Creek_1**, where finer-grained siltstones of the transgressive systems tract mantle sequence boundary River 8.1. The maximum flooding surface for sequence River 8.1 is interpreted at the inflection point for the logs (at 1775m in Desert Creek_1). Above River 8.1f, there is a thick siltstone-dominated highstand systems tract with a slightly progradational log trend (**Fig. 4.1**). Transgressive systems tract and highstand systems tract deposits of sequence River 8.1 are equivalent to “member R4r” siltstone in the outcrop belt to the south.

4.5. Term Supersequence

4.5.1. Sequences Term 1.1 and Term 2.1

A significant fall in gamma-ray and density values, and an increase in sonic velocity at 1681m in Desert Creek_1 indicates sequence boundary Term 1.1 (**Fig. 4.1**). At Desert Creek_1 and **Argyle Creek_1**, facies above Term 1.1 sequence boundary are siltstone and shale. However, outcrop sections to the south show that thick lowstand sand-dominated turbidite facies of the Termite Range Formation overlie Term 1.1. Seismic sections reveal that the coarse-grained strata observed in outcrops (sequences Term 1.1 and the lower part of Term 2.1) are missing through onlap at the position of Desert Creek_1 and Argyle Creek_1 (**Chapter 5**). At the well sites, fine-grained transgressive systems tract facies of sequence Term 2.1 directly overlie the amalgamated Term 1.1 and Term 2.1 sequence boundary. The retrogradational trend of the gamma-ray log represents marine flooding up to the maximum flooding surface (Term 2.1f) at about 1672m in Desert Creek_1. The carbonaceous siltstone at this surface has a TOC value of 1.4% *(Dunster et al., 1993[a])*. Above Term 2.1f, relatively fine-grained facies of the highstand systems tract have a progradational gamma-ray trend.

4.5.2. Sequence Term 3.1

Sequence Term 3 comprises three, unusually thick higher-order sequences. These three higher-order sequences correlate in the south to thick sandy lowstand deposits, with intervening shaly transgressive facies. Sequence boundary Term 3.1 is marked by a subtle change in log trends, from progradational below to aggradational above (**Fig. 4.1**). Siltstone-dominated facies of sequence Term 3.1 in Desert Creek_1 have a distinctive mounded geometry on seismic sections that are interpreted as lowstand fans (**Chapter 5**). These fine-grained rocks lack the classic sharp-based, boxcar log signals of sandstone-dominated basin-floor fans, and are interpreted as mudstone-dominated slope fans.

4.5.3. Sequence Term 3.2

This siltstone-dominated sequence is only preserved in Desert Creek_1. The base of the sequence (sequence boundary Term 3.2) is marked by a sharp decrease (albeit small) in the gamma-ray log and sonic log (**Fig. 4.1**), and a change to more variable resistivity values. On seismic sections south of Desert Creek_1, the interval immediately above sequence boundary Term 3.2 is characterised by well-developed south-prograding clinoforms interpreted as a lowstand progradational complex. The lowstand systems tract observed in seismic sections is not preserved further north at Desert Creek_1. Instead, thick transgressive siltstones occur immediately above sequence boundary 3.2.

4.5.4. Sequence Term 3.3

At 1424m in Desert Creek_1 there is an abrupt decrease in the gamma-ray log and a corresponding resistivity kick that marks sequence boundary Term 3.3. Sequence Term 3.3 lacks a lowstand systems tract, but has a two part log motif separated by a maximum flooding surface (Term 3.3f) at 1408m (**Fig. 4.1**). The lower part (transgressive systems tract) of the sequence is retrogradational, whilst the upper part represents progradational sedimentation (highstand systems tract) during falling relative sea level.

4.5.5. Sequence Term 4.1

In both Desert Creek_1 and Argyle Creek_1, the base of sequence Term 4.1 is marked by significant changes in log signals and the presence of coarser facies relative to surrounding siltstones. In Argyle Creek_1 at 1051m, the base of the sequence is represented by a 15m thick sandstone-dominated facies with a sharp-based log character (**Fig. 4.3**). In Desert Creek_1 at 1375m, the same sequence boundary is mantled by a 10m thick sandy siltstone. These basal facies from both wells correlate to a much thicker sandstone-dominated succession ("member H1s") in outcrop farther to the south (**Fig. 4.1**). Seismic sections exhibit mounded fan geometries at the base of sequence Term 4.1 (**Chapter 5**). The basal section of Term 4.1 is thus interpreted as a lowstand systems tract correlating to submarine fan deposits of “member H1s”. Above the sandstone-rich facies in Argyle Creek_1 and the sandy siltstone in Desert Creek_1, there is a broadly retrogradational log signal up to a peak on the gamma-ray, sonic, and resistivity logs. This peak (1315m in Desert Creek_1) represents the maximum flooding surface Term 4.1f. The retrogradational siltstones represent transgressive systems tract deposits overlying and downlapping onto the lowstand fan. Above Term 4.1f the logs are progradational, and in Argyle Creek_1 the lithology log also becomes sandier upwards. The cleaning-upwards lithology trend and the initially aggradational, then progradational log trend indicates progressive shallowing in response to falling relative sea level.

4.5.6. Sequence Term 5.1

Sequence boundary Term 5.1 is marked by a decrease in gamma-ray and sonic values, and an increase in resistivity that correspond to the incoming of sand in the lithology log. Again, Argyle Creek_1 is sandier than Desert Creek_1. At Desert Creek_1, the basal, sandy part of the sequence has a progradational log trend and is interpreted as submarine fans of a lowstand systems tract. At 770m in Argyle Creek_1 (**Fig. 4.3**) and 1210m in Desert Creek_1 (**Fig. 4.1**), there is a change to much higher gamma-ray values and a decrease in sand content. This point represents the transgressive surface (Term 5.1t) when gravity flow sedimentation ceased and lowstand submarine fans were buried by sediments deposited during rising relative sea level. Overlying Term 5.1t is a thick siltstone-dominated transgressive systems tract (representing the upper part of “member H2”) with some carbonaceous intervals (TOC of 0.3% at 1061m in Desert Ck_1, *Dunster et al., 1993[a]*). The retrogradational log trend of the transgressive systems tract continues upward to a major gamma-ray peak at 1068m (maximum flooding surface Term 5.1f) in Desert Creek_1. Above this surface the log trend is progradational until a sharp change in all log signals, and a significant facies change (eg 1055m in Desert Creek_1) that represents the base of the Lawn Supersequence.

4.6. Lawn Supersequence

4.6.1. Sequences Lawn 1.1 and Lawn 1.2

The lower, sandstone-rich part of this sequence is equivalent to “member H3”, the Bulmung Sandstone Member of *Sweet and Hutton (1982)*. This sandstone represents a major change in basin-fill trends, from generally deep water sedimentation dominated by sediment gravity flow processes (submarine fans and turbidites) of the Term Supersequence, to volcaniclastic, storm-affected relatively shallow-marine facies immediately above sequence boundary Lawn 1.1. Subdivision into two higher-order sequences has been made following detailed correlation to drillholes on the central Lawn Hill Platform surrounding Century. The sand-rich lowstand systems tract has a spiky log signature due to interbedding of the sandstone with tuffaceous siltstone intervals (**Figs. 4.1** and **4.3**). The top of the lowstand systems tract is marked by an increase in gamma-ray values, higher sonic values, and lower resistivity values at the transgressive surface (Lawn 1.2t). Above Lawn 1.2t the sediments become progressively finer-grained and more carbonaceous reflecting an increase in accommodation accompanying rising relative sea level and the change to low energy, deeper water conditions. A major peak in gamma-ray values at 963m in Desert Creek_1 marks the maximum flooding surface (Lawn 1.2f), above which carbonaceous siltstones and shales of the highstand systems tract have a marked progradational log trend (**Fig. 4.1**).

4.6.2. Sequence Lawn 2.1

Sequence boundary Lawn 2.1 is a siltstone-on-siltstone boundary that is picked on the basis of log responses. Beneath Lawn 2.1 the upper part of the highstand systems tract of sequence Lawn 1.2 is progradational, above Lawn 2.1 the transgressive systems tract of sequence Lawn 2.1 is retrogradational (**Fig. 4.1**). The retrogradational log trend of the transgressive systems tract continues upward in Desert Creek_1 until 860m, where the peak in gamma-ray and sonic logs and the inflection point in the resistivity mark the maximum flooding surface Lawn 2.1f. At Desert Creek_1, the logs above Lawn 2.1f are strongly progradational up to 835m, which represents the top of the highstand systems tract and sequence boundary Lawn 3.1 (**Fig. 4.1**).

4.6.3. Sequence Lawn 3.1

The base of this sequence is a marked inflection point on most logs; consisting of a gamma-ray low, sonic low and resistivity high. However, the lithology log is similar across this interval and indicates carbonaceous siltstones and shales of "member H4r". The basal part of the sequence has an aggradational to slightly progradational log trend up to about 815m in Desert Creek_1 and probably represents a lowstand systems tract (**Fig. 4.1**). The silt-dominated character of this interval suggests that the lowstand systems tract comprise slope fan deposits. The top of the fan is interpreted at 815m where there is an abrupt increase in gamma-ray values in Desert Creek_1. This surface represents the downlap surface on seismic data. The surface separates coarser submarine fan and turbidite deposits that accumulated during falling relative sea level, from the thick overlying shale-prone, thinly bedded turbidite successions deposited during stillstand or slowly rising relative sea level. The carbonaceous siltstones in Desert Creek_1 from 815-765m have progradational log signals (**Fig. 4.1**) and are interpreted as being part of the lowstand prograding complex (lowstand systems tract) downlapping onto slope fan deposits.

The inflection point at 765 m represents the transgressive surface (Lawn 3.1t), above which retrogradational transgressive systems tract siltstones accumulated during a period of rising relative sea level. These thick transgressive systems tract rocks are variably carbonaceous, and the one geochemical sample at 801m has a TOC of 0.4% *(Dunster et al., 1993[b])*. The maximum flooding surface (Lawn 3.1f) at the top of the thick transgressive systems tract is marked by a major peak in gamma-ray values at 700m in Desert Creek_1. Above Lawn 3.1f, there is about 20m of progradational highstand systems tract carbonaceous siltstone (**Fig. 4.1**).

4.6.4. Sequence Lawn 4.1

Sequence boundary Lawn 4.1 is picked in Desert Creek_1 at an inflection point in log trends generated by a siltstone on siltstone contact (**Fig. 4.1**). The lower part of the sequence shows strongly retrogradational log signals associated with a fining-up from siltstone to carbonaceous silty-shale. Maximum flooding surface Lawn 4.1f is indicated at 586m by a gamma peak and associated highly carbonaceous shale. Above Lawn 4.1f there is a 20m interval of highstand systems tract displaying a progradational log trend. Our interpretation at Desert Creek_1 differs from *McConachie and Dunster (1996)* who interpreted sequence Lawn 4.1 as an extensive highstand systems tract based on an apparent progradational trend in the resistivity curve. However, resistivity curves are very sensitive to the presence of hydrocarbons *(Rider, 1986)*. Thus, the apparent cleaning-up resistivity trend at Desert Creek_1 (and **Egilabria_1**) indicates increasing TOC content as the silty-shales fine upward to the maximum flooding surface Lawn 4.1f.

Lawn 4.1 is also well documented at Egilabria_1 and **Beamesbrook_1**. Well logs at Beamesbrook_1 show a retrogradational parasequence set containing three dirtying-up trends within the Lawn 4.1 transgressive systems tract (**Fig. 4.4**). The Lawn 4.1 highstand is characterised by progradational log trends above Lawn 4.1f. Egilabria_1 and Beamesbrook_1 both have high TOC and ditch-gas concentrations in Lawn 4.1, particularly around maximum flooding surface Lawn 4.1f (6 to 7% TOC). At Beamesbrook_1, low resistivity values characterise the Lawn 4.1f surface and represent an important anomaly generated by either syndepositional sulphide precipitation, postdepositional mineralisation, or the presence of graphite (the latter considered unlikely, owing to the low levels of metamorphism in the northern Lawn Hill Platform).

4.7. Wide Supersequence

4.7.1. Sequence Wide 1.1

Sequence boundary Wide 1.1 is marked by an abrupt change in log trends at 1642m in **Egilabria_1**. This includes an increase in resistivity and sonic velocity, and a decrease in gamma values. The Wide 1.1 sequence boundary is a major unconformity within the basin (the Wide Supersequence boundary), and correlates with the base of Century host ("member H4s") strata. The initial change in log trends is due to a 16m thick micritic to finely crystalline, argillaceous limestone at Egilabria_1 *(Dunster et al., 1993[b])*, and a siltstone-dominated interval at **Beamesbrook_1** *(Dunster et al., 1989)*. Increasing gamma values and decreasing sonic velocities associated with a change in lithology to carbonaceous siltstones and shales (**Figs. 4.2** and **4.4**) indicates a transgressive systems tract. A gamma-ray maximum is present in both wells at maximum flooding surface Wide 1.1f. Shales from the condensed section at Beamesbrook_1 show high TOC values (7.0%), and possibly correlate to the Century host shales described by *Andrews (1998)*. A subsequent cleaning-up log trend defines the Wide 1.1 highstand systems tract.

4.7.2. Sequence Wide 2.1

Sequence boundary Wide 2.1 is interpreted at 1572m in Egilabria_1 at a change in log trends generated by aggradational very fine-grained silty sandstones overlying deep marine carbonates (**Fig. 4.2**). Above the silty sandstone package, an increase in gamma values and decrease in sonic velocities coincides with a marine flooding surface (Wide 2.1f) and a lithological change to black carbonaceous siltstones with a high TOC value (7.0%). At Beamesbrook_1, the base of sequence Wide 2.1 contains a thick siltstone characterised by high resistivity values and a transgressive trend in the gamma and sonic curves (**Fig. 4.4**). Beamesbrook_1 also shows the same marked increase in gamma and decrease in sonic velocity and resistivity at marine flooding surface Wide 2.1f associated with a lithological change to shales with a low TOC value (0.09%). Well-log trends through sequence Wide 2.1 are interpreted as indicating a transgressive systems tract that contains at least one locally correlative marine flooding surface.

4.7.3. Sequence Wide 3.1

Sequence boundary Wide 3.1 is interpreted at 1553m in Egilabria_1 at a sudden decrease in gamma and increase in sonic velocity and resistivity (**Fig. 4.2**). Changes in log trends are due to the presence of interbedded siltstones and very fine-grained, lithic, micaceous, quartz arenites. Gamma values within the sandstones are relatively high, plotting around the siltstone base-line for Egilabria_1. Sequence Wide 3.1 is therefore correlated to the arkosic Widdallion Sandstone member which has high total gamma count readings in outcrop sections *(Krassay et al., 1997)*. A similar change in log trends also occurs at Beamesbrook_1, more so in gamma and sonic values and less in resistivity (**Fig. 4.4**). The absence of a sharp break in the resistivity log is due to a lateral facies change to interbedded siltstones and shales at Beamesbrook_1. Log trends at Egilabria_1 show an initial broad aggradational trend as the sandstone content gradually decreases from 60% to 40%. A transgressive surface (Wide 3.1t) is interpreted at 1400m where gamma values increase significantly and the sandstone content decreases to just 20% (**Fig. 4.2**). Transgressive surface Wide 3.1t is also apparent in gamma logs from Beamesbrook_1 (**Fig. 4.4**). Overall, sequence Wide 3.1 is interpreted as a thick lowstand systems tract that floods into a thin upper transgressive systems tract.

4.8. Doom Supersequence

4.8.1. Sequence Doom 1.1

The base of the Doom Supersequence is picked at 1341m in Egilabria_1 where there is a marked increase in gamma-ray values (**Fig. 4.2**). This gamma increase could easily be mistaken as representing a maximum flooding surface from the underlying Wide 3.1 transgressive systems tract. However, other logs clearly show a blocky log trend with an abrupt break from the underlying transgressive trend. The blocky log trend is associated with an increase in sandstone content from 20% to 50%. Sandstones above Doom 1.1 have higher gamma-ray values and are significantly dirtier than underlying sandstones, with up to 50% lithic fragments *(Dunster et al., 1993[b])*. The blocky log trend ends suddenly as the lithology changes to a thin (25m thick) zone of interbedded siltstone, limestone, and sandstone (**Fig. 4.2**). A set of two cleaning-up (progradational) log trends associated with siltstones and minor shales overlie this condensed interval. Gamma values subsequently increase at 1150m as the siltstones become carbonaceous. The overall log trends of sequence Doom 1.1 show the following log responses typical of lowstand submarine fan systems described by *Vail and Wornardt (1990)*:

- The basal high-gamma sandstone displays a blocky character with sharp bases and tops typical of basin floor fans.

- A condensed carbonate interval overlies the basin floor fan and is followed by a progradational interval of interbedded siltstones and shales typical of levee channel and overbank deposits within slope fans.

- An upper transgressive interval possibly marks a period of fan abandonment at the end of the sequence.

At Beamesbrook_1, siltstones that occur above sequence boundary Doom 1.1 display the same high-gamma, and blocky sonic and resistivity response as the lowstand basin fan sandstone at Egilabria_1 (**Fig. 4.4**). Beamesbrook_1 also shows the same set of progradational parasequences despite being associated with a finer grained lithology. It is likely that a lateral facies change occurs between Egilabria_1 and Beamesbrook_1 associated with a change from proximal to distal fan environments. Doom 1.1 is the last preserved sequence beneath the South Nicholson Group unconformity at Beamesbrook_1.

4.8.2. Sequence Doom 2.1

Sequence boundary Doom 2.1 is interpreted at 1100m in Egilabria_1 at the base of a sharply defined cleaning-up log trend (**Fig. 4.2**). The sharp-based log trend is generated by a package of siltstones and minor limestones interpreted as a new lowstand fan system. A retrograding trend commences at 1050m at the Doom 2.1 transgressive surface (Doom 2.1t). The subsequent transgressive systems tract is characterised by decreasing siltstone and increasing limestone and shale lithologies. Maximum flooding surface Doom 2.1f is interpreted at 990m where a turn-around to progradational log trends occurs in association with a coarsening-up from shales to siltstones and dolomites.

4.8.3. Sequence Doom 3.1

Sequence boundary Doom 3.1 is picked in Egilabria_1 at 952m based on a marked change in log trends associated with an interval of interbedded fine grained sandstones and siltstones (**Fig. 4.2**). *Dunster et al. (1993[b])* note a distinct “salt and pepper” colouring within the sandstones, owing to the presence of lithic fragments, coarse muscovite, and rare biotite. *Dunster et al. (1993[b])* propose that this change in mineralogy marks a shift in sediment provenance. A blocky trend in the gamma and sonic logs characterises the basal sandstones (**Fig. 4.2**), which are interpreted as turbidite deposits within a lowstand systems tract. Above the lowstand sandstones, gamma and sonic logs show irregular, spiky log-trends, suggesting thin interbeds of contrasting lithologies. The resistivity log shows a broader retrogradational and progradational trend and is used to define the overlying systems tract. A transgressive surface (Doom 3.1t) is picked at the top of the last major sandstone bed at 891m. A subtly retrogradational parasequence set within a transgressive systems tract is interpreted between 891-790m (**Fig. 4.2**). The position of the maximum flooding surface (Doom 3.1f) is equivocal due to large variations in log signals of crystalline dolomite versus siliciclastic facies. Maximum flooding surface Doom 3.1f most likely occurs within siltstone at

788m where there is an inflection point on most logs, particularly the resistivity log. The presence of mixed carbonate facies around the level of the maximum flooding surface may reflect a relatively distal palaeo-environment with condensed carbonate sedimentation occasionally disturbed by minor clastic input. The Doom 3.1 highstand systems tract shows an overall progradational gamma-ray trend.

4.8.4. Sequence Doom 4.1

Sequence boundary Doom 4.1 is interpreted at 713m in Egilabria_1 where the gamma-ray and resistivity logs show a marked change in trend at the base of a thick sandstone package (**Fig. 4.2**). The basal sandstone is fine grained, and again characterised by a distinct speckled "salt and pepper" colouring, due to the presence of up to 50% lithic fragments. Clasts include well-rounded glassy black grains, translucent green and turquoise grains, dark grey and black mudstone, and black limestone *(Dunster et al., 1993[b])*. As with underlying sequences Doom 3.1 and Doom 1.1, the presence of a dirty basal sandstone is interpreted as indicating turbidite deposits within a lowstand systems tract**.** A lowstand sandstone which grades from quartz packstone/wackestone to fine-grained calcareous sandstone is overlain by an arenaceous limestone unit *(Dunster et al., 1993[b])*. These are interpreted as shelf carbonates deposited within a transgressive systems tract. The remaining sequence is dominated by fine- to medium-grained, sub-lithic (up to 20% lithic fragments) quartzose sandstones, and interbedded siltstones. An irregular spiky log trend probably indicates a high degree of interbedding of facies, perhaps turbidites or shelf tempestites within a highstand systems tract (**Fig. 4.2**). Previous interpretations by *Dunster et al. (1993[b])* placed the base of the South Nicholson Group at Doom 4.1. However, our revised interpretations clearly show the base of the South Nicholson Group belongs higher up at a major erosion surface present within most Comalco drill holes (**Fig. 1.7.3**).

4.8.5. Sequence Doom 5.1

The final preserved sequence boundary of the Doom Supersequence (Doom 5.1) is picked in Egilabria_1 at 568m, at the base of a fine- to medium- to occasionally coarse-grained quartzose sandstone (**Fig. 4.2**). The sandstone is characterised by thick blocky log trends. These blocky log trends, combined with the coarse-grained, amalgamated nature of the sandstones, indicate coastal or fluvial deposits within a lowstand systems tract. A sharp transgressive surface (Doom 5.1t) occurs above the lowstand sands at 524m. The subsequent transgressive systems tract contains at least one retrogradational parasequence within interbedded sandstones and siltstones.

4.9. Post-Isa Super Basin Sequences

4.9.1. South Nicholson Group

The base of the South Nicholson Group is very distinct at Egilabria_1 and Argyle Creek_1, marked by a sharply based blocky trend in gamma and sonic logs, and a sharply based progradational trend in the resistivity log (**Figs. 4.2** and **4.3**). Only one sequence is picked within the South Nicholson Group at Egilabria_1. This is characterised by a thick interval (497-400m) of fine- to medium-grained and medium- to coarse-grained quartz sandstones. The blocky log trend that characterises the South Nicholson Group is interpreted as fluvial deposition within a lowstand systems tract. A thin, red, micaceous siltstone *(Dunster et al., 1993[b])* between 360 and 359m probably relates to fluvial overbank sedimentation. At Beamesbrook_1, a thin interval of interbedded, fine- to very fine-grained quartz sandstone and shale between 580 and 570m is also interpreted as part of the South Nicholson Group (**Fig. 4.4**), based on seismic geometries around the well. Evidence of additional South Nicholson Group sequences is missing, owing to erosion prior to deposition of the Mesozoic Carpentaria Basin successions.

4.9.2. Phanerozoic

The base of the Mesozoic Carpentaria Basin is interpreted from palaeontological reports, as well as dramatic changes in well log trends at Beamesbrook_1 (Egilabria_1 and Desert Creek_1 log trends are obscured by well casing). The Carpentaria Basin forms a 300-560m thick cover dominated by siltstones between Egilabria_1 and Beamesbrook_1. The main significance of the Carpentaria Basin in relation to mineral exploration of the underlying Proterozoic host rocks is its potential to limit economic recovery, owing to its increasing thickness to the east.

4.10. Basin Fill History Indicators in Comalco Well Log Trends

River 5.1 is the oldest sequence preserved in more than one Comalco well. A major change in accommodation and sedimentation occurs between the deep marine sandstones and siltstones of River 5.1, and the underlying shallow marine carbonates of the Loretta Supersequence. Seismic data image the Loretta Supersequence as tilted up and eroded toward the Murphy Inlier (**Chapter 2**). Older and shallower River 1.1 through 4.1 sequences have onlapped against the regionally tilted Loretta Supersequence south of the wells thus explaining the abrupt deepening of strata from Loretta into River 5.1.

Sequence River 6.1 is well preserved at Desert Creek_1, but is missing through onlap onto River 5.1 at Argyle Creek_1. Sequences River 7.1 and 8.1 have similar thicknesses and overall log trends in both wells (**Fig. 1.7.3**).

However, Argyle Creek_1 is missing the lowstand systems tract from River 7.1, while Desert Creek_1 is missing the lowstand systems tract of sequence River 8.1. No evidence exists in either well for the significant syndepositional growth of River Supersequence strata observed in seismic sections (**Chapter 2**). This is because both wells are drilled on the thin shoaling sides of River age tilt blocks.

The Term Supersequence boundary is highly erosional, removing most of the underlying River 8.1 highstand systems tract. At Argyle Creek_1 and Desert Creek_1, this sequence boundary represents the amalgamation of two sequences, with Term 1.1 and much of Term 2.1 missing through onlap. Sequences Term 2.1 and 3.1 are thinner, sequence Term 4.1 is missing, and sequences Term 5.1, 6.1, and 7.1 are all coarser grained at Argyle Creek_1 (**Fig. 1.7.3**). This indicates that the position of Argyle Creek_1 was more proximal during deposition of the Term Supersequence. The various Term sequence boundaries also show greater erosion at Argyle Creek_1 than at Desert Creek_1. Well logs from Argyle Creek_1 and Desert Creek_1 document a period dominated by gravity flow turbidite sedimentation.

Well log sequences within the Lawn Supersequence are very similar in terms of facies, thickness, and log signals at both Argyle Creek_1 and Desert Creek_1. One difference is more erosion of the highstand systems tract of sequence Lawn 1.1 at Argyle Creek_1. Lawn 2.1, 3.1, and 4.1 all show type-2 sequence boundaries characterised by inflection points in well log and lithofacies trends. This contrasts with the marked basinward shift in facies typical of type-1 sequence boundaries seen at the base of the Lawn Supersequence. *Van Wagoner et al. (1990)* proposed that type 2 sequence boundaries form in basins characterised by high regional subsidence rates. The sudden onset of deep marine carbonaceous siltstone and shale deposition following sequence Lawn 1.1 is consistent with a period of high regional subsidence rates throughout deposition of most of the Lawn Supersequence.

Lawn 4.1 is present in Desert Creek_1, Egilabria_1, and Beamesbrook_1 as an organic-rich silty-shale interval, but is missing at Argyle Creek_1 due to truncation by the Wide Supersequence boundary (**Fig. 1.7.3**). The Lawn 4.1 maximum flooding surface (Lawn 4.1f) shows the highest TOC values throughout the Lawn Supersequence (up to 7%). Well log trends also show overall fining-upward through the Lawn Supersequence up to Lawn 4.1f. It is thus likely that Lawn 4.1f represents the second-order maximum flooding surface for the Lawn Supersequence. Based on organic geochemical data, *McConachie and Dunster (1996)* proposed that sequence Lawn 4.1 was once a prolific petroleum source rock interval throughout the northern Lawn Hill Platform. Only a small amount of progradation occurs above Lawn 4.1f, indicating that the Lawn Supersequence was formed during a period of broad regional subsidence.

Sequence boundary Wide 1.1 is present in all wells as an abrupt drop in gamma values. The absence of sequence Lawn 4.1 at Argyle Creek_1 indicates a regional erosional surface exists beneath the Wide 1.1 sequence. The presence of a regional erosion surface so close to the Lawn 2nd-order maximum flooding surface indicates that a major tectonic event initiated the Wide Supersequence. Structural evidence presented in Chapter 3 suggest this tectonic event was a brief period of compression in the earliest phase of the Isan Orogeny.

The preserved thickness of “member H4s”-equivalent strata in sequences Wide 1.1 and 2.1 varies considerably, from a maximum of 150m at Desert Creek_1, to a minimum of 50m at Argyle Creek_1 (**Fig. 1.7.3**). Sequence Wide 1.1 is very similar in log character and thickness at Beamesbrook_1, Egilabria_1, and Desert Ck_1. Each well shows an initial transgression to maximum flooding surface Wide 1.1f, subsequent progradation of siltstones and shales within a highstand systems tract, and an upper deep marine carbonate unit. Further west at Argyle Creek_1, Wide 1.1 is characterised by a blocky trend associated with siltstones from the highstand systems tract; no Wide 1.1 transgressive systems tract is apparent at Argyle Creek_1. Sequence Wide 2.1 shows a westward thinning from 60m thick at Beamesbrook_1 to 35m thick at Desert Creek_1, and is absent at Argyle Creek_1. Units within “member H4s” tend to thin northwards and possibly westwards by the transgressive systems tract pinching out, presumably through onlap. Seismic interpretations in **Chapters 2** and **5** confirm that sequences Wide 1.1 and 2.1 thin northwards through the onlap of strata.

Sequence Wide 3.1 is present in all wells, although Argyle Creek_1 only shows partial preservation of the sequence owing to erosion by the South Nicholson Group. In all cases, the lithologs and, to a lesser extent, the gamma logs show a broad transgressive trend within Wide 3.1. An apparent gamma-low in Desert Creek_1 at 350m is due to the presence of well casing, and was incorrectly interpreted as a sequence boundary by *McConachie and Dunster (1996)*. Sequence Wide 3.1 shows a westward- and northward-thinning trend from a maximum of 300m at Beamesbrook_1, to 100m at Desert Creek_1. Thinning of the sequence is attributed to onlap within the lowstand systems and transgressive systems tracts. Seismic interpretations in **Chapters 2** and **5** show Wide 3.1 is associated with a series of northward-thinning wedges, with Desert Creek_1 drilled on the shoaling side of one wedge, and Egilabria_1 and Beamesbrook_1 drilled toward the deepening sides of two separate wedges. In most wells, siltstones and silty shales dominate lithologies. However, Egilabria_1 shows an anomalously high sandstone content, suggesting it is closer to the source of the Widdallion Sandstone member.

Sequences Doom 2.1 through Doom 5.1 are preserved at Egilabria_1, but at the other three wells erosion prior to the deposition of the South Nicholson Group have removed them (**Fig. 1.7.3**). Between Egilabria_1 and Beamesbrook_1, at least 600m of section was lost, with sequences Doom 2.1 to Doom 5.1 removed. Further west at Argyle Creek_1, the South Nicholson Group erodes all five Doom sequences. This evidence contradicts observations from the seismic data by *McConachie and Dunster (1998)* that the South Nicholson Group becomes conformable with the Isa Superbasin north of the Elizabeth Creek Fault Zone.

Well log trends at Egilabria_1 show initial deepening and fining-up in the Doom 1.1 through Doom 3.1 sequences. A 2nd-order maximum flooding surface is interpreted at Doom 3.1f based on the thick condensed section of deep marine carbonates. A subsequent 2nd-order regression is interpreted in sequences Doom 4.1 and 5.1 based on the rapid shallowing and coarsening up of sediments indicated in well logs, together with the change in sediment provenance noted by *Dunster et al. (1993[b])*. *Bradshaw et al. (1998)* propose that this regression was driven by the main onset of the Isan Orogeny at about 1585Ma. Doom 5.1 was probably the last sequence deposited in the Isa Superbasin before regional uplift and erosion during the Isan Orogeny.

At Egilabria_1, medium-grained fluvial sandstones dominate the South Nicholson Group. Only a thin remnant of the South Nicholson Group is preserved at Beamesbrook_1. At Argyle Creek_1, fine-grained coastal or fluvial sandstones at the base, and a thick shelf (glauconitic) siltstone interval at the top dominate the South Nicholson Group. *Dunster et al. (1993[b])* interpreted the fluvial sandstones of the South Nicholson Group at Egilabria_1 as a continuation of the final shallowing and coarsening-up trend of the Doom sequences. However, a major (1000m) erosional hiatus clearly exists between sequence Wide 3.1 and the South Nicholson Group at Argyle Creek_1, thus refuting the foreland sedimentation continuum model of *McConachie and Dunster (1998)* and *Dunster et al. (1993[b])*. Additional evidence from seismic data and SHRIMP zircon ages clearly indicates that fluvial sandstone deposition in the South Nicholson Group occurred at least 80 to 100my after deposition of the Isa Superbasin (**Section 1.7**).

List of figures

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CHAPTER 5

Evolution of Contemporaneous Depositional Systems in the Isa Super Basin

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Chapter 5

EVOLUTION
of
CONTEMPORANEOUS DEPOSITIONAL SYSTEMS
in the
ISA SUPER BASIN

(B.E. Bradshaw, D.L. Scott, P.N. Southgate, A.A. Krassay, J.F. Lindsay, R.W. Page, T.T. Sami, and M.J. Jackson)

5.1. Introduction

The aim of this chapter is to detail the basin-fill history of the Isa Superbasin through the interpretation of contemporaneous depositional systems (ie systems tracts) within each sequence. These systems tracts are used to determine the spatial and temporal relationships of mapped lithofacies members from the McNamara Group on the Lawn Hill Platform to the Fickling Group on the southern Murphy Inlier.

Sweet et al. (1981) presented a one-to-one correlation of formations within the McNamara and Fickling Groups based on lithofacies *associations (see their Fig. 4*). These authors proposed that the Fickling Group is a condensed version of the McNamara Group (ie each Formation continued through and gradually thinned onto the Murphy Inlier). Each Group contained basal igneous rocks overlain by carbonates and upper clastics. *McConachie and Dunster (1998)* used the Comalco seismic and well log data with limited outcrop control to propose that there is not a one-to-one correlation of the McNamara and Fickling Groups (**Fig. 5.1.1**). In the *McConachie and Dunster (1998)* model, the igneous rocks of the Isa Superbasin occur in a basal "rift phase" seismic package that extends relatively continuously between the two areas (**Fig. 1.2.4**). Carbonates of the lower McNamara Group belong to a "passive margin phase" seismic unit and thin through onlap and truncation so that the Lady Loretta Formation correlates chronostratigraphically to the Fish River Formation, Walford Dolomite, and possibly the Mount Les Siltstone. Clastic units from the upper McNamara Group are placed in a "foreland basin" package, which thins through onlap so that the Shady Bore Quartzite and Riversleigh Siltstone lack time equivalents in the Fickling Group. In this model, the Termite Range Formation correlates to the Mount Les Siltstone, while the Lawn Hill Formation correlates with the Doomadgee Formation.

Bradshaw et al. (1996) integrated outcrop gamma ray curves with preliminary seismic and well log interpretations to develop an initial sequence stratigraphic correlation for the NABRE project (*see their Fig. 1*). In this early NABRE model, only the upper McNamara Group was correlated to the upper clastic units of the Fickling Group. The northerly onlap of strata resulted in the preservation of only the youngest sequences within each upper McNamara

Group Supersequence. *Bradshaw et al. (1996)* interpreted the Mount Les Siltstone as correlating to the upper Riversleigh Siltstone, the lower Doomadgee Formation (Pfd_{1-2}) with the Pmh_{1-4} members of the Lawn Hill Formation, and the upper Doomadgee Formation (Pfd_3) with the Widdallion Sandstone and Pmh_6 members of the upper Lawn Hill Formation.

Bradshaw and Scott (1997) refined the earlier NABRE correlation model with new seismic and outcrop data. In this revision, increased resolution was provided for correlations in the upper clastic sequences. These authors also proposed correlations between the Lady Loretta Formation and Walford Dolomite, and suggested that the underlying McNamara Group carbonates were absent in the Fickling Group due to truncation by the Loretta Supersequence boundary. Clastics units from the Gunpowder Creek Formation and Torpedo Creek Formation correspond to the Pff_{2-3} and Pff_1 members of the Fish River Formation, respectively.

In this chapter, the final NABRE seismic, outcrop, and well log interpretations are integrated to place mapped lithofacies members within a sequence stratigraphic framework. These interpretations provide the basis for high-resolution depositional models for the basin-fill history of the Isa Superbasin in the northern Lawn Hill Platform. Well logs are tied to seismic sections using checkshot surveys published in the Comalco well completion reports for Argyle Creek_1, Desert Creek_1, and Egilabria_1 (**Fig. 2.1.2**; *Dunster et al. 1993a, b, c*). Checkshot data were unavailable for Beamesbrook_1. Sonic velocity curves are used for time-depth conversions. Gamma and sonic logs with interpreted sequence boundaries (**Chapter 4**) are plotted on seismic sections (**Figs. 5.1.2, 5.1.3, 5.1.4** and **5.1.5**). Potential errors in the placement of well log picks onto the seismic sections are mainly from drill hole deviation. Egilabria_1 is the only well with a significant deviation with the measured depth up to 58m greater than corrected true vertical depth. Synthetic seismograms are available for all four wells and have been used to verify the accuracy of picks onto the seismic sections, particularly at Egilabria_1. Outcrop sections are not constrained by velocity surveys but are integrated into the seismic sections using thicknesses derived from average velocities determined from well logs and seismic sections (**Table 2.1**).

Integrated interpretations of seismic, well logs and outcrop sequences are used to correlate strata from the McNamara Group to the Fickling Group at scales ranging from 2nd order tectonic cycles, to 3rd and 4th order tectonic and eustatic cycles (**Figs. 5.1.6** and **5.1.7**). The correlations are summarised in **Table 5.1**. References for the original definitions of lithostratigraphic units are shown in **Table 5.2**. In subsequent sections, the current placement of lithostratigraphic members within a sequence stratigraphic framework is shown using interpretations of flattened seismic sections. This technique permits the stratigraphic architecture at any given time to be more easily visualised. Models are presented to summarise the evolution of depositional systems within each Supersequence. These models also highlight how outcrop belts north and south of the seismic grid once formed connected, contemporaneous depositional systems.

Table 5.1 Sequence stratigraphic correlations of time-equivalent lithofacies formations in the northern Isa Superbasin.

Super-Sequence	McNamara Group	Fickling Group (east)	Fickling Group (west)
Doom	Lawn Hill Fm (H5, H6)	Doomadgee Fm (Pfd3)	Doomadgee Fm (Pfd3)
Wide	Lawn Hill Fm (H4s, H5)	Doomadgee Fm (Pfd3)	Doomadgee Fm (Pfd3)
Lawn	Lawn Hill Fm (H3)	Doomadgee Fm (Pfd2)	Doomadgee Fm (Pfd3)
Term	Lawn Hill Fm (H1r, H1s, H2)	Doomadgee Fm (Pfd1-2)	Doomadgee Fm (Pfd3)
River	Riversleigh Siltstone (R2s, R3r, R3s, R3c, R4r)	Mt Les Siltstone	Mt Les Siltstone, Doomadgee Fm (Pfd1-2)
Loretta	Lady Loretta Fm	Walford Dolomite	Walford Dolomite
Gun	upper Gunpowder Creek Fm	Fish River Fm (Pff3)	Fish River Fm (Pff3)
Prize	Torpedo Ck Fm, lower Gunpowder Creek Fm	Fish River Fm (Pff1-2)	Fish River Fm (Pff1-2)

Table 5.2 Key to abbreviations of lithofacies members used in text and figures.

Member	Formation	Group	Author
H6	Lawn Hill	McNamara	Andrews (1998)
H5	Lawn Hill	McNamara	Andrews (1998)
H4s	Lawn Hill	McNamara	Andrews (1998)
H4r	Lawn Hill	McNamara	Andrews (1998)
H3	Lawn Hill	McNamara	Andrews (1998)
H2	Lawn Hill	McNamara	Andrews (1998)
H1s	Lawn Hill	McNamara	Andrews (1998)
H1r	Lawn Hill	McNamara	Andrews (1998)
R4r	Riversleigh Siltstone	McNamara	Andrews (1998)
R3c	Riversleigh Siltstone	McNamara	Andrews (1998)

(continued next page)

Table 5.2 (con't)

Member	Formation	Group	Author
R3s	Riversleigh Siltstone	McNamara	Andrews (1998)
R3r	Riversleigh Siltstone	McNamara	Andrews (1998)
R2s	Riversleigh Siltstone	McNamara	Andrews (1998)
Pfd_{1-3}	Doomadgee	Fickling	Sweet et al. (1981)
Pfl_{1-5}	Mount Les Siltstone	Fickling	Rohrlach et al. (1998)
Pfw	Walford Dolomite	Fickling	Sweet et al. (1981)
Pfw_b	Walford Dolomite	Fickling	Sweet et al. (1981)
Pff_{1-3}	Fish River	Fickling	Sweet et al. (1981)
Ptp_{1-7}		Peters Creek Volcanics	Sweet et al. (1981)

5.2. Fish River Formation - Lower McNamara Group (Prize and Gun Supersequences)

Depositional systems within the Prize and Gun Supersequences cannot be constrained by current Comalco or WMC well data. Outcrop sections measured on the southern flanks of the Murphy Inlier, particularly at the northern end of line 91BN-30, help constrain the Fickling Group lithofacies members associated with the Big and Prize Supersequences. Correlations of McNamara Group strata to the southern ends of seismic sections are more problematic. The closest outcrops of these strata are at Kamarga Dome some 60km south. Despite these limitations, we attempt to correlate lithofacies formations within the seismic sequence stratigraphic framework proposed in **Chapter 2**.

5.2.1. Prize Supersequence

Depositional systems tracts from the Prize Supersequence appear to correlate well between outcrop sections on the Lawn Hill Platform and flattened seismic sections (**Figs. 5.2.1** and **5.2.2**). Transgressive fluvial to coastal sandstones of the Torpedo Creek Quartzite correlate with the continuous parallel seismic reflections of the Prize Supersequence. Highstand inner ramp siltstones of the lower Gunpowder Creek Formation are correlated to the upper most Prize seismic reflections above an apparent truncation surface.

A measured outcrop section from the northern end of line 91BN-30 (**Fig. 2.1.2**) shows that the lower members of the Fish River Formation, Pff_1 and Pff_2, correlate to a thin remnant of the Prize Supersequence on this seismic section (**Fig. 5.1.7**). This measured section begins with a lowstand fluvial conglomeratic sandstone composed of eroded clasts from the Peters Creek Volcanics (**Figs. 1.6.1** and **1.6.3**). An overlying package of thick retrograding peritidal to subtidal sandstones (ie the Pff_1 member) is consistent with seismic interpretations of the Prize Supersequence transgressing over the Peters Creek Volcanics dome (**Fig. 2.2.1**). Highstand inner ramp siltstones of Pff_2 correlate with the upper part of the Prize Supersequence. Using these seismic and outcrop interpretations, we would place the Pff_{1-2} members of the Fish River Formation in the upper part of the Prize Supersequence.

A conceptual depositional model for the Prize 2 sequence is presented in **Figure 5.2.3**. In this model, lowstand fluvial conglomerates are deposited in areas of local incision. Thick peritidal to subtidal sandstones of Pff_1 deepen and fine up into the thin inner ramp siltstones of Pff_2 during a marine transgression. The southern Murphy Inlier is interpreted as a more proximal depositional setting relative to the Lawn Hill Platform, as shown by the onlap of reflections over the Peters Creek Volcanics dome. It is likely that a lateral facies change occurs within the upper part of the transgressive deposits from inner ramp proximal and distal tempestite siltstones in the Gunpowder Creek Formation *(Sami et al. in press)*, to shallow marine sandstones in the Pff_1 member of the Fish River Formation. The highstand deposits are interpreted as very thin and composed of low gradient clinoforms which prograde to the south. Inner ramp siltstones of the Pff_2 member of the Fish River Formation occur mainly within the highstand systems tract and are essentially equivalent to the inner ramp highstand siltstones of the lower Gunpowder Creek Formation. Much of the highstand was subsequently eroded during formation of the Gun Supersequence boundary.

5.2.2. Gun Supersequence

Lower McNamara Group strata from the Gun Supersequence (ie upper Gunpowder Creek, Paradise Creek, and Esperanza Formations) are correlated to seismic sections with some confidence. The well defined transgressive and prograding geometry of seismic reflections in the Gun Supersequence provides strong support for this correlation. Most seismic sections show good evidence for a basal transgressive systems tract that we correlate to the transgressive proximal and distal tempestite deposits and deep water authigenic sediments of the upper Gunpowder Creek Formation (**Fig. 5.2.2**; *Sami et al. in press*). In one location on the Argyle Creek seismic composite (**Fig. 2.1.2**), transgressive deposits have formed above at least two incision surfaces within a large incised valley system (**Fig. 5.2.2**). Lowstand deposits associated with this incised valley are correlated to conglomerates found at the base of the upper Gunpowder Creek Formation (eg at Crocodile Waterhole where they occur adjacent to synsedimentary growth faults; *Southgate et al., in press [a]*).

Above the transgressive systems tract there are at least three sets of south- to southeast-prograding clinoforms (**Figs. 5.2.1** and **5.2.2**). The first two clinoform sets are interpreted as part of the same third-order highstand systems tract from the Gun 2 sequence. The Gun 2.5 sequence boundary is a fourth-order surface that separates the two lower clinoform sets. Studies of outcrop sections by *Sami et al. (in press)* and *Southgate et al. (in press [b])* demonstrate that the Gun 2.5 boundary is tectonically enhanced. The Gun 2 highstand deposits correlate to progradational deepwater to lagoonal and peritidal carbonates of the Paradise Creek Formation. Onlapping and prograding reflections of the overlying Gun 3 sequence correlate to the Esperanza Formation. The Gun 3 sequence is only partially preserved on most seismic sections. The Loretta Supersequence boundary truncates increasing amounts of the Gun 3 sequence to the north.

Seismic interpretations of the Gun Supersequence suggest that the upper Gunpowder Creek Formation correlates to the upper Fish River Formation on the Murphy Inlier (**Fig. 5.1.7**). Thin lowstand conglomerates at the base of the Pff_3 member are equivalent to similar lowstand conglomerates occasionally present at the base of the upper Gunpowder Creek Formation. An overlying package of aggrading peritidal to shallow marine sandstones in Pff_3 is correlated to the transgressive inner to outer ramp siltstones of the upper Gunpowder Creek Formation. Field observations of the Pff_3 member show that it begins with a thin lowstand fluvial deposit, which transgresses into peritidal to shallow marine sandstones. This is consistent with seismic observations of the Gun Supersequence often containing incised valleys and a marked transgressive surface (**Figs. 2.2.1** and **2.2.2**, **5.2.1** and **5.2.2**). Using the seismic and outcrop interpretations, we place the upper Pff_3 Fish River Formation member in the lower part of the Gun Supersequence.

A conceptual depositional model for the Gun 2 sequence is presented in **Figure 5.2.4**. Thin lowstand deposits composed of fluvial to shallow marine sandstones form in areas of local incision. A marine transgression drowned the basin resulting in the deposition of a northerly-onlapping suite of transgressive deposits. We propose that there is a lateral facies change within this transgressive systems tract from inner to outer ramp siltstones of the upper Gunpowder Creek Formation on the Lawn Hill Platform, to the coastal sandstones of the Pff_3 member over the southern flanks of the Murphy Inlier. Relatively steep, south- and southeast- prograding clinoforms characterise the overlying highstand deposits. A major (fourth-order) transgression in the Gun 2.5 sequence, separates the third-order highstand deposits into two phases of progradation. In the south, the Gun 2 highstand systems tract corresponds with the deep to shallow marine carbonates of the Paradise Creek Formation. We propose that time equivalent shallow marine carbonates and siliciclastics were originally present on the Murphy Inlier. Truncation at the Loretta Supersequence boundary subsequently removed these deposits.

5.3. Walford Dolomite - Lady Loretta Formation (Loretta Supersequence)

Depositional systems associated with the Loretta Supersequence are constrained within the seismic grid by the Argyle Creek_1 and Desert Creek_1 wells (**Figs. 5.1.2** and **5.1.3**). A thin remnant of the Loretta Supersequence is also penetrated by WMC drill holes from the Walford Creek Prospect near the end of line 91BN-30 (**Figs. 1.1.1**, **2.1.2** and **5.1.7**). Correlations of lower McNamara Group strata to the southern ends of seismic lines are again unconstrained, with the nearest outcrop of Lady Loretta Formation at Kamarga Dome some 60km south. However, the greater well control together with SHRIMP zircon ages from both the Walford Dolomite (1649±7Ma) and Lady Loretta Formation (1647±4Ma) allow correlations to be made across the seismic grid.

The Lady Loretta Formation can be tied from the Lawn Hill Platform region into seismic sections and well logs using the distinct seismic sequences found toward the base of the Loretta Supersequence. In outcrop sections, the Loretta 1 sequence contains the basal breccia unit of the Lady Loretta Formation and is correlated to the basal transgressive wedge found on many seismic sections (**Fig. 2.5.1**). Because the Argyle Creek_1 and Desert Creek_1 wells are located just north of the pinchout of this seismic unit they cannot confirm the correlation. The overlying Loretta 2.1 sequence is defined in the Lady Loretta Formation as a package of subtidal carbonates which retrograde into thin marine siltstones and shales, and are in turn overlain by prograding subtidal carbonates. A similar fourth-order transgressive-regressive carbonate cycle is found at the base of the Argyle Creek_1 well, which is correlated to the Loretta 2.1 sequence. The thickness of transgressive and highstand deposits in Loretta 2.1 are similar in outcrop and seismic sections, supporting their correlation (**Figs. 5.3.1** and **5.3.2**). The Loretta 2.2 sequence is a thick zone of no outcrop in the Lady Loretta Formation, which is presumed to represent a recessive shale and siltstone interval. Such a recessive interval probably correlates to the transgressive carbonaceous siltstones and dolomites at the top of the Loretta Supersequence in Argyle Creek_1. The recessive outcrop zone is also about the same thickness as a transgressive unit found in seismic sections (**Figs. 5.3.1** and **5.3.2**).

In much of the seismic grid aggradational subtidal to peritidal carbonates of the Lady Loretta Formation are severely truncated by the River Supersequence boundary (**Figs. 5.3.1** and **5.3.2**). Thus, the youngest sequences from the Lady Loretta Formation are absent at Argyle Creek_1 and Desert Creek_1. In the southeastern part of the seismic grid truncation at the River Supersequence boundary is lacking. Here thicknesses of the Loretta Supersequence are similar to those measured in outcrop further south. In this SE region of the seismic grid the aggrading subtidal to peritidal carbonates of the Lady Loretta Formation correspond to relatively continuous, parallel seismic reflections. Each seismic reflection is interpreted to approximate a fourth-order outcrop sequence (**Fig. 5.3.1**). This aggrading package of shallow marine carbonates and associated continuous parallel seismic reflections is interpreted as the third-order highstand systems tract for the Loretta 2 sequence.

SHRIMP zircon ages indicate that the Lady Loretta Formation correlates to the Walford Dolomite. WMC well WFDD17 was drilled near the northern end of line 91BN-30 (**Figs. 1.1.1** and **2.1.2**). The well penetrates to within ~50m of the Loretta Supersequence boundary on the seismic line. Walford Dolomite strata in WFDD17 correlate to a thin remnant of the Loretta Supersequence (**Fig. 5.1.7**). Northerly thinning of the Loretta Supersequence on the Argyle Creek seismic composite (**Fig. 5.1.2**) is mainly through erosional truncation by the overlying River Supersequence boundary. However, the Loretta 1 and Loretta 2.1 sequences appear to pinchout south of the Murphy Inlier due to onlap at the base of the Loretta Supersequence. Thus, the basal Walford Dolomite (Pfw_b) member intersected at the Walford Creek Prospect correlates to the Loretta 2.2 sequence, the upper transgressive package in Argyle Creek_1 and the zone of no outcrop in the Lady Loretta Formation. Aggrading carbonates from the Loretta 2 highstand deposits are only preserved in western outcrops of the Walford Dolomite (**Section 1.6.4**).

A model for the deposition of the Loretta Supersequence is presented in **Figure 5.3.3**. In the model, a south- to southeast-thickening wedge develops south of the main Loretta unconformity during a period of regional tilting and monocline development. The basal breccia of the Lady Loretta Formation forms within a lowstand wedge and is composed of eroded debris from Gun and Prize strata. Marine siltstones subsequently transgressed the breccia to form a thin transgressive systems tract.Sequence Loretta 1 pinches out against the main erosion surface and lacks stratigraphic equivalents toward the Murphy Inlier.

The lowermost subtidal to peritidal carbonates of Loretta 2 comprise two transgressions in which shallow marine carbonate platforms retrograde into inner ramp siltstones. Each of these flooding events is interpreted as representing a fourth-order transgression, which combined may define a third-order transgressive systems tract. The Loretta 2 transgressive deposits are present on the southern flanks of the Murphy Inlier as the basal Walford Dolomite member (Pfw_b). This correlation suggests similar lithofacies and depositional environments in the north and south. A thick, third-order highstand systems tract, composed of several fourth-order sequences, progrades and aggrades over the transgressive deposits. South on the Lawn Hill Platform, the highstand deposits are composed of subtidal carbonates, which gradually aggrade into peritidal carbonates. Lithofacies on the southern flanks of the Murphy Inlier are slightly more proximal with peritidal carbonates dominating throughout. Thus, the highstand systems tract was probably a south- to southeast-prograding carbonate ramp with very low-angle clinoforms and depositional gradients. The highstand deposits were subsequently eroded in eastern areas during the River extension event, but preserved further west as the Walford Dolomite.

5.4. Mount Les Siltstone - Riversleigh Siltstone (River Supersequence)

Depositional systems associated with the River Supersequence are constrained by several wells which penetrate the seismic sequences. The Argyle Creek_1 and Desert Creek_1 wells both penetrate relatively thin, River Supersequence strata from the shoaling sides of River-age tilt-blocks (**Figs. 5.1.2** and **5.1.3**). Mount Les Siltstone strata in the WMC holes correlate to the thin updip part of a south-thickening wedge that begins just north of Argyle Creek_1 (**Fig. 5.1.7**). The River Supersequence outcrops as Riversleigh Siltstone strata in the Musslebrook Creek area on the Lawn Hill Platform 25km from the southern end of the Argyle Creek seismic composite. However, the River Supersequence outcrop composite used to correlate Riversleigh Siltstone strata with seismic sections comes from the Freemans Creek and Gregory River transects about 90km from the southern edge of the Comalco seismic grid (**Fig. 5.4.1**). Despite the large distance separating the seismic grid and outcrop sections of the Riversleigh Siltstone, confident correlations can be made to the Comalco and WMC wells using gamma curve trends, seismic sequence stratigraphy, and SHRIMP zircon ages (**Fig. 1.1.1**). Middle to upper Riversleigh Siltstone strata from the Lawn Hill Platform are correlated to the Mount Les Siltstone by integrating all of these data. The Riversleigh Siltstone outcrop composite is tied with the southern end of the Argyle Creek seismic composite where the River sequences attain their maximum thickness (**Fig. 5.4.2**). Similar thicknesses are present in outcrop and seismic data for each River sequence.

Submarine fan sandstones from “member R2s” in the Riversleigh Siltstone correlate to the River 5 sequence. The River 5 lowstand systems tract is generally not imaged at seismic resolution (**Figs. 5.4.1** and **5.4.2**). However, a thin lowstand systems tract composed of silty sandstones is present at Argyle Creek_1, Desert Creek_1, and the Walford Creek Prospect, and correlates to the medium-grained lowstand sandstones at the base of “member R2s”. Most of the “R2s member” sandstones correspond to a northward-onlapping transgressive systems tract on seismic sections (**Figs. 5.4.1** and **5.4.2**). In well logs, the transgressive deposits of sequence River 5 consist of siltstones transgressing into carbonaceous shales, the latter associated with massive pyrite lenses in the Walford Creek Prospect. A highstand systems tract marked by low-angle, south-prograding clinoforms is documented in seismic data (**Fig. 5.4.2**). The highstand systems tract correlates to prograding “R2s member” sandstones at Freemans Creek, and the prograding siltstones and tuffaceous shales of Pfl_3 at the Walford Creek Prospect. Pfl_3 has a SHRIMP zircon age of 1640±7Ma. We correlate the “R2s member” of the Riversleigh Siltstone on the Lawn Hill Platform to the $Pfl_{1\text{-}3}$ members of the Mount Les Siltstone on the southern Murphy Inlier. If this correlation is correct, then there is a significant change in lithofacies across the region with strata from sequence River 5 finer-grained and more condensed than the underlying River deposits.

Riversleigh Siltstone “member R3r” correlates to the River 6 sequence (**Fig. 5.4.2**). The River 6 sequence is characterised by a thick transgressive wedge in which seismic reflections onlap to the north (**Fig. 5.4.2**). In outcrop sections at Gregory River, the “R3r member” has a thick recessive shale interval interpreted as representing a transgressive systems tract. About 10km north of Gergory River in the Flat Tyre region, drill hole data shows that the “R3r member” forms a very thin transgressive systems tract associated with carbonaceous siltstones and pyritic carbonaceous shales *(Andrews, 1998; Krassay et al., in press [a])*. A SHRIMP zircon age of 1644±8Ma for the River 6 sequence comes from tuffaceous beds at Flat Tyre *(Page et al. in press)*. The northward thinning of strata from Gregory River to Flat Tyre is similar to the northward thinning of sequence River 6 on seismic data. Thus, a transgressive wedge of similar geometry to that documented in the seismic data is likely to be present in the Gregory River region. A thin progradational siltstone from the “R3s member” forms the River 6 highstand deposits at Gregory River. This is consistent with seismic data that show a very thin suite of highstand deposits at the top of sequence River 6. Well logs from Desert Creek_1 and the Walford Creek Prospect show similarities to the Flat Tyre drill holes. That is, a well developed transgressive systems tract composed of carbonaceous silty shales transgressing into carbonaceous shales, dolomites, and massive pyrite beds, overlain by a thin progradational silty-shale. We interpret the “R3r member” of the Riversleigh Siltstone and the Pfl_4 member of the Mount Les Siltstone as belonging to the River 6 sequence.

Riversleigh Siltstone “member R3s” correlates to the River 7 sequence. River 7 stands out on most seismic sections as a distinct northward-thinning wedge and is often associated with incised valleys and/or canyons on the updip shoaling side of tilt-blocks (**Figs. 5.4.1** and **5.4.2**). Incised valleys and canyons in sequence River 7 are infilled by marine siltstones at Desert Creek_1, and fluvial to shallow marine conglomerates and sandstones in drill holes and field sections from the western outcrop belt of the Murphy Inlier (**Fig. 1.1.1**). The “R3s member” at Gregory River consists of thick inner ramp sandstones and siltstones with a broadly aggradational gamma trend. An overlying no outcrop zone probably represents a recessive shale interval. Seismic data shows that correlative strata are characterised by a thick transgressive wedge in which strata thin through onlap to the north (**Figs. 5.4.1** and **5.4.2**). These thick transgressive wedges, together with the incised valleys and canyons, indicate that River 7 formed during a period of significant subsidence and tilt-block rotation. Highstand deposits of River 7 are comparatively thin and have some south-prograding clinoforms (**Fig. 5.4.1**). However, as wells are generally on the attenuated shoaling sides of tilt-blocks, well logs through River 7 only show thin transgressive and highstand deposits (eg Desert Creek_1, Argyle Creek_1, and Walford Creek, **Figs. 4.1** and **4.3**).

A model for the deposition of the sequence River 7 is shown in **Fig. 5.4.3**. The thickest portion of sequence River 7 develops on the northern side of the Elizabeth Creek Fault Zone. It is possible that the Elizabeth Creek Fault was an active growth fault at this time. A thick third-order transgressive systems tract develops in which sediments gradually deepen and fine from inner ramp silty sandstones to mid ramp siltstones and carbonaceous shales. A fourth-order highstand systems tract develops within the transgressive wedge in which silty sandstones prograde to the south. This highstand represents a period of decreased accommodation, probably related to either a decline in subsidence rates or a eustatic sea level fall. The transgressive wedge thins to the north and onlaps against incised valleys and submarine canyons eroded into sequence River 6 during the early phases of tilt-block rotation. Strata from the transgressive wedge thicken abruptly across the Nicholson River Fault Zone and thin toward the Murphy Inlier. Strata may locally thicken into the Fish River Fault Zone where WMC drill holes document evidence of fault activity in the form of syndepositional fault breccias *(Rohrlach et al., 1998).* However, this local thickening would be antithetic to the main Nicholson River growth fault. Above the main southern depocenter of the wedge the overlying highstand siltstones and silty sandstones are comparatively thinner. These highstand deposits do not appear to thicken across growth faults suggesting that subsidence rates and tectonic activity decreased during highstand time. We correlate the inner ramp siltstones and sandstones of the “R3s member” of the Riversleigh Siltstone on the Lawn Hill Platform to the inner ramp siltstones and outer ramp carbonaceous shales of the Pfl_5 Mount Les Siltstone member on the eastern outcrop belt of the Murphy Inlier. Lithofacies between the two regions tend to be similar though slightly finer-grained in the attenuated strata from the Mount Les Siltstone. As yet, no equivalents to the lowstand conglomerates and sandstones of the western Pfd_3 Doomadgee Formation member are documented in the Gregory River region.

The “R3c-R4s members” of the Riversleigh Siltstone correlate to the River 8 sequence. A lithostratigraphic equivalent of the “R3c member” lowstand sandstone appears to be present at Argyle Creek_1. The sandstone at Argyle Creek_1 ties to a reflection doublet on many seismic sections (**Fig. 5.4.2**). However, the lowstand sandstone is absent at Desert Creek_1 (**Fig. 5.4.1**). This reflection doublet is interpreted as a discontinuous lowstand systems tract, and is consistent with observations by *Andrews (1998)* of the discontinuous nature of “R3c member” sandstones on the Lawn Hill Platform. Recessive shales from the “R4r member” correlate to a northward-onlapping wedge at the southern end of the Argyle Creek seismic composite (**Fig. 5.4.2**). The transgressive wedge thins rapidly and ties with retrogradational carbonaceous silty shales at Argyle Creek_1 and Desert Creek_1. Equivalents of the “R4s sandstone member” are generally not present in seismic data due to the regional northward-truncation of the River Supersequence by the Term Supersequence boundary. However, a progradational siltstone package at the top of the River 8 sequence in Desert Creek_1 may represent south-prograding highstand deposits equivalent to the “R4s member”. No chronostratigraphically equivalent strata of “members R3c-R4s” exist in the Fickling Group due to the truncation of sequence River 8 by the Term Supersequence boundary towards the Murphy Inlier.

5.5. Doomadgee Formation - Lawn Hill Formation (Term, Lawn, Wide, and Doom Supersequences)

Depositional systems within the Term, Lawn, Wide, and Doom Supersequences are constrained by the Comalco and WMC wells. All four Comalco wells penetrate the three younger Supersequences, while Term is penetrated by Desert Creek_1 and Argyle Creek_1 (**Figs. 5.1.2 to 5.1.5**). Two of the WMC holes from the Walford Creek Prospect penetrate strata from the Term, Lawn, and Wide Supersequences, and one hole (WFDD17) possibly penetrates a thin remnant of the Doom Supersequence (**Figs. 1.1.1** and **2.1.2**). Upper McNamara Group strata from the Term through Doom Supersequences outcrop immediately southeast of the Argyle Creek seismic composite. The Term Supersequence outcrop composite comes from field sections measured through the Termite Range Formation in the Musslebrook Creek region (~25km south of the seismic grid), and the Pmh_{1-2} members of the Lawn Hill Formation in the northern Lawn Hill region (~50km south of the seismic grid). The Lawn through Doom outcrop composite comes from field sections measured in the Pmh_{3-5} members of the Lawn Hill Formation also from the Musslebrook Creek and northern Lawn Hill regions. The close proximity of outcropping strata from the Termite Range and Lawn Hill Formations to the seismic grid, along with numerous SHRIMP zircon ages and the extensive penetration of strata by wells, allows us to very confidently correlate the Lawn Hill Formation on the Lawn Hill Platform to the Doomadgee Formation in the Walford Creek Prospect area.

5.5.1. Term Supersequence

The Term Supersequence outcrop composite is tied to the southern end of the Argyle Creek seismic composite where the supersequence attains its maximum thickness (**Figs. 5.5.1** and **5.5.2**). Thicknesses of the Term Supersequence are very similar in outcrop and seismic data. The Term 1 sequence, which correlates with the lower “T1 member” of the Termite Range Formation, is only present at the southern end of the Argyle Creek seismic composite (**Fig. 5.5.1**). Elsewhere in the seismic grid the Term 1 sequence is absent through the northward-onlap of strata against a southerly-inclined ramp of the underlying River Supersequence. Transgressive deposits at the base of the Term 1 sequence also onlap to the north. These sediments are overlain by a highstand deposits in which seismic reflections display a south-prograding clinoform geometry.

Sequence Term 2 is also well imaged at the southern end of the Argyle Creek seismic composite. In outcrop, the Term 2 sequence represents a transition from the lowstand sandstones of the “T2 member” of the Termite Range Formation, to the transgressive carbonaceous shales and siltstones of the lower “H1r member” of the Lawn Hill Formation. Seismic data show lowstand deposits at the base of sequence Term 2 containing mounded fan to clinoformal reflections which downlap to the south and onlap to the north. The lowstand deposits thin rapidly to the north, mainly through the onlap of strata against inclined Term 1 strata. The fan-like geometry of seismic reflections is consistent with outcrop observations of sand-rich turbidite fans in the Termite Range Formation. Overlying strata from the lower part of the “H1r member” of the Lawn Hill Formation are poorly represented in the seismic data. A thin set of northward-onlapping reflections in **Fig. 5.5.1** probably represents the carbonaceous siltstones and shales from the transgressive systems tract. Sequence Term 2 thins to a reflection doublet that forms the base of the Term Supersequence north and northeast of the main depocenter (**Fig. 5.5.3**). Well logs at Desert Creek_1 and Argyle Creek_1 (**Figs. 4.1** and **4.3**) show that this doublet is probably a condensed section of carbonaceous siltstones and shales formed between the transgressive and highstand deposits of Term 2.

The integrated well log and seismic sequence stratigraphy of sequence Term 3 is best imaged in the Desert Creek region. Here lowstand deposits are defined by a thick set of mounded fan reflections, overlain by a thin set of south-prograding clinoforms (**Fig. 5.5.3**). A prominent toplap surface (Term 3.2) separates the two sets of reflections and is interpreted as the upper surface of a fan. The Term 3 lowstand deposits correlate to a progradational shale to siltstone package in the “H1r member” of the Lawn Hill Formation (**Fig. 5.5.3**). The lowstand deposits also tie to an aggradational to progradational siltstone to sandy siltstone package at Desert Creek_1. In sequence Term 3 the transgressive deposits are characterised by a series of relatively parallel reflections which onlap to the north (**Fig. 5.5.1** and **5.5.3**). The Term 3 transgressive deposits are thickest at the southern end of the Argyle Creek seismic composite, where they correlate to carbonaceous shales from the “H1r member” of the Lawn Hill Formation (**Fig. 5.5.1**). In the Desert Creek region, the transgressive deposits are much thinner due to the loss of strata through onlap to the north. Well logs at Desert Creek_1 tie the Term 3 transgressive systems tract to a thin retrogradational siltstone package (**Fig. 5.5.3**). Highstand deposits in Term 3 are apparent in the Desert Creek region where a series of south-prograding clinoforms downlap onto a maximum flooding surface (Term 3.3; **Fig. 5.5.3**). A set of south-prograding clinoforms is also apparent at the southern end of the Argyle Creek seismic composite (**Fig. 5.5.1**). The Term 3 highstand systems tract correlates to a progradational siltstone package from the “H1r member” of the Lawn Hill Formation. A similar progradational siltstone package is also present in the Term 3 highstand deposits at Desert Creek_1 (**Fig. 4.1**).

The “H1s member” sandstone and overlying upper “H1r member” shale from the Lawn Hill Formation correlate to the Term 4 sequence. Seismic data in the Desert Creek region show several mounded reflections downlapping to the south and north which we interpret as lowstand, basin floor fans (**Fig. 5.5.3**). At the southern end of the Argyle Creek seismic composite, the Term 4 lowstand has a more continuous, sheet like appearance, but includes some possible channel-levee complexes toward the top (**Fig. 5.5.2**). The lowstand deposits thin towards the north and northeast where they are represented by a single seismic reflection. Well logs at Argyle Creek_1 (**Fig. 4.3**) tie the Term 4 lowstand deposits to a thin submarine sandstone unit. The Term 4 lowstand deposits correlate to submarine fan sandstones of “member H1s”

(Lawn Hill Formation) on the Lawn Hill Platform, and the evaporitic dolarenites of the eastern Pfd_1 member (Doomadgee Formation) in the Walford Creek Prospect. The Term 4 transgressive deposits are defined by a series of northward onlapping reflections (**Fig. 5.5.2**), which tie to a slightly retrogradational package of inner ramp sandstones and siltstones at Desert Creek_1, Argyle Creek_1, and the Walford Creek Prospect. Highstand deposits are hard to define in sequence Term 4 due to the absence of any clear downlap surfaces. However, seismic data south of Argyle Creek image submarine channels, suggesting that the Term 4 highstand deposits may contain channel-levee complexes. Well logs at Walford Creek and Argyle Creek_1 tie the Term 5 highstand deposits to a slightly progradational sandstone and siltstone package. The Term 4 highstand systems tract is absent in the Desert Creek region either through lack of deposition or subsequent erosion by the Term 5 sequence boundary.

A model for the deposition of the Term 4 sequence is presented in **Figure 5.5.4**. The thickest portion of sequence Term 4 develops in the southwest corner of the seismic grid around the Elizabeth Creek Fault Zone. Outcrop studies further south on the Lawn Hill Platform show that sequence Term 4 remains about this thick until the Termite Range Fault Zone *(Andrews, 1998; Krassay et al., in press [b]).* The most pronounced thickening of sequence Term 4 occurs in the lowstand submarine fan sandstones of “member H1s” from the Lawn Hill Formation. The lowstand sands appear to thicken relatively abruptly across a flexure zone whose hinge was located toward the southwestern corner of the seismic grid. This flexural thickening of strata appears to occur throughout the whole Term Supersequence at about the same position in the seismic grid. A similar flexural thickening of Term sequences 4-6 may also occur south of the seismic grid across the Termite Range Fault Zone *(Andrews 1998; Krassay et al., in press [b]).* Coarse evaporitic dolarenites from the Pfd_1 member of the eastern Doomadgee Formation comprise Term 4 lowstand deposits. These sediments represent the initial onlap of strata from the Term Supersequence over an emergent Murphy Inlier. Older Term sequences pinched out further south through onlap against the truncated River Supersequence.

Following the initial phase of lowstand fan deposition, a period of broader subsidence promoted a marine transgression that extended over the Murphy Inlier (**Fig. 5.5.4**). A recessive outcrop zone in the “H1r member” (Lawn Hill Formation) probably represents deep marine carbonaceous siltstones and shales from the Term 4 transgressive systems tract. Transgressive deposits gradually coarsen and shallow northwards into the very fine-grained, inner ramp sandstones and siltstones found at Argyle Creek_1 and in the eastern Pfd_2 member of the Doomadgee Formation. As subsidence rates declined, sedimentation rates began to increase leading to deposition of the Term 4 highstand deposits. At Argyle Creek_1 and the Walford Creek Prospect, inner ramp sandstone and siltstone deposition continued, with the sand to silt ratio increasing gradually towards the top of the highstand systems tract. Further south on the Lawn Hill Platform, the Term 4 highstand deposits are composed of carbonaceous siltstones and shales from “member H1r”. The presence of channel-levee features in the Term 4 highstand deposits suggest gravity flow turbidite deposition associated with either syndepositional tectonic activity or over-steepened basin margins.

Term 5 represents a relatively thin sequence at the top of the Term Supersequence. Seismic data south of Argyle Creek_1 image several small channels incised into relatively continuous, parallel reflections (**Fig. 5.5.2**). The channelled package is interpreted as the Term 5 highstand systems tract, whilst the parallel reflections are interpreted as the Term 5 transgressive deposits. Well logs at Argyle Creek_1, Desert Creek_1, and the Walford Creek Prospect tie the Term 5 transgressive deposits to a package of coarse- to fine-grained inner ramp sandstones retrograding into deeper water siltstones. However, Term 5 highstand deposits are generally absent in well logs. Seismic data suggests that the highstand deposits were probably eroded by the Lawn Supersequence boundary in the north (**Fig. 5.5.3**). On the Murphy Inlier, the Term 5 transgressive deposits form part of the eastern Pfd_2 member of the Doomadgee Formation. On the Lawn Hill Platform, the Lawn 5 sequence begins with a transgressive siltstone package from the uppermost “H1r member”. This is overlain by progradational, tuffaceous siltstones, sandstones, and breccias of the “H2s member” from the Lawn Hill Formation *(Andrews 1998; Krassay et al., in press [b]). Andrews (1998)* notes that the “H2s member” may represent a period of volcanic activity and tectonically controlled regression at the end of the Term Supersequence. Seismic data indicate that this tectonically controlled regression probably began during the previous Term 4 highstand.

5.5.2. Lawn Supersequence

The Lawn Supersequence boundary is generally conformable with strata from the underlying Term Supersequence. Some truncation of the underlying Term 5 highstand deposits takes place towards the Murphy Inlier. However, the amount of truncation is an order of magnitude less than seen at the Term, River, and Loretta Supersequence boundaries. Our definition of a Supersequence boundary beneath sequence Lawn 1 is based on considerations of the dramatic change in the tectonostratigraphic character. The transition from the broad northward-thinning wedge, filled with thick basin floor fan and channel levee deposits in Term, to the tabular planar package of tuffaceous sandstones, carbonaceous siltstones, and shales that dominate the Lawn Supersequence is apparent throughout the seismic data. A correlative unconformity is present in the McArthur Basin further northwest where *Jackson and Southgate (in press)* identify a major time break (up to 10My) between the extensively silicified top of the Looking Glass Formation and the base of the Amos Formation.

The Lawn composite outcrop section is tied to the southern end of the Desert Creek seismic composite where it is close to its maximum thickness (**Fig. 5.5.5**). The gamma log and lithological trends at Desert Creek_1 match those from the Lawn Hill Platform outcrop composite. The thickness of Lawn sequences closely match correlative outcrop sequences on the Lawn Hill

Platform (**Fig. 5.5.5**). The Lawn Supersequence thins dramatically to the north mainly through truncation by the overlying Wide Supersequence boundary. Lawn also thins to the northeast through the onlap of strata. However, as Egilabria_1 and Beamesbrook_1 (**Figs. 4.2** and **4.4**) only penetrate the upper most Lawn 4 sequence, we cannot be certain which of the other three sequences continue through to the northeast parts of the seismic grid.

The Bulmung Sandstone ("H3 member") and lower most part of the "H4r member" of the Lawn Hill Formation correlate to the Lawn 1 sequence. Lowstand sandstones from the "H3 member" correlate to interbedded very fine sandstones and tuffaceous siltstones at Desert Creek_1 and Argyle Creek_1 (**Figs. 4.1** and **4.3**). Seismic data throughout the Desert Creek and Argyle Creek areas show the lowstand sandstones and siltstones correlate to a regionally continuous basal reflection doublet. The doublet extends northwards onto the Murphy Inlier where it correlates with similar interbedded sandstones and siltstones from the eastern Pfd_2 member of the Doomadgee Formation. SHRIMP zircon ages from tuffaceous siltstones within the eastern Pfd_2 member (1613±5Ma) confirm that it correlates with the Bulmung Sandstone (1611±4Ma; *Page et al., in press*). The overlying transgressive deposits are too thin to produce onlapping reflections, their presence is confirmed by well data which show the lowstand sands retrograding into carbonaceous siltstones and shales. The transgressive deposits continue onto the Murphy Inlier where they form the interbedded very fine-grained sandstones and siltstones at the top of the eastern Pfd_2 member of the Doomadgee Formation. A thin highstand systems tract is indicated on seismic data by south-prograding clinoforms, which correlate to a progradational carbonaceous siltstone and shale package in well logs. Highstand deposits are absent on the Murphy Inlier due to truncation by the overlying Wide Supersequence.

A model for the deposition of sequence Lawn 1 is presented in **Figure 5.5.6**. Overall, the sequence shows a gradual thinning to the north and northeast. The lowstand systems tract extends as a fairly continuous sheet from the Lawn Hill Platform to the Murphy Inlier. There appears to be little change in lithofacies within the lowstand, with interbedded coastal to inner ramp sandstones and tuffaceous siltstones dominating throughout. The lack of a significant lateral change in lithofacies and depositional environments within the Lawn 1 lowstand systems tract indicates that the region was dominated by a relatively shallow, low gradient seafloor, with abundant sands transported into the basin. The rapid fining into carbonaceous siltstones and shales indicates a rapid transgression and accompanying reduction in sediment flux. No evidence exists in either outcrop or seismic data for any associated syndepositional faulting or flexuring as occurred in the underlying Term and River Supersequences. Rapid transgression was probably driven by broad regional subsidence. A lack of tuffaceous beds above the lowstand sandstones may indicate that the transgression was driven by a cessation of volcanic activity and associated declines in crustal temperatures. Subsequent highstand deposition is limited to a package of progradational carbonaceous siltstones. Progradation was probably driven by declining subsidence rates.

The remaining Lawn sequences are dominated by thick transgressive deposits which thin north through the onlap of strata (**Fig. 5.5.5**). Lowstand and highstand systems tracts are rare, and where present are thin compared to the transgressive deposits. The Lawn 2 through 4 sequences correlate to recessive carbonaceous siltstones and shales of the “H4r member” from the Lawn Hill Formation. Well data show that the same carbonaceous siltstones and shales are still present within the seismic grid area. No equivalent lithofacies are preserved beneath the Wide Supersequence boundary on the Murphy Inlier. However, the absence of significant lateral facies changes between the Lawn Hill Platform and the Comalco wells suggests that carbonaceous siltstones and shales originally blanketed the Murphy Inlier. Well data also show that the sequences become finer and more carbonaceous from sequence Lawn 2 to the maximum flooding surface in sequence Lawn 4. The regional subsidence that commenced after deposition of the Lawn 1 lowstand thus continued until the end of sequence Lawn 4. The sequence boundaries which punctuate each period of subsidence and associated transgressive deposits may have been formed either by changes in rates of subsidence, or by eustatic sea level fluctuations.

5.5.3. Wide Supersequence

The Wide Supersequence boundary varies from a relatively conformable contact with underlying Lawn sequences in the southern end of seismic lines, to a major truncation surface in the north that removes the Lawn 2 through Lawn 4 sequences. In the south, the Wide Supersequence boundary is locally erosional over positive flower structures. A supersequence is interpreted to occur above this regional unconformity and correlative conformity based on the change from the tabular and planar geometry of the underlying Lawn Supersequence, to a series of complex geometries associated with syndepositional growth across wrench fault systems in the Wide Supersequence. The geometry and lithofacies seen in seismic sections reflects the syndepositional tectonic activity during Wide Supersequence time.

The Wide outcrop composite section is tied to the middle of the Egilabria composite seismic section in **Figure 5.5.7**. Because the Wide outcrop composite comes from an area where these sequences are thin compared to the main depocenter at the Century sub-basin the tie is made to the northeast parts of the seismic grid away from the main depocentre. The “H4s member” of the Lawn Hill Formation correlates to the Wide 1 and 2 sequences. Well logs at Egilabria_1, Beamesbrook_1, and Desert Creek_1 (**Figs. 4.1**, **4.2** and **4.4**) show similar gamma log trends and lithofacies to outcrops of “member H4s” *(Bradshaw et al., 1998).*

In most areas sequence Wide 1 forms a very condensed third-order sequence. The Wide 1 sequence generally contains a thin transgressive and highstand systems tract corresponding to a reflection doublet at the base of the Wide Supersequence. The transgressive deposits at the base of sequence Wide 1 correspond to deep marine, dolomitic siltstones in the Comalco wells and correlative strata in “member H4s”. The Wide 1 transgressive deposits are generally represented by a basal high-amplitude seismic reflection. The transgressive deposits continue onto the Murphy Inlier where they form the coarse-grained, shallow marine, dolomitic sandstones of the eastern Pfd_3 member from the Doomadgee Formation. Seismic data show that the Wide 1 transgressive deposits thicken substantially into the Elizabeth Creek sub-basin at the southwest end of the Egilabria seismic composite (**Fig. 2.9.2**). The Wide 1 transgressive deposits thin northeast of the Elizabeth Creek sub-basin through the onlap of seismic reflections. In most areas the overlying highstand deposits are below seismic resolution. However, highstand deposits are interpreted in the Elizabeth Creek sub-basin where clinoforms prograde to the southwest (**Fig. 5.5.7**). The Wide 1 highstand systems tract correlates to a sandy siltstone to siltstone package in “member H4s”. Well logs show a correlative package of highstand siltstones and dolomites in Egilabria_1, Beamesbrook_1, and Desert Creek_1. The Wide 1 highstand systems tract is be absent on the Murphy Inlier.

Sequence Wide 2 is very similar to sequence Wide 1. In most areas Wide 2 comprises a thin condensed sequence that locally thickens into the Elizabeth Creek Sub-basin. Transgressive deposits at the base of Wide 2 tie to a retrogradational package of deep marine sandy siltstone and siltstone in well logs from Desert Creek_1, Egilabria_1, and Beamesbrook_1 (**Figs. 4.1**, **4.2** and **4.4**). However, the transgressive deposits pinch out through onlap to the northwest and lack equivalent strata in Argyle Creek_1 or the Doomadgee Formation. Correlative Wide 2 transgressive deposits are present in a retrogradational sandy-siltstone package at the top of “member H4s” on the Lawn Hill Platform *(Bradshaw et al., 1998).* Wide 2 transgressive deposits are only resolved by seismic data where they thicken into the Elizabeth Creek sub-basin (**Fig. 5.5.7**). Here, they form a wedge that thins through onlap of seismic reflections to the northeast. Wide 2 highstand deposits are also evident in the Elizabeth Creek sub-basin where they form a thin set of southwest prograding clinoforms (**Fig. 5.5.7**). The Wide 2 highstand deposits are absent in well logs and outcrop sections outside of the Elizabeth Creek sub-basin.

Most of the Widdallion Sandstone (“H5”) member of the Lawn Hill Formation correlates to the Wide 3 sequence. Wide 3 shows a good correlation in gamma log trends between the Widdallion Sandstone outcrop section and well logs at Egilabria_1 and Beamesbrook_1 (**Fig 5.5.7***; Bradshaw et al., 1998, their Fig. 16*). The Wide 3 sequence is finer-grained and thinner northeast of the Widdallion Sandstone outcrop section, suggesting that the main Wide 3 depocenter is south of the seismic grid. Sequence Wide 3 is present in one well on the Murphy Inlier (WFDD17) where it forms a thin package of carbonaceous silty shales in the upper part of the eastern Pfd_3 member of the Doomadgee Formation. In many areas, Wide 3 shows syndepositional growth across wrench faults. On seismic sections the Wide 3 sequence forms northward-thinning wedges above the highly reflective and condensed Wide 1 and Wide 2 sequences. The internal geometry of Wide 3 is complex. Some basal and upper reflections onlap towards the north. However, seismic reflections within Wide 3 also alternate from north-onlapping to south-prograding reflectors (**Figs. 2.9.4** and **2.9.5**). Possible mechanisms for generating this alternating reflection geometry include: debris flows generated during intermittent fault movements; and progradation of deltas into wrench grabens from a northerly source. Another common feature of the Wide 3 sequence is incision surfaces that we interpret as submarine canyons and channel-levee complexes (**Fig. 2.9.4**).

Sequence Wide 3 is initially characterised by a broadly aggradational to slightly retrogradational gamma-ray trend in well logs at Egilabria_1 and Beamesbrook_1 (**Figs. 4.2** and **4.4**) and also in outcrop sections through the Widdallion Sandstone. The package ranges from deep water sandstones on the Lawn Hill Platform, to interbedded sandstones and siltstones at Egilabria_1, and interbedded siltstones and shales at Beamesbrook_1. This lower aggradational package is interpreted as a lowstand systems tract. However, the seismic geometry of sequence Wide 3 indicates a complex period of subsidence and synchronous progradation within south-dipping tilt-blocks. A marked retrogradational trend is evident in gamma logs at the top of sequence Wide 3. This retrogradation is interpreted as representing a transgressive event. Some seismic sections near Egilabria_1 and Beamesbrook_1 show an onlap surface at this level confirming the presence of transgressive deposits (*Bradshaw et al., 1998*, their Figs. 28 and 30).

A model for the deposition of sequence Wide 3 is shown in **Figure 5.5.8**. The model comprises a series of southward-thickening wedges and associated syndepositional growth faults. A thick lowstand systems tract is deposited during a phase of syndepositional growth fault activity. The lowstand deposits are composed of the deep marine Widdallion Sandstone in the southernmost wedge. Comalco well data shows that there is a lateral facies change to deep marine siltstones in the north. This supports the hypothesis of *Andrews (1998)* that the Widdallion Sandstone was sourced from a southern provenance. Within each wedge, subsidence rates are highest in the growth section and decrease northwards along the shoaling side of tilt-blocks. Consequently, lowstand sediments onlap to the north in the growth sections, but show syndepositional southward-progradation of deltas, submarine fans, and debris flows on the shoaling margins. The Walford Creek Prospect occurs on the shoaling margin of the northern-most tilt-block. Sediments continue to be fine-grained and carbonaceous indicating sediment-starved conditions despite the location in an area of low subsidence rates. Gamma logs through the Wide 3 sequence at WFDD17 have a progradational trend through the carbonaceous siltstones and shales as expected in this zone of low accommodation. The Wide 3 sequence ends with a transgression, which probably drowns provenance areas for the Widdallion Sandstone.

5.5.4. Doom Supersequence

The Doom Supersequence boundary appears to be mostly conformable with strata from the underlying Wide Supersequence. No evidence exists in seismic or well log data for a truncation surface beneath sequence Doom 1. Our definition of a supersequence boundary beneath Doom 1, as with sequence Lawn 1, is based on considerations of the dramatic change in tectonostratigraphic style. The complex geometry of the Wide sequences changes to the tabular planar geometry of the Doom sequences. The Doom Supersequence is poorly preserved in most areas due to major truncation at the base of the South Nicholson Group. The Doom 1 through Doom 3 sequences are present in the Doom outcrop composite and are tied to the Egilabria seismic outcrop section in **Figure 5.5.7**. However, the Doom Supersequence is best represented in the Egilabria_1 well which penetrates five Doom sequences, the maximum number found preserved anywhere within the Isa Superbasin. There are no definite occurrences of Doom sequences on the Murphy Inlier, although a thin remnant may be present in the weathered regolith at the top of WFDD 17.

Sequence Doom 1 begins with a pair of high-amplitude (positive and negative polarity) parallel reflections, which are distinctive on all seismic profiles (**Fig. 5.5.7**). The negative polarity reflection stands out in eastern areas as an unusually thick black zone containing some south-prograding clinoforms. The reflective basal unit of sequence Doom 1 ties with high-gamma sandstones and siltstones at Egilabria_1 and Beamesbrook_1 (**Figs. 4.2** and **4.4**) and a high-gamma sandstone unit found toward the top of the Widdallion Sandstone member of the Lawn Hill Formation. *Jackson and Southgate (in press)* also describe a high-gamma feldspathic sandstone at the base of sequence Doom 1 in the McArthur region. South of the Murphy Inlier the basal unit is interpreted as a 'basin floor sheet'. Above the basal unit, seismic reflections are lower amplitude, discontinuous to chaotic, and display a shingled and channelled geometry (**Fig. 5.5.7**). Clinoforms with bidirectional downlap are often present. The overlying disrupted seismic unit correlates with aggradational sandstones and siltstones in Egilabria_1 and Beamesbrook_1, and the uppermost sandstones of the Widdallion Sandstone member. Doom 1 is interpreted as a continuous and extensive lowstand deposit. The overlying shingled and channelled unit shows some similar facies to channel-levee complexes found within lowstand slope fans and prograding wedges in passive margin basins. The presence of a lowstand basin floor sheet and channel-levee complexes, in the absence of a recognised shelf break, suggests some initial basin margin instability at the beginning of the Doom Supersequence. However, the tabular ramp geometry and lack of syndepositional growth faults in sequence Doom 1 indicate that this tectonic activity was not associated with local depocenters or sub-basins as envisaged in the underlying Wide sequences.

Sequence Doom 2 is characterised by a series of parallel, continuous reflections. The base of sequence Doom 2 is generally conformable with the underlying Doom 1 sequence. However, in some areas minor erosion (~20m) is evident to produce incised canyons (**Fig. 2.9.5**). One northerly-prograding clinoform reflection is present above the sequence boundary on the Egilabria seismic composite. The clinoform ties with lowstand deep marine siltstones at Egilabria_1. Transgressive deposits occur above the lowstand, and are characterised by moderate to high-amplitude reflections which onlap to the north. The reflective nature of the transgressive deposits are consistent with observations from Egilabria_1 of increasing interbeds of dolostone and deep marine siltstones toward the Doom 2 maximum flooding surface. An upper reflection pair represents deep marine siltstones and dolostones from the highstand systems tract at Egilabria_1 (**Fig. 2.9.5**). The deep marine siltstones from sequence Doom 2 correlate to similar inner ramp siltstones found in rare outcrops of “member H6” from the uppermost Lawn Hill Formation. Sequence Doom 2 stands out from the underlying Doom 1 sequence by its uniform, planar internal geometry which suggests that tectonic activity had waned in the Isa Superbasin.

A model for the deposition of the Doom 1 and 2 sequences is shown in **Figure 5.5.9**. Apart from a subtle northward thinning of the Doom 1 sequence seismic interpretations lack any significant regional variations in thickness. A regional basin floor sheet forms at the beginning of the Doom Supersequence. The feldspathic sediments, which comprise this basin floor sheet, change laterally from the medium- to coarse-grained submarine sandstones of the Widdallion Sandstone in the south, to the deep marine sandstones and siltstones found in the Comalco wells to the north. Doom 1 strata are finer-grained above the basin floor sheet. The slightly progradational nature of sediments in drill hole and outcrop, along with the presence of clinoforms and channels in seismic data, suggest that sedimentation rates exceeded accommodation rates. Instability of basin margins is evidenced by the disrupted nature of reflections. The Doom 2 sequence lacks evidence of any associated instability during its deposition. It is possible that in the absence of rapid tectonic subsidence, eustatic sea level fluctuations are the main control on accommodation cycles in Doom 2 and several overlying sequences. In Doom 2 the increase in dolostone interbeds indicates that the Isa Superbasin was sediment starved at this time. An increase in regional subsidence rates within the Isa Superbasin probably drove sediment starvation within Doom 2.

The Doom 3 sequence is mostly absent except on seismic sections located near Egilabria_1. Where present, the Doom 3 sequence boundary is conformable with sequence Doom 4 (**Fig.5.5.7**). A series of moderate-amplitude, semi-continuous to continuous, southward-prograding clinoforms occur above the sequence boundary. The clinoforms tie with an interbedded sandstone, siltstone, and carbonate interval from the lowstand systems tract at Egilabria_1. The overlying transgressive deposits are imaged on seismic sections as a distinct high-amplitude reflection doublet (**Fig. 5.5.7**). The highly reflective nature of these transgressive deposits is consistent with the presence of thick dolostone beds at Egilabria_1. A highstand systems tract is clearly defined at the top of sequence Doom 3 by a series of low to moderate-amplitude, semi-continuous, northward-prograding clinoforms (**Fig. 5.5.7**).

The accommodation cycles and associated depositional systems in sequence Doom 3 continue the trend of increasing subsidence seen in sequence Doom 2. However, the northerly prograding clinoforms in the Doom 3 highstand represent the first time seismic data shows widespread evidence for northward prograding depositional systems. The change in clinoform direction may be indicative of uplift in the south associated with the Isan Orogeny.

Sequence Doom 4 shows a more irregular internal geometry than sequences Doom 2 and 3 (**Fig. 5.5.7**). The base of sequence Doom 4 is characterised by a conformable surface. A negative polarity reflection above the sequence boundary is interpreted as the Doom 4 lowstand systems tract. The lowstand deposits are overlain by a semicontinuous, moderate-amplitude reflection (**Fig 5.5.7**). This lower reflection ties with a thin condensed carbonate interval from the Doom 4 transgressive deposits at Egilabria_1. A package of moderate-amplitude and relatively continuous, northward-prograding clinoforms, downlaps onto the thin transgressive deposits. These downlapping reflections are noticeably steeper than clinoforms from the underlying sequences, and give sequence Doom 4 a more irregular appearance (**Fig. 5.5.7**). The northward-prograding Doom 4 highstand deposits correlate to a relatively thick package of interbedded, inner ramp sandstones and siltstones in Egilabria_1. Integrated seismic and well log data indicate that the Doom 4 sequence represents a period of increased coarse clastic sedimentation sourced from the south. By Doom 4 time, accommodation and sedimentation cycles were probably entirely driven by tectonic processes associated with the Isan Orogeny.

Sequence Doom 5 is only partially preserved near Egilabria_1 (**Fig. 5.5.7**). The base of sequence Doom 5 is an unconformable sequence boundary with incised valleys eroding up to 30m into Doom 4. Only the lowstand systems tract of sequence Doom 5 is preserved beneath the South Nicholson Group (**Fig. 5.5.7**). The lowstand deposits are characterised by a continuous, moderate-amplitude seismic reflection which onlaps both north and south onto the incised sequence boundary. The seismic geometry of the Doom 5 lowstand systems tract is consistent with interpretations of a lowstand fluvial sandstone at Egilabria_1. The beginning of fluvial incision and deposition in sequence Doom 5 possibly indicates an end to deposition within the Isa Superbasin as accommodation space rapidly declined in response to the Isan Orogeny.

5.6. Basin Fill History of the Isa Superbasin

The integration of outcrop and well log sequence stratigraphy with seismic sequence stratigraphy has produced a detailed (third-order) basin infill history of the Isa Superbasin. Each of the nine Supersequences from the Isa Superbasin shows a unique tectonostratigraphic evolution and associated set of contemporaneous depositional systems. The distribution of depositional systems within a sequence stratigraphic framework is summarised on the

Argyle Creek seismic composite in **Figure 5.6.1**. The temporal distribution of depositional sequences is summarised in **Figure 5.6.2** as a chronostratigraphic chart derived from plotting the depositional systems of **Figure 5.6.1** in units of time rather than depth. We have also summarised the sedimentation rates and accommodation history of each sequence in **Figure 5.6.3**. Sedimentation rates shown are only relative values derived by dividing the maximum compacted thickness of each sequence on the Argyle Creek seismic composite by the approximate time interval of sedimentation shown by SHRIMP zircon ages. The relative sea level curve of **Figure 5.6.3** is an approximation derived from limited palaeodepth data (ie sedimentary structures and the interpreted accommodation history of each sequence).

Third-order sequences in the Isa Superbasin generally show evidence for tectonically-driven accommodation cycles. This evidence comes from the common association of sequences with growth faults, local sub-basins, volcanoclastic sediments, high concentration debris flows and turbidites, and angular unconformities in the north. Most of the fourth-order sequences documented in outcrop sections *(Southgate et al., in press [a, b]; Krassay et al., in press [a, b])* probably represent a combination of tectonically- and eustatically-driven accommodation cycles. Third-order sequences deposited during periods of tectonic quiescence (eg Lawn 2 through Lawn 4, Doom 1 through Doom 3) may also be associated with eustatic cycles overprinted on a second-order regional subsidence trend.

Several previous studies interpret a broad rift-sag succession within the Isa Superbasin *(McConachie et al., 1993; O'Dea et al., 1997; Betts et al., 1998).* The *McConachie et al. (1993)* rift-sag-foreland basin model for the Isa Superbasin has been refuted throughout this Record based on revised seismic, well log, outcrop, and geopotential studies. *O'Dea et al. (1997)* and *Betts et al. (1998)* have developed a rift-sag model for the Isa Superbasin based on outcrop studies south of the Comalco seismic grid. These authors *(op cit)* model a series of three syn-rift sequences which correspond to the Bigie Formation and Fiery Creek Volcanics (ie Big Supersequence), Surprise Creek Formation (ie lower Prize Supersequence), and Torpedo Creek to lower Gunpowder Creek Formations (ie upper Prize Supersequence). A sag succession then comprises the remainder of the Isa Superbasin, which includes episodic syndepositional fault activity during periods of thermal subsidence *(Betts et al., 1998).* The sag succession is terminated at about 1590Ma by the Isan Orogeny.

The evidence presented herein and other NABRE studies *(eg Scott et al., in press; Southgate et al., in press [a])* propose that a major tectono/thermal event at about 1730Ma initiated an extensional system (**Chapter 3**). Details of the igneous and sedimentary successions (**Sections 1.5** and **2.1)**, and the Big Event deformation in the Northern Lawn Hill Platform combine to form the basement template upon which the Isa Superbasin was deposited. The subsequent accommodation history of the Isa Superbasin does not support the quiescent sag phase of *O'Dea et al. (1997)* and *Betts et al. (1998).* Instead, several periods of tectonically-enhanced subsidence are punctuated by episodes of uplift and erosion. The depositional and accommodation histories of the Prize through Doom Supersequences are summarised in the following sections. In these discussions, reference is made to recent models for the sequence stratigraphy and contemporaneous depositional systems of extensional systems *(Prosser, 1993; Ravnas and Steel, 1998)* to improve our understanding of tectonostratigraphic cycles within the Isa Superbasin.

5.6.1. Post-Rift Subsidence in the Prize Supersequence

The Prize Supersequence is a clastic ramp margin dominated by an extensive transgressive deposits in which thick fluvial and coastal sandstones transgress into thin inner ramp siltstones. A thin highstand systems tract composed of inner ramp siltstones progrades over the thick transgressive deposits. The rate of deposition for the Prize Supersequence was about 90m (compacted sediment) per million years (**Fig. 5.6.3**). The thick transgressive sandstones that characterise the Prize Supersequence extend from the Warrina Park Quartzite in the Mount Isa region, to the Torpedo Creek Formation on the Lawn Hill Platform, and the lower Fish River Formation (Pff_1 member) on the southern Murphy Inlier (**Fig. 5.6.1**).

Deposition of this regionally extensive sandstone unit within the Prize Supersequence may be related to post-tectonic subsidence following the climax of a tectono-magmatic event in the underlying Big Supersequence. Seismic and geophysical data support a period of extension within the 'Big event' (**Chapter 3**). *Prosser (1993)* notes that the early post-rift period is when drainage basins are established and expand resulting in the rapid influx of coarse sediments. The Prize Supersequence forms a tabular seismic package composed mainly of coarse fluvial and coastal sandstones, which supports the possibility that this represents a post-rift subsidence period. The subsequent transgression into marine siltstones of the Moondarra Siltstone (Mount Isa region), lower Gunpowder Creek Formation (Lawn Hill Platform), and Pff_2 member of the Fish River Formation (Murphy Inlier) may represent a late post-rift stage in which the source areas have degraded *(Prosser, 1993).* Our interpretation of the Prize Supersequence as a period of post-rift subsidence differs from the syn-rift interpretation of *O'Dea et al. (1997)* and *Betts et al. (1998).*

5.6.2. Post-Thermal Sag in the Gun Supersequence

A large time break of ~25My occurs between the Prize and Gun Supersequences (**Fig. 5.6.2**). The exact cause of this large depositional hiatus is uncertain. Locally, igneous intrusions such as the Sybella Granite may have been associated with a period of uplift and low regional accommodation (**Sections 1.2** and **2.11**). The Gun Supersequence is thus interpreted as a period of post-thermal subsidence.

The Gun Supersequence is characterised by a series of thick highstand carbonate ramps and platforms in which shallow marine to inner ramp carbonates prograde to the southeast and east. Thin, transgressive middle to outer ramp siltstones and shales occur at the base of the prograding carbonate platforms and divide the Gun Supersequence into at least two third-order sequences. The rate of accumulation of the carbonates was on the order of 100m (compacted thickness) per million years (**Fig. 5.6.3**). The thick carbonate successions of the Paradise Creek and Esperanza Formations extend from outcrops on the Lawn Hill Platform into the Gun Supersequence (**Fig. 5.6.1**). However, the only remnant of Gun on the southern Murphy Inlier is a transgressive sandstone from the Pff_3 member of the Fish River Formation. Toward the Murphy Inlier the highstand carbonates documented in outcrop sections on the Lawn Hill Platform have been eroded by the Loretta Supersequence boundary. The highly progradational nature of highstand carbonates in the Gun Supersequence means that a time break will occur beneath the clinoforms. As this hiatus increases basinwards (to the southeast and east; **Fig. 5.6.2**), associated condensed sections and hardground mineralisation should also become more abundant.

The development of a regionally extensive carbonate platform in the Gun Supersequence following the 25My break after the 'Prize clastic ramp', indicates a period of tectonic quiescence with minimal clastic input and slow regional subsidence on the Lawn Hill Platform. A dramatic change in depositional systems occurs further south in the Mount Isa region. Here the Gun Supersequence thickens into a package of deep marine dolomitic siltstones and shales (Moondarra Siltstone to Spear Siltstone) of the Mount Isa Group. Depositional systems and accommodation cycles in the Mount Isa region were most likely driven by local tectonic activity. The thin, clastic-dominated transgressive systems tracts which occur in the Gun 2 and 3 sequences over the Lawn Hill Platform are probably a northerly extension of clastic depositional systems from the Mount Isa region formed during periods of increased regional subsidence.

5.6.3. Post-Tectonic Accommodation in the Loretta Supersequence

A regional truncation surface separates the Loretta and Gun Supersequences in the northern Lawn Hill Platform. On the southern Murphy Inlier this truncation surface results in a large time break (~15My) between Gun strata from the upper Fish River Formation and Loretta strata from the Walford Dolomite (**Fig. 5.6.2**). It is uncertain whether this truncation surface occurs further south. The tectonic process responsible for generating the truncation surface in the north was probably associated with either uplift of the Murphy Inlier, or differential subsidence. Truncation of Gun strata fed a south-thickening wedge containing the basal breccia of the Lady Loretta Formation.

A period of tectonic quiescence within the Loretta Supersequence followed this initial disturbance and resulted in the formation of a thick southeast- to east-prograding carbonate platform. The platform carbonate extended from the Walford Dolomite on the southern Murphy Inlier to the Lady Loretta Formation on the Lawn Hill Platform (**Fig. 5.6.1**). Most of the Loretta carbonate platform is composed of a single very thick highstand systems tract. This carbonate platform aggraded at a rate of about 100m (compacted thickness) per million years; similar to depositional rates of the underlying Gun carbonate ramp (**Fig. 5.6.3**). Transgressive shales at the base of the Loretta carbonate platform may have formed during an initial period of regional subsidence following the deposition of the basal breccia wedge. However, convincing evidence is lacking in seismic and outcrop data for syndepositional tectonic activity in the Loretta Supersequence. It is therefore likely that the fourth-order accommodation cycles which built up the Loretta 2 carbonate platform were associated with eustatic sea level cycles.

5.6.4. Extensional Tectonics in the River Supersequence

A south-dipping erosional unconformity separates the River and Loretta Supersequences in the seismic coverage area. Field data from the Lawn Hill Platform show the River 1 through 4 sequences (Shady Bore Quartzite and “R1r to R2r members” of the Riversleigh Siltstone) as pinching out through onlap just south of the seismic grid. A minimum of 14m of the Loretta Supersequence is truncated by the River Supersequence boundary in the Kamarga Dome region *(Krassay et al., in press [a])*. The combined effects of onlap and truncation at the River Supersequence boundary results in a time gap of about 10My between River age Mount Les Siltstone strata and Loretta age Walford Dolomite strata on the southern Murphy Inlier (**Fig 5.6.2**). The unconformity at the River Supersequence boundary is associated with a major bend in the Apparent Polar Wander Path (**Fig. 1.2.8**). Seismic data documents active extensional tectonics during deposition of the River Supersequence (**Figs. 2.1.2** and **5.6.1**). Sedimentation rates during the River 5 through 8 sequences were about 200m (compacted thickness) per million years (**Fig. 5.6.3**). This rate is twice that of the underlying carbonates and clastics from the Loretta, Gun, and Prize Supersequences.

The second-order accommodation and sedimentation trend in the River Supersequence resembles the sediment balanced or overfilled rift basin succession of *Ravnas and Steel (1998).* Early rift phase conditions are interpreted during deposition of fluvial to coastal quartz sandstones and carbonates of the Shady Bore Quartzite (sequences River 1 and 2). Rift climax conditions characterised by syndepositional growth faulting and rapid subsidence/transgression occur during deposition of the deep marine siltstones and carbonaceous shales, and submarine fan sandstones in the Riversleigh Siltstone “members R1r to R3r” and Mount Les Siltstone (sequences River 3 to 6). Late rift stage conditions with decreased syndepositional growth faulting and increasing deposition of turbidite sandstones occurs in the upper Riversleigh Siltstone “members R3s to R4s” and Mount Les Siltstone (sequences River 7 to 8).

In the northern Lawn Hill Platform, the sequences River 5 through 8 have thick northward-onlapping transgressive wedges and thin lowstand and highstand deposits. The thick transgressive wedges result from third-order rift climax periods when tilt-blocks are generated and syndepositional growth faults are active. Drill holes from the Walford Creek Prospect document syndepositional talus slope breccias at the base of eroded footwalls from the

Fish River Fault *(Rohrlach et al., 1998).* This facies also suggests an association with rift climax periods.

Lowstand deposits in the River Supersequence vary from infilled channels and incised valleys eroded into uplifted tilt-blocks (eg the western Pfd_1 member of the Doomadgee Formation in sequence River 7), to broad regionally extensive sheets of turbidite sandstones (eg the "R2s member" of the Riversleigh Siltstone in sequence River 5). These lowstand sandstones are probably third-order equivalents of the rift initiation phase of *Prosser (1993)* and *Ravnas and Steel (1998).*

Highstand deposits of the River Supersequence form thin progradational siltstones and sandstones at the top of each sequence and usually show no evidence for syndepositional growth across River age faults. The River highstand deposits are third-order post-rift successions formed when faults were temporarily inactive allowing sedimentation rates to exceed subsidence rates. Tectonically-driven subsidence throughout River Supersequence time probably overprints the signature of eustatic sea level fluctuations. However, eustacy may have driven some of the more subtle fourth-order accommodation cycles such as the brief prograding depositional system within the River 7 transgressive deposits (**Figs. 5.4.1** and **5.4.2**).

5.6.5 Post-Extensional Subsidence in the Term Supersequence

The Term Supersequence boundary forms a major onlap and minor truncation surface. On seismic sections, most of the Term Supersequence onlaps to the north. As a result, only sequences Term 4 and Term 5 are present in the eastern $Pfd_{1\text{-}2}$ members of the Doomadgee Formation on the Murphy Inlier (**Fig. 5.6.1**). The Term Supersequence boundary also erodes the River 8 sequence to the north. The combined effects of onlap and truncation on the Term Supersequence boundary results in about a 12My hiatus between the River age Mount Les Siltstone and Term age lower Doomadgee Formation on the southern Murphy Inlier (**Fig. 5.6.2**).

Sedimentation rates for the submarine debris flow sandstones of the Termite Range Formation (sequence Term 1 and Term 2 lowstand deposits) were initially very high at about 230m (compacted thickness) per million years (**Fig. 5.6.2**). These are the highest documented sedimentation rates within the Isa Superbasin and infer a larger and rejuvenated siliciclastic provenance area during this time. During deposition of the deep marine siltstones, shales, and submarine fan sandstones of the $Pmh_{1\text{-}2}$ members of the Lawn Hill Formation (Lawn 2 transgressive deposits to Lawn 5 sequence), sedimentation rates dropped slightly to about 160m (compacted thickness) per million years (**Fig. 5.6.2**). Sedimentation rates are derived from the main Term Supersequence depocenter in the southwest corner of the seismic grid. Within the depocenter, Term sequences are dominated by thick lowstand fans and northward-onlapping transgressive deposits. Highstand deposits are comparatively thin.

The Term Supersequence is initially characterised by submarine debris flow sandstones from the Termite Range Formation (lowstand deposits for sequences Term 1 and 2; **Fig. 5.6.1**). The lithofacies stacking trend of coarse-grained Termite Range Formation sandstones (Term 1 sequence) overlying the finer-grained "R4s member" sandstones of the Riversleigh Siltstone (River 8 sequence) are similar to the idealised lithofacies trend in the post-rift stage of a rifted basin *(Prosser, 1993; Ravnas and Steel, 1998).* Thus, the Term Supersequence boundary and overlying Termite Range Formation may represent a post-rift sag phase. The subsequent flooding into the shale-dominated Pmh_1 member of the Lawn Hill Formation at the Term 2 transgressive surface probably indicates an increase in post-rift subsidence rates. Each subsequent Term sequence transgresses progressively further northwards, with sequences Term 4 and 5 transgressing across the Murphy Inlier. In the Lawn Hill Platform area, a relatively abrupt decrease in thickness and change of facies occurs in member Pmh_1 across the Termite Range Fault Zone. However, the Termite Range Formation shows no thickness or facies variations (**Fig. 1.7.7**). Thus, the Term 1 sequence and Term 2 lowstand deposits appear to display a symmetrical "long horn" style sag geometry, while the remaining Term Supersequence has an asymmetrical northward-thinning sag geometry. The change in sag geometry may result from a thermal anomaly around the Termite Range Fault Zone.

5.6.6. Post-Thermal Sag in the Lawn Supersequence

The Lawn Supersequence boundary is generally conformable with strata from the underlying Term Supersequence. The conformable nature of the Lawn Supersequence boundary suggests that very little time (a few million years at most) separates Term age lower Doomadgee Formation (Pfd_{1-2}) strata from Lawn age Doomadgee Formation (upper Pfd_2) strata on the southern Murphy Inlier (**Fig. 5.6.2**). *Andrews (1998)* and *Krassay et al. (in press [b])* document a tectonically-enhanced regression beginning in the underlying "H2 member" tuffaceous siltstones and shales (Term 5 highstand deposits), and climaxing in the tuffaceous Bulmung Sandstone. It is therefore possible that the Lawn Supersequence boundary was generated by regional uplift associated with a period of volcanic activity in the Isa Superbasin.

Sedimentation rates for the Lawn Supersequence were in the order of 70m (uncompacted sediment thickness) per million years (**Fig. 5.6.3**). This is one-half to one-third of the sedimentation rates documented in older clastic systems from the River and Term Supersequences, and reflects the sediment starved conditions associated with the highly carbonaceous siltstones and shales in the Lawn Supersequence. The Lawn Supersequence boundary was initially covered by a thin but regionally extensive lowstand sandstone; the tuffaceous shallow marine Bulmung Sandstone and correlative eastern Pfd_2 member of the Doomadgee Formation (**Fig. 5.6.1**). However, subsequent depositional systems are dominated by thick transgressive deposits composed of deep marine ("H4r member") carbonaceous shales and siltstones which thin through onlap to the north.

The rapid flooding from lowstand, shallow marine, tuffaceous sandstones into deep marine shales and siltstones indicates a major transgression early in the history of the Lawn Supersequence. No evidence exists in either outcrop or seismic data for any associated syndepositional fault or flexural thickening of these thick transgressive deposits. Rapid transgression was therefore probably driven by broad regional subsidence. A lack of volcanoclastic sediments above the tuffaceous Bulmung Sandstone may indicate that the transgression was driven by a cessation of volcanic activity and associated declines in crustal temperatures. Subsidence rates continued to increase until the end of deposition in the Lawn Supersequence. The sequence boundaries which punctuate each period of flooding in the Lawn Supersequence are probably associated with eustatic sea level fluctuations.

5.6.7. Strike-Slip Tectonics in the Wide Supersequence

On the southern ends of seismic lines the Wide Supersequence boundary varies from a conformable to disconformable contact with underlying Lawn sequences. In the north a major truncation surface is present. The truncation surface removes sequences Lawn 2 to Lawn 4 on the southern Murphy Inlier. This truncation surface results in an extensive hiatus of about 15My between Lawn age strata from the Pfd_2 member and Wide age strata from the Pfd_3 member of the Doomadgee Formation on the southern Murphy Inlier (**Fig. 5.6.2**). Sedimentation rates in the Wide Supersequence were initially very low on the order of 30m (compacted sediment thickness) per million years for the “H4s member” equivalent Wide 1 and 2 sequences (**Fig. 5.6.3**). These rates increase significantly in areas of local thickening of the Wide 1 and 2 sequences such as at the Elizabeth Creek and Century sub-basins (~50 to 95m per million years). Sedimentation rates during deposition of the submarine Widdallion Sandstone in the Wide 3 sequence were about 70m (compacted sediment thickness) per million years.

Seismic data show that the Wide Supersequence was associated with a period of strike-slip tectonics in which thick wedges of transgressive siltstones and lowstand sandstones developed locally against syndepositional growth faults. Highstand deposits are rare or absent. The overall 2nd-order seismic geometry of the Wide Supersequence is very similar to the idealised rift basin geometry outlined by *Prosser (1993)*, with Wide 1 and 2 representing early rift phase sequences, and the Wide 3 sequence forming the main growth package during the rift-climax stage. The vertical stacking pattern of lithofacies is also similar to the sediment-underfilled rift basin model of *Ravnas and Steele (1998).* That is, a coarsening up from the transgressive deep marine (“H4s member”) siltstones and shales of sequences Wide 1 and 2, into the lowstand submarine (“H5 member”) sandstones of sequence Wide 3, and subsequent fining-up into deep marine siltstones in the Wide 3 transgressive systems tract.

The stacking pattern in the Wide Supersequence contrasts with the sediment-overfilled trend documented in the River Supersequence. We suggest that this contrast in rift-fill styles is due to the nature of preceding accommodation cycles and styles of deformation. In the case of the River Supersequence, the preceding Loretta Supersequence had filled available accommodation with peritidal carbonates. Thus, at the onset of extension in the River Supersequence, a relative fall in sea level resulted in exposure of a large provenance area for the Shady Bore Quartzite sandstones. Subsequent regional subsidence drowned these source areas in the rift-climax stage during deposition of the Riversleigh Siltstone and Mount Les Siltstone.

In the case of the Wide Supersequence, the preceding Lawn Supersequence was an underfilled thermal sag basin containing deep marine carbonaceous shales and siltstones. Initial strike-slip deformation produced erosion over positive flower structures. The Wide 1 sequence boundary documents a relative fall in sea level. However, lithofacies throughout the Lawn Hill Platform indicate that the associated basinward shift in lithofacies was from outer ramp shales in sequence Lawn 4 to inner ramp siltstones in sequence Wide 1. Thus, at the onset of extension in sequence Wide 1 most of the Isa Superbasin was submerged, hinterlands were very distal to the Lawn Hill Platform, and sediment supply was low. However, as strike-slip deformation climaxed in sequence Wide 3, the uplift associated with horst- and tilt-blocks may have subaerially exposed nearby hinterland resulting in an influx of sandstone into the rift basins. The lateral facies change in sequence Wide 3 from sandstones in the south, to siltstones on the southern Murphy Inlier indicates that such rejuvenated hinterlands were located in the south.

5.6.8. Post-Extensional Subsidence in the Doom Supersequence

The Doom Supersequence boundary is relatively conformable with strata from the underlying Wide Supersequence. No evidence exists in seismic or well log data for a truncation surface beneath Doom 1. The conformable nature of the Doom Supersequence boundary means that very little time (a few million years at most) separates Wide age upper Doomadgee Formation (lower Pfd_3) strata from Doom age Doomadgee Formation (upper Pfd_3) strata on the southern Murphy Inlier (**Fig. 5.6.2**). Our definition of a supersequence boundary at Doom 1 is based on considerations of the dramatic change in tectonostratigraphic styles from the complex geometry of the Wide sequences to the tabular, passive ramp margin geometry of the Doom sequences. Sedimentation rates for the Doom Supersequence in the Egilabria_1 well area were on the order of 70m (uncompacted thickness) per million years (**Fig. 5.6.3**). This is about the same rate as the underlying Wide 3 sequence.

Basin fill patterns in the Doom Supersequence initially show some similarities to the Lawn Supersequence. The Doom Supersequence begins with a regionally extensive, lithologically immature lowstand sandstone sheet in sequence Doom 1 after which sediments rapidly retrograde into the deep marine siltstones and carbonates of sequences Doom 2 and 3. The lowstand sheet in Doom 1 probably represents the transition from the rift-climax in the Wide 3 sequence to a period of passive ramp margin sedimentation. The establishment of a large basin-wide drainage basin over a feldspathic source area would explain the regional occurrence of the distinct high-gamma sandstones at the base of sequence Doom 1, and is consistent with the models of *Prosser (1993).* Subsequent sediment starvation within sequences Doom 2 and 3 was probably driven by the increasing degradation of source areas as a ramp margin basin was established.

The final accommodation history of the Doom Supersequence differs from Lawn in showing a tectonically-enhanced regression. Sediments rapidly shoal and coarsen-up from the relatively planar, deep marine siltstones and carbonates of sequence Doom 3, to the northward-prograding inner ramp sandstones of sequence Doom 4, capped by the fluvial sandstones of sequence Doom 5. The fluvial Doom 5 sequence represents the final preserved sediment package in the Isa Superbasin. We suggest the end to deposition was driven by decreased accommodation associated with uplift in the south during the early phases of the Isan Orogeny.

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CHAPTER 6

Mineral Exploration Potential of the Northern Lawn Hill Platform

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Chapter 6

MINERAL EXPLORATION POTENTIAL of the NORTHERN LAWN HILL PLATFORM

(P.N. Southgate, B.E. Bradshaw, D.L. Scott and A.A. Krassay)

6.1. Introduction

The preceding sections of this CD ROM provide a detailed chronostratigraphic and structural synthesis of the evolution of the northern Lawn Hill Platform. The seismic dataset facilitates insights into basin geometry and sediment architecture that are normally not available in northern Australia. Burial of Proterozoic successions beneath shallow cover, poor outcrop and structural complexity usually combine to obscure the early basin history. However, insights gained from the 3D and 4D understanding of basin evolution outlined here permits new play concepts to be visualised for the prospective regions of northern Australia. The analysis provides details on the geometry of sub-basins that are known to be associated with sediment-hosted massive sulphide deposits. It shows the timing of structural events which:

- control the formation of sub-basins which host mineralisation,
- determine periods of fluid flow and
- document the age of each fault system and its interconnectivity with faults of different age, a crucial aspect for determining the fairways for fluid migration.

Predicting and identifying potential mineral exploration targets that lie buried beneath shallow cover requires new exploration strategies. In the absence of direct geochemical indicators and outcropping gossans, many companies have used airborne EM and magnetics in an attempt to identify prospective horizons. Indeed, the Cannington deposit was discovered after identification of an airborne magnetic anomaly. However, these techniques do not clarify relationships between sub-basin geometry, growth faults and potential plumbing systems. In contrast, strategies employed in this study identify subsurface prospective stratigraphic intervals, the shape of associated sub-basins and the overall stratigraphic and structural architecture.

On the Lawn Hill Platform, sediment-hosted Zn-Pb-Ag sulphide occurrences are known to occur in the Gun Supersequence (Kamarga deposit), Loretta

Supersequence (Lady Loretta deposit), River Supersequence (Grevillea prospect), Lawn Supersequence (Lawn Hill mineral field, including Silver King and Watsons Lode) and Wide Supersequence (Century deposit). On the southern flanks of the Murphy Inlier fault-controlled galena mineralisation occurs as disseminated crystals and veinlets in silicified dolostones of the Loretta Supersequence. In the River Supersequence sulphide mineralisation occurs at the Walford Creek Prospect, Gorge Creek and Lead Hill.

The relative timing of host rock deposition and sulphide mineral precipitation can vary within an individual deposit or prospect as well as between deposits. At the McArthur River deposit coincident Pb/Pb model ages from ore *(Carr et al., 1996)* and SHRIMP zircon ages from tuffaceous horizons in the host sediments *(Page and Sweet, 1998)* of 1640Ma are consistent with either a sedimentary exhalative or early diagenetic age for mineralisation *(Gustafson and Williams, 1981; Hinman, 1996; Large et al., 1998)*. At Century, *Broadbent et al. (1998)* proposed a deep-burial model for ore formation with fluid migration taking place during the early stages of basin inversion at burial depths somewhere between 800m and 3km. A Pb/Pb model age of 1575Ma *(Carr et al., 1996)* indicates that ore precipitation at Century took place some 20my after deposition of the host sediments at 1595Ma *(Page and Sweet, 1998)*. At the Walford Creek prospect *Rohrlach et al. (1998)* document four stages of mineralisation. Initial sulphide precipitation took place from exhalative-hydrothermal fluids to form microbial pyrite mounds. Subsequent phases of disseminated Pb-Zn sulphide mineralisation took place during both early and much later burial diagenesis suggesting repeated episodes of metal-bearing fluid migration *(Carr et al., 1996; Rohrlach et al., 1998)*. *Jones (1986)* interprets the coarsely crystalline Pb-Zn sulphide and barite mineralisation at the Kamarga prospect as precipitating in open space conditions as veins and breccias and as replacements of the host dolostones during late stage burial diagenetic processes.

In many exploration programs difficulties involved with understanding 3D and 4D geological information inhibits our ability to predict the migration pathways of metal bearing fluids and the likely sites of sulphide precipitation. While the aforementioned studies indicate a variety of syngenetic to deep burial play concepts as legitimate targets in any exploration program the information is frequently lacking for determining the time of fluid migration and the pathways along which these fluids moved. In summary, we need to be able to:

- identify a source for the fluids,
- determine the timing of generation of a fertile brine,
- understand the timing and pathway(s) of fluid migration and
- better predict the location of a trap for the deposit and a seal that may have controlled the migration pathway.

Figure 6.1.1 provides a summary of the basin fill for the McNamara and Fickling Groups and upper Peters Creek Volcanics. The diagram depicts stratigraphic architecture in the third dimension (depth) and the fourth dimension (time). The Walford Creek prospect occurs at the northern end of the line. Lithologies are generalised from drill core, cuttings and seismic facies.

The cross section highlights several fluid flow mechanisms:

- A north-directed and layer parallel thermobaric-compactive drive related to increased subsidence rates and sediment loading in the south.

- A topographically driven circulation system related to emergence of the Murphy Inlier during falls in relative sea level (times of Supersequence boundary formation).

- Vertical fluid migration along fault segments undergoing dilation during tectonic events (times of Supersequence boundary formation).

Using these drivers for fluid flow it is possible to visualise new play concepts, better understand the location of existing prospects and ask questions that may further our understanding of the base metal mineral system(s) in the Isa Superbasin.

6.2. New Insights into Existing Prospects and Plays

Rohrlach et al., 1998 combined drillcore, outcrop geology and ground-based transient electromagnetic geophysics to delineate a north thickening, fault-bounded sub-basin as the host for the Walford Creek prospect. The ENE to EW trending Fish River Fault formed the northern boundary of the sub-basin and sediments thickened progressively toward this structure. The sub-basin was reconstructed to a depth of approximately 300m. The Mount Les Siltstone, which is host to this low-grade Zn-Pb-Cu-Ag deposit, is anomalously thick (310m) in the prospect area and thins to the east (~150m) and west (~100m). Pyrite deposition occurred in association with hydrothermal springs venting along the active Fish River Fault. Sub-economic mineralisation (2-5% zinc) occurs in the Mount Les Siltstone over an 8.5km strike length *(Rohrlach et al., 1998)*.

The datasets are local in scale and emphasised the importance of north thickening sub-basins with south-dipping growth faults on their northern side. However, the seismic dataset clearly indicates that the Fish River Fault is a relatively small structure, antithetic to the principal, north-dipping Nicholson River Fault Zone (**Fig. 2.1.2**). The cross section shown in **Figure 6.1.1** also shows the location of the Walford Creek prospect at the northern, up-dip extremity of the megawedge. This position is close to any possible drainage point of basinal fluids migrating updip by a compaction mechanism. The prospect also lies close to the likely intersection of basinal fluids with topographically driven fluids, possibly sourced over an emergent Murphy Inlier, thus raising the potential for a zone of fluid mixing in this region. As well as providing information on possible drainage pathways for the metal-bearing fluids, the geometry shown in **Figure 6.1.1** has implications for fault orientations. In the south-thickening megawedge are dilational fault segments on south-dipping antithetic faults the preferred sites for the vertical fluid transport of north-directed basinal fluids? The corollary statement also has implications for play concepts. Where growth faults are north-facing (eg South Nicholson Fault) will their northerly dip inhibit vertical fluid migration? The answers to these questions will depend on the orientation of the intraplate stress field. That is, as the principal strain varies, faults of different orientations may open and close. The structural framework for the region outlined in **Chapter 3** provides an interpretation of where dilational fault segments and small transtensional or strike-slip basins developed at 1640Ma and 1595Ma. An improved understanding of sediment architecture and possible lateral fluid migration pathways may assist in predicting which fault orientations are likely to be the preferred focal points for draining basinal fluids and acting as vertical conduits for their focussed discharge into reactive host strata.

Strike-slip sub-basins of 1640Ma and 1595Ma are identified in the seismic data to the south of the Walford Creek prospect. Pyrite is the principal sulphide phase found at Walford Creek so that fluid composition is a major risk with exploration along the southern Murphy Inlier. However, minor amounts of galena and sphalerite in this prospect and along the Murphy Inlier indicate the presence of lead and zinc in the fluid systems. If the basinal fluids were enriched in Fe before Pb and Zn enrichment took place, it is possible to conceive of a chemically-partitioned basinal fluid flow system emanating from the depocentre of the megawedge. In this scenario, Pb-Zn rich basinal fluids were focussed toward dilating fault segments on the South Nicholson Fault concurrent focussing of earlier and further migrated Fe rich fluids into the Fish River Fault beneath the Walford prospect. Alternatively, fluids responsible for pyrite mineralisation at the Walford prospect may have been topographically driven, with metals leached from strata to the north of the prospect. In either scenario, strike-slip basins of 1640Ma and 1595Ma age are targets for exploration with fluid migration fed by thermobaric-compactive flow from the depocentre of the megawedge.

6.3. River and Wide Supersequence Plays

Seismic interpretations presented in **Chapters 2** and **3** document extensive evidence for thickening of River and Wide Supersequence strata in fault-bounded graben or half graben (**Figs. 6.3.1** and **6.3.2**).

6.3.1. River Supersequence

Most of the sub-basins on the northern sides of River faults show evidence for growth of River sequences 5 and 6, which are known to host sub-economic mineralisation in the Walford Creek Prospect (**Fig. 1.6.4**). Sub-basins imaged in seismic sections reach thicknesses of up to 675m against the Nicholson River Fault, 1360m against the Egilabria Strain Zone and 2280m against the Elizabeth Creek Fault (**Fig. 6.3.1**). *Rohralch et al. (1998)* document a 310m thick section at the Walford Creek Prospect.

The map in **Figure 6.3.1** shows the distribution of River sub-basins and depths to the top and base of the River Supersequence. Unfortunately, all of these sub-basins are well below depths of economic recovery (500m). Immediately south of the Elizabeth Creek Fault, strata are highly deformed. Geological mapping in the Constance Range region shows outcrops of Lawn Hill Formation ($Pmh_{1\text{-}4}$) and Termite Range Formation immediately south of the Argyle Creek seismic composite (**Fig. 2.1.2**). Using the map data, the base of the Lawn Supersequence appears to outcrop immediately south of the Elizabeth Creek Fault (**Fig. 6.1.1**). When compared to the depth of the Lawn Supersequence boundary in seismic interpretations from the Argyle Creek composite, it is apparent that strata on the southern side of the Elizabeth Creek Fault are inverted by about 1500m. If strata are consistently uplifted by this order of magnitude along the extent of the Elizabeth Creek Fault, River Supersequence rocks may outcrop south of the Elizabeth Creek Fault. Most regional seismic lines show the River Supersequence thickening substantially into the Elizabeth Creek Fault (**Figs. 2.1.2** to **2.1.4**), which suggests it was a major syndepositional structure. The Term depocenter in the western part of the seismic grid has buried the River Supersequence too deep (3940-5970m) for a 1500m throw on the south side of the Elizabeth Creek Fault to expose the River Supersequence. However, the Term Supersequence thins substantially to the east, resulting in a shallower depth of burial for the River Supersequence (1355-3375m on the Central seismic composite and 1595-3875m on the Egilabria seismic composite). Thus, the Elizabeth Creek Fault in the southeastern corner of the seismic grid may uplift rocks of River age to recoverable depths to produce a potential prospect area.

6.3.2. Wide Supersequence (Elizabeth Creek)

Most Wide Supersequence sub-basins occur on the northern side of syndepositional faults and show evidence for extensive growth in Sequence Wide 3 (Widdallion Sandstone equivalent) and only minor growth of Sequences Wide 1 and 2 (**Figs. 2.9.4** and **6.3.2**). Most sub-basins contain a maximum of 250m thickness for Sequences Wide 1 and Wide 2, significantly less than the 300m thickness associated with the Century deposit (**Fig. 6.3.3**). Most sub-basins also have the base of the Wide Supersequence just below depths of economic recovery (>500m). A notable exception occurs at the southwest end of the Egilabria seismic composite where the Wide 1 and 2 sequences thicken substantially and occur within <350m of Mesozoic surface cover (**Fig. 6.3.2**). Details of this area of potential mineralisation were documented in *Bradshaw et al. (1998)* as the Elizabeth Creek Prospect.

The play is imaged on seismic line 89BN-07 and is based on the series of evolutionary steps proposed by *Broadbent et al. (1998)* for the Century Mine (**Fig. 6.3.4**).

- Deposition of ~590m of "H4s" carbonaceous siltstones and organic-rich shale interbeds within a southward-thickening wedge, the Elizabeth Creek sub-basin, at 1595Ma (**Fig. 6.3.5a**). The Elizabeth Creek sub-basin was probably generated by growth across a WNW fault in the Elizabeth Creek Fault Zone. The Elizabeth Creek sub-basin thins to only 90m over a distance of 25km and is of similar dimensions to the Century sub-basin (**Fig. 6.3.3**). Potential host organic-rich shale beds will also pinch-out as the sub-basin thins northwards. This thinning of host strata limits potential mineralisation to a zone extending ~20km along the southwestern end of the "H4s" wedge.

- Deep burial of the Elizabeth Creek sub-basin beneath a cover of ~1500m of the remaining Wide and Doom Supersequences between 1595–1585Ma (**Fig. 6.3.5b**). This falls within the range of overburden cover of 800 to 3000m proposed for the Century ore body *(Broadbent et al., 1998)*.

- Regional deformation of the Isa Superbasin during the Isan Orogeny resulted in a network of late-stage faults and fractures (**Fig. 6.3.5c**). The late-stage faults provided potential conduits for metal-bearing brines. The brines may have originated in either igneous basement or from reservoir rocks hosting fluids that migrated in response to earlier tectonic events. According to *Broadbent et al. (1998)* the Century ore body formed through a complex series of stages in which sulphide-bearing fluids generated hydrocarbons within a source-reservoir and restricted fluid circulation to an overpressured zone. Subsequent reactions between hydrocarbon reductants and metal-bearing fluids precipitated high purity sphalerite at the gas/oil interface. Formation of the Century ore body was terminated when the overpressured system was breached by a network of minor fault systems and reactivation of the Termite Range Fault.

- Palinspastic reconstruction of line 89BN-07 shows the development of "dome and basin" folding and a network of late-stage fault systems reactivated from earlier fault trends that sole into igneous basement (**Fig. 6.3.5c**). It is difficult to determine the precise timing of folding and faulting. However, truncation at the tops of two anticlines resulted in the partial erosion of the Lawn 4 sequence prior to Wide Supersequence deposition. This truncation suggests an initial pulse of compression and folding prior to 1595Ma. Subsequent folding is likely to have occurred during the early phases of the Isan Orogeny. Thus, it is likely that the anticlines formed structural traps to both the hydrocarbons generated in the "H4s" equivalent strata and any fluids transported through the late-stage fault systems. Several of the late-stage fault systems appear to terminate below the upper surface of the Doom Supersequence and were likely conduits for sulphate-bearing fluids. At least one late-stage fault offsets all strata and would have breached any overpressured reservoir developed in the smaller northeastern anticline.

- The Elizabeth Creek Fault immediately southwest of the seismic line is also likely to have been reactivated and to have breached the overpressured zone in the southwestern anticline. Both anticlines are characterised by high-amplitude reflections within Century-equivalent strata. The northeastern anticline is particularly reflective. However, this is currently buried beneath about 1450m of overburden and is, thus, below economic recovery. The southwestern anticline is a broader feature in which several high-amplitude reflections continue from the more reflective northeastern structure. These high-amplitude reflections may represent mineralised intervals within depths of economic recovery (~350m of Carpentaria Basin overburden; **Fig. 6.3.5**). A depth limit of ‹500m for economic recovery restricts the area of prospectivity to a 7km zone at the southwest end of seismic line 89BN-07. *Bradshaw et al. (1998)* named the potentially prospective southwestern end of line 89BN-07 the Elizabeth Creek Prospect.

6.4. Sandstone Hosted Play Concepts

In **Figure 6.1.1**, shale deposits provide potential seals for underlying lowstand sandstone units at the position of onlap pinchout. This stratigraphic architecture is likely to have trapped any hydrocarbons migrating out of the basin depocentre. Carbonaceous sediments are known in the Gun, Loretta, River and Lawn Supersequences and any of these sediments may have formed possible source rocks for subsequent hydrocarbon migration. If such hydrocarbons migrated through lowstand sandstones they may have been trapped at the position of onlap, the overlying transgressive shales forming the seal. Trapped hydrocarbons in sandstone units provide the opportunity for a reductant in these rocks and a mechanism for sulphide precipitation if metal-bearing fluids subsequently migrated into a sandstone-hosted petroleum reservoir.

6.5. Future Work – AMIRA PROJECT P552

AMIRA Project P552 will utilise the results of AMIRA projects P384/384A and the time-series basin framework and stratigraphic architectural studies outlined in this CD ROM and other NABRE products to address five fundamental questions related to the origin of these deposits:

- Which parts of the stratigraphy provide the source rocks for base metals?
- At what burial depths or temperatures did the basinal brine(s) become enriched in base metals?
- What is the timing of brine expulsion and sulphide precipitation?
- Where in the basin were the fertile brines resident and along which pathways did they migrate?
- What are the relationships between metal bearing brine and organic matter at the site(s) of metal precipitation?

These issues will be addressed through the collection and analysis of datasets necessary to determine burial history and mineral paragenesis. The new mineral paragenesis and geochemical datasets will be integrated with the NABRE basin framework studies. Ideas and concepts will be tested through a series of fluid flow models. Significant new insights into the temporal and spatial controls on ore formation are expected. The acquired datasets will constrain and guide exploration programs in the Isa Superbasin. The results of the study will have important global implications in the exploration for sediment-hosted Pb-Zn deposits.

The proposal is based on a collaborative strategy between researchers at AGSO, CODES (University of Tasmania), University of Queensland, Queens University, Canada and CSIRO. The work will be conducted as a series of integrated modules, with particular attention paid to regular interaction between the research teams and with the sponsors.
The modules are:

- Module 1: Volcanological and Metal Source Studies (CODES, University of Tasmania)
- Module 2: Stratigraphic Architectural Studies, Bigie-Surprise Creek-Fiery Creek (AGSO)

- Module 3: Mineral Paragenesis Studies (Queens University, University of Queensland and AGSO)

- Module 4: Burial History and Thermal Maturation Studies (University of Queensland and AGSO)
- Module 5: Geochemical, Thermal and Mechanical Fluid Flow Modelling (CODES, University of Tasmania and CSIRO)

List of figures

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APPENDIX

Sequence Stratigraphic Methodology

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Appendix

SEQUENCE STRATIGRAPHIC METHODOLOGY

Traditionally, exploration for sediment-hosted mineralisation in northern Australia has depended on lithostratigraphic concepts for regional correlations of strata. However, lithostratigraphic correlations do not realistically represent the time-transgressive nature of facies boundaries. For the past 30 years, petroleum exploration geologists have developed correlation techniques using unconformity-bounded stratigraphic sequences to overcome this inadequacy. These techniques, called sequence stratigraphy, are a viable alternative to lithostratigraphy for developing the chronostratigraphic framework for basins. Importantly, the surfaces that internally divide sequences into their component systems tracts (lowstand, transgressive, highstand and shelf margin systems tracts) and parasequences (progradational cycles bounded by marine flooding surfaces) are chronostratigraphic surfaces that cut across diachronous lithofacies boundaries (**Fig. A1**). The geometric arrangement and hierarchy of sequences reflect interplay between fluctuations in basin accommodation versus sediment supply at a variety of scales.

Subsurface sequence boundaries are identified through analysis of seismic data and well logs. Wire-line logs such as gamma-ray curves provide high-resolution details on the stacking patterns of sedimentary cycles at a number of scales. Such detail is generally not observed through traditional lithostratigraphic techniques. Individual sedimentary cycles and groups of cycles can be correlated between different localities on the basis of their wireline-log patterns. Multi-channel seismic reflection data, by comparison, are generally acquired at a much coarser resolution than well logs. However, seismic reflections follow gross bedding and provide important details on the geometry of sedimentary strata and constrain interpolation between wells.

Well-Log Trends & Sedimentary Cycles

Regional correlations of wireline curves are not based solely on identifying individual spikes on the curves. 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. The following synopsis is largely taken from *Rider, 1986, Van Wagoner et al., 1990* and *Emery & Myers, 1996*. Most wireline logs are interpreted through the identification of five widely recognised trends, corresponding to individual sedimentary cycles (**Fig. A2**).

- 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. Cleaning-up trends may occasionally result from a gradual change from clastic to carbonate deposition, or a gradual decrease in anoxic conditions.

- A dirtying-up or bell-shaped gamma trend shows a progressive upward decrease in gamma readings, which commonly indicates overall fining-upward successions, typically within shale-prone intervals. Dirtying up trends are common in fluvial successions, tidal channels, and estuarine fills. In shallow marine settings, dirtying-up trends often indicate the retreat or abandonment of a shoreline–shelf system. In deep marine settings, the dirtying-up motif may record the waning or abandonment period of submarine fan deposition.

- Boxcar or blocky gamma-ray curve segments are sharp-based low-gamma units with internally relatively consistent gamma readings set within a higher gamma background. 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. Boxcar trends are commonly found in fluvial channel sands, turbidites, aeolian sands, and occasionally within evaporites.

- 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. 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 fan system.

- 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. 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.

Parasequences and Systems Tracts

The bounding surfaces of individual log trends often coincide with marine flooding surfaces associated with either fluctuations in sediment supply (eg avulsion and lobe switching) or high-frequency variations in sea-level. Units bound by these conformable marine-flooding surfaces are most common in shallow marine settings and are termed parasequences. Parasequences may, in turn, form distinct two-dimensional stacking patterns or parasequence sets (**Fig. A1**). Systems tracts represent larger scale, three-dimensional depositional units bounded by major sequence stratigraphic surfaces (sequence boundaries, transgressive surfaces, maximum flooding surfaces). The surfaces bounding systems tracts are associated with major increases and decreases in the accommodation history of sedimentary sequences (ie lowstands, transgressions and highstands. Systems tracts and parasequence sets are often synonymous, particularly in shallow marine settings. However, in areas of high subsidence and sediment input, more than one parasequence set may exist within a systems tract. When present, parasequence sets form three distinct stacking cycles within systems tracts:

- Stacking of progressively sandier cycles is related to shoaling/emergence of previous depositional environments and overall regressive sedimentation. Such a stacking pattern is termed progradational to denote the basinward movement of a theoretical 'shoreline' over time. Lowstand and highstand prograding wedges generally consist of progradational parasequence sets. Progradational parasequences are characterised on seismic sections by downlapping (clinoform) geometry. Lowstand systems tracts (LST) are generally succeeded by a sequence boundary and bounded above by a transgressive surface. Highstand systems tracts (HST) are bounded below by a maximum flooding surface and above by a sequence boundary.

- Stacking of progressively more shaly cycles (though each cycle may contain coarsening-up parasequences) is related to drowning of previous depositional environments and overall transgressive sedimentation. Such a stacking pattern is termed retrogradational to denote the landward movement of a shoreline over time. The transgressive systems tract (TST) consists entirely of a retrogradational parasequence set bounded below by a maximum progradation surface (often coincident with the sequence boundary), and above by a maximum flooding surface. Retrogradational parasequences are identified on seismic sections by onlapping geometry.

- Stacking of fairly uniform cycles is related to progressive building up of the sediment pile over time. Such a stacking pattern is termed aggradational to denote no movement of a shoreline through time. Early phases of HST development and the upper part of LSTs are often characterised by aggradational parasequence sets. Aggradational parasequences are generally manifested on seismic sections as topset geometry with no associated clinoforms.

Interpretation of Sequence Stratigraphic Surfaces

Sequence boundaries are unconformities and correlative conformities associated with subaerial erosion and in some places correlative marine erosion surfaces. 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.

A marine flooding surface shows evidence of an abrupt increase in water depth, commonly accompanied by minor submarine erosion or nondeposition. Marine flooding surfaces are usually interpreted where gamma values suddenly increase above a cleaning-up trend. The transgressive surface is the first significant marine flooding surface across the shelf within a sequence. 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.

The maximum flooding surface marks a change from retrogradation within the TST to progradation associated with the HST. On seismic sections, the maximum flooding surface is interpreted as the downlap surface above the TST. On well logs, the maximum flooding surface usually occurs at a major peak in gamma-ray counts between a retrogradational and progradational trend. Maximum flooding surfaces pass laterally into shelfal condensed intervals *(Loutit et al., 1988)*. The gamma-ray maxima may relate to shale-prone, organic-rich intervals with anomalously high uranium and thorium contents, owing to the association of these elements with organic matter, or mineralised hardgrounds with anomalous concentrations of syndepositional manganese and phosphorous. Minor gamma-ray spikes caused by bed-scale shale packages or individual ‘hot’ beds such as tuffs are distinguished from regionally significant maximum flooding surfaces by the lack of change in gamma-ray trend surrounding each minor ‘spike’.

List of Figures

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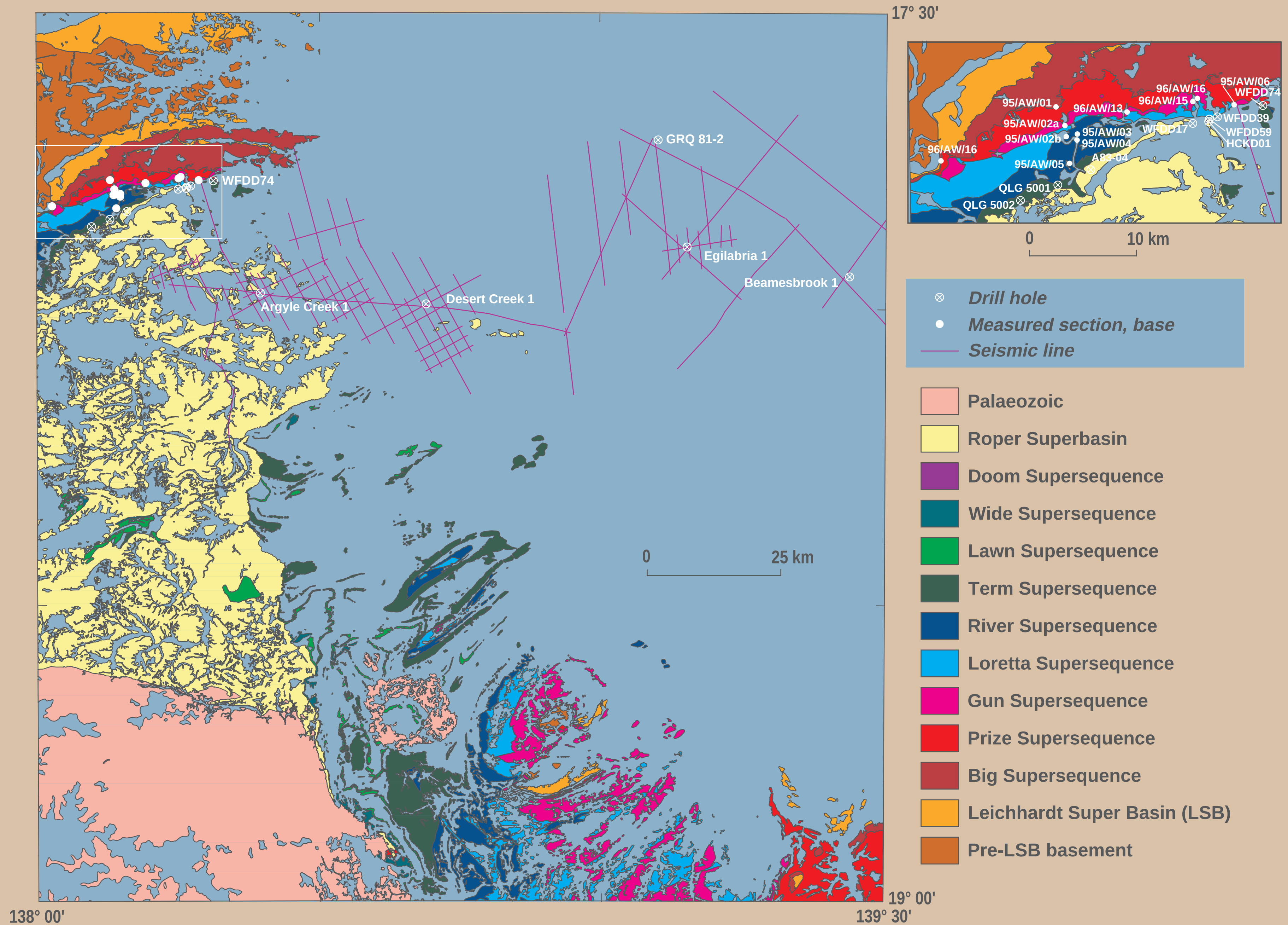

Figure 1.1.1 Geology map with formations grouped at supersequence level with seismic line, well and outcrop section locations shown. Inset shows detail of outcrop sections

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12/A/417

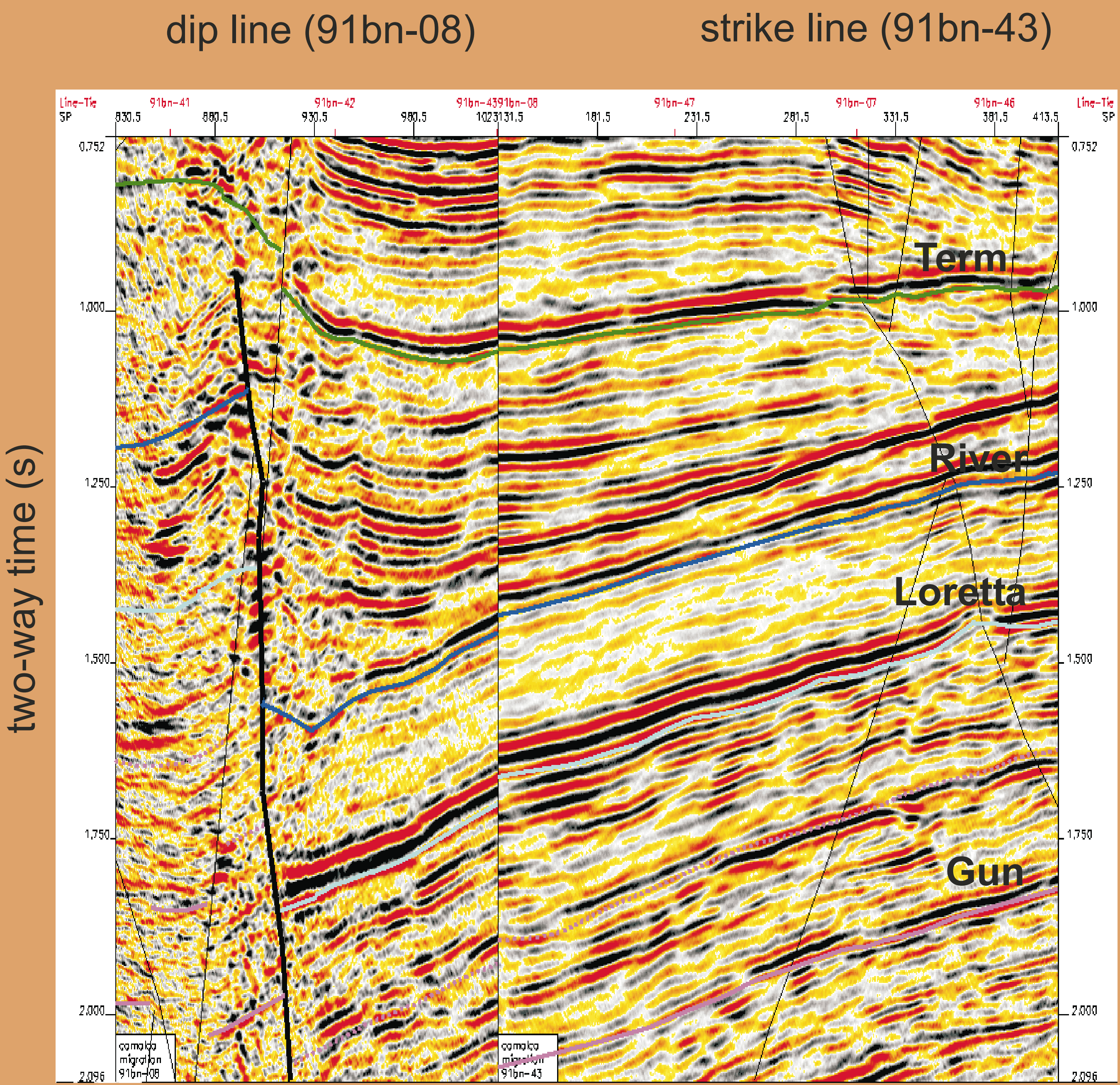

Figure 1.1.2 Example of migration mistie from Desert Creek (Line 91bn-08 and 91bn-43)

Carpentaria/Karumba Basins
Mesozoic

South Nicholson Basin
Mesoproterozoic

Leichardt Superbasin
Palaeoproterozoic

Georgina Basin
Cambrian

Isa Superbasin
Palaeoproterozoic

Murphy Inlier
Igneous/metamorphic basement
Palaeoproterozoic

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Figure 1.2.1 Intracratonic basins of the northern Lawn Hill Platform

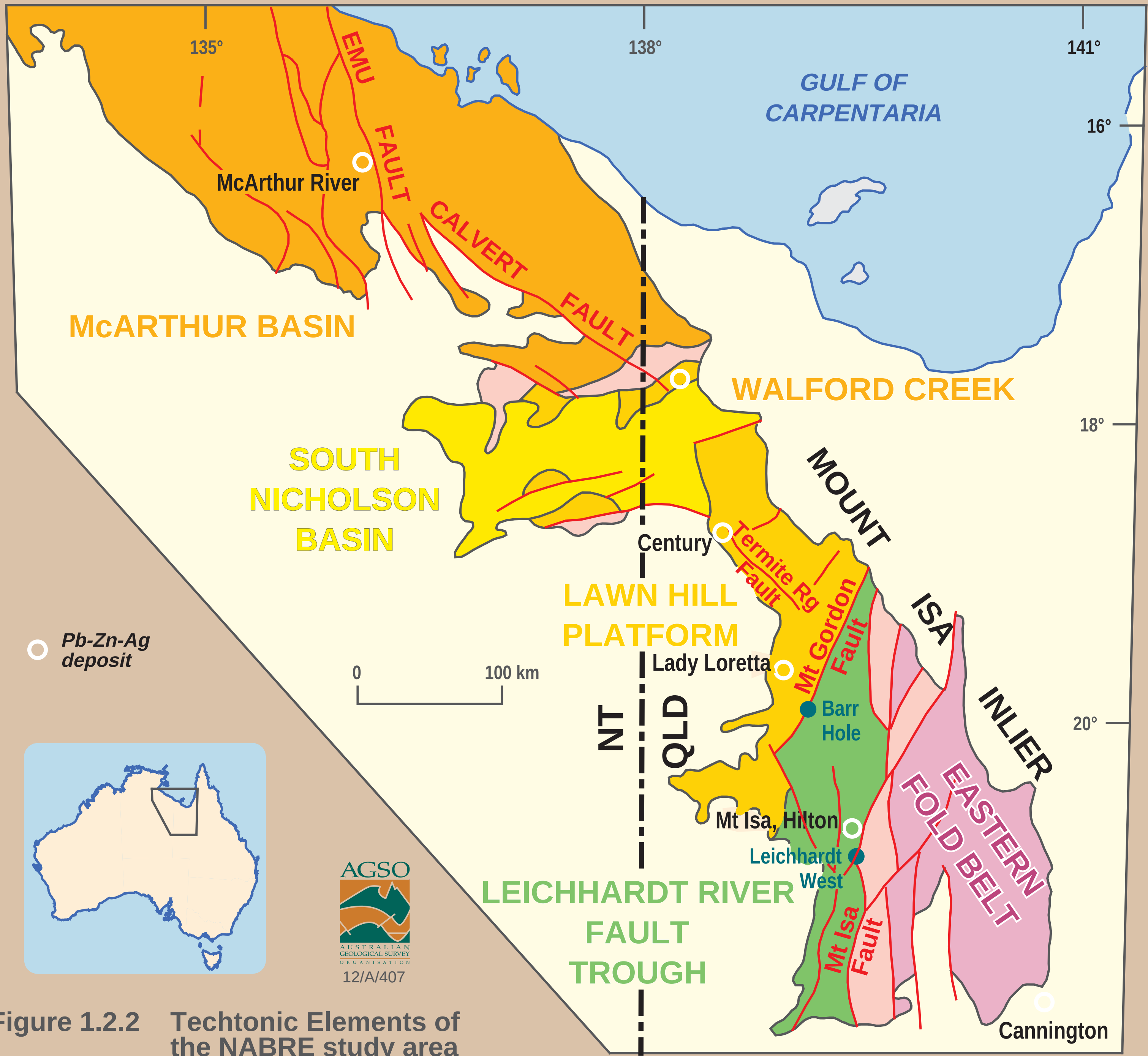

Figure 1.2.2 Techtonic Elements of the NABRE study area

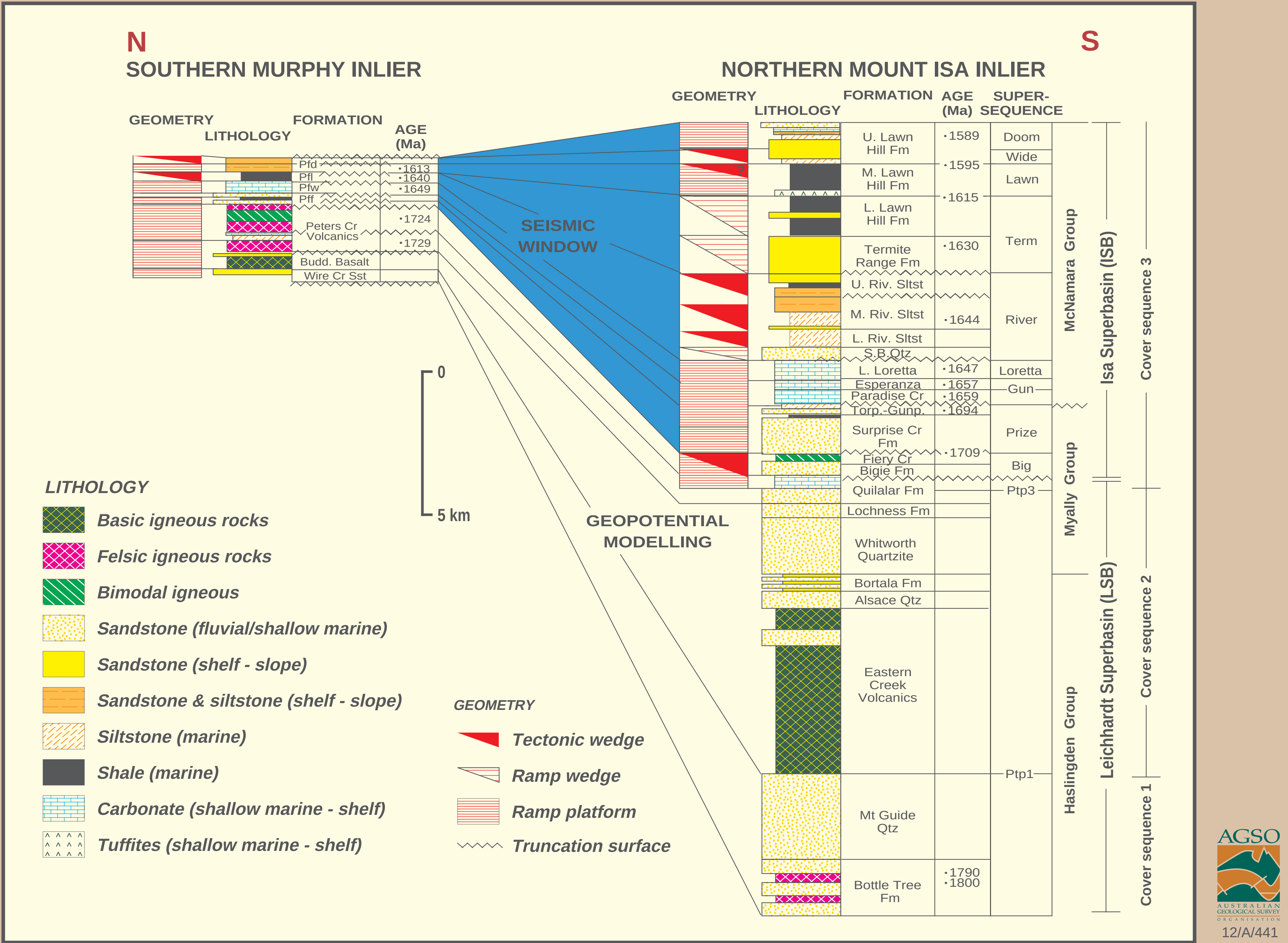

Figure 1.2.3 Correlation of basin events

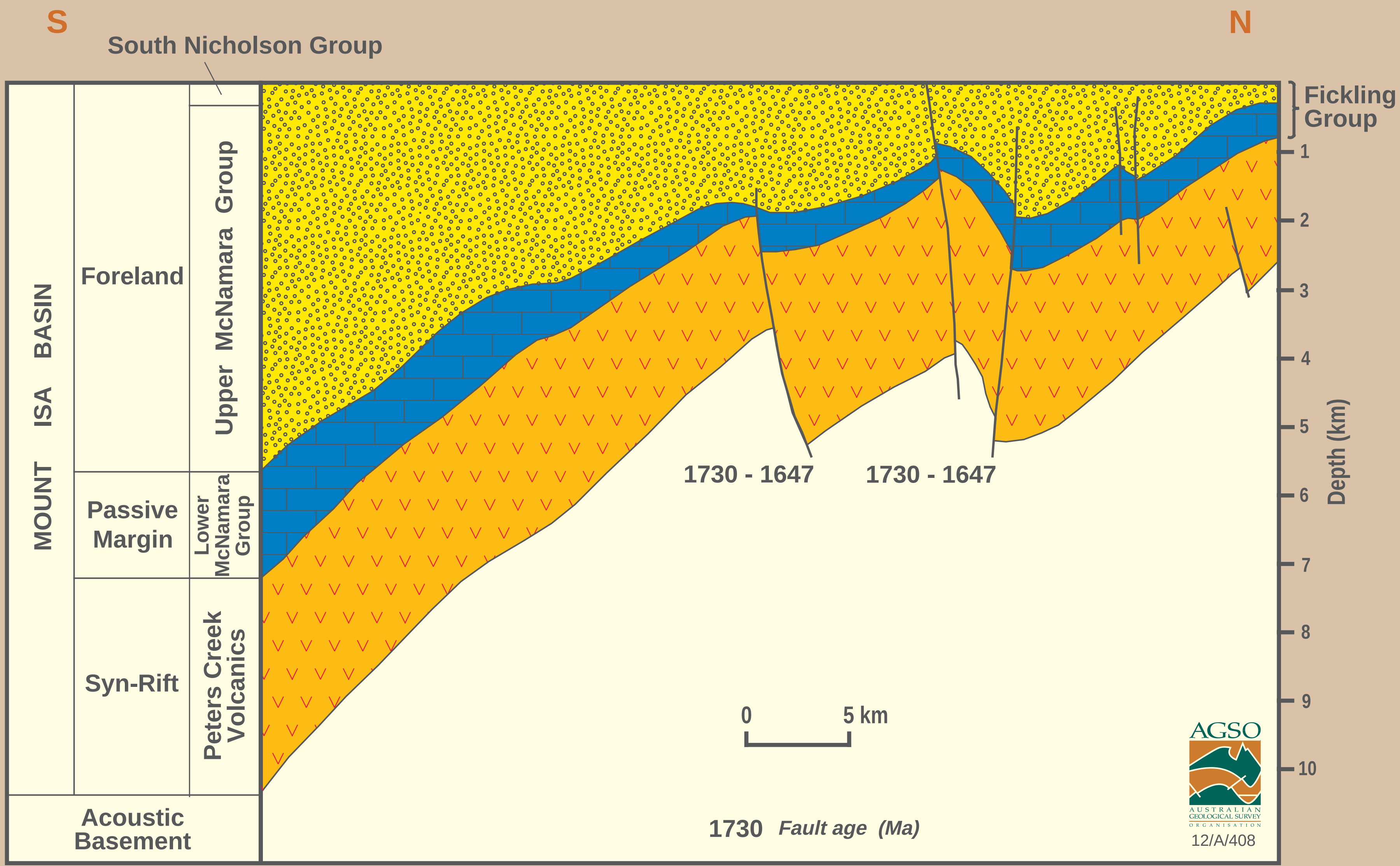

Figure 1.2.4 The "Mount Isa Basin"interpretation of McConachie et al. (1993)

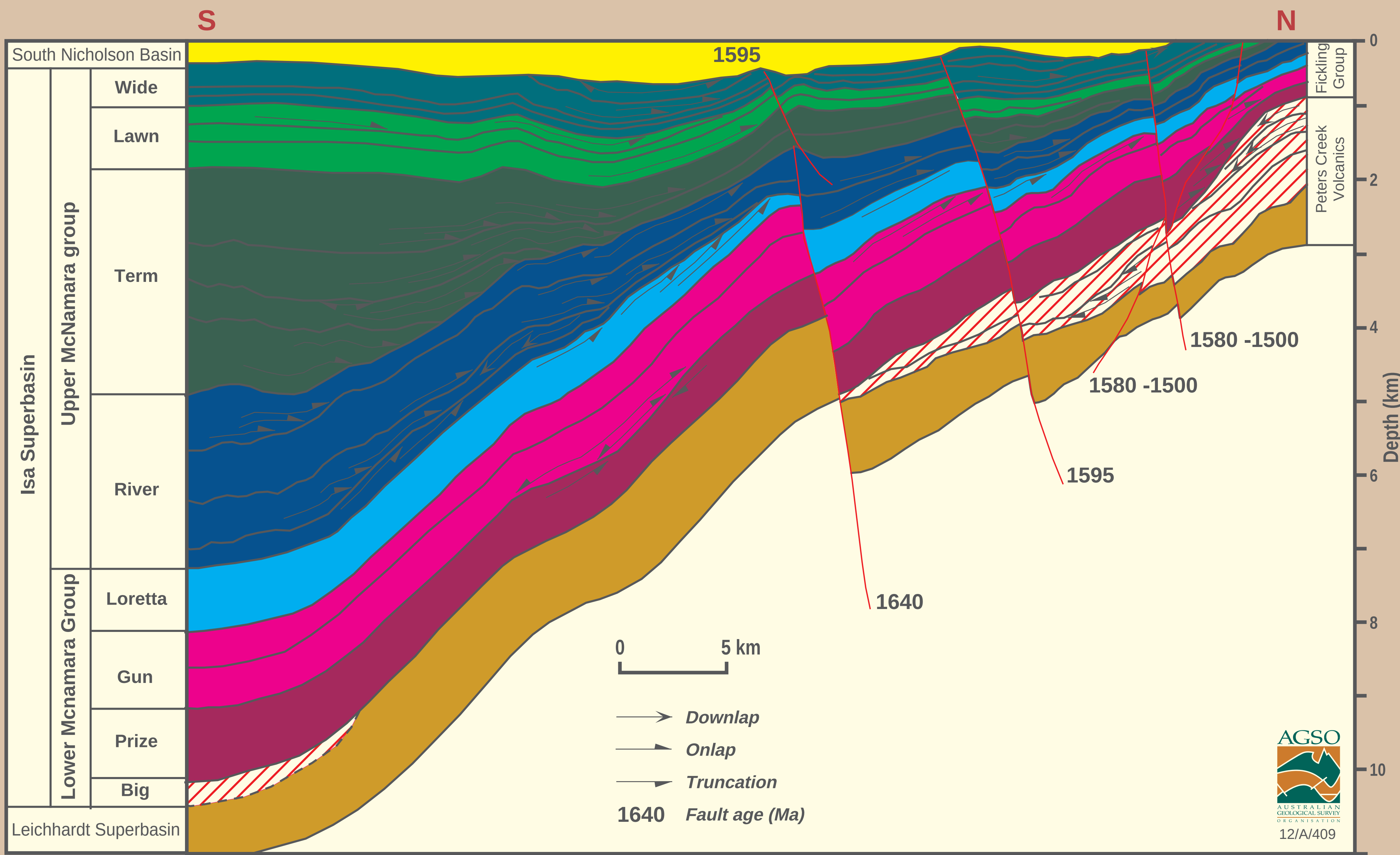

Figure 1.2.5 The Isa Superbasin interpretation of the Comalco seismic data

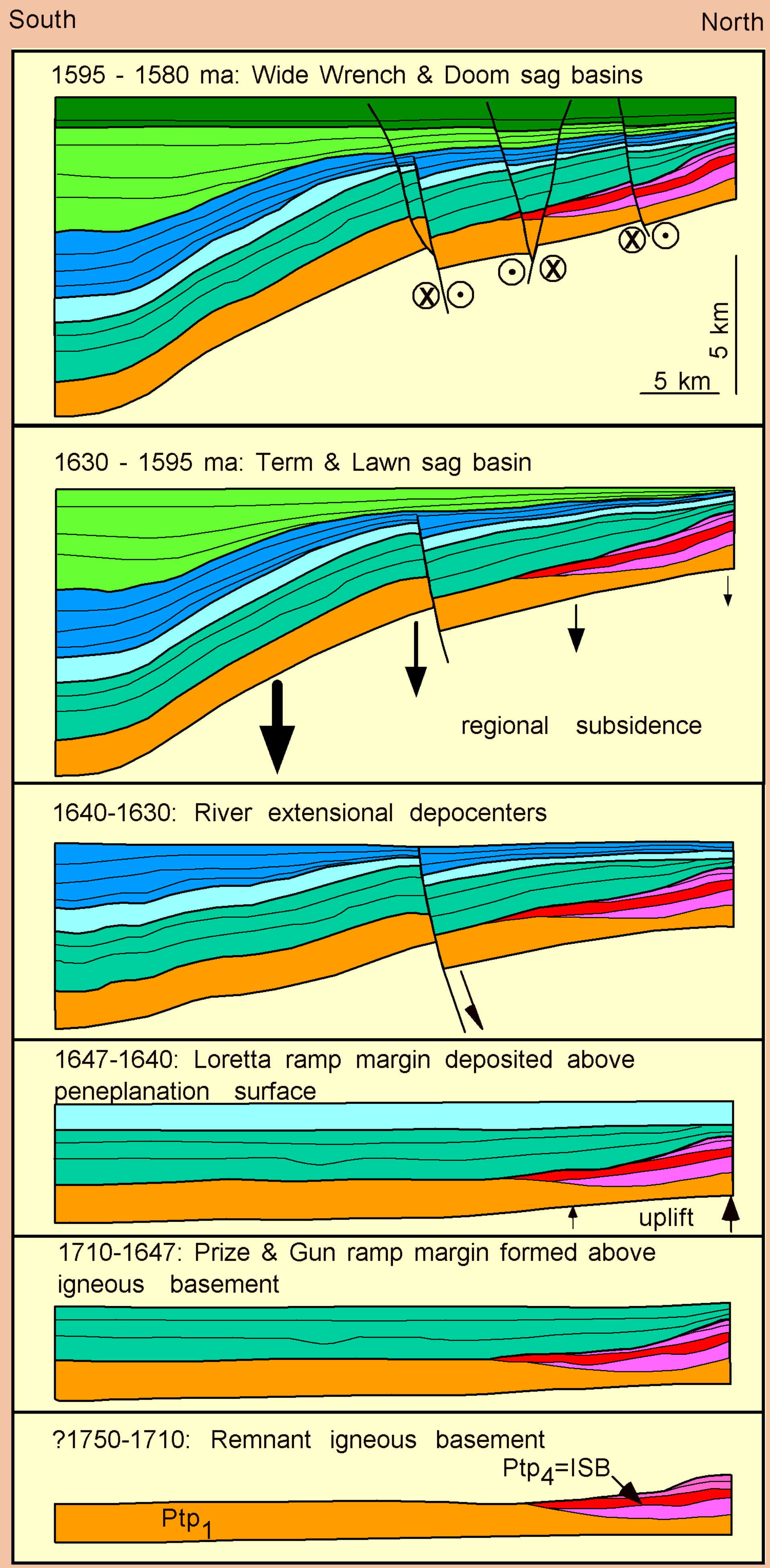

Figure 1.2.6 Basin phase reconstruction of the Isa Superbasin

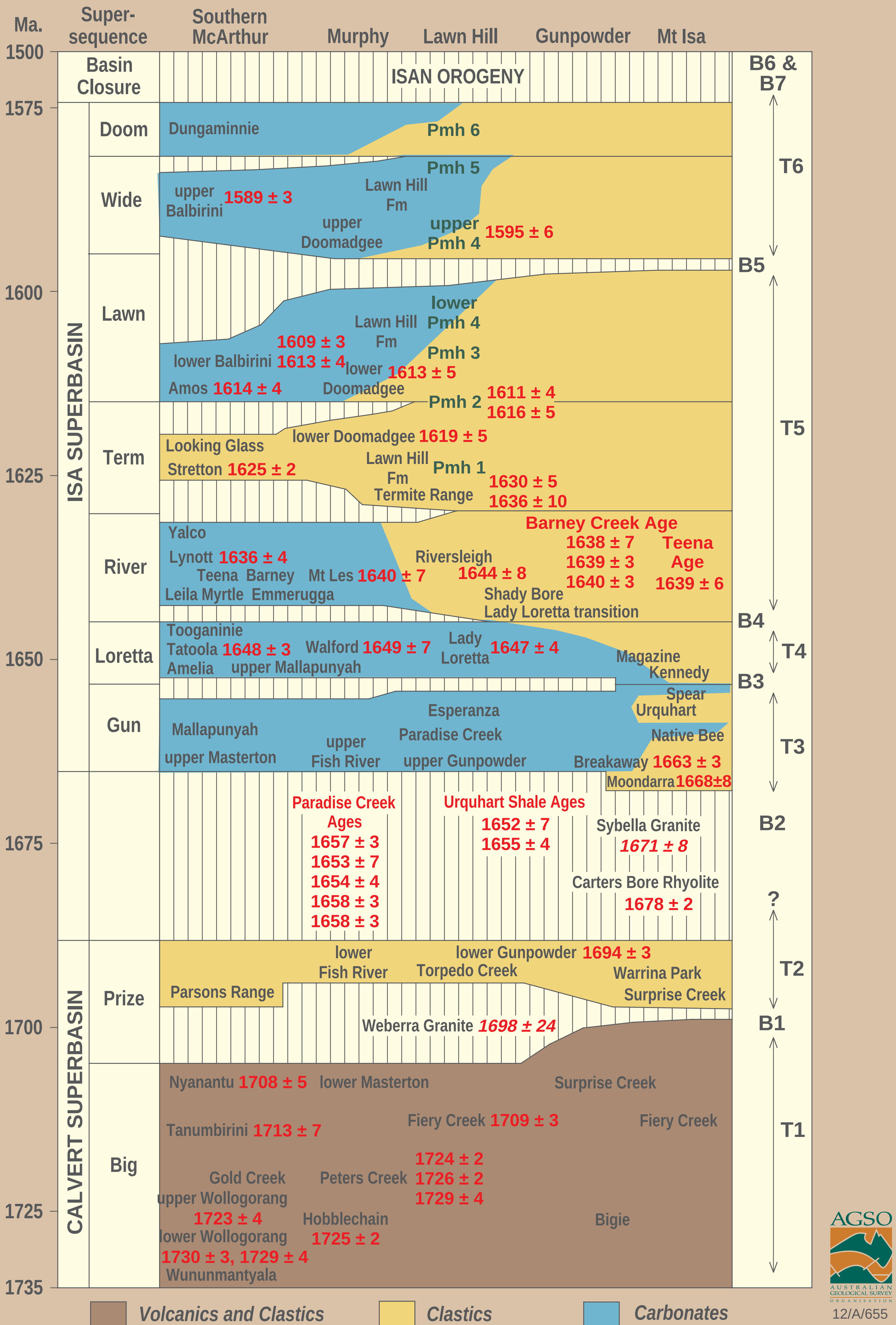

Figure 1.2.7 Basin Event Chart

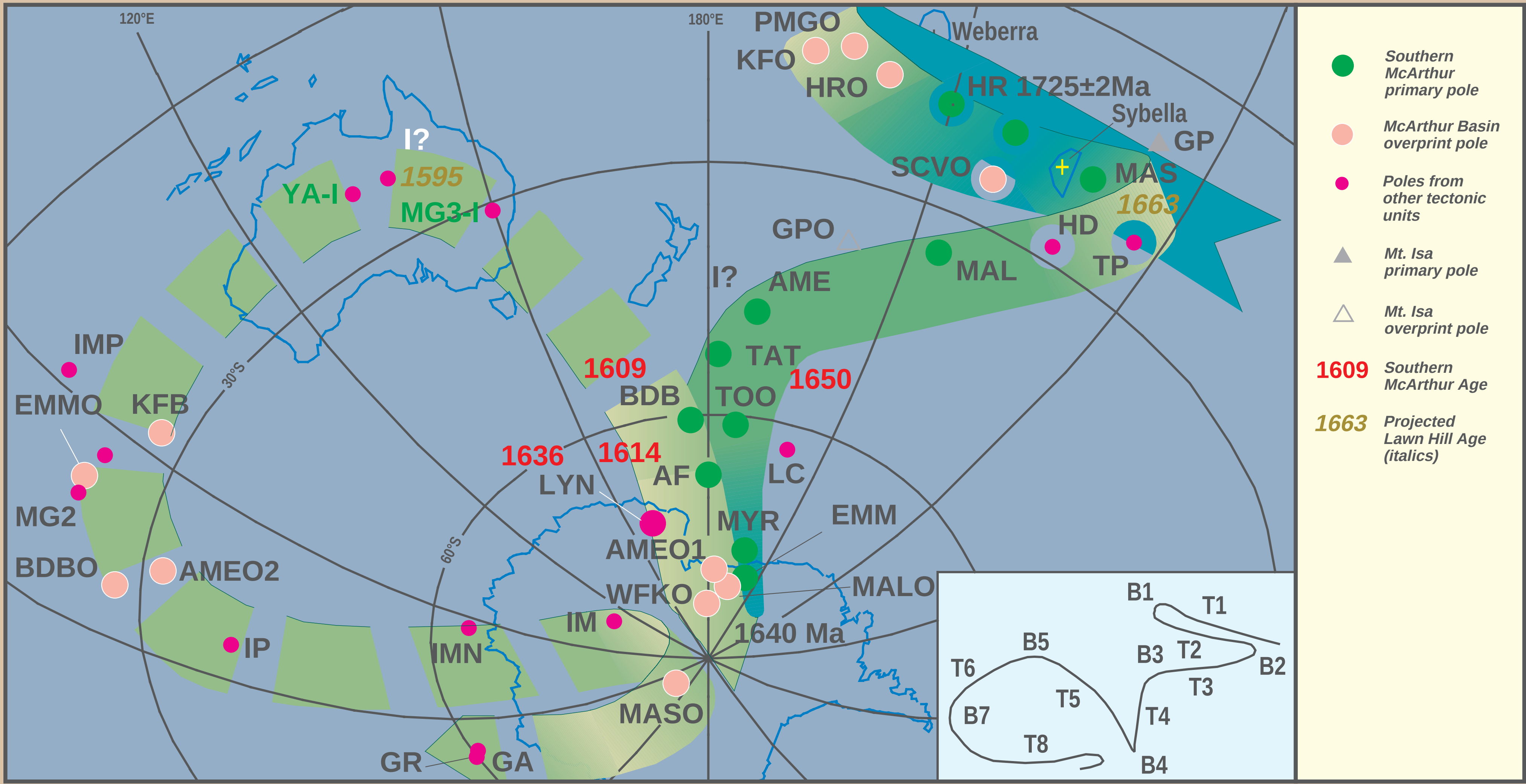

Figure 1.2.8 Apparent Polar Wander Path (APWP)

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20-7/368

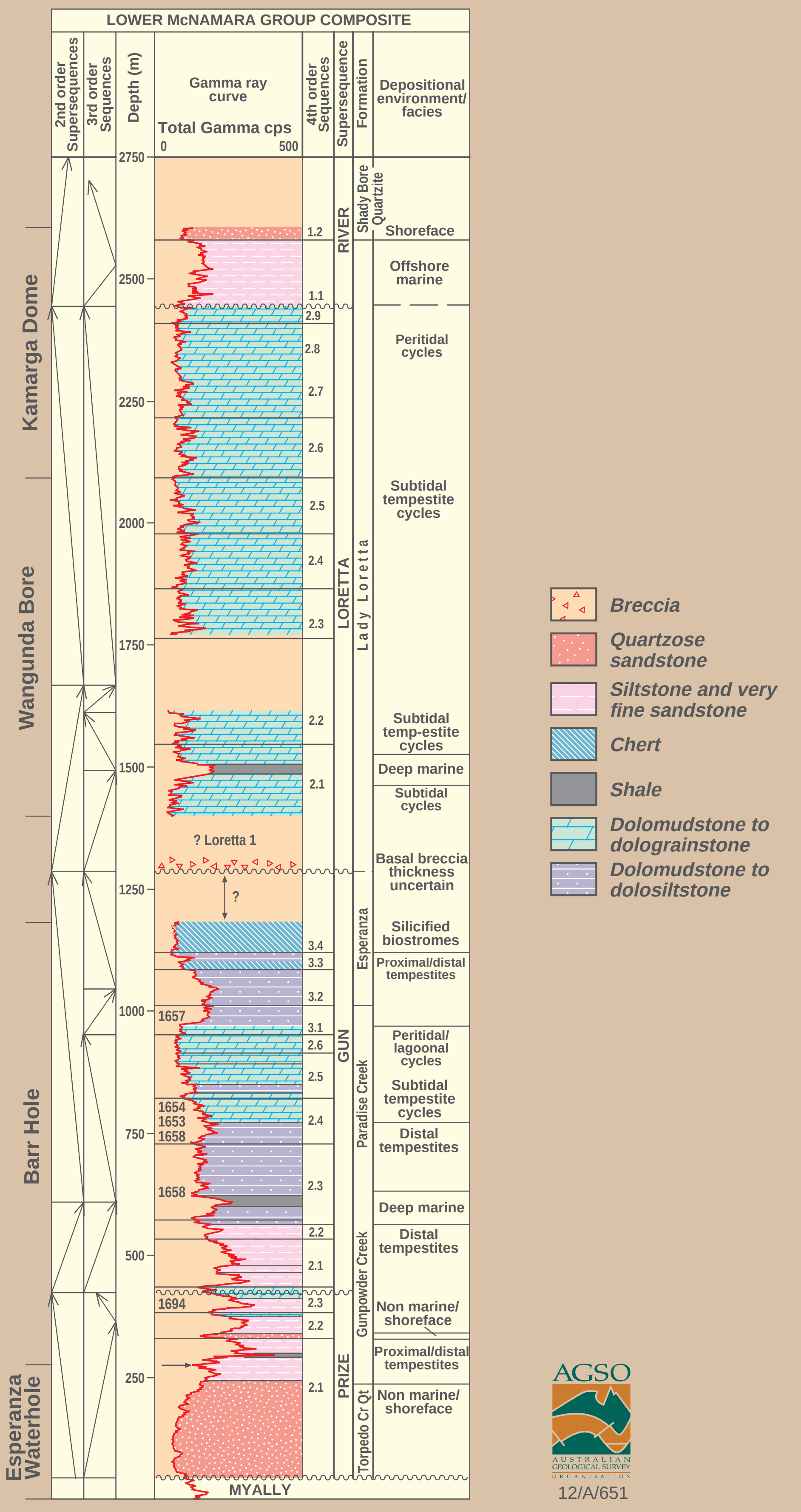

Figure 1.3.1 Lower McNamara Group Composite outcrop section for the upper Prize, Gun and Loretta Supersequences at Barr Hole, Wangunda Bore and Kamarga Dome on the Lawn Hill Platform

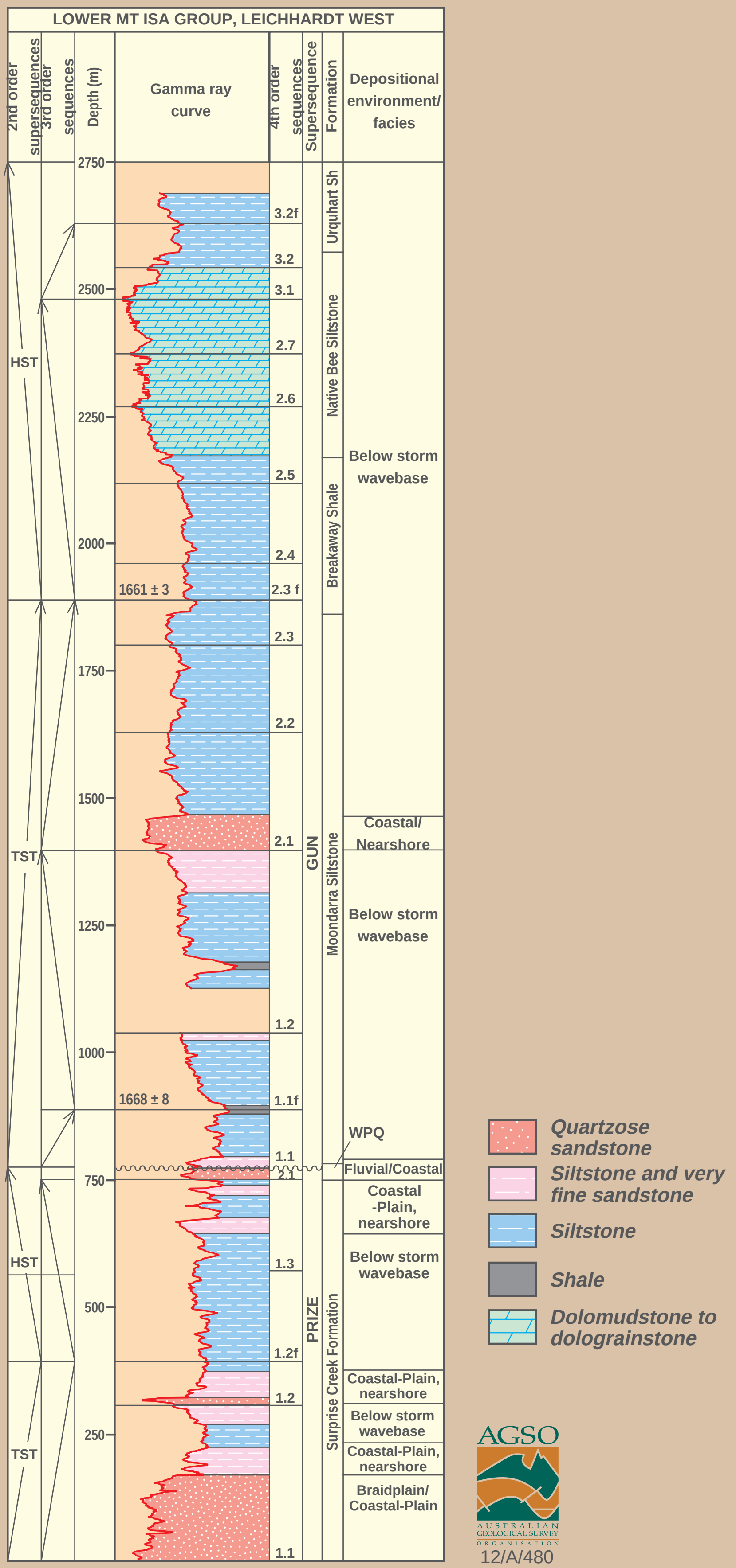

Figure 1.3.2 Lower McNamara Group Composite outcrop section for the lower Prize and lower Gun Supersequences at Leichhardt West in the Leichhardt River Fault Trough

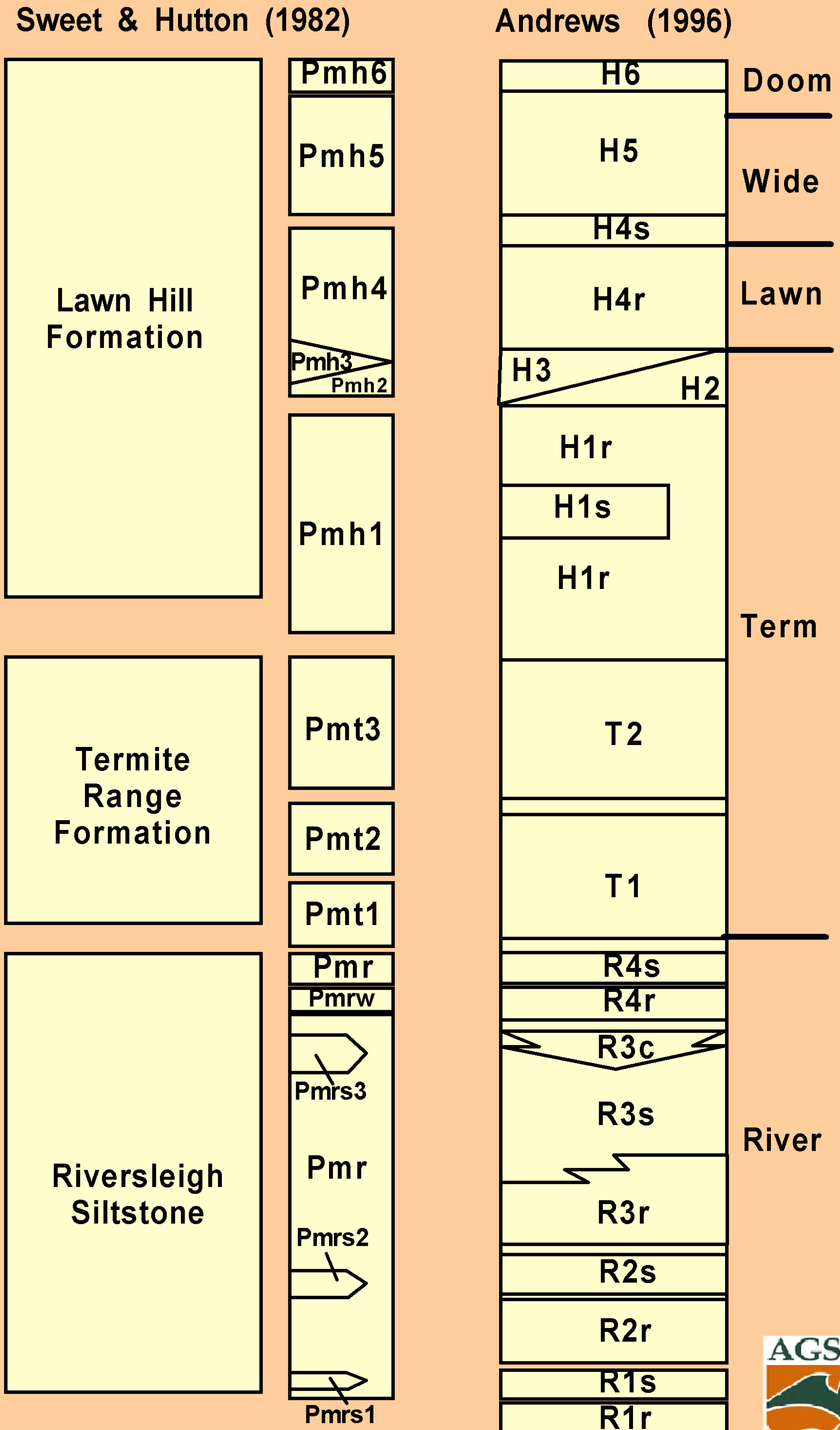

Figure 1.4.1 Upper McNamara Group lithostratigraphic nomenclature diagram correlating to the River, Term, Wide and Doom Supersequences

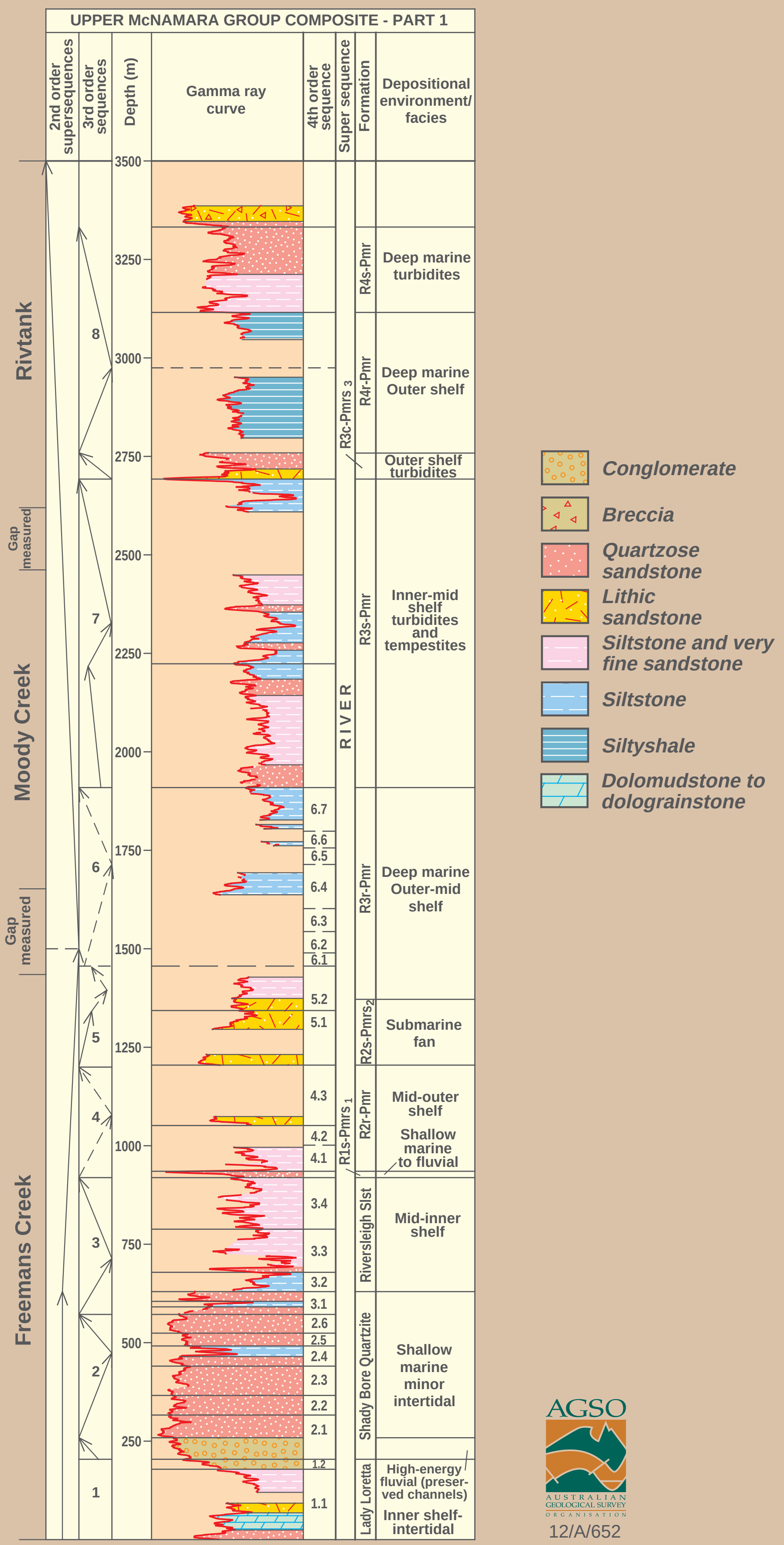

Figure 1.4.2 Composite gamma-ray and lithofacies logs for the River Supersequence

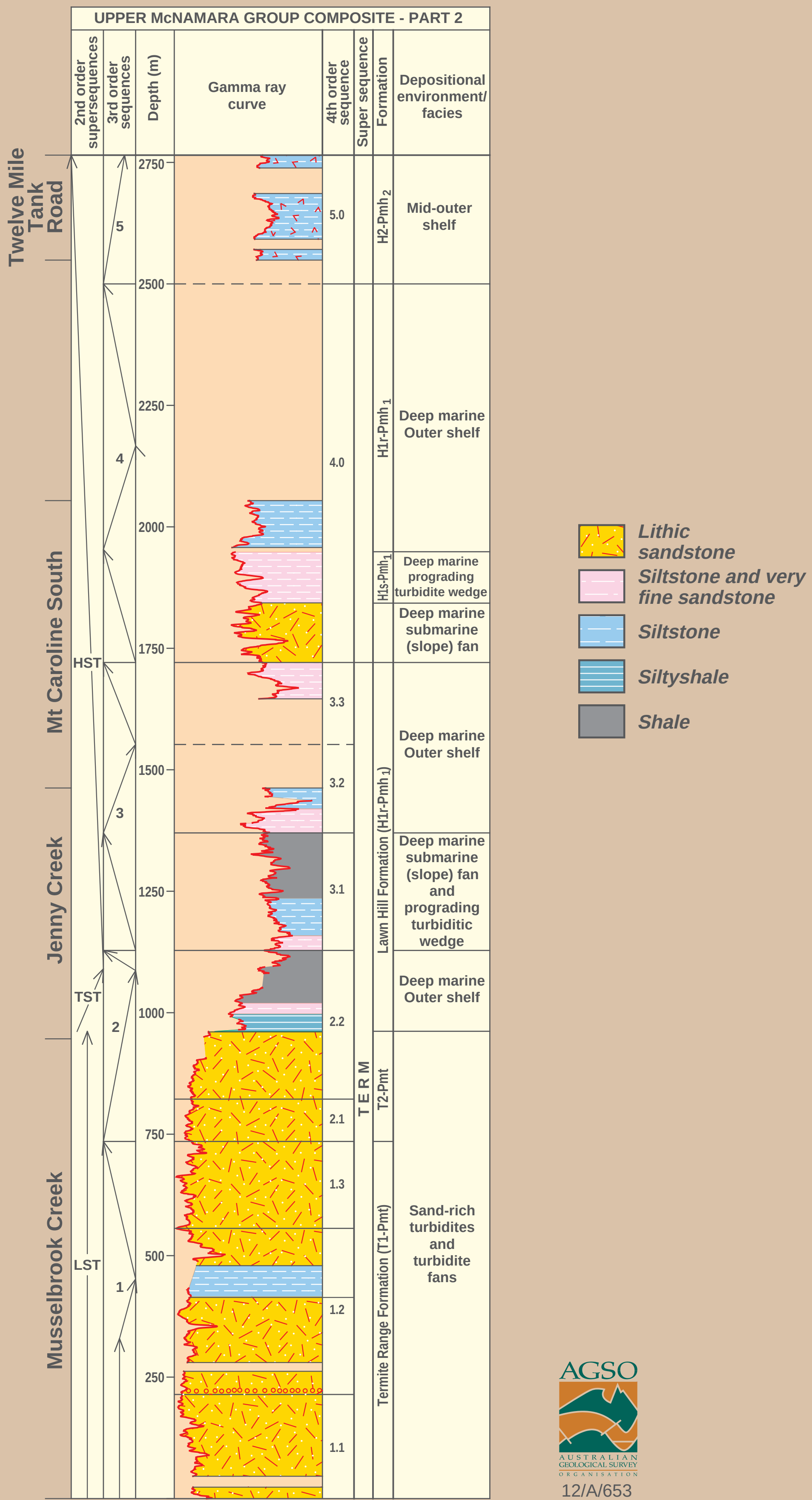

Figure 1.4.3 Composite gamma-ray and lithofacies logs for the Term Supersequence

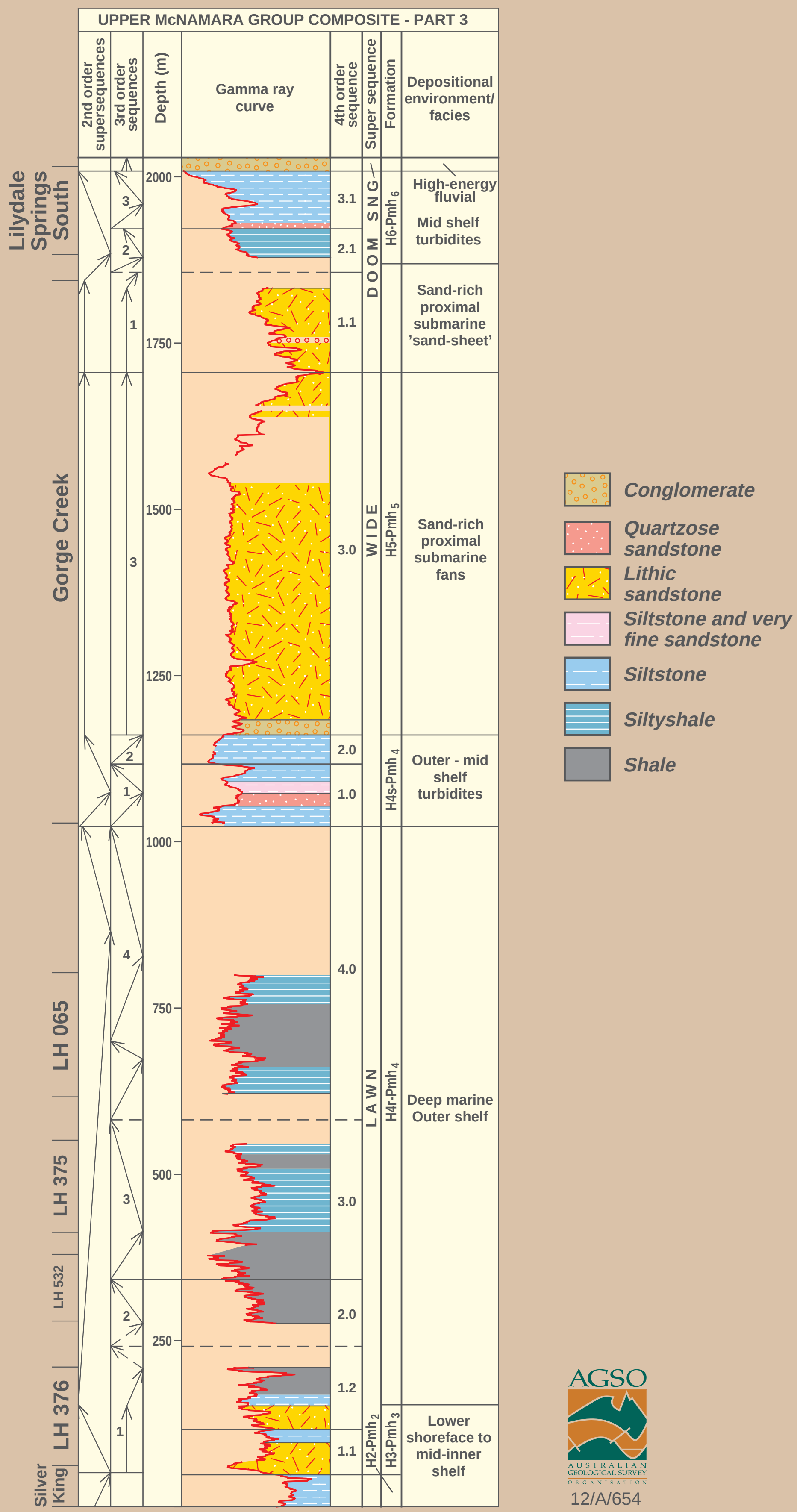

Figure 1.4.4 Composite gamma-ray and lithofacies logs for the Lawn, Wide and Doom Supersequences

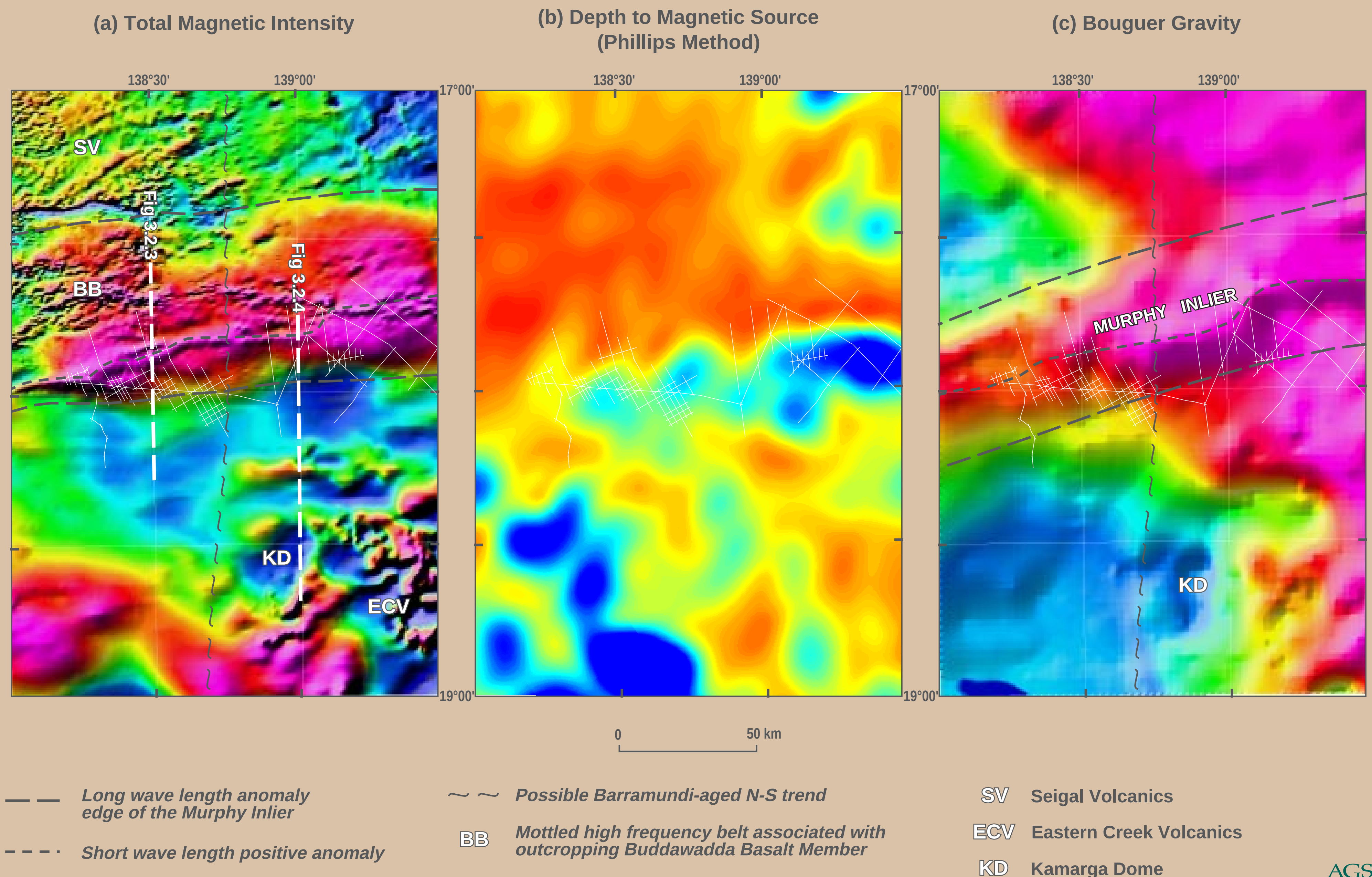

Figure 1.5.1 Geophysical images of the Westmoreland and Lawn Hill 1:250,000 map sheet area (a) Total Magnetic Intensity Image (b) Depth to magnetic sources using the Phillips Deconvolution Method (c) Bouguer Gravity Image

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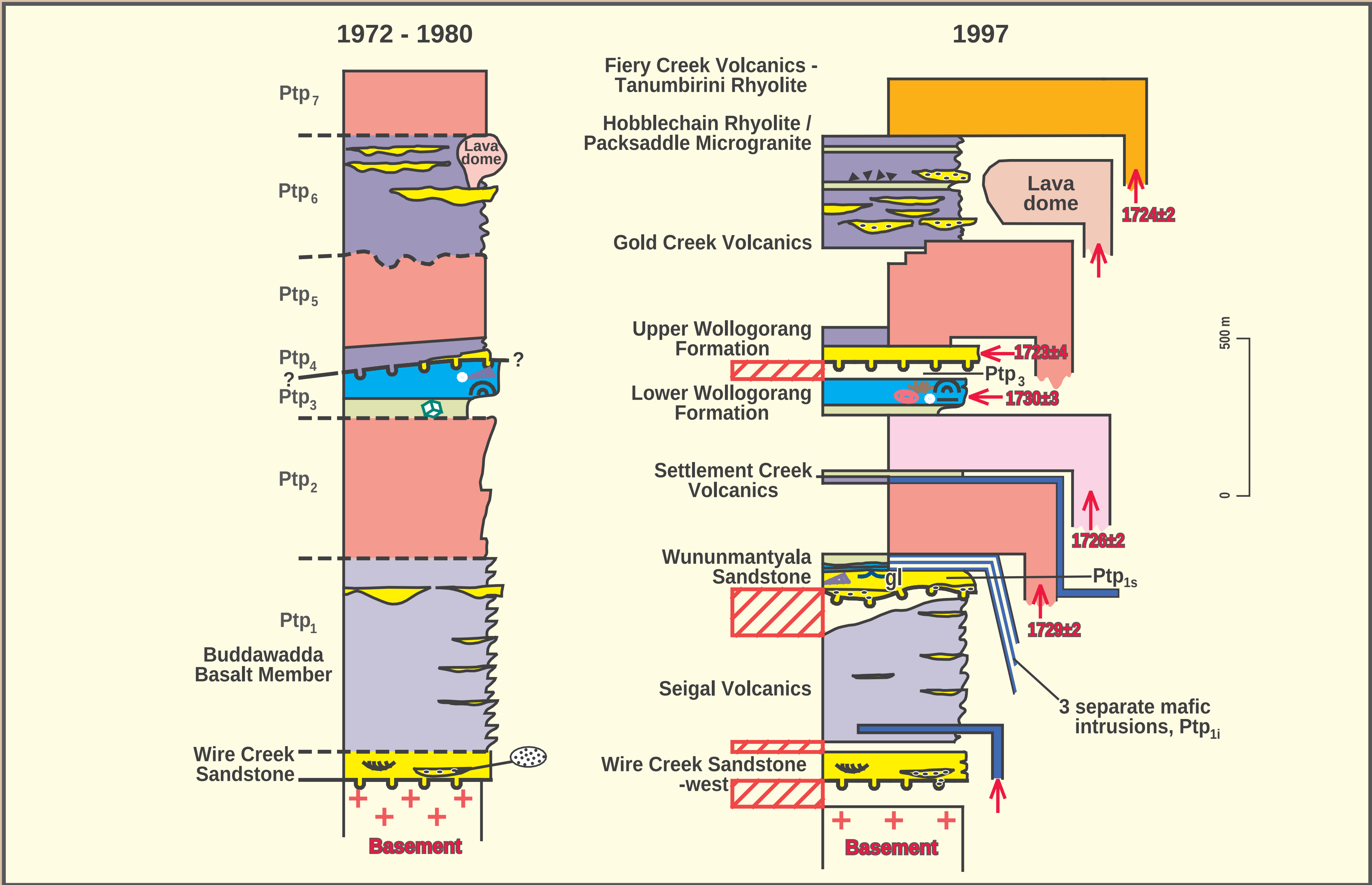

Figure 1.5.2 Stratigraphic columns elucidating the changes to the traditional understanding of the Peters Creek Volcanics on the left resulting from integration of recent regional U-Pb SHRIMP geochronology, palaeomagnetic and field investigations focussed on the Murphy Inlier with existing geochemical and geological data

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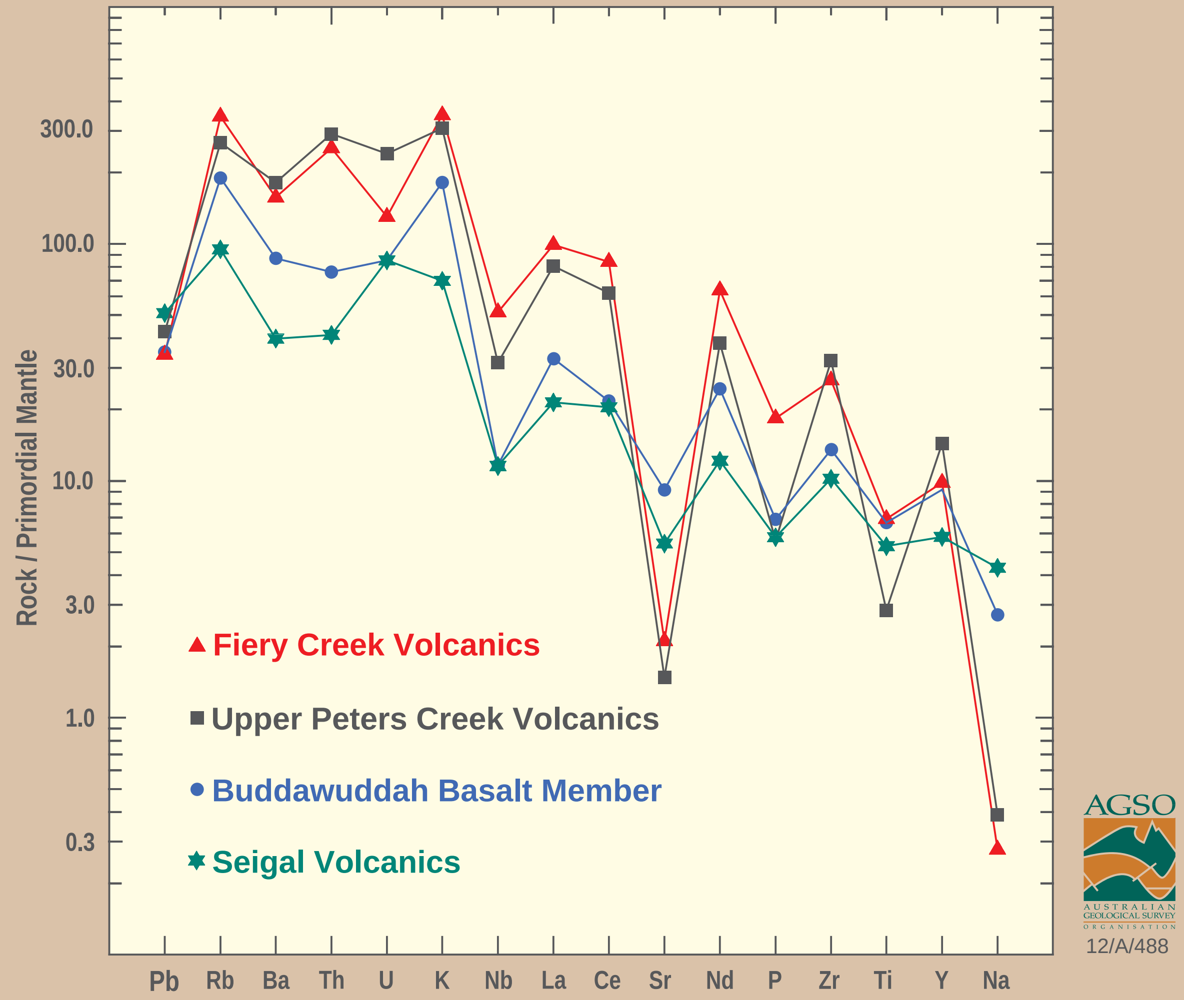

Figure 1.5.3 'Spider' diagram of relative element abundances of the Seigal, Fiery Creek and Peters Creek Volcanics. The Buddawadda Basalt member of the Peters Creek is shown separately from members 2-7. Note the affinity between the Buddawadda Basalt and the Seigal Volcanics and their differences to the upper Peters Creek and Fiery Creek Volcanics that also show strong geochemical affinity

Peters Creek Volcanics (PCV)

NORTHERN Megawedge	Extrusive	Intrusive	Felsic	Mafic	Sediment	Geochem	Paleomag	Geochron (Ma)	SOUTHERN Megawedge
	x	X	X			G3		1709±3	FCV
Ptp 7	X		X			G3	P2b	1724±2	
Ptp 6	X	x		X	x	G2	P2b		
	X	x		X	x	G2	P2c		FCV
Ptp 5		X	X			G3	P2b		
Ptp 4	X			X					
	?x	?x		x	X				Quilalar Fm
Ptp 3					X			~1730±4	
Ptp 2		X	X			G3		{1726±2 1729±4	
Ptp 1i		X		X		G2	P2a		
uncon					X		P1		Lochness Fm
Ptp 1	X			X		G1	P(op)		
	X			X		G1			ECV

Haslingden Group

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Figure 1.5.4 Comparison of historical and recent NABRE geochronological, geochemical, palaeomagnetic and geological data for the igneous units from the north and south outcrop belts around the seismic grid. Geochemical data are grouped (G1 to G3) by compositional affinities (Mackenzie, unpubl.). Palaeomagnetic poles are labelled with a relative age (1>2, a>b>c) as determined by their positions in the apparent polar-wander path (APWP). P(op) = overprint, no primary pole is available; the P2c pole of the FCV appears to be younger than the Ptp $_{5\text{-}7}$pole; the sample was obtaine dfrom a section where no Quilalar or felsic FCV are preserved. Geochronological data are obtained from U-Pb SHRIMP analysis of samples from the indicated units, except for Ptp $_3$, which is estimated from ages obtained from correlative lower Wollogorang Formation. uncon = unconformity established by recent field work. X = major component or mode of emplacement; x = minor component or mode of emplacement

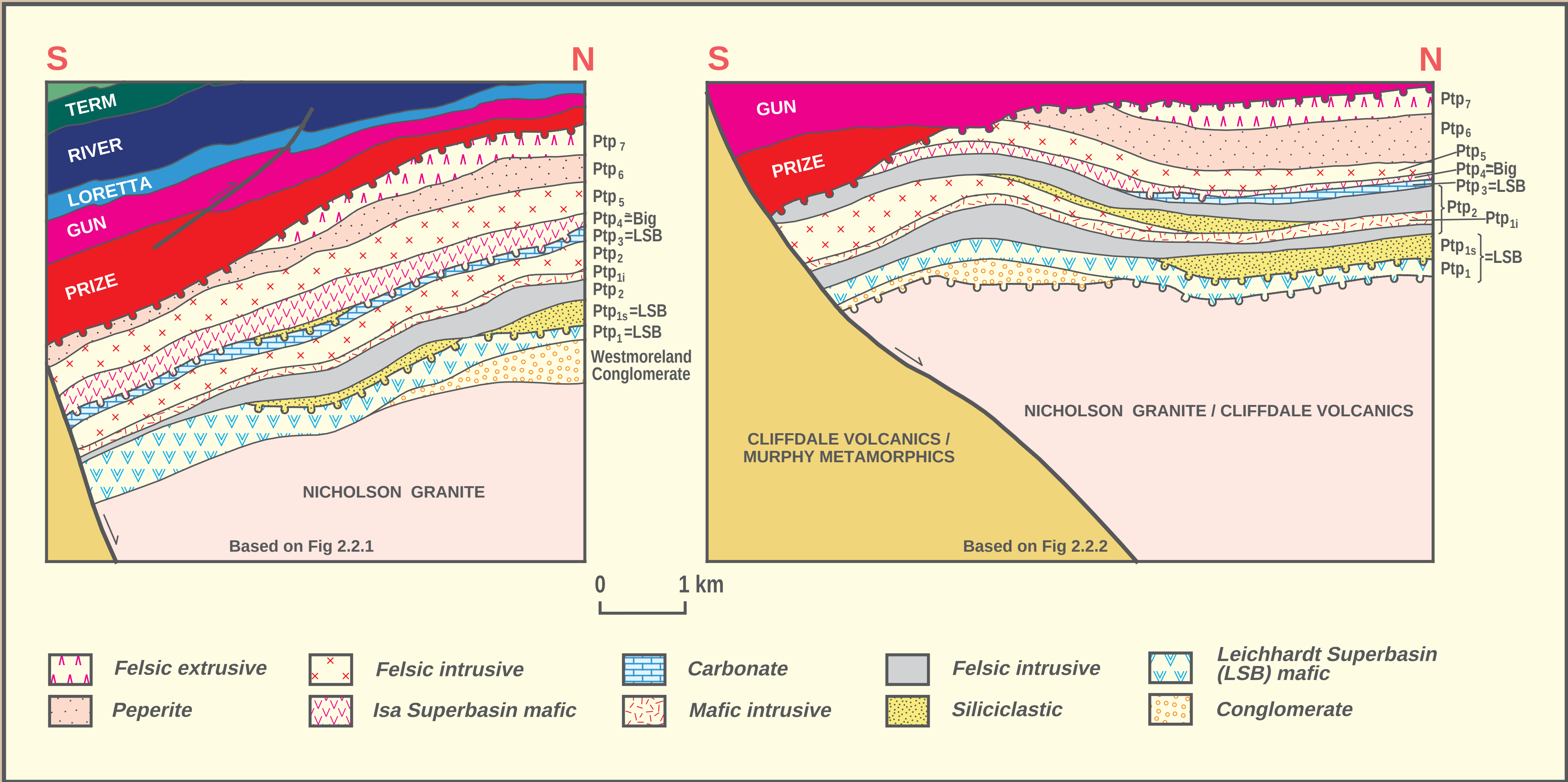

Figure 1.5.5 Geological interpretations of the seismic data (Figs. 2.2.1 and 2.2.2) that image the Murphy Inlier. To view the regional context of these interpretations the reader is referred to the regional composite profiles provided in Figs. 2.1.2 and 2.1.3. Schematic interpretations of the relationship of the Murphy Inlier and the Peters Creek Volcanics to the Isa Superbasin found in Figs. 1.2.3, 1.2.5 and 1.2.8

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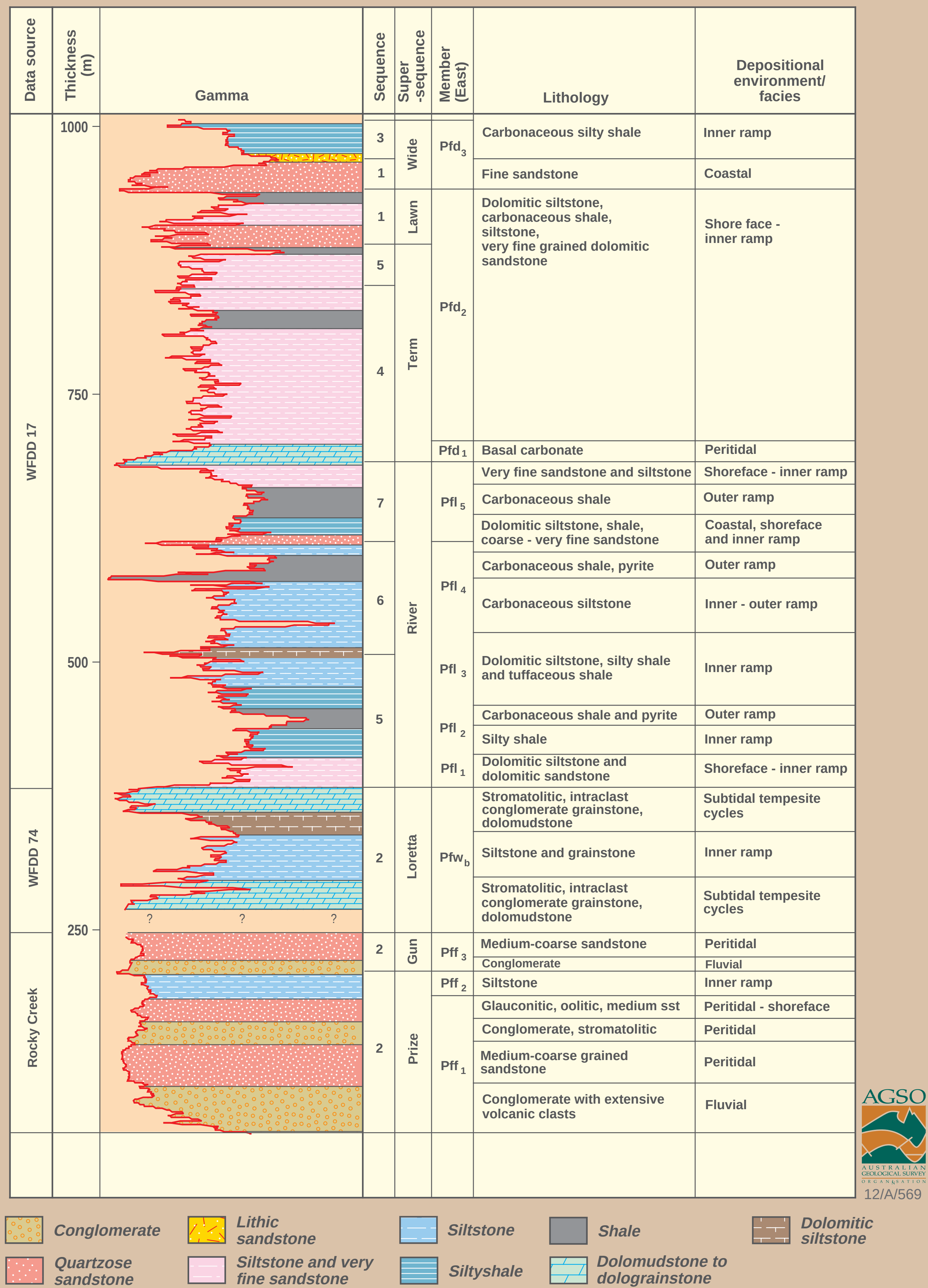

Figure 1.6.1 Sequence stratigraphy of the Fickling Group, eastern Murphy Inlier, based on analysis of composite gamma curve and lithofacies trends

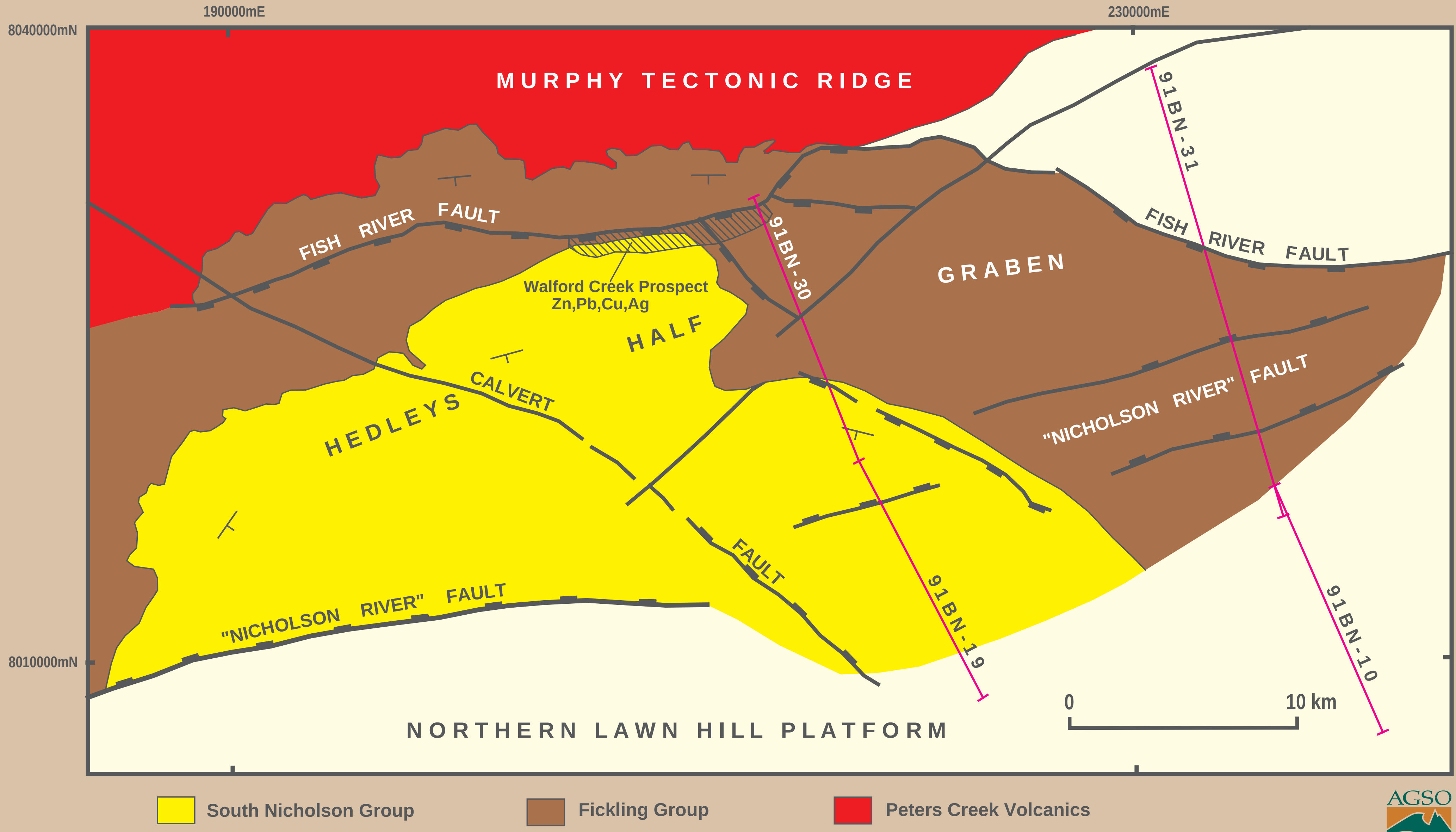

Figure 1.6.2 Map of the Murphy Inlier and Fickling Group showing major faults, outcrop section locations and mineral prospect areas referred to in the text

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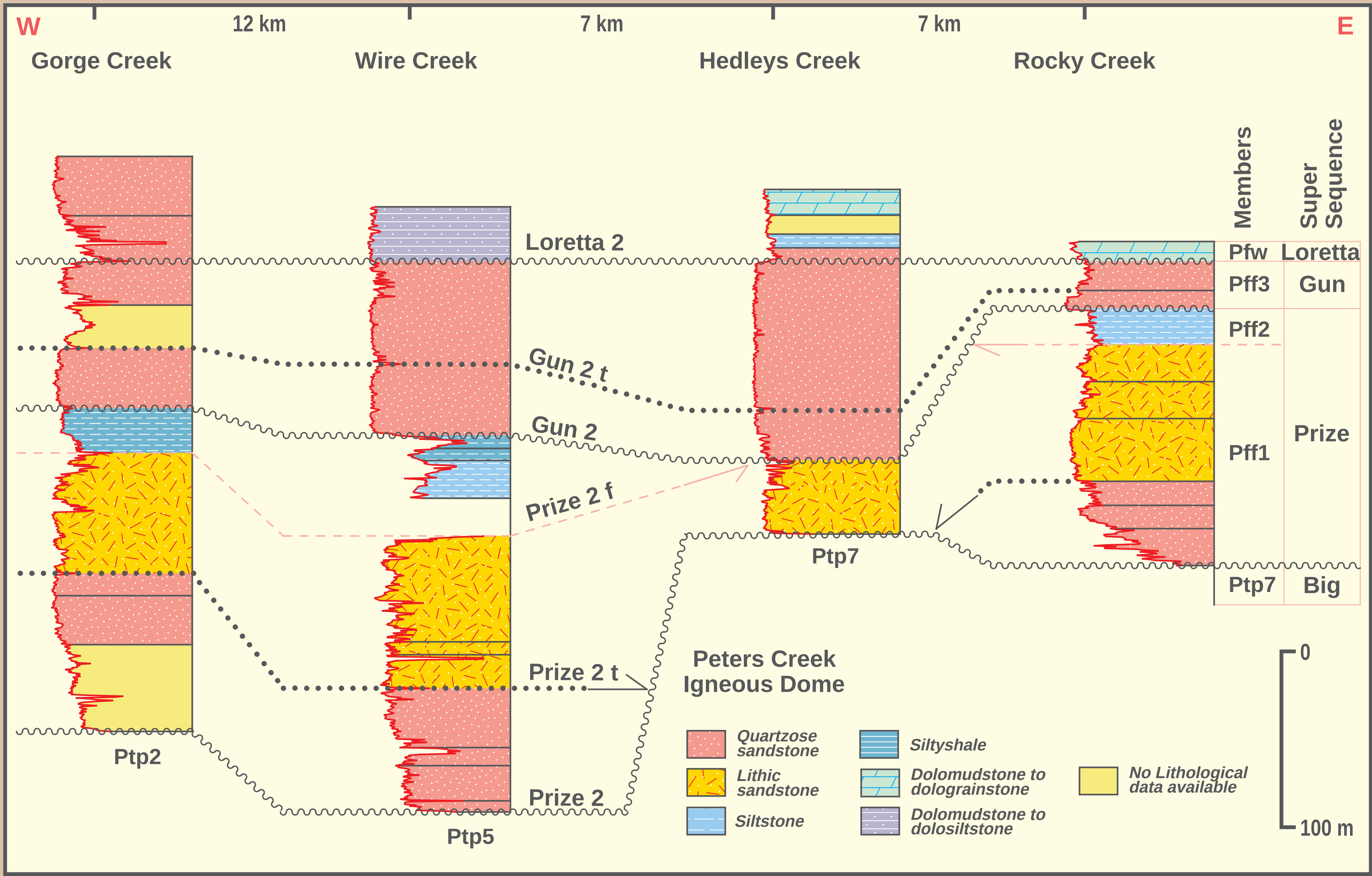

Figure 1.6.3 Cross-section of outcrop logs of the Prize and Gun Supersequences (Fish River Formation) along the Murphy Inlier

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12/A/557

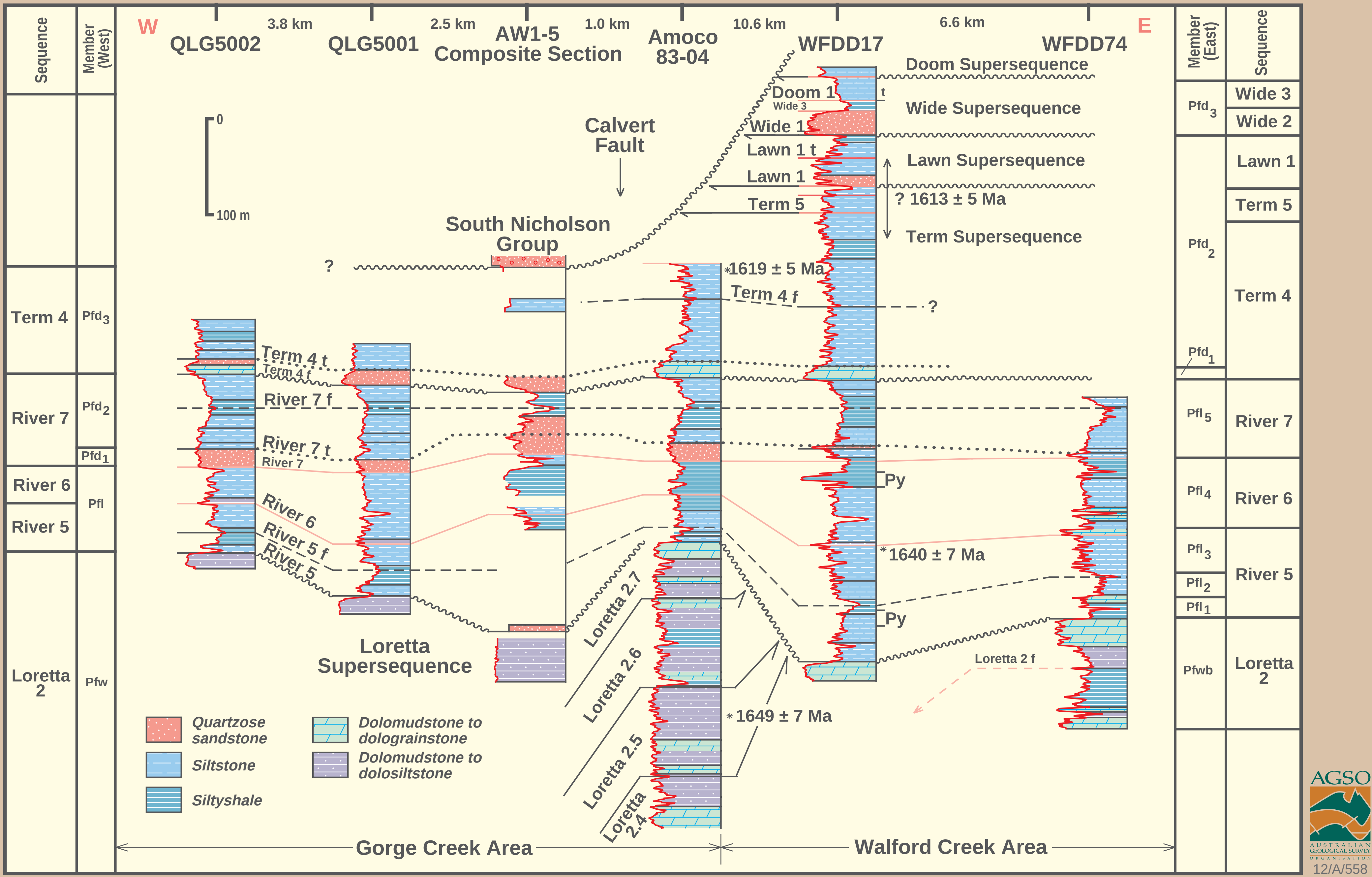

Figure 1.6.4 Cross-section of the Loretta through Doom Supersequences along the Murphy Inlier

approximate beginning of Argyle Creek seismic composite section

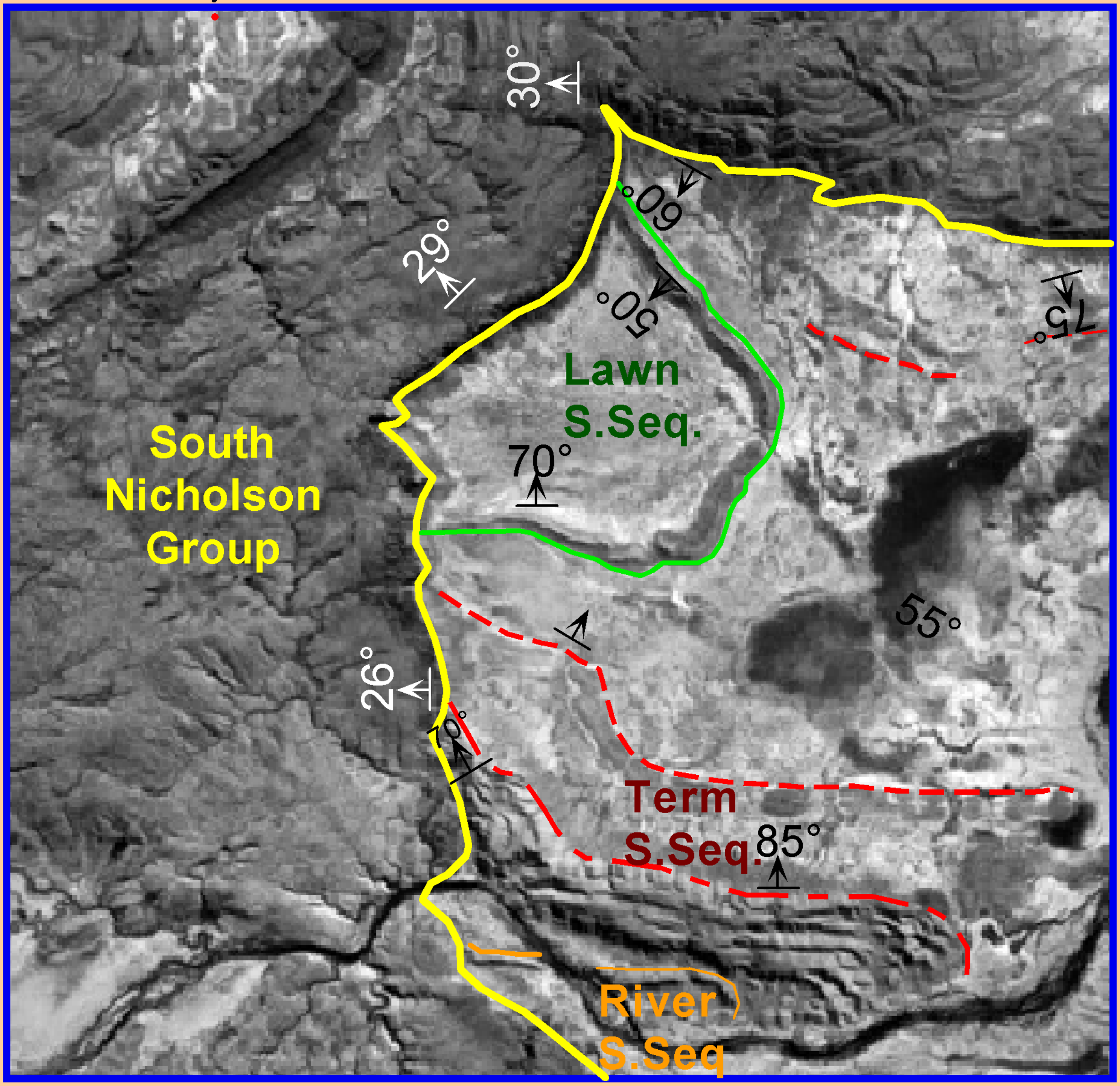

Figure 1.7.1 Aerial photo interpretation of the angular unconformity at the base of the South Nicholson Group or Basin, 10km south of Elizabeth Creek

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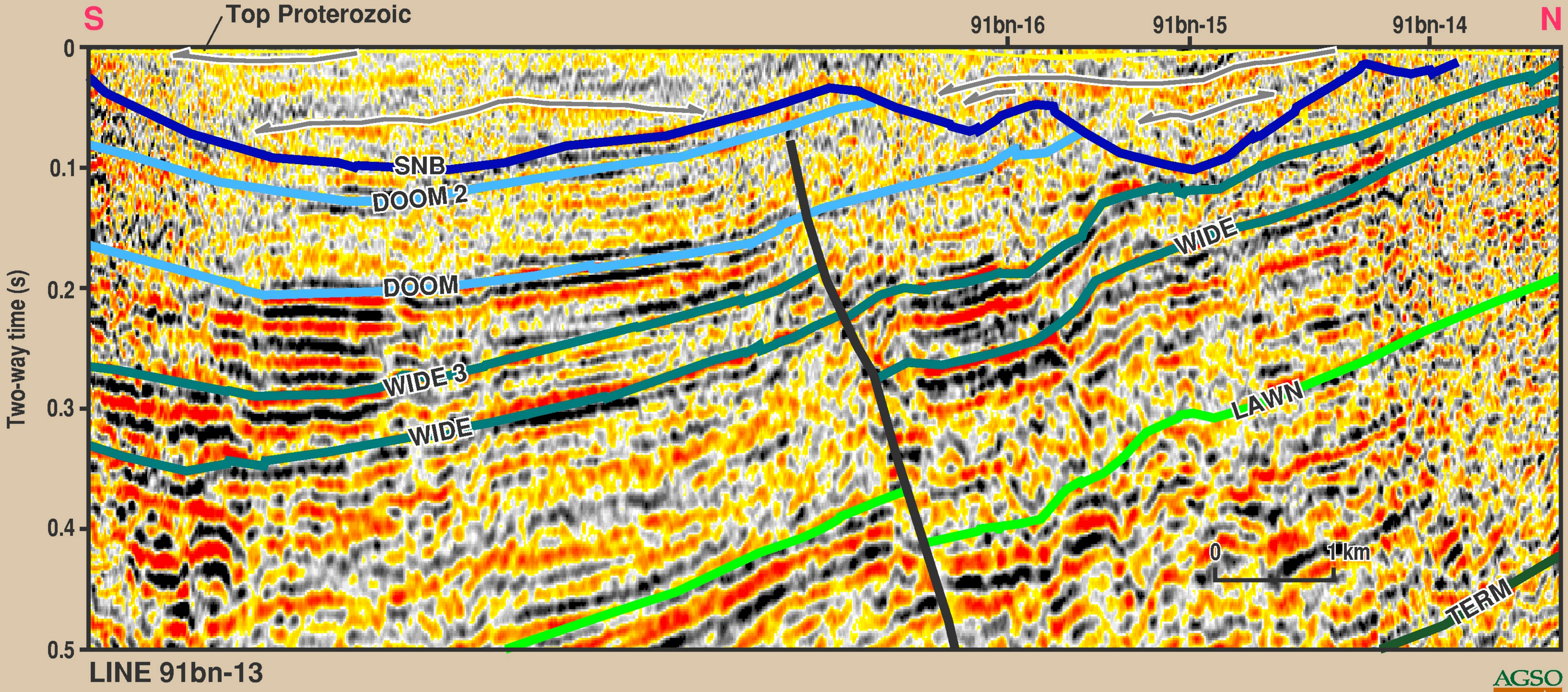

Figure 1.7.2 Seismic geometry of South Nicholson Basin (SNB) overlying the Isa Superbasin in northwestern Lawn Hill Platform. The base of the South Nicholson Group is erosional, and most of the Doom Supersequence has been removed

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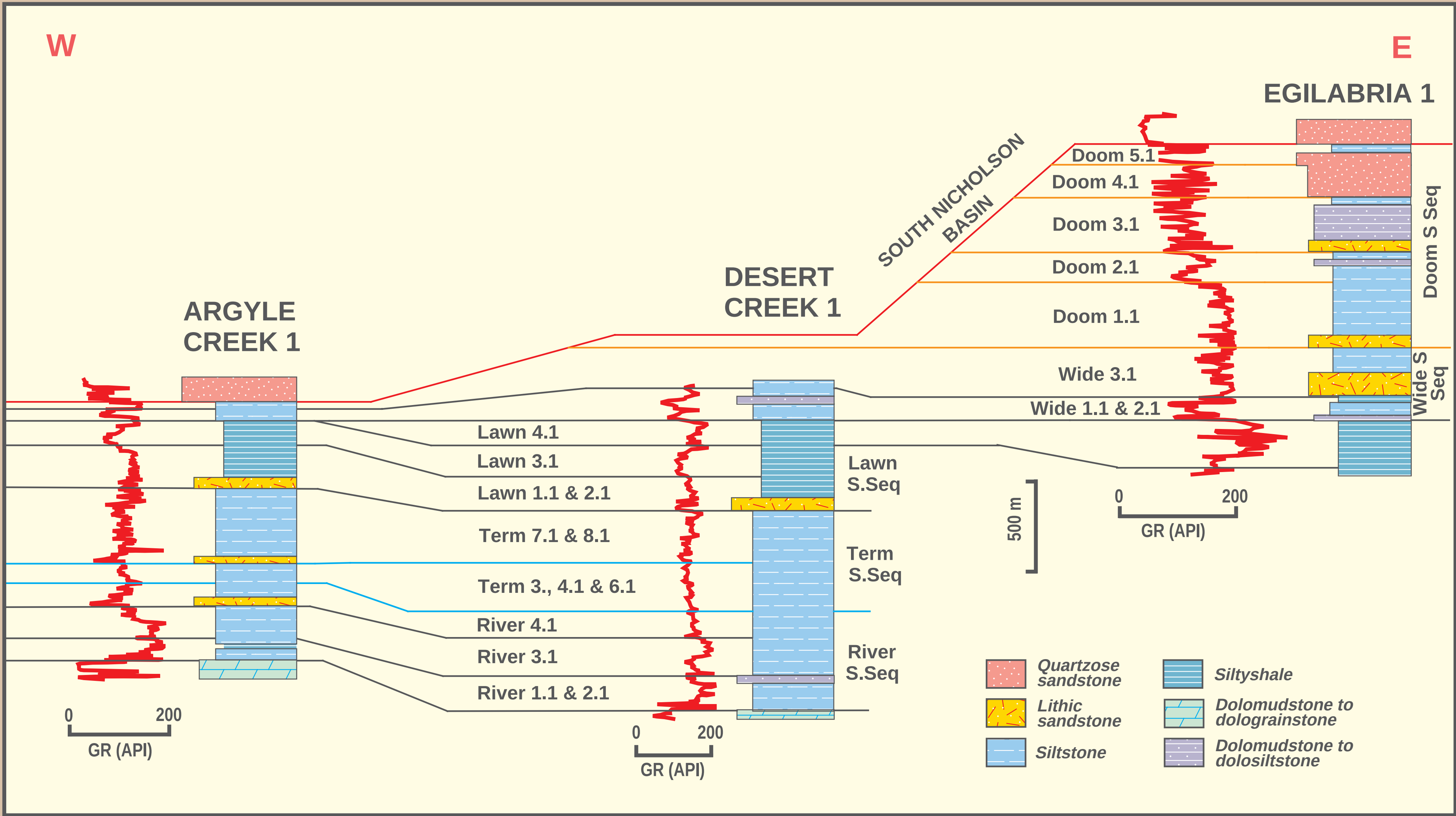

Figure 1.7.3 Evidence for extensive erosion of Isa Superbasin beneath the South Nicholson Group in Comalco well log data

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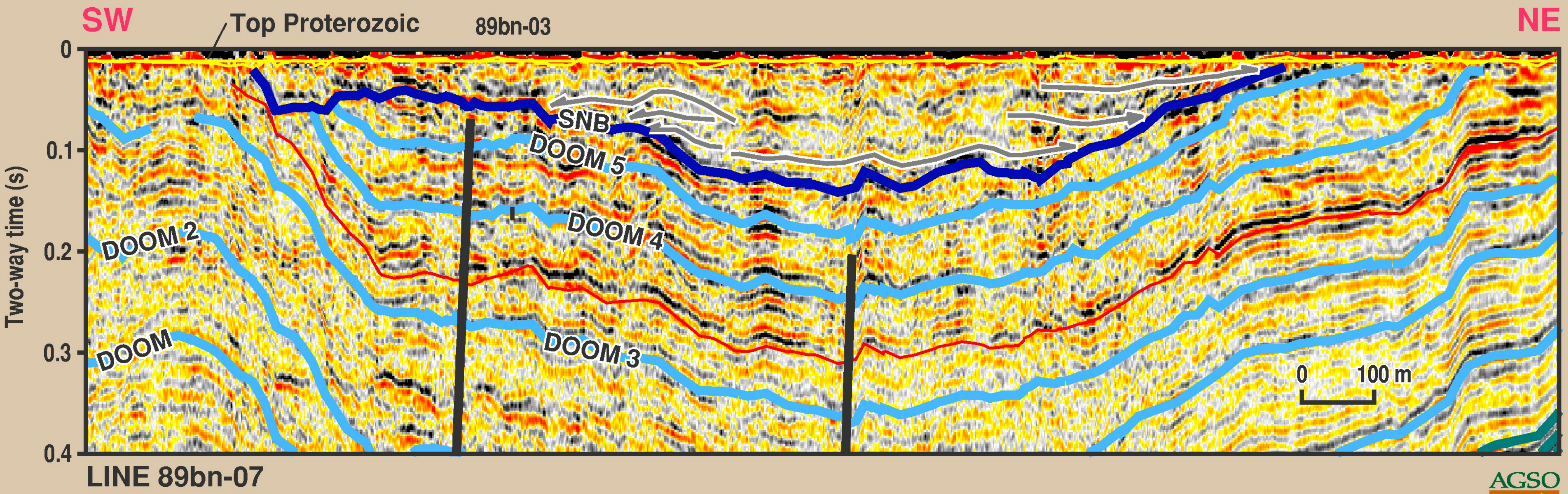

Figure 1.7.4 Seismic example of locally conformable relationship between South Nicholson Group (SNB) and Isa Superbasin. This relationship suggests deposition of the SNB commenced before deformation caused topography was fully peneplaned

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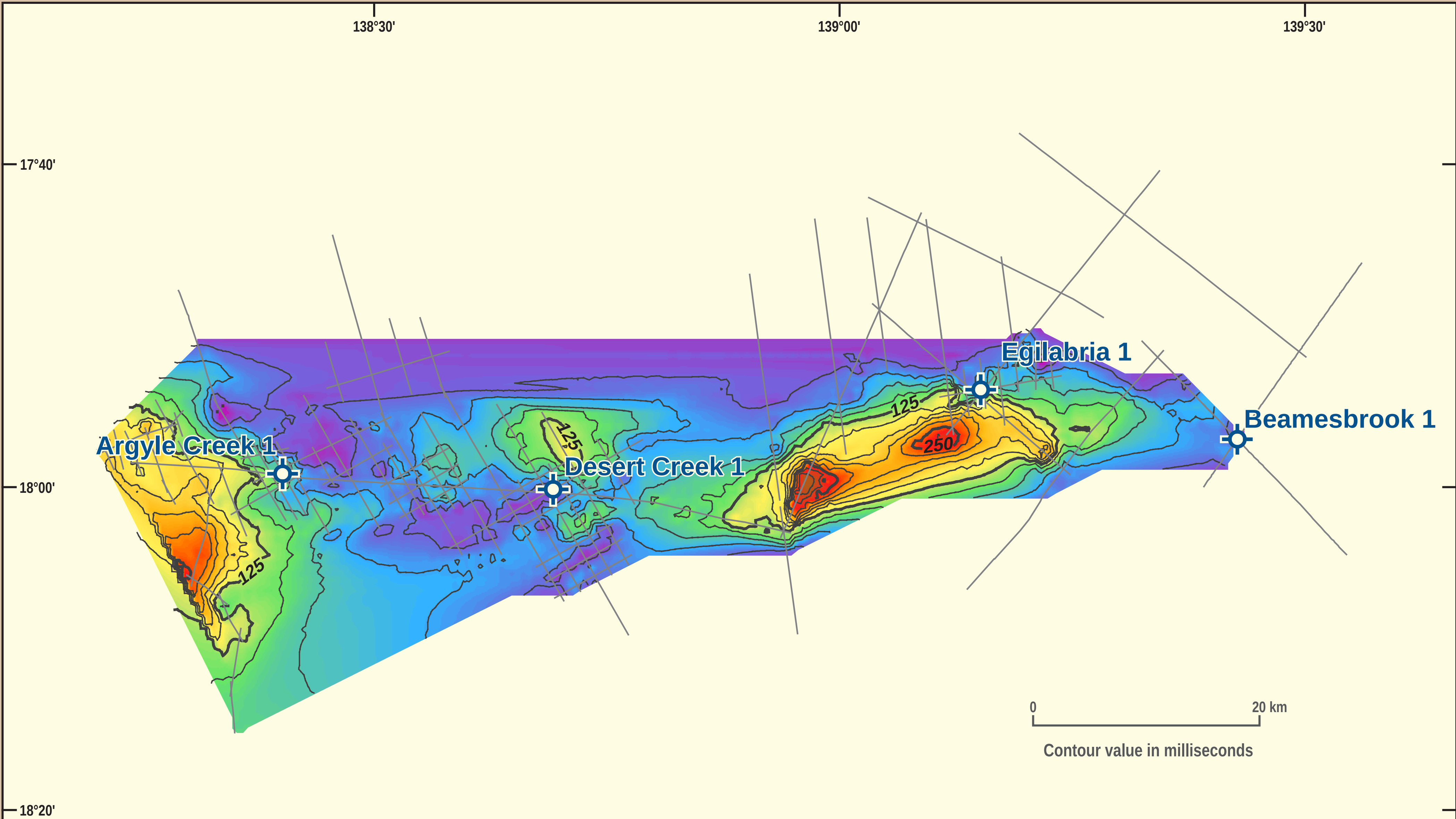

Figure 1.7.5 Isochron map of South Nicholson Group (Basin) within the Comalco grid

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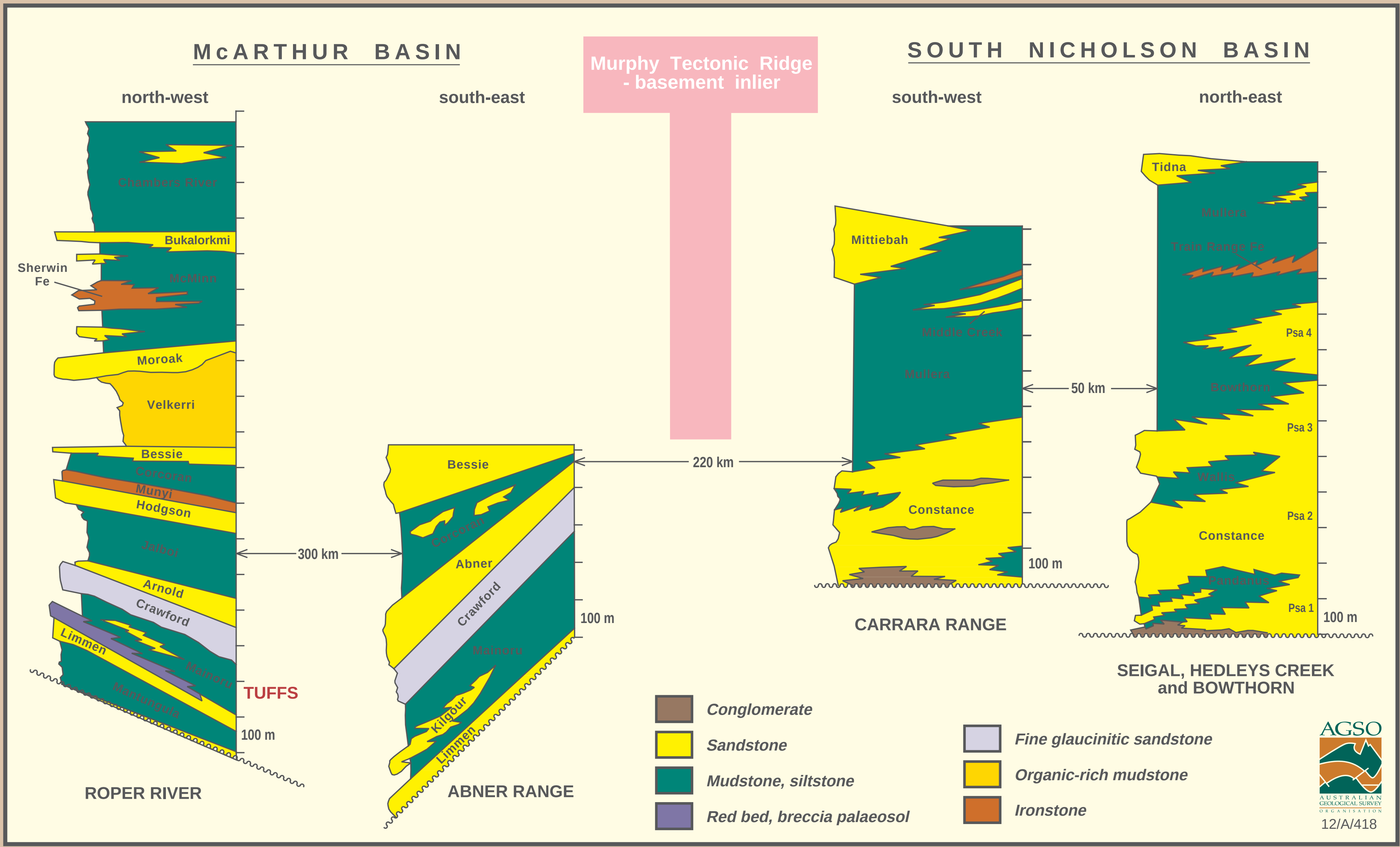

Fig 1.7.6 Representative lithostratigraphic sections through the Roper Group in the southern part of the McArthur Basin and the northern part of the Lawn Hill Platform

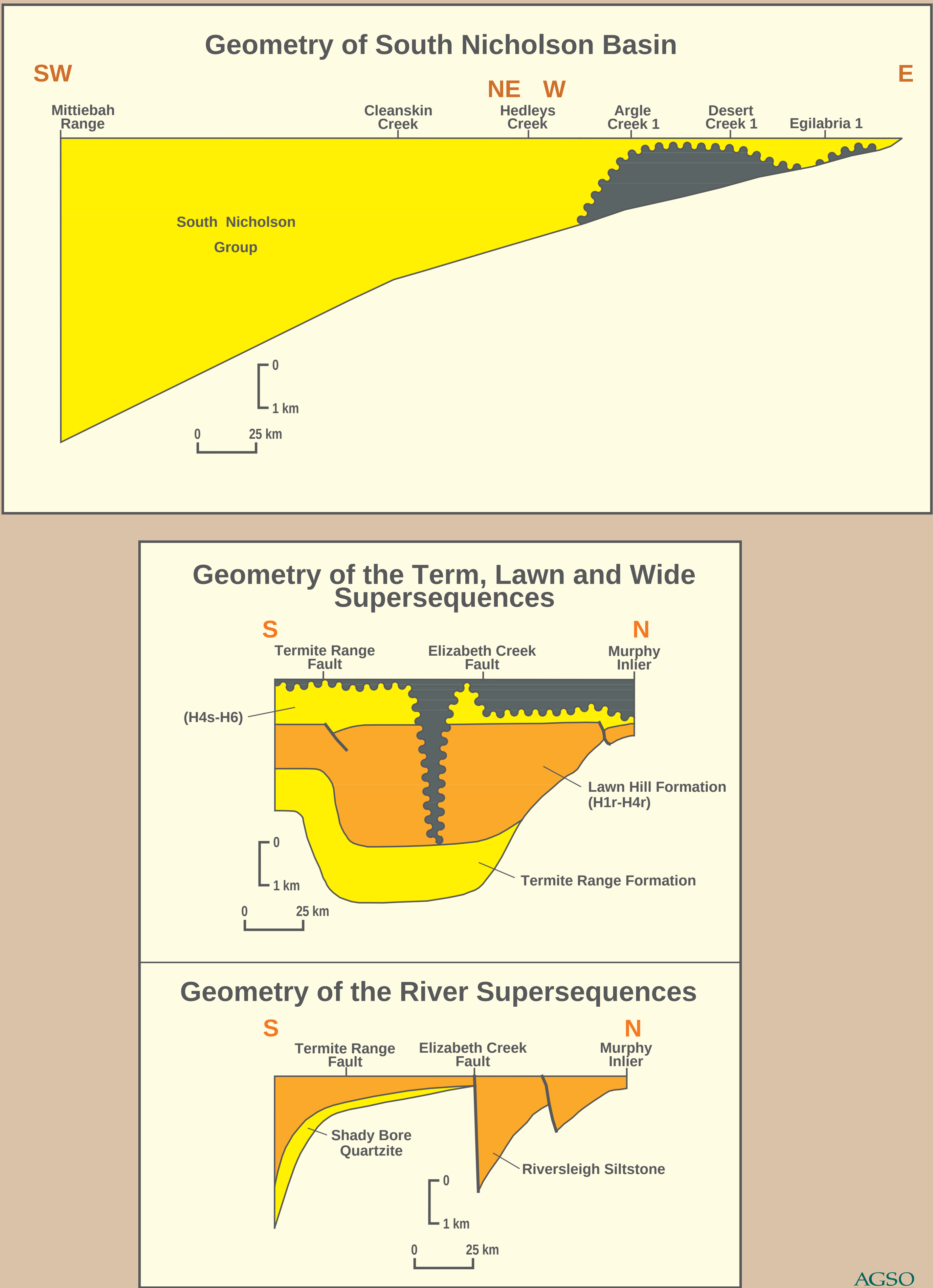

Figure 1.7.7 Inferred geometry of the South Nicholson Basin compared to older fault-controlled sub-basin geometries within the Isa Superbasin

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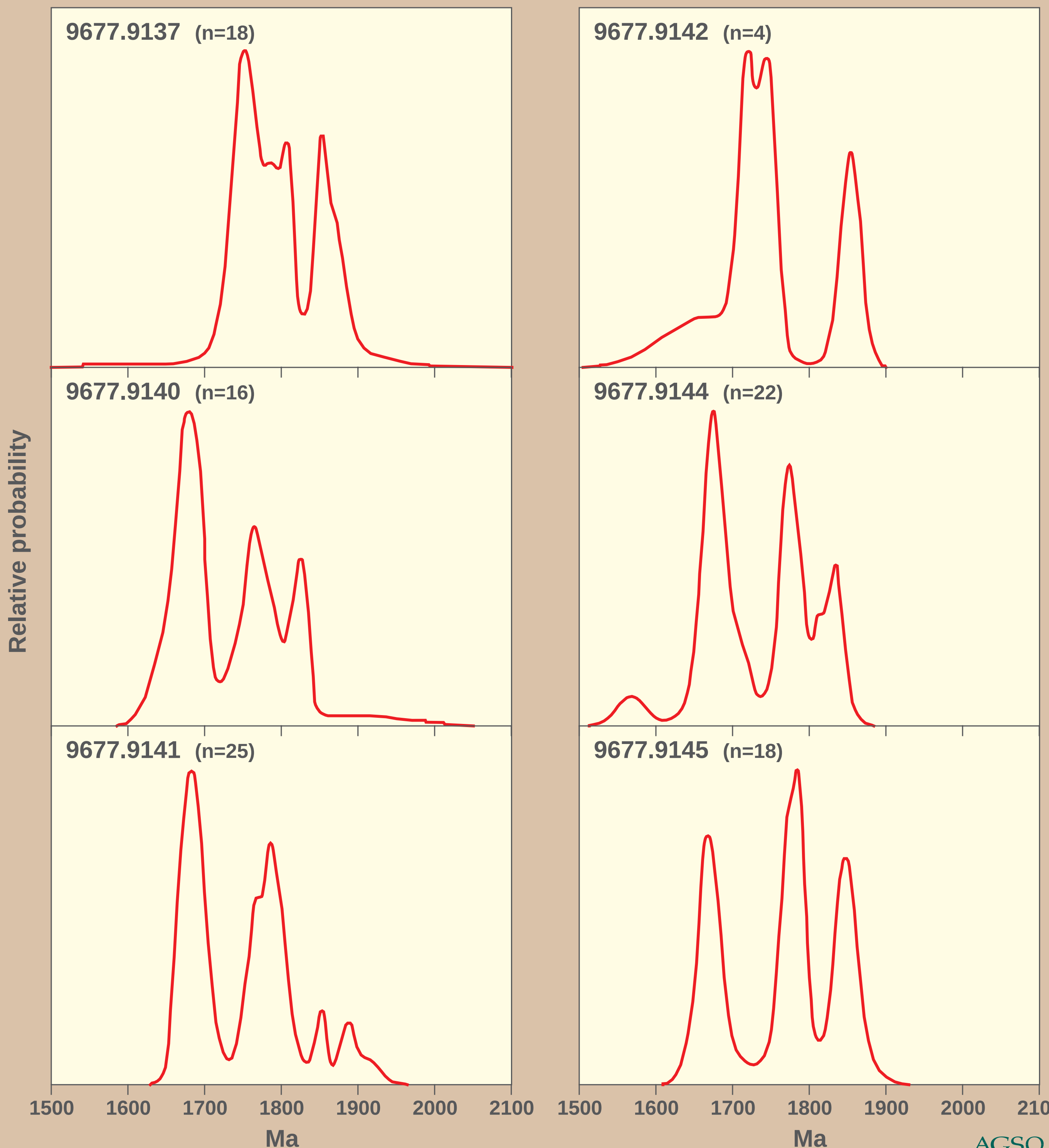

Figure 1.7.8 Histogram plots showing ages of provenance terranes revealed by SHRIMP analysis of samples from the Mullera Formation, South Nicholson Group

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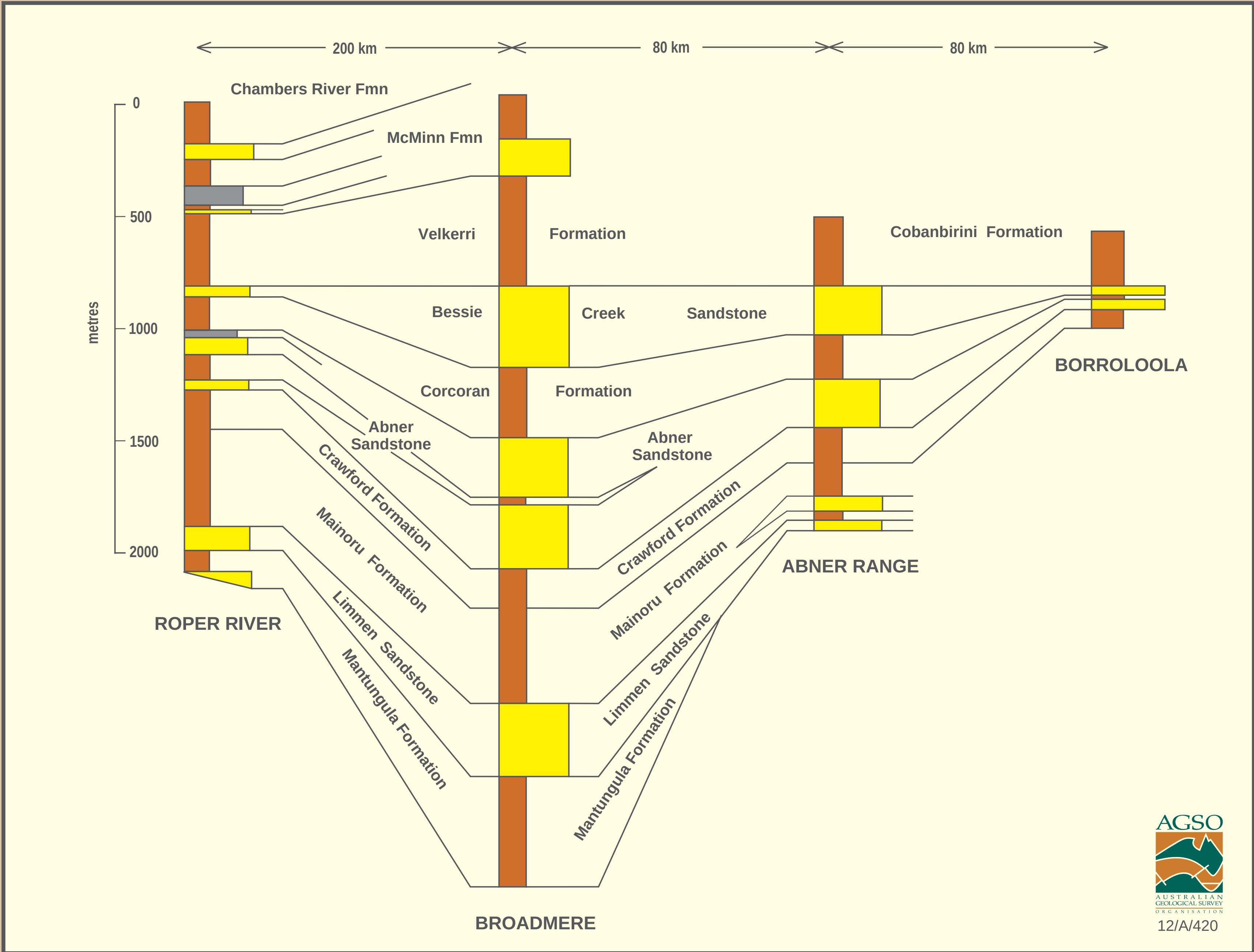

Figure 1.7.9 Thickness variations of main units within the Roper Group (correlated to the South Nicholson Group) to the northwest of the Murphy Inlier

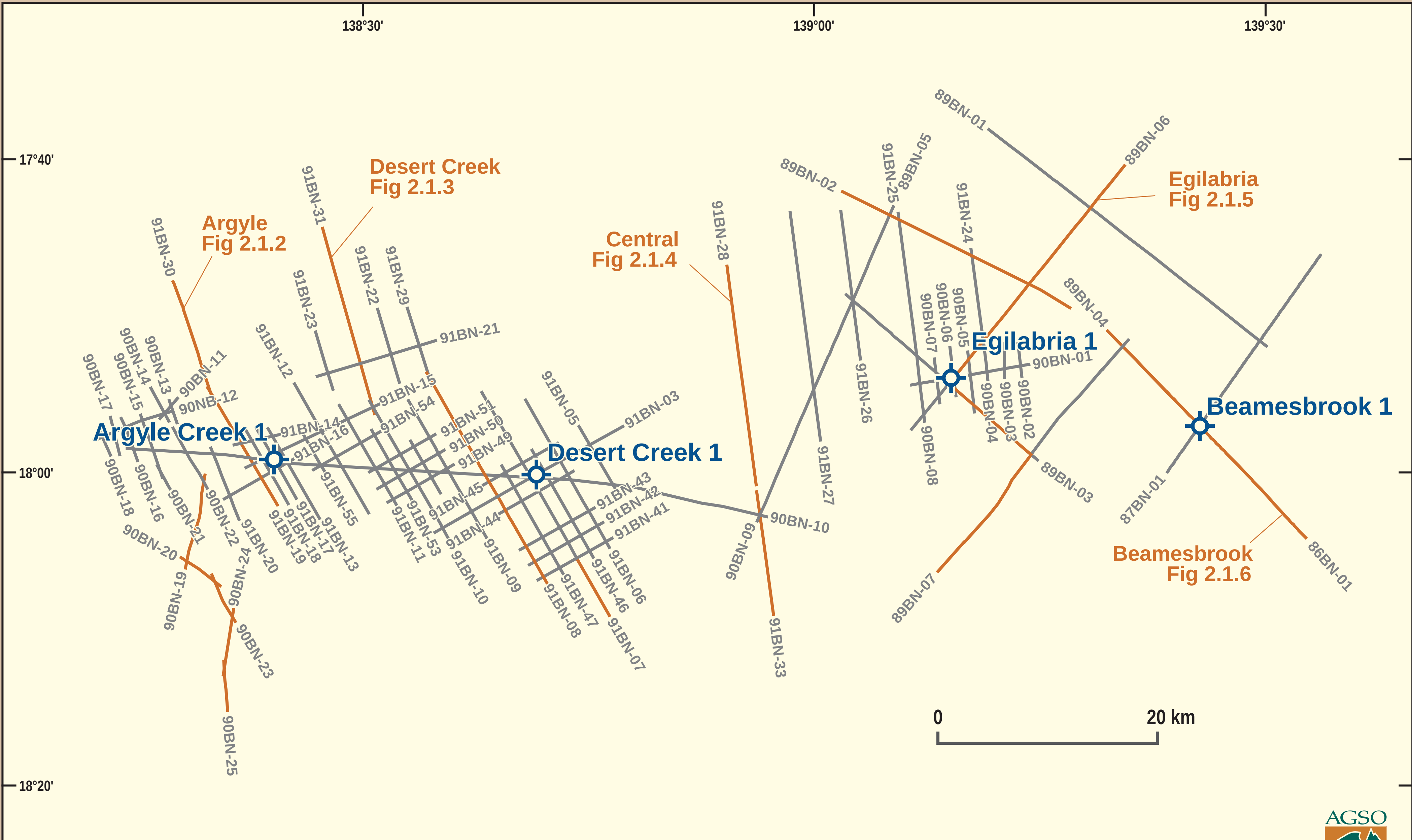

Figure 2.1.1 Seismic and well log location map high-lighting regional composite lines shown in Figs. 2.1.2 to 2.1.6

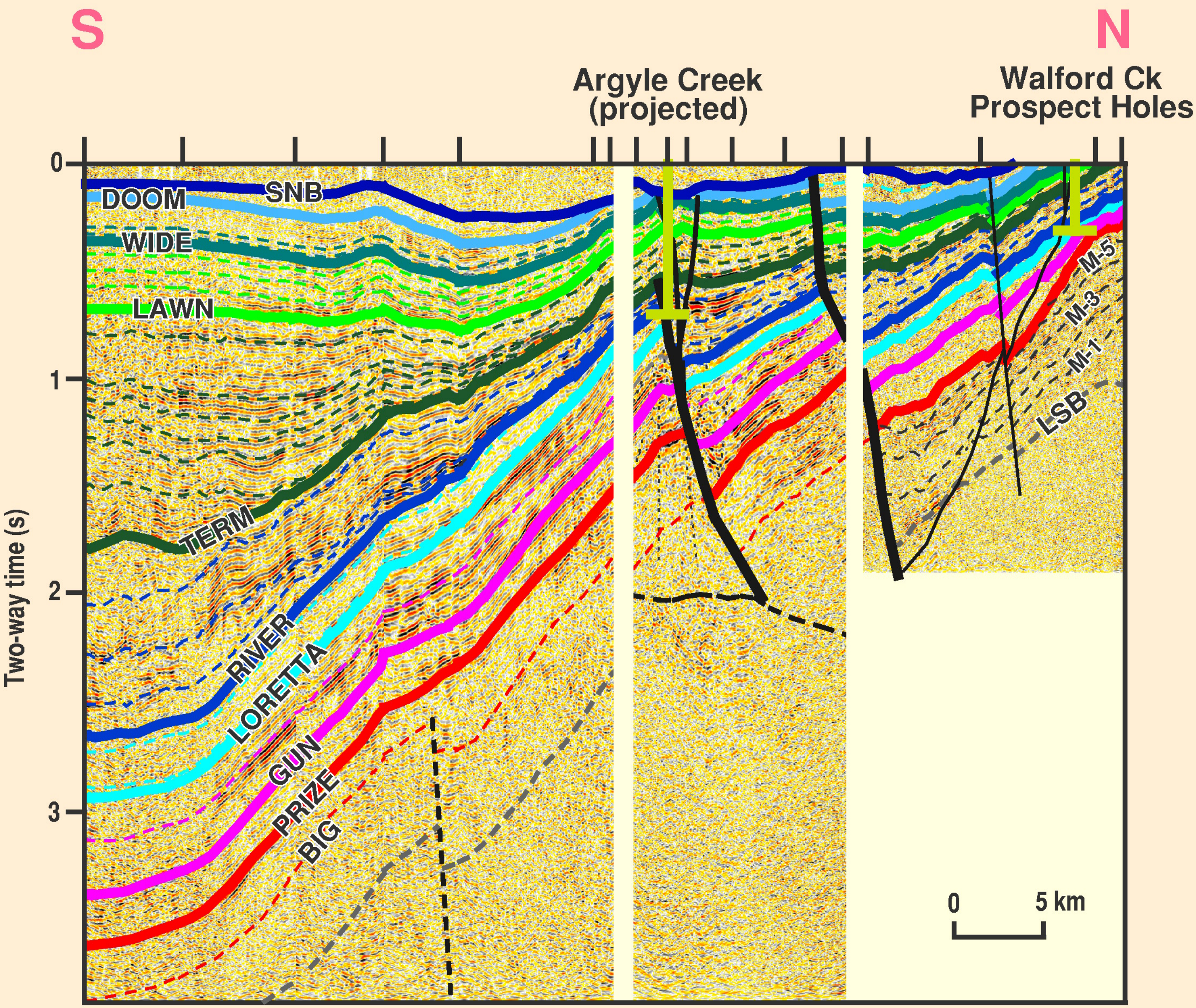

Figure 2.1.2 Argyle Creek composite section showing geometry of Isa Superbasin basin phases

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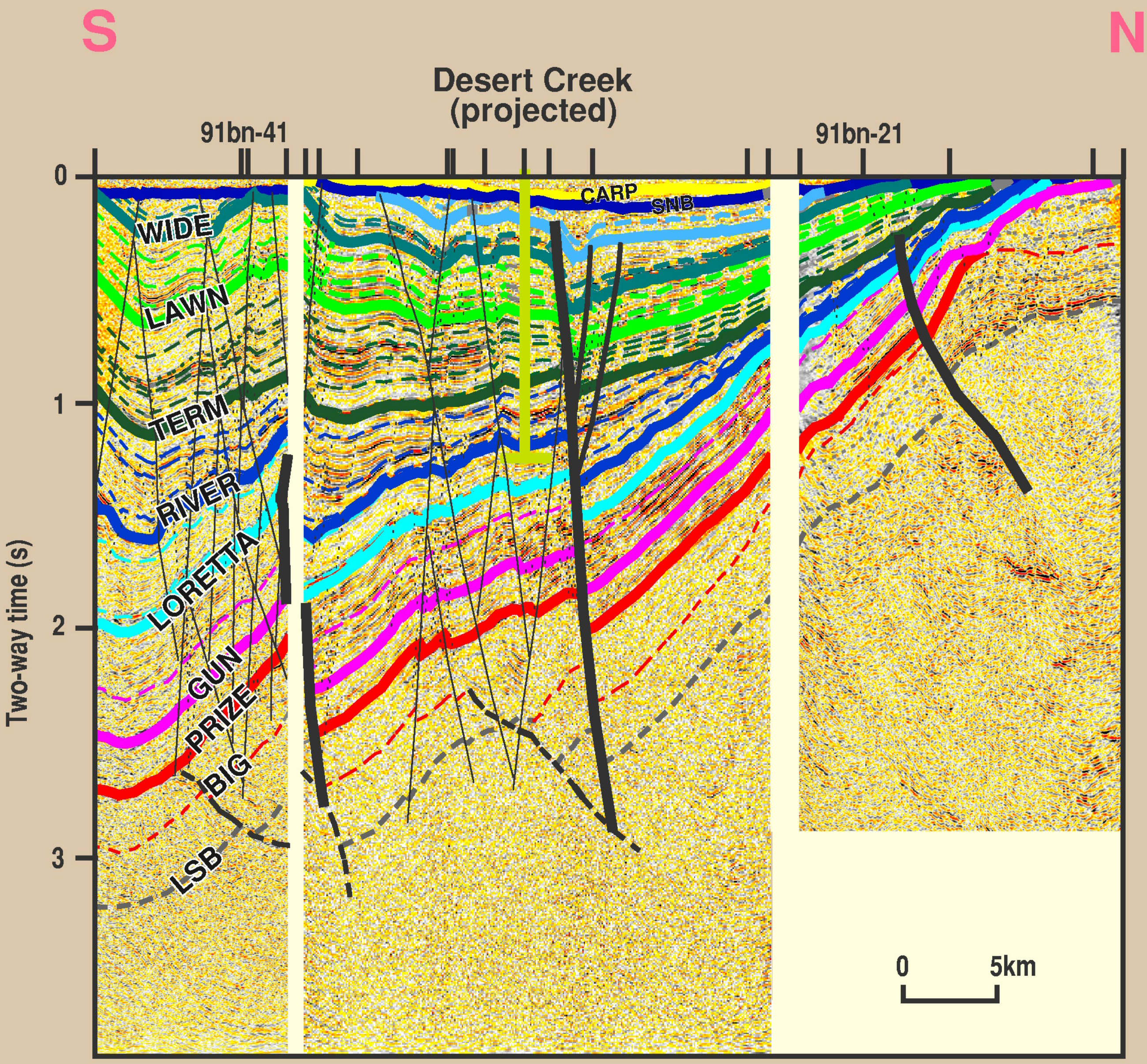

Figure 2.1.3 Desert Creek composite section showing geometry of Isa Superbasin basin phases

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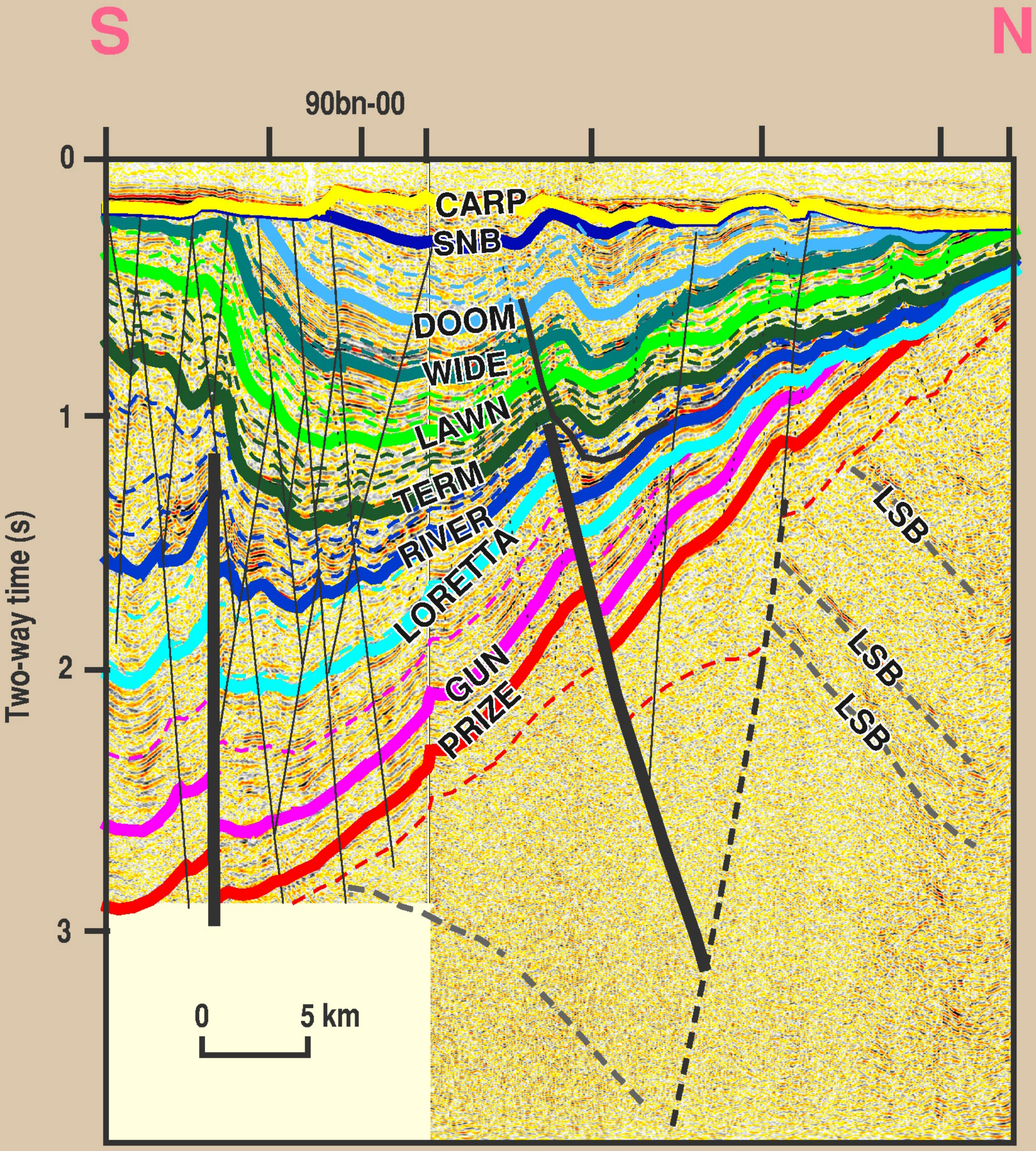

Figure 2.1.4 Central composite section showing geometry of Isa Superbasin basin phases

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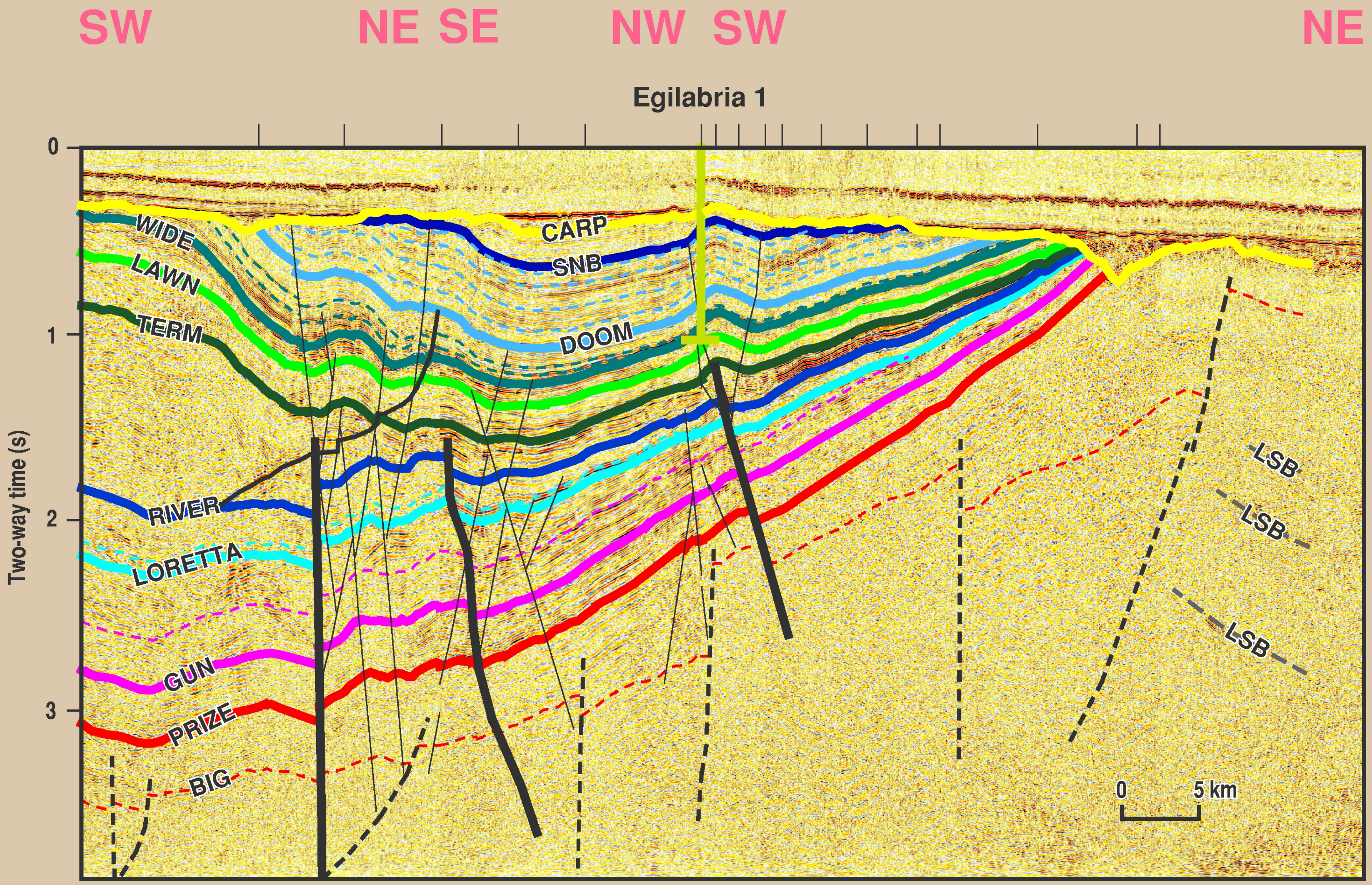

Figure 2.1.5 Egilabria composite section showing geometry of Isa Superbasin phases

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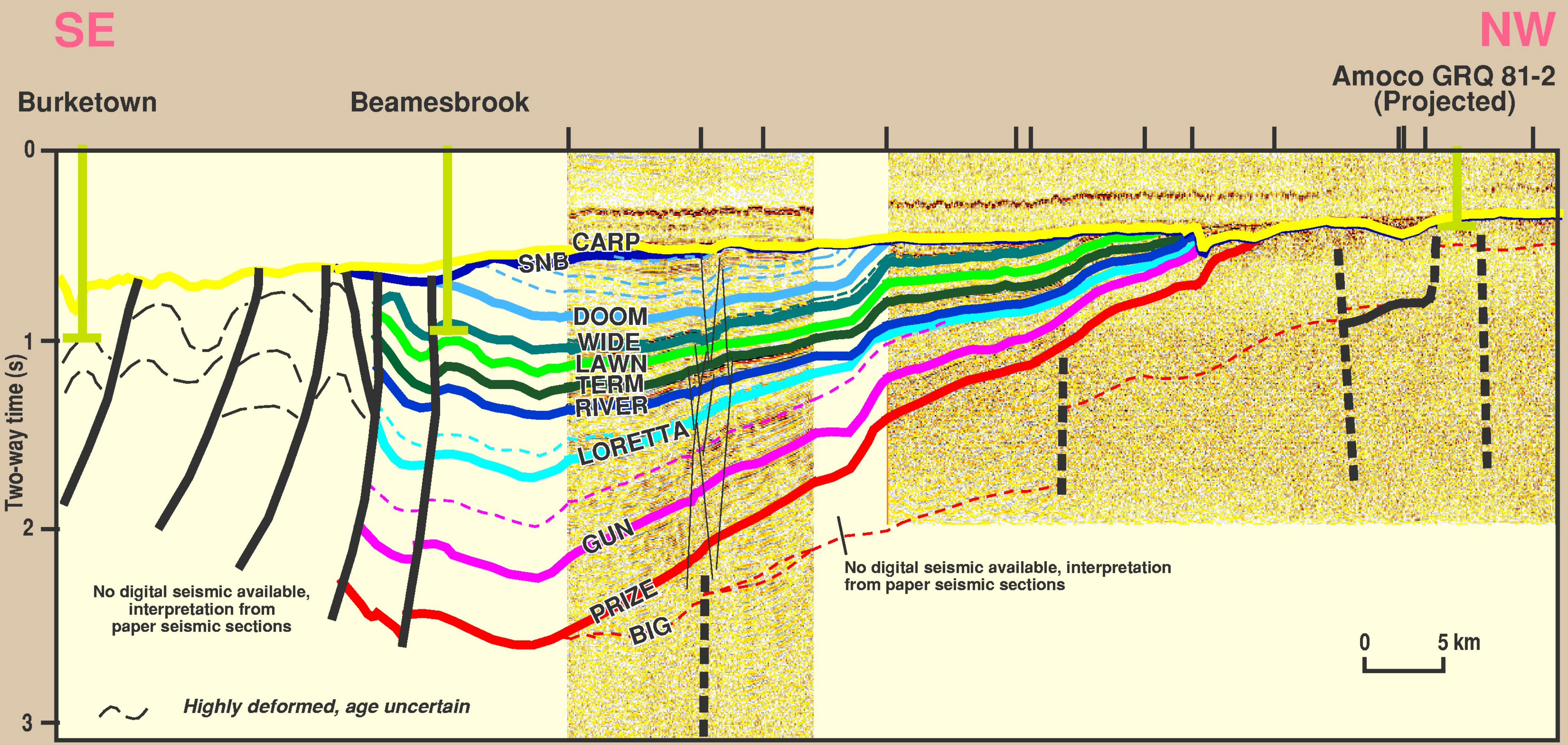

Figure 2.1.6 Beamesbrook composite section showing geometry of Isa Superbasin basin phases

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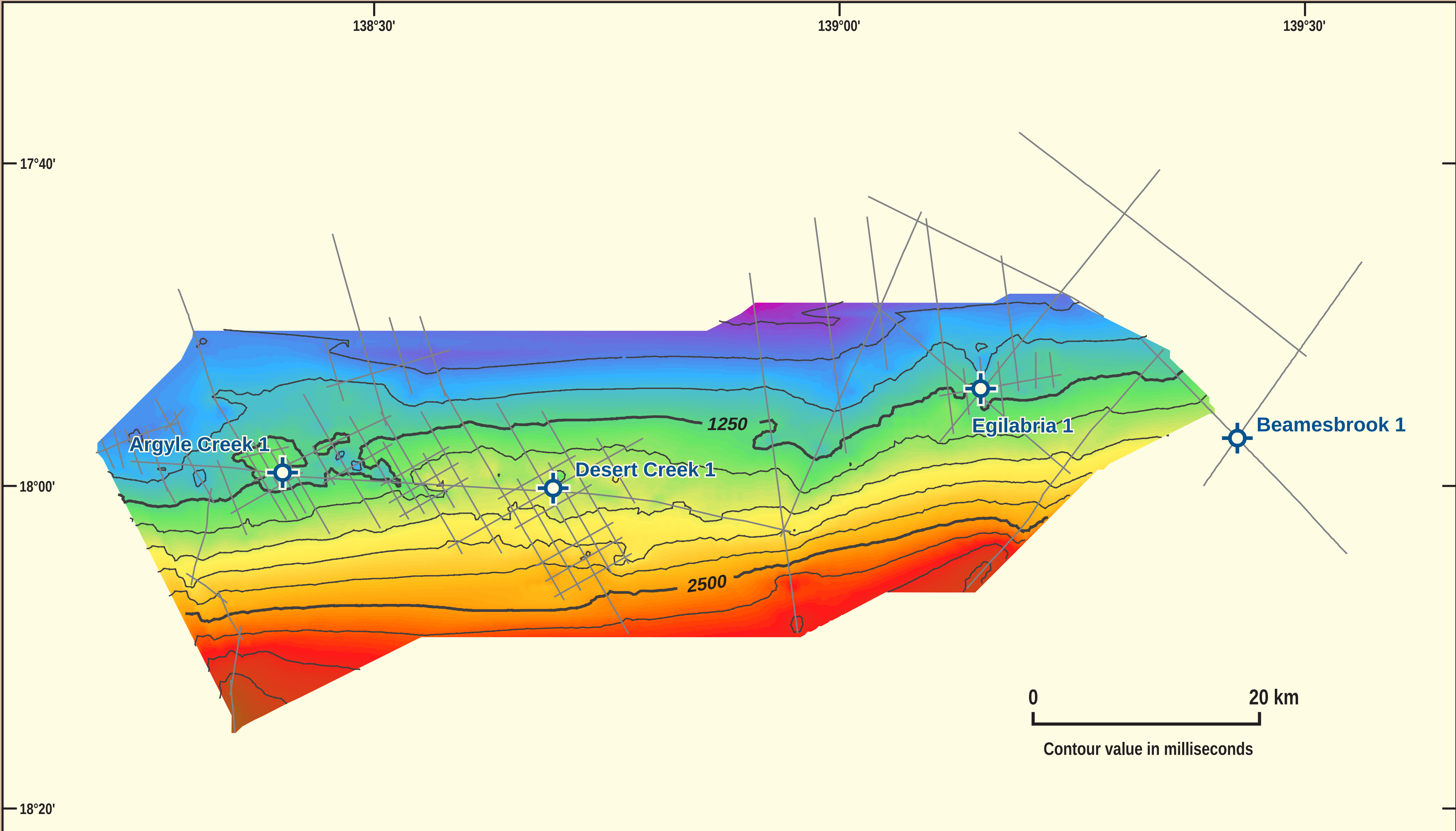

Figure 2.1.7 Isochron map of the total Isa Superbasin megawedge (Prize-Doom)

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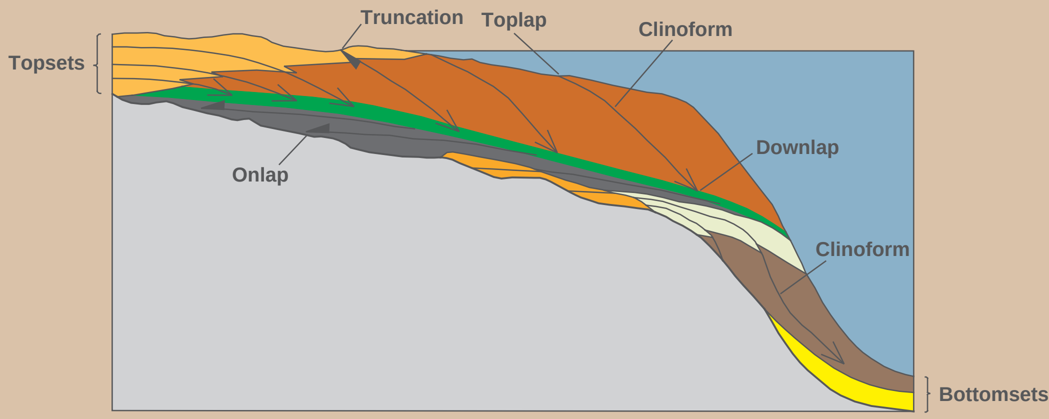
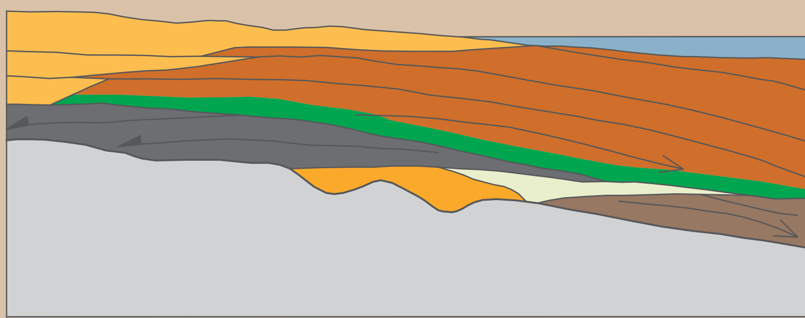
12/A/455

(A) Shelf-break Margin



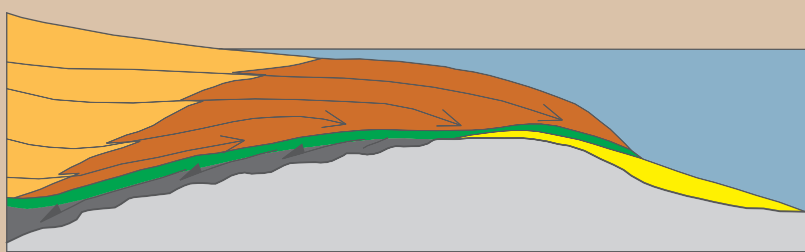
from Emery & Myers (1996)

(B) Ramp Margin



from Van Wagoner et al. (1990)

(C) Foreland Basin



from Swift et al. (1990)

- *Fluvial/estrine sandstone (lowstand)*
- *Submarine fan sandstones (lowstand)*
- *Coastal/shallow marine sandstones (lowstand)*
- *Shelf and slope shales, siltstones (lowstand)*
- *Transgressive shales,siltstones and sandstones*
- *Condensed section deposits*
- *Coastal/shallow marine sandstones (highstand)*
- *Shelf and slope shales, siltstones (highstand)*

Figure 2.1.8 **Idealised sequence stratigraphy models for three basin types (passive margin, ramp and foreland**

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12/A/447

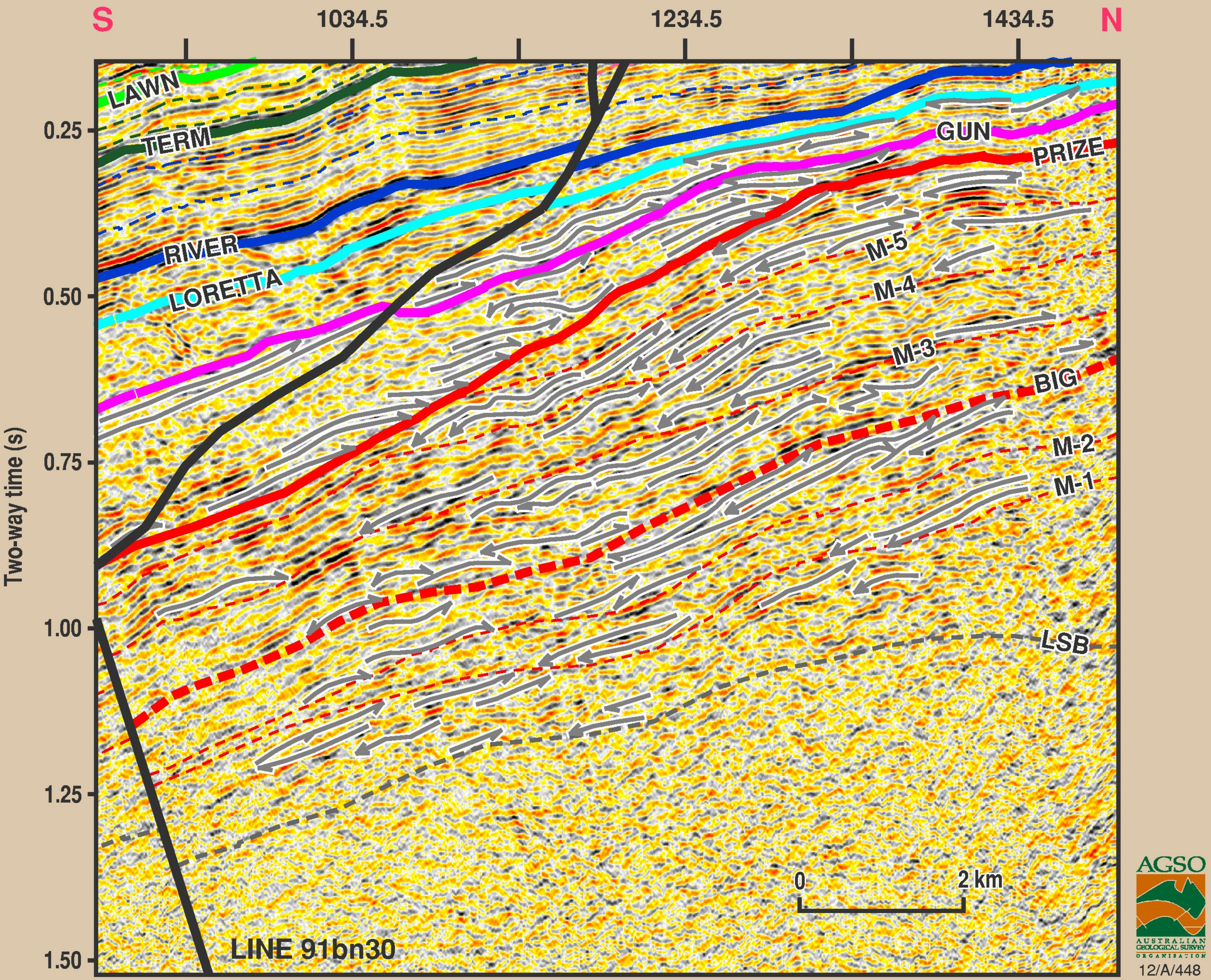

Figure 2.2.1 Seismic sequence stratigraphy of Big, Prize and Gun Supersequences over the Peters Creek magmatic dome line 91bn-30 (unflattened). LSB = Leichhardt Superbasin. M1-M5 relate to magmatic members of the Peters Creek Volcanics. This section comprises the northern end of the Argyle Creek composite Line (fig. 2.1.2)

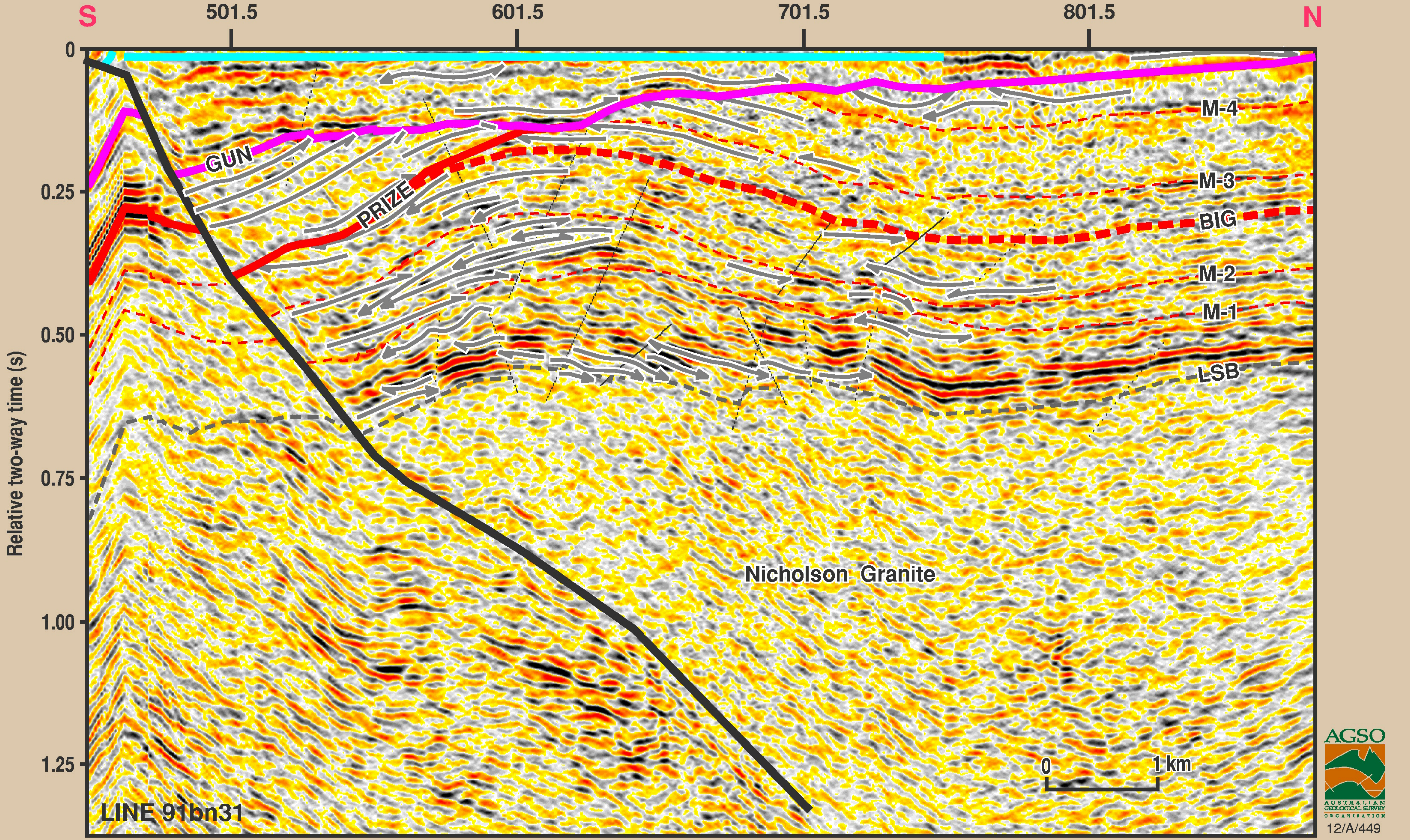

Figure 2.2.2 Seismic sequence stratigraphy of Big, Prize and Gun Supersequences over the Peters Creek magmatic dome, line 91bn-31 (flattened on Loretta). LSB = Leichhardt Superbasin. M1-M5 relate to magmatic members of the Peters Creek Volcanics. This section comprises the northern end of the Desert Creek composite Line (fig 2.1.3)

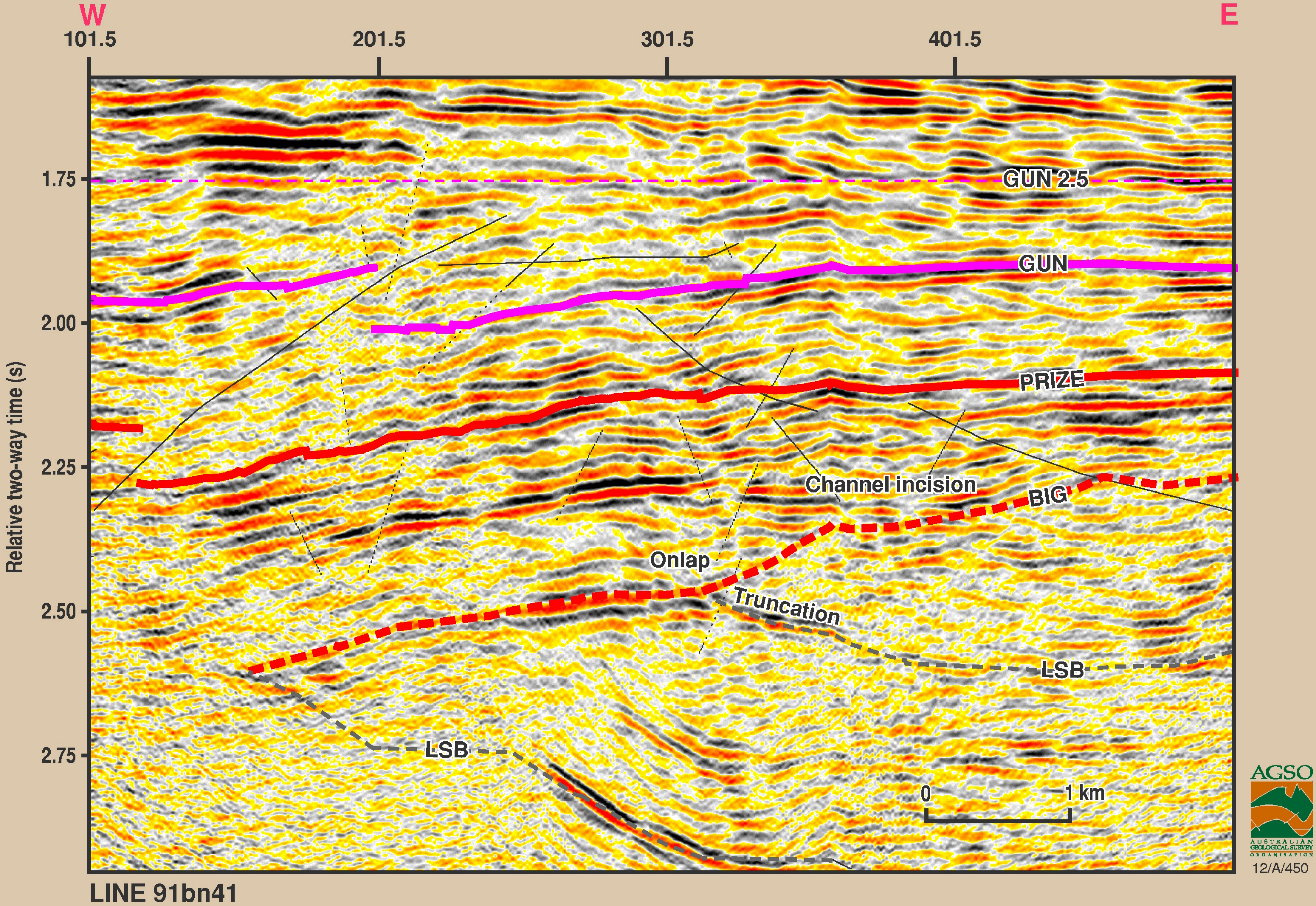

Figure 2.2.3 Onlap and insision of the Big Supersequence, showing angular unconformity with reflection interpreted as the Eastern Creek Volcanics (ECV) of the Leichhardt Superbasin, Line 91bn-41 (unflattened)

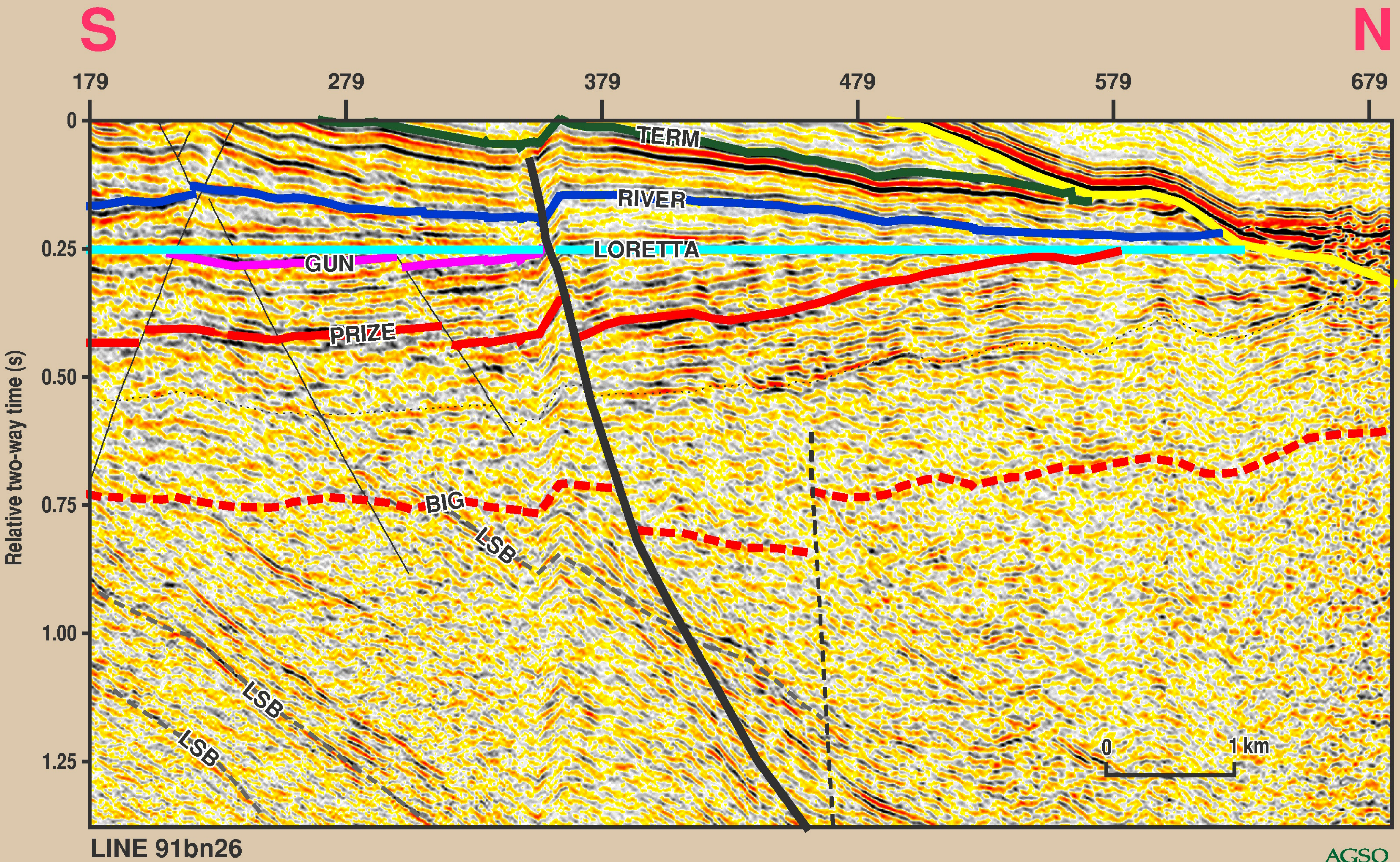

Figure 2.2.4 Seismic sequence stratigraphy of Big, Prize, Gun and Loretta Supersequences truncating Leichhardt Superbasin reflections, Line 91bn-26 (flattened on Loretta)

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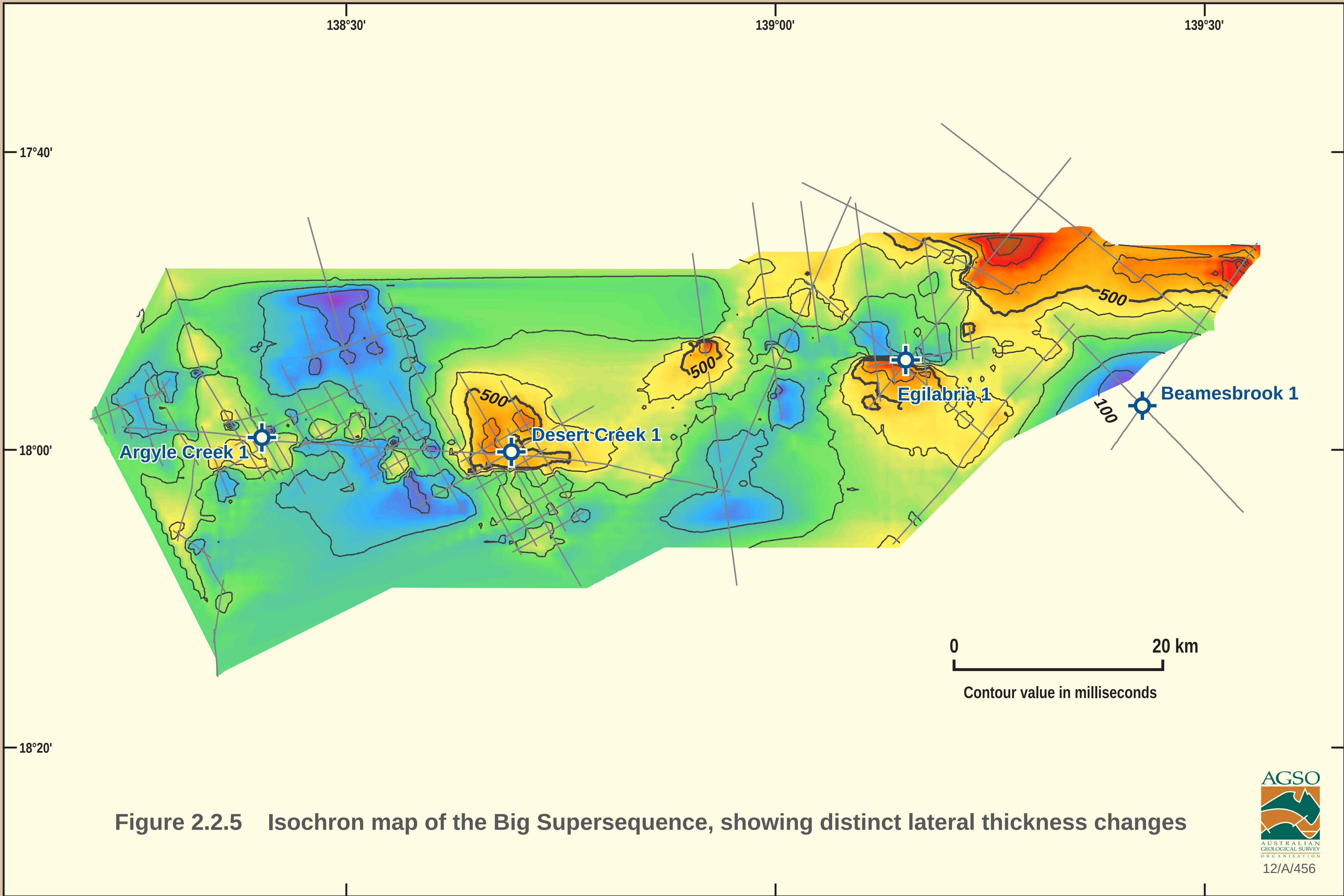

Figure 2.2.5 Isochron map of the Big Supersequence, showing distinct lateral thickness changes

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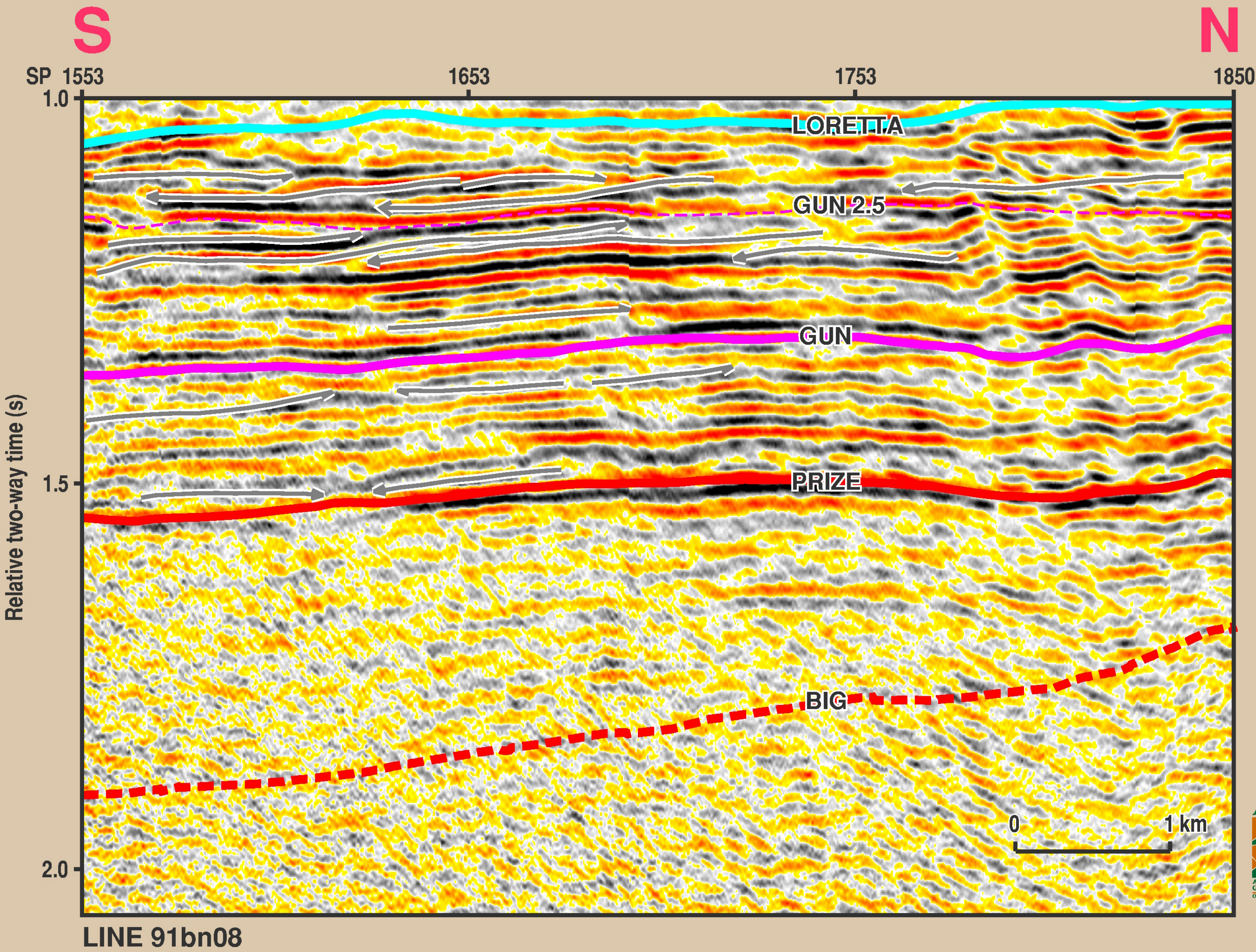

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Figure 2.3.1 Seismic sequence stratigraphy of the Prize and Gun Supersequences, Line 91bn-08 (unflattened)

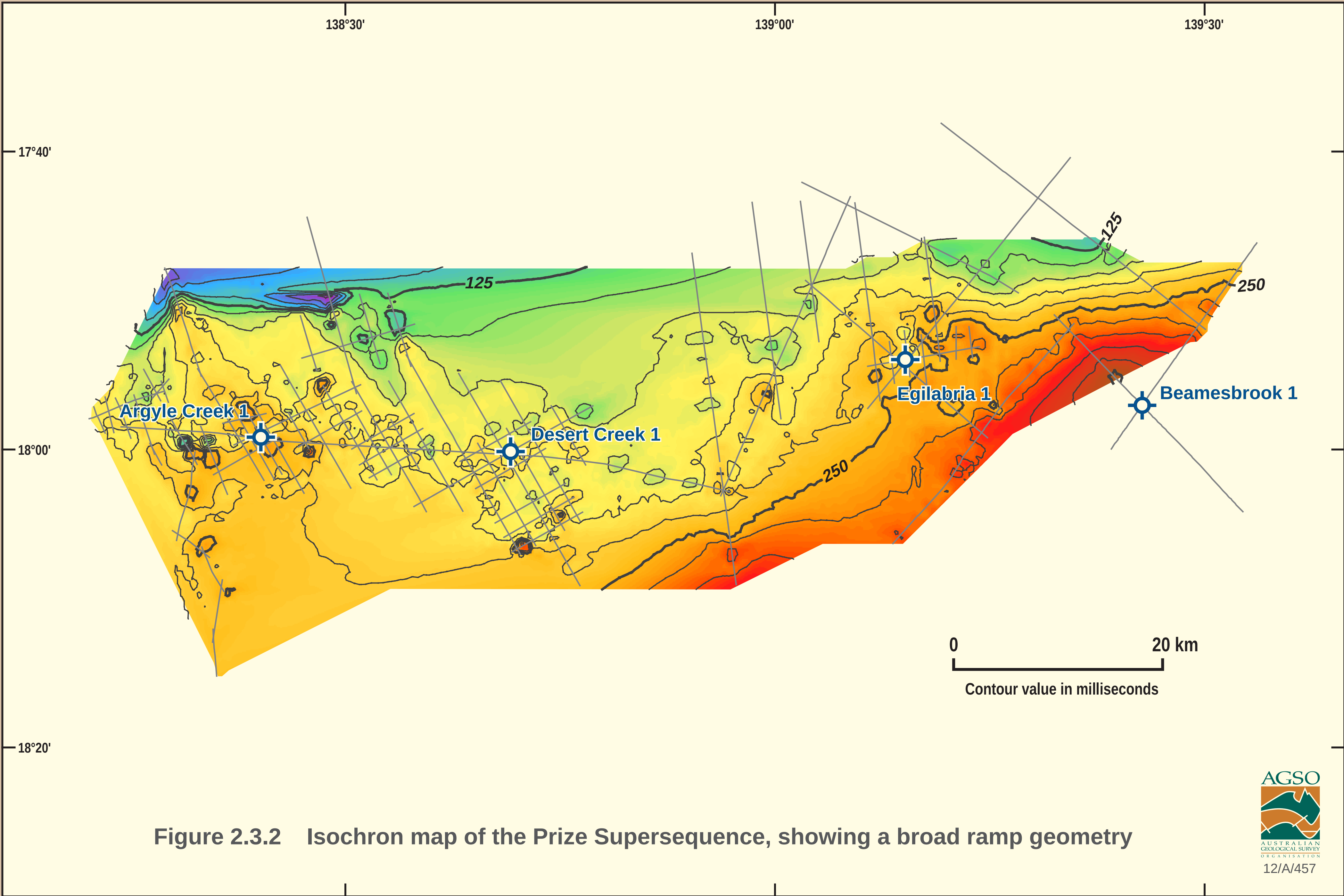

Figure 2.3.2 Isochron map of the Prize Supersequence, showing a broad ramp geometry

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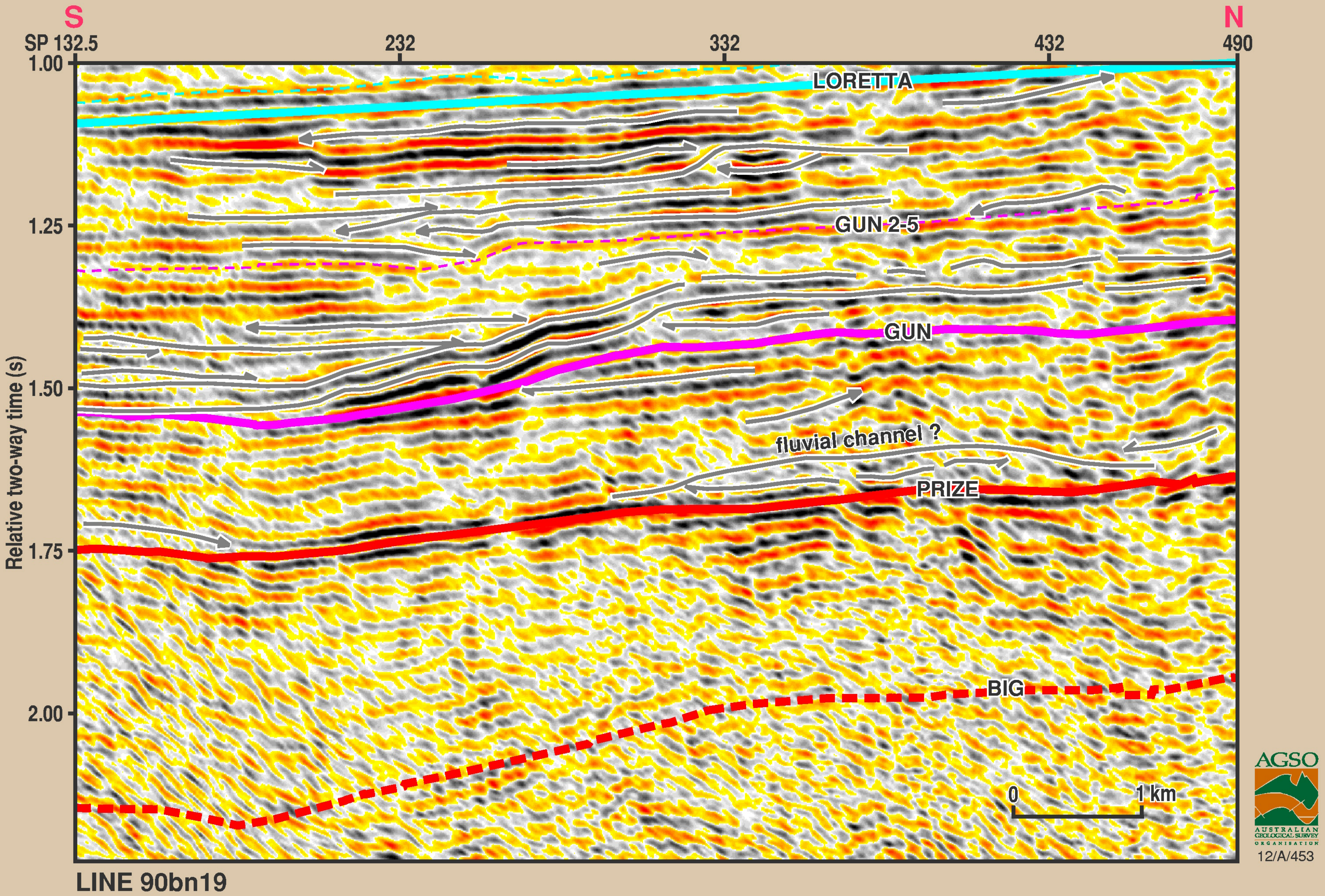

Figure 2.3.3 Seismic sequence stratigraphy of Prize and Gun Supersequences, Line 90bn-19 (unflattened). This section is part of the Argyle composite line (Fig. 2.1.2)

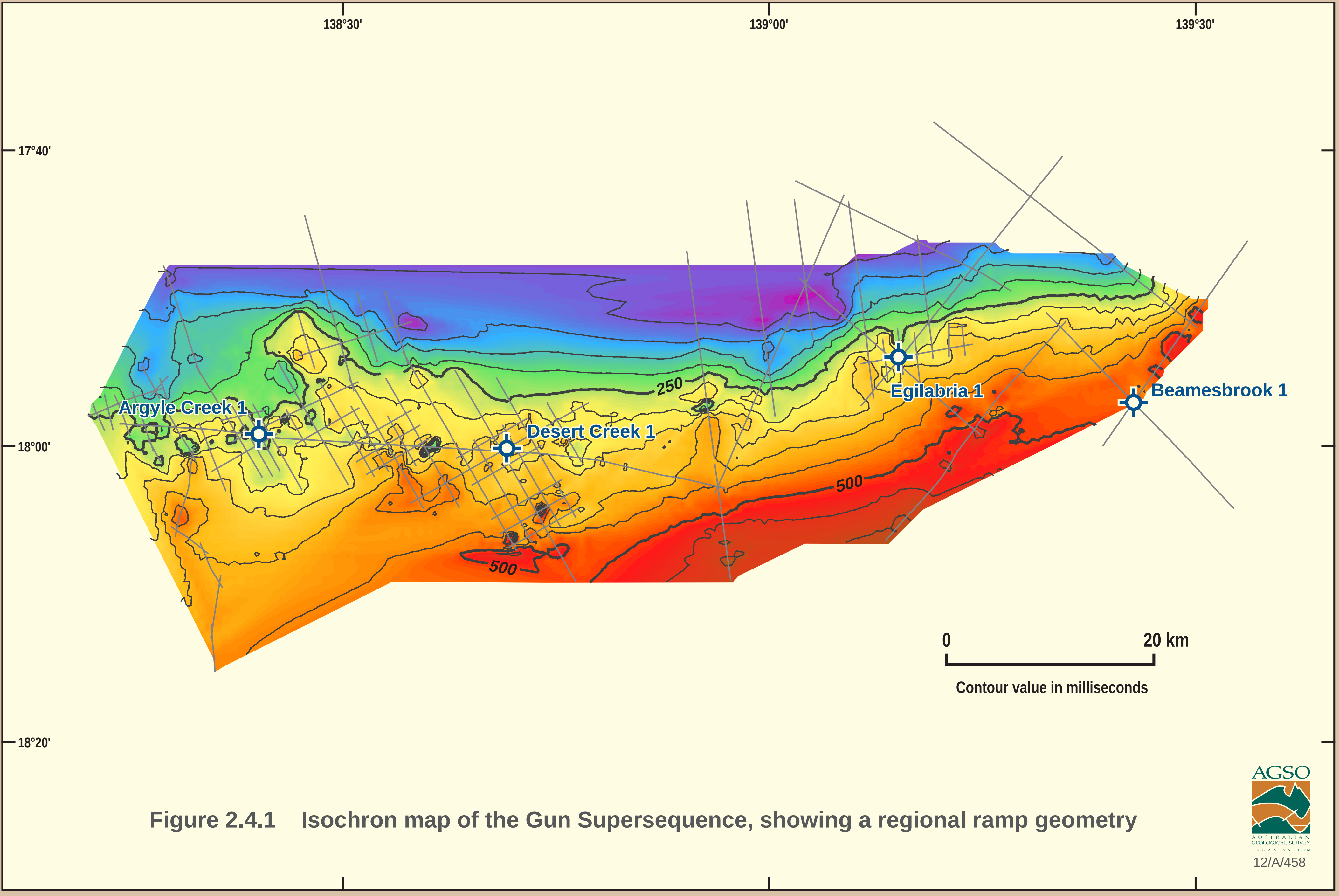

Figure 2.4.1 Isochron map of the Gun Supersequence, showing a regional ramp geometry

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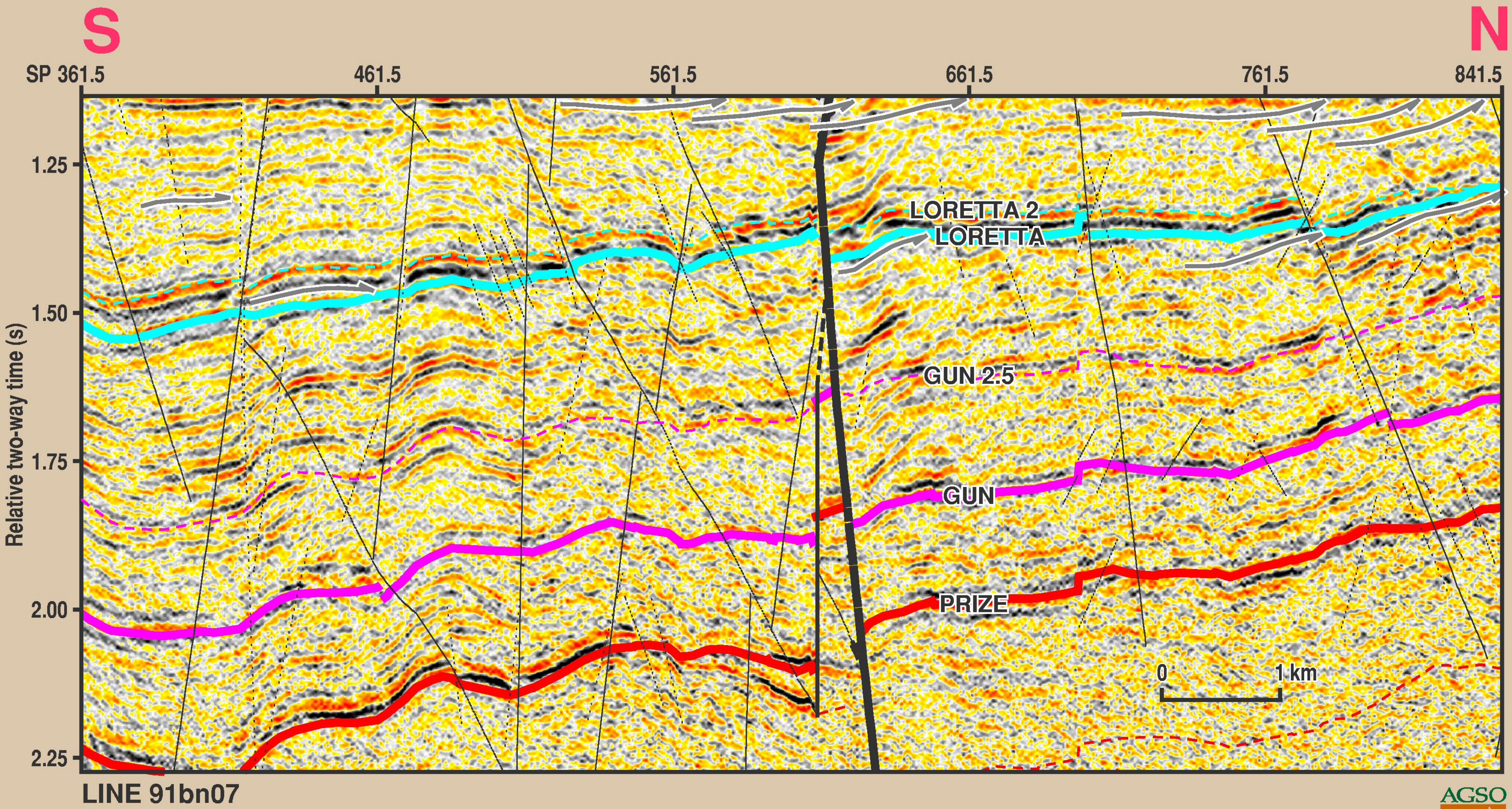

Figure 2.5.1 Seismic sequence stratigraphy of the Loretta Supersequence, Line 91bn-07 (flattened on River). This section is part of the Desert Creek composite (Fig. 2.1.3)

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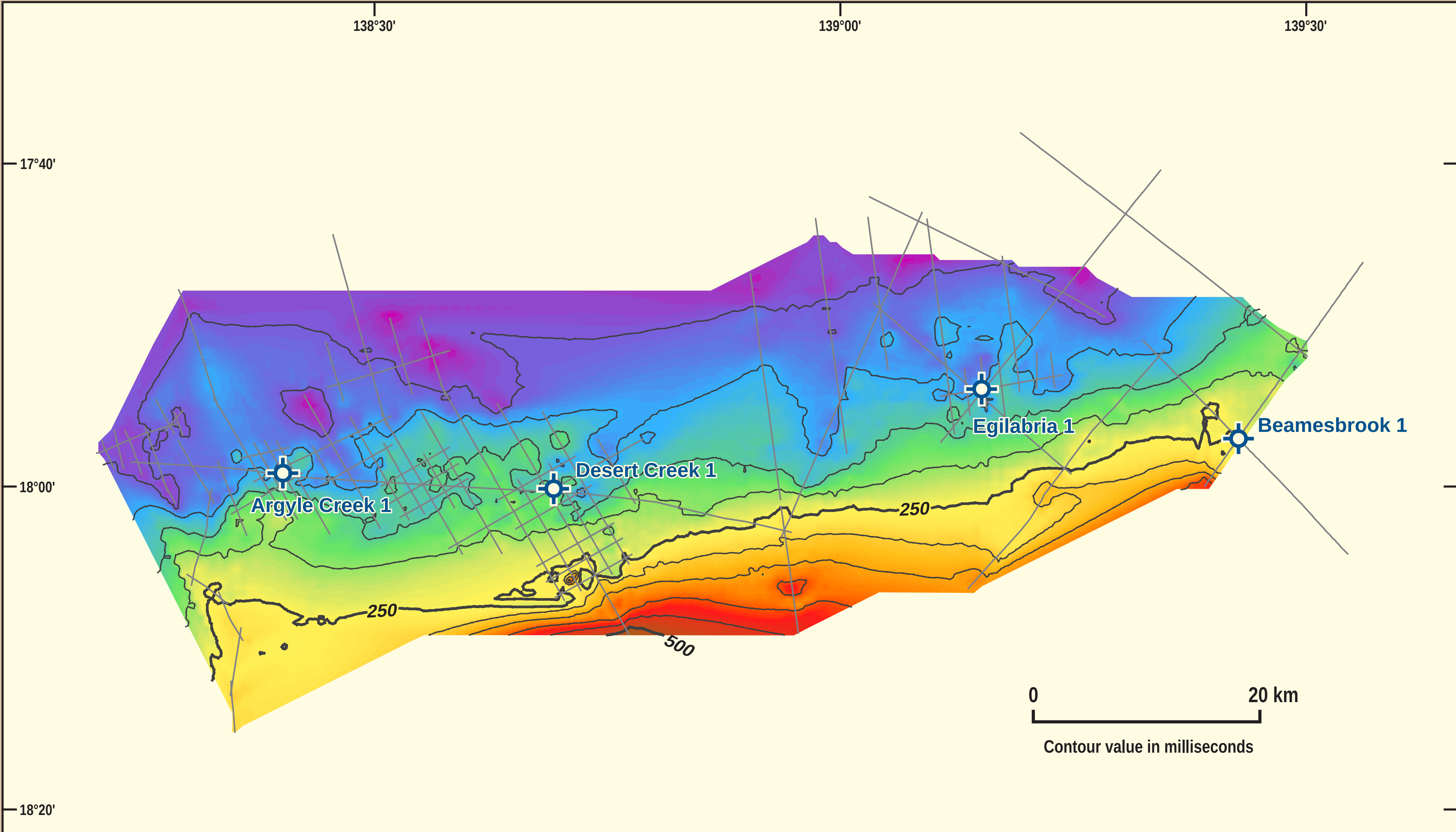

Figure 2.5.2 Isochron mao of the Loretta Supersequence, showing nearly tabular geometry of the seismic grid

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12/A/459

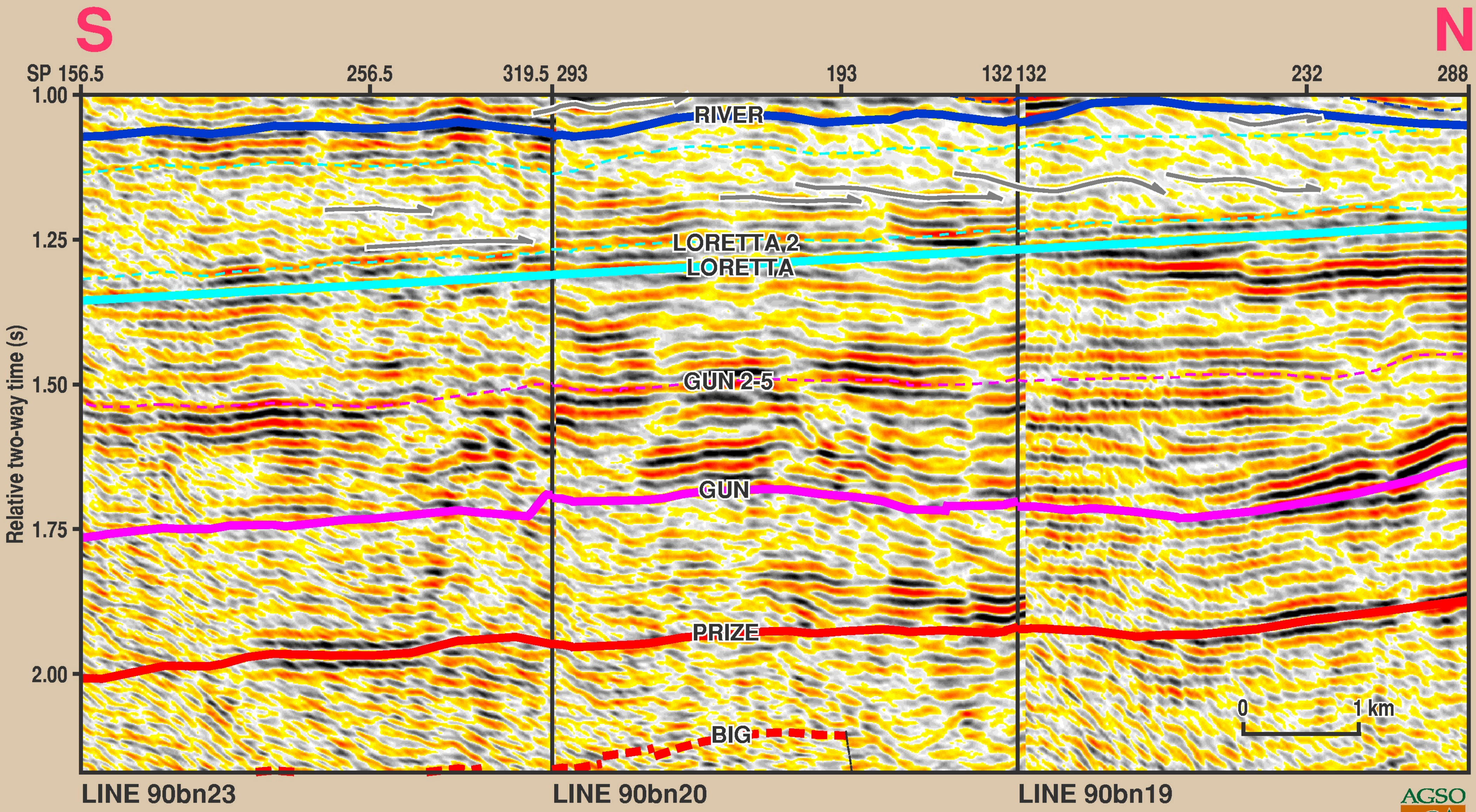

Figure 2.5.3 Seismic sequence stratigraphy of the Loretta Supersequence showing progradation of deformed evaporites over deeper marine carbonates, Lines 90bn-23, 20 and 19 (flattened on River). This figure is part of the Argyle Creek composite (Fig. 2.1.2)

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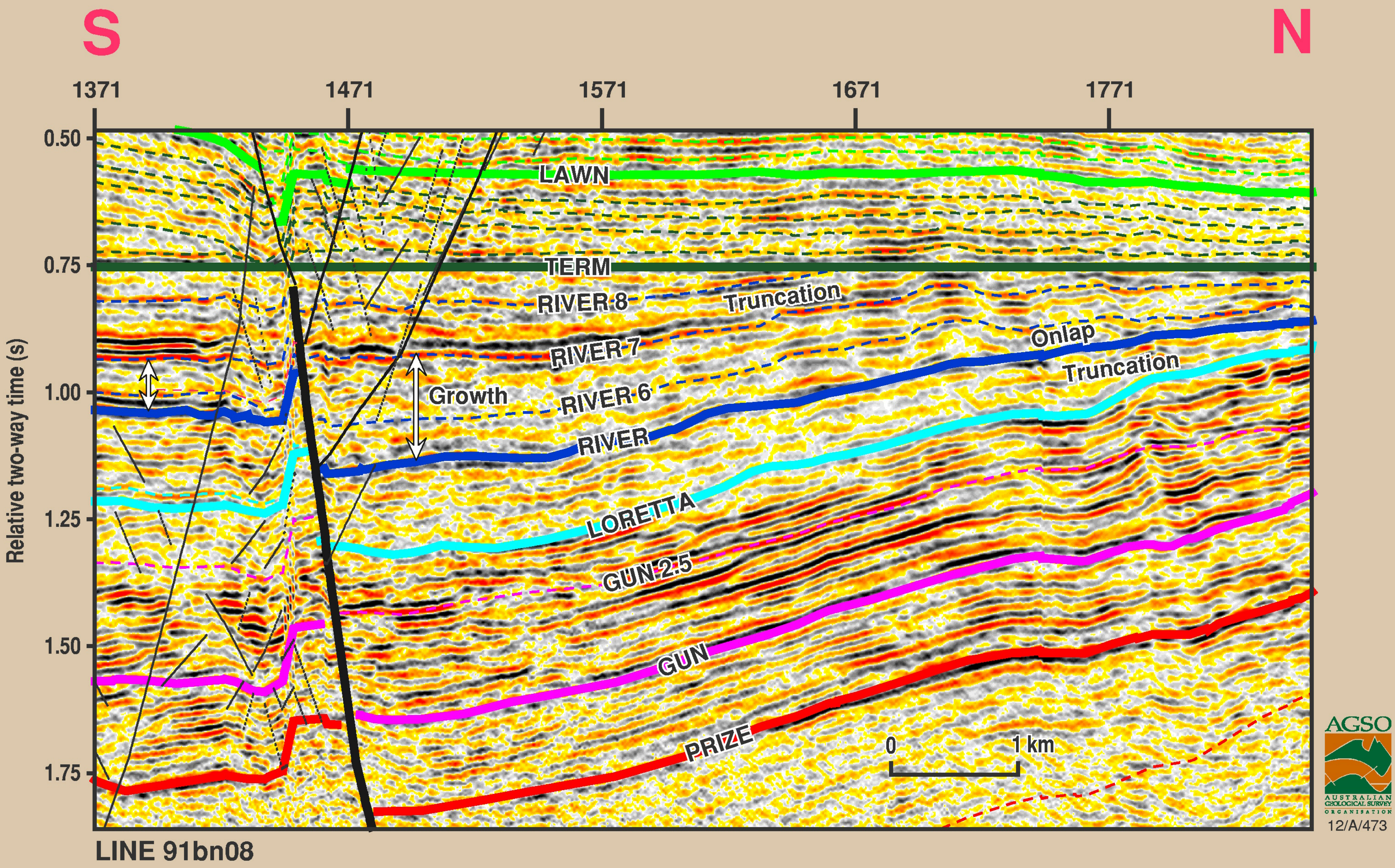

Figure 2.6.1 Seismic sequence stratigraphy of the River and Term Supersequences, showing distinct growth of the River Supersequence across a fault, Line 91bn-08 (flattened on Term)

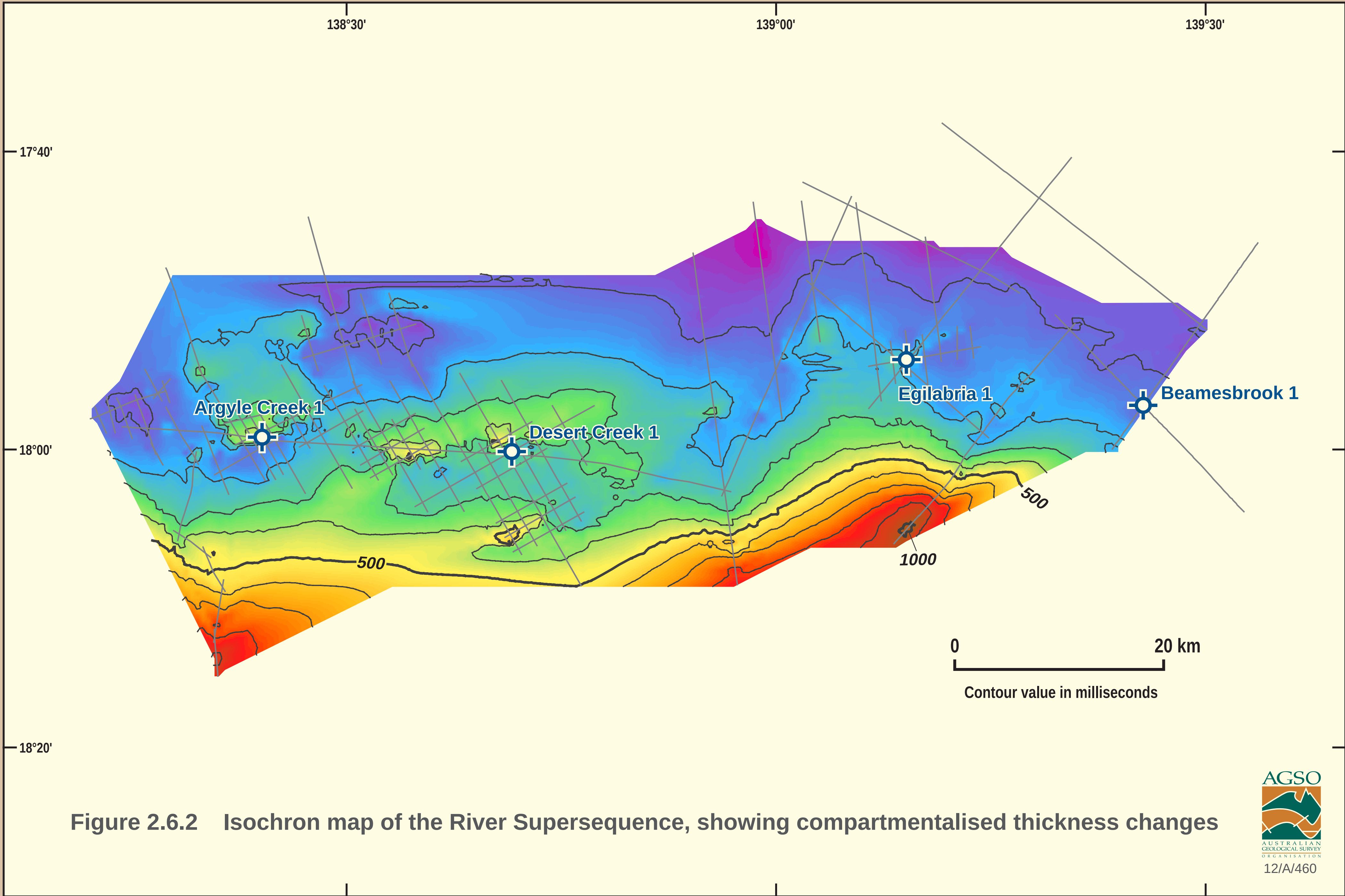

Figure 2.6.2 Isochron map of the River Supersequence, showing compartmentalised thickness changes

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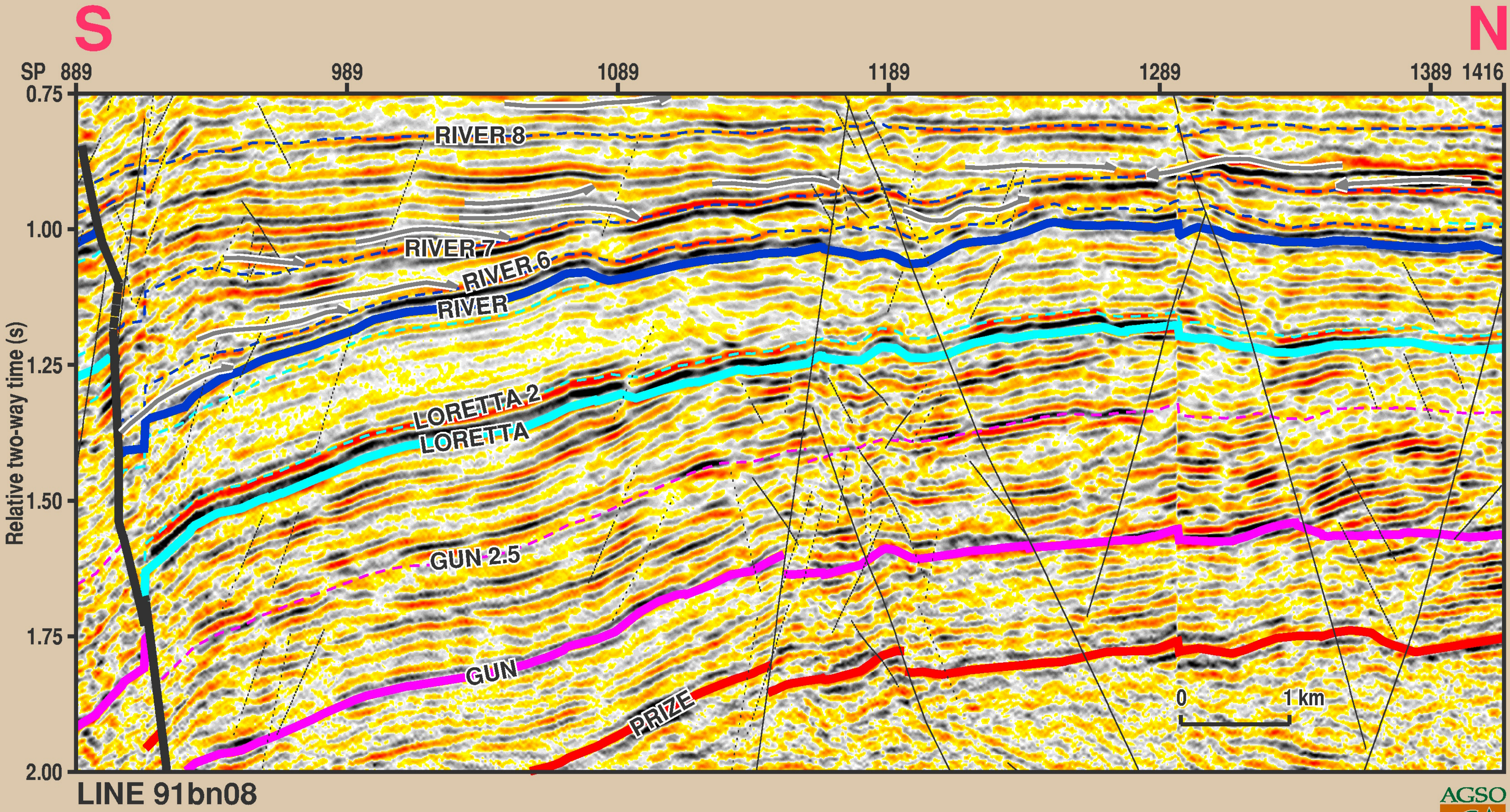

Figure 2.6.3 Seismic sequence stratigraphy of the River Supersequence showing tectonic wedges in the hanging wall block, Line 91bn-08 (flattened on term)

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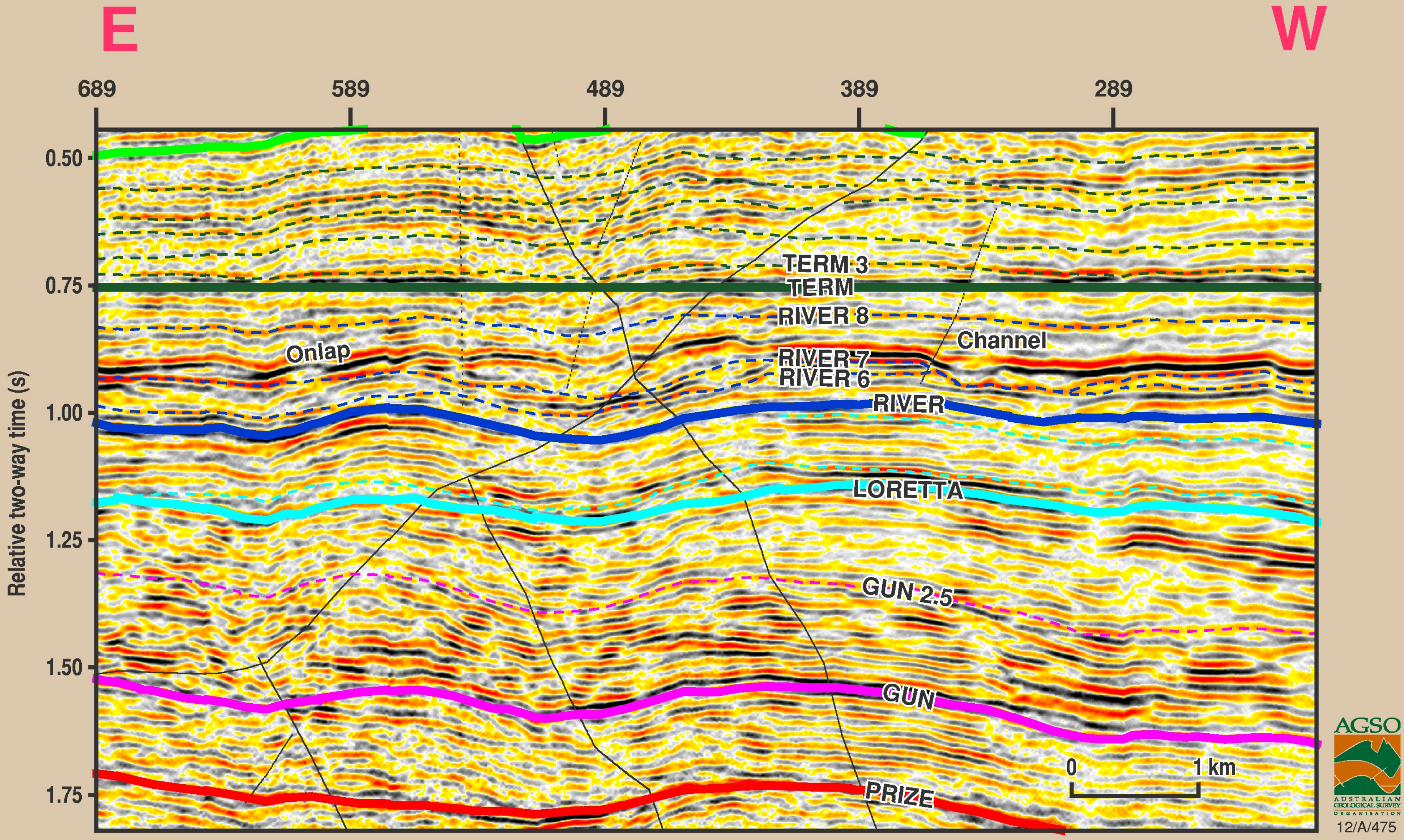

LINE 91bn03

Figure 2.6.4 Seismic sequence stratigraphy of the River supersequence showing channel fill geometry, composite of Line 91bn-03 and 91bn-08 (flattened on Term)

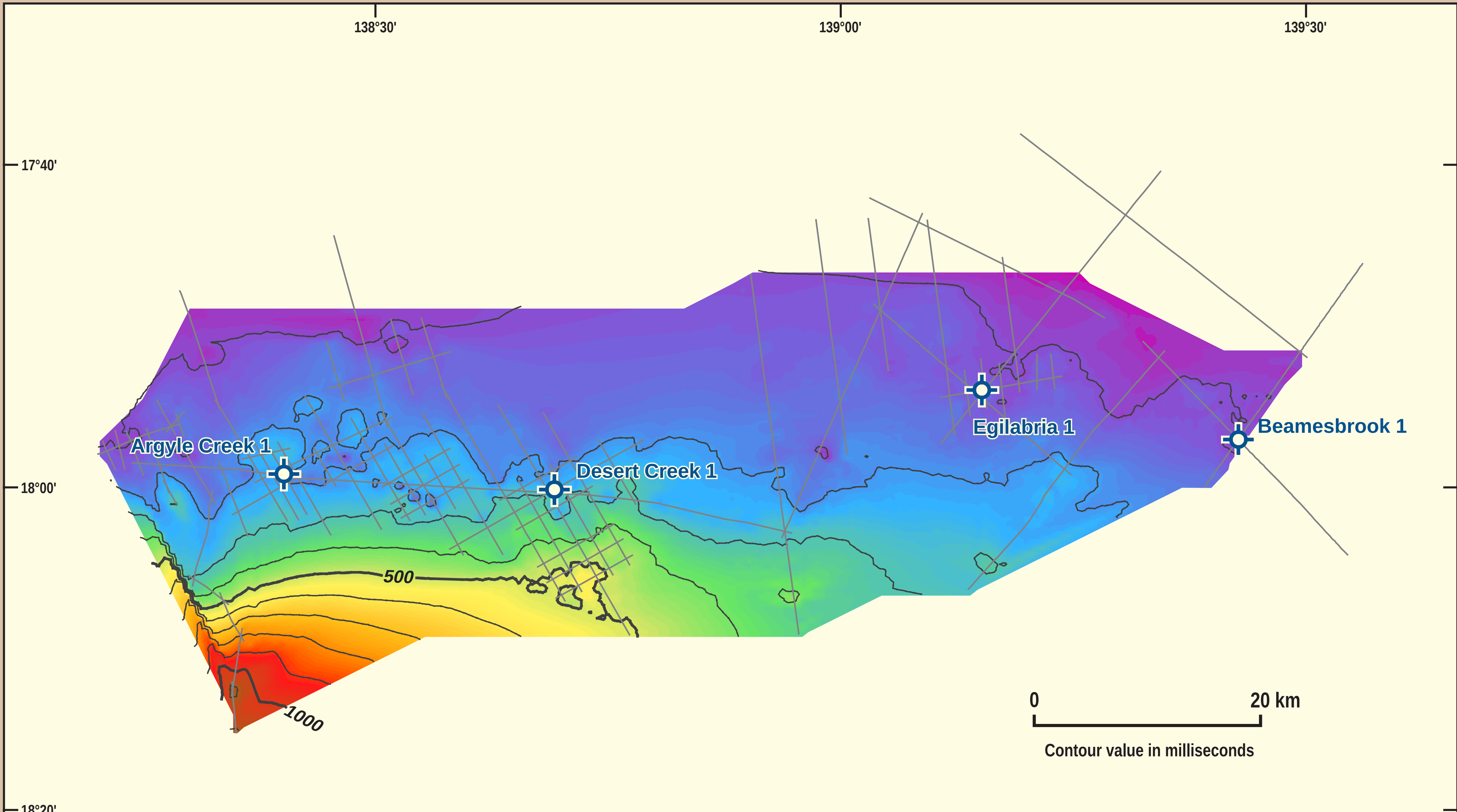

Figure 2.7.1 Isochron map of the Term Supersequence, showing a change to southeast thickening

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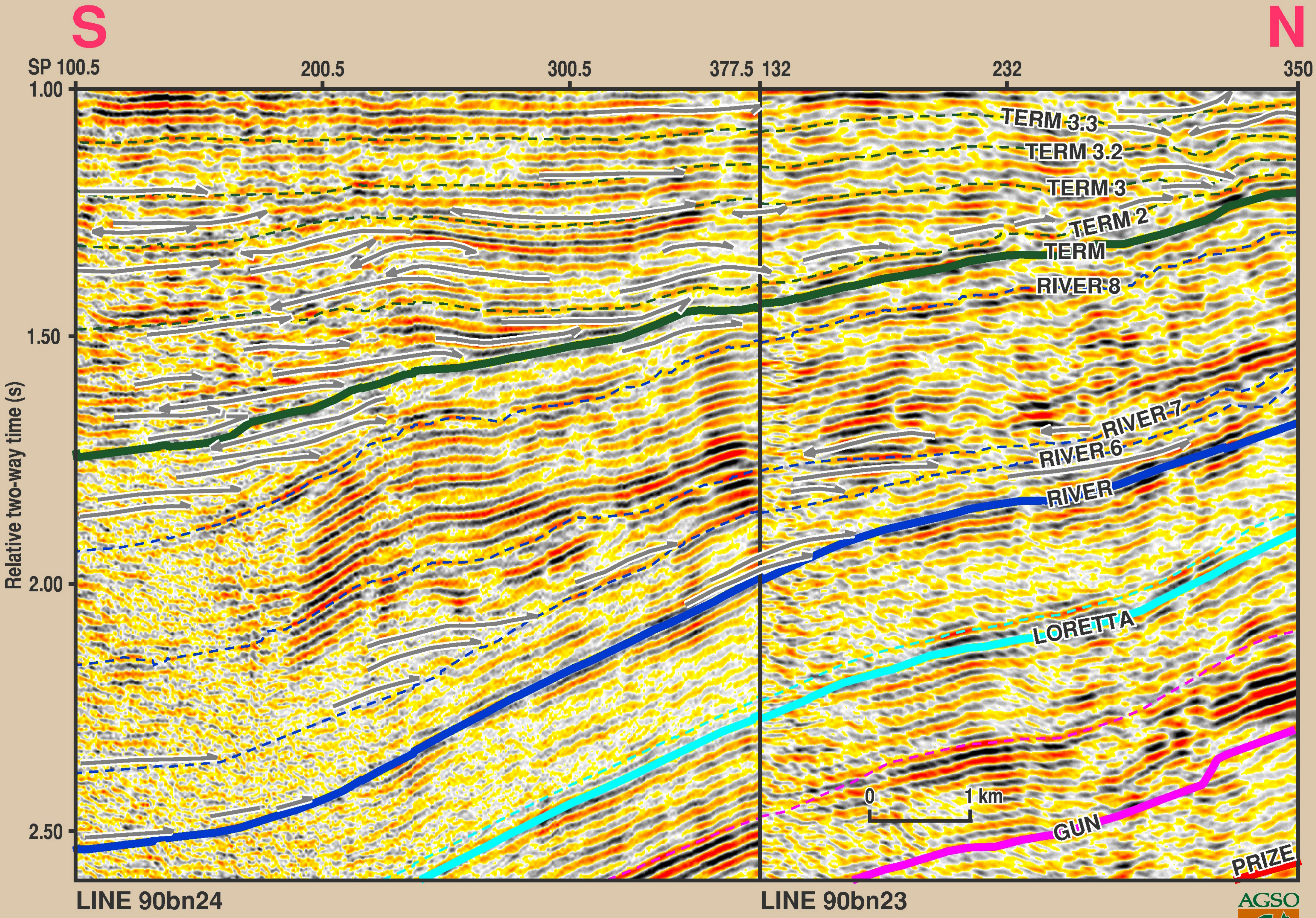

Figure 2.7.2 Seismic sequence stratigraphy of the River and Term Supersequences, Lines 90bn-24 and 90bn-23 (flattened on Term 4)

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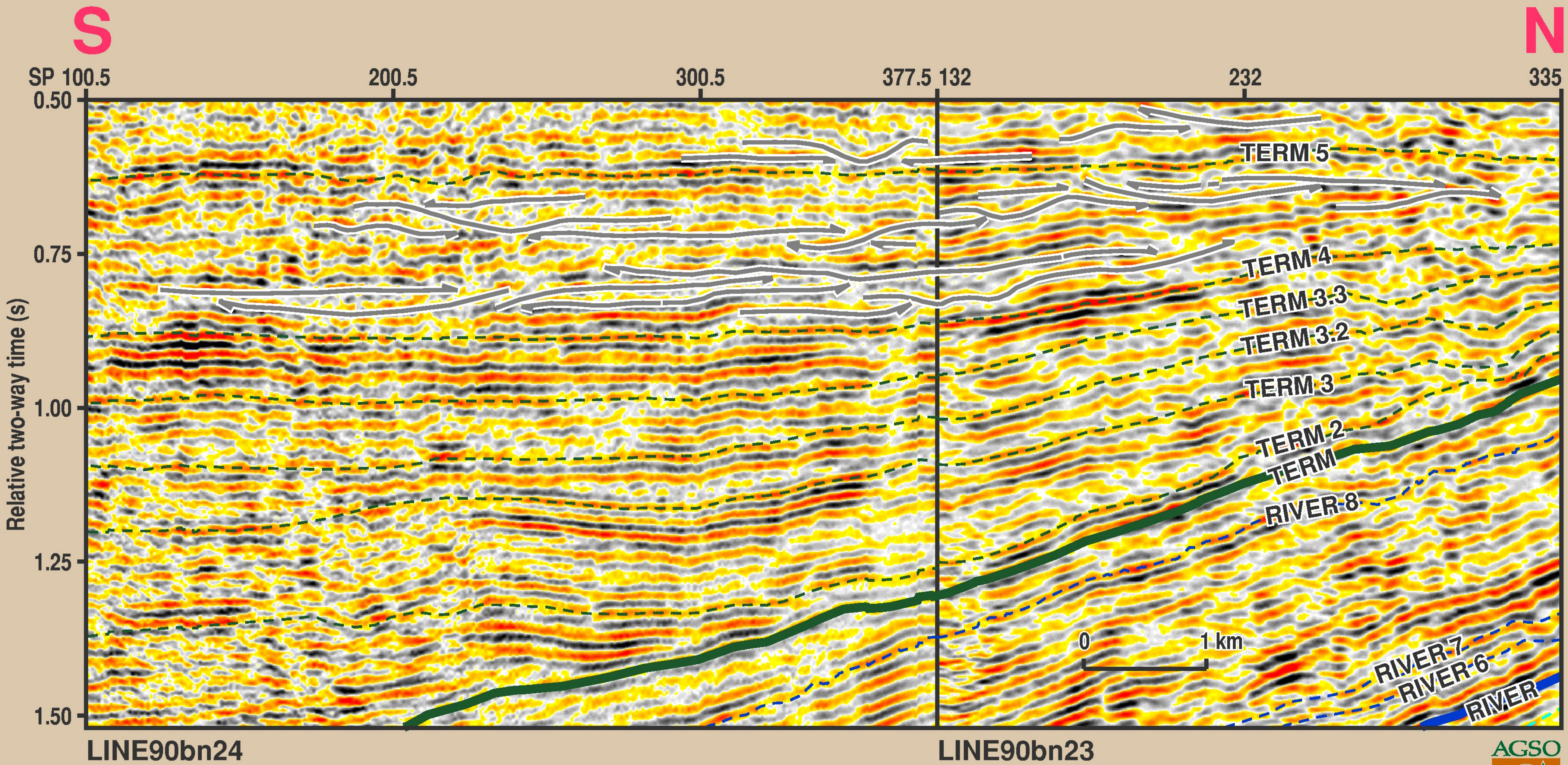

Figure 2.7.3 Seismic sequence stratigraphy of the Term Supersequence showing fan and channel levee configurations, Lines 90bn-24 and 90bn-23 (flattened on Lawn)

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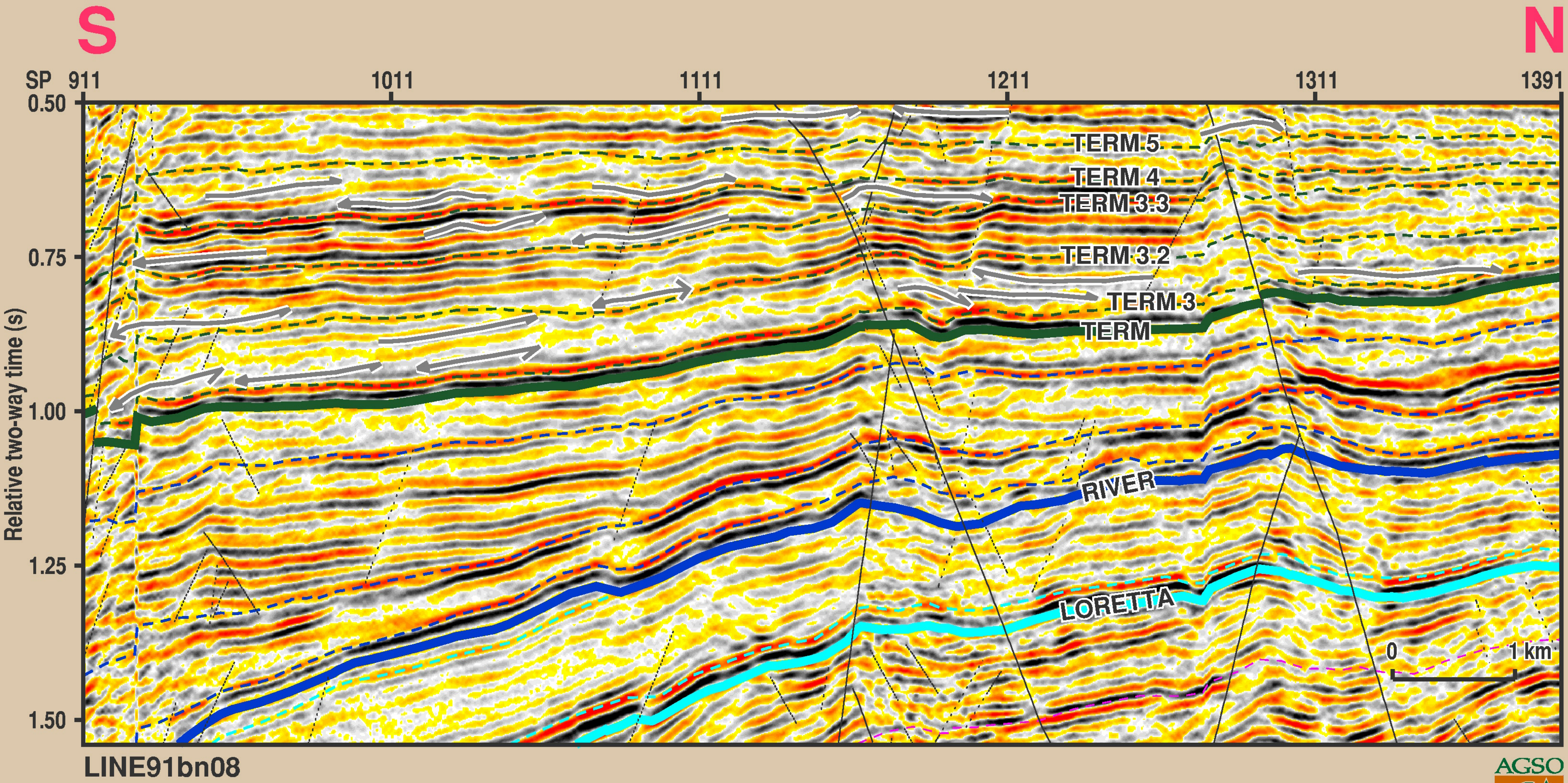

Figure 2.7.4 Seismic sequence stratigraphy of the Term Supersequence showing fan and channel levee geometry, Line 91bn-08 (flattened on Lawn)

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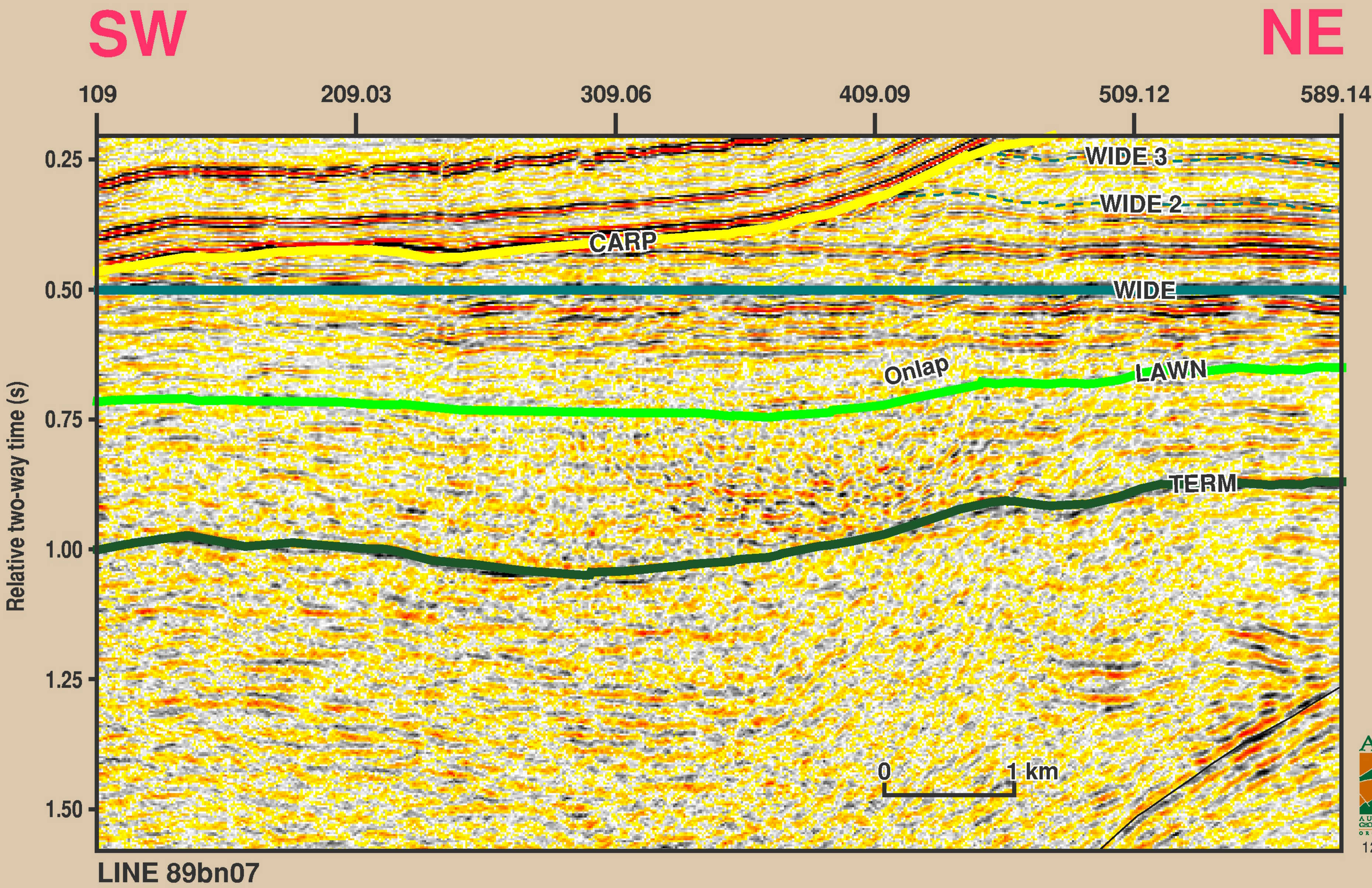

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Figure 2.8.1 Seismic sequence stratigraphy of the Lawn Supersequence showing onlapping geometry, Line 89bn-07 (flattened on Wide)

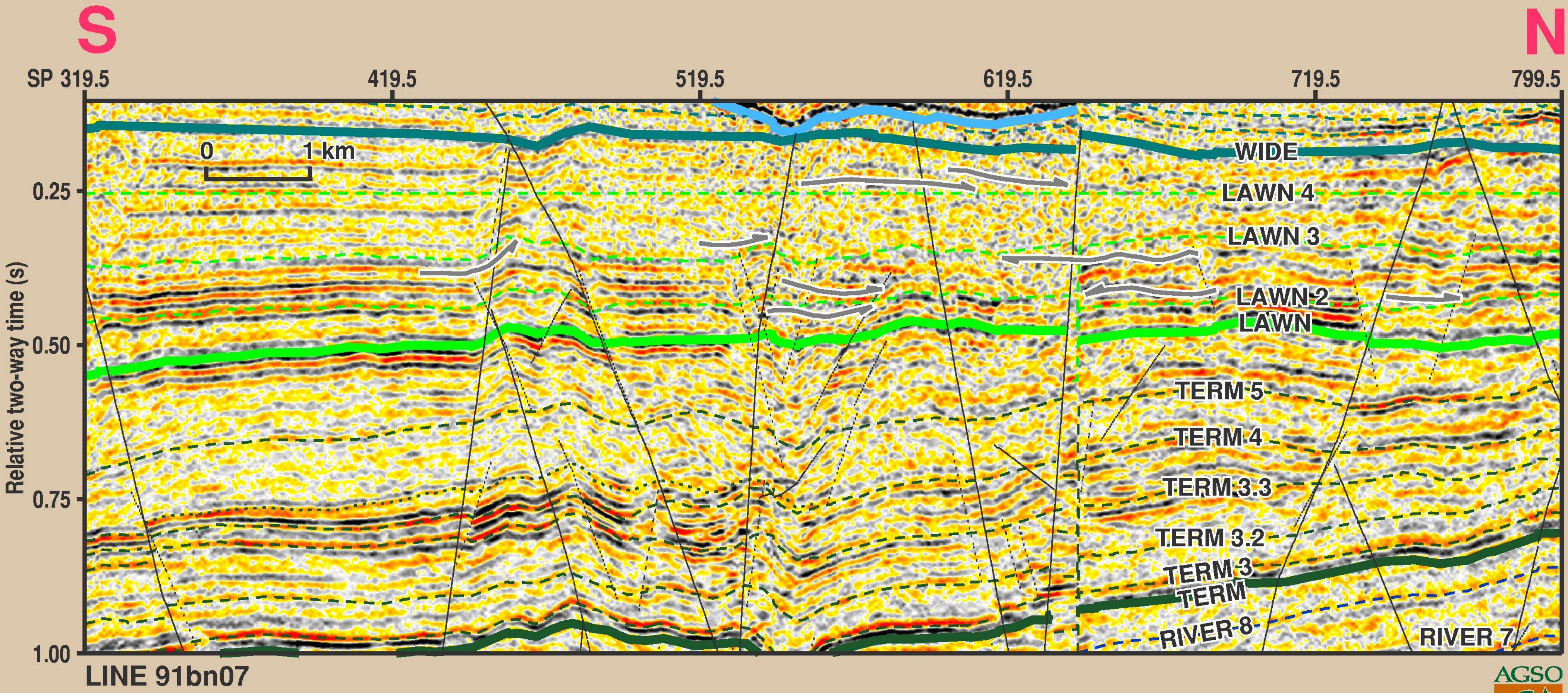

Figure 2.8.2 Seismic sequence stratigraphy of the Lawn Supersequence, Line 91bn-07 (flattened on Lawn 4)

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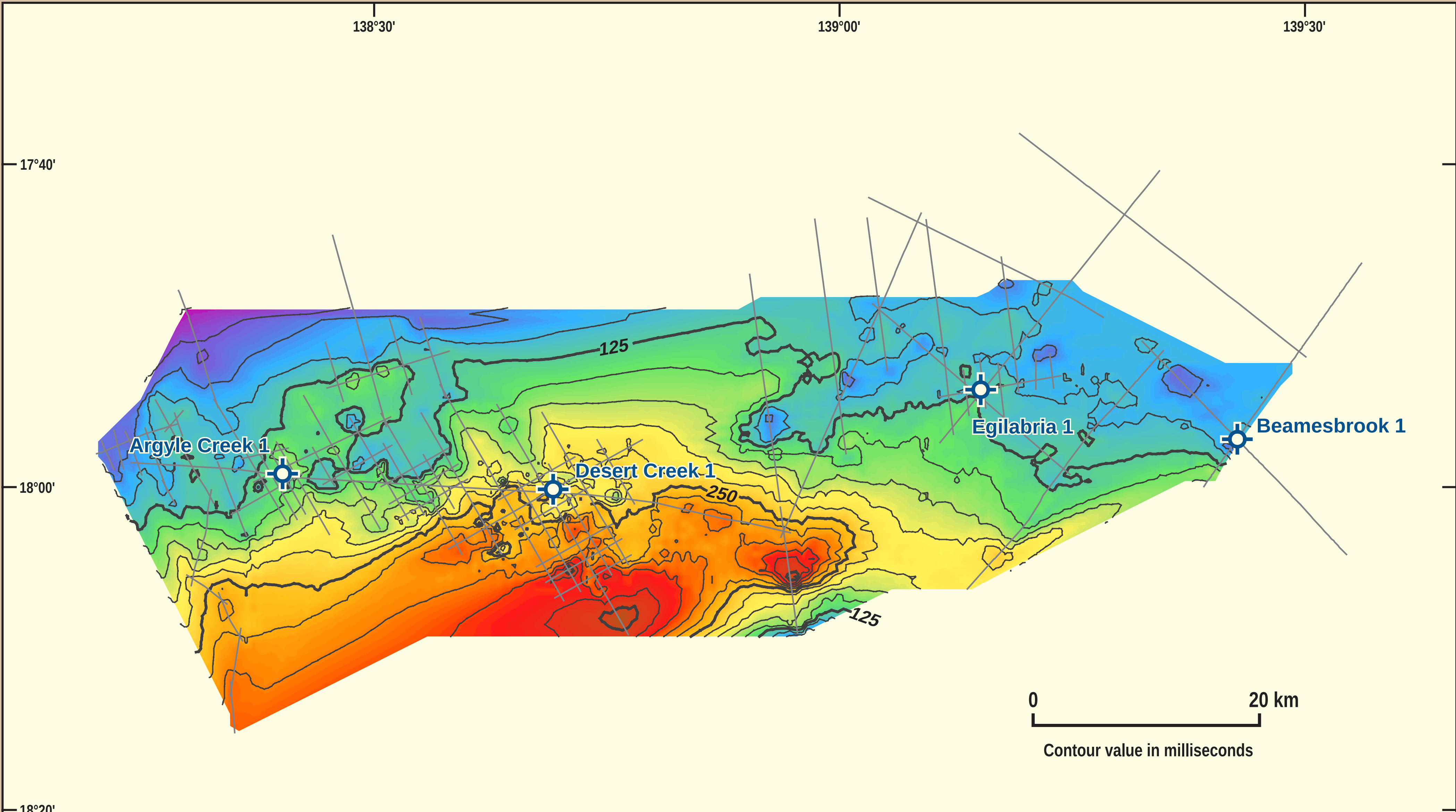

Figure 2.8.3 Isochron map of the Lawn Supersequence

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12/A/462

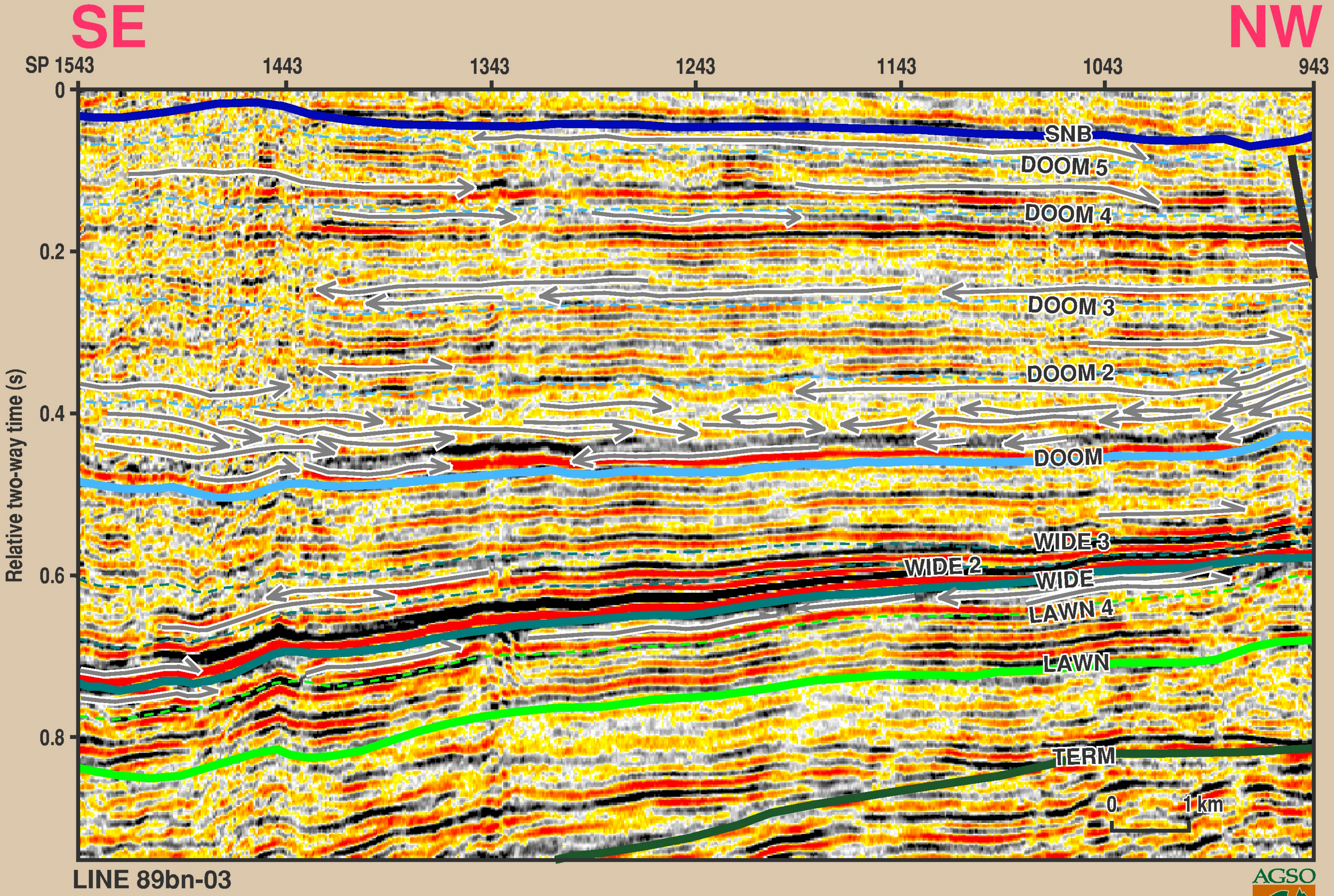

Figure 2.9.1 Seismic sequence stratigraphy of the Wide and Doom Supersequences, Line 89bn-03 (flattened on Doom 4)

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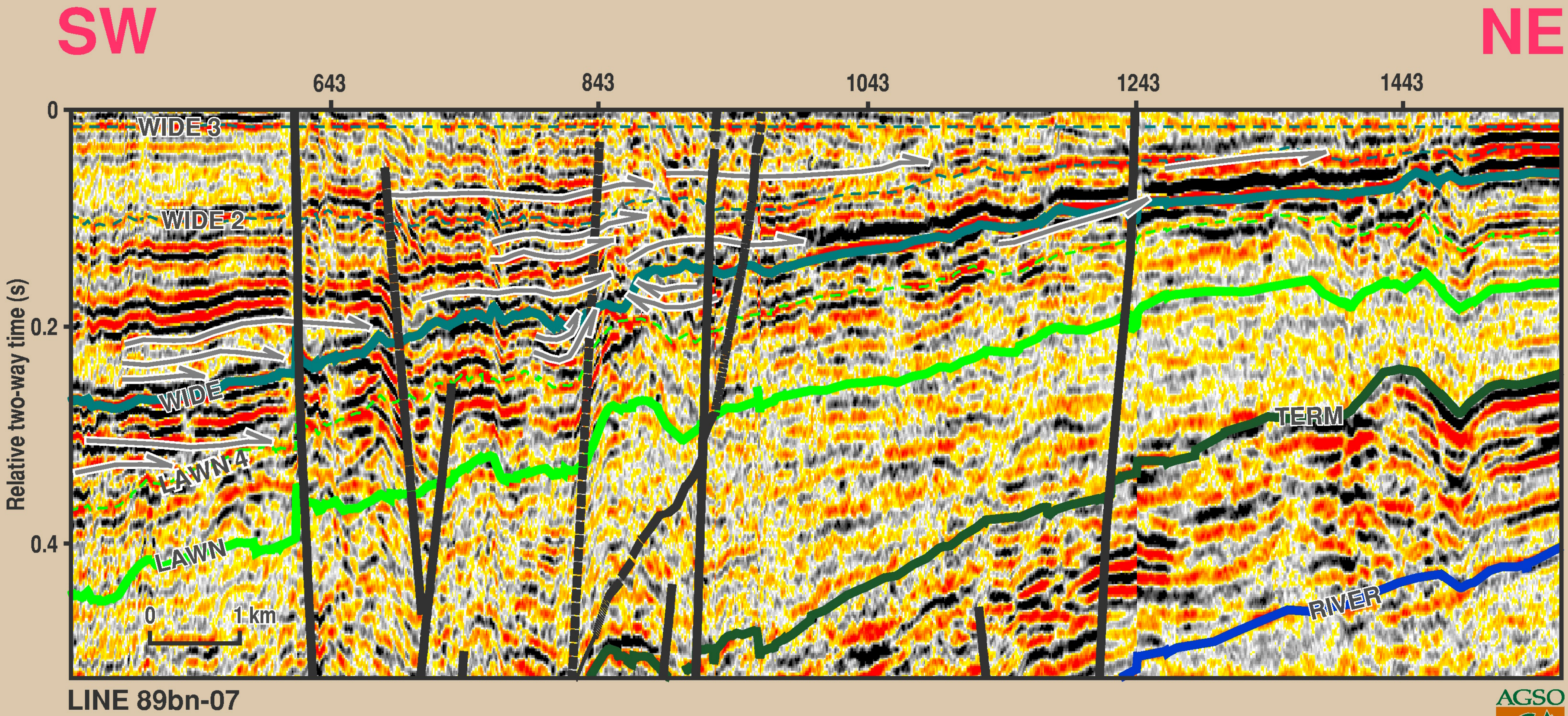

Figure 2.9.2 Seismic sequence stratigraphy of the Wide Supersequence showing onlapping geometry, Line 89bn-07 (flattened on Wide 3)

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12/A/483

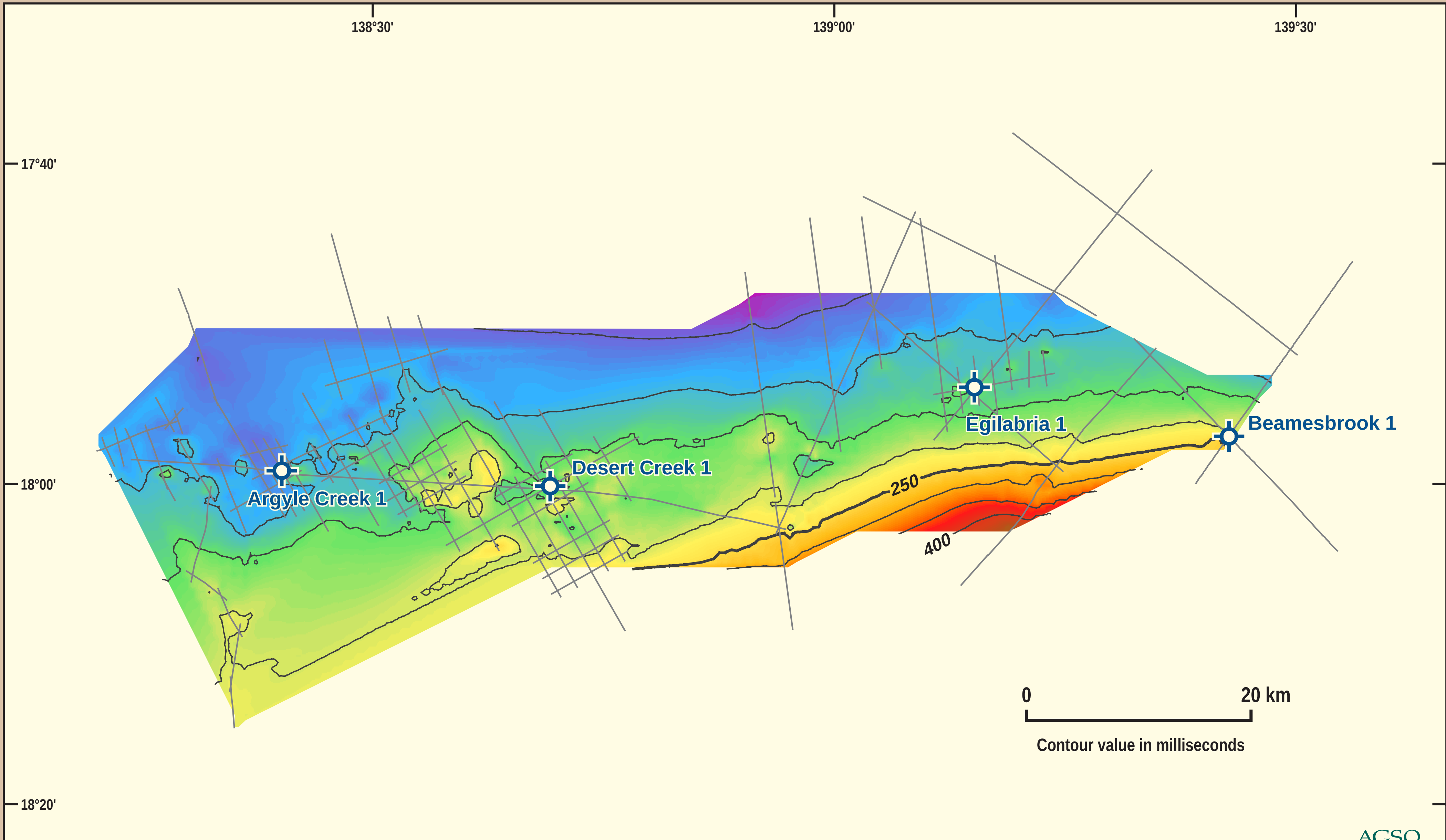

Figure 2.9.3 Isochron map of the Wide Supersequence, showing local, focused thickness variations

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12/A/463

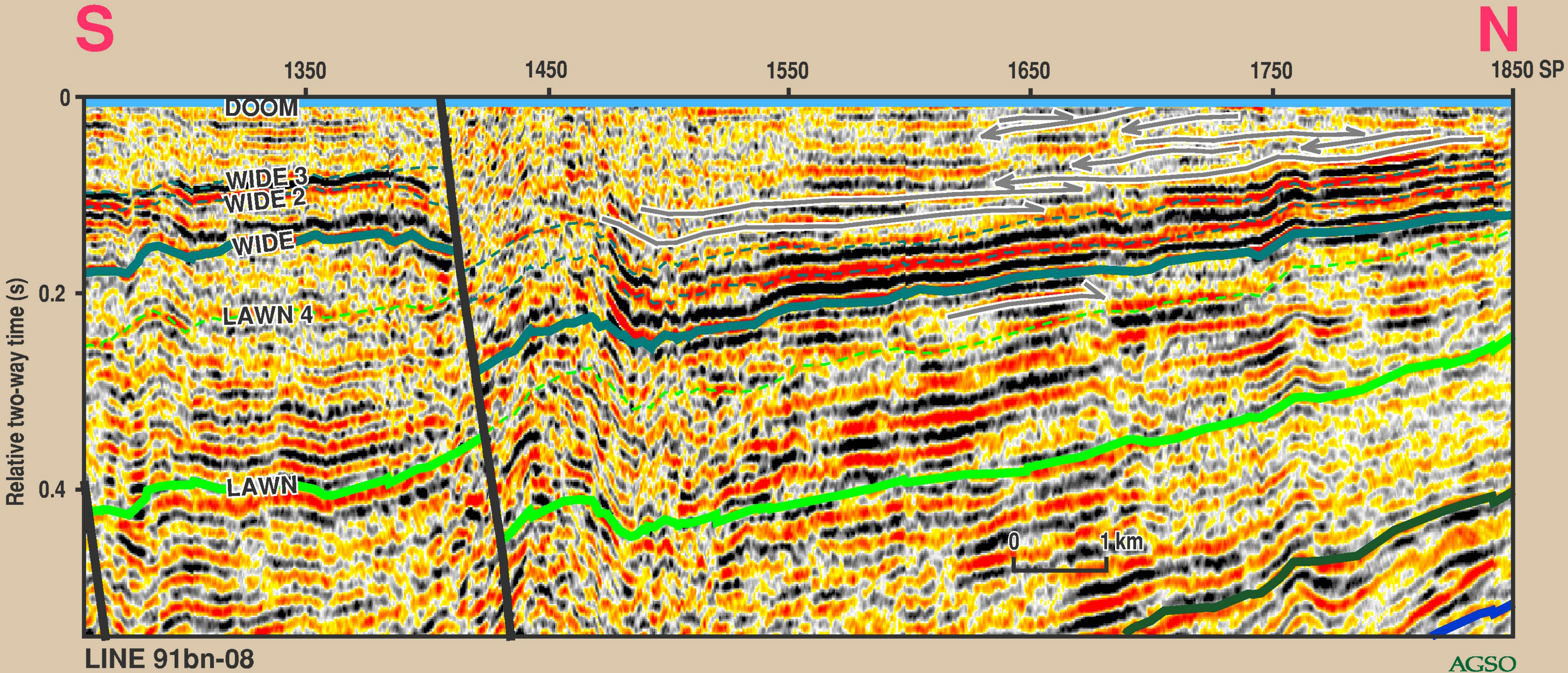

Figure 2.9.4 Seismic sequence stratigraphy of the Wide Supersequence showing onlapping geometry and syndepositional growth, Line 91bn-08 (flattened on Doom)

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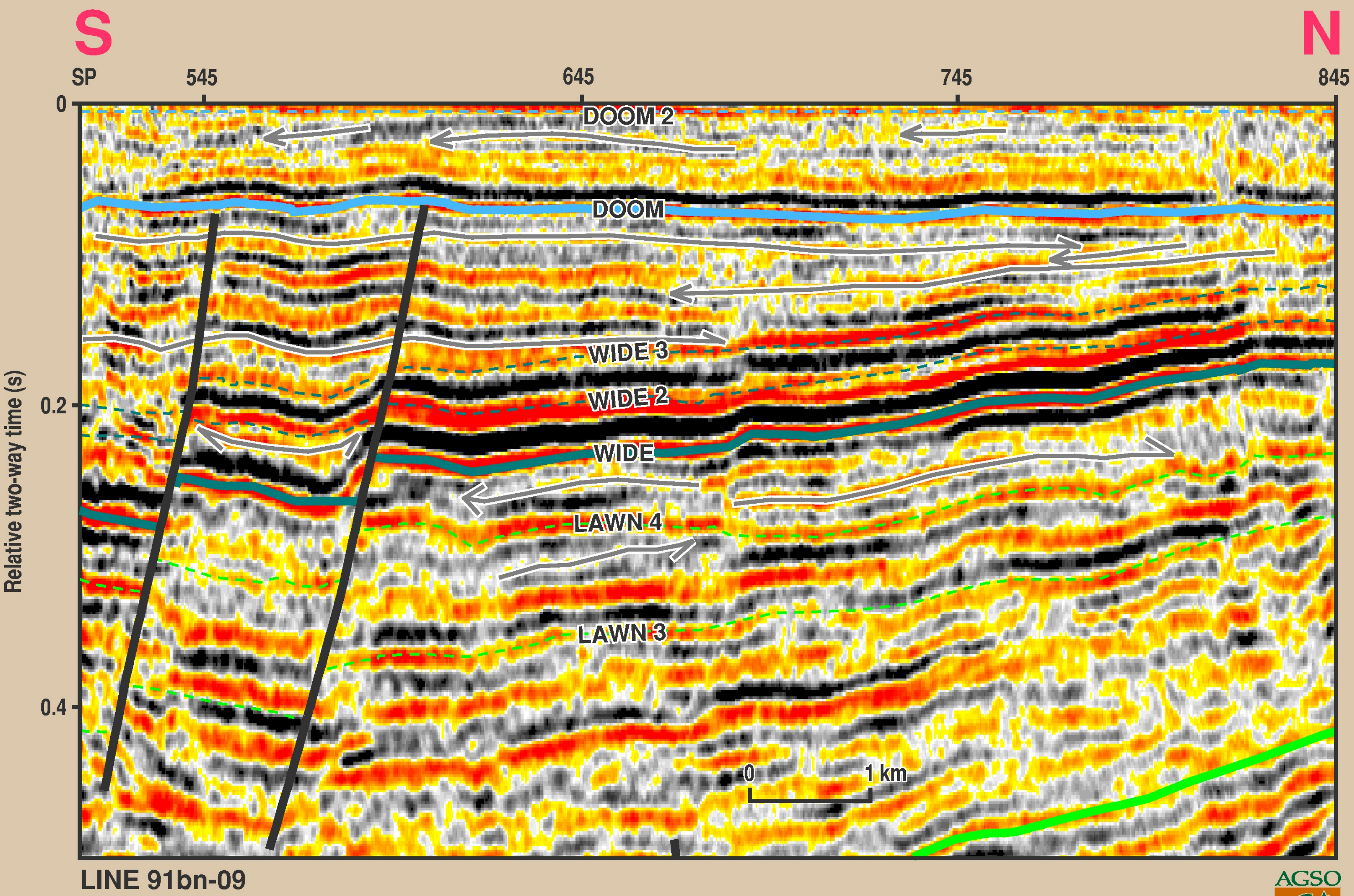

Figure 2.9.5 Seismic sequence stratigraphy of the Wide and Doom Supersequences, Line 91bn-09 (flattened on Doom 2)

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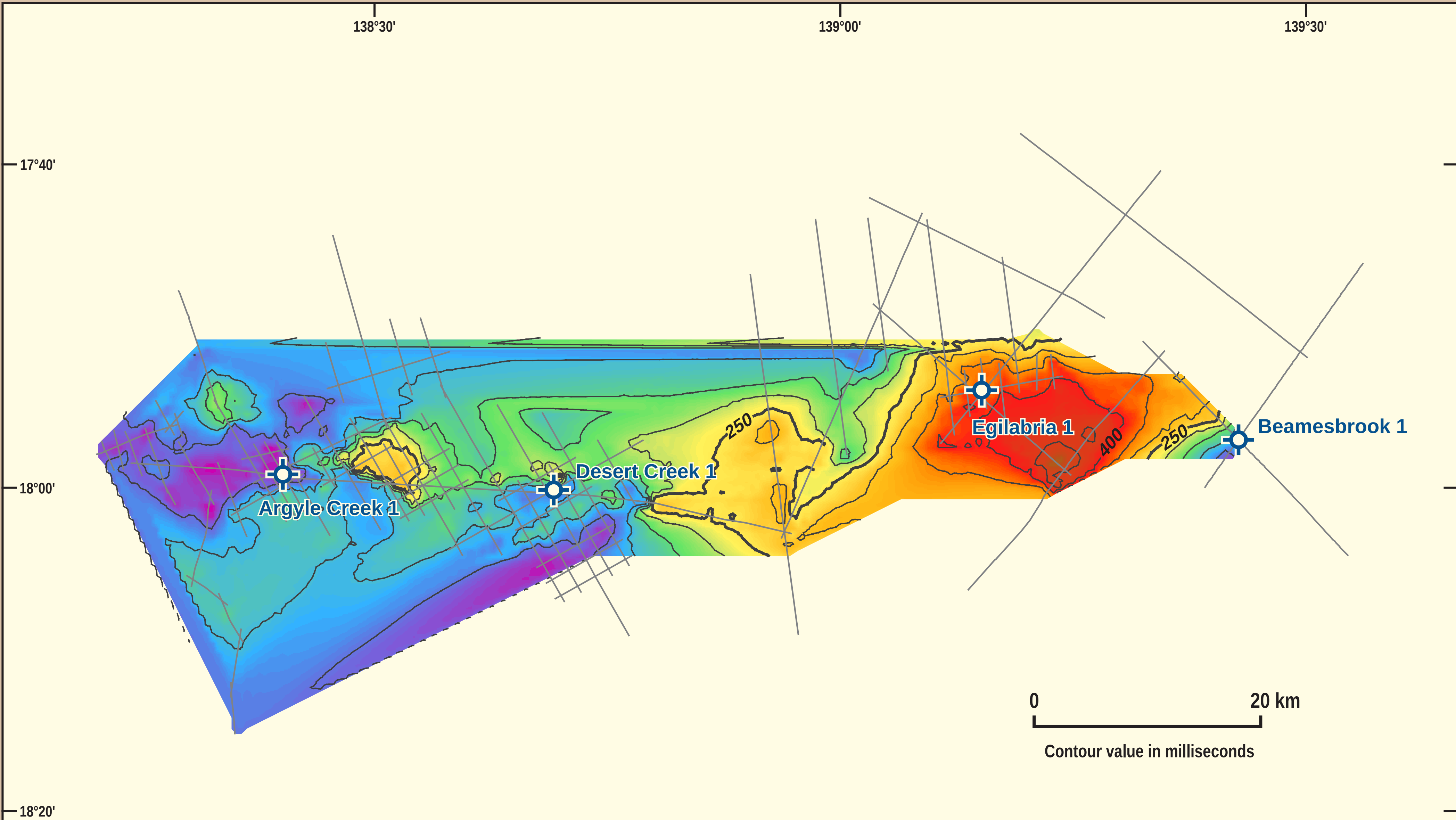

Figure 2.10.1 Isochron map of the Doom Supersequence

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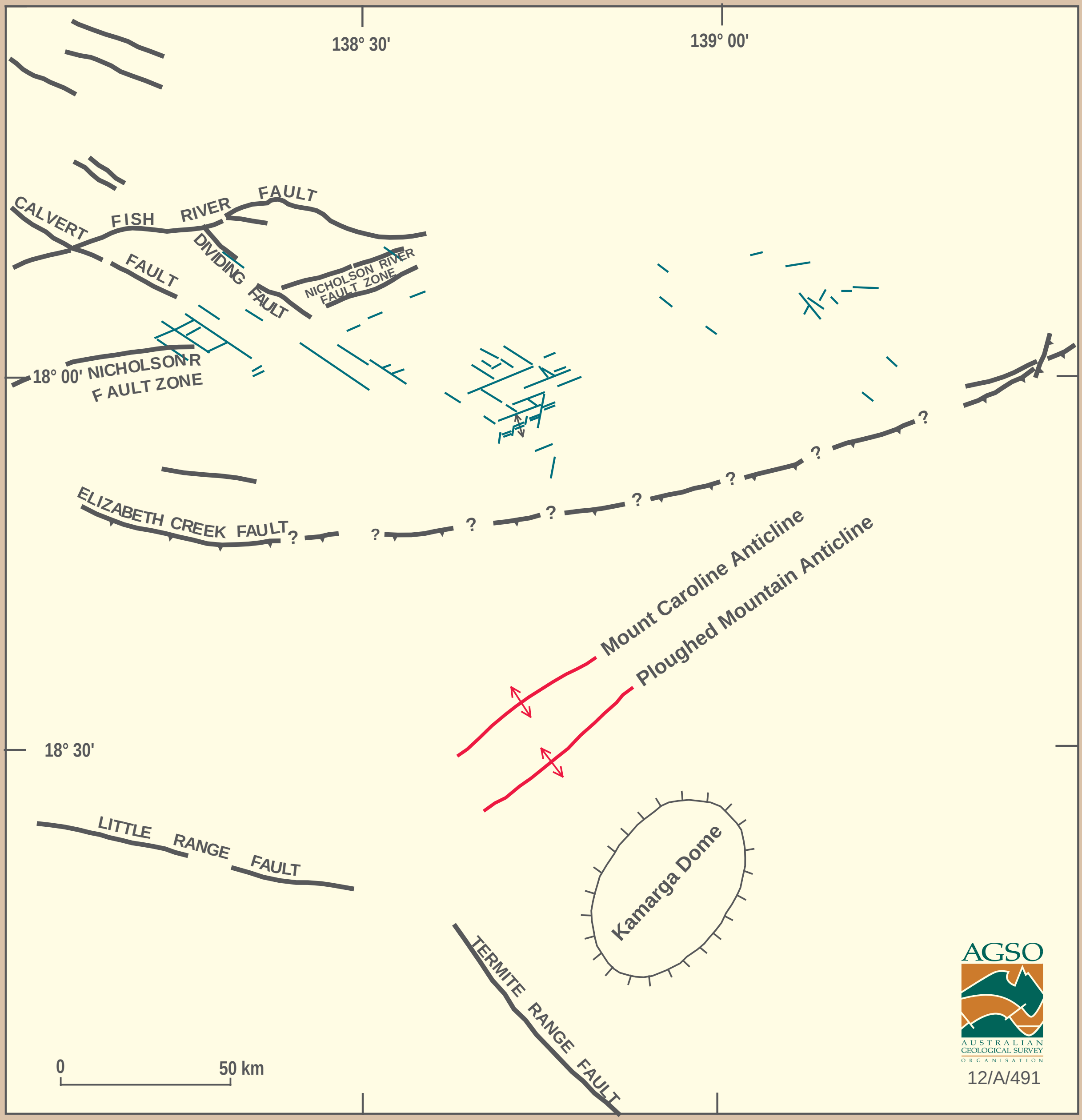


Figure 3.1.1 Late Stage Structures in the northern Lawn Hill Platform

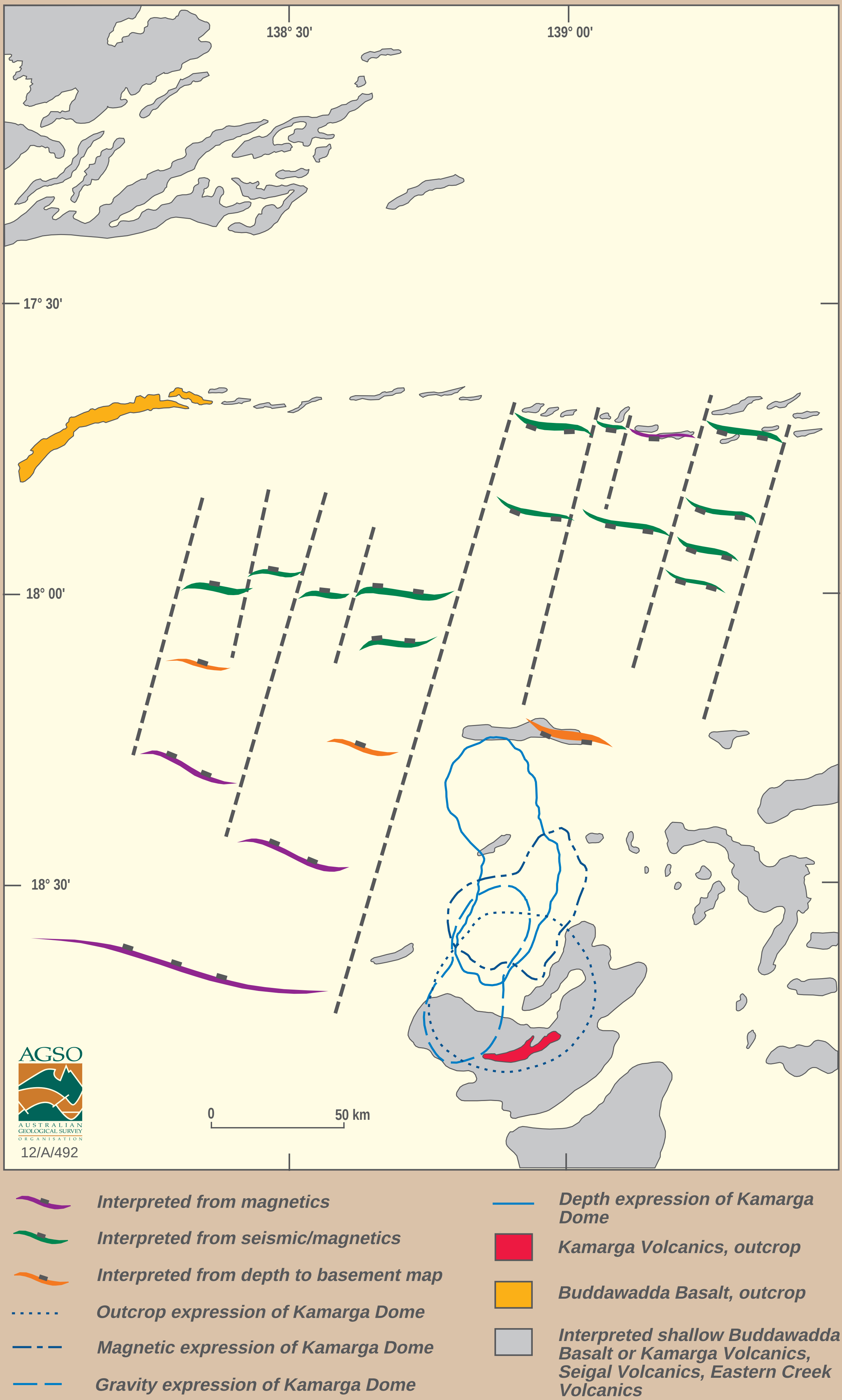


Figure 3.2.1 Basement structures in the northern Lawn Hill Platform

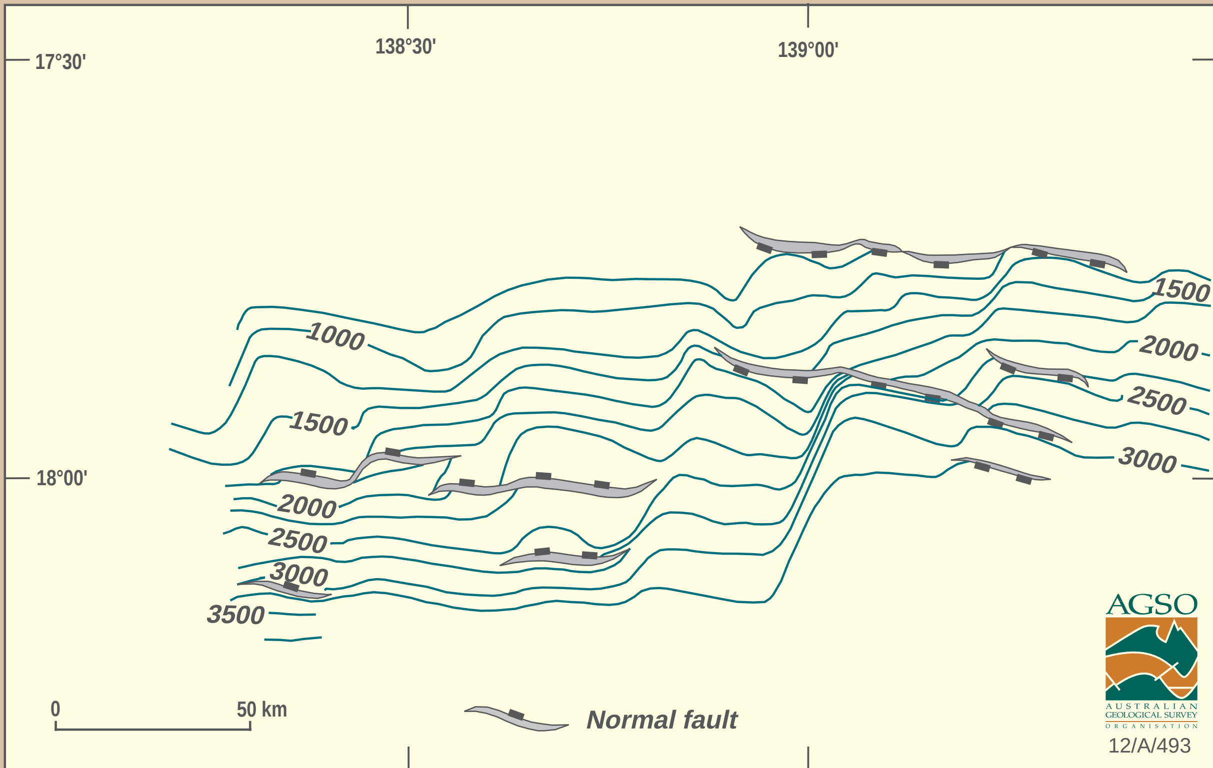


Figure 3.2.2 Time structure map on Big 1

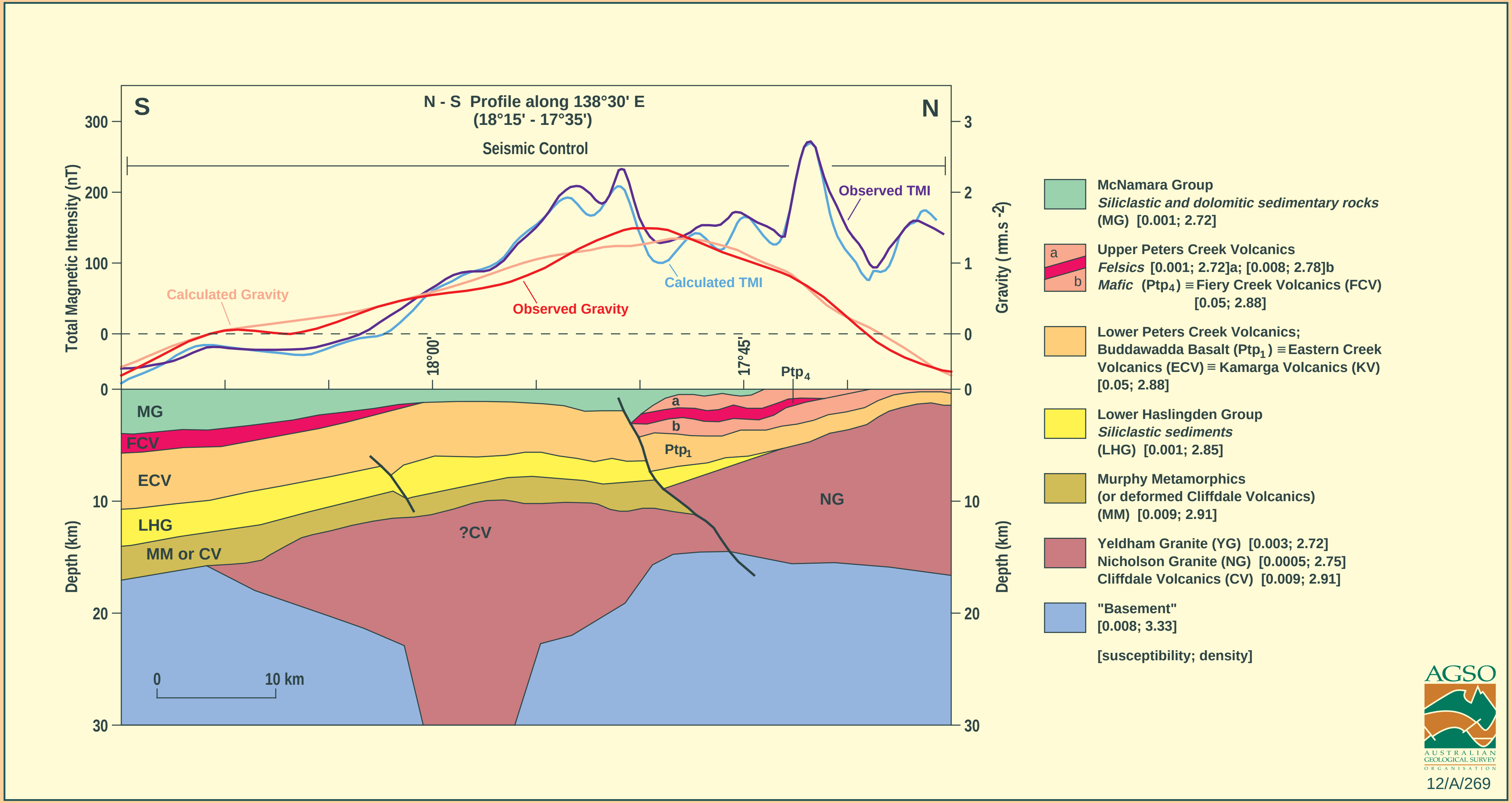


Figure 3.2.3 Geological model from the western side of the Comalco seismic grid compared to observed geophysical data

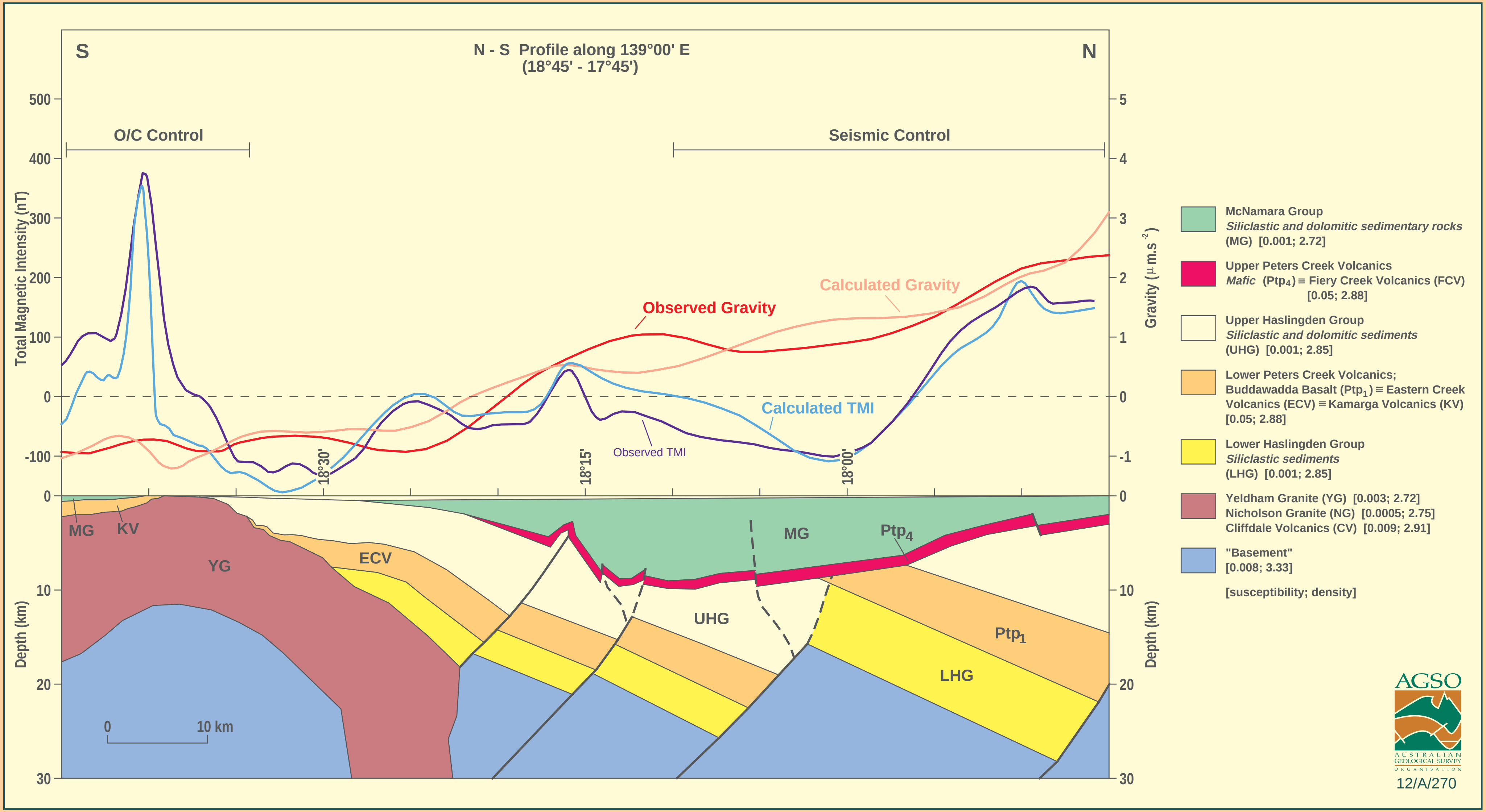
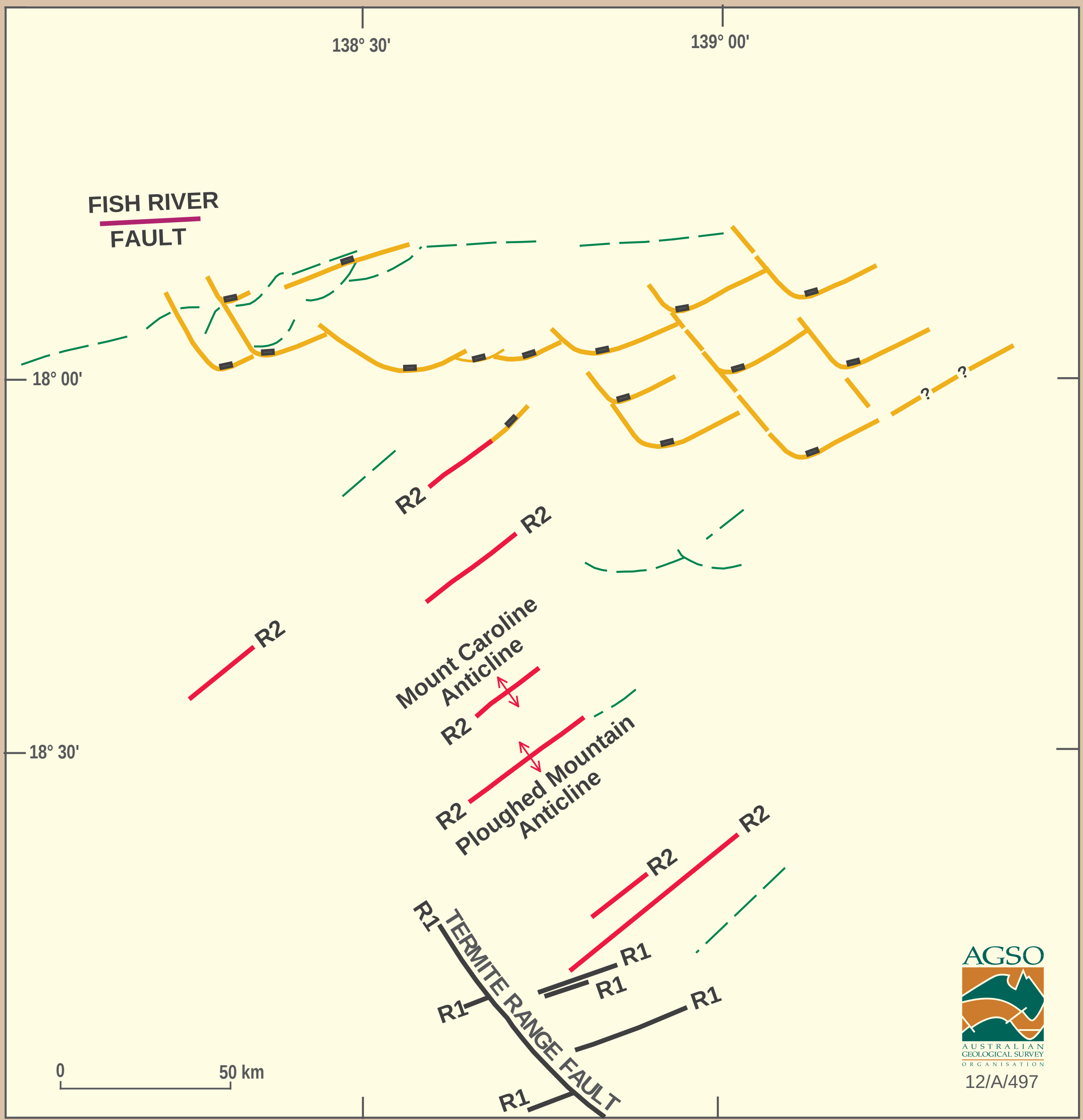


Figure 3.2.4 Geological model from the eastern side of the Comalco seismic grid compared to observed geophysical data



Fault, interpreted from garvity

Fault, interpreted from seismic

Lineament, interpreted from magnetics

R1 Outcrop

R2 Outcrop

Figure 3.3.1 River event (~1640Ma) structure

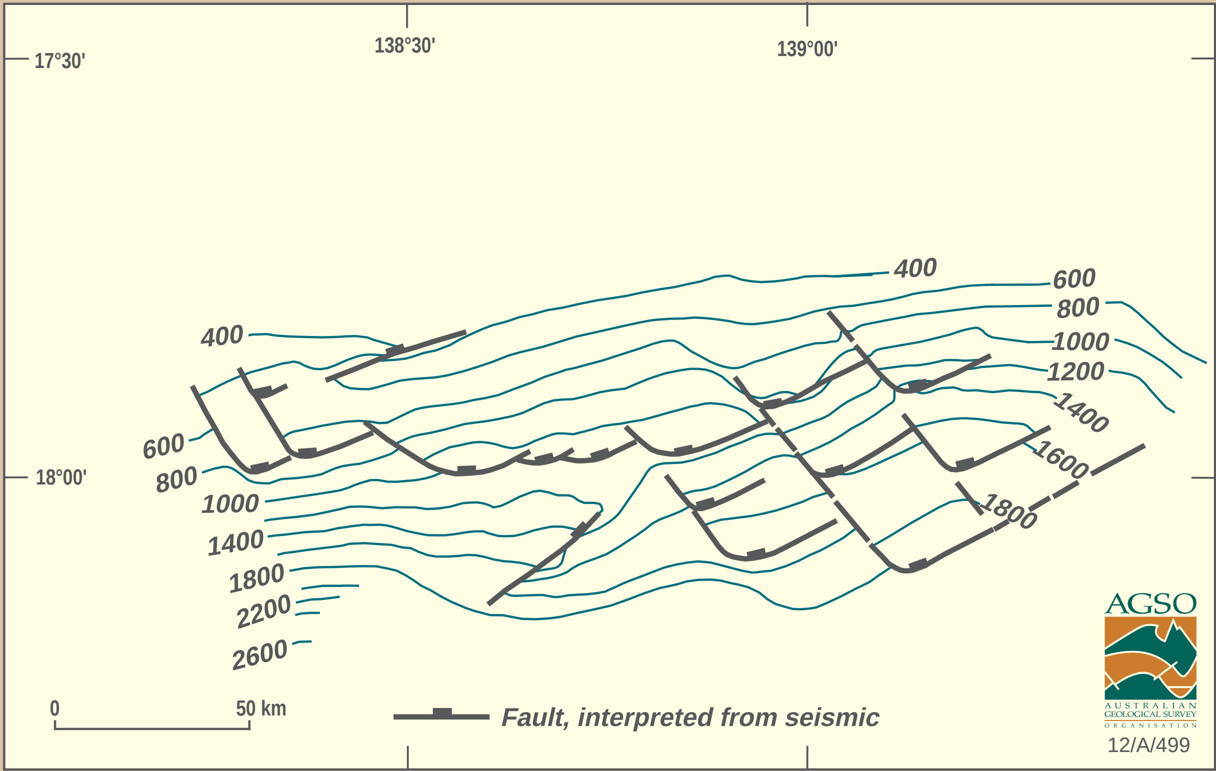


Figure 3.3.2 Time structure map on River 1

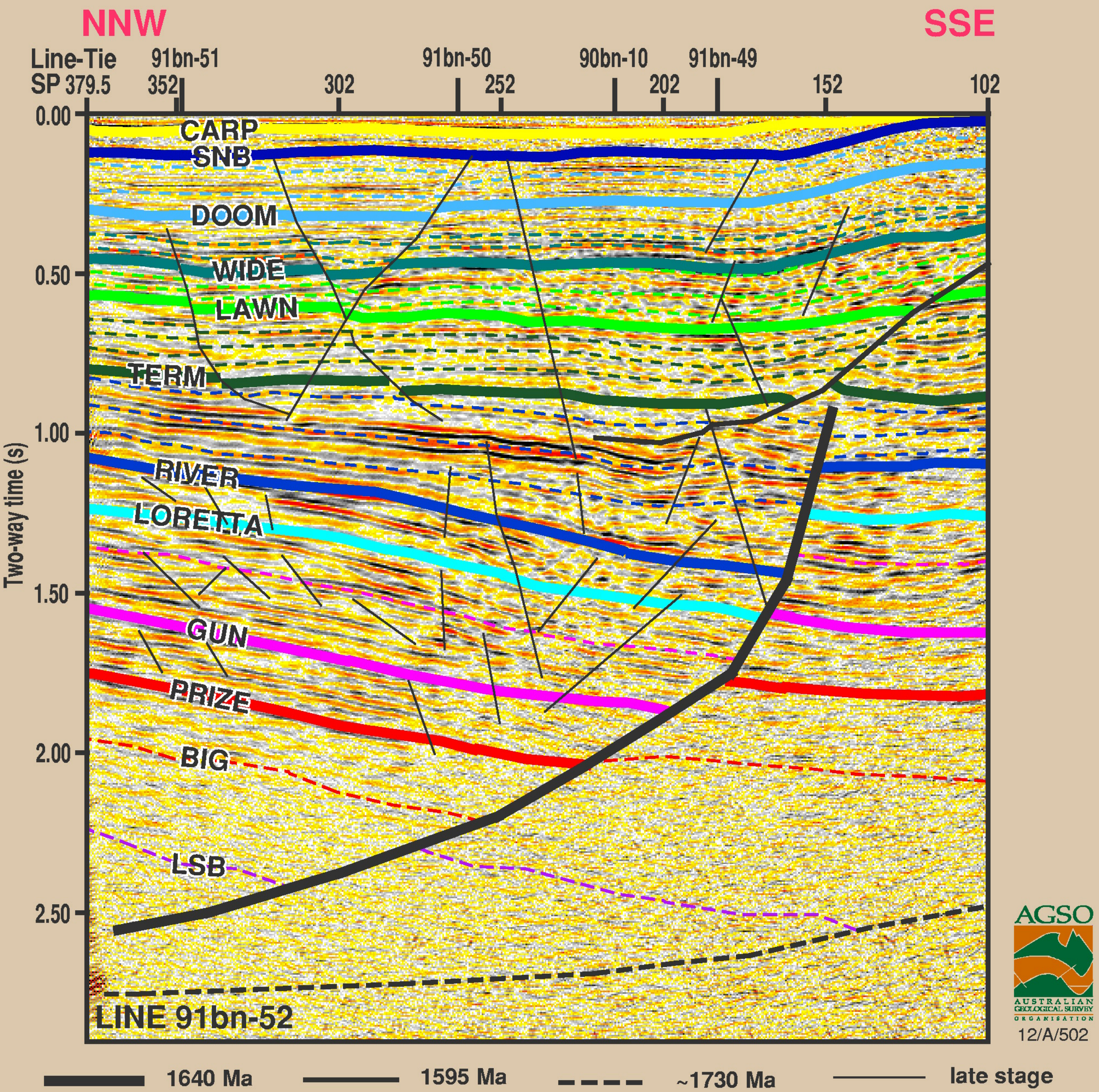


Figure 3.3.3 River event listric normal growth fault

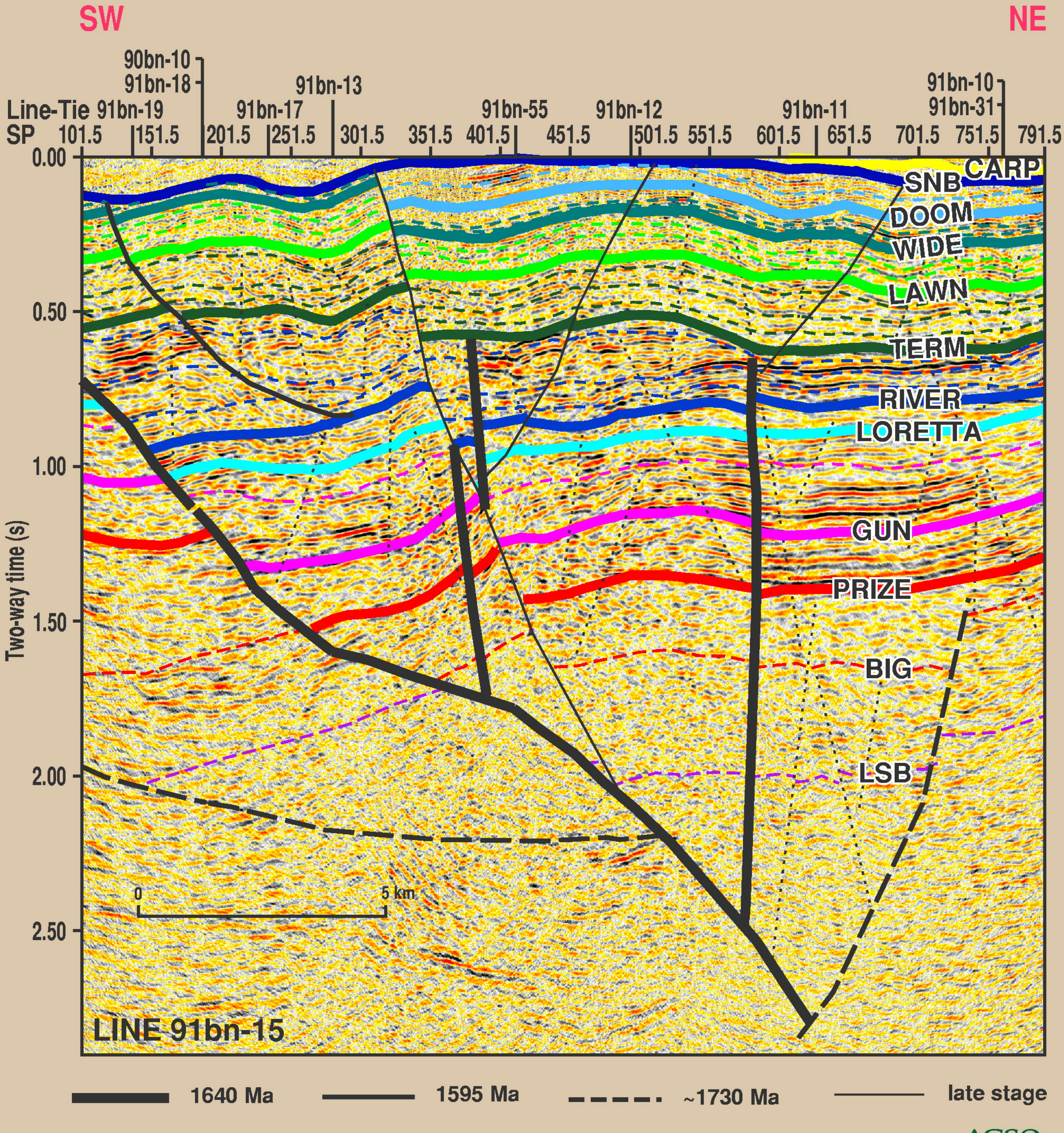


Figure 3.3.4 Linked River event structures

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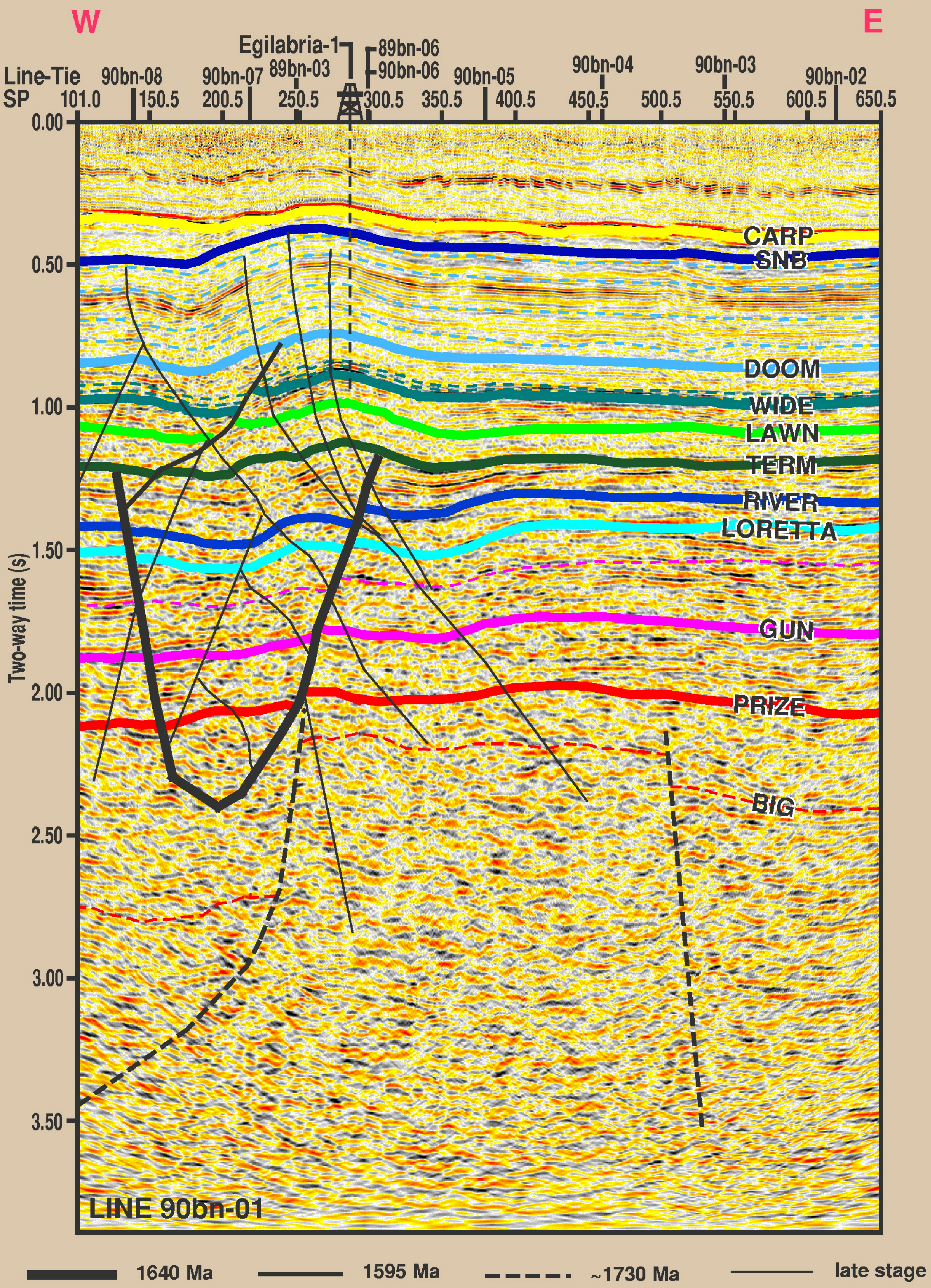

Figure 3.3.5 Linked River event structures

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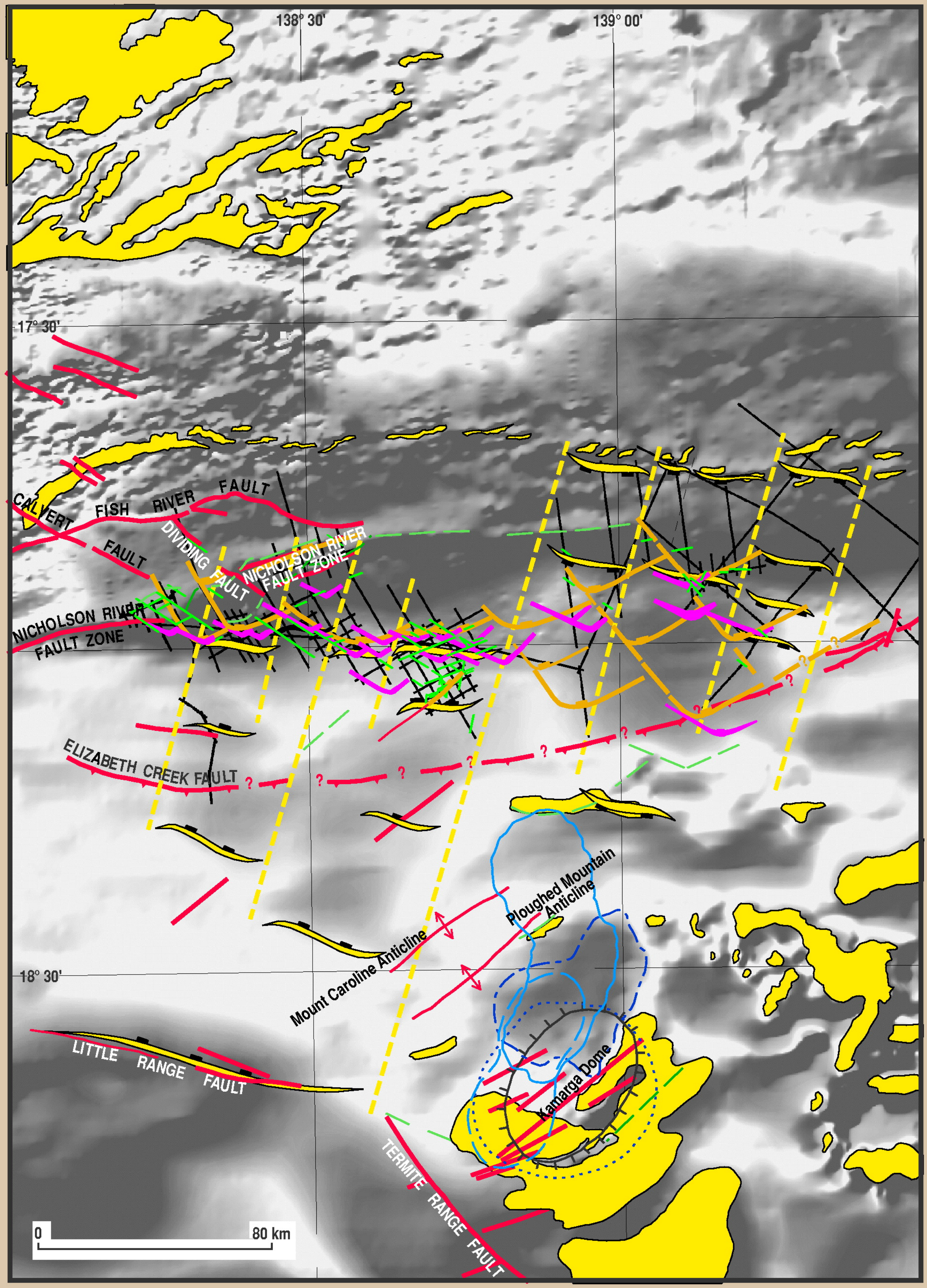

<1585 Ma fault/joint interpreted from seismic

1595 Ma wrench fault, interpreted from seismic

1640 Ma fault, interpreted from seismic

~1730 Ma fault interpreted from seismic/magnetics

Fault, interpreted from garvity

Lineament, interpreted from magnetics

Magnetic expression of Kamarga Dome

Gravity expression of Kamarga Dome

Depth expression of Kamarga Dome

Outcrop expression of Kamarga Dome

Outcropping and interpreted shallow Buddawadda Basalt or Kamarga Volcanics, Seigal Volcanics, Eastern Creek Volcanics

Outcrop fault

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Figure 3.3.6 Structures Synthesis

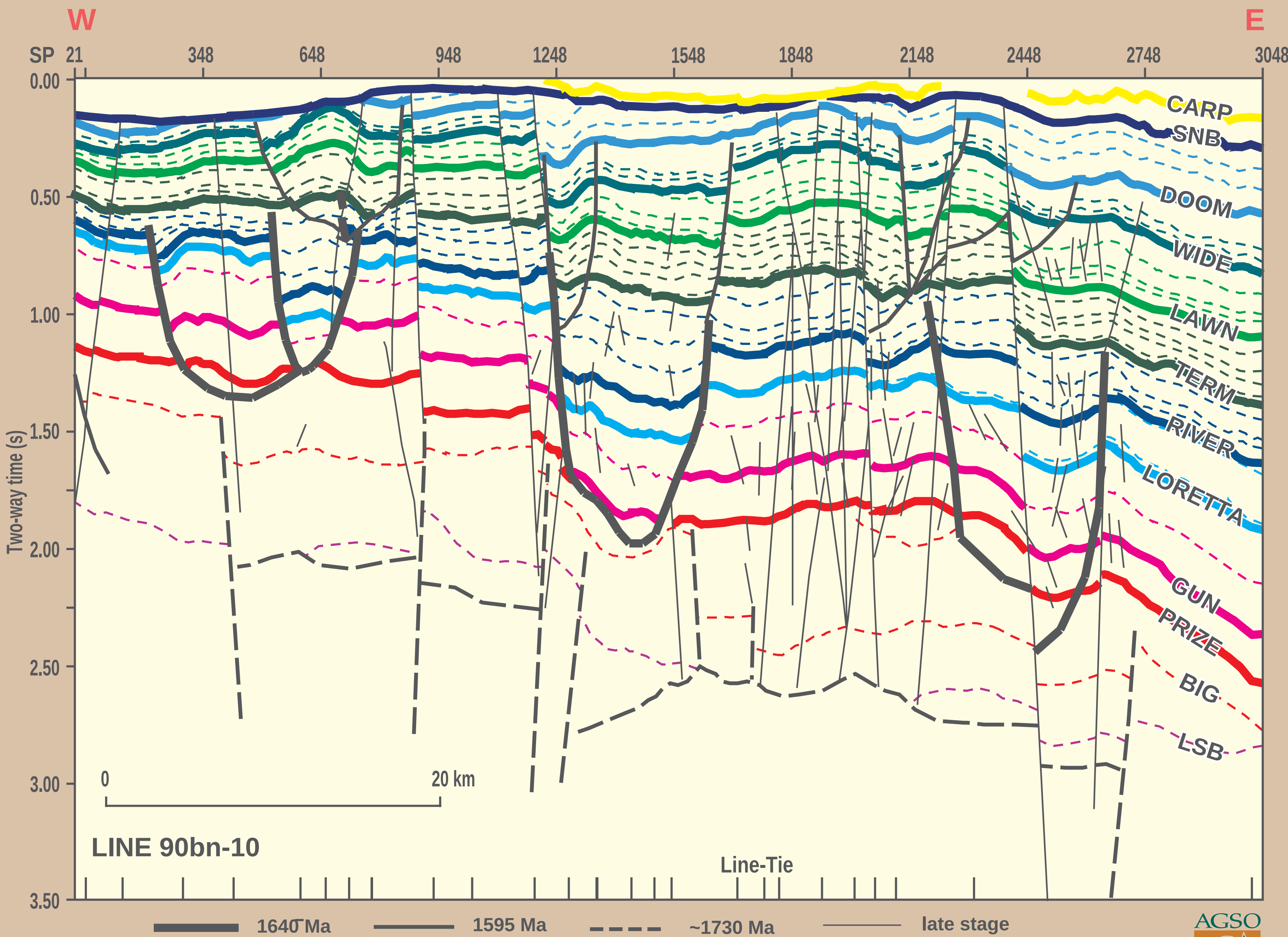

Figure 3.3.7 Line drawing of regional E-W line 90bn-10

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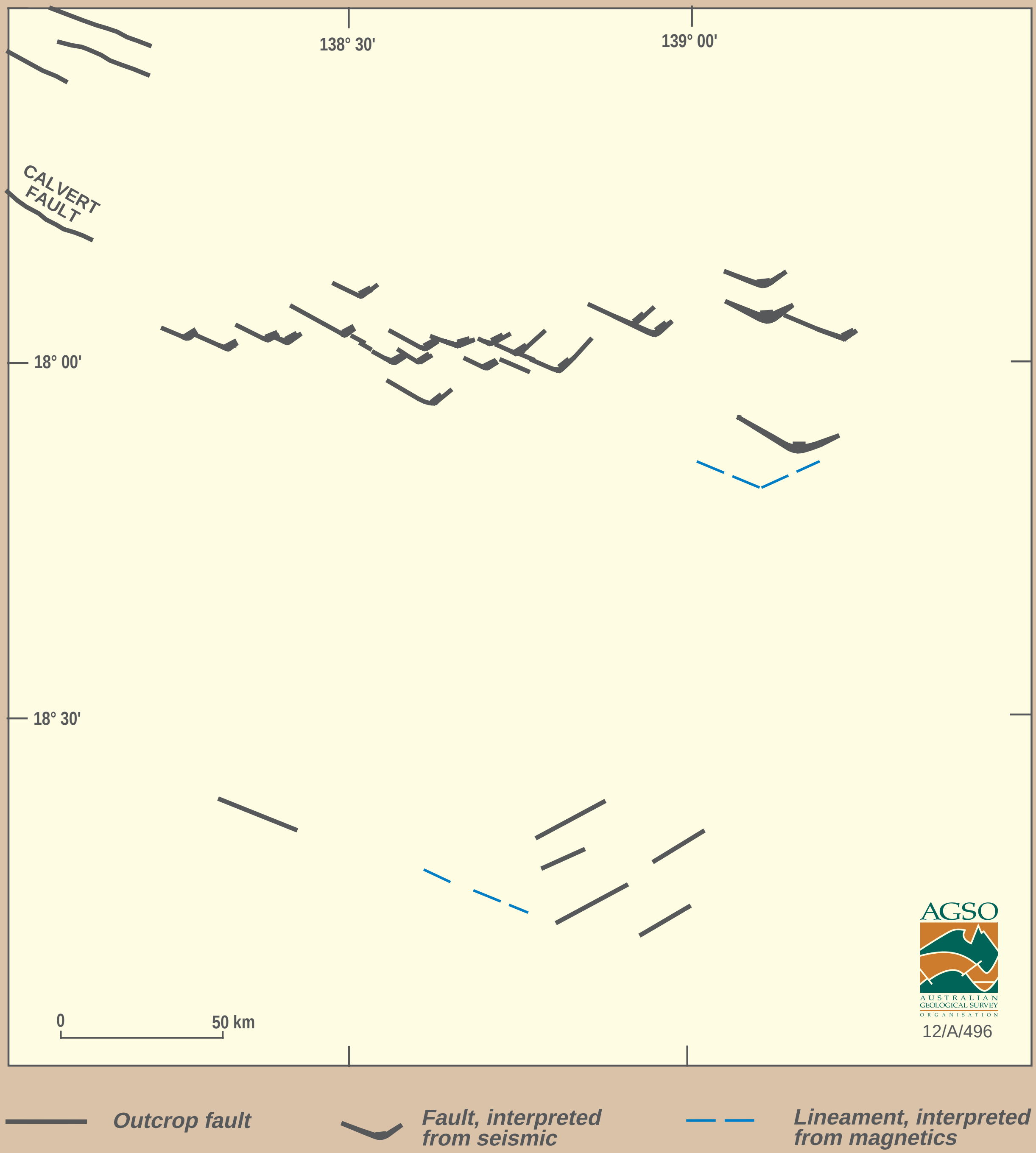

Figure 3.3.8 Wide event (~1595Ma) structure

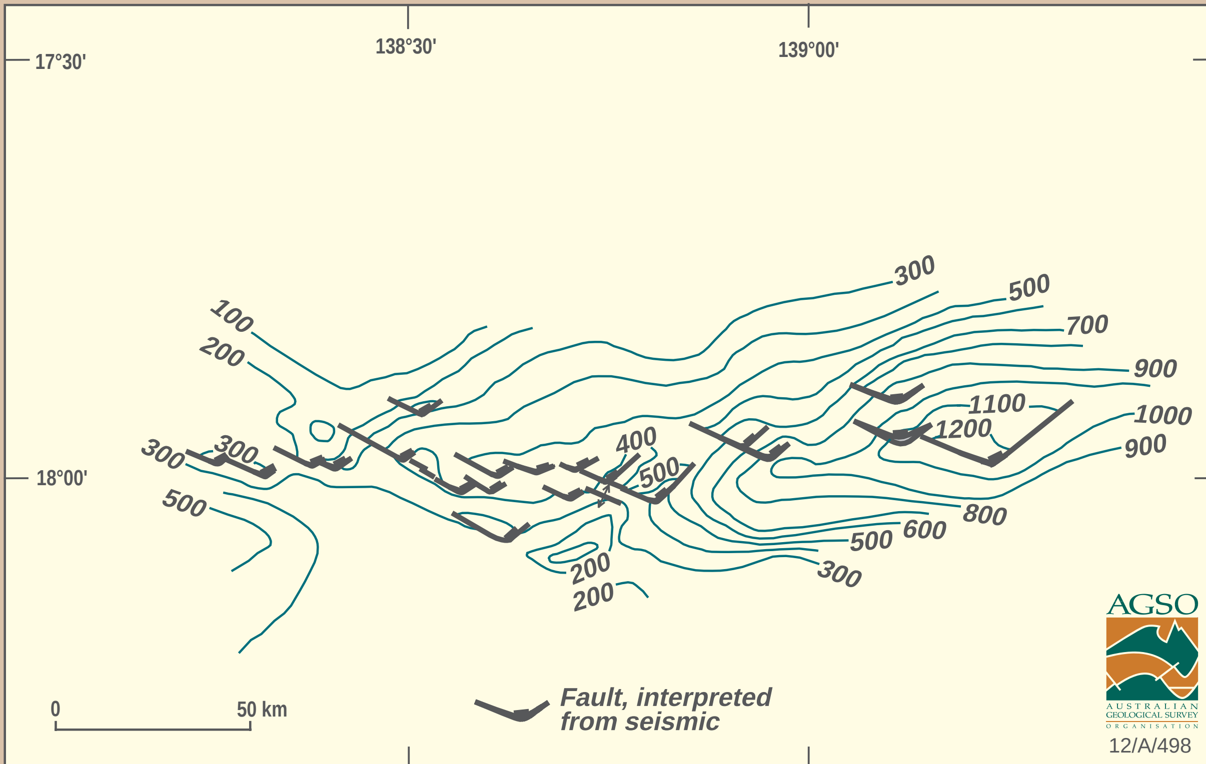

Figure 3.3.9 Time structure map on Wide 1

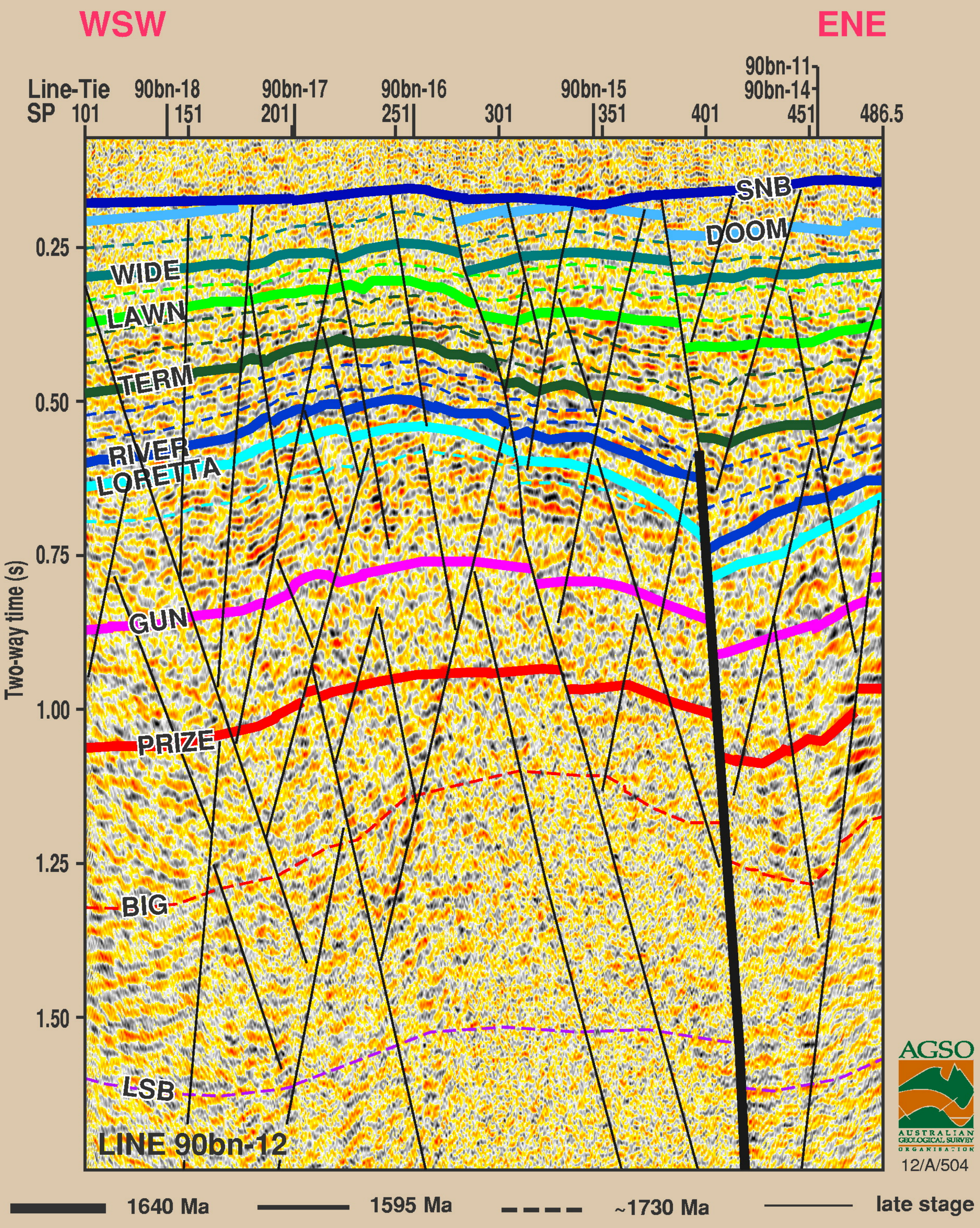

Figure 3.3.10 Late stage conjugate fractures

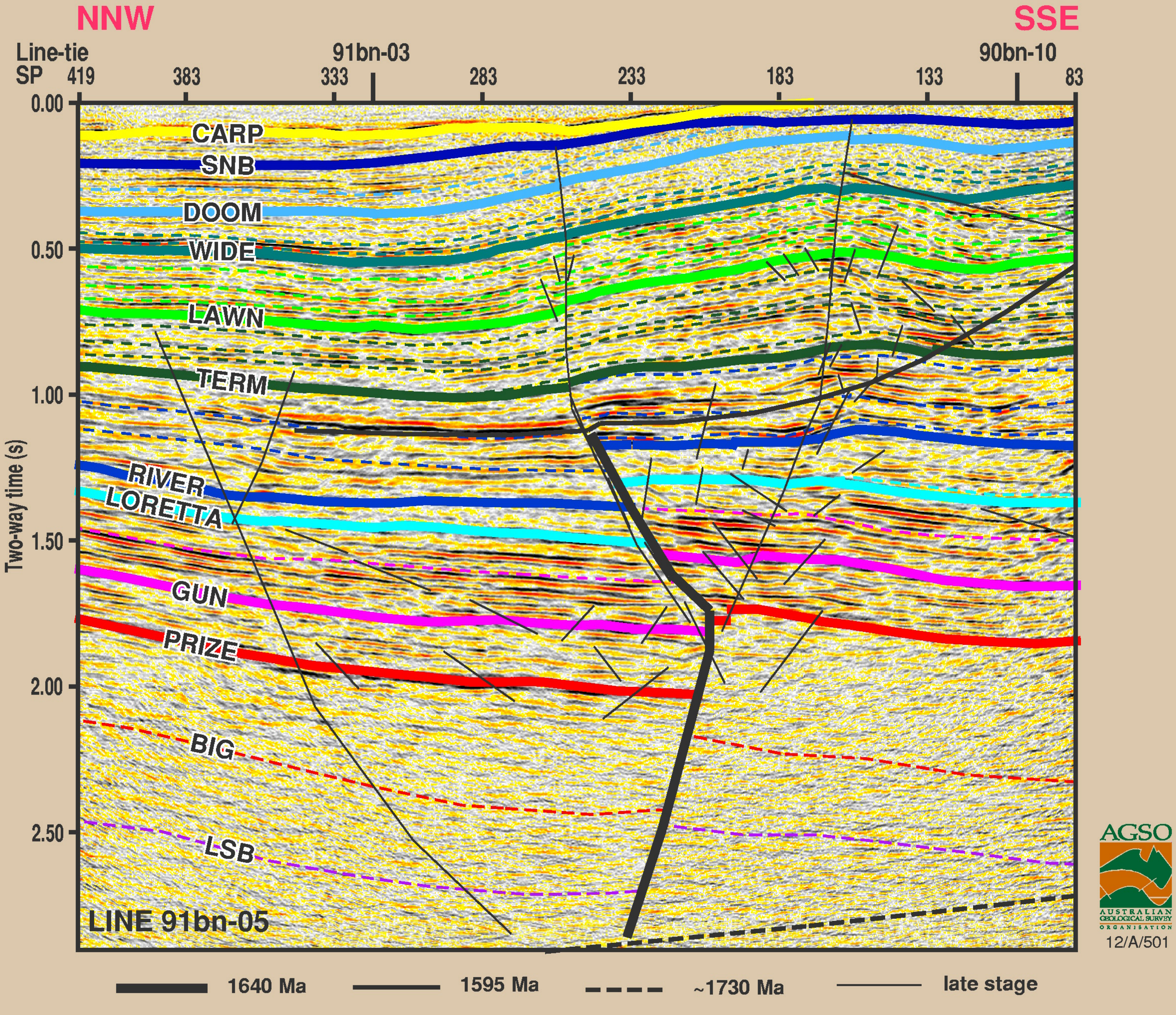

Figure 3.3.11 Overturned River event normal fault

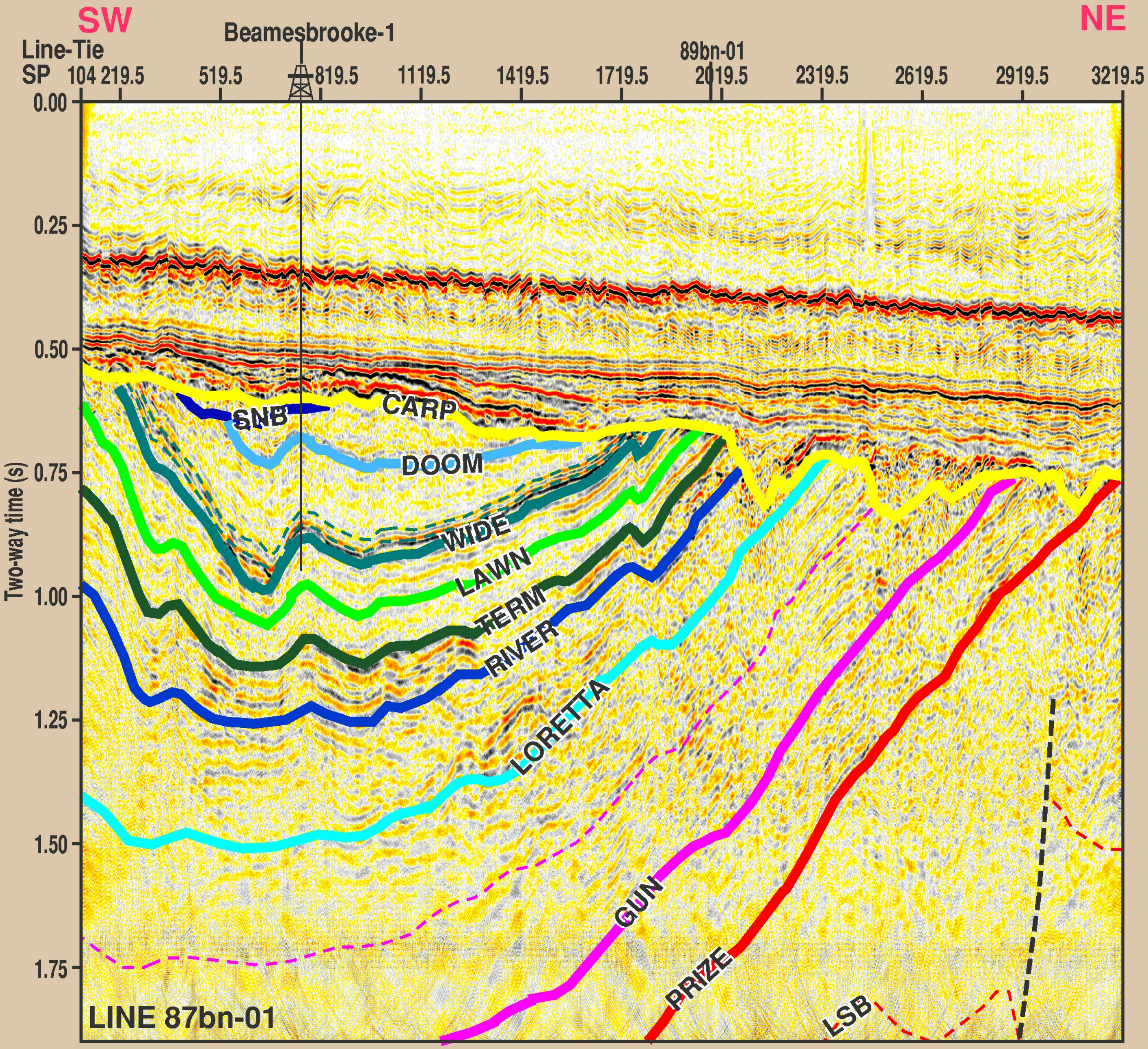

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Figure 3.3.12 Regional synform

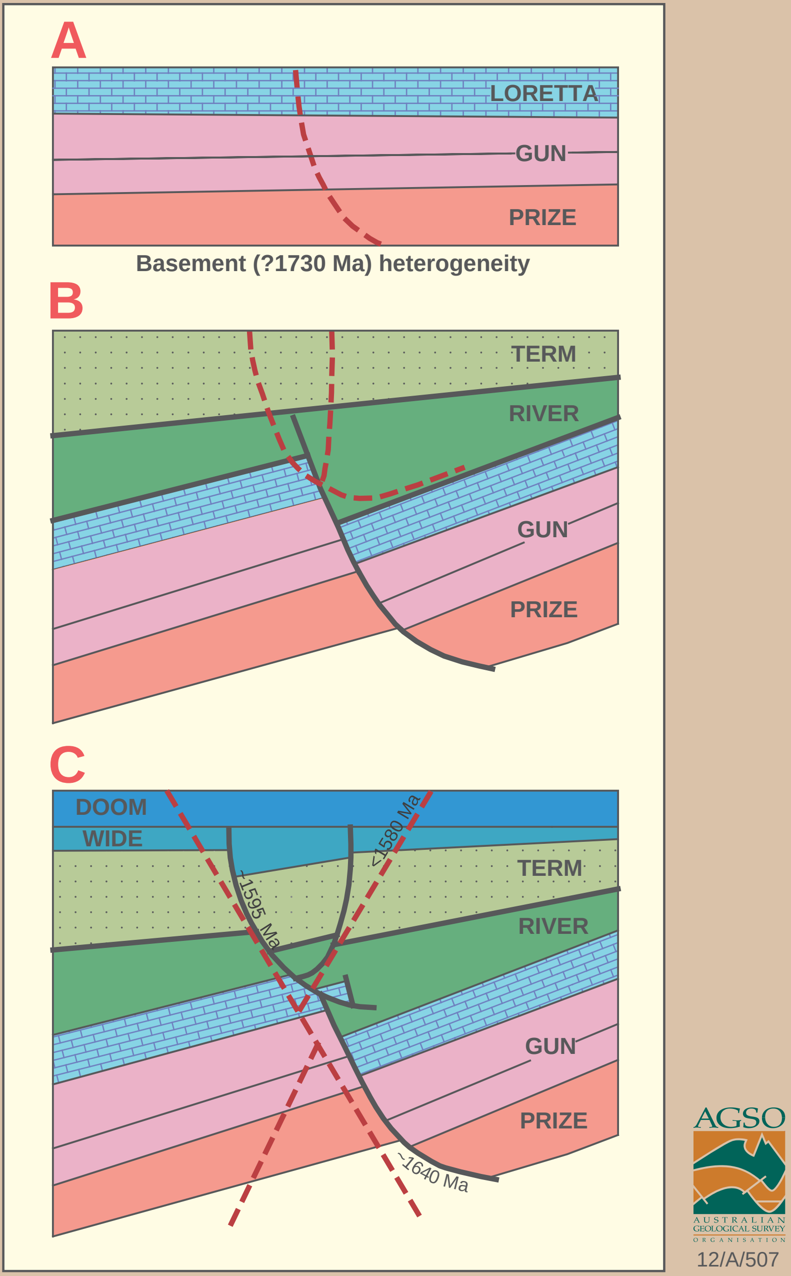

Figure 3.5.1 Fault history

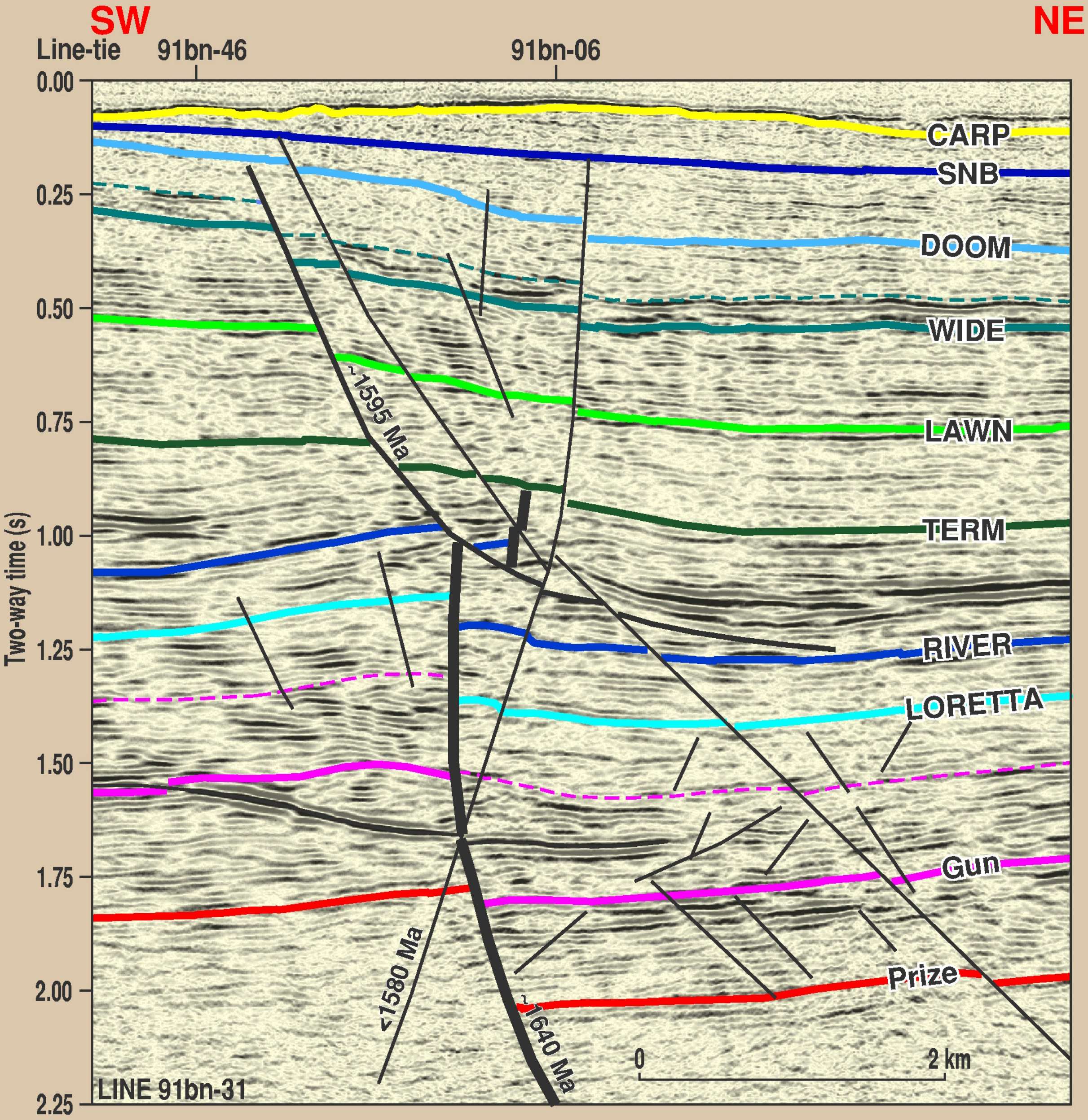

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Figure 3.5.2 Interpreted three stage fault system

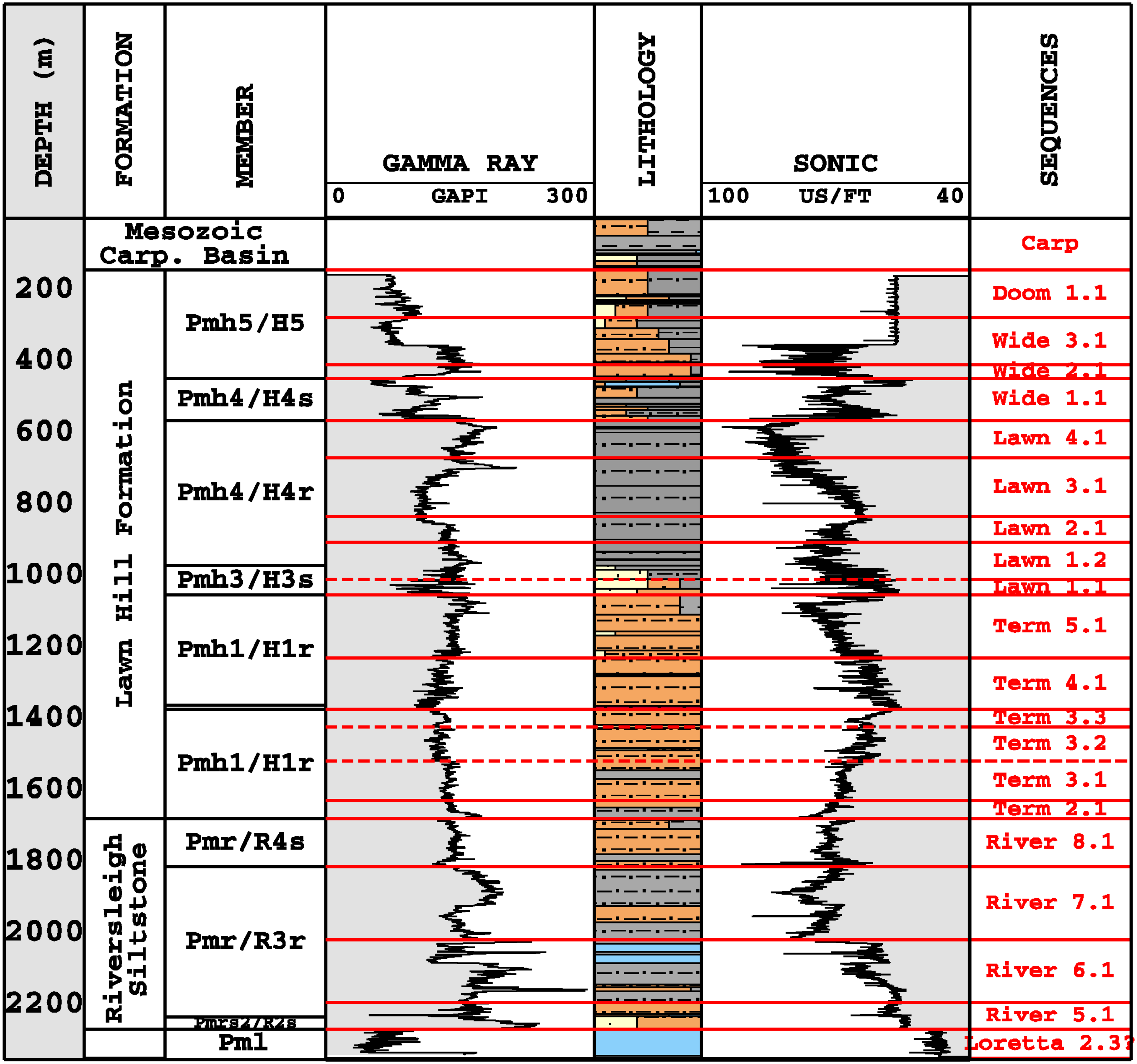

Figure 4.1 Desert Creek 1

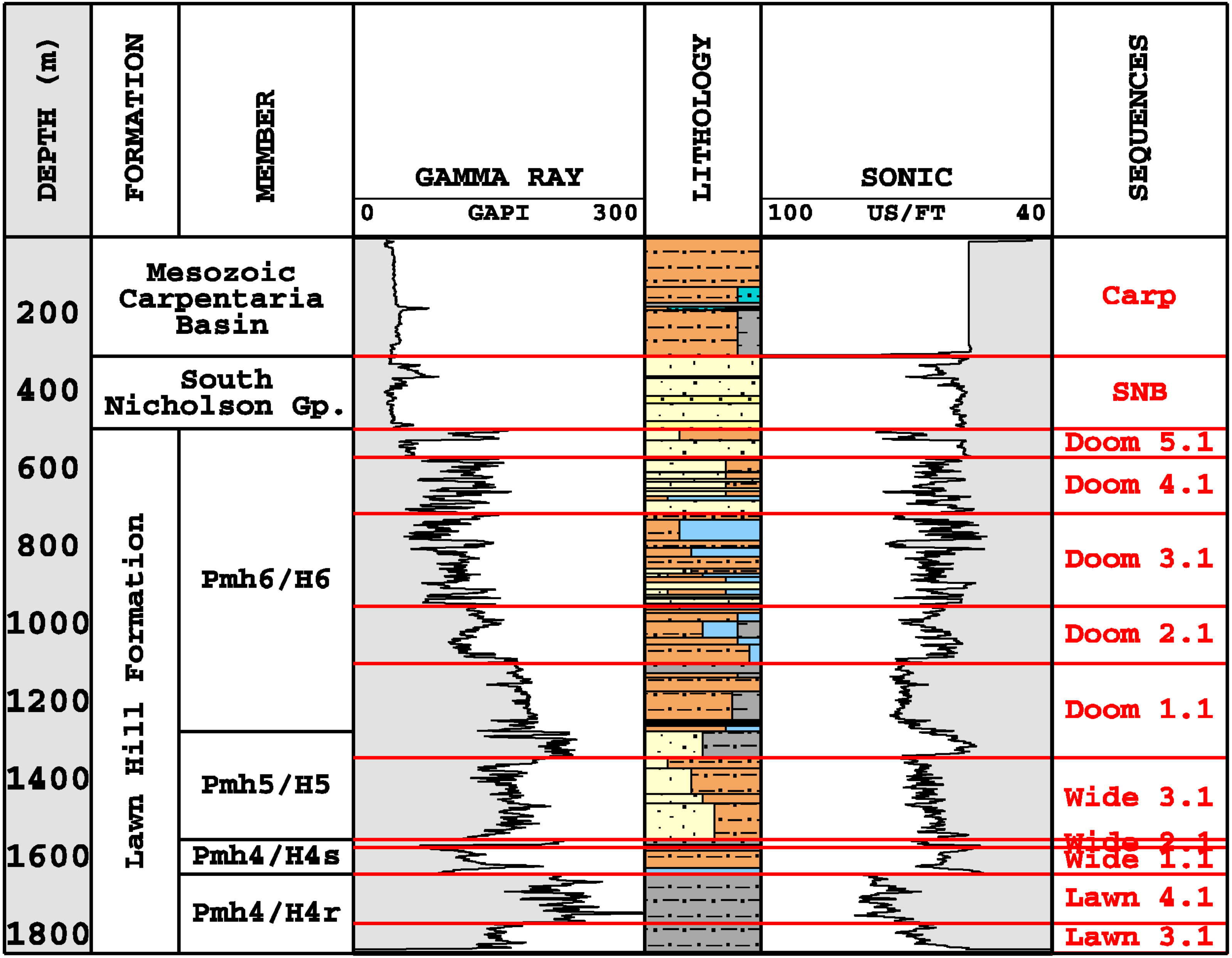

Figure 4.2 Egilabria 1

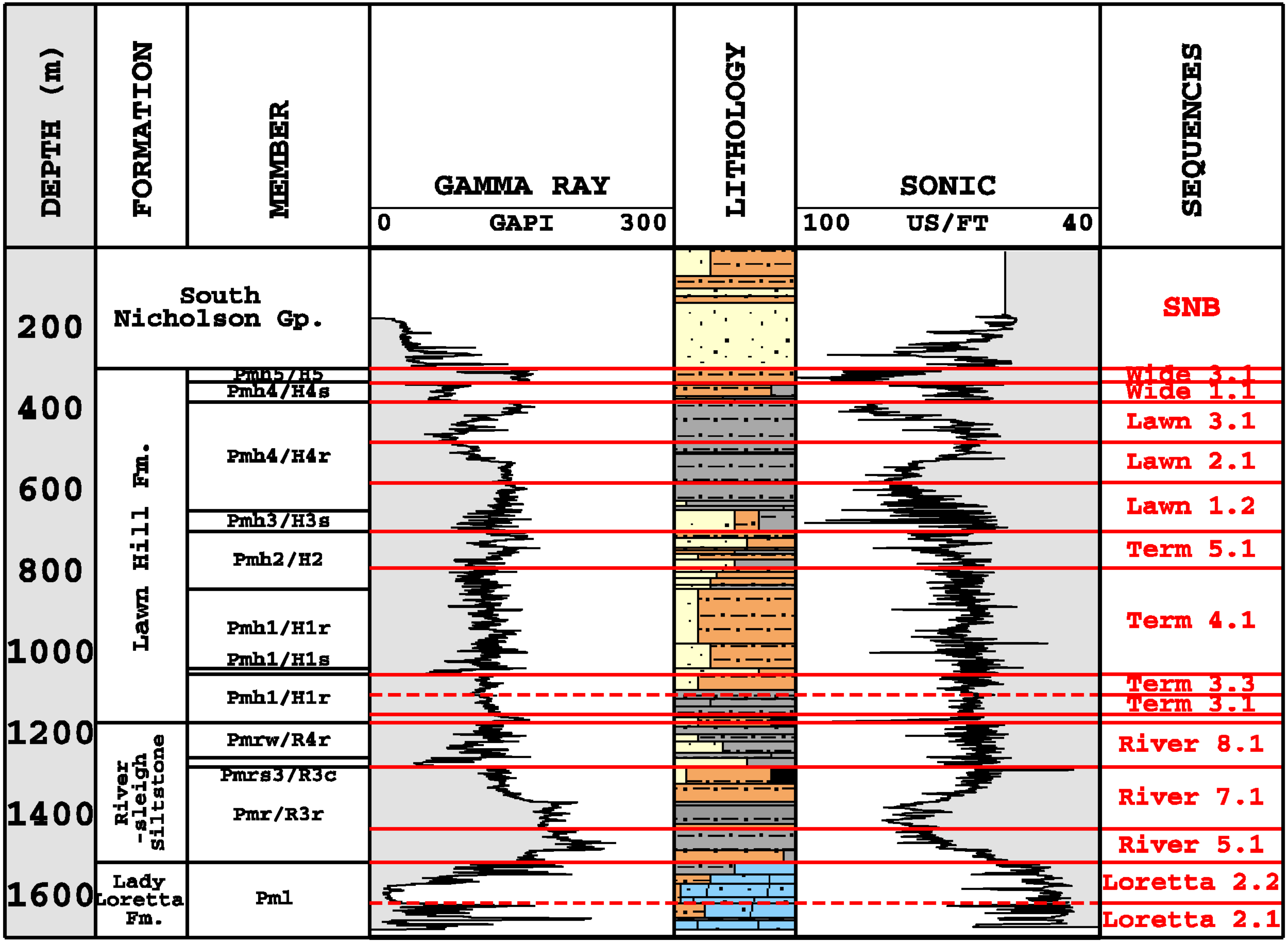

Figure 4.3 Argyle Creek 1

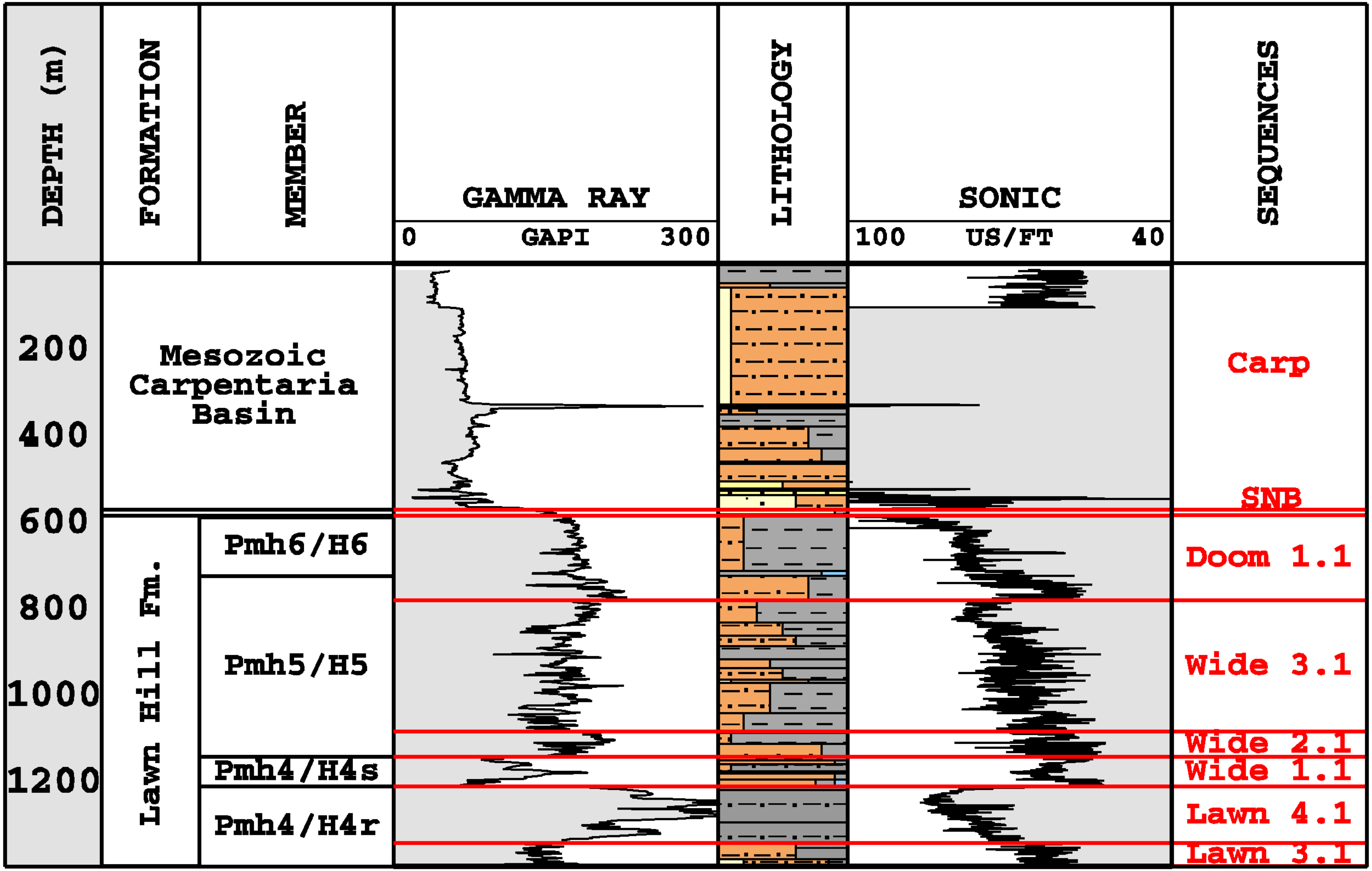

Figure 4.4 Beamesbrook 1

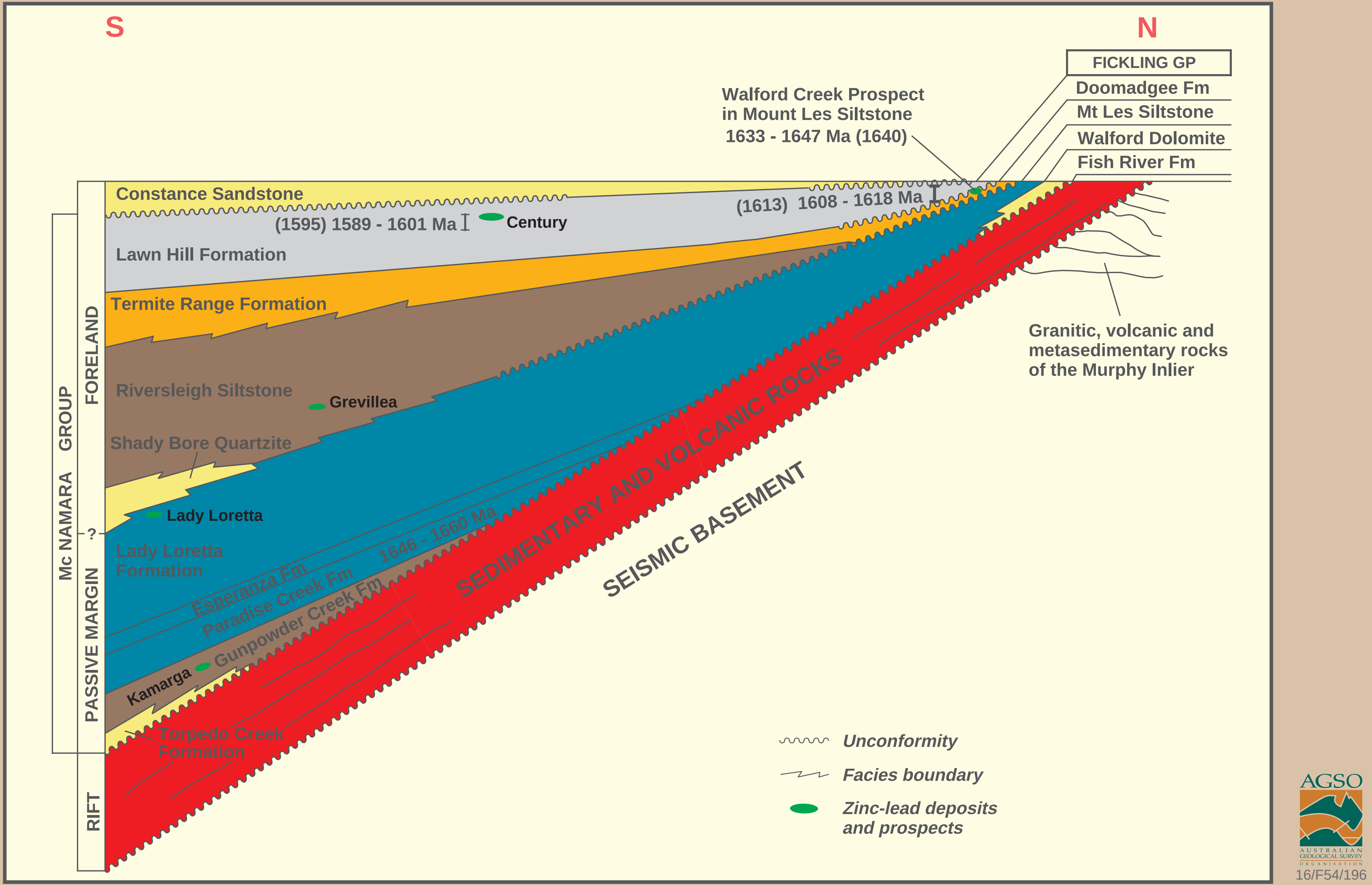

Figure 5.1.1 McConachie and Dunster (1998) correlation of McNamara and Fickling Groups

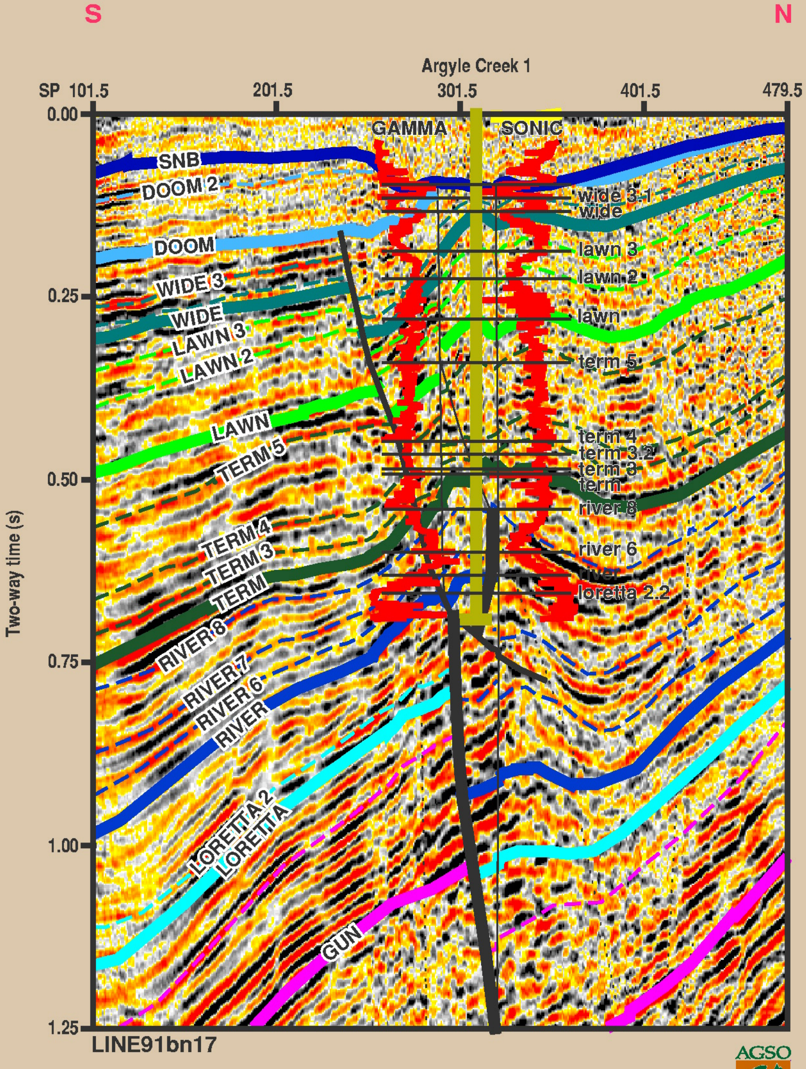

Figure 5.1.2 Argyle Creek 1 well tied to seismic line 91bn-17

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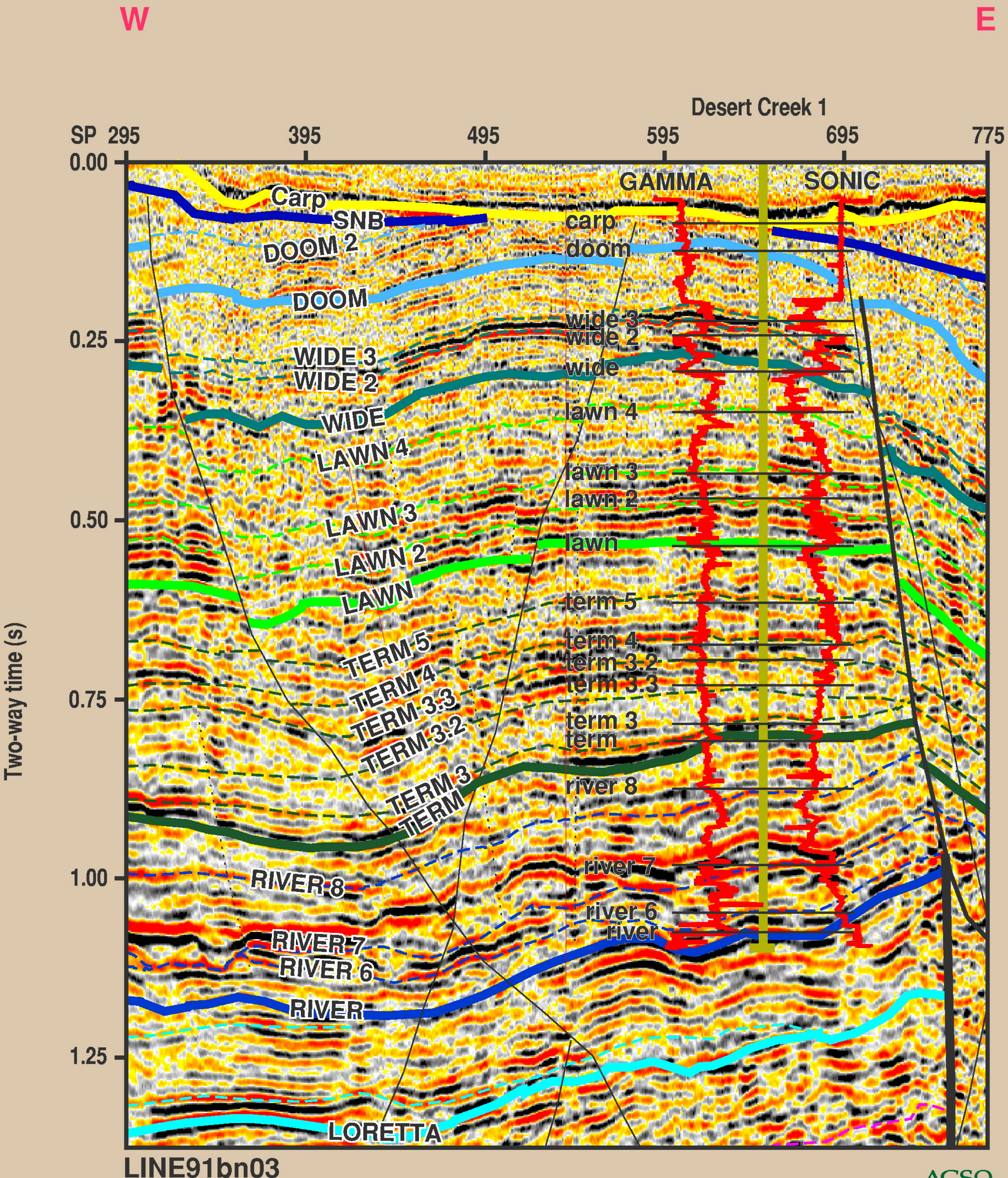

Figure 5.1.3 Desert Creek 1 well tied to seismic line 91bn-03

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26/A/188

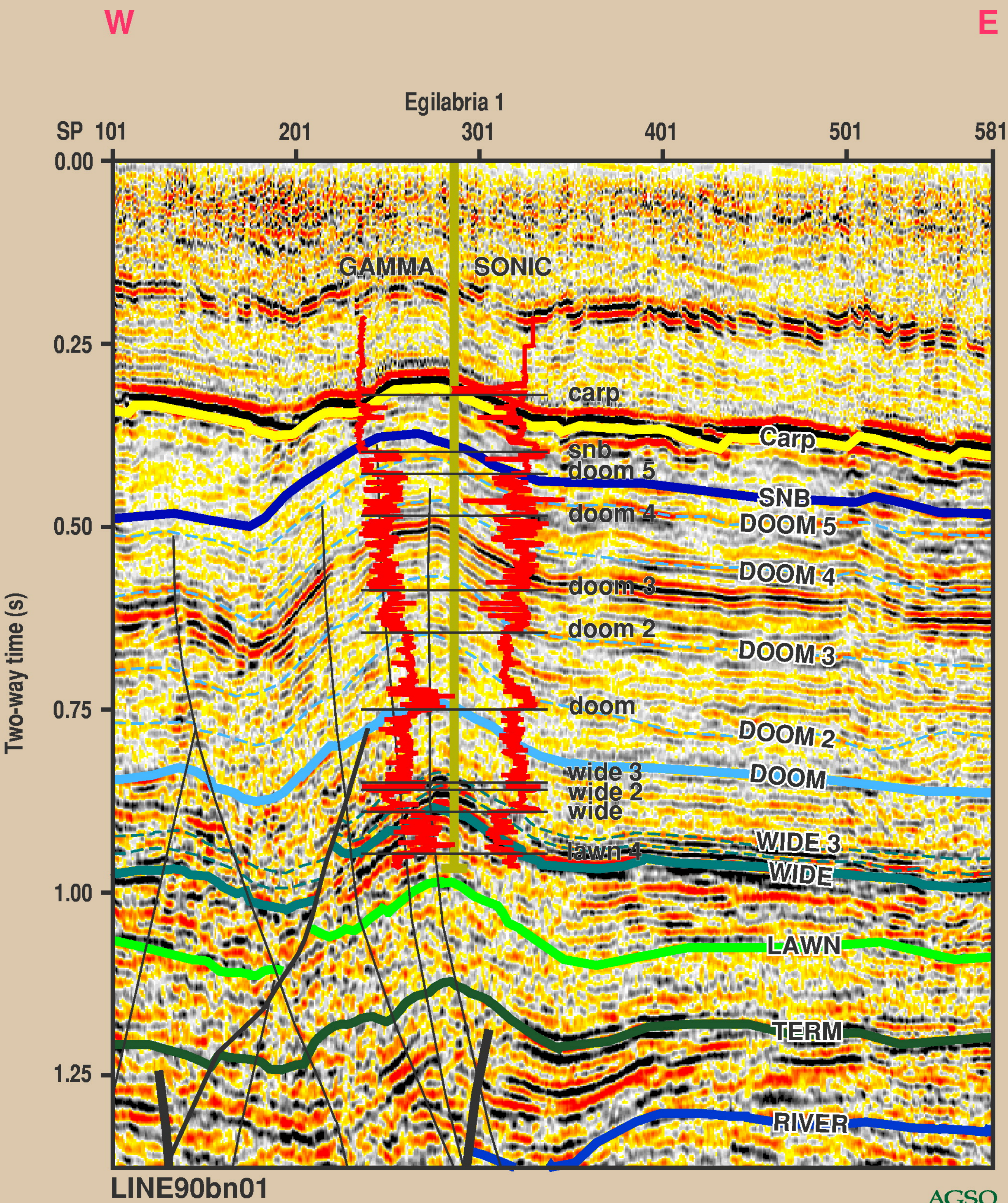

Figure 5.1.4 Egilabria 1 well tied to seismic line 90bn-01

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26/A/189

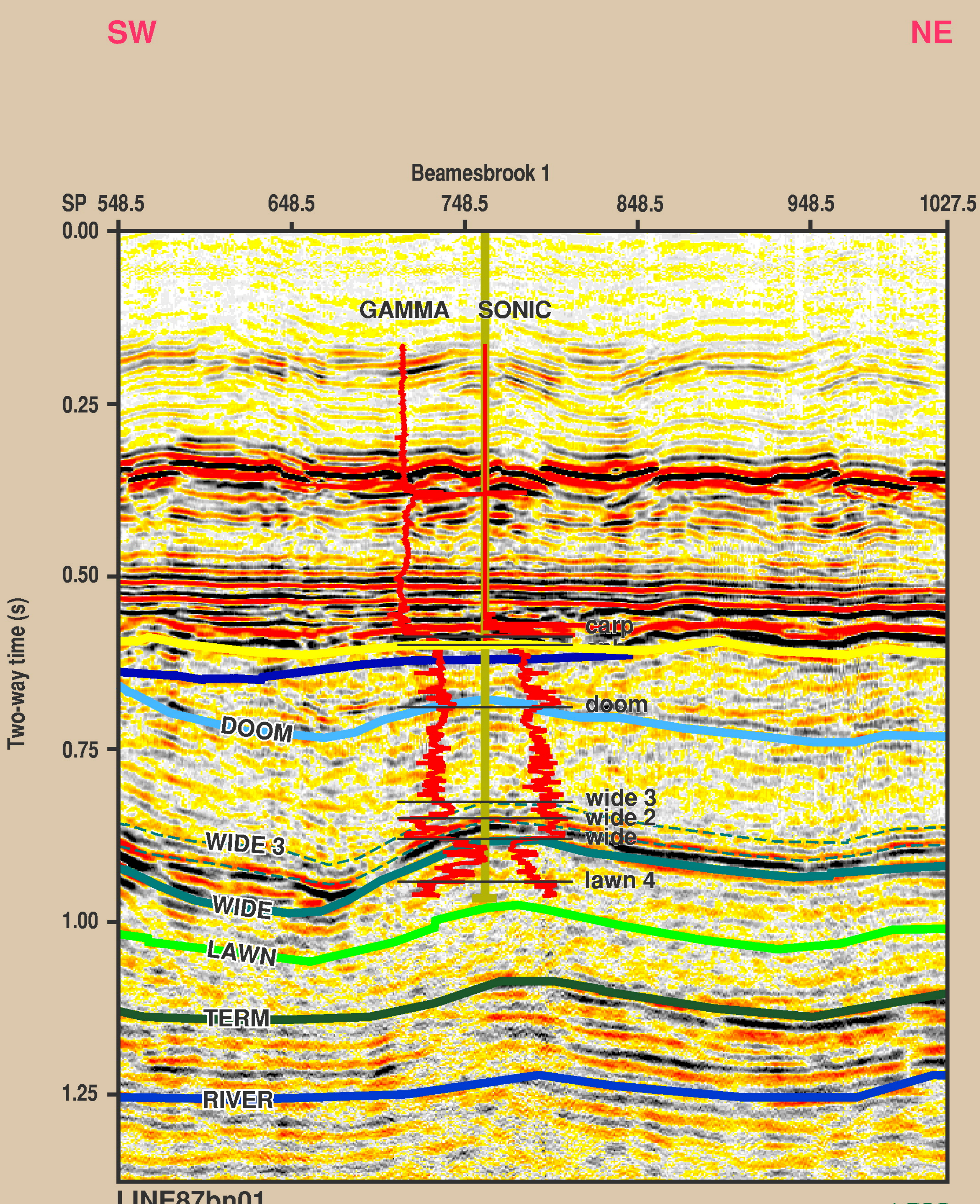

Figure 5.1.5 Beamesbrook 1 well tied to seismic line 87bn-01

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26/A/190

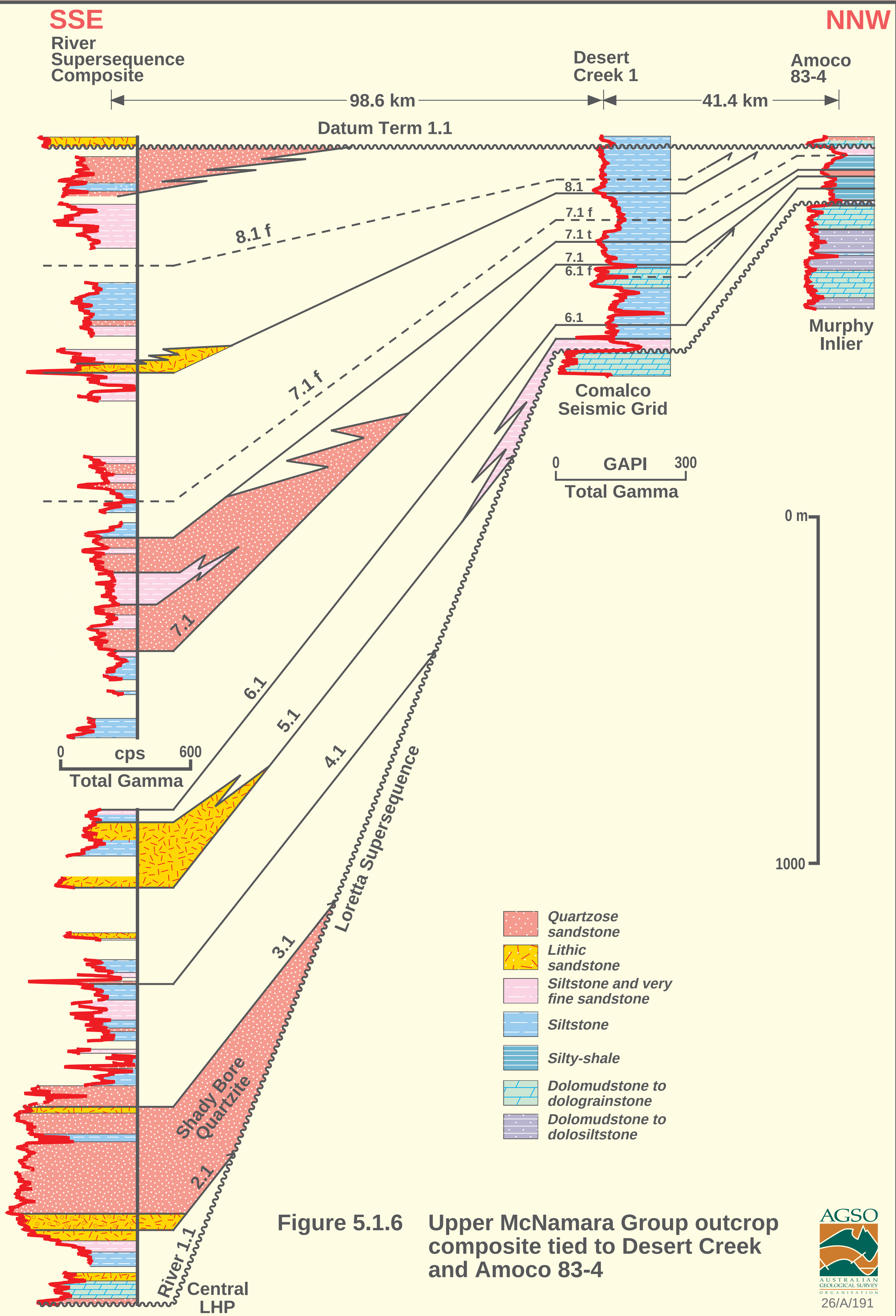

Figure 5.1.6 Upper McNamara Group outcrop composite tied to Desert Creek and Amoco 83-4

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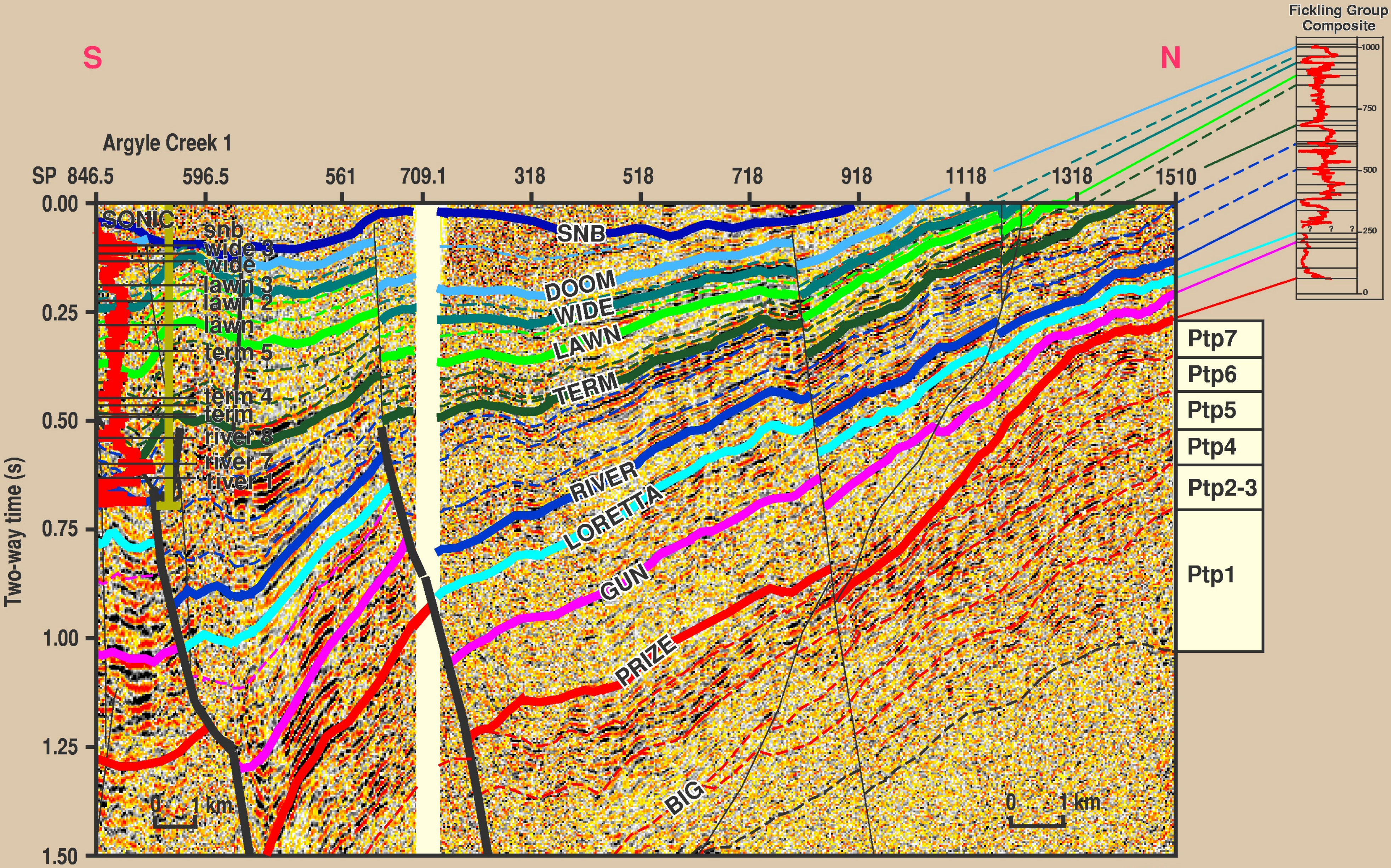

Figure 5.1.7 Argyle Creek composited seismic section tied to Fickling Group outcrop and well logs

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12/A/559

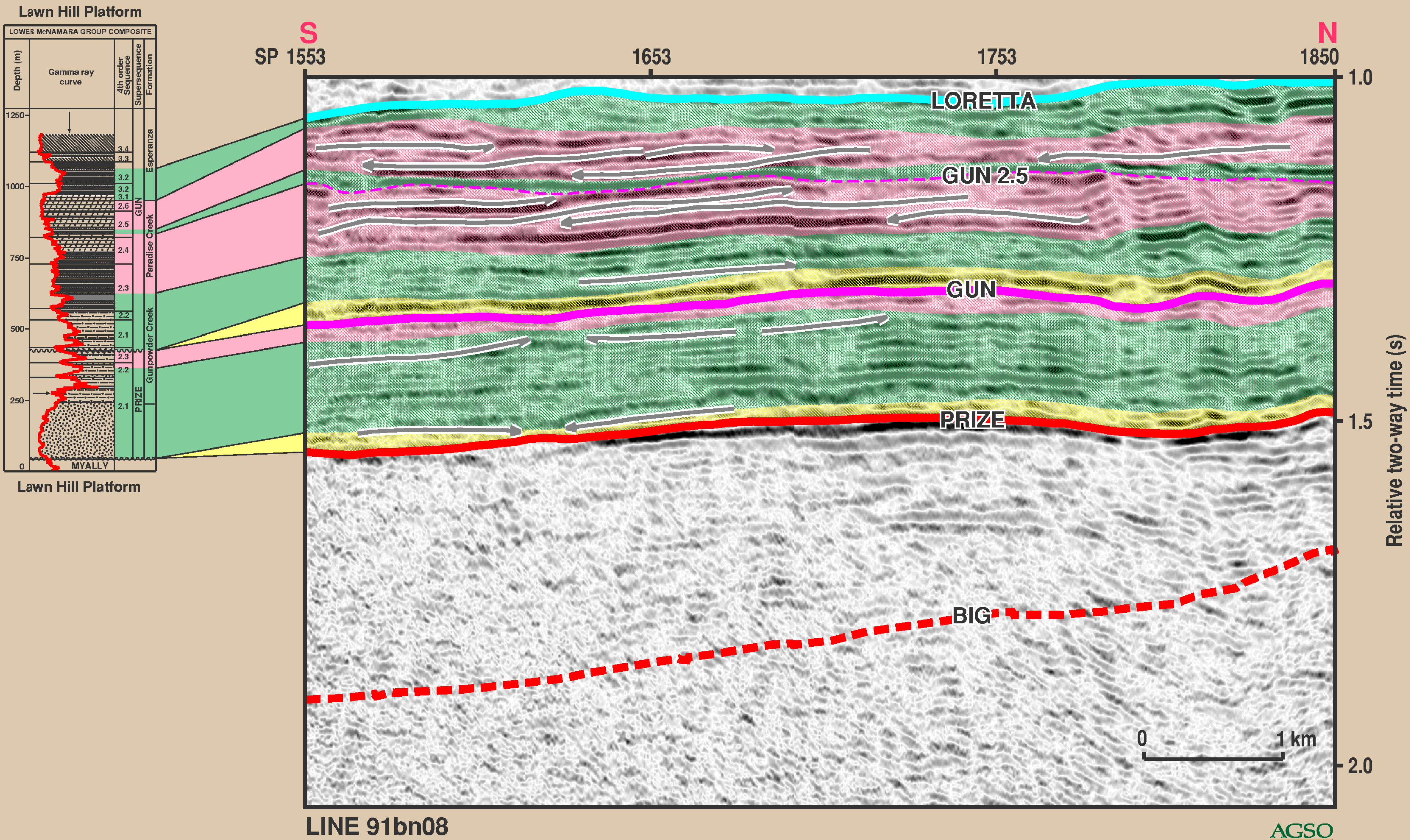

Figure 5.2.1 Lower McNamara Group outcrop composite tied to flattened seismic section from 91bn-08

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12/A/560

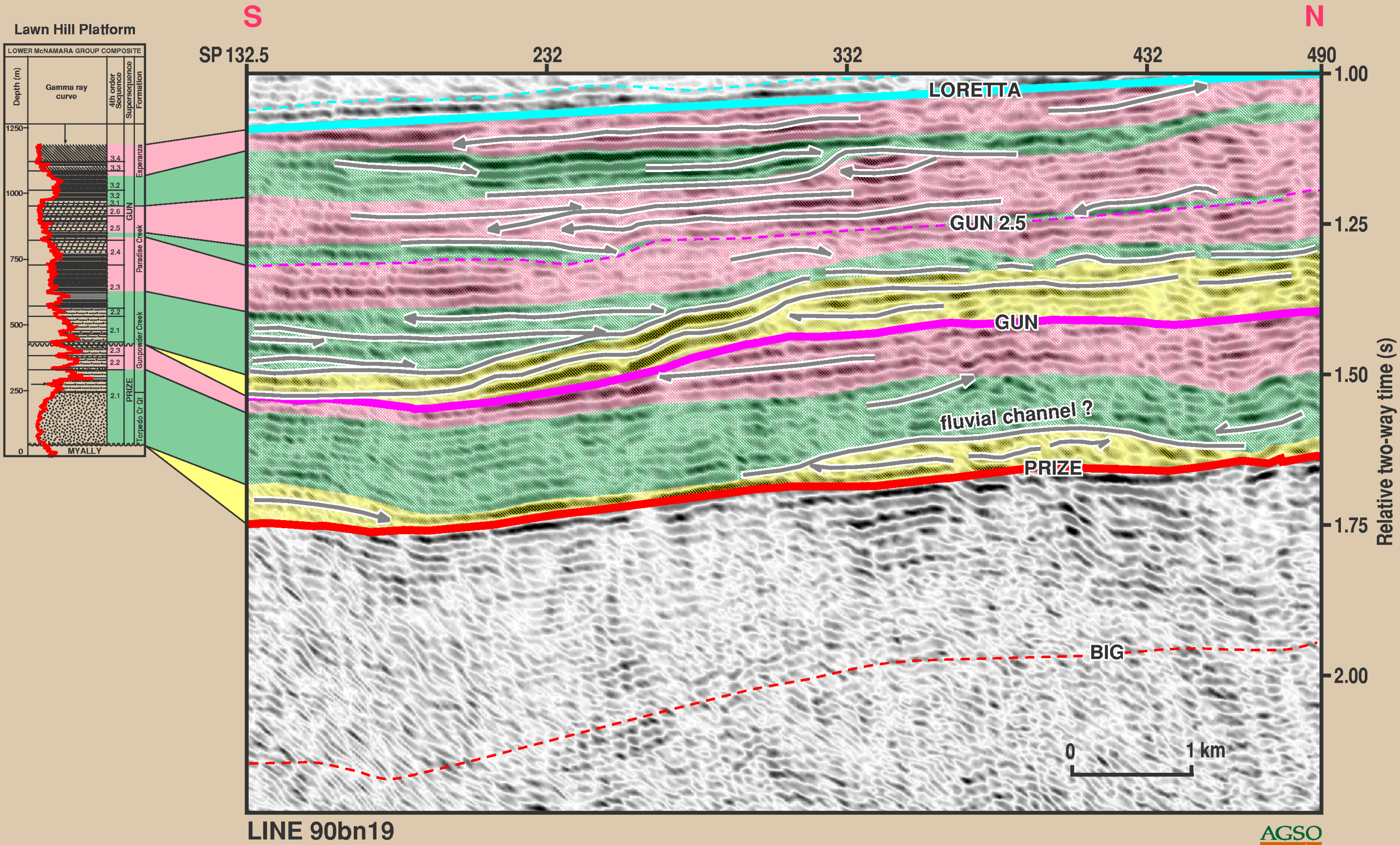

Figure 5.2.2 Lower McNamara Group outcrop composite tied to flattened seismic section from 91bn-19

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12/A/561

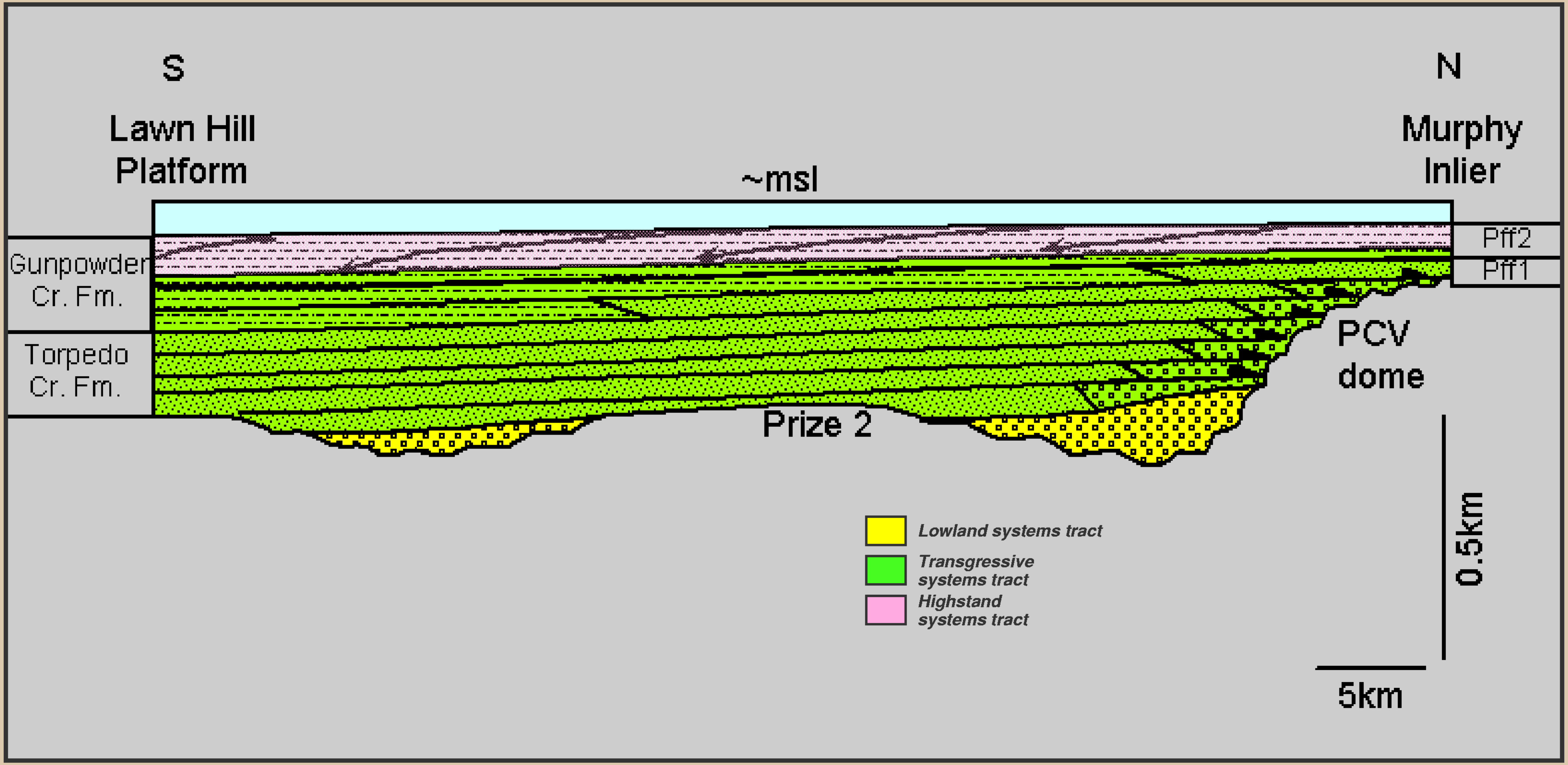

Figure 5.2.3 Sequence stratigraphic model for deposition of Prize 2 sequences

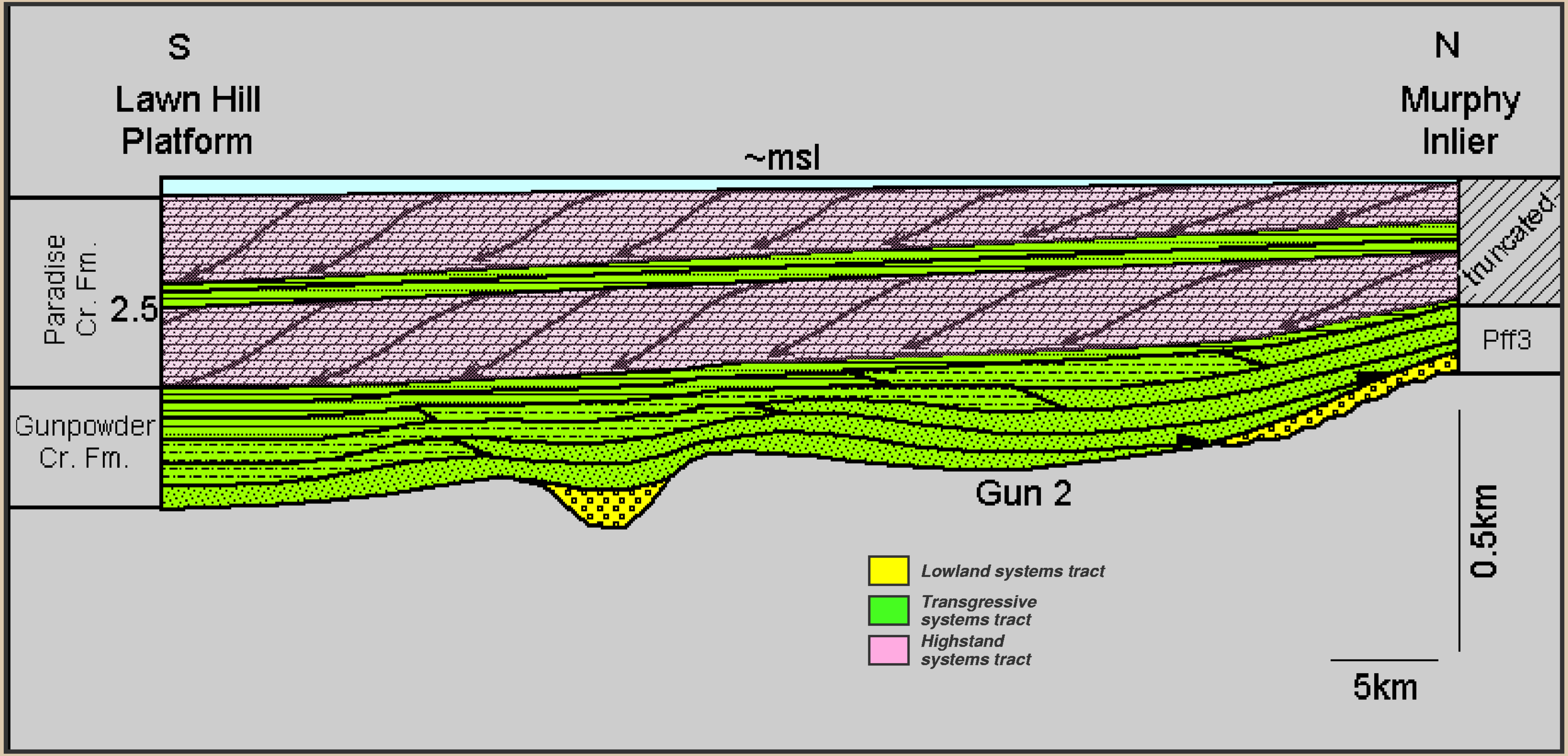

Figure 5.2.4 Sequence stratigraphic model for deposition of Gun 2 sequences

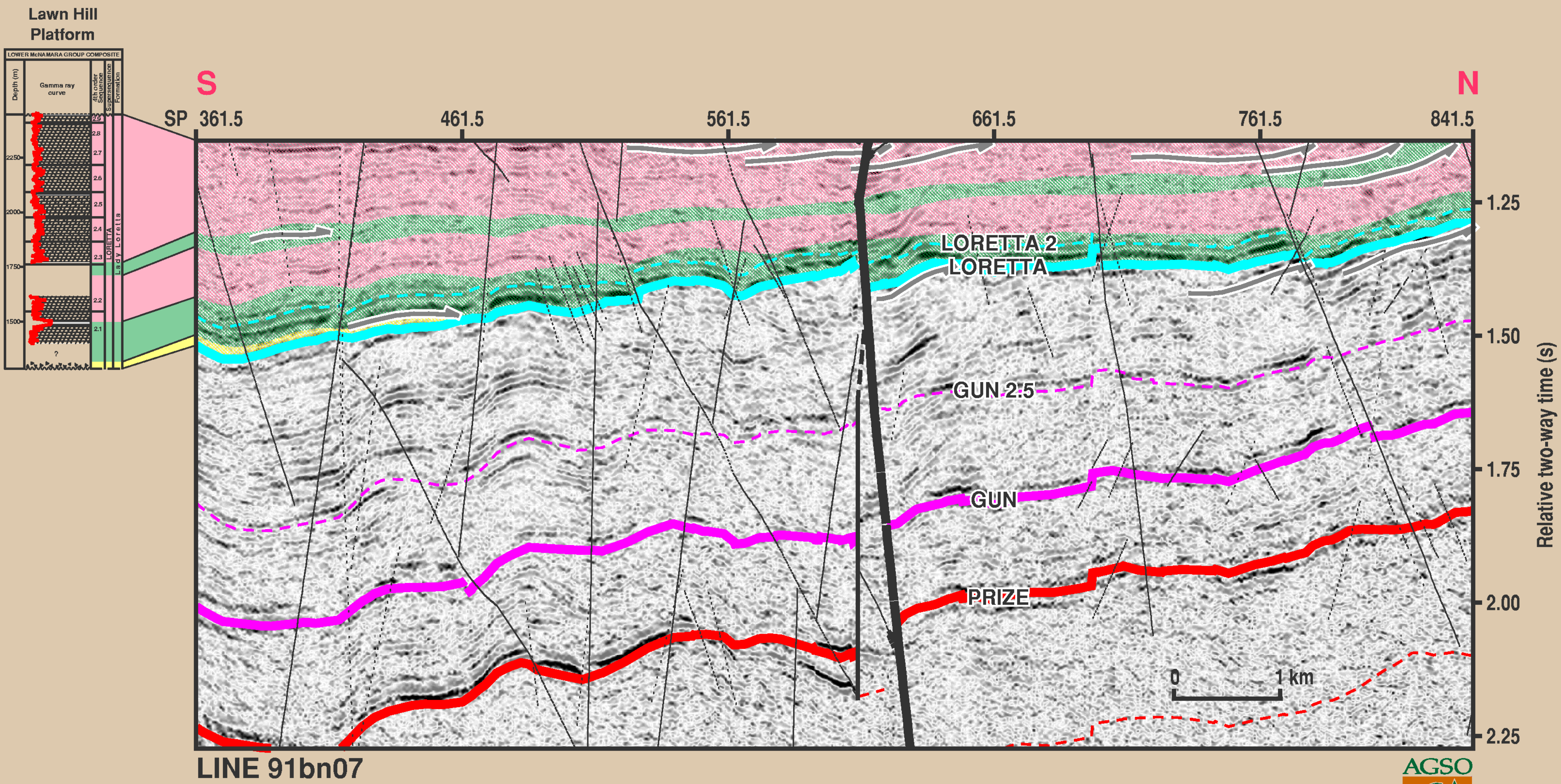

Figure 5.3.1 Loretta Supersequence composite tied to flattened seismic section from 91bn-07

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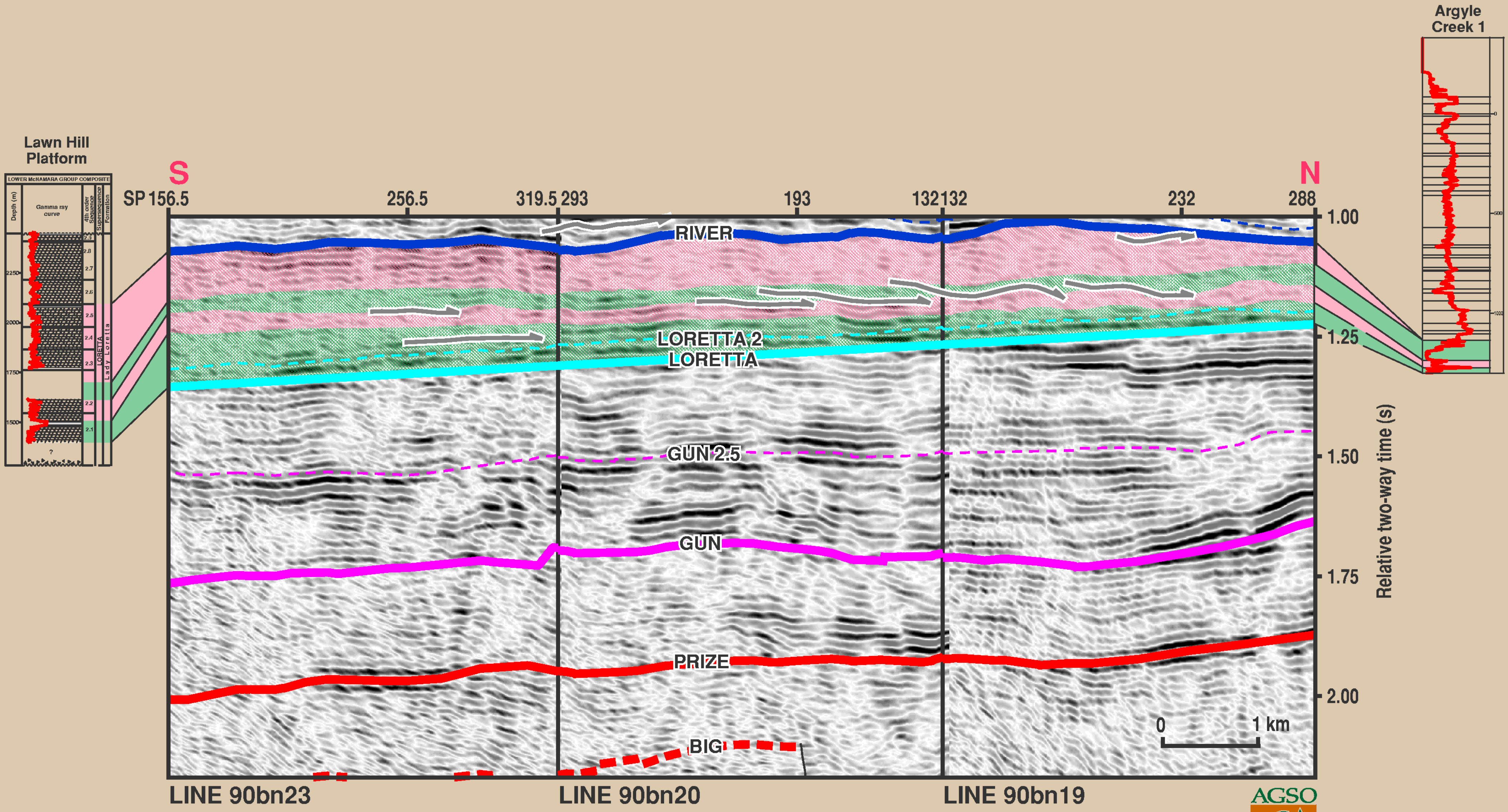

Figure 5.3.2 Loretta Supersequence composite and Argyle Creek well tied to flattened seismic section from Argyle composite line (Figure 2.1.2).

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12/A/563

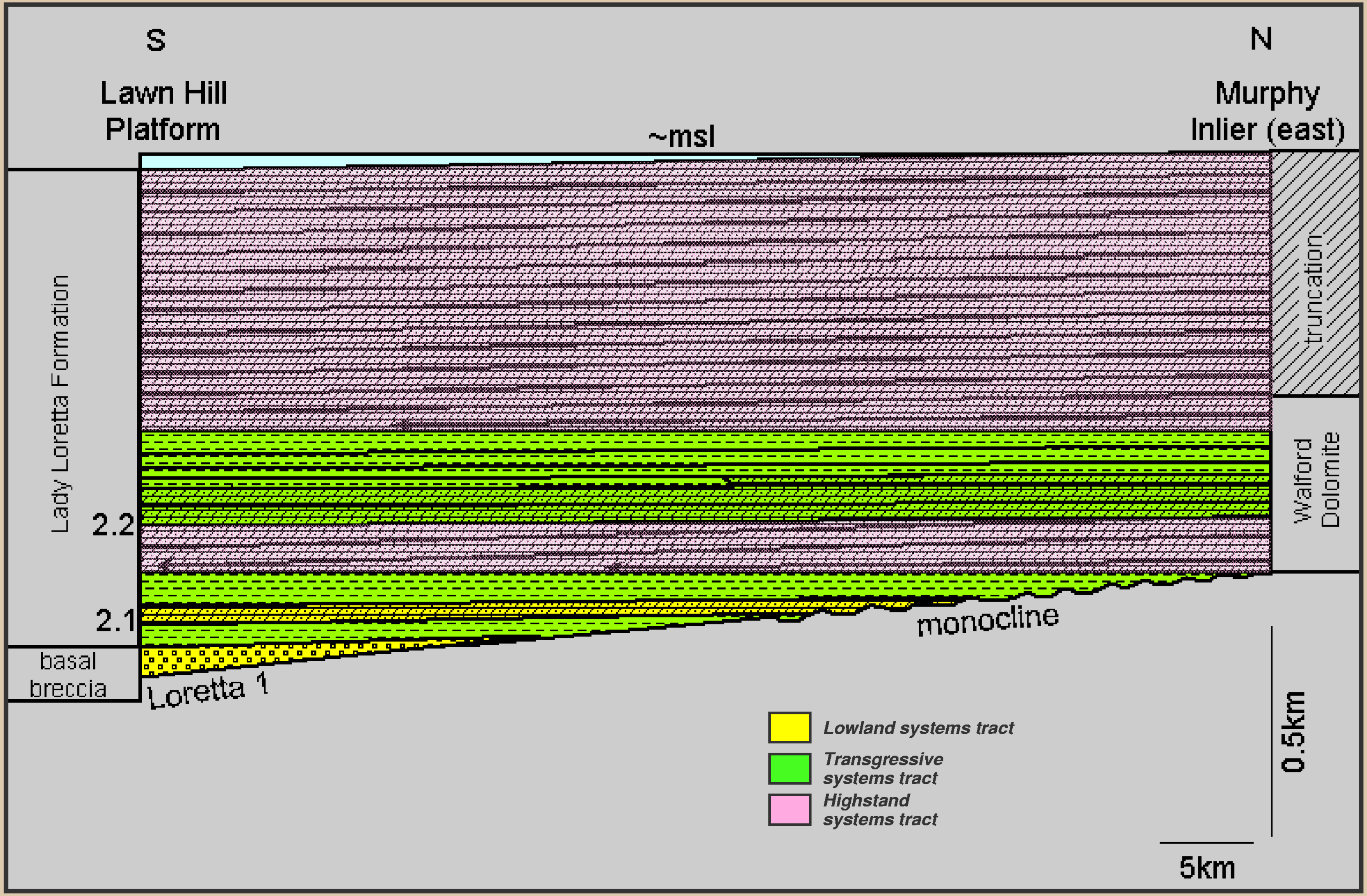

Figure 5.3.3 Sequence stratigraphic model for deposition of Loretta 1 and 2 sequences

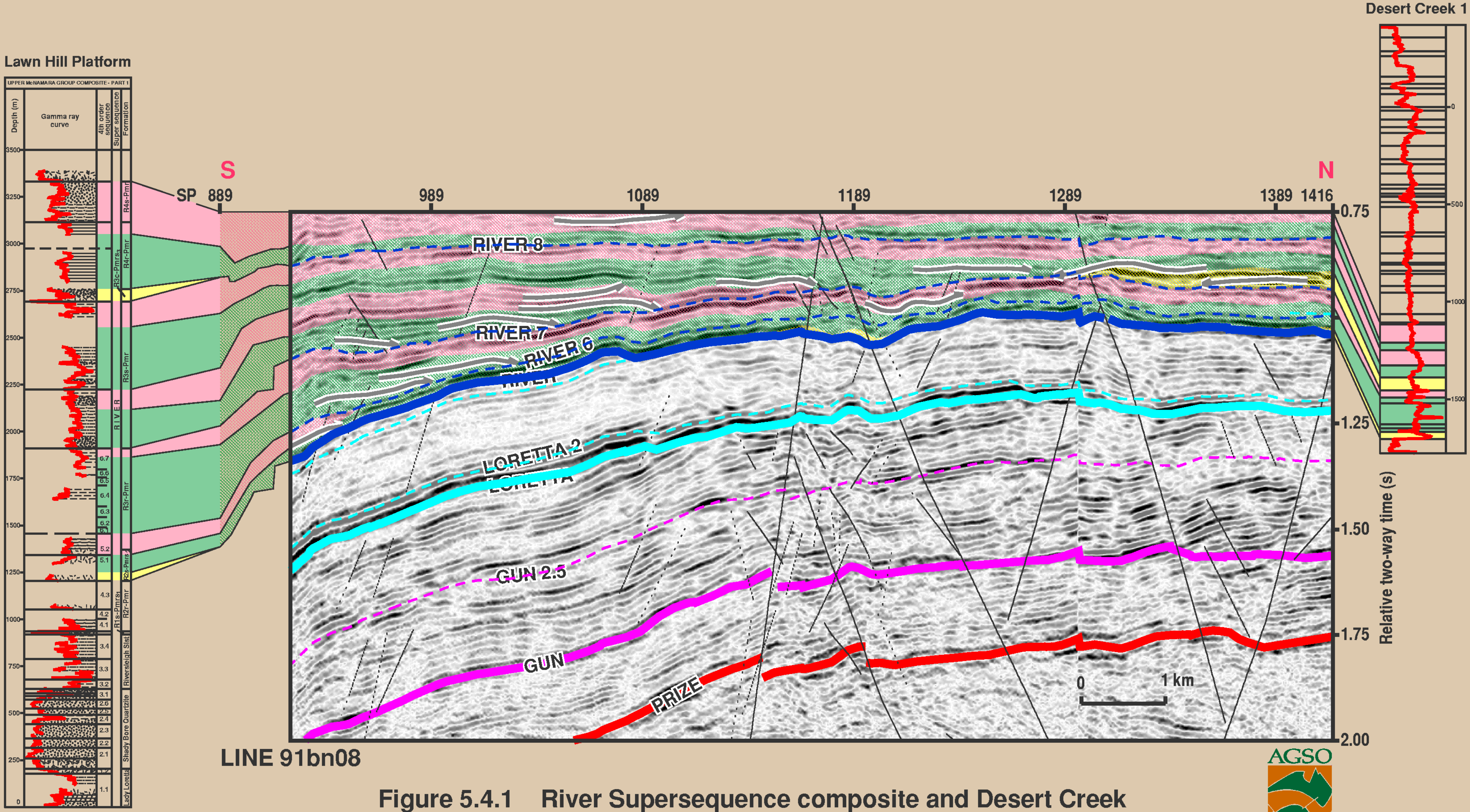

Figure 5.4.1 River Supersequence composite and Desert Creek tied to flattened seismic section from 91bn-08

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12/A/564

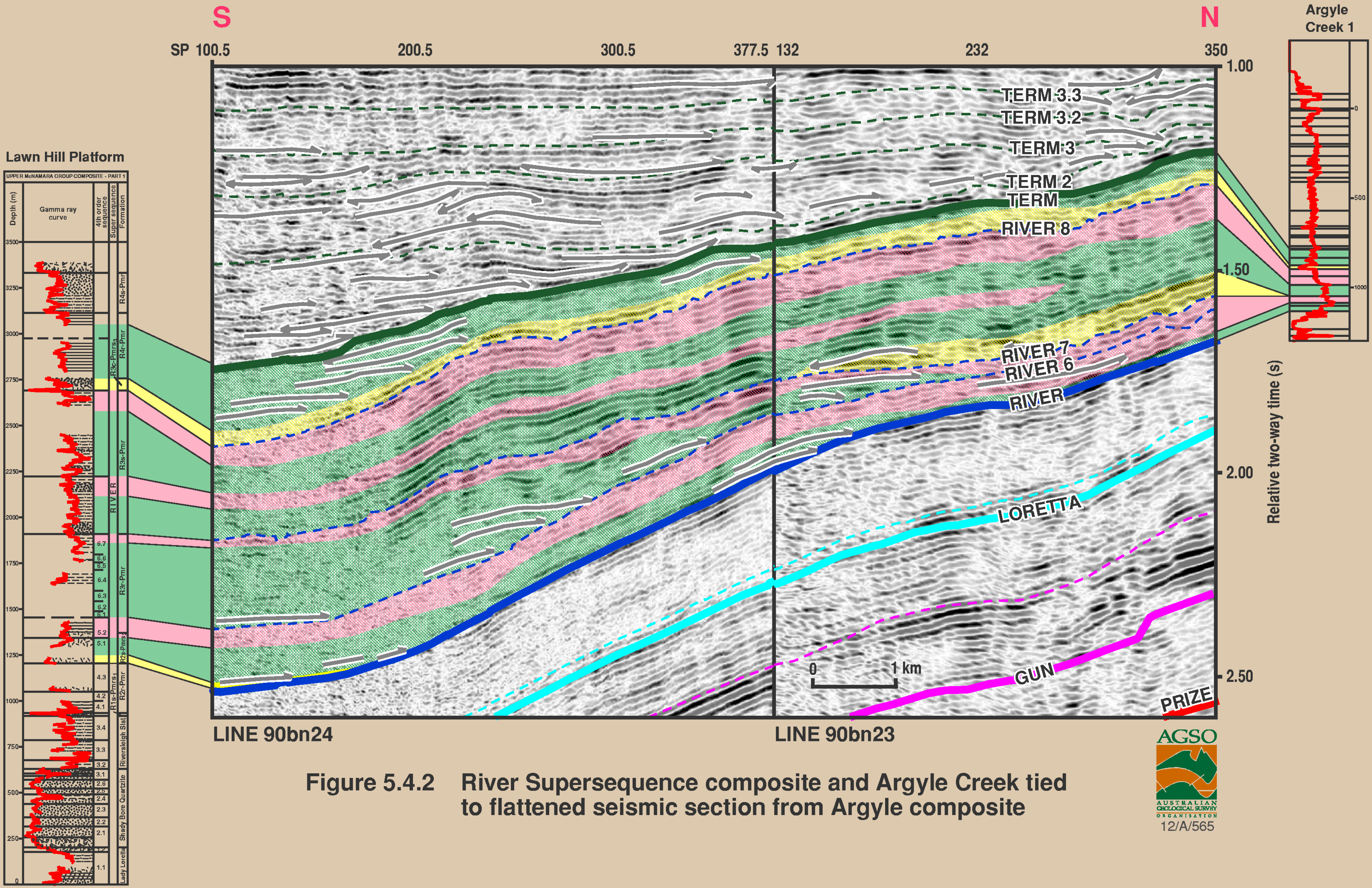

Figure 5.4.2 River Supersequence composite and Argyle Creek tied to flattened seismic section from Argyle composite

12/A/565

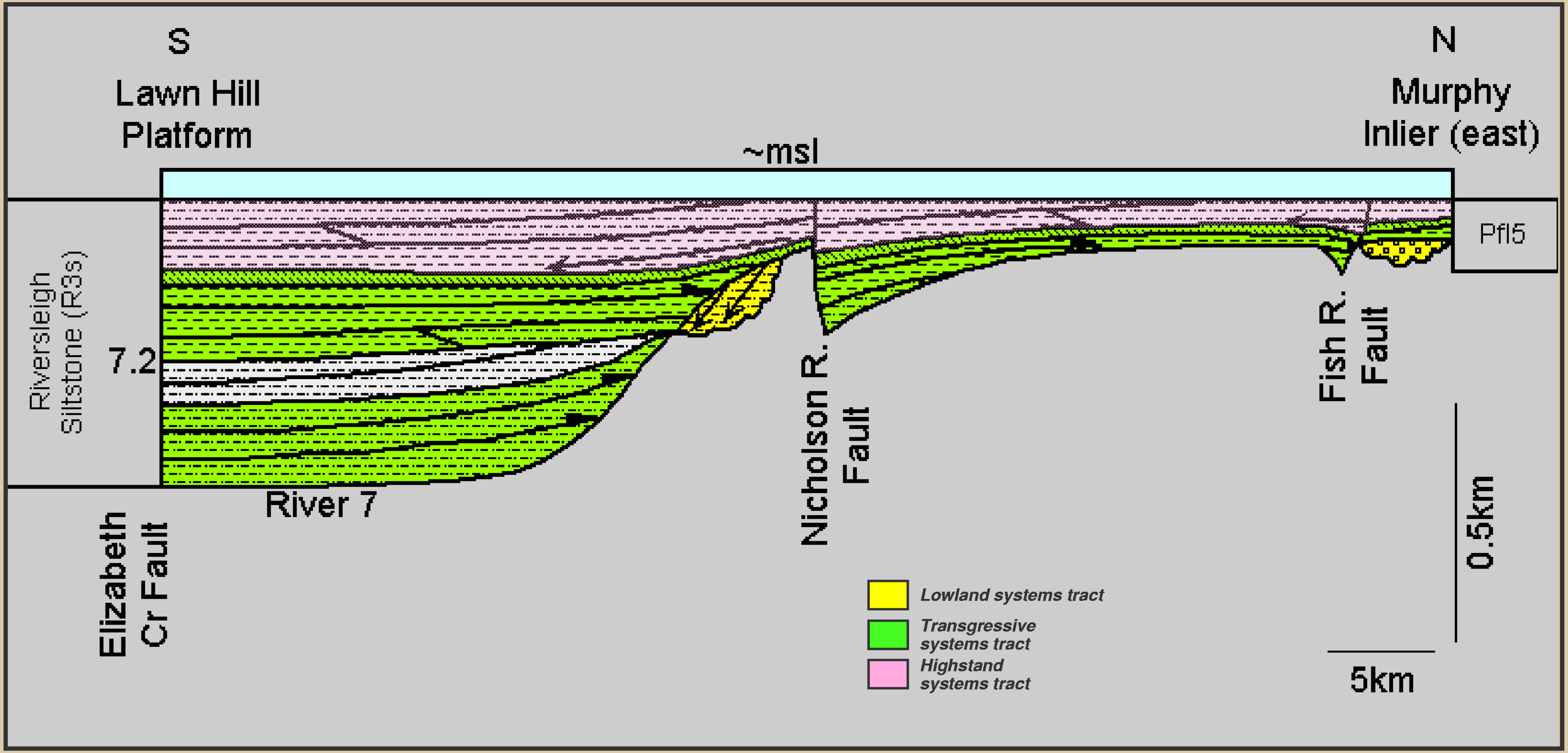

Figure 5.4.3 Sequence stratigraphic model for deposition of River 7 sequences

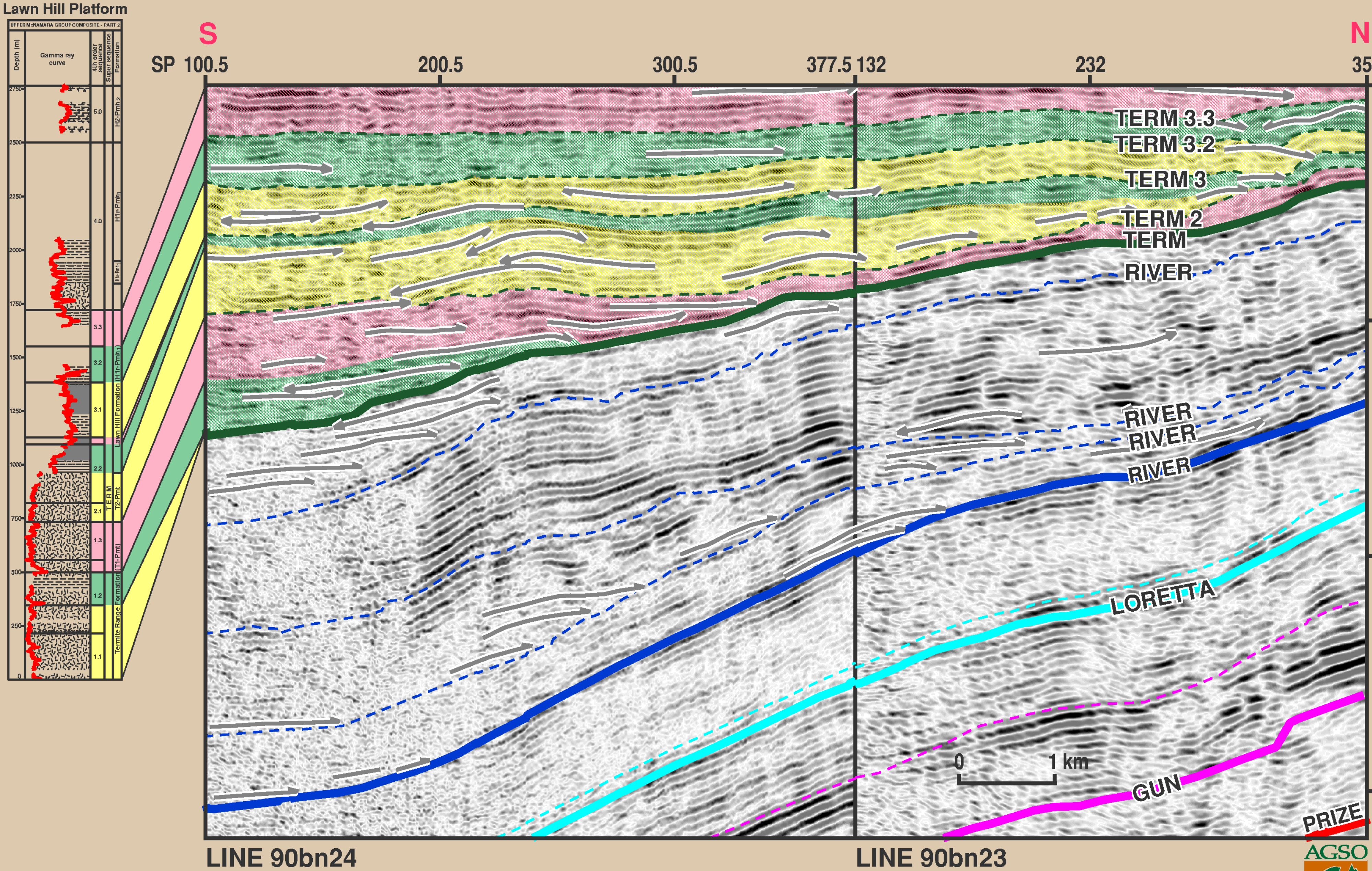

Figure 5.5.1 Term Supersequence composite tied to flattened seismic section from the Argyle composite, highlighting sequences Term 1 through 3

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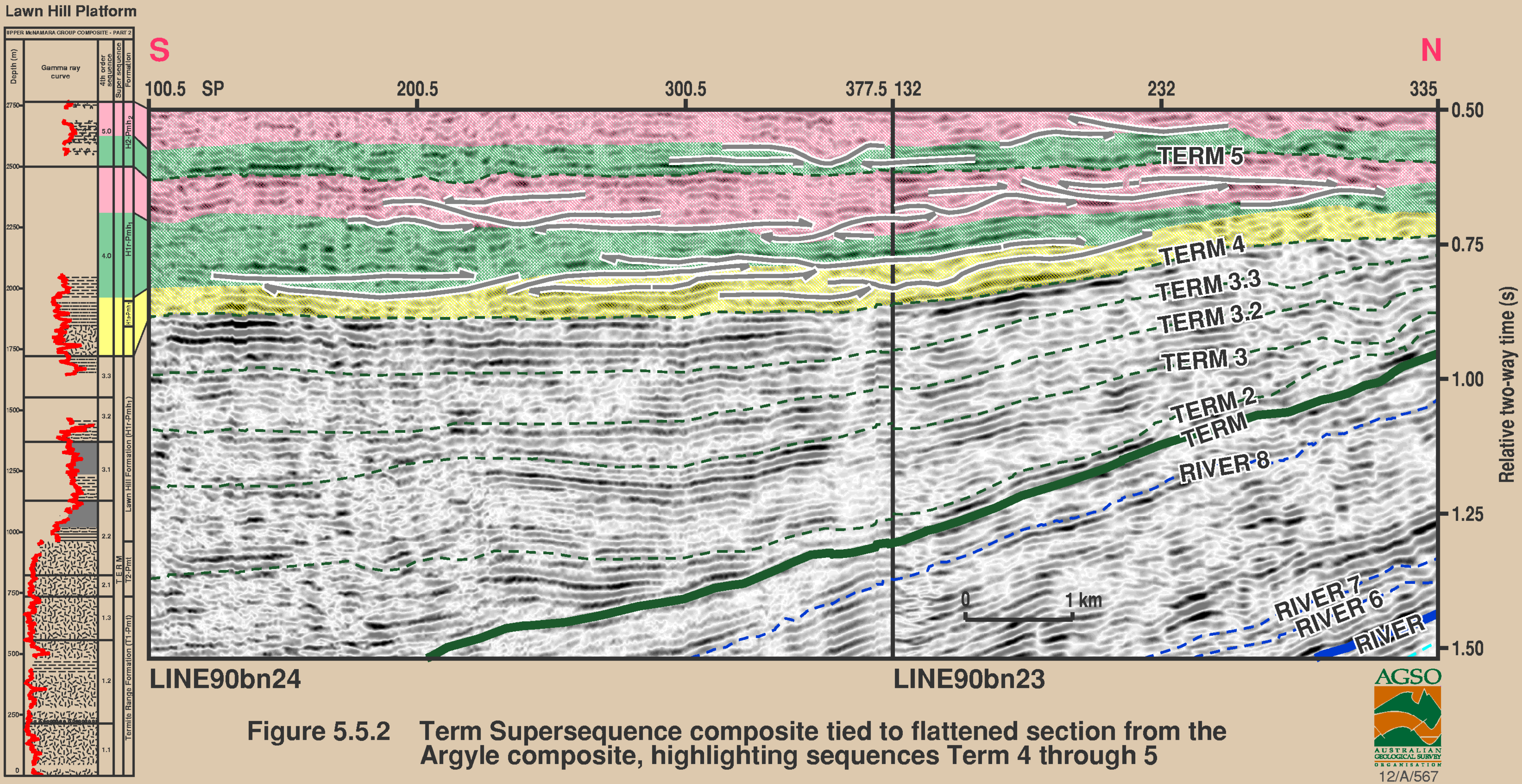

Figure 5.5.2 Term Supersequence composite tied to flattened section from the Argyle composite, highlighting sequences Term 4 through 5

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12/A/567

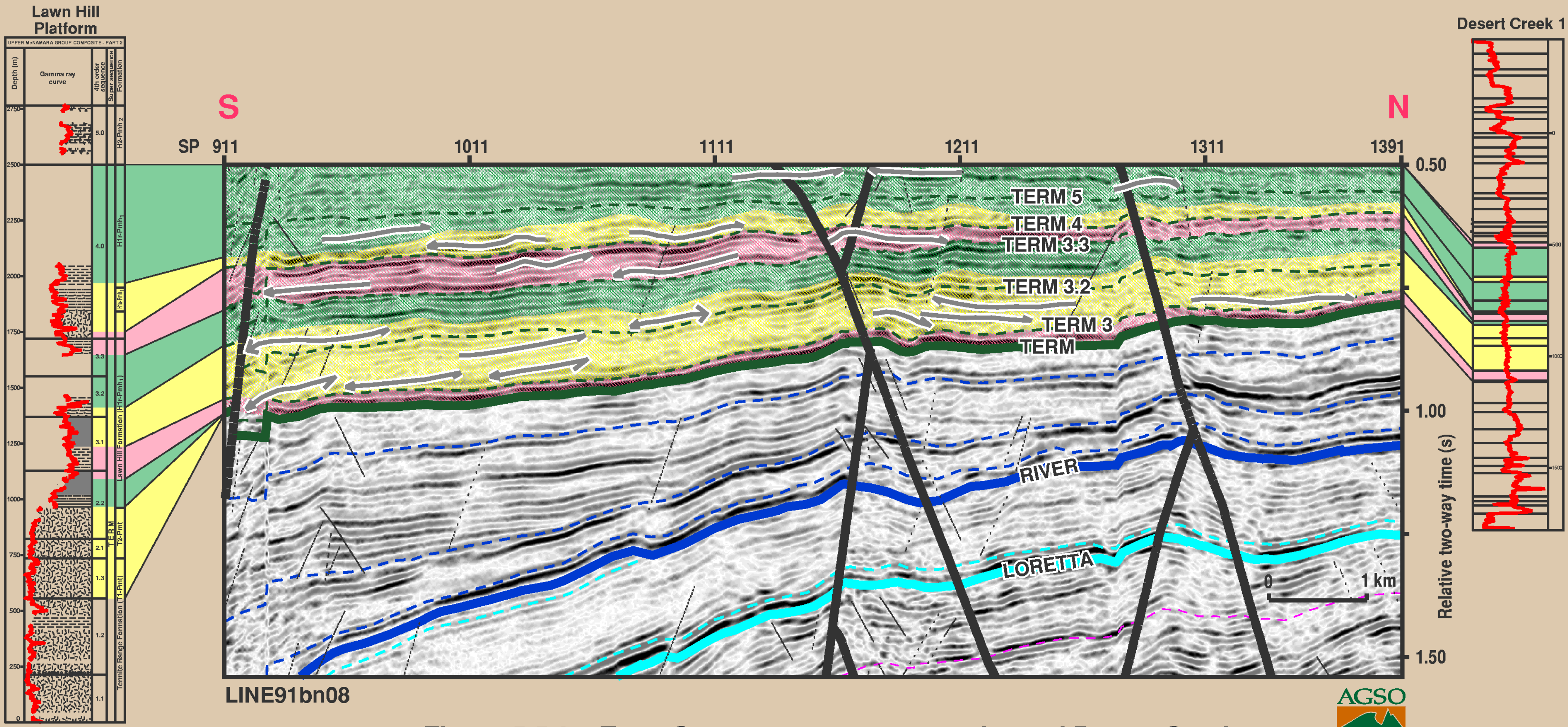

Figure 5.5.3 Term Supersequence composite and Desert Creek tied to flattened seismic section from 91bn-08

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12/A/568

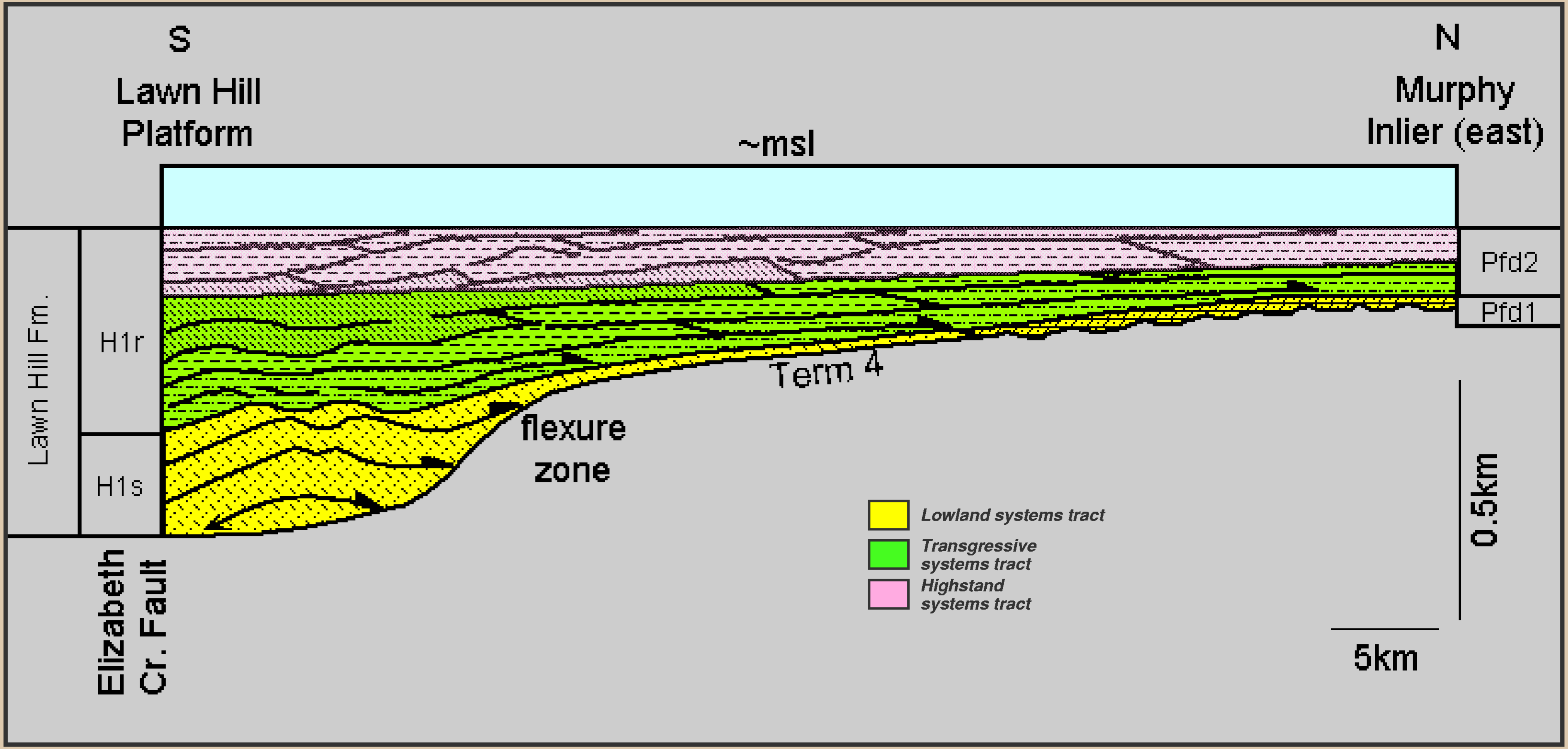

Figure 5.5.4 Sequence stratigraphic model for deposition of Term 4 sequences

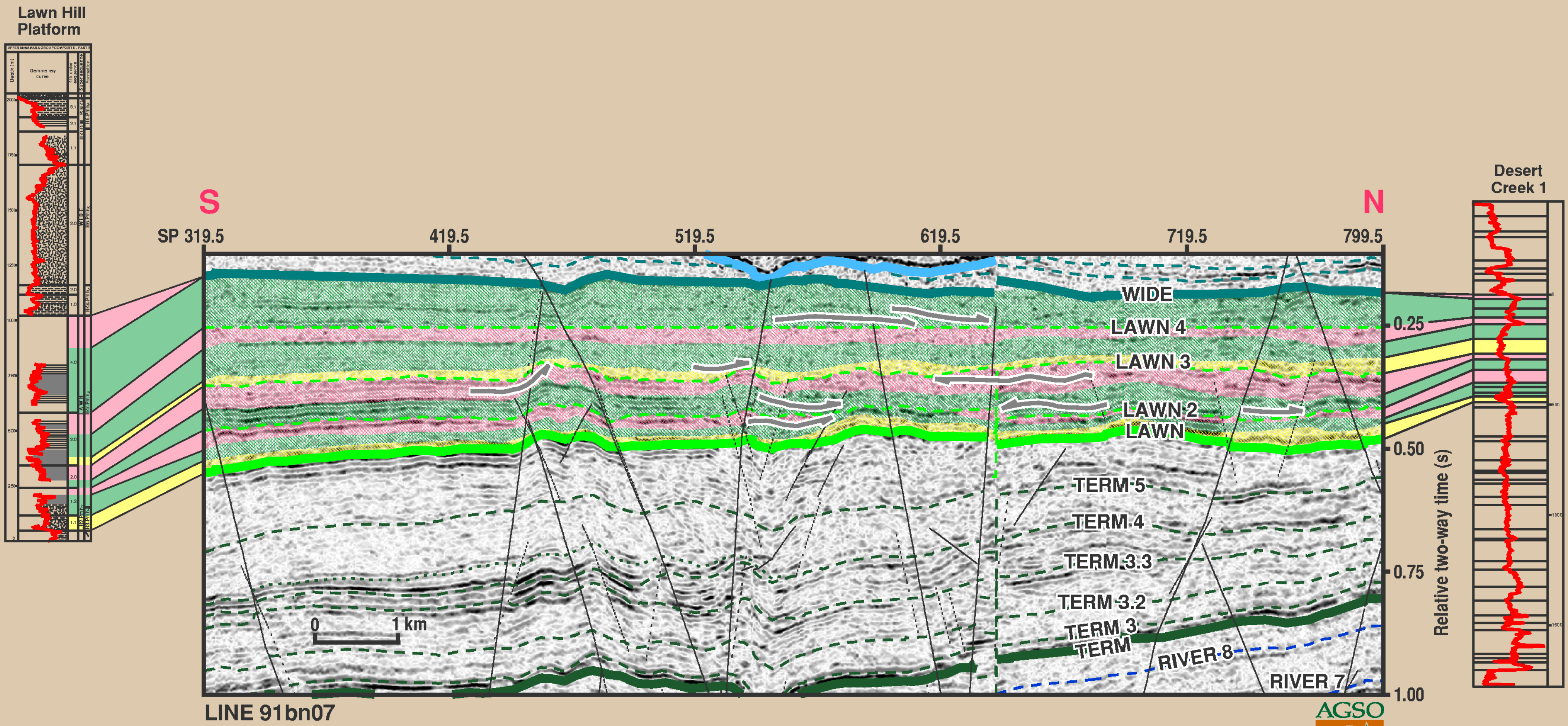

Figure 5.5.5 Lawn Supersequence composite and Desert Creek tied to flattened seismic section from 91bn-07

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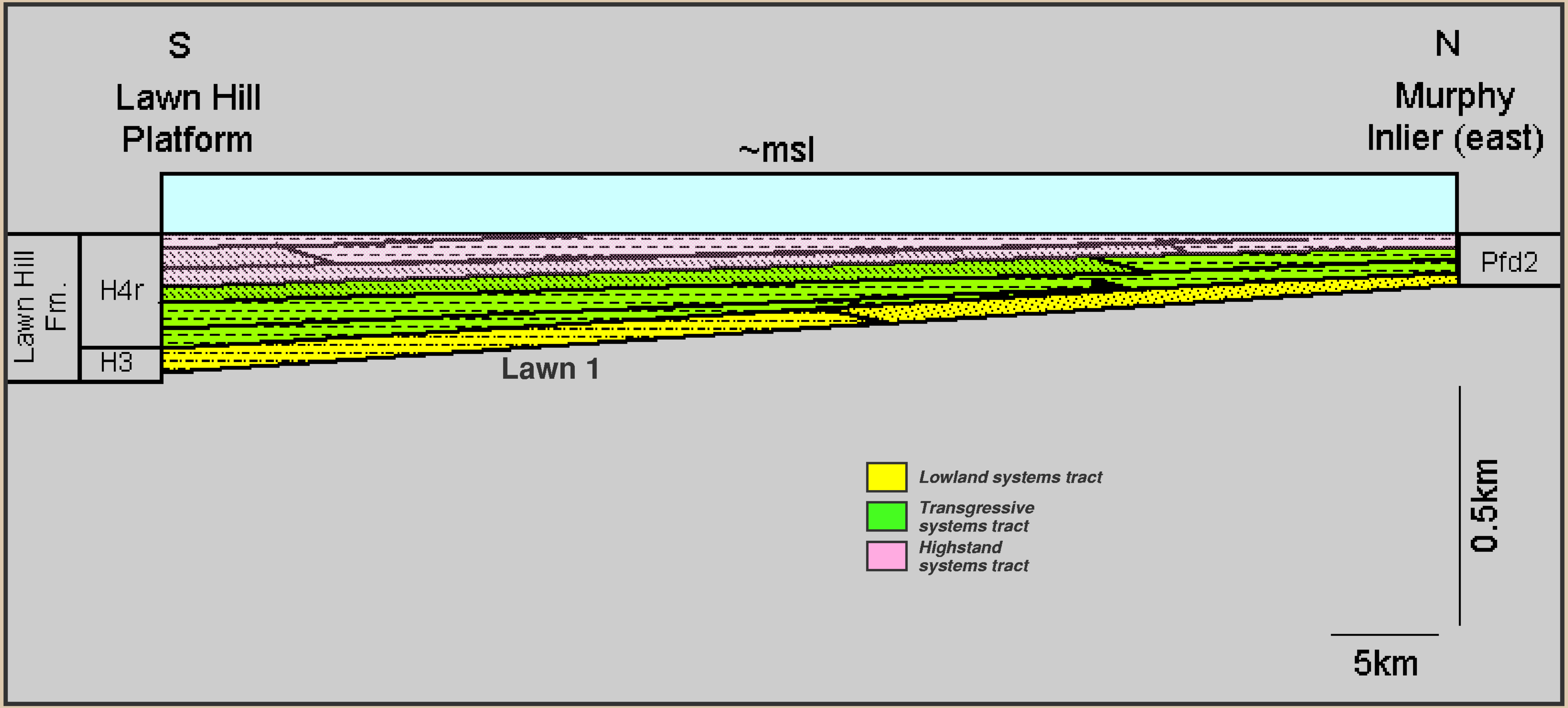

Figure 5.5.6 Sequence stratigraphic model for deposition of Lawn 1 sequences

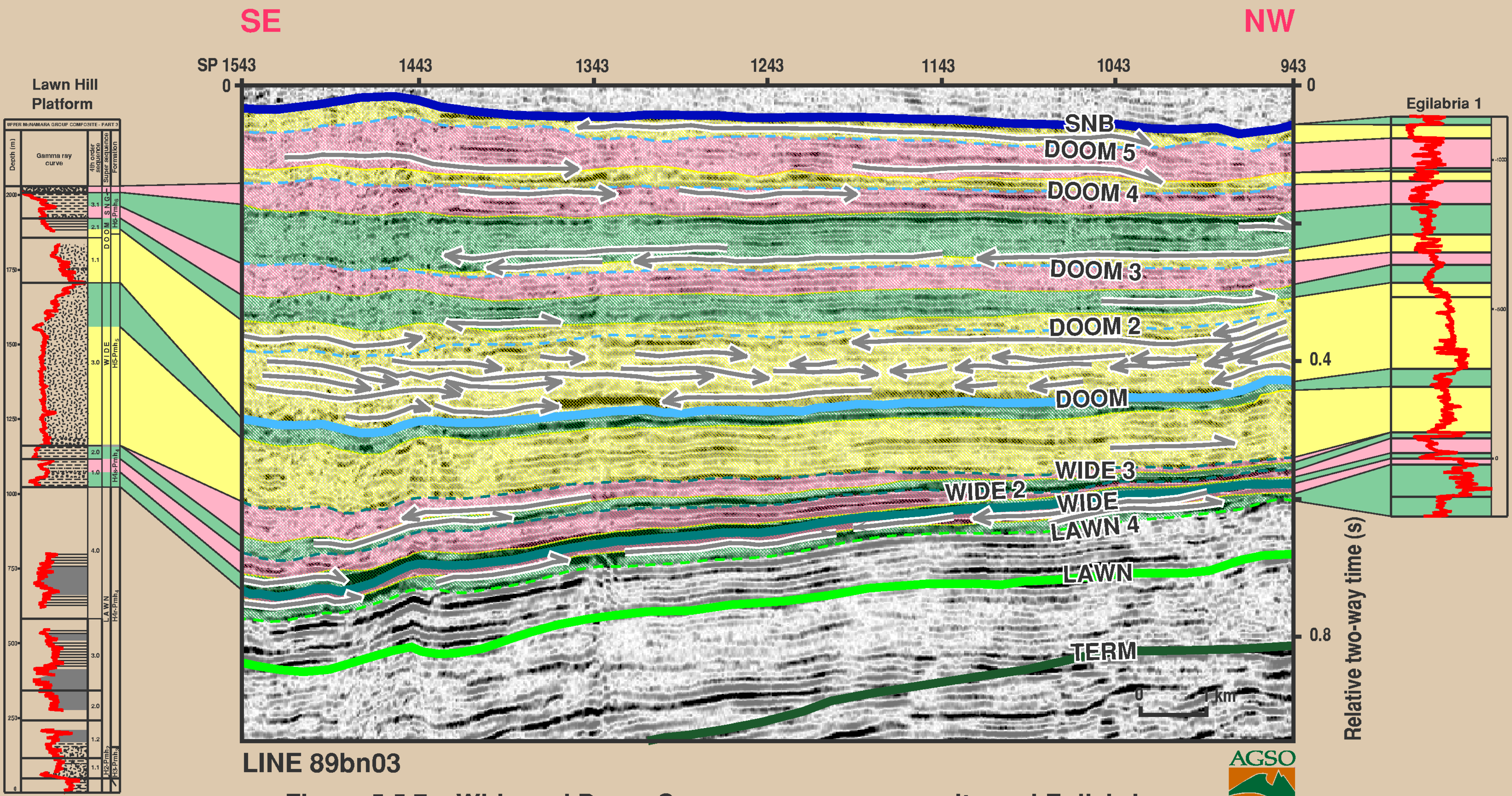

Figure 5.5.7 Wide and Doom Supersequence composite and Egilabria tied to flattened seismic section from 89bn-03

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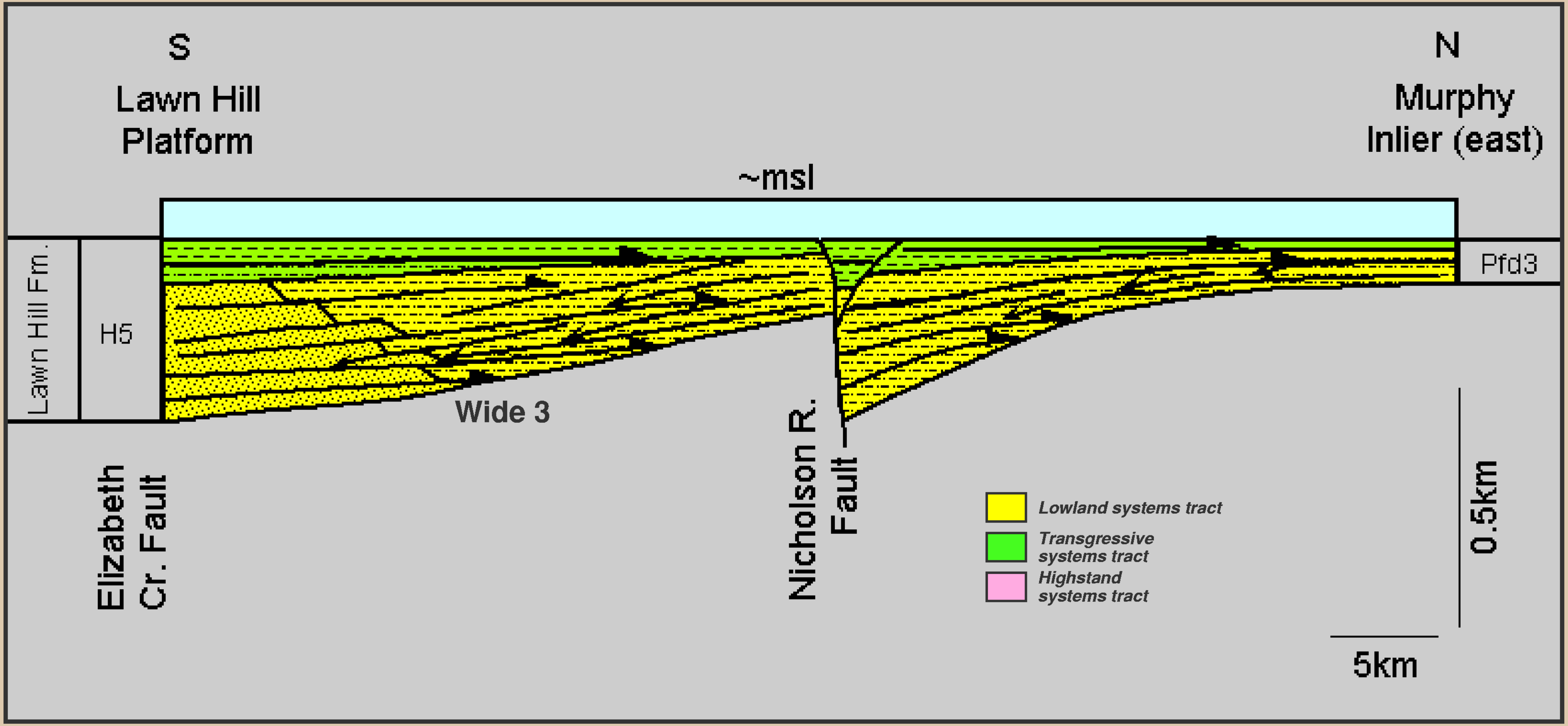

Figure 5.5.8 Sequence stratigraphic model for deposition of Wide 3 sequence

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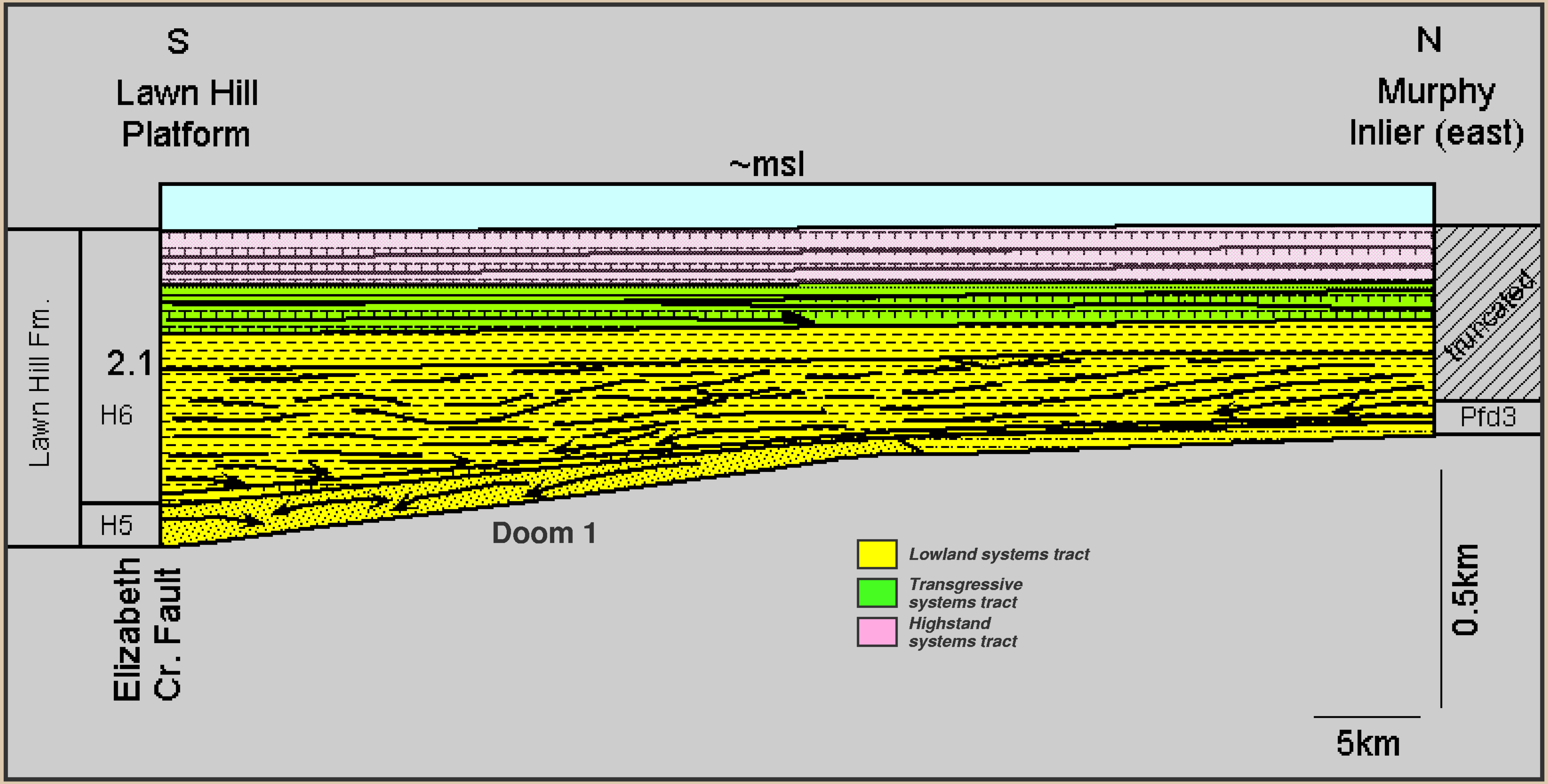
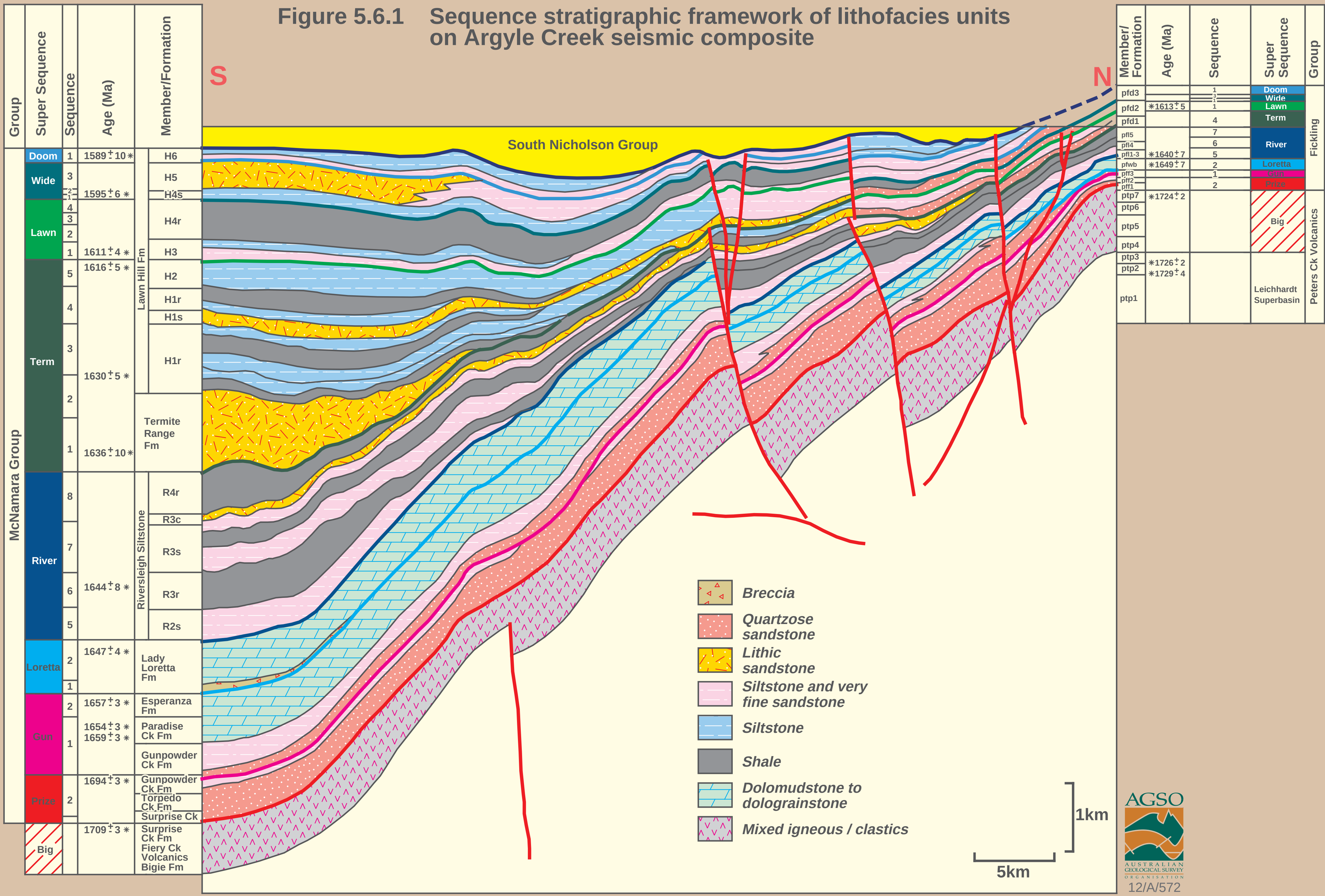


Figure 5.5.9 Sequence stratigraphic model for deposition of Doom 1 and 2 sequences

Figure 5.6.1 Sequence stratigraphic framework of lithofacies units on Argyle Creek seismic composite



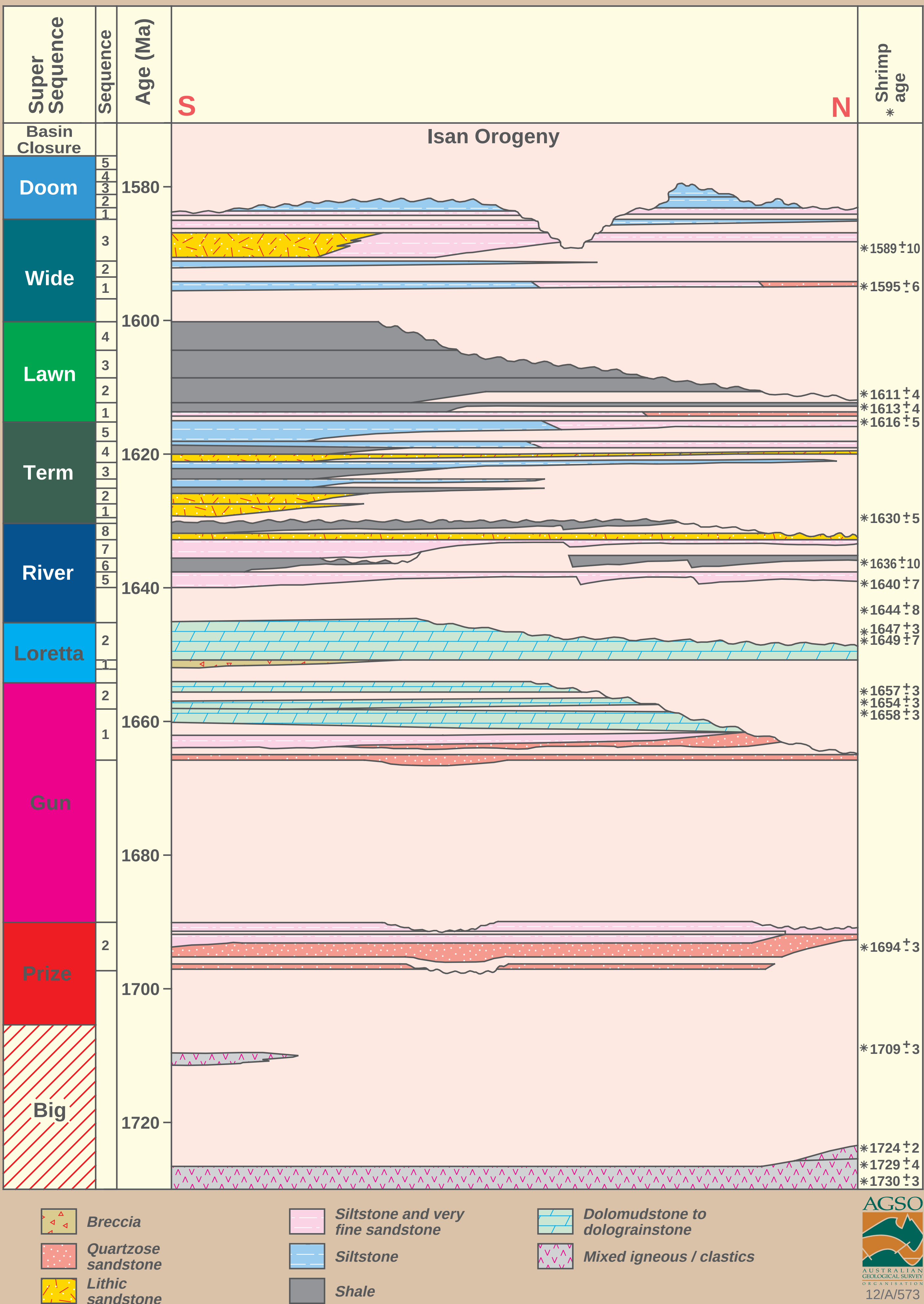


Figure 5.6.2 Chronostratigraphic chart for Isa Superbasin from Argyle Creek seismic composite

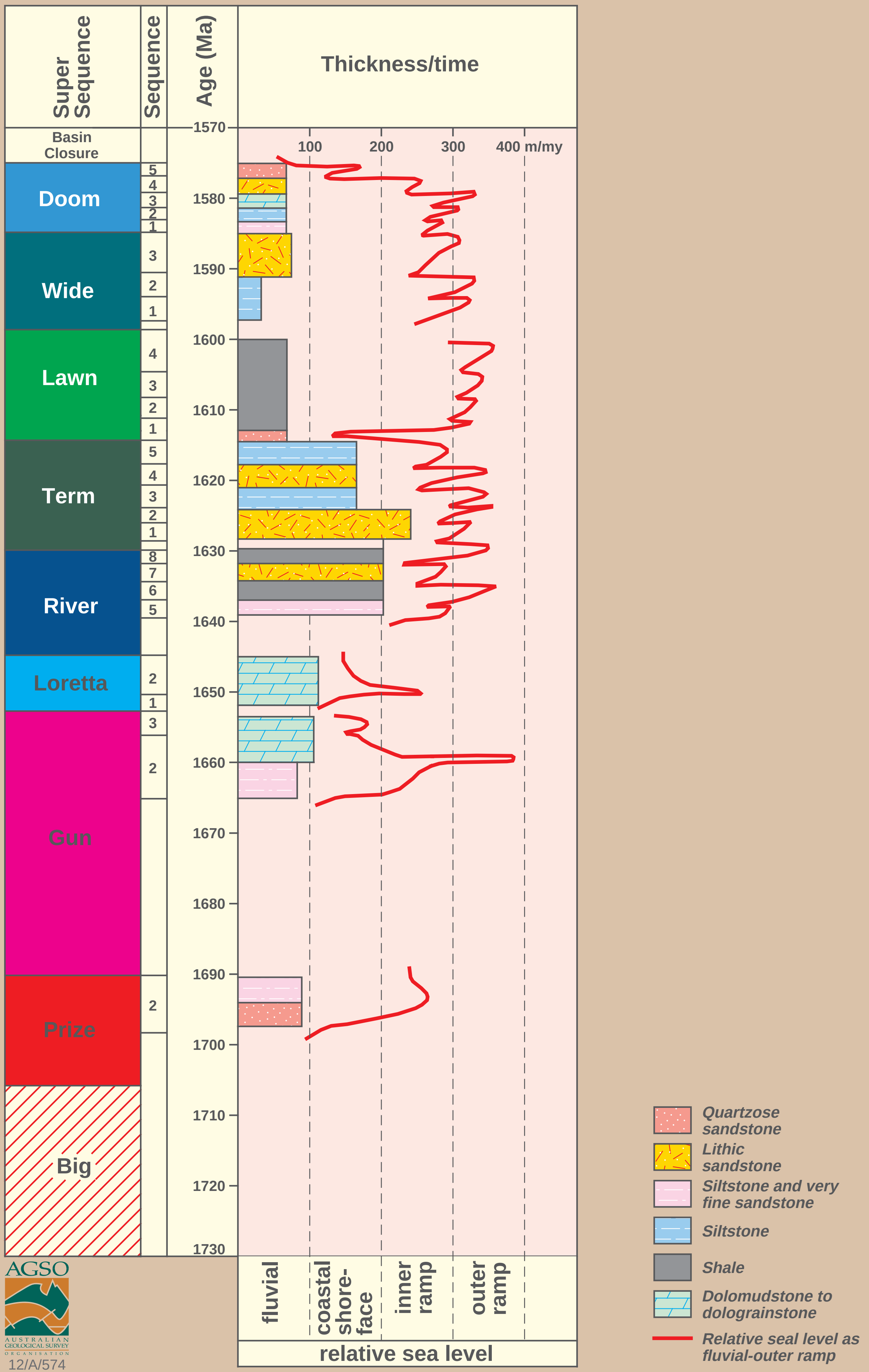


Figure 5.6.3 Approximate depositional rates and relative sea level curve for Isa Superbasin in the Northern Lawn Hill Platform

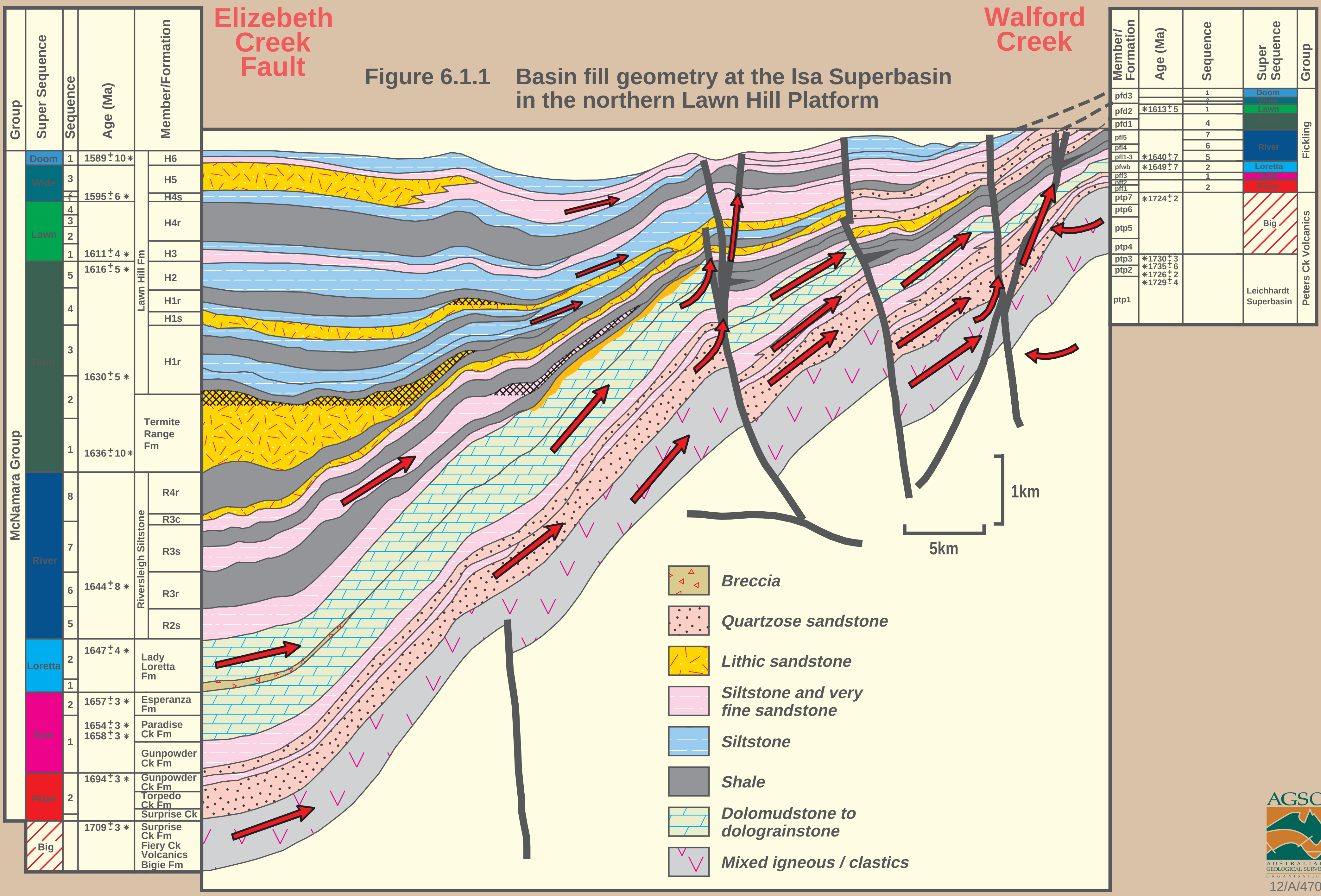


Figure 6.1.1 Basin fill geometry at the Isa Superbasin in the northern Lawn Hill Platform

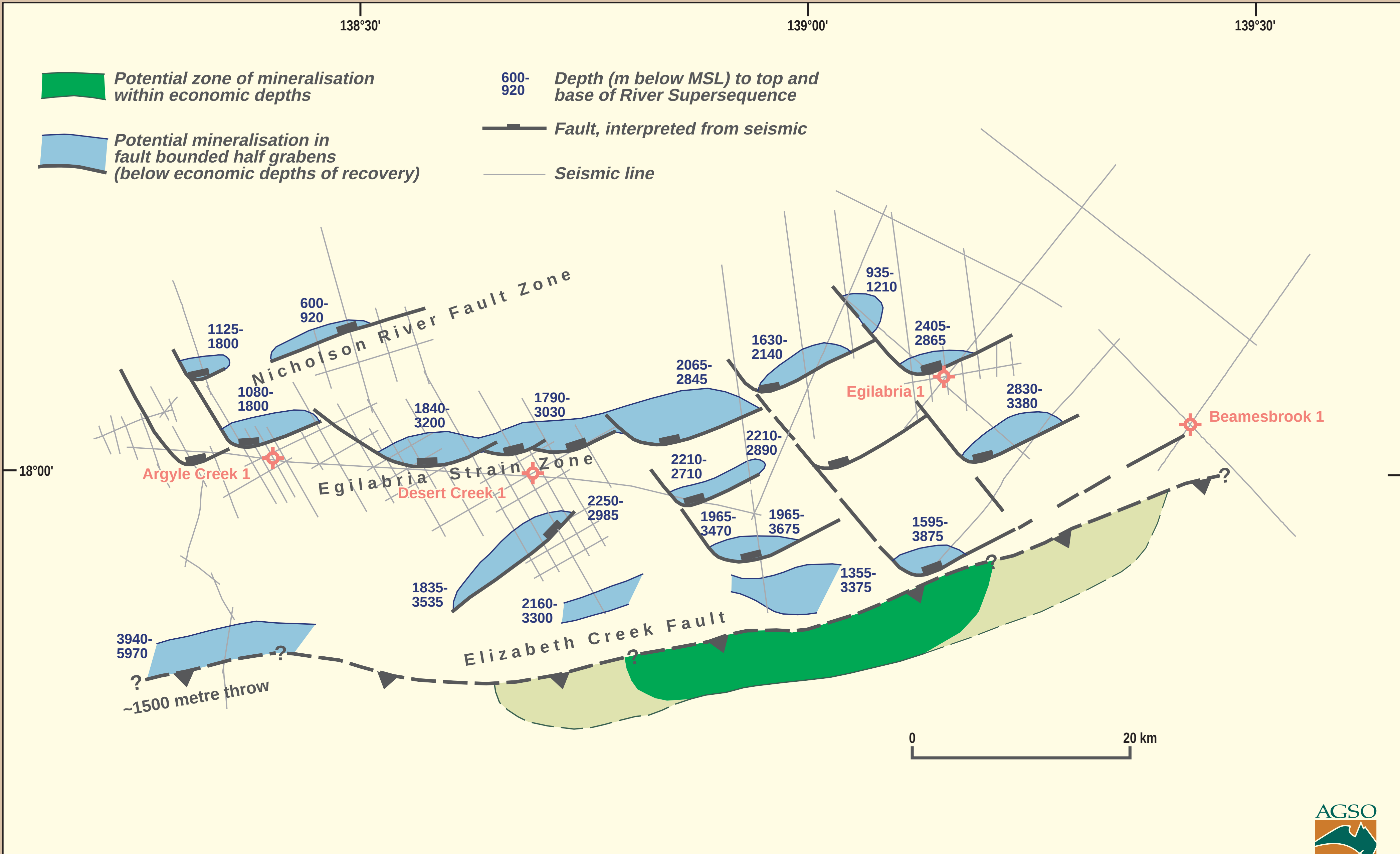


Figure 6.3.1 Potential mineral systems in the River Supersequence

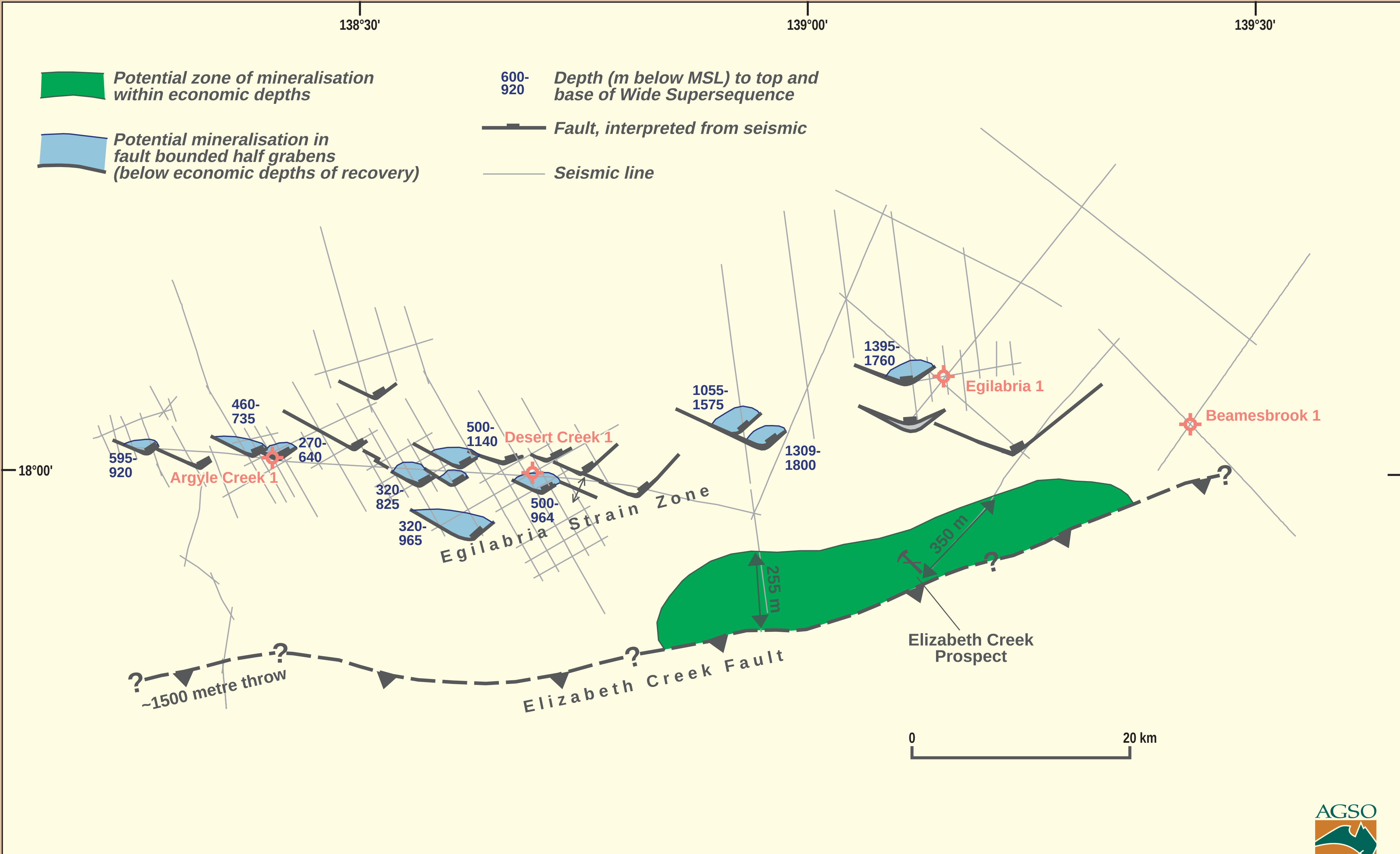


Figure 6.3.2 Potential mineral systems in the Wide Supersequence

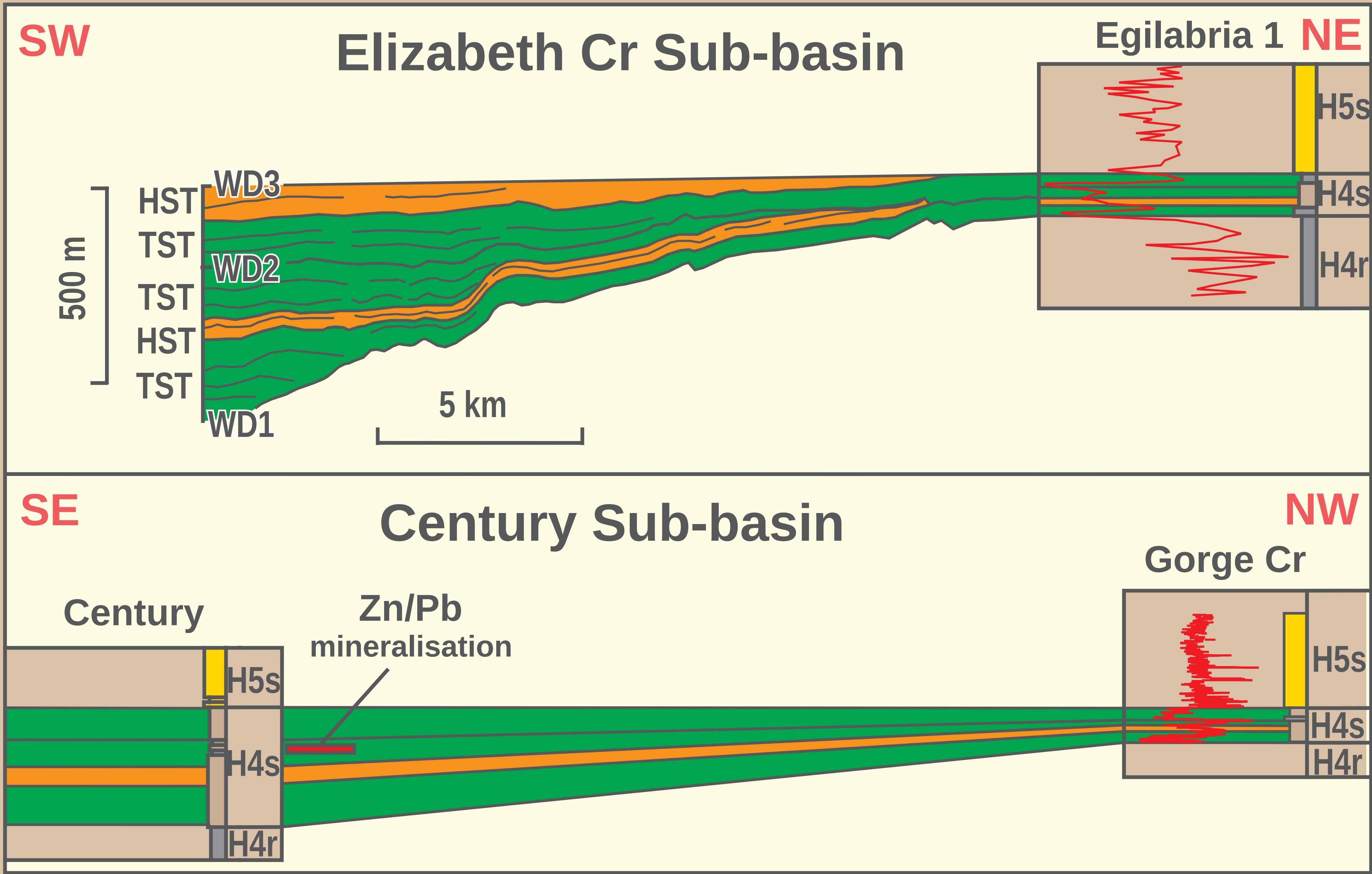


Figure 6.3.3 Comparisons between the geometry and depositional systems in the Elizabeth Creek and Century sub-basins

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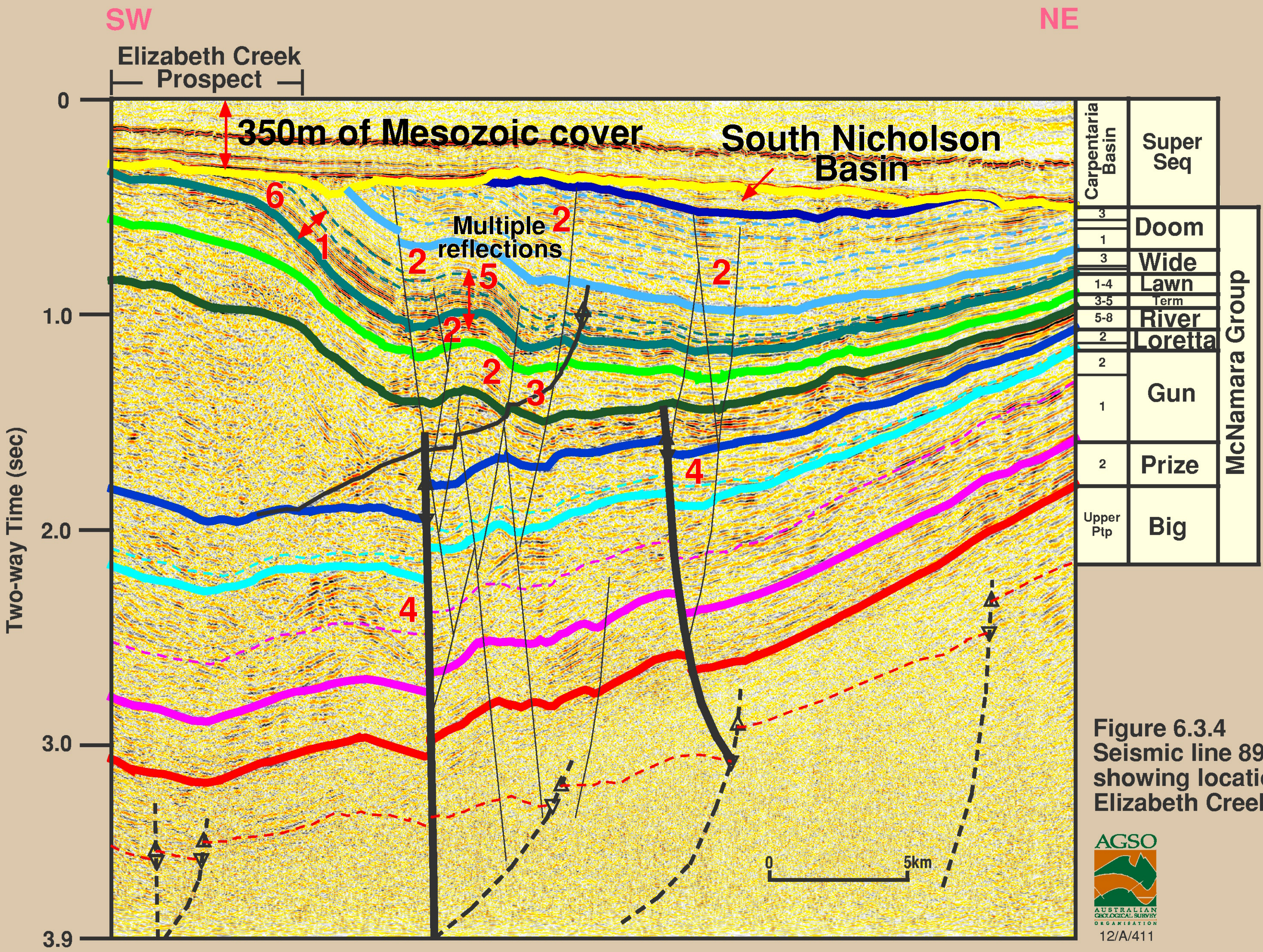

Figure 6.3.4
Seismic line 89BN-07
showing location of the
Elizabeth Creek Prospect

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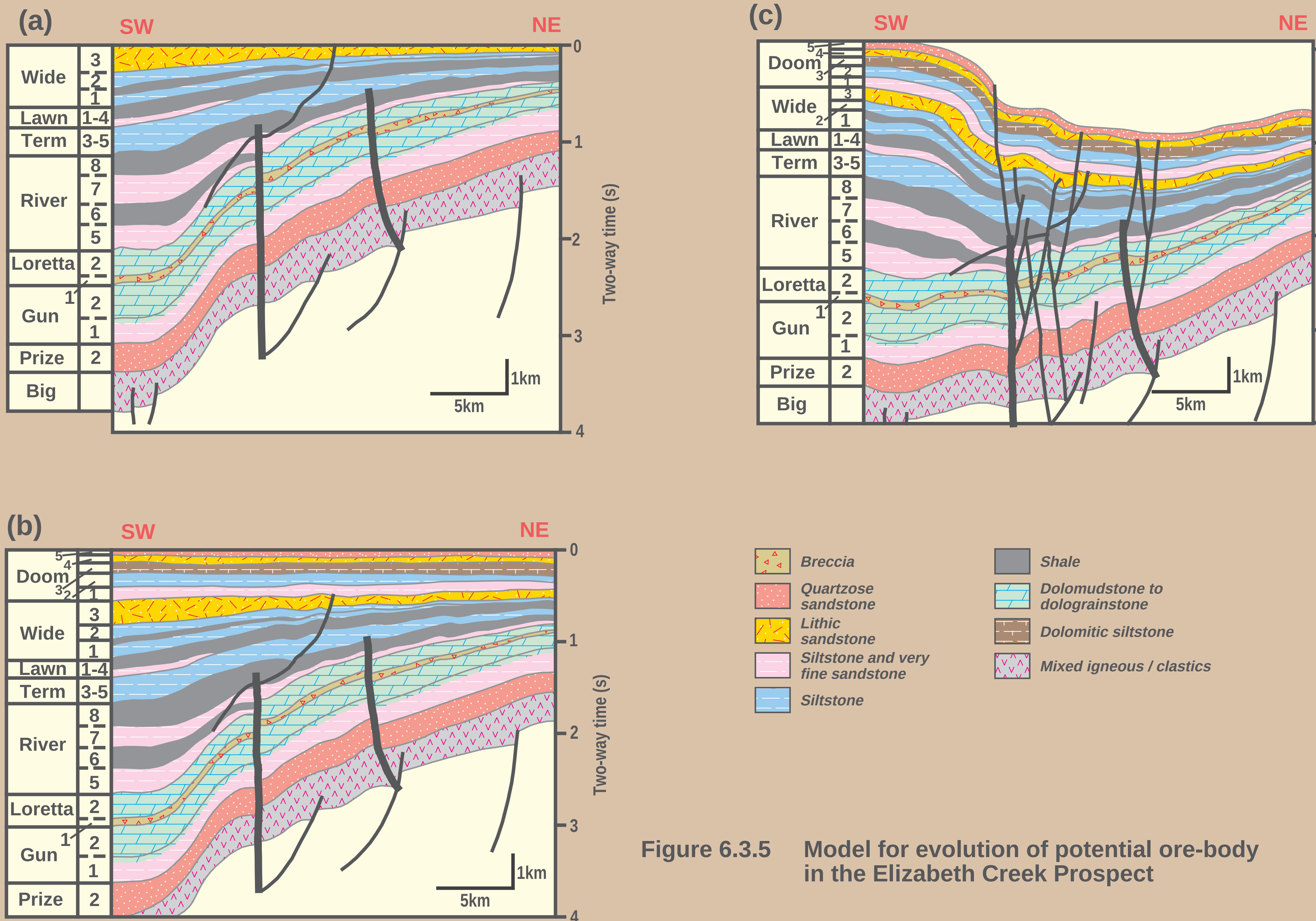

Figure 6.3.5 Model for evolution of potential ore-body in the Elizabeth Creek Prospect

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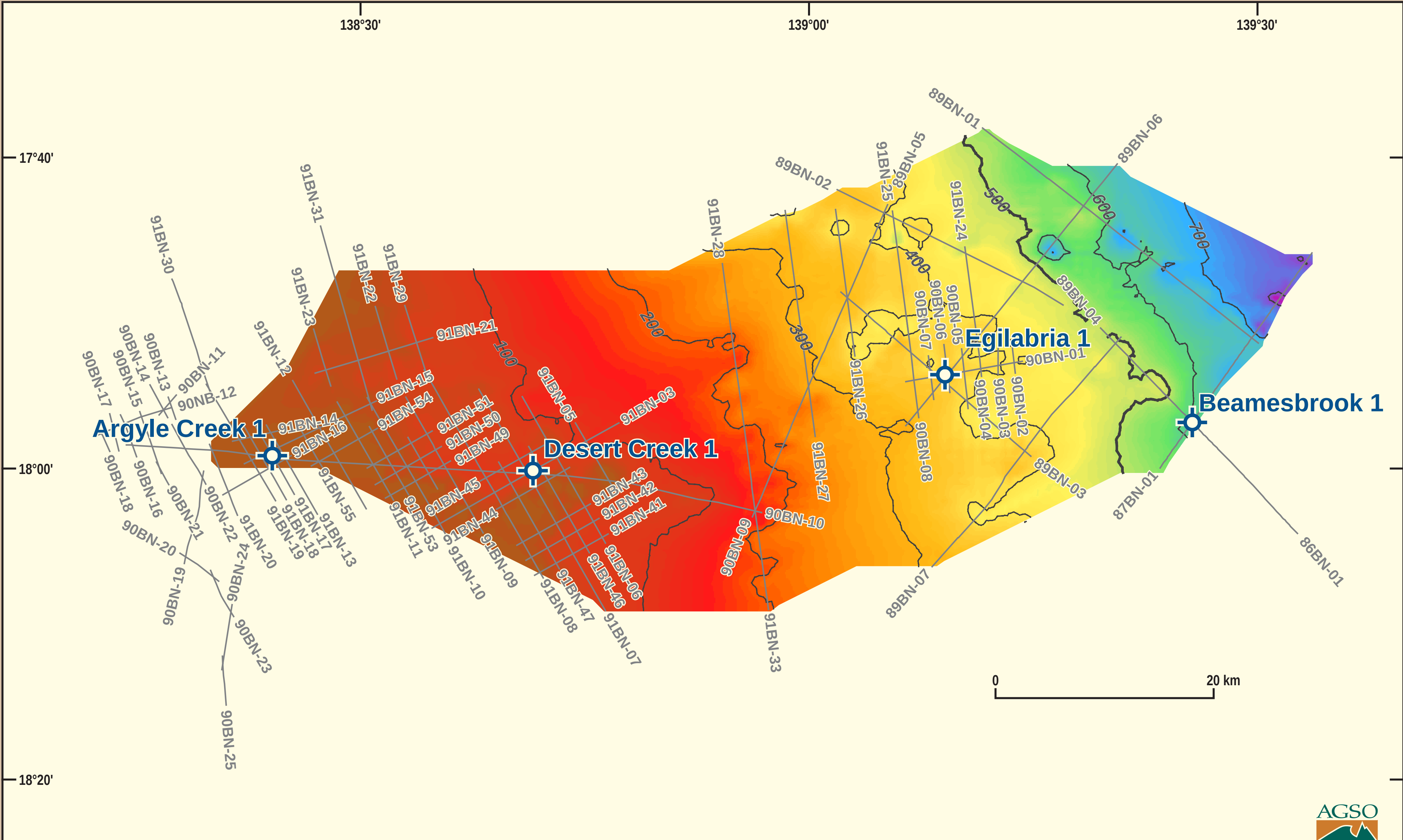


Figure 6.3.6 Carpentaria Basin isochron map

12/A/467

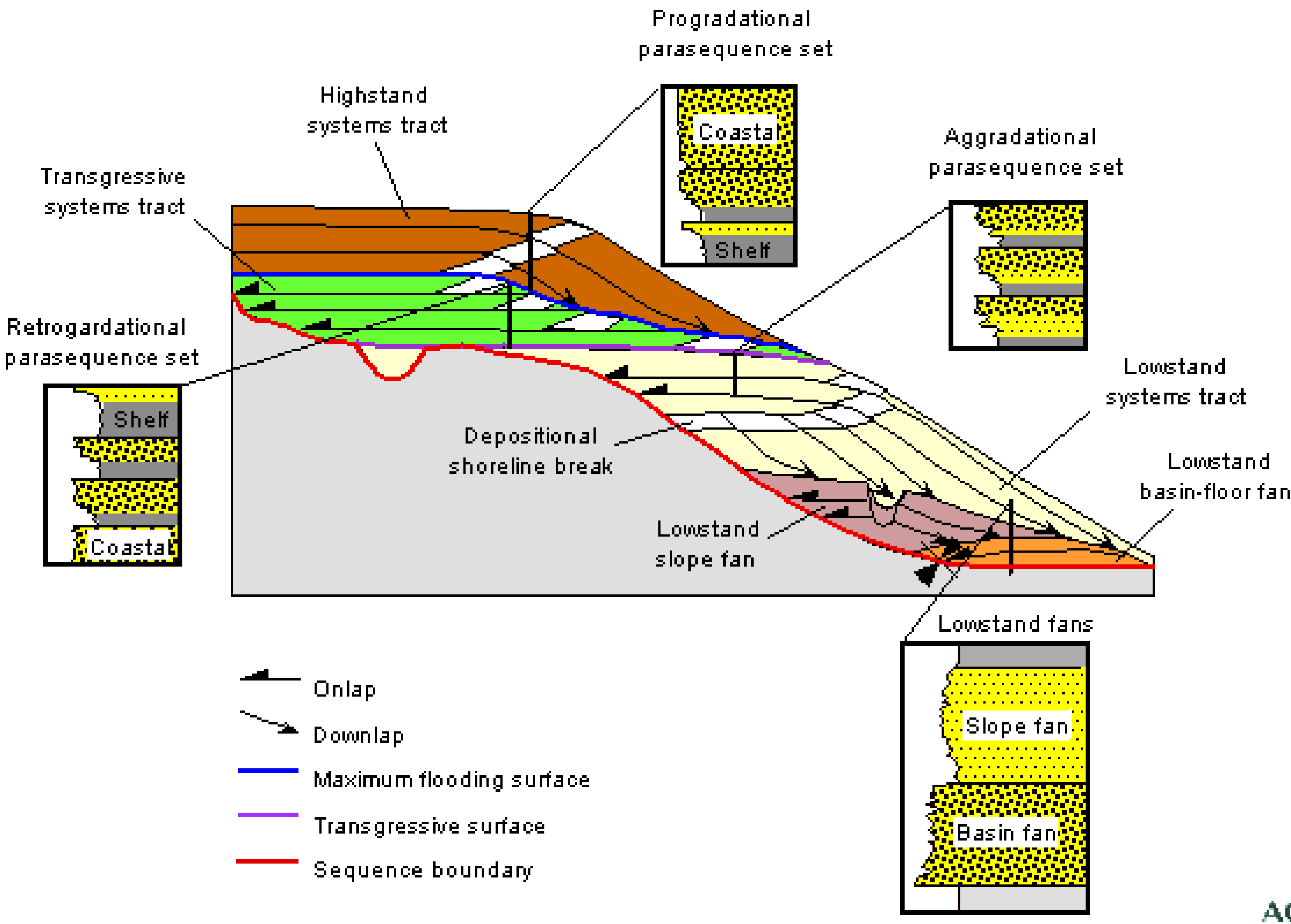
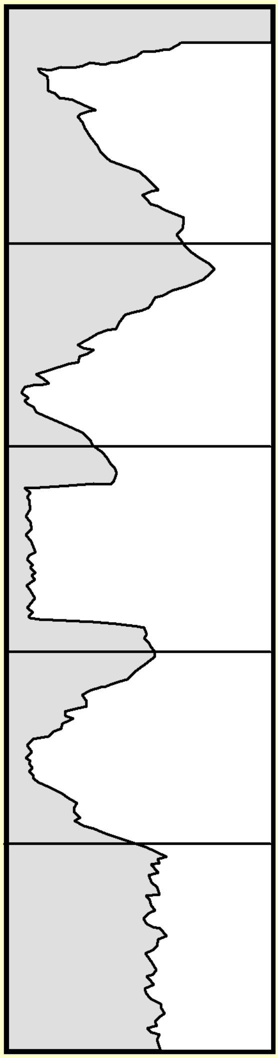


Figure A1 Geometry of parasequences defined by terminations that mark surfaces separating systems tracts



CLEANING-UP TREND
(or funnel trend)
Gradual upward decrease in gamma.

DIRTYING-UP TREND
(or bell trend)
Gradual upward increase in gamma.

BOXCAR TREND
(or blocky trend)
Low gamma, sharp boundaries, no internal change.

BOW TREND
(or symmetrical trend)
Gradual decrease then increase in gamma.

IRREGULAR TREND

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Figure A2 Idealised gamma ray log trends

ADDENDUM

Integrated Basin Analysis of the Isa Superbasin Using Seismic, Well-Log and Geopotential Data: An Evaluation of the Economic Potential of the Northern Lawn Hill Platform,

AGSO cd-rom RECORD 1999/19, comprises 3 CD roms.

1. Double CD:
   The archival seismic and well log dataset was issued in mid-1999 as a double CD ROM labelled Preliminary Edition Data Release. It contains .rtl plotfiles of interpreted seismic lines and .pdf files of each seismic line, enabling each line to be viewed on the screen.

2. Single CD:
   The final report (this CD ROM) was issued in June 2000 as a single CD ROM. This report integrates seismic, drill core, wireline, outcrop and potential filed datasets from the northern and central Lawn Hill Platform to provide a detailed understanding of the geological evolution of this part of northern Australia. The report accompanies the set of archival seismic lines issued in the Preliminary Edition Data Release.

Exploration company requests for early access to the interpreted seismic lines resulted in the two stage release of Record 1999/19.

Readers will notice that some discrepancies may exist between terminology used in this CD ROM and that provided in the NABRE thematic issue of the Australian Journal of Earth Sciences, Volume 47/3.
These discrepancies result from the evolution of ideas as the datasets were integrated.
Our understanding in early 1999 is recorded in the CD ROM. The papers in AJES 47/3 provide scientific concepts at the end of the NABRE project in February 2000.

The main impact of this change concerns the definition of the Isa Superbasin.
In the CD ROM the Isa Superbasin includes the stratigraphic interval from 1730 Ma to 1575 Ma. ie the Big to Doom Supersequences.
However, as datasets were integrated we realised the need to divide the Isa Superbasin into two Superbasins: the earlier Calvert Superbasin, 1730-1590 Ma and the Isa Superbasin 1670-1575 Ma.

These changes are discussed in papers by Jackson et al. and Southgate et al. in AJES volume 47/3.
Some of the diagrams used in this CD ROM (eg. the Basin Event Chart, Fig. 1.2.7) refer to both the Calvert and Isa Superbasins.

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It is recommended that this CD be referred to as:
Bradshaw B.E. and Scott D.L.
Integrated Basin Analysis of the Isa Superbasin using Seismic, Well-Log and Geopotential Data: An Evaluation of the Economic Potential of the Northern Lawn Hill Platform.
Australian Geological Survey Organisation. AGSO Record 1999/19

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