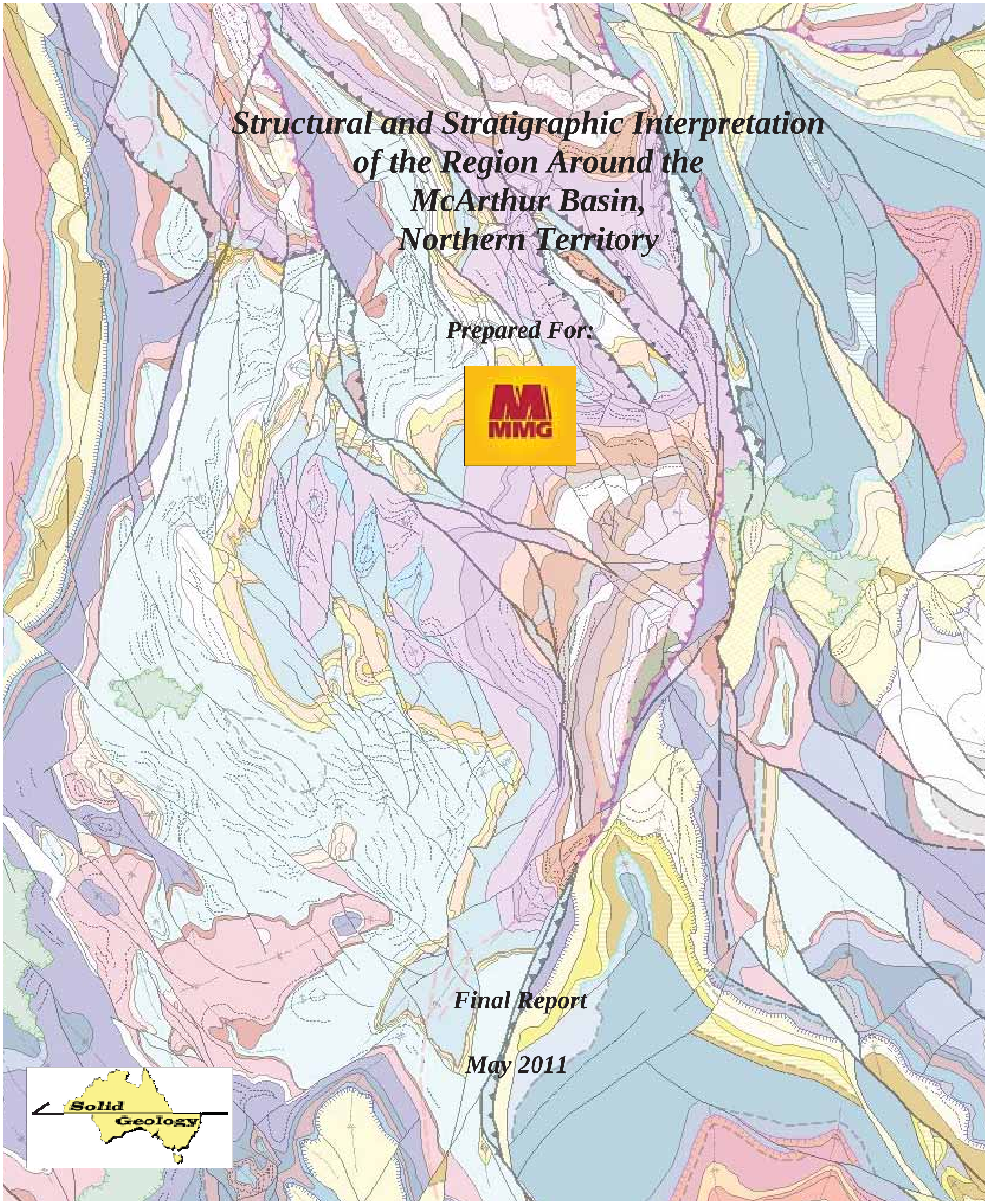

Structural and Stratigraphic Interpretation of the Region Around the McArthur Basin, Northern Territory

Prepared For:

MMG

Final Report

May 2011

Solid Geology

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1 Introduction

At the request of Larry Stewart of MMG Ltd. a structural / stratigraphic interpretation of the region around the McArthur Basin, Northern Territory (**Figure 1**) was undertaken by the author (Dr. Stephen King). The main aim of the interpretation was to produce a solid geology map, interpreting the Proterozoic geology under cover where possible.

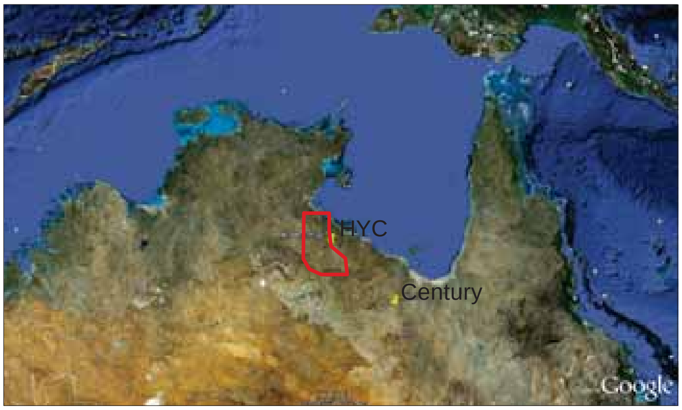
Data Sources

The main data sources utilised during the map interpretation were:

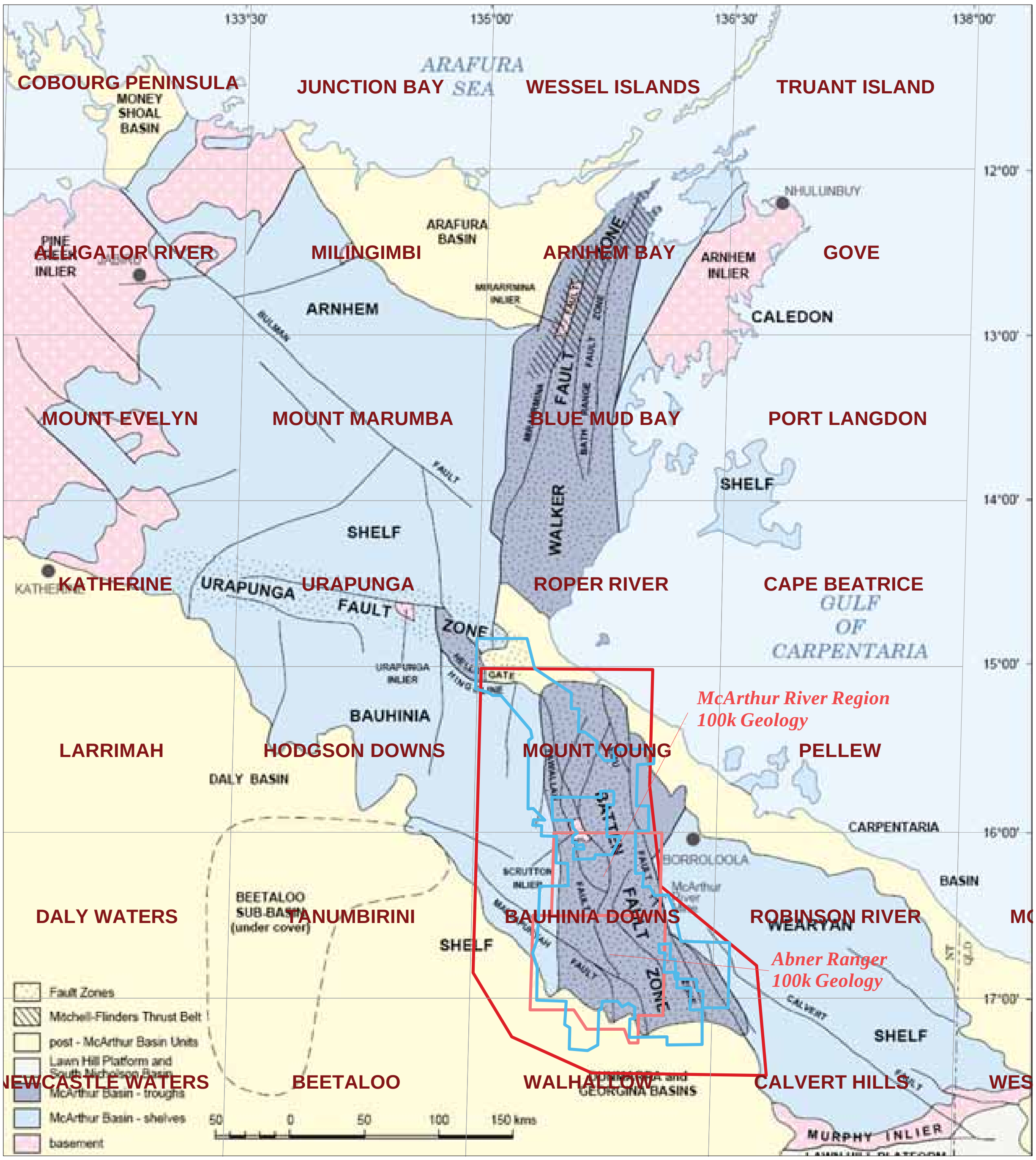
- 1:250,000 scale geology polygons and polylines in Mapinfo format. The polygon shapes also include the geology depicted in the 1:100,000 Abner Range and McArthur River Region sheets. However, the interpreted faults shown on those sheets are not included in the 1:250,000 Mapinfo dataset. Data was available for the following sheets (see **Figure 1**):
  - Mount Young
  - Bauhinia Downs
  - Walhallow
  - Robinson River

  Other digital data that accompanied these sheets included:
  - Structural measurements - not always in the same format.
  - Mineral occurrence data
  - Stratigraphic drill hole locations
  - bedding trends
  - fold axes
- A raster scan of the 1:250,000 scale Calvert Hills Sheet.
- Raster scans, registered in Mapinfo, of the 1:100,000 Abner Range and McArthur River Region sheets (see **Figure 1** for location). These represent the only 1:00,000 scale mapping in the area.
- 1:1.000,000 geology polygons for the Northern Territory.
- Regional ternary radiometrics image (U=blue, Th=green, K=Red) gridded to 100m cell size (McArthur_100m_RAD_KThU_RGB_Unf.tab) - other radiometrics data sets were available but this proved to be the most useful.
- Aeromagnetic images and grids including:

Figure No.1 Location of Batten Trough Study Area



Location of study area (dark red polygon) within the Batten Fault Zone of the Northern Territory.
Coverage of airborne EM imagery (blue polygon).
1:250,000 Sheet Boundaries and names (grey boxes)
1:100,000 geology sheets (pink)



Scale 1 : 400,000

- McArthurBasin_MagRTP_tilt
  - Batten_Trough_TMI
  - Batten_Trough_VD (Grey Scale)

- Landsat TM imagery, bands 2,4,7 as RGB image. Downloaded from NASA Zulu web site to cover the region. Pixel size 15m.
- Airborne EM images (see **Figure 1** for coverage) produced by Rob Angus of RAMA Geoscience including:
  - McArthurBain_AEMMerge_EarlyCh - an image of the early channel response highlighting features nearer surface. A grid of this image was also supplied allowing local stretching where required.
  - McArthurBain_AEMMerge_MidChan - a mid channel image. A grid of this image was also supplied allowing local stretching where required.
  - McArthurBain_AEMMerge_LateCha - an image highlighting responses from deeper levels
  - McArthurBain_AEMMerge_Tau - decay constant image.

  Coverage of the EM data is not complete.
- Regional Bouger gravity images
- Google Earth images. As no digital aerial photograph or high resolution satellite imagery base could be supplied on which to compile the interpretation a series of image tiles have been downloaded from Google Earth and registered in Mapinfo. A total of 63 tiles have been downloaded and registered using the standard version of Google Earth (**Figure 2**) - each tile (1894 x 1090 pixels) covers an area of approximately 29km E-W by 17km N-S and have been captured to ensure overlap of the images. If required, higher resolution (4800 pixels E-W) tiles can be downloaded using Google Earth Professional.
- Previous work in the area, referred to during the study included:
  - Interpretation of a seismic line across the Batten Trough (see **Figure 2 & 3**) by Rawlings et. al. (2004).
  - NTGS review paper on the McArthur Basin (Ahmad et. al.)
  - McGoldrick (2010)

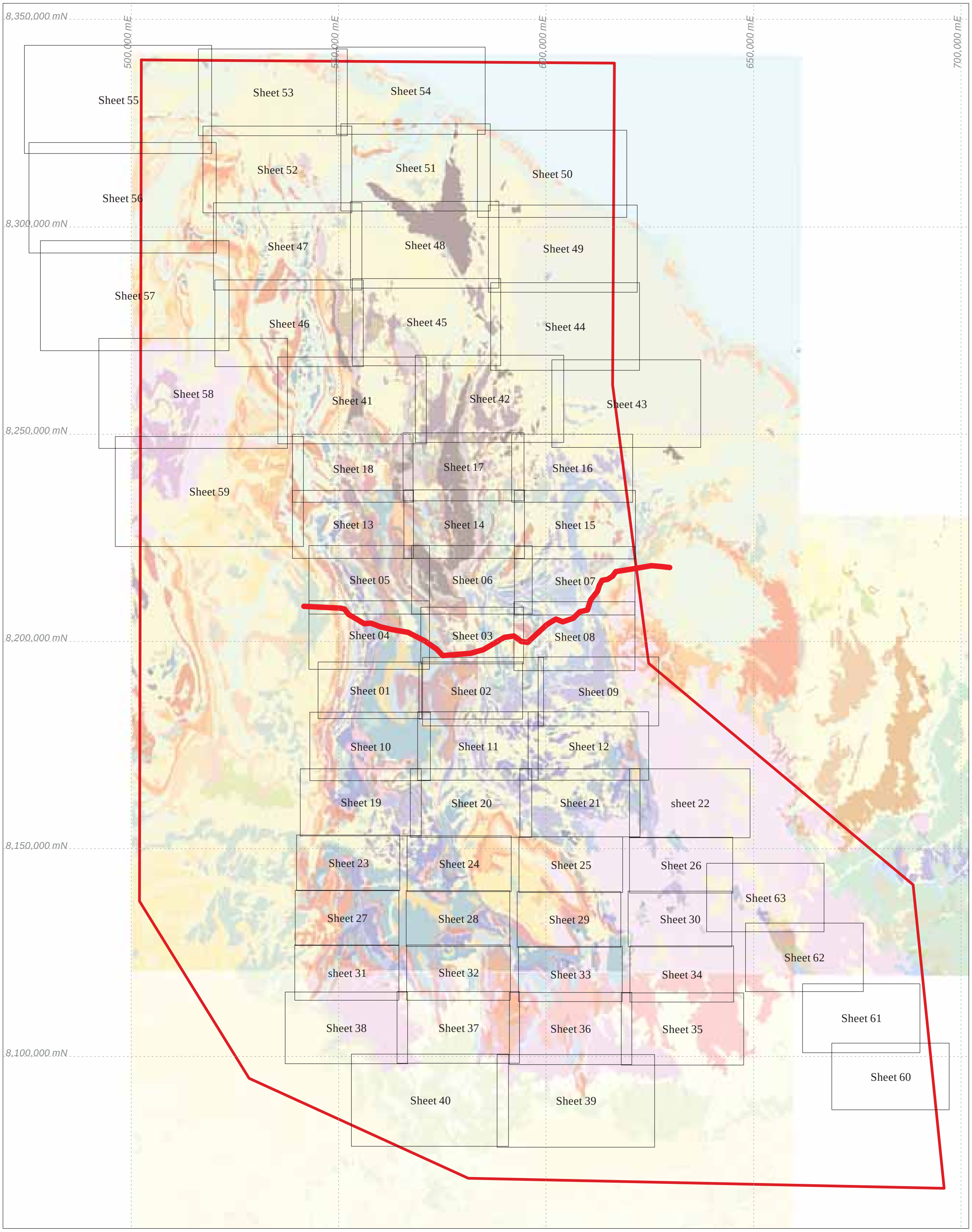
The interpretation has been compiled in Australian Map Grid Zone 53 (GDA94). Google earth images have been captured in Lat/Long WGS84 Zone 53 South which is the equivalent projection.

Aims and Objectives

The main aims and objectives of this study are to:

- create a solid geology map for the study area which interprets units under thin surficial and Cretaceous/Tertiary cover

Figure No.2 Coverage of Google Earth Image tiles

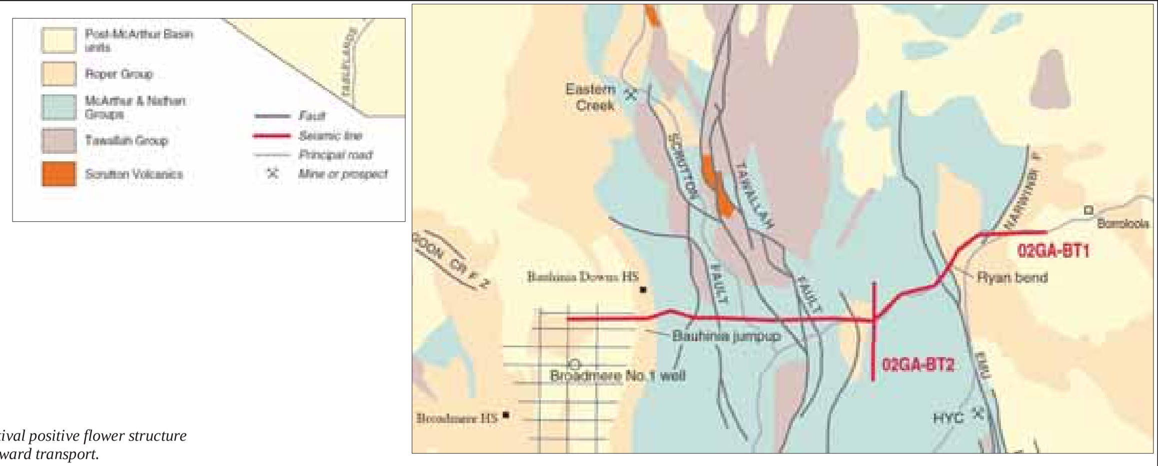


Scale 1:1,300,000

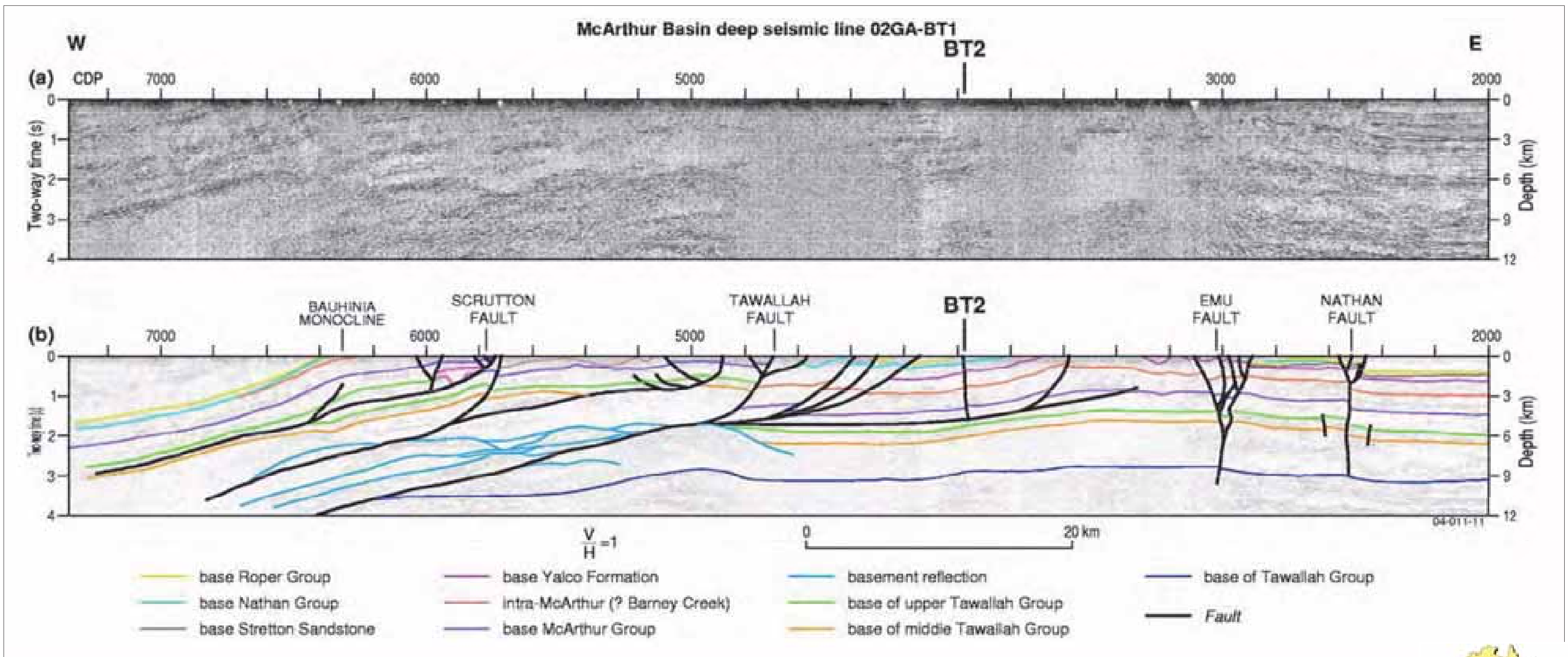
Location of Google Earth image tiles created for the study area. The sheet numbers are included in the file names. The location of the Geoscience Australia seismic line is also shown as the thick red line.

Solid Geology

Figure No. 3 Geoscience Australia seismic line and interpretation



Geoscience Australia seismic line location and interpretation. The Emu Fault has been interpreted as a sub-vertival positive flower structure in a strike-slip fault. The Tawallah Fault has been interpreted as a Post Roper Group Thrust structure with eastward transport.



- Tag units with a variety of geological parameters to allow thematic maps by age, litho-type, sequence etc. to be created and analysed.
- define the fault architecture of the study area and highlight significant structures.
- define major structural block boundaries which have enhanced potential for controlling significant mineral deposits.
- define the stratigraphic sequences in the study area - differentiating recessive sequences which are potential hosts to clastic hosted base Pb / Zn mineralisation.
- attempt to identify structures active during sedimentation through recognition of associated thickness changes of the sequence.
- identify target areas based on the interpreted elements.

2 Background

A number of papers were supplied by MMG Ltd. as initial background reading to the interpretation. The following paragraphs summarise the pertinent information from each that is considered useful to constraining the current interpretation.

Rawlings et. al 2004 - Seismic Interpretation

Seismic interpretation of the southern McArthur Basin was undertaken by Geoscience Australia (Rawlings et. al 2004). The interpreted seismic section and its location are reproduced in **Figure 3** (see **Figure 2** for more detailed geological background for line location). Conclusions from that study include (*further comments will be made on these conclusions after the interpretation resulting from this report has been presented*):

- There is very little evidence for the existence of growth faults in the McArthur Basin sequence although the McArthur Group rocks do increase gradually in thickness to the east whilst the preserved Roper Group sequence increases to the west.
- East of the Narminbi Fault (*incorrectly labelled as Nathan Fault in their section*) the entire succession is essentially horizontal.
- There is no evidence for the existence of the Batten "Trough" or asymmetric half grabens.
- A gently east dipping carbonate ramp at McArthur times rather than a trough is suggested as a more likely environment of deposition - with third order sub-basins developed along the Emu Fault.
- The regional fault system is interpreted in terms of a series of west-dipping faults forming part of an east-propagating major thrust belt, with larger displacements in the west and diminishing to the east. The frontal thrust of the system is interpreted to lie 6km west of the Emu Fault Zone.
- The Roper Group is interpreted to lie above the westernmost thrust ramp and suggests a post-Roper Group timing for the thrusting.

- Fault geometries are consistent with an east to northeast orientated compressional axis.
- The Emu Fault is interpreted as a near vertical strike-slip fault containing an inverted flower. The movement history on the fault comprised:
    - Mid-McArthur Group sinistral shearing affecting sedimentation on transtensional fault bends.
    - Post-Roper Group dextral movement inverting the earlier formed zones into positive flower structures

McArthur Basin Development - Duffett et.al.

- Roper Group thickens from 1km in the east to 5km in the west marking a change in depocentre from the McArthur Basin.
- The Buklara Sandstone is up to 300m thick in the south of the McArthur Basin.
- Basement structures established in the Barramundi Orogeny around 1850Ma subsequently had an important role in development and inversion of the McArthur Basin sequence. NNW, NW and NE trends have been identified.
- North-South extension was present during Tawallah Group deposition but was interrupted by E-W compression in mid-Tawallah Group time.
- Strike-slip movements were present during McArthur Group deposition.
- Extension resulting in block faulting was present at the commencement of the Barney Creek Formation resulting in NNW-SSE and E-W trending half grabens to the west of the Emu Fault which may have been active as a transfer fault at that time.
- An inversion event, possibly synchronous with the HYC mineralising event; the mineralisation occurs towards the top of the Barney Creek Formation. The inversion was related to NW-SE compression.
- N-S trending depocentres then redeveloped creating space for the sequence up to and including the Caranbirini Member.
- After this slow thermal subsidence seems to have been the main influence on Basin development until Roper Group deposition.
- The final deformational event affecting all Proterozoic units comprised NE-SW compression.

This paper contains a representation of the stratigraphic column that is common to most papers and was adopted as a starting point for the interpretation in this report - it has been reproduced as **Figure 4**.

McGoldrick et. al 2010

McGoldrick et. al. analysed litho-facies variation around the southern McArthur Basin from measured sections and drill holes resulting in the following conclusions:

- The upper McArthur Group rocks have a dominantly shallow marine / carbonate platform association.
- The Barney Creek Formation has a shale dominant deeper water association.

Figure No.4 McArthur Basin stratigraphic column from Duffett et.al.

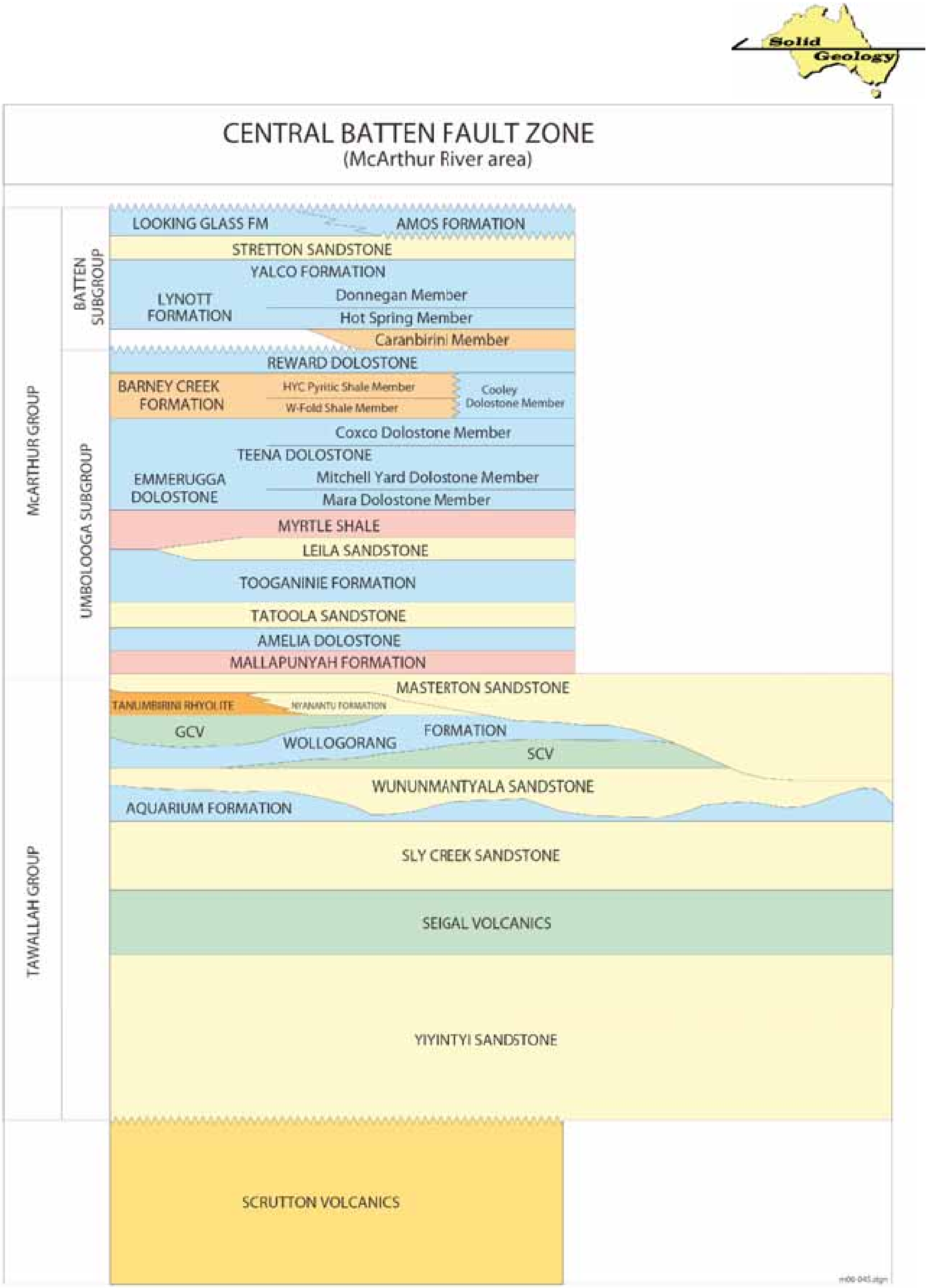


Figure 2. Lower McArthur Basin stratigraphy, modified after Pietsch *et al* (1991) and S Bull (pers comm 1998). Units are colour-coded according to dominant composition, with felsic volcanics orange, sandstones yellow, mafic igneous units green, dolostones light blue, oxidised shales and siltstones red and reduced carbonaceous shales and siltstones brown.

- Mapping and drill hole logging established 26 different litho-facies associations within the Barney Creek Sequence which were grouped into seven different specific depositional environments
  - **Continental** - sheet conglomerates
  - **Peritidal** - cauliflower chert dololutite, Coxco needles, halite clasts, microbialite.
  - **Shallow-subtidal** - Flat pebble conglomerates, grainstone
  - **Deep-subtidal** - Plumose structured microbialite, planar laminated dololutite, wormy dolostone, Coxco Needles
  - **Platform margin** - Wavy microbialite.
  - **Slope** - Clast-supported dolorudite and dolarenite, mega breccia blocks
  - **Basinal** - red-green dolomitic siltstone, fine dolomitic sandstone, massive carbonaceous shale (+/- py), nodular argillaceous dolostone.
- The River Super Sequence comprising the stratigraphy from the Leila Sandstone to the top of the Yalco Formation has been subdivided into 3 sequences:
  - **The Emmerugga Depositional Sequence** - Leila Sandstone to base of the Teena Dolostone
  - **The Barney Creek Depositional Sequence** - Teena Dolomite to the top of the Reward Dolomite
  - **The Lynott Depositional Sequence** - Caranbirini Member to the top of the Yalco Formation
- The facies developed during sinistral transpression on the Emu Fault created in N-S extension (**Comment**: *transpression cannot occur in extensional environments*) with the basin architecture controlled by the Emu, Tawallah and Hot Spring Faults which have both syn-sedimentary and post-depositional fault movements. North to NW trending segments of these structures were transtensional. Structures trending east of north were transpressional (**Comment:** *in a N-S extensional setting the NE trending structures would be equally transtesional, it requires a strike-slip setting to create the geometry he describes - see* ***Figure 6b***).
- PB-Zn deposits developed in pyritic shales in sub-basins on the seaward side or marine side of carbonate platforms in a far-field back-arc setting.
- There is lateral continuity of the formations in the Lower McArthur River Group.
- In the vicinity of the Gorge Prospect (**Figure 5a** for location) a cobble conglomerate overlies the Reward Dolomite in an erosive contact. A catastrophic debris flow reworking the Lower McArthur Group rocks from a proximal source. Close to a collapsing passive margin (**Comment:** *how does this relate to the back-arc setting mentioned above?*).
- Evidence for syn-sedimentary extension at Gorge Prospect where neptunian dykes infill normal faults on the contact between the Teena Dolomite and Barney Creek Formation - indicate ENE to E-W extension (**Comment:** *this is at 90 degrees to his extensional environment direction*) . Folding related to gravitational slopes has also been interpreted - folds have northerly trending axes.

Figure No.5 Prospect and sub-basin locations around the HYC deposit

5a) Location of Gorge Porospect from McGoldrick (2010)

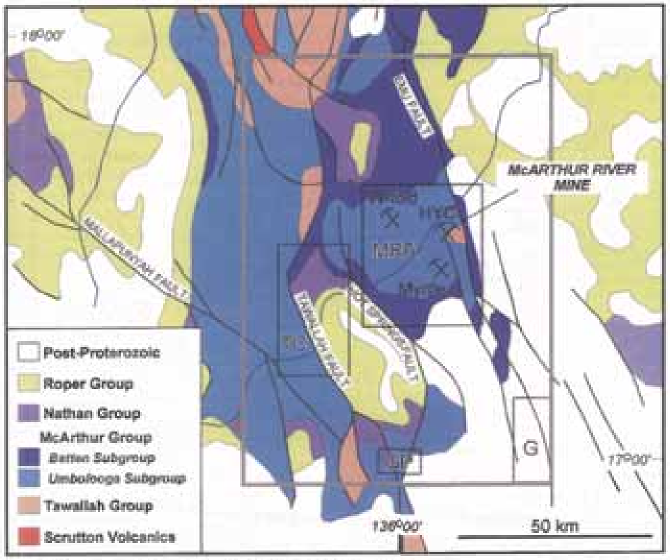


FIG. 2. Geology map of the southern McArthur basin, showing the distribution of the major late Paleoproterozoic to Mesoproterozoic lithostratigraphic units; subareas referred to in the text and subsequent figures are indicated. G = Glyde basin, Figure 10; GP = Gorge prospect, Figure 8, MRA = McArthur River area, Figure 9; TC = Top Crossing area, Figure 11; gray box outlines the area shown in Figure 12.

5c) Locations of "sub-basins" around HYC. The term sub-basin refers to preserved stratigraphy in synclines rather than depositional entities. (From McGoldrick 2010)

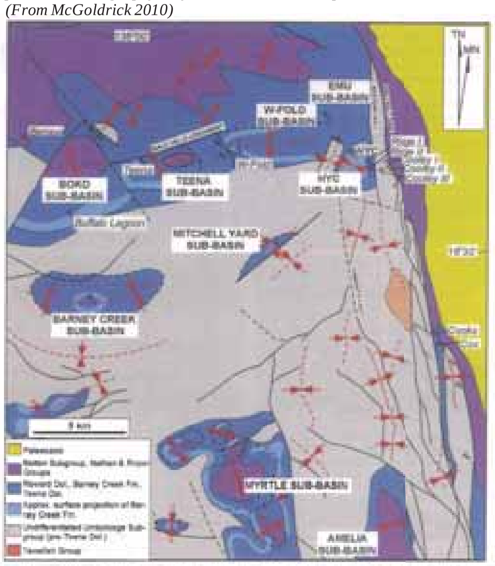


FIG. 9. Previously recognised structural sub-basins in the southern McArthur basin (Walker et al., 1977; Jackson et al., 1987).

5b) Geology around HYC showing the trace of the ore zone (From NTGS review paper)

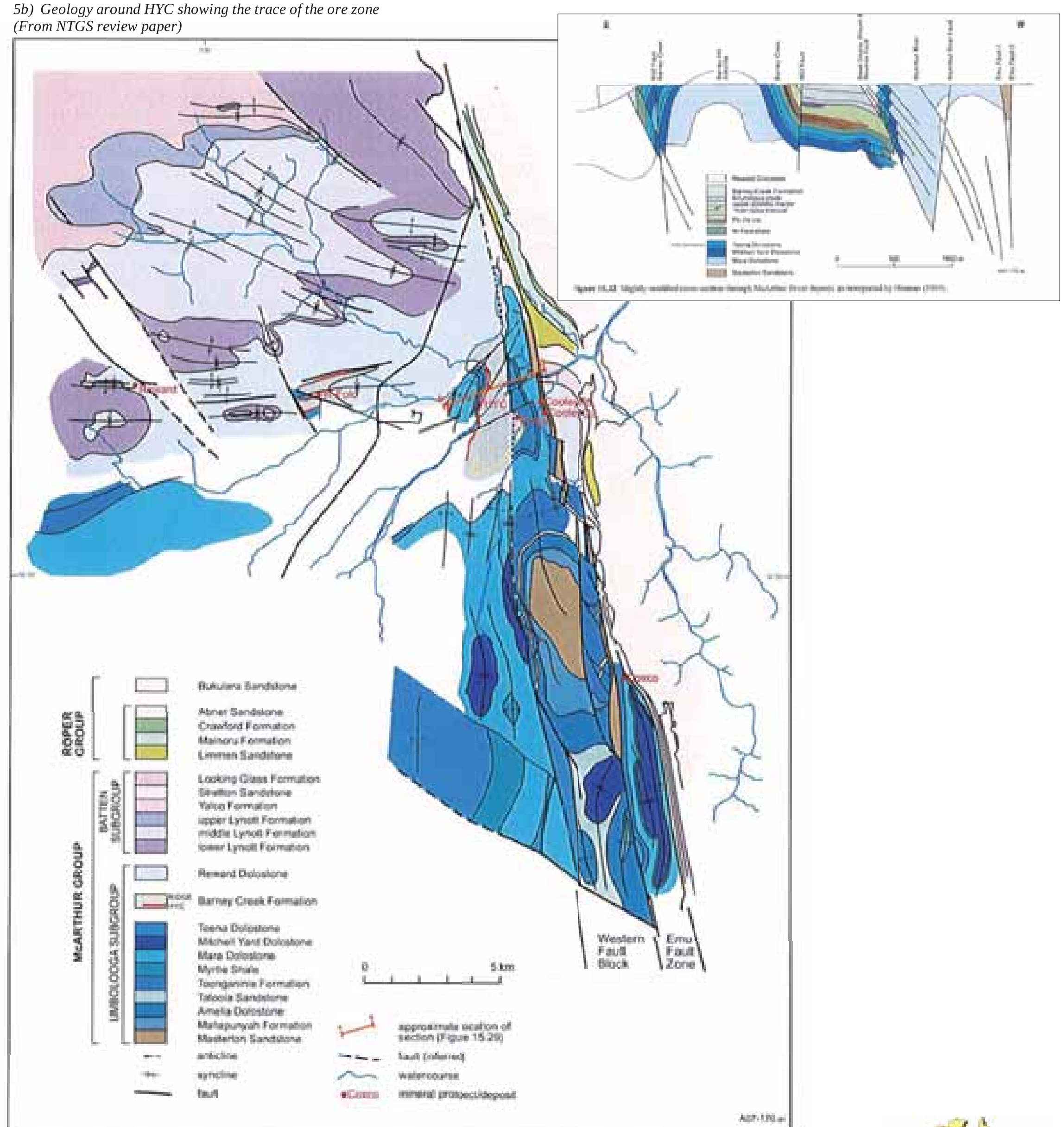


Figure 15.31. Surface geology in vicinity of McArthur River deposit (after Hinman 1995).

Figure No.6 McGoldrick (2010) facies mapping around the margins of the Abner Range

Figure 6a

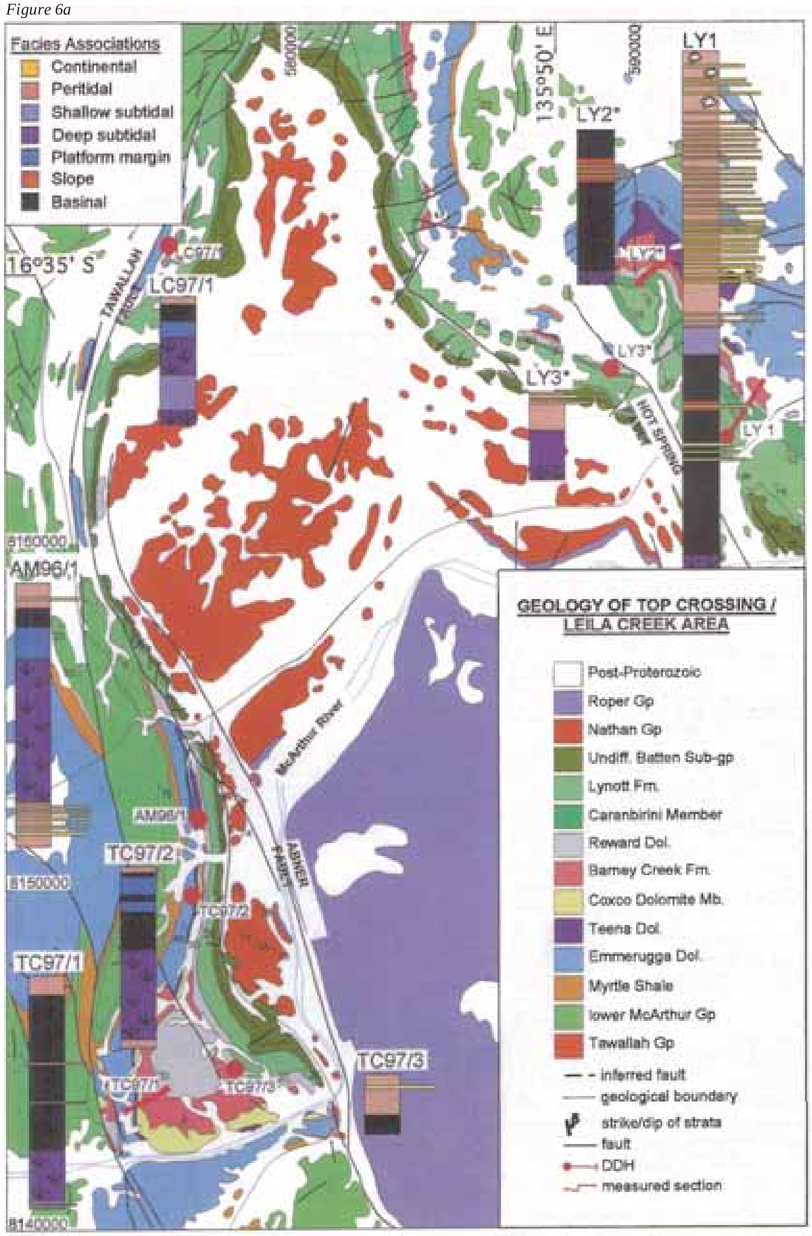


FIG. 11. Summary logs of facies associations from measured sections throughout the Top Crossing and/or Leila Creek areas. Geology is modified from Jackson et al. (1987).

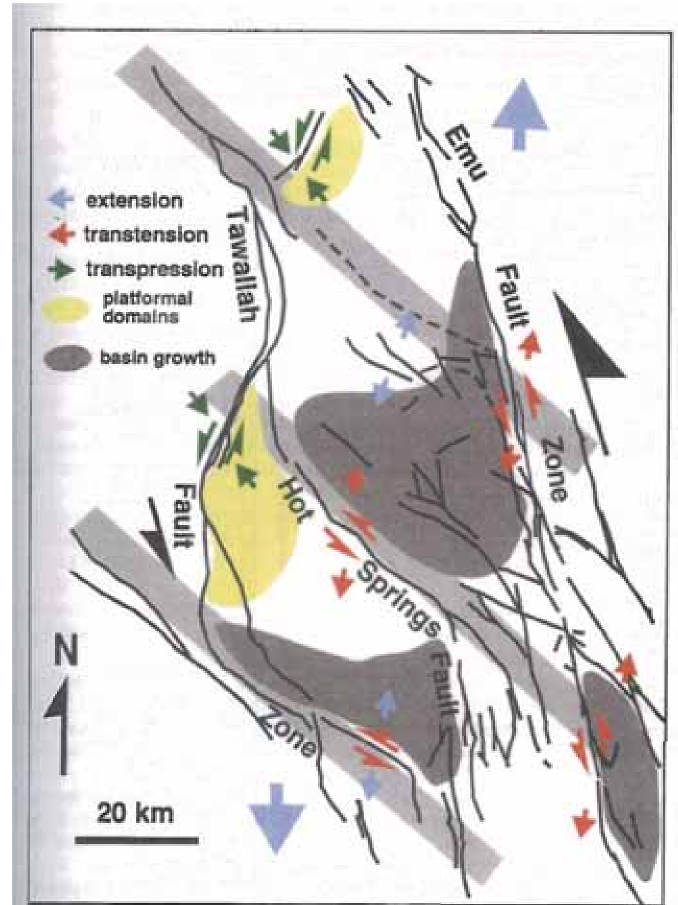


FIG. 12. Synoptic diagram showing the structures controlling sub-basin development in the southern McArthur basin. Thicker basinal sequences develop adjacent to faults with the greatest displacement (e.g., Emu fault at McArthur River). The northwest-trending corridors are basement structures defined by Leaman (1998).

Figure 6b McGoldrick's (2010) structural model for formation of sub-basins. In the text he describes the sub-basins as forming in a N-S extensional regime (as indicated by the blue arrows). However, his model is not compatible with N-S extension - what his blue arrows show is actually the relative plate motion vectors - this is a sinistral transtension model on the Emu Fault orientation.

- There is a sharp change from the deep sub-tidal Emmerugga Sequence to shallow-water lithofacies of the Teena Dolomite superseded by basinal Barney Creek carbonaceous shales. The Barney Creek Sequence is not characterised by a layer cake stratigraphy.
- The Upper Barney Creek Sequence is characterised by a gradual shallowing.
- The most rapidly subsiding sub-basins were the HYC and Glyde sub-basins with up to 900m of pyritic shale and silt. Depo-centres formed as pull-apart basins of limited extent. Thickest sedimentation against the Tawallah Fault occurs where it trends NW (**Figure 6b**).
- The Hot Spring Fault was active during Barney Creek Formation sedimentation and the block between the Tawallah Fault and the Hot Spring Fault was platformal with lesser deposition (**Figure 6a**).

3 Interpretation

The structural/stratigraphic interpretation resulting from this project is presented as **Enclosure 2** at 1:250,000 scale. The Mapinfo tables and accompanying style files and image data sets are included on the DVD accompanying this report. The Enclosures and report figures have also been included on the DVD as workspaces that can be opened directly from the DVD.

The interpretation was carried out on screen in Mapinfo using the Discover geological tools for Mapinfo. Multiple mapper windows were viewed and panned simultaneously using Discovers Maplinking tools. The main windows used during the interpretation were:

- The Google Earth image tiles (**Enclosure 3**). A second computer screen was used for displaying Google Earth interactively so that areas could be viewed at different scales as required. This allowed the resolution of much greater detail than is visible at the resolution of the imported tiles. During interpretation the boundaries, faults and bedding trends etc were generally viewed on the "live" google earth screen at scales of 1:10,000 to 1:25,000 and then drawn into the Mapinfo window using the lower resolution image as a guide - in this way much more detail has been included in the interpretation.
- The radiometrics image (see **Enclosure 4**) which contains a number a distinctive high and low radiometric packages within the sequence.
- The Landsat imagery - occasionally some of the resistant units have more characteristic signatures in this image than in the visible spectrum of the Google Earth tiles.
- Published geology at both 1:250,000 and 1:100,000 scale. During the interpretation it was noted that there are numerous attribute data errors in the 1:250,000 scale geology polygons.

The aeromagnetic data was of limited use for the exposed geology of the McArthur Group as, other than the volcanic lithologies, the signatures are generally quiet. This data set was mainly used to define major structures under thick Cretaceous or Cambrian cover and to delineate the extent of the Settlement Creek and Gold Creek Volcanics using the tilt and first vertical derivative images. The Roper Group stratigraphy is much more magnetic and units can be relatively easily followed - The Limmen Sandstone can be used as a marker in the tilt image. The tilt image does display an association between linear highs and some of the major faults, especially some segments of the Tawallah Fault. These highs are generally offset from the fault and suggest that the Tawallah Fault dips to the west. They may be generated by either:

- magnetite rich breccias in the faults,
- dykes intruding the faults at depth or
- slices of the Siegal Volcanics entrained in the fault or in the cores of hangingwall anticlines above the fault

The Airborne EM data was rather disappointing in that the Barney Creek Formation did not appear to have an associated consistently conductive signature. The anomaly identified by Sandfire Resources in the HYC area as related to the deposit stratigraphy seems almost certainly to be related to conductive material in McArthur River drainage system (**Figure 7**) - possibly from eroding the Nathan and Roper Groups. The Yalco anomaly also seems to partly have some association with the creek system. The main conductive packages are in the Nathan and Roper Groups - especially the Mainoru Formation of the Roper Group. The only formations within the McArthur Group that seem to be weakly conductive on a consistent basis are the Amelia Formation and part of the Hotspring Member.

The Stratigraphic Sequence

As mentioned above, the stratigraphic column shown in **Figure 4** was used as a basis for the interpretation. When using the Discover tools for map making the styles for various stratigraphic units need to be defined in the Geostyles module or in a Colourmap that can be applied to the constructed polygons to maintain consistent tagging and graphical styles. As similar styles to the published 1:250,000 geology polygons were to be used the following methodology was used to create a Mapinfo table that could be used:

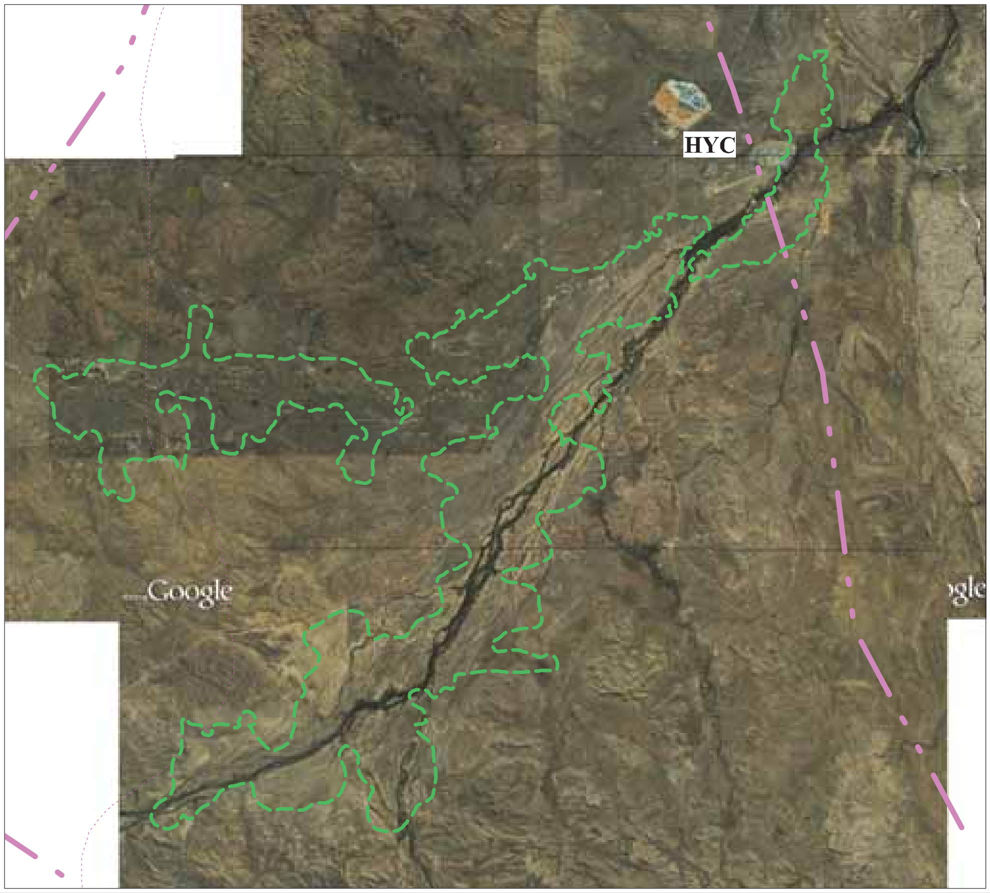
- As a colourmap table for applying graphical styles and lithology tags.
- As a lookup table summarising the characteristics and attribute data (Formation, Member, lithology, description etc) for each of the interpreted units. This lookup table can then be used to update the interpreted polygons with the attribute data so that various thematic maps can be created.
- As a legend file to be used in the final interpretation map.

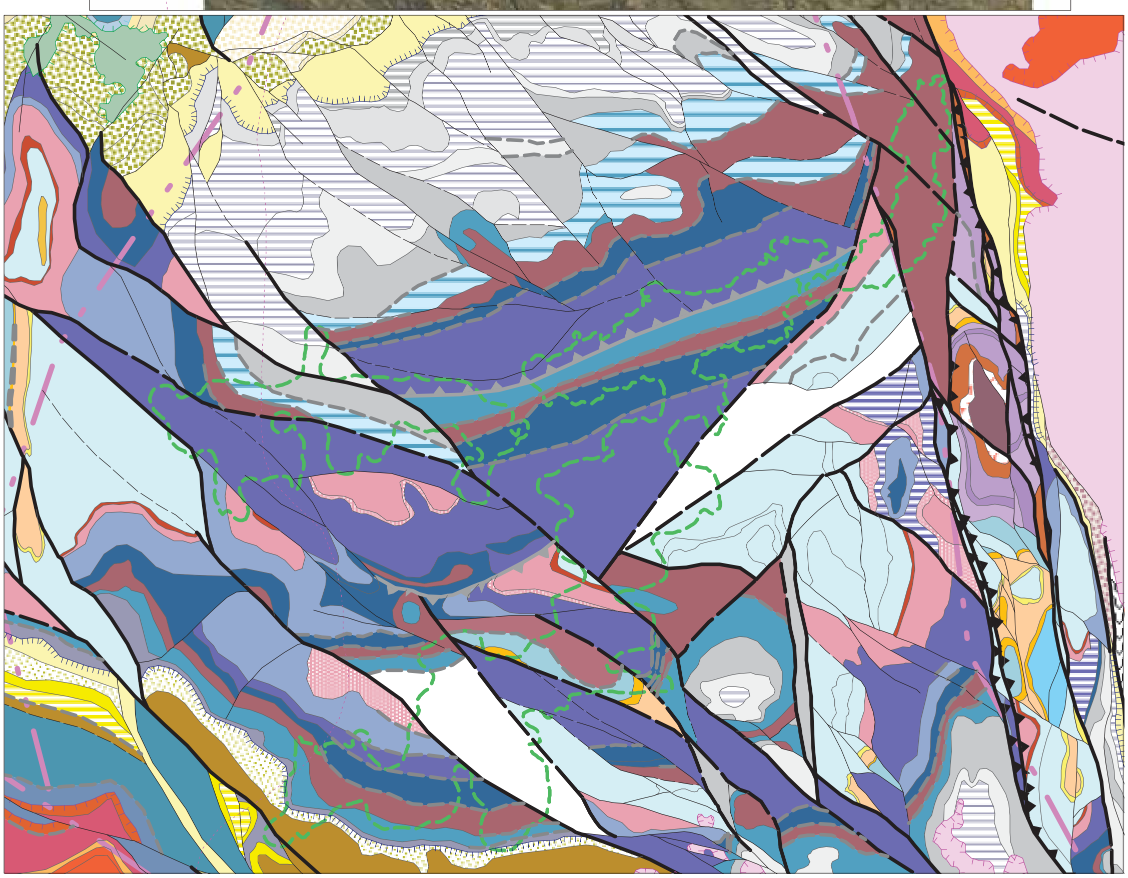
This involved the following steps:

- Create a single table that contains all of the 1:250,000 geology polygons from the available sheets. This required the modification of some tables as the table structure for each map can vary (this table "McArthur 250k geol Comp lith polys.TAB" is included on the DVD).
- Once this table was created a Colourmap table was built from it using the Colourmap menu in Discover (McArthur_interp_Colourmap.TAB). This creates polygon rectangles in the mapper for each individual lithology graphical style. The lithology code for each of the polygons was chosen as an attribute. The process also encodes

Figure No.7 Location of AEM anomaly at HYC

Scale 1:250,000





Scale 1:250,000 *Outline of early channel AEM anomaly contour attributed by Sandfire resources to hard rock Geology. Note that in the geology may the anomaly does not match the distribution of units in the interpretation whilst the contour is a close match for surficial sediments in mcthe creek system.*

the RGB values and graphical style descriptions into the browser. This process creates more than one entry for some lithologies as they are represented with different colours in some sheets. As the interpretation is a solid geology map many of the styles are not required (those styles for superficial cover over basement rocks). An original version of the table was retained which can be used in conjunction with the 250,000 data.

- The next step is to create a lookup table that contains all of the attribute data that is associated with each of the lithology types. This is done via an SQL "Group by" query on the combined 1:250,000 geology polygons using the lithology code to list all the unique code values. The query is then saved as a stratigraphic lookup table. Duplicate entries are then removed as well as all of the entries that represent multiple Formation or Member codes where these units have not been differentiated within the polygon.

- Once these two tables were established extra entries were added for units that appear in the 1:100,000 sheets but not in the 1:250,000 maps. The codes for these units were taken off the maps.

- The two tables then needed to be merged so that the information in the attribute lookup table could be added to the Colourmap table. The Colourmap table would then be the only table required for lookup and graphical style needs. The table structure of the Colourmap table was changed to add the required fields and the fields were updated using the lithology code as a join.

- As the interpretation progressed some of the Formations or Members could be further sub-divided based on their associated signatures in the radiometrics or Google Earth images. New entries were added for these and appropriate graphic styles defined that were compatible with existing entries.

- One of the aims of the study is to investigate the distribution of various geological parameters (thickness changes, sequence distribution, location of recessive units etc.) relative to the major fault system once the interpretation was complete. To accommodate this the structure of the Colourmap table was amended to include appropriate fields. The final structure of the Colourmap table is shown in **Figure 8** and the structure of the interpretation polygon table (McArthur Region interp fills final.TAB) in **Figure 9**. The main descriptive fields added to the polygon table are:
    - **Mapcode** - lithology codes derived from 1:250,000 and 1:100,000 geology sheets. Codes for new units defined during the interpretation have also been added.
    - **Defined in current project** - A "Y/N" field designed to flag those units that have been defined during this project.
    - **Order_Code** - This is a numerical code that has been added for two purposes:
        - To enable the browser of the Colourmap to be sorted into stratigraphic order.
        - To enable easy selection of different segments of stratigraphy in the final map if required.

      The following number code ranges were used (see Colourmap browser for the full list of codes assigned to subunits) - the higher the number the older the lithology:

        - 0 - Water

Figure No.8 Structure of ColourMap table (graphic definition fields not shown)

MapCode	Definec	Order_Cod	GeolRegion	Eon	Group	SubGroup	Super_Sequence	Sequence	Formation	Member	LithClass	RockCategory	LithPrim	LithSub	LithOther	Evaporite	Recessive_Resistai	LithDescn1	LithDescn2	LithDescn3	Radiometrics_	Magneti	Google_Earth_Appearance
-Praj		5,720	McArthur Basi	Proterozoic	Roper Group		South Nicholson		Abner Sandstone	Jalboi member	Sedimentary	Siliciclastic	mudstone	sandstone	conglomera			Recessive: interbedded red mudstone, fer					More recessive in places strong bedding
-Prax		5,730	McArthur Basi	Proterozoic	Roper Group		South Nicholson		Abner Sandstone	Arnold Sandstone Member	Sedimentary	Siliciclastic	sandstone				Resistant	Ridge-forming: pseudo-karstically weath					Well bedded ridge white-grey
-Prr		5,800	McArthur Basi	Proterozoic	Roper Group		South Nicholson		Crawford Formation (NT)		Sedimentary	Siliciclastic	sandstone	siltstone			Resistant	-Prr: Ridge-forming: red-brown, fine-grai	convolute beds		High		Well bedded unit usually on scarps
-Pru		5,850	McArthur Basi	Proterozoic	Roper Group		South Nicholson		Mainoru Formation		Sedimentary	Siliciclastic	sandstone	siltstone			Recessive	-Pru: Recessive: red-brown micaceous sil	fine-grained sandstone and silts				Very conductive unit poorly exposed flat expanses
-Prg		5,860	McArthur Basi	Proterozoic	Roper Group		South Nicholson		Mainoru Formation	Kilgour Sandstone Membe	Sedimentary	Siliciclastic	sandstone				Resistant						Found in Abner Range resistant sandstone very co
-Pri		5,900	McArthur Basi	Proterozoic	Roper Group		South Nicholson		Limmen Sandstone		Sedimentary	Siliciclastic	arenite				Resistant	-Pri: Ridge-forming: fine-grained, structu	trough cross-beds, tool marks, f		Very Low	Medium	Characteristic sandstone ridge - generally cream w
-Pnn		6,100	McArthur Basi	Proterozoic	Nathan Group		Doom		Mantungula Formation		Sedimentary	Siliciclastic sediment	Siltstone				Recessive	Micaceous siltstone			Low		Flat poorly exposed
-Png		6,600	McArthur Basi	Proterozoic	Nathan Group		Wide		Dungaminnie Formation		Sedimentary	Chemical	dolarenite	dolostone	sandstone		Resistant	Upper: laminated sandy dolarenite and do			Medium		Low olive yellow ridges
-Pnz		6,700	McArthur Basi	Proterozoic	Nathan Group		Wide		Balbarini Dolostone		Sedimentary	Chemical	dololutite			y		-Pnz: Generally recessive: dololutite, stro	and in places cauliflower chert		Low		Poorly exposed and recessive - poorly bedded - lo
-Pny		6,800	McArthur Basi	Proterozoic	Nathan Group		Lawn		Smythe Sandstone		Sedimentary	Siliciclastic	conglomerate	sandstone				Ridge-forming: massive, coarse polymict			Very Low		Thickly bedded grey sandstone ridges
-Pk		6,900	McArthur Basi	Proterozoic	Nathan Group		Lawn		Karns Dolomite		Sedimentary	Chemical sediment	Dolomite/Dol	chert		y		Stromatolitic, evaporitic, intraclastic and					
-Pk>s		6,950	McArthur Basi	Proterozoic	Nathan Group		Lawn		Lower Karns Dolomite		Sedimentary	Siliciclastic sediment	Sandstone					White fine- to medium-grained quartzose					
-Pm		7,000	McArthur Basi	Proterozoic	McArthur Group		Lawn		Undivided McArthur Group		F	F						McArthur Group:undivided at map scale;					
-Pmm		7,150	McArthur Basi	Proterozoic	McArthur Group	Batten	Lawn		Amos Formation		Sedimentary	Chemical	dolostone	siltstone	sandstone		Recessive	Upper: massive karstic-weathering dark-g					Recessive red brown - restricted development
-Pmo		7,200	McArthur Basi	Proterozoic	McArthur Group	Batten	Term		Looking Glass Formation		Sedimentary	Chemical	dolostone	dolarenite			Resistant	Recessive:silicified,commonly stromatoli			Medium		Well bedded with cream banding - resistant
-Pmr		7,250	McArthur Basi	Proterozoic	McArthur Group	Batten	Term		Stretton Sandstone		Sedimentary	Siliciclastic	sandstone				Resistant	Ridge-forming:fine-to medium -grained, t			Medium		Cream grey resistant sandstone can be thickly bed
-Pmr>2	y	7,260	McArthur Basi	Proterozoic	McArthur Group	Batten	Term		Stretton Sandstone	Stretton Upper	Sedimentary	Siliciclastic	sandstone				Resistant	Ridge-forming:fine-to medium -grained, t			High		Cream yellow ressitant sandstone - high to mediun
-Pmr>1	y	7,270	McArthur Basi	Proterozoic	McArthur Group	Batten	Term		Stretton Sandstone	Stretton Lower	Sedimentary	Siliciclastic	sandstone				Resistant	Ridge-forming:fine-to medium -grained, t			High		Red brown colours - medium high rad with High b
-Pmnj		7,300	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Yalco Formation		Sedimentary	Chemical	dolostone	dolarenite	sandstone	y	Resistant	Ridge-forming:thinly interbedded stroma			Low		Smooth olive slightly resistant
-Pmnj>2	y	7,310	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Yalco Formation	Yalco Upper	Sedimentary	Chemical	dolostone	dolarenite	sandstone	y	Recessive	Ridge-forming:thinly interbedded stroma			Low		Red-Brown recessive med rad variable to low rad
-Pmnj>1	y	7,320	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Yalco Formation	Yalco Lower	Sedimentary	Chemical	dolostone	dolarenite	sandstone	y	Resistant	Ridge-forming:thinly interbedded stroma			Very Low		MAssive resistant sandstone pinkish cream colour
-Pmnd		7,410	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Donnegan Member	Sedimentary	Siliciclastic	siltstone	sandstone	dolarenite		Recessive / Res	Recessive:dolomitic siltstone,fine-tocoar			Very High		Generally low lying with bedding evident where e
-Pmnh		7,420	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Hot Spring Member	Sedimentary	Siliciclastic	siltstone	sandstone	dolarenite	y	Resistant	Ridge-forming:thin-bedded dolonitic silts	sandstones are rippled and cros		Very Low		Massive olive green poorly bedded weakly resista
-Pmnh>3	y	7,423	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Hot Spring Member 3	Sedimentary	Siliciclastic	siltstone	sandstone	dolarenite	y	Recessive	Ridge-forming:thin-bedded dolonitic silts	sandstones are rippled and cros		Very Low		Dark olive slightly recessive low rad signatures
-Pmnh>2	y	7,424	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Hot Spring Member 2	Sedimentary	Siliciclastic	siltstone	sandstone	dolarenite	y	Resistant	Ridge-forming:thin-bedded dolonitic silts	sandstones are rippled and cros		Low		Grey yellow sandstone unit resistant
-Pmnh>1	y	7,425	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Hot Spring Member 1	Sedimentary	Siliciclastic	siltstone	sandstone	dolarenite	y	Resistant	Ridge-forming:thin-bedded dolonitic silts	sandstones are rippled and cros		High		Bedded yellow and cream units moderately resista
-Pmnc		7,440	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Caranbirini Member	Sedimentary	Siliciclastic	siltstone	dolarenite	breccia	y	Recessive	Recessive:thin-bedded dolomitic siltstone			High		Yellow and light green colours - bedded with char
-Pmnc>5	y	7,445	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Caranbirini Member 5	Sedimentary	Siliciclastic	siltstone	dolarenite	breccia	y		Recessive:thin-bedded dolomitic siltstone			High		Generally well exposed - less well bedded light oli
-Pmnc>4	y	7,446	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Caranbirini Member 4	Sedimentary	Siliciclastic	siltstone	dolarenite	breccia	y	Resistant	Recessive:thin-bedded dolomitic siltstone			Very High		Well bedded cream and green bands forming ridge
-Pmnc>3	y	7,447	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Caranbirini Member 3	Sedimentary	Siliciclastic	siltstone	dolarenite	breccia	y	Recessive	Recessive:thin-bedded dolomitic siltstone			Low		Recessive similar to pmnc>1
-Pmnc>2	y	7,448	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Caranbirini Member 2	Sedimentary	Siliciclastic	siltstone	dolarenite	breccia	y	Resistant	Recessive:thin-bedded dolomitic siltstone			High		Well bedded low broad ridges - cream banding - s
-Pmnc>1	y	7,449	McArthur Basi	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Caranbirini Member 1	Sedimentary	Siliciclastic	siltstone	dolarenite	breccia	y	Recessive	Recessive:thin-bedded dolomitic siltstone			Low		Generally recessive and poorly exposed
-Pmx		7,450	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Barney Creek	Reward Dolostone		Sedimentary	Chemical	dololutite			y	Resistant	-Pmx: Ridge-forming and recessive: dolo	sulfate evaporites; oncoids, ooi		Very High		Massive sometimes cream coloured - brown ridge
-Pmx>1		7,460	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Barney Creek	Reward Dolostone Low Rad		Sedimentary	Chemical	dololutite			y	Resistant	-Pmx: Ridge-forming and recessive: dolo			Low		Low rad signature in vicinity of HYC
-Pmq		7,500	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Barney Creek	Barney Creek Formation		Metamorphic	Meta-chemical sedime	shale	siltstone		y	Recessive	-Pmq: Recessive: thinly bedded to lamina			Very High		Generally poorly exposed - not obviously bedded
-Pmp		7,550	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Barney Creek	Teena Dolostone		Sedimentary	Chemical	dololutite				Resistant	-Pmp: Recessive: thinly bedded to lamina			Very High		Massive slightly resistant some weak bedding buff
-Pmpc		7,560	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Barney Creek	Teena Dolomite	Coxco Dolomite Member	Sedimentary	Chemical	dolostone	shale	sandstone	y		-Pmpc: Recessive:grey crystalline dololut			Very High		Massive slightly recessive
-Pme		7,600	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Emmerugga Dolostone		Sedimentary	Chemical	dolostone				Resistant	-Pme: Undivided Emmerugga Dolostone			Low		
-Pmei		7,610	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Emmerugga Dolomite	Mitchell Yard Dolomite M	Sedimentary	Chemical	dolostone				Resistant	-Pmei: Generally recessive:massive,dark			Very Low		Better bedded near Emu Fault - but more massive
-Pmea		7,630	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Emmerugga Dolomite	Mara Dolomite Member	Sedimentary	Chemical	dolostone	siltstone	dolarenite	y	Resistant	-Pmea: Ridge-forming:dololutite,stromat			Low		Massive generally exposed but not riges - can be g
-Pme>1	y	7,640	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Emmerugga Dolostone	Emmerugga HighRad	Sedimentary	Chemical	dolostone				Resistant	-Pme: Undivided Emmerugga Dolostone			High		Higher rad signatures Oilve colours - near Emu Fa
-Pmf		7,650	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Myrtle Shale		Sedimentary	Siliciclastic	siltstone			y	Recessive	-Pmf: Recessive: thinly bedded to laminat			High		Myrtle shale generally flat recessive - cream grey t
-Pmf>1	y	7,660	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Myrtle Shale	Myrtle Sandstone	Sedimentary	Siliciclastic	siltstone			y	Resistant	-Pmf: Recessive: thinly bedded to laminat			High		Sandstone ridge sometimes at top of Myrtle Shale
-Pmi		7,700	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Leila Sandstone		Sedimentary	Siliciclastic	sandstone				Resistant	-Pmi: Recessive and ridge-forming: dark			High		Resistant sandstone ridge.
-Pmi>1a	y	7,705	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Leila Sandstone	Leila Base	Sedimentary	Siliciclastic	sandstone				Recessive	-Pmi: Recessive and ridge-forming: dark			Low		Red brown recessive similar to -Pmt>1
-Pmi>1	y	7,710	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Leila Sandstone	Leila Lower	Sedimentary	Siliciclastic	sandstone				Resistant	-Pmi: Recessive and ridge-forming: dark			High		Buff sandstone ridge somewhat similar to Tatoola
-Pmi>2	y	7,720	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Leila Sandstone	Leila Central	Sedimentary	Siliciclastic	sandstone				Recessive	-Pmi: Recessive and ridge-forming: dark			High		Dark flat and recessive
-Pmi>2a	y	7,725	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Leila Sandstone	Leila Central 2	Sedimentary	Siliciclastic	sandstone					-Pmi: Recessive and ridge-forming: dark			Low		Slightly recessive can have grey "Emmerugga" ap
-Pmi>3	y	7,730	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Leila Sandstone	Leila Upper	Sedimentary	Siliciclastic	sandstone				Resistant	-Pmi: Recessive and ridge-forming: dark			High		Sandstone ridge similar to -Pmi>1
-Pmt		7,750	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Loretta		Tooganinie Formation		Sedimentary	Chemical	dololutite			y	Recessive	-Pmt: Generally recessive: dololutite, stro	pseudomorphs after gypsum an		High		Strongly bedded and quite well exposed
-Pmt>1	y	7,760	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Loretta		Tooganinie Formation	Tooganinie Lower	Sedimentary	Chemical	dololutite			y	Recessive	-Pmt: Generally recessive: dololutite, stro	pseudomorphs after gypsum an		Low		Low rad zone on contact to Tatoola - more shale ri
-Pmt>2	y	7,770	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Loretta		Tooganinie Formation	Tooganinie Marker	Sedimentary	Chemical	dololutite			y	Resistant	-Pmt: Generally recessive: dololutite, stro	pseudomorphs after gypsum an		High		Thin poss sandstone marker poss similar to Tatool
-Pmt>3	y	7,780	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Loretta		Tooganinie Formation	Tooganinie Rough	Sedimentary	Chemical	dololutite			y	Resistant	-Pmt: Generally recessive: dololutite, stro	pseudomorphs after gypsum an		High		Resistant poorly bedded facies of Tooganinie
-Pmd		7,800	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Loretta		Tatoola Sandstone		Sedimentary	Siliciclastic	sandstone			y	Resistant	-Pmd: Upper: ridge forming: mainly medi	thinly bedded, usually fine-grai	mud clast imp	High		Orange/yellow smooth sandstone ridge
-Pmd>3	y	7,810	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Loretta		Tatoola Sandstone	Tatoola Sandstone Upper	Sedimentary	Siliciclastic	sandstone			y	Resistant	Upper: ridge forming: mainly medium-gr			High		Orange yellow sandstone ridge marker - thicker in
-Pmd>2	y	7,820	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Loretta		Tatoola Sandstone	Tatoola Sandstone Central	Sedimentary	Siliciclastic	sandstone			y	Recessive				High		Flat area between sandstone ridges - low rad in so
-Pmd>1	y	7,830	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Loretta		Tatoola Sandstone	Tatoola Sandstone Lower	Sedimentary	Siliciclastic	sandstone			y	Resistant	Lower: ridge-forming: tabular, thinly bec			High	Low	Orange yellow sandstone ridge marker - thicker in
-Pma		7,850	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Gun		Amelia Dolostone		Sedimentary	Chemical	dololutite	dolarenite				-Pma: Recessive: stromatolitic dololutite	development of sideritic 'marbl		Low		Dark red-brown weakly bedded or massive
-Pma>1	y	7,860	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Gun		Amelia Dolostone	Amelia Dolostone High R	Sedimentary	Chemical	dololutite	dolarenite				-Pma: Recessive: stromatolitic dololutite	development of sideritic 'marbl		High		Generally massive and exposed grey to buff colou
-Pml		7,900	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Gun		Mallapunyah Formation		Metamorphic	Meta-chemical sedime	shale			y		-Pml: Mainly recessive: red to purple dolo	desiccation cracks, and gypsum				High in west low in east
-Pml>4	y	7,910	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Gun		Mallapunyah Formation	Mallapunyah Top	Metamorphic	Meta-chemical sedime	shale			y	Resistant	-Pml: Mainly recessive: red to purple dolo	desiccation cracks, and gypsum		Low	Low	Massive buff ridge - sandstone or dolomite - varia
-Pml>3	y	7,920	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Gun		Mallapunyah Formation	Mallapunyah Upper	Metamorphic	Meta-chemical sedime	shale			y	Recessive	-Pml: Mainly recessive: red to purple dolo	desiccation cracks, and gypsum		High	Low	Brown low lying weakly bedded
-Pml>2	y	7,930	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Gun		Mallapunyah Formation	Mallapunyah Central	Metamorphic	Meta-chemical sedime	shale			y	Resistant	-Pml: Mainly recessive: red to purple dolo	desiccation cracks, and gypsum		Low	Low	Massive buff ridge - sandstone or dolomite - varia
-Pml>1	y	7,940	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Gun		Mallapunyah Formation	Mallapunyah Lower	Metamorphic	Meta-chemical sedime	shale			y	Recessive	-Pml: Mainly recessive: red to purple dolo	desiccation cracks, and gypsum		Low Medium	Low	Bedded dark brown generally low lying
-Pms		7,950	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Gun		Masterton Sandstone		Sedimentary	Siliciclastic	sandstone			y	Resistant	-Pms: Ridge-forming: pink, brown and bu	minor units; distinctly ferrugin		Very Low		Massive white yellow sandstone - very thickly bed
-Pms>3	y	7,960	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Gun		Masterton Sandstone	Masterton Upper	Sedimentary	Siliciclastic	sandstone			y	Resistant	-Pms: Ridge-forming: pink, brown and bu	minor units; distinctly ferrugin		Very Low		Darke brown less ortho sst content less resistant -
-Pms>2	y	7,970	McArthur Basi	Proterozoic	McArthur Group	Umbolooga	Gun		Masterton Sandstone	Masterton Central	Sedimentary	Siliciclastic	sandstone			y	Recessive	-Pms: Ridge-forming: pink, brown and bu	minor units; distinctly ferrugin		High		Dark and recessive may be volcanic or dolerite?
-Pth		8,000	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Hobblechain Rhyolite		Volcanic	Mafic extrusive	Rhyolite					Pink, porphyritic (K-feldspar-quartz), ma					
-Pt		8,000	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Undifferentiated Tawallah G		Igneous	Mafic extrusive	basalt	sandstone				-Pt: Undivided Tawallah Group					
-Ptc		8,050	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Echo Sandstone		Sedimentary	Siliciclastic sediment	Sandstone					Pink, medium-grained, locally pebbly, lit					
-Ptcu		8,051	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Echo Sandstone	Pungalina Member	Sedimentary	Siliciclastic sediment	Conglomerate					Lower pebble to boulder conglomerate wi					
-Ptcu>1		8,052	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Echo Sandstone	Lower Pungalina Member	Sedimentary	Siliciclastic sediment	Lithic Arenite					Pink medium-grained lithic sandstone wit					
-Ptcu>2		8,053	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Echo Sandstone	Upper Pungalina Member	Sedimentary	Siliciclastic sediment	Dolomitic Sil					Dolomitic siltstone and fine-grained sand					
-Ptt		8,060	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Tanumbirini Rhyolite		Igneous	Felsic extrusive	rhyolite					Recessive: deeply weathered, porphyritic			Very High		Buff coloured weakly resistant
-Ptn		8,100	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Wununmantyala Sandstone		Sedimentary	Siliciclastic	sandstone					Ridge-forming: red to mauve-grey, locally	shale interbeds		Low	Low	Generally quite dark brown and flat not very resist
-Ptnw		8,110	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Wununmantyala Sandstone	Wuraliwuntya Member	Sedimentary	Siliciclastic sediment	Sandstone	Mudstone			Resistant	Fine-grained and rarely medium-grained	marks, flute casts		Very Low	Low	Less resistant than Masterton - cream grey massive
-Ptn>1	y	8,120	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Wununmantyala Sandstone	Wununmantyala 1	Sedimentary	Siliciclastic	sandstone				Resistant	Ridge-forming: red to mauve-grey, locally	shale interbeds		Very Low	Low	Cream ye
-Ptg		8,200	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Gold Creek Volcanics		Igneous	Mafic extrusive	basalt				Resistant	-Ptg: Recessive: amygdaloidal vesicular b	autoclastic, flow-banded rhyoli		Very High	1VD Noi	More resi
-Pte		8,250	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Settlement Creek Volcanics		Igneous	Mafic extrusive	basalt	dolerite			Recessive	-Pte: Recessive: red-brown to dark grey s	dololutite breccia; potash-meta		Very High	1VD Noi	Olive-Ye
-Ptlr		8,300	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Rosie Creek Sandstone		Sedimentary	Siliciclastic	sandstone	siltstone			Resistant	Ridge-forming: sandstone, very fine- to c			Very Low	Low	Smooth s
-Ptlr>3	y	8,310	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Rosie Creek Sandstone	Rosie Creek Sandstone Up	Sedimentary	Siliciclastic	sandstone	siltstone			Resistant	Ridge-forming: sandstone, very fine- to c			Very Low	Low	white-bro
-Ptlr>2	y	8,320	McArthur Basi	Proterozoic	Tawallah Group	Tawallah			Rosie Creek Sandstone	Rosie Creek Sandstone Ce	Sedimentary	Siliciclastic	sandstone	siltstone			Recessive	Ridge-forming: sandstone, very fine- to c			Low	Low	Recessiv

Figure No.9 Structure of Interpreted geology fill polygon table

MapCode	Defined_	Order_Code	GeolRegion	Eon	Group	SubGroup	Super_Sequence	Sequence	Formation	Member	LithClass	RockCategory	LithPrim	LithSub	LithOther	Evaporite_	Recessive_	LithDescn1	LithDescn2	LithDescn3	Radiometrics_a	Google_Earth_Appearance	Magnetics_app
-Pmnh		7,420	McArthur Basin	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Hot Spring Member	Sedimentary	Siliciclastic	siltstone	sandstone	dolarenite	y	Resistant	Ridge-forming:thin-bedded dolonitic siltstone an	sandstones are rippled and cross-b		Very Low	Massive olive green poorly bed	
-Pmnh		7,420	McArthur Basin	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Hot Spring Member	Sedimentary	Siliciclastic	siltstone	sandstone	dolarenite	y	Resistant	Ridge-forming:thin-bedded dolonitic siltstone an	sandstones are rippled and cross-b		Very Low	Massive olive green poorly bed	
-Pmnd		7,410	McArthur Basin	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Donnegan Member	Sedimentary	Siliciclastic	siltstone	sandstone	dolarenite		Recessive	Recessive:dolomitic siltstone,fine-tocoarse-grain			Very High	Generally low lying with beddi	
-Pru		5,850	McArthur Basin	Proterozoic	Roper Group		South Nicholson		Mainoru Formation		Sedimentary	Siliciclastic	sandstone	siltstone			Recessive	-Pru: Recessive: red-brown micaceous siltstone t	fine-grained sandstone and siltstor			Very conductive unit poorly ex	
-Pri		5,900	McArthur Basin	Proterozoic	Roper Group		South Nicholson		Limmen Sandstone		Sedimentary	Siliciclastic	arenite				Resistant	-Pri: Ridge-forming: fine-grained, structureless q	trough cross-beds, tool marks, flar		Very Low	Characteristic sandstone ridge -	
-Pms		7,950	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Gun		Masterton Sandstone		Sedimentary	Siliciclastic	sandstone			y	Resistant	-Pms: Ridge-forming: pink, brown and buff, fine-	minor units; distinctly ferruginous		Very Low	Massive white yellow sandston	
-Pmei		7,610	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Emmerugga Dolomite	Mitchell Yard Dolomite M	Sedimentary	Chemical	dolostone				Resistant	-Pmei: Generally recessive:massive,dark grey,ka			Very Low	Better bedded near Emu Fault -	
-Ptl>7	y	8,610	McArthur Basin	Proterozoic	Tawallah Group				Sly Creek Sandstone	Sly Creek 7	Sedimentary	Siliciclastic	arenite				Resistant	-Ptl: Ridge-forming: quartz arenite, mainly fine-	minor graded bedding, infrequent		Low	brown / white interbedded	Low
-Pmd		7,800	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Loretta		Tatoola Sandstone		Sedimentary	Siliciclastic	sandstone			y	Resistant	-Pmd: Upper: ridge forming: mainly medium-gra	thinly bedded, usually fine-graine	mud clast impressic	High	Orange/yellow smooth sandstor	
-Pri		5,900	McArthur Basin	Proterozoic	Roper Group		South Nicholson		Limmen Sandstone		Sedimentary	Siliciclastic	arenite				Resistant	-Pri: Ridge-forming: fine-grained, structureless q	trough cross-beds, tool marks, flar		Very Low	Characteristic sandstone ridge -	
-Pmnh		7,420	McArthur Basin	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Hot Spring Member	Sedimentary	Siliciclastic	siltstone	sandstone	dolarenite	y	Resistant	Ridge-forming:thin-bedded dolonitic siltstone an	sandstones are rippled and cross-b		Very Low	Massive olive green poorly bed	
-Pmea		7,630	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Emmerugga Dolomite	Mara Dolomite Member	Sedimentary	Chemical	dolostone	siltstone	dolarenite	y	Resistant	-Pmea: Ridge-forming:dololutite,stromatolitic do			Low	Massive generally exposed but	
-Pmd>2	y	7,820	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Loretta		Tatoola Sandstone	Tatoola Sandstone Central	Sedimentary	Siliciclastic	sandstone			y	Recessive				High	Flat area between sandstone ric	
-Pmf		7,650	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Myrtle Shale		Sedimentary	Siliciclastic	siltstone			y	Recessive	-Pmf: Recessive: thinly bedded to laminated, con			High	Myrtle shale generally flat rece	
-Pmi>2a	y	7,725	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Leila Sandstone	Leila Central 2	Sedimentary	Siliciclastic	sandstone					-Pmi: Recessive and ridge-forming: dark grey an			Low	Slightly recessive can have gre	
-Pmea		7,630	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Emmerugga Dolomite	Mara Dolomite Member	Sedimentary	Chemical	dolostone	siltstone	dolarenite	y	Resistant	-Pmea: Ridge-forming:dololutite,stromatolitic do			Low	Massive generally exposed but	
-Pmp		7,550	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Barney Creek	Teena Dolostone		Sedimentary	Chemical	dololutite				Resistant	-Pmp: Recessive: thinly bedded to laminated dolc			Very High	Massive slightly resistant some	
-Pru		5,850	McArthur Basin	Proterozoic	Roper Group		South Nicholson		Mainoru Formation		Sedimentary	Siliciclastic	sandstone	siltstone			Recessive	-Pru: Recessive: red-brown micaceous siltstone t	fine-grained sandstone and siltstor			Very conductive unit poorly ex	
-Prax		5,730	McArthur Basin	Proterozoic	Roper Group		South Nicholson		Abner Sandstone	Arnold Sandstone Member	Sedimentary	Siliciclastic	sandstone				Resistant	Ridge-forming: pseudo-karstically weathered, str				Well bedded ridge white-grey	
-Pmx		7,450	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Barney Creek	Reward Dolostone		Sedimentary	Chemical	dololutite			y	Resistant	-Pmx: Ridge-forming and recessive: dololutite, st	sulfate evaporites; oncoids, ooids,		Very High	Massive sometimes cream colo	
-Pri		5,900	McArthur Basin	Proterozoic	Roper Group		South Nicholson		Limmen Sandstone		Sedimentary	Siliciclastic	arenite				Resistant	-Pri: Ridge-forming: fine-grained, structureless q	trough cross-beds, tool marks, flar		Very Low	Characteristic sandstone ridge -	
Kl		2,000	Carpentaria Basin	Phanerozoic					Undivided Cretaceous Se		Sedimentary	Siliciclastic	sandstone					Kl: Clayey, micaceous and ferruginous sandstone					
-Pmq		7,500	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Barney Creek	Barney Creek Formation		Metamorphic	Meta-chemical se	shale	siltstone		y	Recessive	-Pmq: Recessive: thinly bedded to laminated, dol			Very High	Generally poorly exposed - not	
-Pmx		7,450	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Barney Creek	Reward Dolostone		Sedimentary	Chemical	dololutite			y	Resistant	-Pmx: Ridge-forming and recessive: dololutite, st	sulfate evaporites; oncoids, ooids,		Very High	Massive sometimes cream colo	
-Pri		5,900	McArthur Basin	Proterozoic	Roper Group		South Nicholson		Limmen Sandstone		Sedimentary	Siliciclastic	arenite				Resistant	-Pri: Ridge-forming: fine-grained, structureless q	trough cross-beds, tool marks, flar		Very Low	Characteristic sandstone ridge -	
-Pmq		7,500	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Barney Creek	Barney Creek Formation		Metamorphic	Meta-chemical se	shale	siltstone		y	Recessive	-Pmq: Recessive: thinly bedded to laminated, dol			Very High	Generally poorly exposed - not	
-Pny		6,800	McArthur Basin	Proterozoic	Nathan Group		Lawn		Smythe Sandstone		Sedimentary	Siliciclastic	conglomerate	sandstone				Ridge-forming: massive, coarse polymict conglo			Very Low	Thickly bedded grey sandstone	
-Ptl		8,600	McArthur Basin	Proterozoic	Tawallah Group				Sly Creek Sandstone		Sedimentary	Siliciclastic	arenite				Resistant	-Ptl: Ridge-forming: quartz arenite, mainly fine-	minor graded bedding, infrequent		Low	White - cream upstanding mass	Low
-Pms>3	y	7,960	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Gun		Masterton Sandstone	Masterton Upper	Sedimentary	Siliciclastic	sandstone			y	Resistant	-Pms: Ridge-forming: pink, brown and buff, fine-	minor units; distinctly ferruginous		Very Low	Darke brown less ortho sst cont	
-Pmd>1	y	7,830	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Loretta		Tatoola Sandstone	Tatoola Sandstone Lower	Sedimentary	Siliciclastic	sandstone			y	Resistant	Lower: ridge-forming: tabular, thinly bedded, us			High	Orange yellow sandstone ridge	Low
-Pmf		7,650	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Myrtle Shale		Sedimentary	Siliciclastic	siltstone			y	Recessive	-Pmf: Recessive: thinly bedded to laminated, con			High	Myrtle shale generally flat rece	
-Pmd>1	y	7,830	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Loretta		Tatoola Sandstone	Tatoola Sandstone Lower	Sedimentary	Siliciclastic	sandstone			y	Resistant	Lower: ridge-forming: tabular, thinly bedded, us			High	Orange yellow sandstone ridge	Low
-Ptn		8,100	McArthur Basin	Proterozoic	Tawallah Group	Tawallah			Wununmantyala Sandsto		Sedimentary	Siliciclastic	sandstone					Ridge-forming: red to mauve-grey, locally feldsp	shale interbeds		Low	Generally quite dark brown anc	Low
-Pmd>2	y	7,820	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Loretta		Tatoola Sandstone	Tatoola Sandstone Central	Sedimentary	Siliciclastic	sandstone			y	Recessive				High	Flat area between sandstone ric	
-Pma		7,850	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Gun		Amelia Dolostone		Sedimentary	Chemical	dololutite	dolarenite				-Pma: Recessive: stromatolitic dololutite (stratifo	development of sideritic 'marble' a		Low	Dark red-brown weakly beddec	
-Pmd>3	y	7,810	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Loretta		Tatoola Sandstone	Tatoola Sandstone Upper	Sedimentary	Siliciclastic	sandstone			y	Resistant	Upper: ridge forming: mainly medium-grained, tl			High	Orange yellow sandstone ridge	
-Pmp		7,550	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Barney Creek	Teena Dolostone		Sedimentary	Chemical	dololutite				Resistant	-Pmp: Recessive: thinly bedded to laminated dolc			Very High	Massive slightly resistant some	
-Pmf>1	y	7,660	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Myrtle Shale	Myrtle Sandstone	Sedimentary	Siliciclastic	siltstone			y	Resistant	-Pmf: Recessive: thinly bedded to laminated, con			High	Sandstone ridge sometimes at t	
-Pmf>1	y	7,660	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Myrtle Shale	Myrtle Sandstone	Sedimentary	Siliciclastic	siltstone			y	Resistant	-Pmf: Recessive: thinly bedded to laminated, con			High	Sandstone ridge sometimes at t	
-Pmea		7,630	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Emmerugga Dolomite	Mara Dolomite Member	Sedimentary	Chemical	dolostone	siltstone	dolarenite	y	Resistant	-Pmea: Ridge-forming:dololutite,stromatolitic do			Low	Massive generally exposed but	
-Pmea		7,630	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Emmerugga Dolomite	Mara Dolomite Member	Sedimentary	Chemical	dolostone	siltstone	dolarenite	y	Resistant	-Pmea: Ridge-forming:dololutite,stromatolitic do			Low	Massive generally exposed but	
-Pmea		7,630	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Emmerugga Dolomite	Mara Dolomite Member	Sedimentary	Chemical	dolostone	siltstone	dolarenite	y	Resistant	-Pmea: Ridge-forming:dololutite,stromatolitic do			Low	Massive generally exposed but	
-Pmi>2a	y	7,725	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Leila Sandstone	Leila Central 2	Sedimentary	Siliciclastic	sandstone					-Pmi: Recessive and ridge-forming: dark grey an			Low	Slightly recessive can have gre	
-Pmf		7,650	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Myrtle Shale		Sedimentary	Siliciclastic	siltstone			y	Recessive	-Pmf: Recessive: thinly bedded to laminated, con			High	Myrtle shale generally flat rece	
-Pmi>1	y	7,710	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Leila Sandstone	Leila Lower	Sedimentary	Siliciclastic	sandstone				Resistant	-Pmi: Recessive and ridge-forming: dark grey an			High	Buff sandstone ridge somewhat	
-Pml		7,900	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Gun		Mallapunyah Formation		Metamorphic	Meta-chemical se	shale			y		-Pml: Mainly recessive: red to purple dolomitic s	desiccation cracks, and gypsum ar			High in west low in east	
-Pmnd		7,410	McArthur Basin	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Donnegan Member	Sedimentary	Siliciclastic	siltstone	sandstone	dolarenite		Recessive	Recessive:dolomitic siltstone,fine-tocoarse-grain			Very High	Generally low lying with beddi	
-Ptl		8,600	McArthur Basin	Proterozoic	Tawallah Group				Sly Creek Sandstone		Sedimentary	Siliciclastic	arenite				Resistant	-Ptl: Ridge-forming: quartz arenite, mainly fine-	minor graded bedding, infrequent		Low	White - cream upstanding mass	Low
-Ptl>7	y	8,610	McArthur Basin	Proterozoic	Tawallah Group				Sly Creek Sandstone	Sly Creek 7	Sedimentary	Siliciclastic	arenite				Resistant	-Ptl: Ridge-forming: quartz arenite, mainly fine-	minor graded bedding, infrequent		Low	brown / white interbedded	Low
-Pmd>1	y	7,830	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Loretta		Tatoola Sandstone	Tatoola Sandstone Lower	Sedimentary	Siliciclastic	sandstone			y	Resistant	Lower: ridge-forming: tabular, thinly bedded, us			High	Orange yellow sandstone ridge	Low
-Pmf		7,650	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Myrtle Shale		Sedimentary	Siliciclastic	siltstone			y	Recessive	-Pmf: Recessive: thinly bedded to laminated, con			High	Myrtle shale generally flat rece	
-Pmd>2	y	7,820	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Loretta		Tatoola Sandstone	Tatoola Sandstone Central	Sedimentary	Siliciclastic	sandstone			y	Recessive				High	Flat area between sandstone ric	
-Pma		7,850	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Gun		Amelia Dolostone		Sedimentary	Chemical	dololutite	dolarenite				-Pma: Recessive: stromatolitic dololutite (stratifo	development of sideritic 'marble' a		Low	Dark red-brown weakly beddec	
Kl		2,000	Carpentaria Basin	Phanerozoic					Undivided Cretaceous Se		Sedimentary	Siliciclastic	sandstone					Kl: Clayey, micaceous and ferruginous sandstone					
Kl		2,000	Carpentaria Basin	Phanerozoic					Undivided Cretaceous Se		Sedimentary	Siliciclastic	sandstone					Kl: Clayey, micaceous and ferruginous sandstone					
-Ptl>7	y	8,610	McArthur Basin	Proterozoic	Tawallah Group				Sly Creek Sandstone	Sly Creek 7	Sedimentary	Siliciclastic	arenite				Resistant	-Ptl: Ridge-forming: quartz arenite, mainly fine-	minor graded bedding, infrequent		Low	brown / white interbedded	Low
-Pmnh		7,420	McArthur Basin	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Hot Spring Member	Sedimentary	Siliciclastic	siltstone	sandstone	dolarenite	y	Resistant	Ridge-forming:thin-bedded dolonitic siltstone an	sandstones are rippled and cross-b		Very Low	Massive olive green poorly bed	
-Ptl		8,600	McArthur Basin	Proterozoic	Tawallah Group				Sly Creek Sandstone		Sedimentary	Siliciclastic	arenite				Resistant	-Ptl: Ridge-forming: quartz arenite, mainly fine-	minor graded bedding, infrequent		Low	White - cream upstanding mass	Low
-Pts		8,800	McArthur Basin	Proterozoic	Tawallah Group				Seigal Volcanics		Igneous	Mafic extrusive	basalt				Recessive	-Pts: Amygdaloidal basalt			Very High	Dark Olive recessive and flat	High
-Ptnw		8,110	McArthur Basin	Proterozoic	Tawallah Group	Tawallah			Wununmantyala Sandsto	Wuraliwuntya Member	Sedimentary	Siliciclastic sedim	Sandstone	Mudstone			Resistant	Fine-grained and rarely medium-grained sandsto	marks, flute casts		Very Low	Less resistant than Masterton -	Low
-Pmi		7,700	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Leila Sandstone		Sedimentary	Siliciclastic	sandstone				Resistant	-Pmi: Recessive and ridge-forming: dark grey an			High	Resistant sandstone ridge.	
-Pto		8,400	McArthur Basin	Proterozoic	Tawallah Group	Tawallah			Wollogorang Formation		Sedimentary	Chemical	dololutite			y	Recessive	-Pto: Recessive: mainly dark grey-weathering, th	near base of formation; upper unit		Low Medium	Generally low flat dark red bro	Low
-Pri		5,900	McArthur Basin	Proterozoic	Roper Group		South Nicholson		Limmen Sandstone		Sedimentary	Siliciclastic	arenite				Resistant	-Pri: Ridge-forming: fine-grained, structureless q	trough cross-beds, tool marks, flar		Very Low	Characteristic sandstone ridge -	
-Ptl>7	y	8,610	McArthur Basin	Proterozoic	Tawallah Group				Sly Creek Sandstone	Sly Creek 7	Sedimentary	Siliciclastic	arenite				Resistant	-Ptl: Ridge-forming: quartz arenite, mainly fine-	minor graded bedding, infrequent		Low	brown / white interbedded	Low
-Pre		5,500	McArthur Basin	Proterozoic	Roper Group		South Nicholson		Bessie Creek Sandstone		Sedimentary	Siliciclastic	sandstone				Resistant	Ridge-forming:pseudo-karstically weathered, str			Very Low	Thin ridge white grey sandston	
-Ptq>2	y	8,520	McArthur Basin	Proterozoic	Tawallah Group				Aquarium Formation	Aquarium Med Rad	Sedimentary	Siliciclastic sedim	Sandstone				Recessive	Brown to green, dolomitic, glauconitic siltstone,			Medium	Dark brown bedded	Low
-Ptq>1	y	8,530	McArthur Basin	Proterozoic	Tawallah Group				Aquarium Formation	Aquarium High Rad	Sedimentary	Siliciclastic sedim	Sandstone				Recessive	Brown to green, dolomitic, glauconitic siltstone,			Very High	Cream yellow in some places o	Low
-Pmf>1	y	7,660	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Myrtle Shale	Myrtle Sandstone	Sedimentary	Siliciclastic	siltstone			y	Resistant	-Pmf: Recessive: thinly bedded to laminated, con			High	Sandstone ridge sometimes at t	
-Pri		5,900	McArthur Basin	Proterozoic	Roper Group		South Nicholson		Limmen Sandstone		Sedimentary	Siliciclastic	arenite				Resistant	-Pri: Ridge-forming: fine-grained, structureless q	trough cross-beds, tool marks, flar		Very Low	Characteristic sandstone ridge -	
-Pty>2	y	8,940	McArthur Basin	Proterozoic	Tawallah Group				Yiyintyi Sandstone	Yiyintyi Sandstone Lower	Sedimentary	Siliciclastic	sandstone				Resistant	Ridge-forming: quartz sandstone, in places felds	rippled in places		Medium	Massive white at base becomes	High 1VD
-Ptl		8,600	McArthur Basin	Proterozoic	Tawallah Group				Sly Creek Sandstone		Sedimentary	Siliciclastic	arenite				Resistant	-Ptl: Ridge-forming: quartz arenite, mainly fine-	minor graded bedding, infrequent		Low	White - cream upstanding mass	Low
-Pto		8,400	McArthur Basin	Proterozoic	Tawallah Group	Tawallah			Wollogorang Formation		Sedimentary	Chemical	dololutite			y	Recessive	-Pto: Recessive: mainly dark grey-weathering, th	near base of formation; upper unit		Low Medium	Generally low flat dark red bro	Low
-Pts		8,800	McArthur Basin	Proterozoic	Tawallah Group				Seigal Volcanics		Igneous	Mafic extrusive	basalt				Recessive	-Pts: Amygdaloidal basalt			Very High	Dark Olive recessive and flat	High
-Ptn>1	y	8,120	McArthur Basin	Proterozoic	Tawallah Group	Tawallah			Wununmantyala Sandsto	Wununmantyala 1	Sedimentary	Siliciclastic	sandstone				Resistant	Ridge-forming: red to mauve-grey, locally feldsp	shale interbeds		Very Low	Cream yellow massive sandsto	Low
-Pmt		7,750	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Loretta		Tooganinie Formation		Sedimentary	Chemical	dololutite			y	Recessive	-Pmt: Generally recessive: dololutite, stromatolit	pseudomorphs after gypsum and h		High	Strongly bedded and quite well	
-Pmea		7,630	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Emmerugga Dolomite	Mara Dolomite Member	Sedimentary	Chemical	dolostone	siltstone	dolarenite	y	Resistant	-Pmea: Ridge-forming:dololutite,stromatolitic do			Low	Massive generally exposed but	
-Ptnw		8,110	McArthur Basin	Proterozoic	Tawallah Group	Tawallah			Wununmantyala Sandsto	Wuraliwuntya Member	Sedimentary	Siliciclastic sedim	Sandstone	Mudstone			Resistant	Fine-grained and rarely medium-grained sandsto	marks, flute casts		Very Low	Less resistant than Masterton -	Low
-Pty>1	y	8,920	McArthur Basin	Proterozoic	Tawallah Group				Yiyintyi Sandstone	Yiyintyi Sandstone Upper	Sedimentary	Siliciclastic	sandstone				Resistant	Ridge-forming: quartz sandstone, in places felds	rippled in places		Very Low	[illegible]	
-Pml		7,900	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Gun		Mallapunyah Formation		Metamorphic	Meta-chemical se	shale			y		-Pml: Mainly recessive: red to purple dolomitic s	desiccation cracks, and gypsum ar			[illegible]	
-Pmnd		7,410	McArthur Basin	Proterozoic	McArthur Group	Batten	River	Lynott	Lynott Formation	Donnegan Member	Sedimentary	Siliciclastic	siltstone	sandstone	dolarenite		Recessive	Recessive:dolomitic siltstone,fine-tocoarse-grain			Very High	[illegible]	
-Pmt		7,750	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	Loretta		Tooganinie Formation		Sedimentary	Chemical	dololutite			y	Recessive	-Pmt: Generally recessive: dololutite, stromatolit	pseudomorphs after gypsum and h		High	[illegible]	
-Pmea		7,630	McArthur Basin	Proterozoic	McArthur Group	Umbolooga	River	Emmerugga	Emmerugga Dolomite	Mara Dolomite Member	Sedimentary	Chemical	dolostone	siltstone	dolarenite	y	Resistant	-Pmea: Ridge-forming:dololutite,stromatolitic do			Low	[illegible]	

        - 20 and 30 - Quaternary and Ceinozoic cover.
        - 100 - Fault Zones
        - 500 - igneous intrusive
        - 2000 - undivided Cretaceous and Tertiary cover.
        - 3000-3300 - Cambrian
        - 5310-5900 - Roper Group
        - 6100-6950 - Nathan Group
        - 7000 - 7970 - McArthur Group
        - 8000 - 8950 - Tawallah Group
        - 9000 - 9400 - Basement (Scrutton Volcanics)
    - **Group**
    - **Sub-Group**
    - **Super Sequence -** taken from the NW Queensland time-space plot (2000) (included here as **Enclosure 1**)
    - **Sequence** - To accommodate subdivision of the River Super Sequence by McGoldrick (2010).
    - **Formation** - Defined from the 1:250,000 geology
    - **Member** - Includes official Member subdivisions from the published geology and newly created sub-units during this study.
    - **LithClass** - Inherited from 1:250,000 geology data, subdivides rocks into Igneous, Metamorphic and sedimentary. (*Interestingly the Barney Creek and Mallapunyah Formations are classified as metamorphic as their rock category is "Meta-chemical sediment").*
    - **RockCategory** - Inherited from 1:250,000 geology data, sub-divides rocks into Silliclastic, Chemical, Chemical sediment, meta-chemical sediment, silliclastic sediment, mafic intrusive, felsic intrusive, mafic extrusive and Regolith.
    - **LithPrim** - Primary lithology - inherited from 1:250,000 geology.
    - **LithSub** - Subsidiary lithology - inherited from 1:250,000 geology.
    - **LithOther** - Other lithology - inherited from 1:250,000 geology.
    - **Evaporite Evidence** - A "Y/N" field added in this study. Any unit that has evidence for gypsum or halite or evaporite castes etc from the rock descriptions have been flagged as "Y".
    - **Recessive Resistant** - A field added in this study to highlight recessive lithologies which may be target horizons for Pb/Zn mineralisation. The possible values are: Resistant, Recessive and Recessive/Res
    - **LithDesc1** - The first 254 characters of the lithology description, multiple fields required for some description due to the restriction of Mapinfo displaying only 254 characters in a text field. These descriptions have mainly been

inherited from the 1:250,000 geology. Where a new sub-unit of the unit has been defined in this project the description from the main unit has been retained. Some of the descriptions are truncated - this problem has been inherited from the 1:250,000 geology data.

- **LithDesc2** - The next 254 characters of the lithology description.
- **LithDesc3** - The next 254 characters of the lithology description - only used for the Tatoola Sandstone.
- **Radiometrics Appearance** - Indication of marker units from the radiometrics RGB image flagging signatures that are high or very high (Pink or Red) and those that are very low (black, dark brown or dark Blue).
- **Magnetics appearance** - identifies those units that have some associated signature in the aeromagnetic images. (This field has not been completed for all units).
- **Google-Earth appearance** - Description of the units in Google Earth Imagery.

The remaining fields in the table relate to the graphic definitions for the objects used by the Colourmap module. Once the interpretation was complete the fields in the polygon table were updated with the information from the Colourmap lookup using the multi-update column tool in Discover.

Interpretation Methodology

The interpretation commenced with delineation of areas of exposed Tatoola Sandstone as this is one of the most recognisable units within the Google Earth imagery. The interpretation expanded up and down stratigraphy using distinctive marker units with the Google Earth imagery and radiometrics to constrain the units. The unit assignations were guided by the published geology but some significant changes have been made and will be described below. Interpretation involved the following strategies:

- Major faults were recognised from prominent features in the Google Earth imagery but also from the relationship between units - identifying areas where stratigraphy is missing or repeated. Where the fault system could be interpreted to form blocks the internal fault architecture and unit boundaries within that block were completed.
- Exposed geology was projected under thin areas of surficial cover where there was reasonable control. Larger areas of Cretaceous and Cambrian cover, where none of the basement structural grain could be seen, have been included in the interpretation as cover sequences with some basement structure interpreted from aeromagnetics and gravity data.
- Faults have been included in the interpretation where they have an effect on stratigraphy or are prominent. Many small scale structures have not been included, even though they are visible in the imagery, as they do not contribute to the regional architecture which is the main focus of the interpretation. The following fault types have been differentiated in the interpretation:
  - **Significant faults** - structures have been assigned significant status where they effect large stratigraphic offsets (hundreds of metres). The offsets vary along

strike so a structure can change to a "Major Fault" and then "Fault" along strike.

- **Major Fault** - prominent structure with extensive strike length or prominent stratigraphic offset.
- **Fault** - All other faults that displace stratigraphy or have strike lengths of several kilometres.
- **Reverse Faults** - The majority of northerly trending faults in the area are compressional - where dip-slip stratigraphic offset occurs it has been assumed to be caused by reverse faults with the structure dipping towards the older block.
- **Inferred Faults** - where structures have been extended below cover they have been tagged as inferred where there is some uncertainty as to their trajectory - major faults can be in this category.
- **Faults From Magnetics** - These have been interpreted in covered areas only.
- **Faults from gravity** - These have been interpreted from gravity gradient zones and are taken to reflect more fundamental structures that affect the basement - they may or may not have an expression in the Proterozoic sequence.

Within the interpreted lines table (McArthur Region interp lines.TAB) browser the features have been tagged with a:

- **Discover_Code** - The style tag that has been assigned to the line in the Geostyles module. These lines have suffixes such as "Line" or "Fill" to group these features together in the dialog box which displays tags alphabetically.
- **Feature_Group** - Gives a common tag to a fault types so they can be extracted easily using a query. Various types of lithology boundary are also grouped in this way.
- **Feature_Type** - Used to group major faults as opposed to smaller structures. This can be used to easily extract only the major structures.
- **Description** - A brief description of the line type and how it is defined.

- Once a lithology area has been defined and enclosed by interpreted lithology boundaries and faults the solid polygon could then be created. This could be done "manually" and would involve cutting and snapping the boundaries and then creating the polygon using the Discover tools. This is a time consuming process (there are around 6000 polygons in the final interpretation - if it only took 1 minute each to create and tag the polygon from the interpreted lines this would represent around 13 days of polygon creation!) and so a different approach has been taken.
  - A separate text annotation layer was created in which the formation or member name of the lithology could be typed as a reminder of the interpreted unit.
  - Once the interpretation linework of lithology boundaries and faults was complete the Discover "Polybuilding' tools were used to automatically extend, break and snap the linework to clean up any undershoots or overshoots. This still requires some manual cleaning up.
  - Once the line work is snapped a copy of the line work table is made. In the copy all lines which have a free end are then deleted leaving only those lines

that are going to form a boundary to a solid polygon. Once the first pass of deletions have been made the "polybuilding" tools can be used to identify any remain "free ends". When this is complete the polygons can be built automatically. Discover creates new polygon for all areas enclosed by line work.

- o The polygons are all created with the same fill pattern and have to be coloured and tagged appropriately. This is done manually using the Colourmap table constructed earlier. This process was found to be a good validation of the interpretation. Each unit was coloured in turn over the Google Earth image base. All the polygons were initially assigned a transparent fill. Tagging started with the Tatoola Sandstone and any other prominent marker units. The unit was followed using the text label overlay as a guide and the unit polygons were "Shift-clicked" to select a large number of polygons from the same unit which were then tagged and coloured using the Geostyles module in Discover. This process allowed a review of the interpreted unit to ensure the correct unit had been interpreted and note any variation in outcrop style or radiometric signature across the study area. As the well constrained marker units were tagged first it helped constrain the unit associations of the blocks between. Even using this method the polygon creation and tagging process took nearly 3 days.
- o When the polygons have been initially tagged with the lithology code the rest of the attribute data can be updated from the lookup table.

The resulting solid geology interpretation is variably constrained and represents the best estimate of the distribution of Proterozoic units constrained by maintaining stratigraphic order and approximate thickness. The interpretation has simplified some of geology depicted in the 1:100,000 geology, especially within the Emu Fault Zone, as it was felt the extra time in digitising these complexities was not warranted given the regional objectives of the project. The interpretation could be improved on as other data sets could be incorporated in future:

- The geology of the units around the HYC deposit is unfortunately poorly exposed and the interpretation is generally inferred and not well constrained in this area. Local geology maps for the mine area, especially those incorporating drilling information, would greatly improve the interpretation in this area. Local maps from other prospect areas could also improve the interpretation of their structural and stratigraphic setting.
- There are numerous government stratigraphic holes drilled through Cretaceous and Cambrian cover which would help constrain the interpretation and distribution of units. The Glyde sub-basin to the south of HYC is under Cambrian cover and is only known from drilling - this has not been incorporated into the current interpretation. Acquisition of such open file drilling information is recommended and used to augment the interpretation.
- The extensive areas of Cambrian and Cretaceous cover in the interpretation currently have no indication as to the depth to Proterozoic rocks. It would be useful if depth contours could be generated from drilling information or depth to magnetic units in the Proterozoic. As this will be an important criteria in under cover exploration decisions.

Mapinfo Interpretation Tables

The interpretation was carried out in Mapinfo and the resulting tables and workspaces are contained on the enclosed DVD. The tables have been saved in a "Direct opening" folder on the DVD - the workspaces in this folder should open directly from the DVD. Workspaces have been included for the Enclosures accompanying this report and the report diagrams where appropriate. The tables have also been included in separate folders which contain associated tables for easy of identification and for copying to a local hard disk.

The tables that make up the final interpretation include:

- McArthur Region interp fills final.TAB - interpreted lithology polygons.
- McArthur Region interp lines.TAB - interpreted polylines including faults (including those from magnetics and AEM) and lithology boundaries
- McArthur Region interp folds.TAB - interpreted fold axes
- McArthur Region interp Bedding trends.TAB - bedding trends
- McArthur Region Geophys Lines.TAB - interpreted lines from gravity and AEM datasets showing gravity gradients, the contour defining some gravity highs and a selected contour to show the conductive anomalies at HYC and Yalco.
- McArthur Seismic Line Location.TAB - location of Geoscience Australia seismic line 2002.
- McArthur Region interp Block Boundaries.TAB - interpreted boundaries to coherent structural blocks. Any significant Pb-Zn deposit would be expected to lie within a Buffer around these boundaries.
- McArthur Region interp Blocks.TAB - Solid polgons of the interpreted structural blocks
- McArthur unconformity relations.TAB - Interpreted unconformable contacts in the interpretation for the Roper Group, Nathan Group and Hotspring Member tagged with the underlying unit name. Used to gauge variation in the amount of stratigraphy missing on the unconformity.
- Struct block dip dir.TAB - Summary dip directions for the coherent structural block stratigraphy.

Tables modified from the published geology:

- McArthur 250k geol Comp lith polys.TAB - Compilation of all of the geology polygons into a standard table structure.
- McArthur 250K struct data.TAB - Compilation of all of the 1:250,000 sheet structural data - structural symbols created using Discover.
- McArthur 250K struct data coloured.TAB - The structural symbols thematically coloured by dip.
- McArthur non zero struct data coloured.TAB - Table containing only data that have non-zero dip values.

Colourmaps and Lookups:

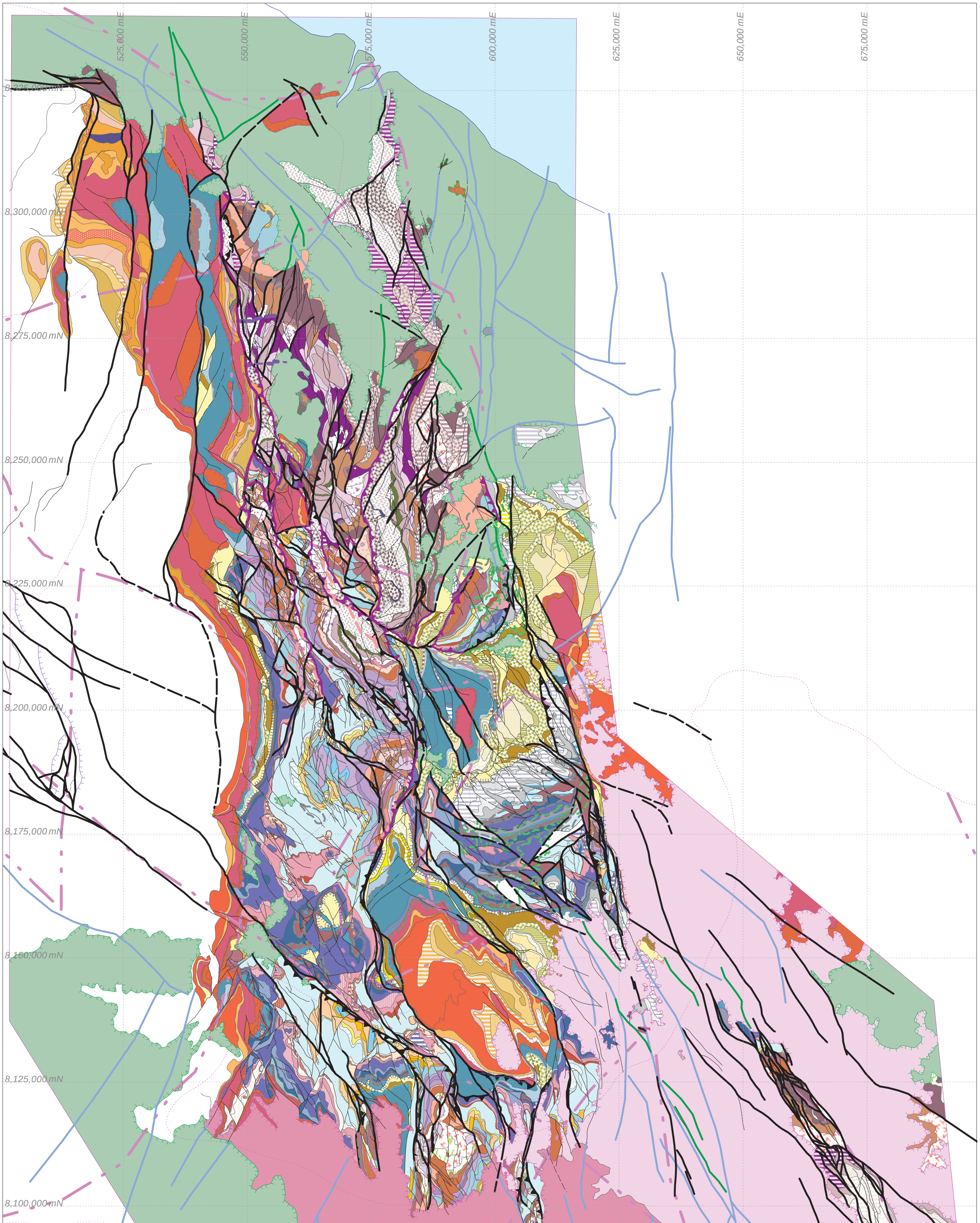
- McArthur Basin Region Strat.xls - table of all stratigraphic units in the 1:250,000 geology sheets.
- McArthur_interp_Colourmap.TAB - Colourmap table used in interpretation as lookup table, Geostyles colourmap and map legend table.

Features of the Interpretation

The following sections contain notes on some of the features that were recognised during the interpretation. The completed interpretation is presented as **Enclosure 2** at 1:250,000 scale and as **Figure 10** with the map legend as **Figure 10b**. The Interpreted major faults and deposit locations are shown in **Figure 11**.

- The Emu Fault changes character along strike and steps to the west moving northward. To the south of HYC it is more complex and has undergone more prominent inversion, developing a positive flower structure involving slivers of Masterton Formation. It is a less significant structure to the north and less complex. The only way to achieve this geometry is to have shearing from WNW trending structures onto restricted segments of the Emu Fault which then localise much greater shortening This pattern has some elements in common with the location of the Century deposit on the Termite Range Fault where the zone changes from a essentially single strand structure to a multi-strand structure moving north - possibly under the influence of structure linking into the fault.
- The McArthur Group is significantly thinner and generally absent to the north of a WNW trending zone parallel to the Mallapunyah Fault which is here termed the Central Transfer (see **Figure 11**). It is not clear if the McArthur Group was deposited in this area, however, the identification of the Tatoola Sandstone in separate inliers suggests that at least the lower McArthur Group was present over the entire are and that the area north of the Central transfer has undergone more significant inversion. The inversion is via a series of NNE trending reverse faults (Lorella Fault, Rosies Fault) which are oblique to the trough and would be created in a sinistral shear system on NNW structures. Note that the northerly trending Batten Fault Zone structures form a wider zone north of the Central Transfers.
- The Central Transfer South comprises a series of en echelon structures at surface rather than a through-going structure and may be a cover response to a basement structure which can be interpreted as a gravity gradient. The transfer also marks a change in transport direction on the Tawallah Fault with east directed transport to the south but west directed to the north. Major reverse faults are much more common to the north corroborating the suggestion that this area has undergone more inversion. Three strands of the Central Transfer Zone have been informally named here (see **Figure 11**):
    - **Central Transfer North** - Which may form the northern boundary to the HYC sub-basin and rotate to the trend NE to link into the Emu Fault Zone.
    - **Central Transfer South** - This comprises en echelon strands and links into the Tawallah Fault - however, it seems to continue in a more cryptic form into the HYC deposit area but reactivated segments of it persist to the east.

Figure No.10 Solid Geology Interpretation



Scale 1:750,000 Zone53 GDA94

Figure No.10b Interpretation legend

Cenozoic materials
Cenozoic materials
Cenozoic materials
Cenozoic materials
Cenozoic materials
Cenozoic materials
Cenozoic materials
Undivided Cretaceous Sediments
Bukalara Sandstone
Top Springs Limestone
Anthony Lagoon beds
Cox Formation
No formal name
McMinn Formation Sherwin Ironstone Member
McMinn Formation Kyalla Member
McMinn Formation Moroak Sandstone Member
Velkerri Formation
Bessie Creek Sandstone
Corcoran Formation
Corcoran Formation Munyi Member
Abner Sandstone
Abner Sandstone Hodgson Sandstone Member
Abner Sandstone Jalboi member
Abner Sandstone Arnold Sandstone Member
Crawford Formation (NT)
Mainoru Formation
Mainoru Formation Kilgour Sandstone Member
Limmen Sandstone
Karns Dolomite
Lower Karns Dolomite
Mantungula Formation
Dungaminnie Formation
Balbarini Dolostone
Smythe Sandstone
Undivided McArthur Group
Amos Formation
Looking Glass Formation
Stretton Sandstone
Stretton Sandstone Stretton Upper
Stretton Sandstone Stretton Lower
Yalco Formation
Yalco Formation Yalco Upper
Yalco Formation Yalco Lower
Lynott Formation Donnegan Member
Lynott Formation Hot Spring Member
Lynott Formation Hot Spring Member 3
Lynott Formation Hot Spring Member 2
Lynott Formation Hot Spring Member 1
Lynott Formation Caranbirini Member
Lynott Formation Caranbirini Member 5
Lynott Formation Caranbirini Member 4
Lynott Formation Caranbirini Member 3
Lynott Formation Caranbirini Member 2
Lynott Formation Caranbirini Member 1
Reward Dolostone
Reward Dolostone Low Rad
Barney Creek Formation
Teena Dolostone
Teena Dolomite Coxco Dolomite Member
Emmerugga Dolostone
Emmerugga Dolostone Emmerugga HighRad
Emmerugga Dolomite Mitchell Yard Dolomite Memb
Emmerugga Dolomite Mara Dolomite Member
Myrtle Shale
Myrtle Shale Myrtle Sandstone
Leila Sandstone
Leila Sandstone Leila Upper
Leila Sandstone Leila Central 2
Leila Sandstone Leila Central
Leila Sandstone Leila Base
Leila Sandstone Leila Lower
Tooganinie Formation
Tooganinie Formation Tooganinie Rough
Tooganinie Formation Tooganinie Marker
Tooganinie Formation Tooganinie Lower
Tatoola Sandstone
Tatoola Sandstone Tatoola Sandstone Upper
Tatoola Sandstone Tatoola Sandstone Central
Tatoola Sandstone Tatoola Sandstone Lower
Amelia Dolostone
Amelia Dolostone Amelia Dolostone High Rad
Mallapunyah Formation
Mallapunyah Formation Mallapunyah Top
Mallapunyah Formation Mallapunyah Upper
Mallapunyah Formation Mallapunyah Central
Mallapunyah Formation Mallapunyah Lower
Masterton Sandstone
Masterton Sandstone Masterton Upper
Masterton Sandstone Masterton Central

Undifferentiated Tawallah Group
Echo Sandstone
Echo Sandstone Pungalina Member
Echo Sandstone Upper Pungalina Member
Echo Sandstone Lower Pungalina Member
Tanumbirini Rhyolite
Gold Creek Volcanics
Settlement Creek Volcanics
Warramana Sandstone
Wununmantyala Sandstone
Wununmantyala Sandstone Wununmantyala 1
Wununmantyala Sandstone Wuraliwuntya Member
Rosie Creek Sandstone
Rosie Creek Sandstone Rosie Creek Sandstone Upper
Rosie Creek Sandstone Rosie Creek Sandstone Central
Rosie Creek Sandstone Rosie Creek Sandstone Lower
Wollogorang Formation
Upper Wollogorang Formation
Lower Wollogorang Formation
Aquarium Formation
Aquarium Formation Aquarium Low Rad
Aquarium Formation Aquarium Med Rad
Aquarium Formation Aquarium High Rad
Sly Creek Sandstone
Sly Creek Sandstone Sly Creek 7
Sly Creek Sandstone Sly Creek 6
Sly Creek Sandstone Sly Creek 5
Sly Creek Sandstone Sly Creek 4
Sly Creek Sandstone Sly Creek 3
Sly Creek Sandstone Sly Creek 2
Sly Creek Sandstone Sly Creek 1
McDermott Formation
McDermott Formation McDermott Lower
McDermott Formation McDermott Central
Seigal Volcanics
Yiyintyi Sandstone
Yiyintyi Sandstone Yiyintyi Sandstone Lower
Yiyintyi Sandstone Yiyintyi Sandstone Upper
Scrutton Volcanics
Scrutton Volcanics Scrutton Volcanics Upper
Scrutton Volcanics Scrutton Volcanics Middle
Scrutton Volcanics Scrutton Volcanics Lower

Lithology Contacts
Interpreted Lithology Boundary
Inferred Lithology Boundary
Unconformity Cretaceous
Unconformity Cambrian
Unconformity Roper Group
Unconformity Nathan
Unconformity Batten Sub Group

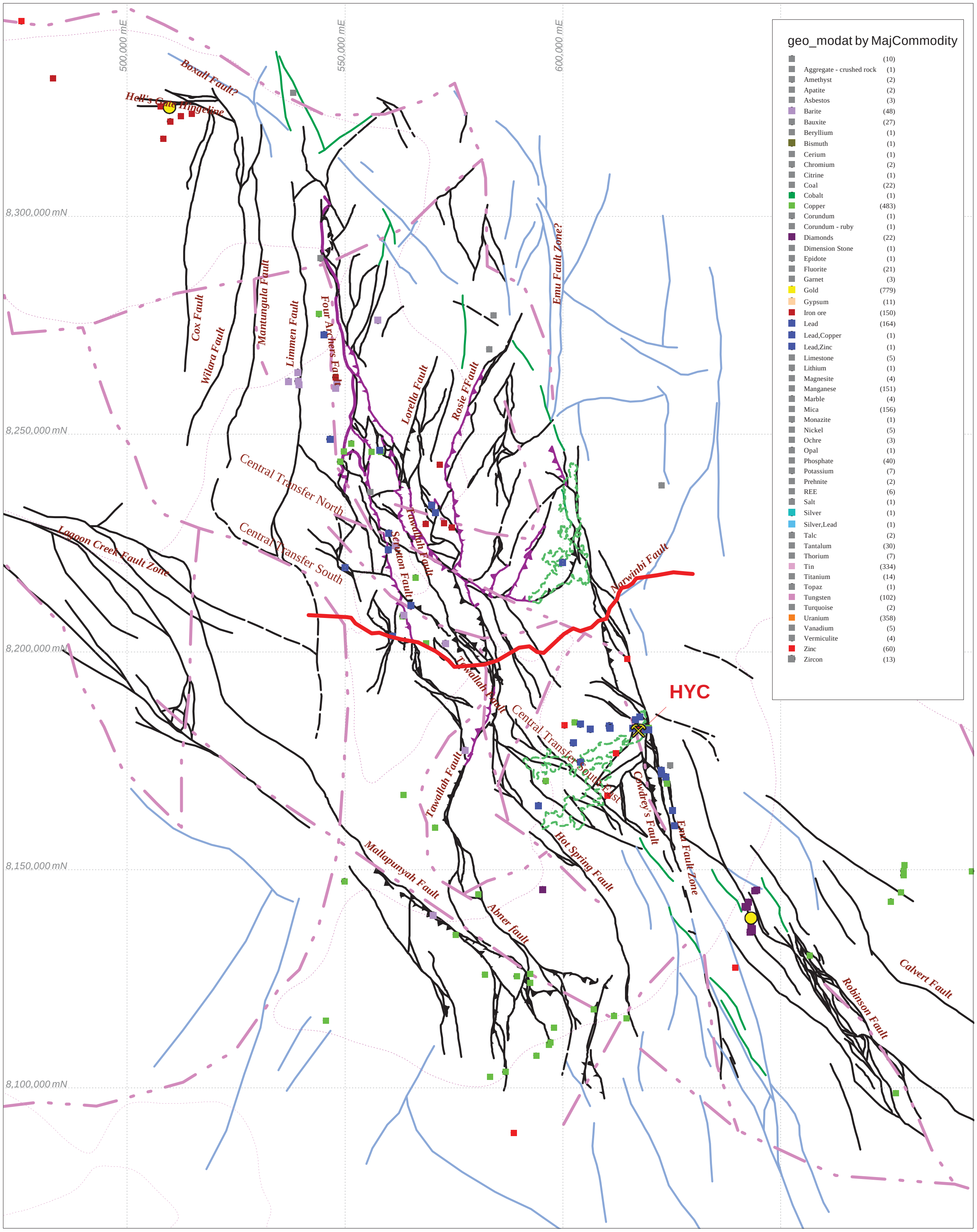
Faults
Interpreted Significant Fault
Thrust or Reverse Fault Significant
Interpreted Major Fault
Thrust or Reverse Fault Major
Inferred Fault Major
Fault
Inferred Fault
Thrust or reverse fault

Lines From Geophysics Interpretation
Gravity Gradient
Gravity High Margin
AEM anomaly Boundary
Interpreted Fault Magnetics
Mag High Fault Axis
Fault interpreted from EM

Folds
Syncline
Anticline

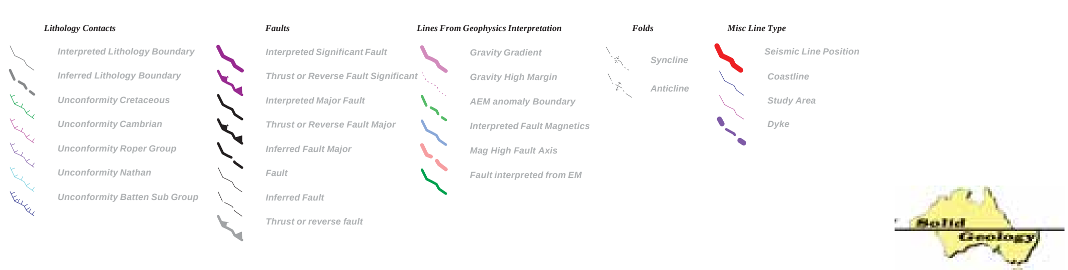
Misc Line Type
Seismic Line Position
Coastline
Study Area
Dyke

Figure No.11 Interpreted major faults and deposits



Scale 1:900,000

Interpreted major faults - the location of the Geoscience Australia seismic line is shown and traverses a complex area of the Central Transfer Zone.



- **Central Transfer South East** - This may be the offset continuation of the Central Transfer South offset by the Tawallah Fault. The presence of this zone has not previously been recognised. It seems to play an important role in formation of the HYC sub-basin and is probably part of the same basement structure as the Lagoon Creek Fault Zone to the west.

- The Geoscience Australia Seismic line (see **Figure 2, 3 and 11**) has traversed the Batten Trough in a rather unfortunate location. The position of the line was clearly dictated by the location of major roads. In the west the line essentially lies within the influence of the complex en echelon structure of the Central Transfer Zone whilst to the east the line traverses the Emu Fault in a location where it is stepping to the west across a number of strands in a zone where there is clearly not much vertical displacement involved but may comprise around 20km of sinistral displacement if the map offset of the Yalco Formation is considered representative (This would account for the NE and NNE trending reverse faults which occur immediately west of the Emu Fault Zone). Geoscience Australia has concluded that the Batten Trough does not affect sediment thicknesses in the McArthur Group but I suspect the answer would have been different if the line had passed through the fault further to the south. They also conclude that the Tawallah Fault and much of the fault deformation is Post Roper Group in age. This seems highly unlikely to me as:
  - There is clearly a much greater density and complexity of faulting affecting the McArthur Group.
  - The Roper and Nathan Groups rest unconformably on a range of units from lower Tawallah Group to Upper McArthur Group. The vast majority of inversion has clearly been completed prior to deposition of the Roper Group.
  - There is evidence for significant sinistral strike-slip on the Emu Fault in McArthur Group rocks but the Roper Group in west of the interpretation only shows evidence for dextral strike slip movements.
  - The fold architecture within the McArthur Group is much more complex than in the Roper Group (this may be because there are significantly different unit thicknesses between the two groups ands because the McArthur Group rocks are coincident with the main axis of inversion).
  - The Mallapunyah Fault shows much greater offset within the McArthur Group than in the Roper Group.
- The Mallapunyah Fault and Central Transfer have clearly been active together during deposition and during a number of phases of reactivation during inversion.

Notes on Sequences and Stratigraphic Units

The following descriptions detail some of the local characteristics of the Formations and Members and observations on their distribution. The interpreted stratigraphic order of the Tawallah Group Formations is different to the published stratigraphy of **Figure 4**, mainly as a result of the interpreted distribution of the Rosie Creek Sandstone Member. In the north, the geological maps depict the Rosie Creek Sandstone lying immediately above the Sly Creek Formation. However, the unit was followed northwards from outcrops further to the south where the Rosie Creek Sandstone was identified more centrally within the Tawallah Group thus resulting in a different, but coherent, interpretation in the north. Changes from the geology map will be noted in the descriptions.

The distribution of each Formation has been extracted as separate Mapinfo tables enabling the distribution of each to the fault and structural block interpretations to be assessed. These tables are included on the accompanying DVD. Extractions have also been made on a Super Sequence and Sequence basis to help analyse the history of sub-basin development and identify potential growth faults. Diagrams illustrating the distribution of the various units and Formations in this section are depicted on a background of major tectonic block boundaries which represent that major structures of the study area. Any rapid changes in stratigraphy related to growth faulting should occur across these boundaries if present. Also included in these diagrams is a colour coded representation of the combined bedding dip files from the 1:250,000 geology. These have been included to help assess whether map unit thickness changes are apparent and related to changes in dip or real. The vast majority of dips in the study area are less that 25 degrees and so direct thickness comparisons can generally be made. Sub-vertical dips are present close to some major fault zones where they have undergone significant inversion.

The sequences and Formations are described from the oldest to the youngest.

Basement

Scrutton Volcanics (**-Pls**) - These are of limited aerial extent in the area, exposed in 3 largely fault bounded inliers with some unconformable contacts with the Yiyintyi Sandstone. The time-space plot of **Enclosure 1** dates them at 1851Ma and places them as equivalent to Cover Sequence 1 of the Mount Isa Block. They have very high radiometric and high magnetic signatures. Three sub units (-Pls>1, -Pls>2, -Pls>3) were established based on variation in Google Earth signatures which are generally flat and red-brown.

Tawallah Group

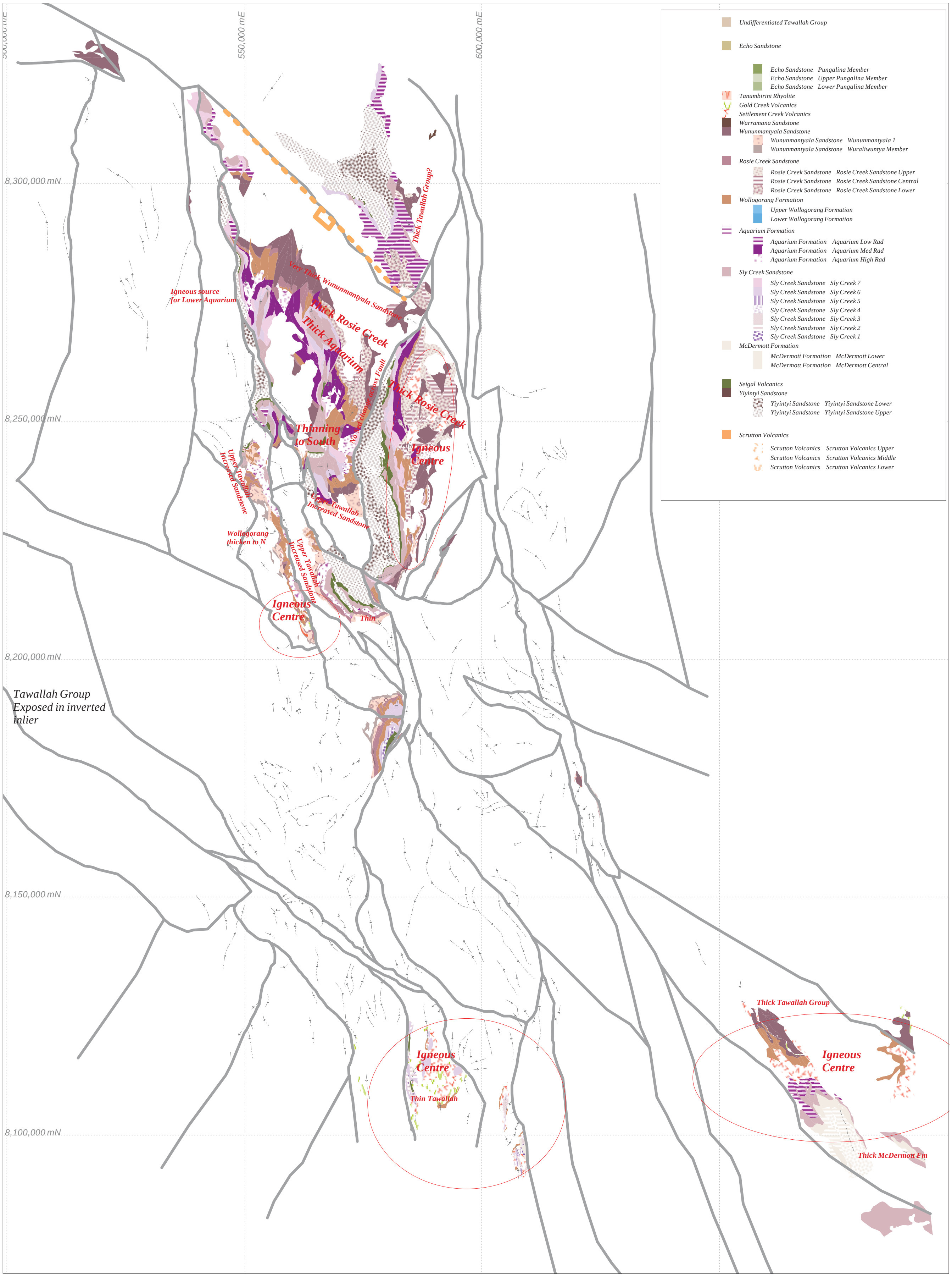
The Tawallah Group is mainly exposed in the north of the area (**Figure 12**) to the north of the Central Transfer in an area that seems to have undergone more extensive inversion. The deposition of the Group has been split into two main time sequences in the time-space plot (**Enclosure 2**):

- Yiyintyi Sandstone, Siegal Volcanics, Sly Creek Sandstone, McDerrmott Formation and Aquarium Formation - These are correlated with Cover Sequence 2 volcanics in the Mount Isa Block from about 1782Ma to 1753Ma as a conformable sequence. These rocks are dominated by quartz-sandstones which are often massive fining upwards through the upper Sly Creek Formation into the Aquarium Formation.
- The Upper Tawallah Group above the Aquarium Formation - a 13Ma time gap is indicated in the time-space plot after deposition of the Aquarium Formation with the volcanics/intrusives in the upper part of the sequence correlated with the Fiery Creek Volcanics. Deposition ends at around 1712Ma. The volcanics indicate the Tawallah Group could have been part of the rifting phase of the Batten Trough but the Tawallah Group extends a considerable distance outside the Batten Fault Zone.

The following notes relate to the individual Formations and interpreted Members:

- **Yiyintyi Sandstone (-Pty)** - Massive upstanding quartz sandstone exposures generally white-grey in Google earth. Two sub units were defined on the basis of the radiometrics (-Pty>1 and -Pty>2). The lower unit -Pty>2 has a higher radiometric

Figure No.12 Distribution of Tawallah Group

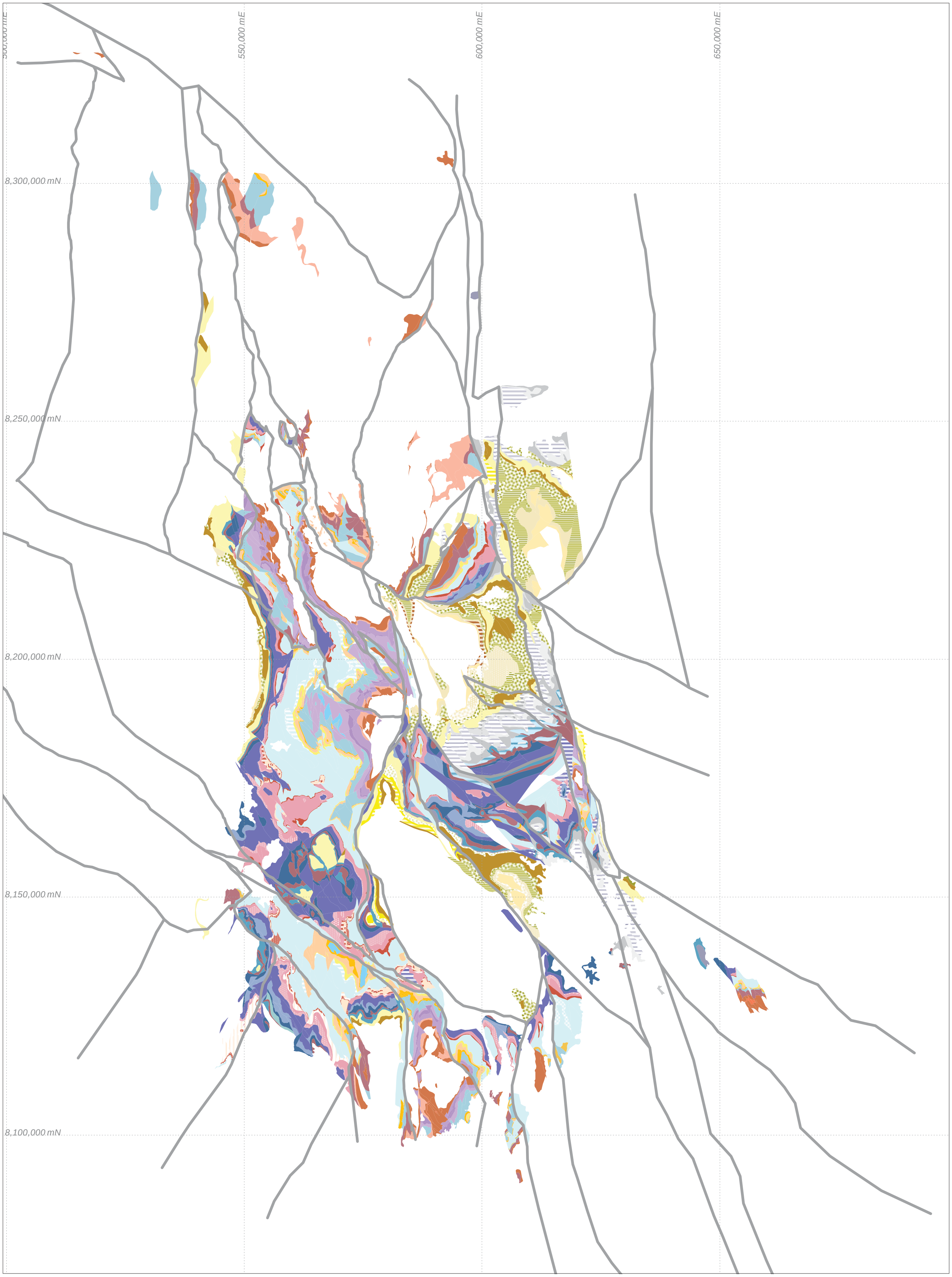


Scale 1:750,000

Igneous centres have been highlighted where the Settlement Creek and Gold Creek Volcanics are present. Interpreted folds are included in the summary.

Solid Geology

Figure No.13 Distribution of McArthur Group

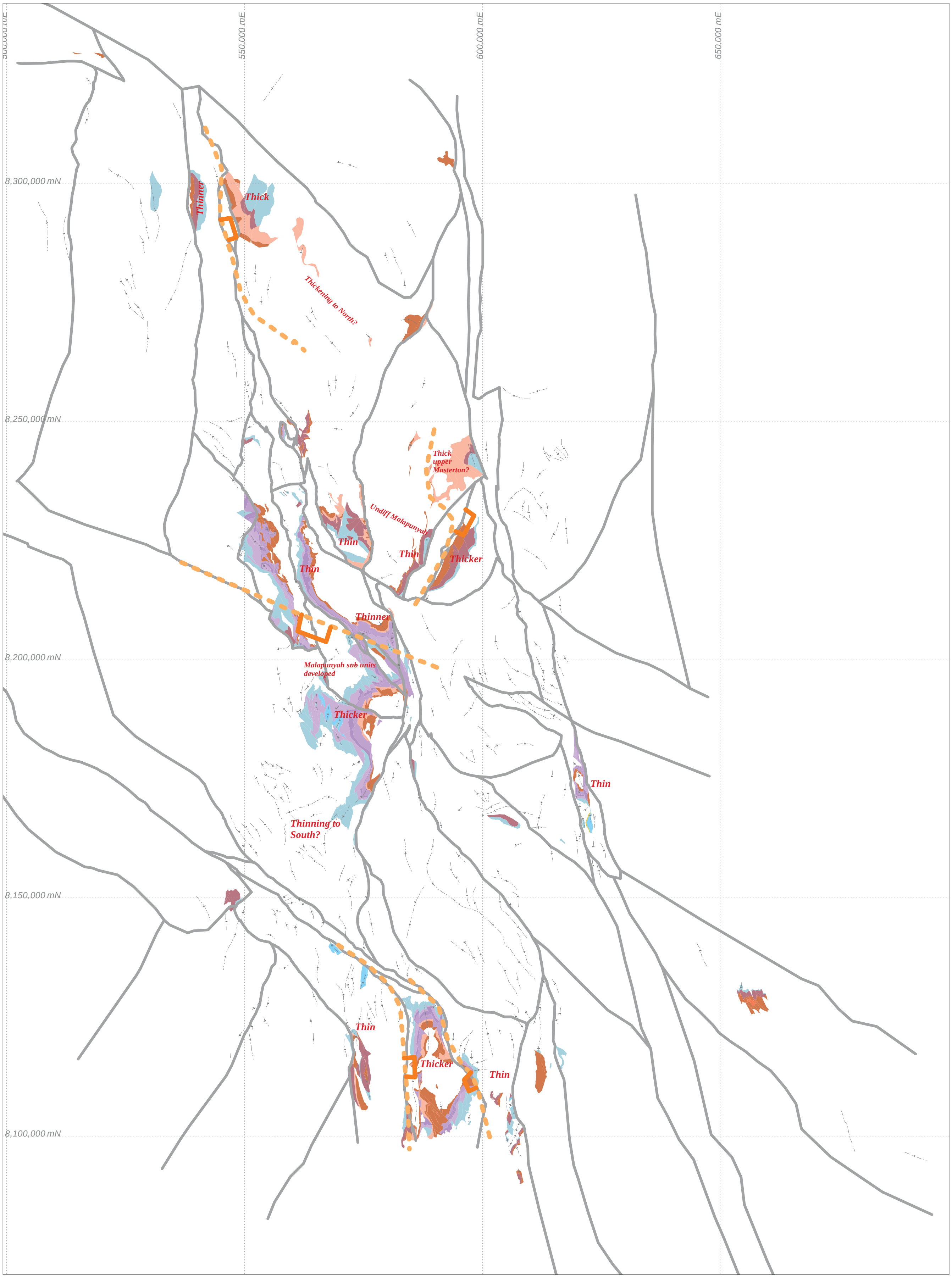


Scale 1:750,000

See Figure 10b for legend of lithologies.

Solid Geology

Figure No.14 Distribution of Gun Super Sequence

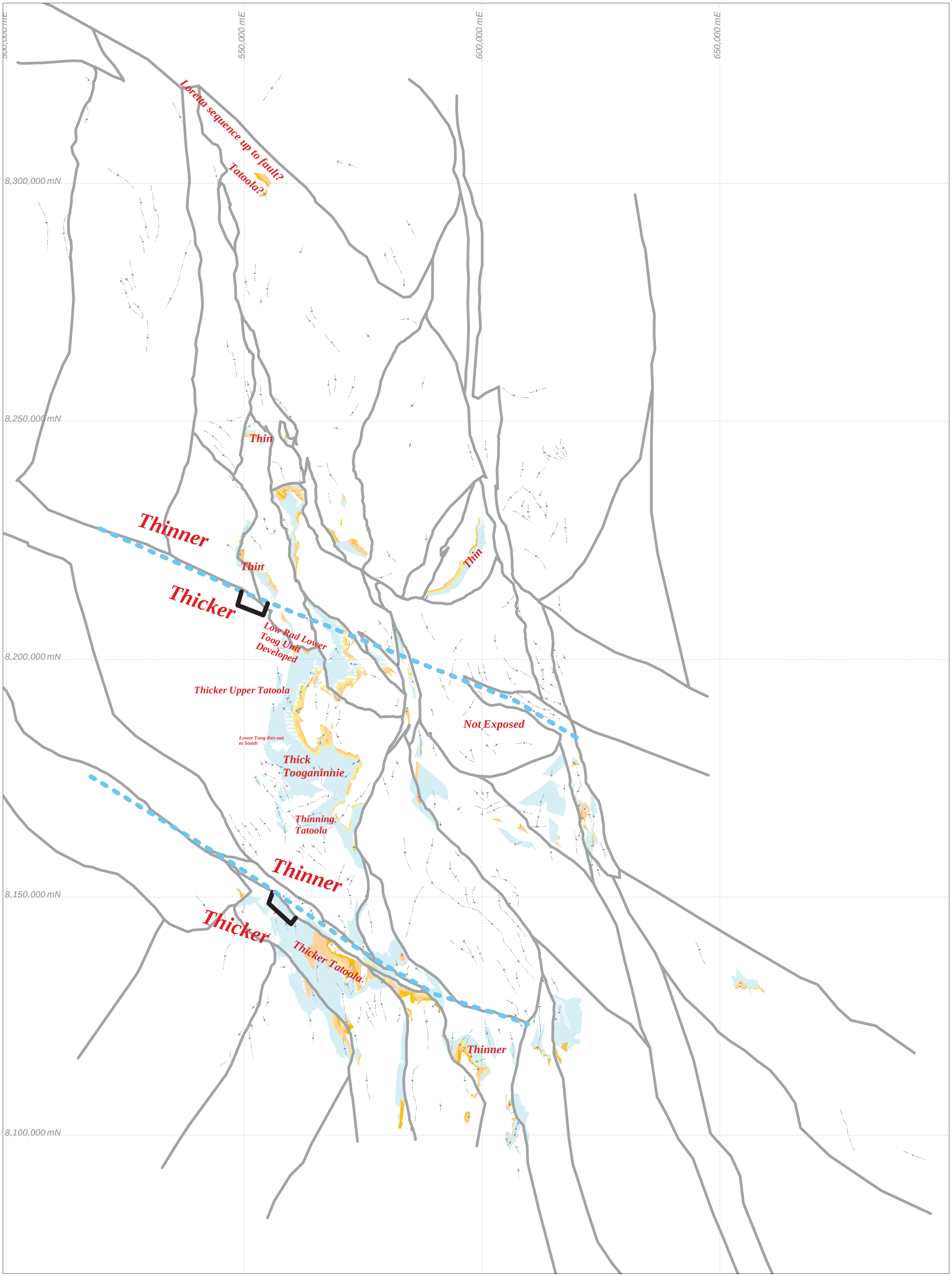


Scale 1:750,000

Distribution of Gun Super Sequence comprising the Masterton Sanstone, Mallapunyah Formation and Amelia Dolomite

See Figure 10b for legend of lithologies.

Figure No.15 Distribution of the Loretta Super Sequence

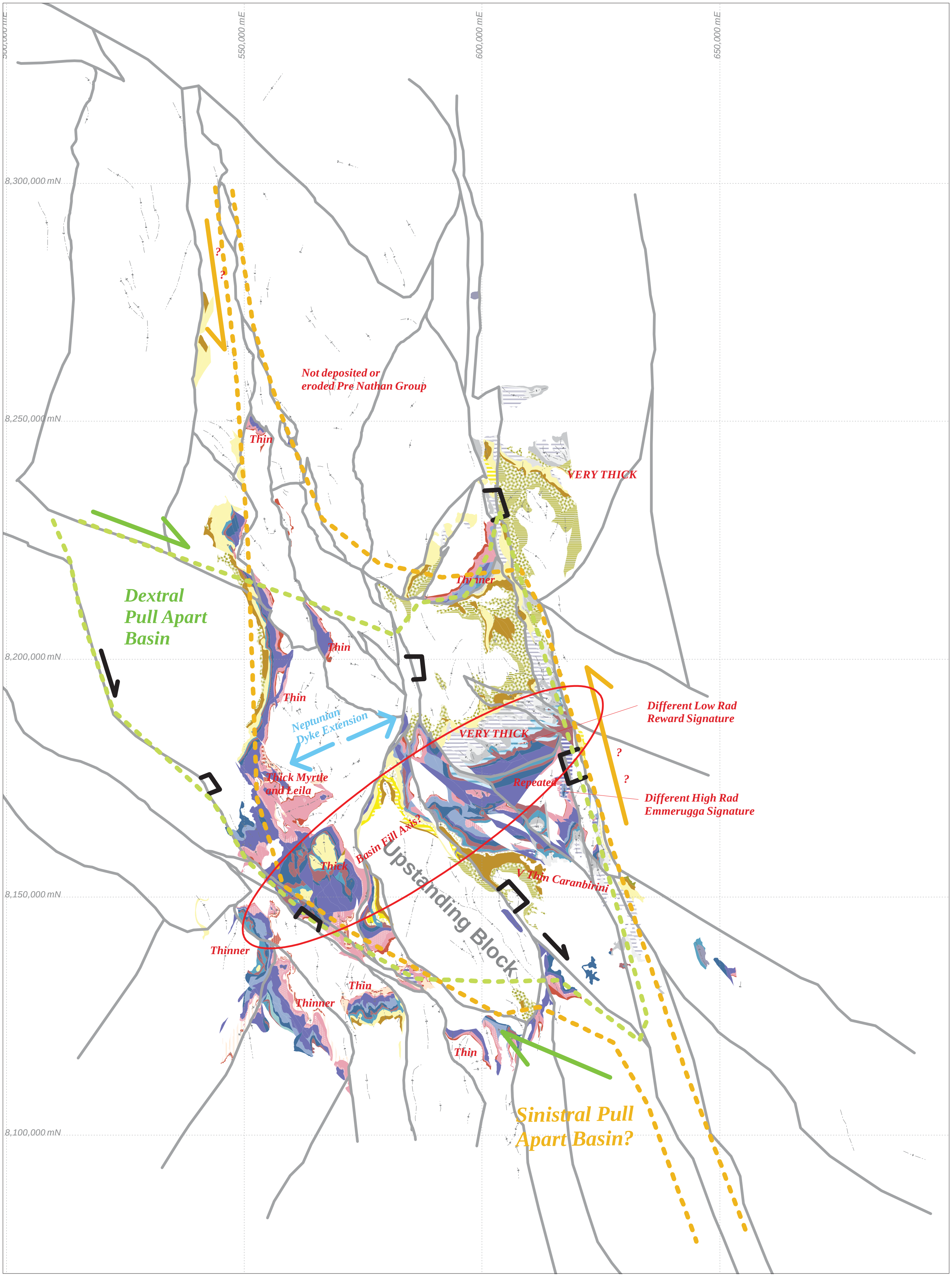


Scale 1:750,000

The Loretta Super Sequence comprises the Tatooa Sandstone and Tooganinie Formation

See Figure 10b for legend of lithologies.

Figure No.16 Distribution of the River Super Sequence



Scale 1:750,000

The River Super Sequence (according to McGoldrick 2010) comprises the Leila Sandstone, Myrtle Shale, Emmerugga Dolomite, Teena Dolomite, Barney Creek Formation. Reward Dolomite, Lynott Formation and Yalco Formation

See Figure 10b for legend of lithologies.

Solid Geology

Figure No.17 McGoldrick (2010) River Sequence definitions

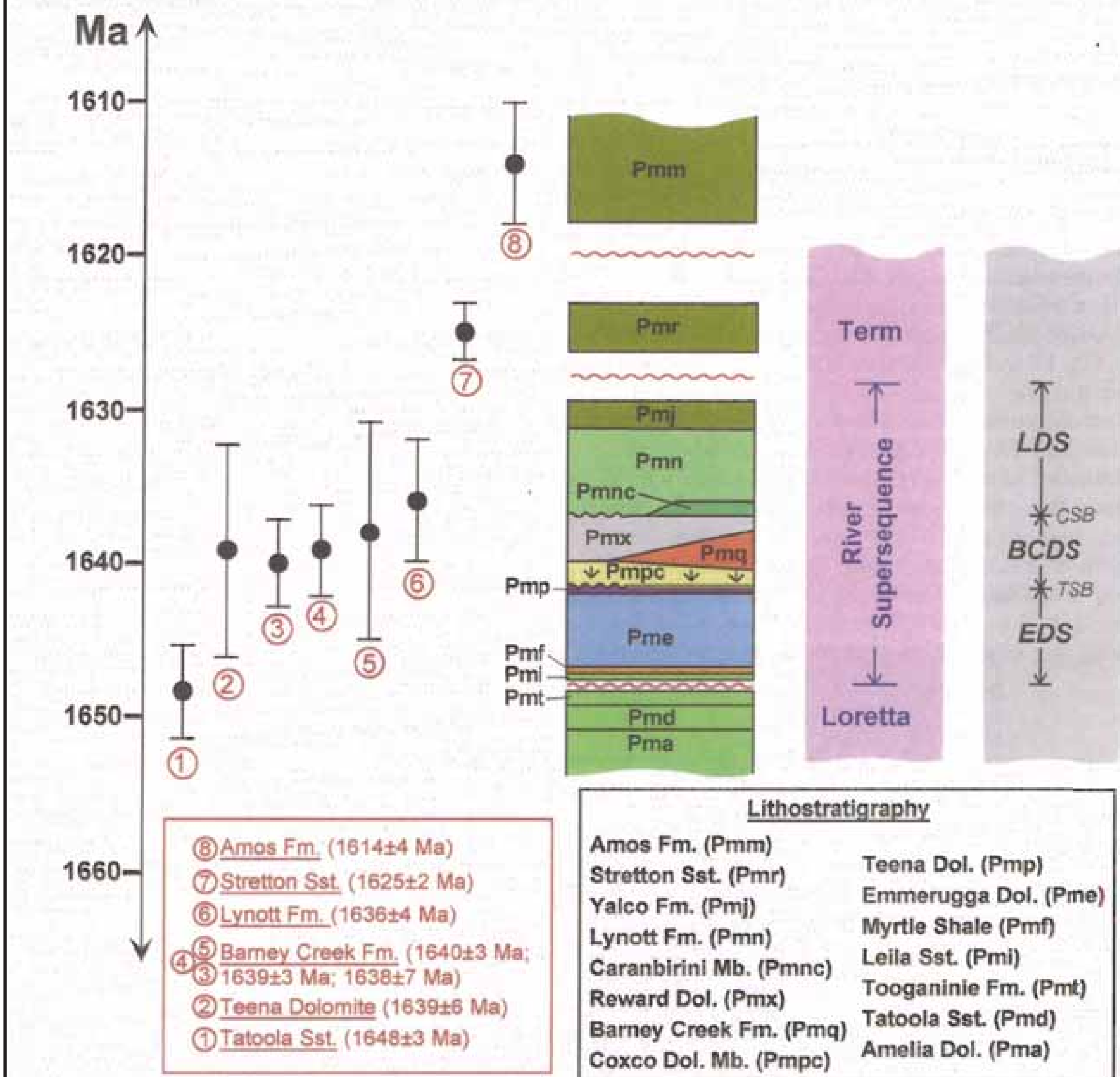
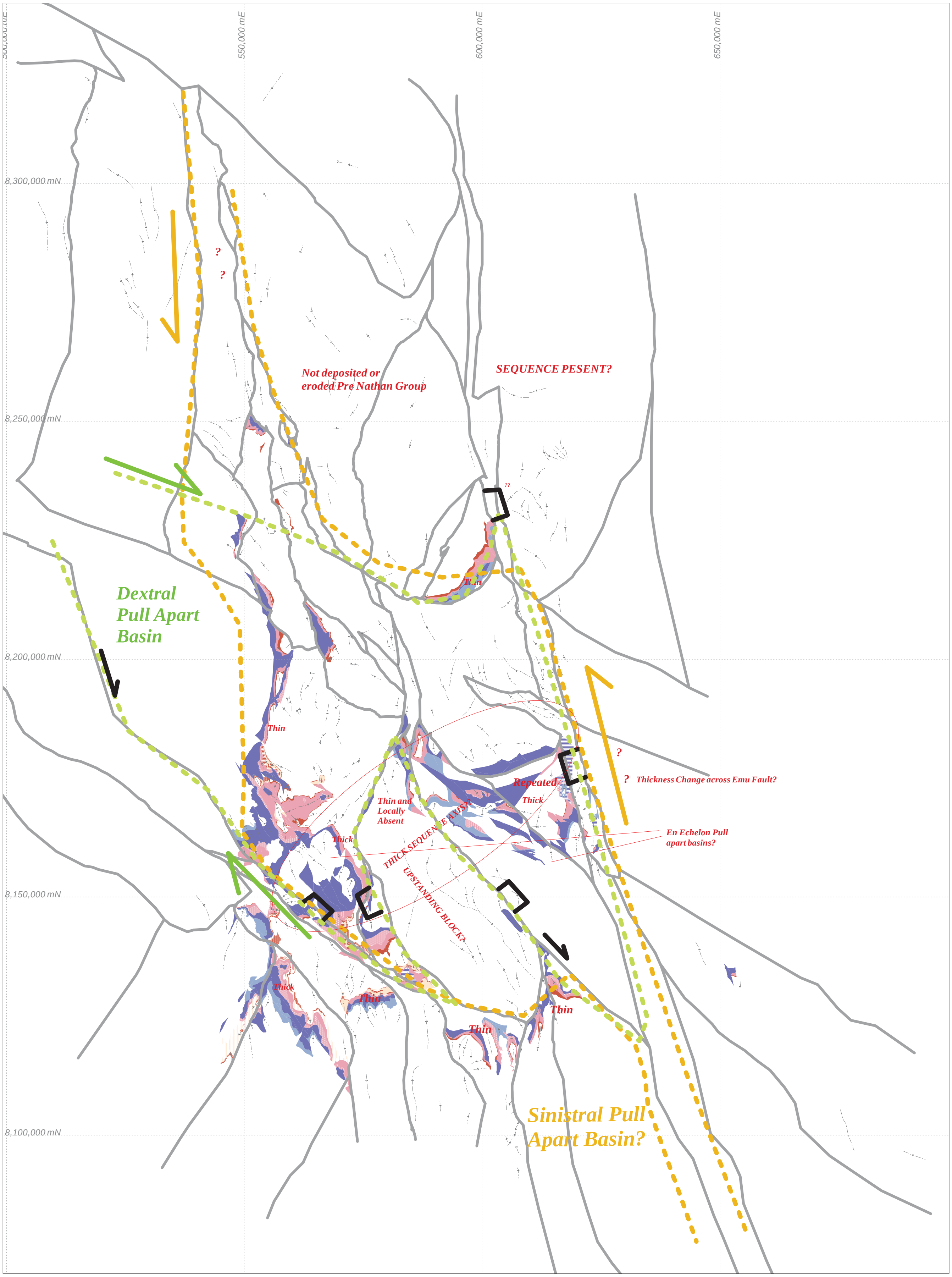


FIG. 3. Synoptic diagram showing the geochronological framework for lithostratigraphic (multicolored) and sequence stratigraphic (pink) subdivisions of southern McArthur basin rocks (Jackson et al., 1987; Page et al., 2000; Southgate et al., 2000). The refined three-fold subdivision of the River Supersequence into the Emmerugga, Barney Creek, and Lynott Depositional Sequences is discussed more fully in the text. CSB = Caranbirini sequence boundary, TSB = Teena sequence boundary. SHRIMP dates for zircons from tuffaceous beds are shown with 2σ error bars and are from Page et al. (2000).

Figure No.18 Distribution of the Emmerugga Sequence

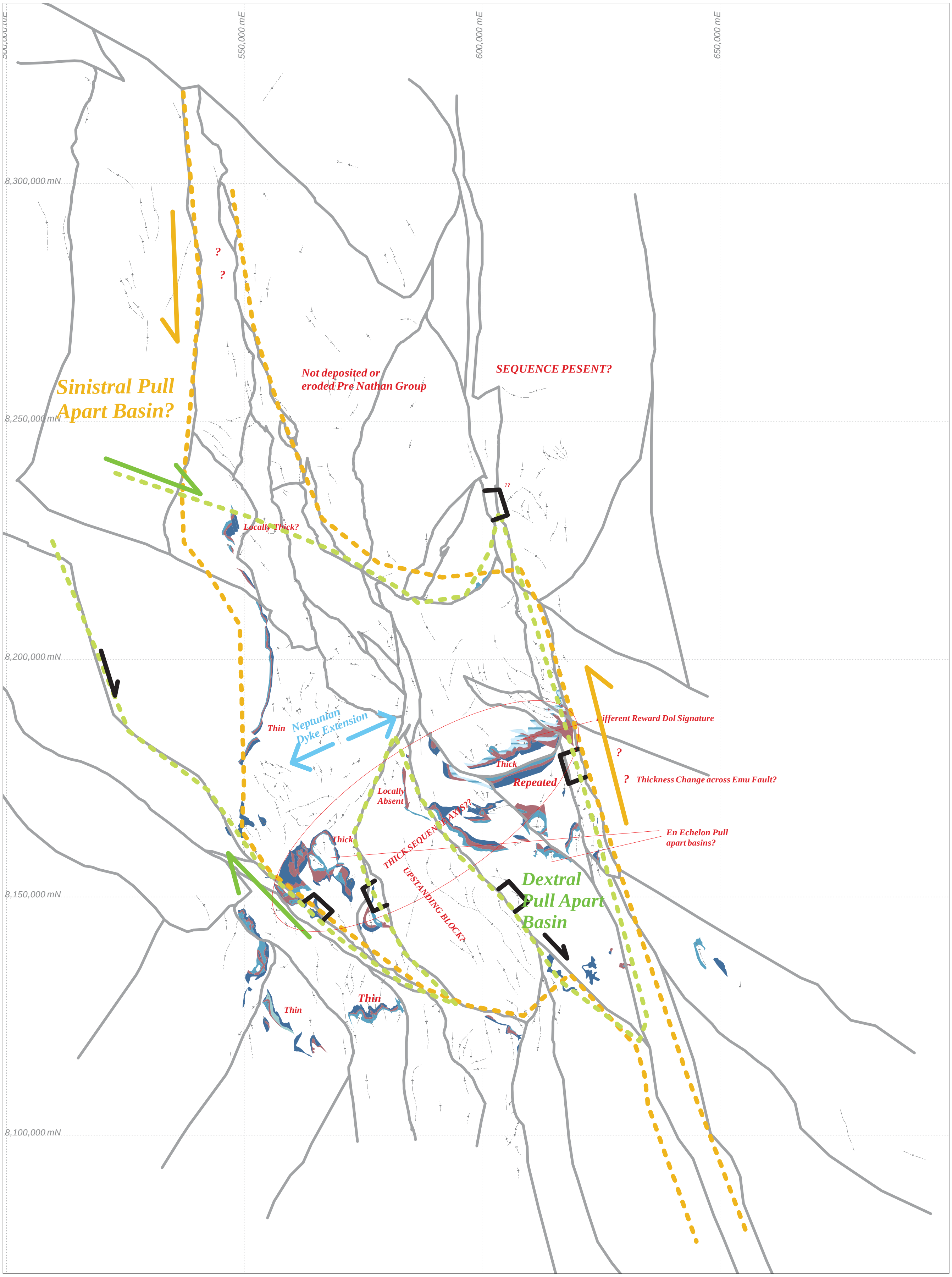


Scale 1:750,000

The Emmerugga Sequence (McGoldrick 2010) comprises the Leila Sandstone, Myrtle Shale and Emmerugga Dolomite

See Figure 10b for legend of lithologies.

Figure No.19 Distribution of the Barney Creek Sequence

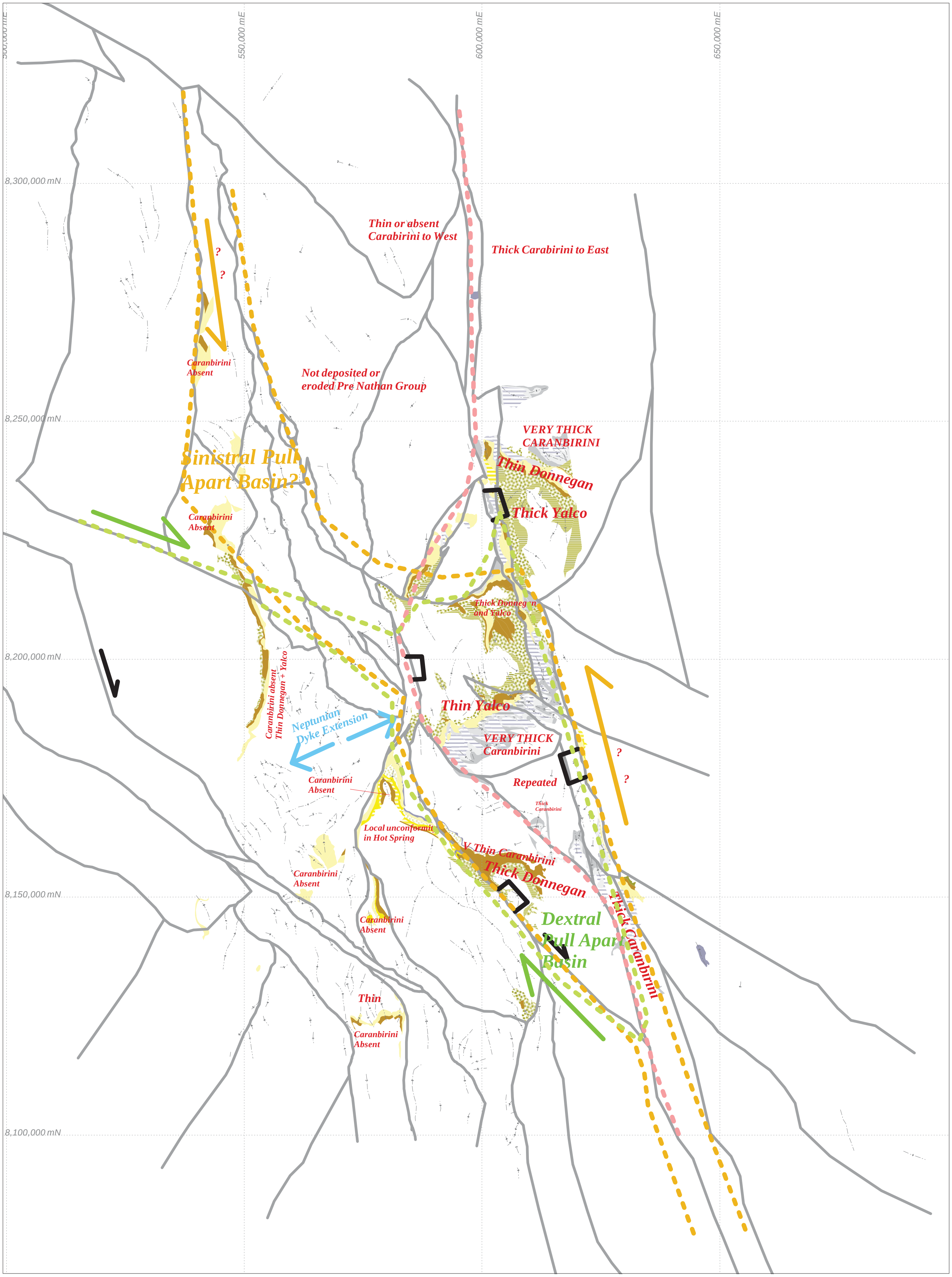


Scale 1:750,000

The Barney Creek Sequence (McGoldrick 2010) comprises the Teena Dolostone, Barney Creek Formation and Reward Dolomite

See Figure 10b for legend of lithologies.

Figure No.20 Distribution of the Lynott Sequence



Scale 1:750,000

The Lynott Sequence (McGoldrick 2010) comprises the Lynott Formation (Caranbirini Mmber, HotSpring Member, Donnegan Member) and the Yalco Formation.

See Figure 10b for legend of lithologies.

Figure No.21 Distribution of the Term Super Sequence

Scale 1:750,000

The Term Super Sequence comprises the Stretton Sandstone and Looking Glass Formation

See Figure 10b for legend of lithologies.

signature and may be more feldspathic - it is also better bedded. The units may thicken to the north.

- **Siegal Volcanics (-Pts)** - These amygdaloidal basalts are a good marker horizon, they have high radiometric and magnetic signatures and form prominent low flat valleys in the Google Earth imagery. They seem to have been extensively developed without much variation in thickness.
- **McDermott Formation (-Ptd)** - This formation shows almost the opposite distribution to the rest of the Tawallah Group in that it is thickest to the S and especially SE whilst it is absent in the north. It is probably a facies variation of the lower part of the Sly Creek Formation.
- **Sly Creek Sandstone (-Ptl)** - The Sly Creek Sandstone is also a quartz sandstone in general but it changes characters across the study area. It is more variable and thinner in the south with up to 7 sub units (-Ptl>1 to -Ptl >7) defined, some of which are recessive. The Formation thickens northwards from the Central Transfer and general becomes more massive but becoming bedded and gradational into the Aquarium Formation above in an upward fining transition (this may be of exploration interest if this represents a change from oxidising to reduced environments). The distribution of this Formation has been changed from that of the published geology and what was mapped as the Rosie Creek Sandstone Member in several areas in the north has been incorporated into the Sly Creek Sandstone as one of the sub units.
- **Aquarium Formation (-Ptq)** - This formation shows considerable variation in radiometric and Google Earth signatures and has been sub-divided into three sub-units (-Ptq>1, -Ptq>2, -Ptq>3), mainly based on radiometric signatures. The Formation is generally recessive and described as " Brown to green, dolomitic, glauconitic siltstone, shale and minor sandstone: locally hornfelsed". The glauconitic content may control the radiometric signatures and may indicate reducing conditions during diagenesis. The distribution of the Formation is generally similar to the published geology but has been expanded in many places and interpreted in some areas where it was not previously recognised. It does not appear to be present to the south of the Central Transfer although it has been interpreted in the Masterton Dome in the Emu Fault Zone. It thickens quite dramatically northward from the Central Transfer to wards what seems to have been the main depo centre for the Tawallah Group in the north of the study area (see **Figure 12**). At some 1:250,000 sheet boundaries the Aquarium Formation has been interpreted on the next sheet as the Wollogorang Formation. In some areas it is difficult to tell these units apart as they are both recessive, in some areas of the interpretation the Wollogorang is interpreted with the Aquarium Formation absent. In many places the geology data indicates the only formation above the Aquarium and below the McArthur Group is the Wununmantyala Formation - this is illustrated in the overstepping relation of the Masterton Formation in **Figure 4**.
- **Wollogorang Formation (-Pto)** - In the stratigraphic table of **Figure 4** the Wollogorang Formation is shown as above the settlement Creek Volcanics but in the maps the only place it is mapped in this position is in the extreme south of the study area. Elsewhere the Wollogorang is shown in contact with the Sly Creek Sandstone and it is this lower stratigraphic position that has been adopted in this study. In places it is difficult to differentiate from the Aquarium Formation where the later does not have a characteristic radiometric signature. The unit is recessive and described as dololutite and shale which could potentially host a CD deposit. The interpreted

distribution is quite different to that of the published geology. Its interpreted thickness is quite variable with some apparently anomalous thick areas in the north but when considered with the distribution of the Aquarium Formation there is a more uniform thickening to the north.

- **Warramana Sandstone (-Ptm)** - Much of the distribution of this unit has been reassigned to the Rosie Creek Sandstone member - only a small area has been retained in the north.

- **Rosie Creek Sandstone (-Ptlr)** - This unit represents a completely different to that depicted in the geology sheets and there is only minor overlap between the two. Unfortunately the interpretation of this unit started in the place of overlap (around 574000E, 8217000N) resulting in the divergence of interpretation. Much of this unit was previously interpreted as either Waramana Sandstone or mainly Wununmantyala Sandstone which have been reassigned. It might be worth considering a different name for this unit to avoid confusion. Three sub units were defined in the interpretation:

  - -Ptlr>1 is the lowest unit and forms smooth upstanding areas of massive sandstone with a pinkish brown colour.
  - -Ptlr>2 represents a recessive unit between the upper and lower sandstone.
  - -Ptlr>3 is a whiter and more textured sandstone unit - possibly with a high quartz sandstone content.

  All of these units have low radiometric signatures but there can be some contamination from the Settlement Creek Volcanics above. The unit is only subdivided in the north where it becomes dramatically thicker, reinforcing the interpretation of a Tawallah Growth Fault in the north (See **Figure 12**). It is much thinner or even absent in the NW.

- **Settlement Creek Volcanics (-Pte)** - These are a mixture of intrusive sills and bi modal volcanics potentially indicative of rifting. The interpreted distribution is more extensive than in the published geology as their distribution has been constrained by high magnetic and radiometric signatures. The interpreted unit represents a volcano-sedimentary package rather than the igneous material alone. **Figure 12** shows that the development of the volcanics is variable with significant volumes in the NE and S and an isolated occurrence in the area of the Central Transform indicating the early history of this zone. In the south this unit comprises the entire Tawallah Group sequence in places.

- **Tanumbirini Rhyolite (-Ptt) and Gold Creek Volcanics (-Ptg)** - Lie above the Settlement Creek Volcanics but are not always present. The extent of the Gold Creek Volcanics has been increased using the radiometric and magnetic signatures - again this probably represents a volcano-sedimentary package. The Tanumbirini Rhyolite has an extremely high radiometric signature.

- **Wununmantyala Sandstone (-Ptn)** - This is interpreted to be the uppermost formation of the Tawallah Group over almost the entire study area other than the volcanic rich southern domain. The Formation comprises two quite distinct domains:

  - A NE domain where the sandstone unit is represented by a dark brown lithology in Google Earth images with moderate bedding and only weakly resistant with some recessive areas.

- A SW domain in which the Formation is represented by two sub-units
    - -Ptn>1 - a resistant massive sandstone with grey and yellow colours
    - -Ptnw - the Wuraliwuntya Member - a darker brown resistant unit in contact with the Masterton Sandstone above.

  The domains seem to be separated by NNW trending fault zones and represent NE fining of the sequence probably into the deeper parts of the Tawallah depocentre.

The Tawallah Group is also exposed in the far west of the interpretation as an inverted inlier in surrounded by Roper Group (see **Figure 12**) the inversion seems to have taken place on en echelon reverse faults during dextral shearing on the Mallapunyah Fault and Central Transfer.

The McArthur Group

The McArthur Group (**Figure 13**) has been subdivided into Super Sequences (see **Enclosure 1**) and some sequences (McGoldrick 2010) and will be described on that basis. **Figure 4** shows that the Masterton Sandstone at the base of the Group has an over-stepping or on lapping angular relationship with the Tawallah Group below. This is slightly misleading and the angular relationship seems to be mainly restricted to the volcanic Tawallah sequence in the south with most contacts involving the Wununmantyala Sandstone. The time-space plot (Enclosure 1) indicates that there is a considerable time gap of around 35Ma between the Lower Masterton Formation and the Upper Masterton Formation. It is not clear to me why this differentiation has been made and there was no indication of such a gap encountered during the interpretation. As a consequence all of the Masterton Sandstone rocks have been assigned to the "Gun" Super Sequence.

- **The Gun Super Sequence** (**Figure 14**) - This comprises the Masterton Sandstone (-Pms), Mallapunyah Formation (-Pml) and Amelia Dolomite (-Pma). The Super Sequence as a whole seems to be thickest between the Central Transfer and the Mallapunyah Fault - local thickening in a N-S sub-basin in the south is also indicated. Thickening of the Masterton Sandstone in the NE is suggested by the units but this area of the interpretation is poorly constrained. It seems likely that this Super Sequence was present across the entire area north of the Central Transfer and has been subsequently removed by inversion. Thickening in the north of the study area is also tentatively interpreted towards the Urapunga Tectonic Ridge.
    - **The Masterton Sandstone** is quite a distinctive resistant ridge of sandstone which is quite variable in thickness. Two sub-units have been defined in places:
        - -Pms>2 - a dark brown recessive internal unit that may reflect a dolerite
        - -Pms>3 - A transitional unit to the Mallapunyah Formation of variable width which seems to represent a fining upwards unit where resistant sandstone becomes banded rather than massive. This is tentatively interpreted as much thicker approaching the Urapunga Ridge in the north.
    - **The Mallapunyah Formation** has been sub-divided into four sub-units in the central and south of the interpretation. From lowest to highest they are:
        - -Pml>1 - Bedded dark brown generally low lying - low to medium radiometrics
        - -Pml>2 - Massive buff ridge - sandstone or dolomite - variable width -

low radiometrics

        - -Pml>3 - Brown low lying weakly bedded - high radiometrics
        - -Pml>4 - Massive buff ridge - sandstone or dolomite - variable width - low radiometrics.

    These sub-units are best developed to the south of the Central Transfer. This formation is partly recessive and is described as having a shale component.

    - **The Amelia Dolostone** is quite a massive unit and its position is well defined by the Tatoola Sandstone marker above. It has a weakly conductive signature. This unit has not been subdivided.

- **The Loretta Super Sequence (Figure 15**) - According to Enclosure 1 this Super Sequence extends from the base of the Tatoola Sandstone to the top of the Mara Dolomite Member of the Emmerugga Formation. However, McGoldrick (2010) indicates that the River Super Sequence above starts at the base of the Leila Sandstone. For the purposes of this study McGoldrick's upper boundary has been adopted.

  Again the Central Transfer and Mallapunyah Fault seem to have a significant effect on the depositional distribution of this Super Sequence with thicker sequences present on the southern side of both these structures. From the distribution of the Tatoola sandstone in inliers to the north of the Central Transfer it is inferred that this sequence was present across the northern part of the study area but has been largely removed by pre-Roper Group inversion - the Roper and Nathan Group rest directly on Tawallah Group rocks. The sequence does not seem to thicken towards the Emu Fault. There is some suggestion that the Tatoola Sandstone is thinner to the east of the Tawallah Fault. The Formations and Members interpreted in this Super Sequence comprise from base to top:

    - **The Tatoola Sandstone** (-Pmd) - One of the most distinctive marker units in the Google Earth imagery. It's distribution has been modified from that of the geology maps and can be sub-divided into 3 members in the majority of the study area:

        - -Pmd>1 - the lower sandstone ridge with a high radiometric signature
        - -Pmd>2 - a recessive unit with low radiometric signature to the south of the Mallapunyah Fault but a higher signature to the north.
        - -Pmd>3 - the upper sandstone ridge member.

      The relative thickness of the sandstone ridge members is variable and often show an inverse relationship. The -Pmd>3 is thicker to the north of the Mallapunyah Fault but -Pmd>1 is thicker to the south. -Pmd>3 is thicker to the south of the Central Transfer.

    - **Tooganinie Formation (-Pmt)** - This is a distinctive well bedded unit in the Google Earth imagery and has a predominantly high radiometric signature. There is some variation that has allowed some sub-division in part:

        - -Pmt>1 - a conspicuous lower radiometric signature present at the base of the Formation between the Central Transfer and the Mallapunyah Fault. This also has a darker brown appearance similar to the Amelia Dolostone and seems to be a locally developed facies which changes thickness quite rapidly and pinches out to the south and north. It does not seem to be present to the east of the Tawallah Fault suggesting that structure was present during sedimentation.

- -Pmt>2 - A marker sandstone unit forming the top of -Pmt>1. This might indicate that -Pmt>1 and -Pmt>2 should be considered as part of the Tatoola Sandstone.
- -Pmt>3 - A rough character to the upper part of the Formation locally developed towards the Emu Fault in the south.

Once more there is not much evidence of the sequence thickening towards the Emu Fault and the most obvious changes taken place on WNW zones - the Mallapunyah Fault, the Central Transfer and possibly the southern margin to the Urapunga Ridge.

- **The River Super Sequence** (**Figure 16**) - Again there is a difference in the definition of the upper boundary to this Super Sequence between **Enclosure 1** and McGoldrick (2010). **Enclosure 1** places the boundary at the base of the Yalco Formation Whilst McGoldrick places it at the top of the Yalco Formation. McGoldrick's definition has been adopted here as we are also using his definitions of the three Sequences he has defined within the River Super Sequence. His definitions are shown in **Figure 17**. This Super Sequence clearly contains the most dramatic thickness changes in the region (See **Figure 16**), with a much more complex architecture involved, including the Emu Fault. It should be noted that this may be partly apparent as this is by far the most commonly exposed sequence to the east of the Tawallah Fault and older sequences are poorly exposed and so changes in distribution cannot be appreciated to the same extent.

  The Mallapunyah, Tawallah, Hot Spring and Emu Faults (through development of the covered Glyde Sub Basin) were active during sedimentation - activity on the Central Transfer is probable but less clear. **Figure 16** indicates the near-field extension direction (ENE-WSW) that was derived from neptunian dykes filling extensional fractures near the Gorge Prospect (McGoldrick 1010). Points noted on the distribution of units include (separate diagrams have been created for the distribution of the 3 Sequences comprising the River Super Sequences to make it easier to appreciate local changes):

  - **Emmerugga Sequence** (**Figure 18) -** This Sequence comprises from base to top:
    - **The Leila Sandstone** (-Pmi) - This resistive sandstone unit is generally thin or even absent in some places - it has a high radiometric signature. However, it has been split into 5 members where sequence thickens locally in the SW around the Mallapunyah Fault but rapidly thins to the east up to the Tawallah Fault.
      - -Pmi>1a - Red brown recessive similar to -Pmt>1 - Low Radiometric signature.
      - -Pmi>1 - Buff sandstone ridge somewhat similar to Tatoola - High radiometric signature.
      - -Pmi>2 - Dark flat and recessive - High radiometric signature
      - -Pmi>2a - Slightly recessive can have grey "Emmerugga" appearance - low radiometric signature.

        - -Pmi>3 - Sandstone ridge similar to -Pmi>1

    - **The Myrtle Shale** (-Pmf) - Generally recessive and flat but can be thinly bedded with cream coloured bands. In places a sandstone unit is developed at the top of the interval and this has been included in the interpretation as -Pmf>1 and is again thickest around the Mallapunyah Fault. Both of these units generally have high radiometric signatures.

    - **The Emmerugga Formation** (-Pme) - This form a conspicuous marker in the radiometrics images as it marks a sharp change to low signatures after an extensive sequence of mainly high signatures. However, there is some variation. In geology maps it is often split into two members and these have been retained here - from base to top they are:

        - **The Mara Dolomite Member (-Pmea)** - Massive generally exposed but generally not ridges - can be grey colours. The published geology describes it as " Ridge-forming:dololutite, stromatolitic dololutite, dolomitic siltstone, dolarenite and dolomitic breccia; columnar, domal and conical stromatolites, often forming bioherm series; common halite casts and quartz nodules after evaporites".

        - **Mitchell Yard Dolomite Member (-Pmei)** - Better bedded near Emu Fault - but more massive and textured elsewhere and more recessive. Often a very low black radiometric signature. Published geology describes it as "Generally recessive: massive, dark grey, karstic-weathering, crystalline dololutite; lacks obvious internal sedimentary structures;".

      A third sub unit (-Pme>1) has been defined near the Emu Fault where there must be some facies change present as the radiometric signature is conspicuously higher. The distribution of the Emmerugga Dolomite has been changed significantly from the published maps including the distribution of the members. The Mitchell Yard Dolomite seems to be thicker SW of the Mallapunyah Fault and approaching the Hot Spring Fault from the east. The distribution of Emmerugga is different from that of the rest of the sequence below and depo centres seem to have changed - the apparent NE trending axis of deposition through HYC seen in the sequences above may have started at this time.

- **Barney Creek Sequence** (**Figure 19**) - The three units of the Barney Creek Sequence all have prominent high radiometric signatures with a characteristic pink tinge in the image and can be traced quite readily around the study area. Unfortunately the McArthur River drainage system renders much of the area unexposed around HYC and the interpretation is often inferred. Some changes have been made to the published maps using information from the NT geology notes for the area (see maps of HYC area in **Figure 5**); the 1:250,000 and 1:100,000 maps depict some outcrops as Emmerugga but these are shown as Barney Creek Formation in local maps of the deposit.

  From base to top the Sequence comprises:

    - **The Teena Dolomite (-Pmp)** - Generally massive, slightly resistant some weak bedding buff yellow colours can be more grey and mottled in places. A sub-unit - the Cocxo Dolomite Member (-Pmpc) is recognised from the characteristic "Coxco Needles" that are commonly present but this unit cannot be readily distinguished in imagery.

- **The Barney Creek Formation** (-Pmq) - Generally poorly exposed - not obviously bedded - can be cream coloured and more resistant. Near the HYC deposit it develops the HYC Pyritic Shale Member and W-Fold Shale Member but these could not be distinguished from imagery. Surprisingly the pyritic shale does not seem to show up as a conductive unit in the AEM data. As mentioned above, the conductor identified by Sandfire Resources seems to relate to unconsolidated sediments in the creek system. McGoldrick assigns the Barney Creek Formation shales to a basinal facies created by rapid deepening on the basin. However, the distribution of units seems to suggest that this was locally variable and even though it occurred rapidly there was not an accompanying influx of coarse clastic sediment. This is compatible with a sediment starved pull-apart setting - such basins can locally accommodate rapid deepening but without associated uplift of the basin margins.
- **The Reward Dolomite (-Pmx)** - Generally massive sometimes cream coloured with an associated high radiometric signature. However, it is exposed as brown ridges around HYC which have a much lower radiometric signature and have been included as a separate member (-Pmx>1). The distribution of this unit has been significantly modified from published maps around the HYC area and a significant proportion of it has been reassigned to the Caranbirini Member above.

Quite rapid thickness variations are present in **Figure 19** and there seems to be an ENE trending axis of thicker sediments extending WSW from HYC that extends as far as the Mallapunyah Fault (Note that some structural repetition of the sequence has been interpreted in the vicinity of HYC). However, the intervening block formed by the Abner Range between the Tawallah and Hot Spring Faults seems to have been upstanding at this time and has a reduced thickness - this is confirmed by facies mapping carried out by McGoldrick (2010). At the Gorge Prospect, which lies at the southern margin of the Abner Range, McGoldrick has also mapped an erosive conglomerate unit at the top of the Reward Dolomite which is interpreted as a semi-regional break and ends of the Sequence, however, this may only represent a local feature developed in a pull-apart basin - the nearby Hot Spring, Mallapunyah and Tawallah Faults all seem to have been active at that time.

- **Lynott Sequence** (**Figure 20**) - This Sequence illustrates the increasing thickness variation of units and contains the largest variations in thickness over short distances within the study area although not all units show the significant variation. The Sequence comprises, from base to top, the **Lynott Formation (-Pmn**) and the **Yalco Formation (-Pmj)**.

  The Lynott Formation has three mapped members whose distribution has been substantially altered during the interpretation - from base to top they are:

  - **The Caranbirini Member (-Pmnc)** - Although there was significant thickness variation in this unit previously it has been increased by reassigning some areas of Reward Dolomite into this unit. The

Member has been split into 5 sub-units based on characteristic radiometric signatures in conjunction with variation in the recessive and resistant nature of the rocks. The rapid thickness variation is the result of infilling of the deeper, but sediment starved, basinal setting created during the Barney Creek Sequence. the Interpreted sub-units from base to top are:

- **-Pmnc>1** - Generally recessive and poorly exposed with a lower radiometric signature
- **-Pmnc>2** - Resistant and well bedded with low broad ridges - cream banding - similar to Donnegan. High radiometric signature.
- **-Pmnc>3** - Recessive similar to pmnc>1.
- **-Pmnc>4** - Well bedded cream and green bands forming ridges - similar to Donnegan
- **-Pmnc>5** - Generally well exposed - less well bedded light olive colours in Google earth and a high radiometric signature.

The thickness of the Caranbirini Member varies rapidly and is very thin on the flanks of the Hot Spring Fault and absent on the Abner Range and to the west of the Tawallah Fault. This is quite a different distribution to the Barney Creek Sequence. **Figure 20** indicates that it remains thick to the east of the Emu Fault - information on regional drilling will be need to see if this relationship continues to the north under cover. The pink thick dashed line in **Figure 20** indicates the approximate margin of thick Caranbirini sediments which is clearly closely associated with the Emu Fault Zone.

- **The Hot Spring Member (-Pmnh)** - Marks a return to coarser sedimentation with interbedded sandstone bands and is described as having common dessication cracks suggesting that the local basins have filled. The character of the unit varies from east to west; it is interbedded and more variable but still with a generally low radiometric signature in the east but approaching the Hot Spring Fault and to the west it becomes more massive and has a quartz sandstone appearance with a very low radiometric signature. Its distribution is different to the Caranbirini Member as it becomes thicker and develops sub-units and local unconformities over the Abner Range between the Hot Spring and Tawallah Faults. In this area it is interpreted to sit directly on the Emmerugga Formation in part and the Member has been further sub-divided through variation in radiometric signatures. To the West of the Tawallah Fault the sandstone must rest unconformably on the Barney Creek Sequence with the Caranbirini Member absent. It does not seem to show thickening towards the Emu Fault
- **The Donnegan Member (-Pmnd)** - This unit is relatively easy to recognise, although it is similar to some of the Caranbirini sub-units, from its very high radiometric signature juxtaposed with the very low signature of the Yalco Formation above. The interpretation (**Figure 20**) indicates it has a different locus of deposition to either of the Members below and is thickest beside the Hot Spring Fault. This may

be worth further investigation as this unit has been identified as having the potential to host a Pb-Zn deposit.

The Yalco Formation seems to mark a return to a similar deposition pattern to that of the Caranbirini Member with thick accumulations near the Emu Fault however, as opposed to the Caranbirini Member, it is present west of the Tawallah Fault in the north but the Nathan Group rests directly on the Hot Spring Member in the SW indicating it has been eroded prior to Nathan Group deposition or was never deposited there.

Two sub-units have been defined based on appearance in the Google Earth imagery - from base to top they are:

- **-Pmnj>1** - A massive resistant sandstone with pinkish-cream colours - very low radiometric signature.
- **-Pmnj>2** - Red-Brown recessive unit with medium radiometric signature variable to low rad and more resistant.

The River Super Sequence (**Figure 16**) marks a change in structural setting for deposition which varies quite rapidly in both a spatial and temporal sense, as illustrated for the component sequences (**Figures 18, 19 & 20**). These changes have been interpreted in terms of developing local pull-apart basins however, the geometry could be created in either of two scenarios, both of which are compatible with the ENE local extensional direction derived from neptunian dykes. Both of these scenarios are illustrated in the above figures:

- Sinistral shearing on NNW trending structures (shown as the orange dashed lines and arrows in the figures) - this seems to be more compatible with the distribution of known Pb-Zn deposits (see **Figure 26**). This is also the scenario which McGoldrick et.al. (2010) modelled (see **Figure 6**).
- Dextral shearing on WNW structures - the Mallapunyah Fault and Central Transfer (this scenario is depicted by the green dashed lines and arrows in the figures.

Deposition of the Caranbirini Member seems to have taken place during a simpler regime. It is possible that both regimes may have operated sequentially to account for the opposing deposition histories of the Caranbirini and Hot Spring Members over the Abner Range. My preference is for the dextral regime which is more compatible with the local extension direction and can more easily account for the en echelon pattern of low and high blocks defined by the HYC sub-basin, Abner Range high and depocentre between the Tawallah and Mallapunyah Faults.

- **The Term Super Sequence (Figure 21**) - This Comprises the Stretton Sandstone and Looking Glass Formation which are sandstone dominated. Less can be said about their original depositional distribution as they are only preserved below the Nathan Group in the east but they do seem to thicken towards the Emu Fault.
    - **The Stretton Sandstone (-Pmr)** - Has been subdivided into two sub-units in the interpretation:
        - **-Pmr>1** - Red-brown colours in the Google Earth imagery, thickly bedded and differentiated from the Hot Spring Member through its medium - high radiometric signature.

- **-Pmr>2** - A cream-yellow sandstone unit, which is more resistant, at the top of the Formation.

- **The Looking Glass Formation (-Pmo)** - Similar to -Pmr>2 but with a white-grey colour and a lower radiometric signature.

- **The Lawn Super Sequence**- This (as defined by Enclosure 1) only comprises the **Amos Formation** (**-Pmm**) in the study area which according to **Figure 4** is a lateral equivalent of the Looking Glass Formation, but clearly lies above it in most of the interpretation. It is generally a recessive red-brown unit.

Post McArthur Group - Pre Nathan Group Deformation

Geoscience Australia concluded from the seismic line across the Batten Trough that the "Trough" did not exist as a depositional entity and that the Tawallah Fault was a post-Roper Group structure. As discussed above, the conclusions drawn from the seismic line need to be qualified by the actual position of the line. It seems highly likely from the distribution of the River Super Sequence units that the Tawallah and Hot Spring Faults were active during deposition. There are also a number of other points that indicate that significant deformation events took place prior to deposition of the Nathan Group. These are summarised in **Figure 22**.

- The Nathan and Roper Groups rest on a range of stratigraphic units - the significant inversion of the Tawallah Group north of the Central Transfer must have taken place prior to deposition of the Nathan Group.
- The fault architecture affecting the McArthur Group rocks is clearly more complex and with larger offsets than in the Roper Group.
- The preserved fold geometries of the Nathan and Roper Groups are much more intact that those of the McArthur Group.

Many of the deformational features can be accounted for in sinistral shearing on the Mallapunyah and Central Transfer with transfer of shearing to the south via N-S orientated reverse fault segments. This allows the local, significant inversion on the HYC Emu Fault strands but not on the strands further north, which may have some component of sinistral shear. It is also consistent with the array of en echelon reverse faults developed to the south of the Mallapunyah Fault which account for the fault not continuing to the SE. In turn this suggests that the fault must also have terminated in this vicinity during deposition which may have been important in developing the Gorge Prospect mineralisation. This interpretation is aided by the fact that the gravity data indicates that the Mallapunyah Fault is of crustal scale and is coincident with a significant gravity gradient. The gradient may have initially been created in near N-S extension when the fault had a normal character - this is consistent with the depositional geometry of the pre- River Super Sequence rocks. Sinistral shearing on the WNW structures also accommodates the reversal in transport direction across the Central Transfer.

There is also an apparent large scale (in the order of 20km) sinistral offset of the Yalco Formation across the Emu Fault. As the rocks generally dip gently north this could be accounted for by either west-side-down movement or a component of sinistral strike slip on the Emu Fault. The former is incompatible with post Roper Group movement on the Emu Fault which is west-side-up. The sinistral shearing could also account for some significant NE trending reverse faults that repeat the sequence (including the Barney Creek Sequence to the

Figure No.22 Structural model for deformation event post McArthur Group - Pre Nathan Group deposition

Scale 1:850,000

Solid Geology

south of HYC) immediately to the west of the Emu Fault.

Nathan and Roper Group Deposition

Although the Nathan Group is sometimes not preserved below the Roper Group unconformity there is not thought to have been a significant deformation event separating their deposition. No significant angular unconformity is present, however, some deformation must separate them as the higher Nathan Group Formations in the outlier west of HYC are not symmetrical about the Roper Group which is deposited on Balbirini Dolostone. The distribution of the preserved Nathan and Roper Group rocks is shown in **Figure 23**.

The following Nathan Group units have been included in the interpretation:

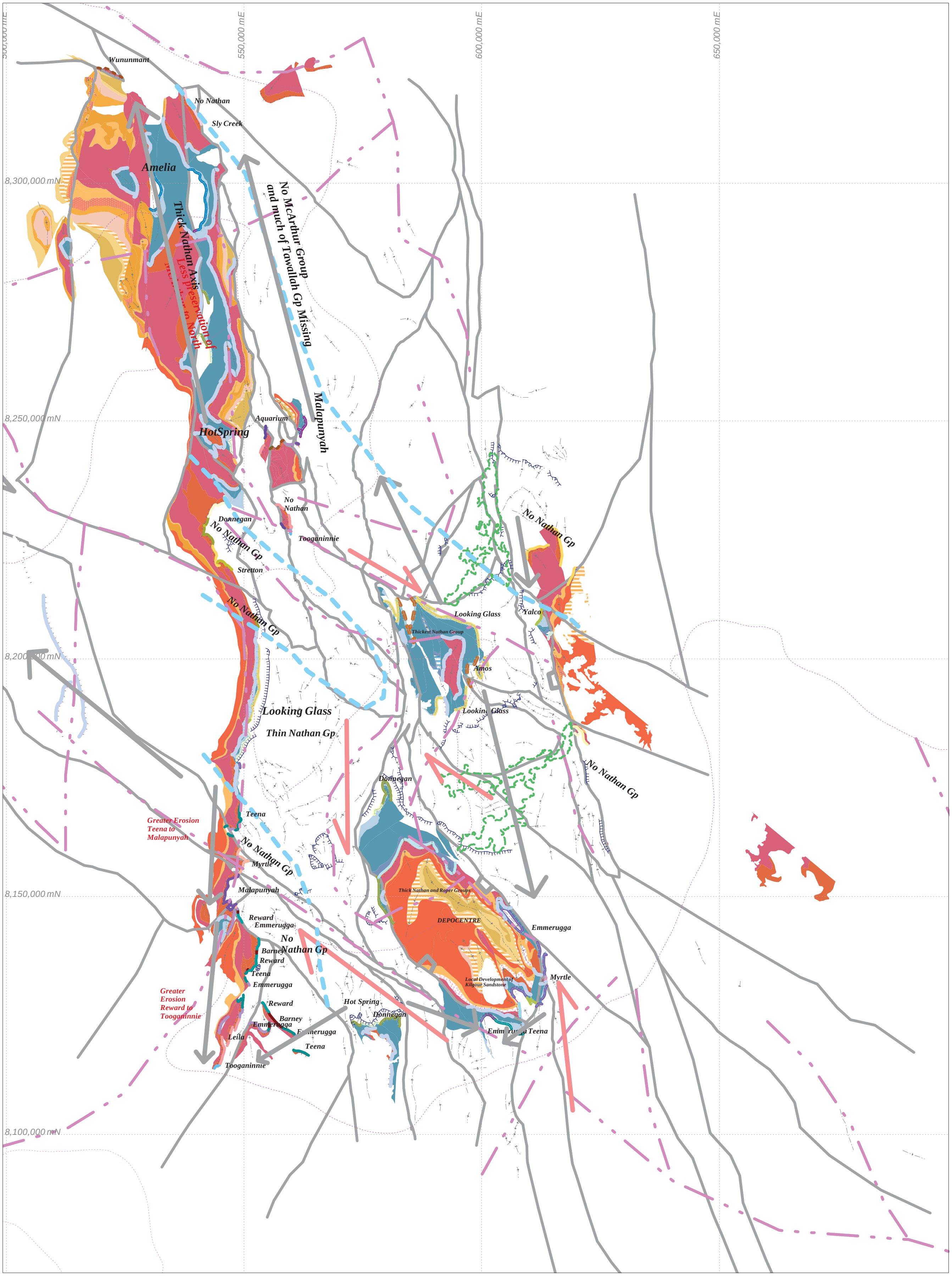
- **The Smythe Sandstone (-Pny)** - This is the basal coarse clastic sequence to the Nathan Group. It's extent has been expanded in comparison to the published maps but in some localities it is absent. It is a conglomeratic sandstone that crops out as thickly bedded sandstone ridges but is more massive in the west. It has a very low radiometric signature.
- **The Balbarini Dolostone (-Pnz)** - Generally poorly exposed and recessive it has been dated as the equivalent time slice to the Lawn Hill Formation hosting the Century deposit. It's radiometric signature is generally low but seems to become higher to the south. It is conductive in the AEM data. The Century mineralisation and deposition has been modelled as occurring during sinistral shear on the Termite Range Fault. This is more compatible with the post McArthur Group deformation scenario of **Figure 22** than the Syn-Nathan deposition presented in **Figure 23**.
- **Dungaminnie Formation (-Png)** - Only preserved on the northern margin of the Abner Range and in the outlier to the north.
- **Mantungula Formation - (-Pnn)** - This Formation was included in the Roper Group previously but as it is a fine grained unit and is only preserved locally below the coarse Limmen Sandstone of the Roper Group it seems to me to make more sense that this would be part of the Nathan Group.

Figure 23 indicates that the preserved thickness of the Nathan Group is widest in a NNW trending axis through the study area which includes the Abner Range and is greatest around the northing of HYC as the upper Nathan Group Members are preserved, which is also approximately the locus greatest preserved thickness of the McArthur Group rocks. The grey arrows in **Figure 23** indicate the direction of aging of the contact relationship between the McArthur Group and the Nathan/Roper Groups. This increases south, north and west away from the area of the Central Transfer. The Nathan Group may be a sag sequence, thickest along the axis of the Batten Trough.

The Roper Group has only been interpreted in enough detail to define the outcrop extent of the McArthur Group and to cover the N-S trending faults defining the Batten Trough as it is not considered to be prospective. The Formations and Members include, from the base upwards:

- **The Limmen Sandstone (-Pri)** - A good resistant, ridge-forming marker described as "fine-grained, structureless quartz arenite with clay clast imprints and minor ripples and cross-beds". It has a very low radiometric signature but is magnetic in the tilt image.
- **Mainoru Formation (-Pru)** - Recessive and described as " red-brown micaceous

Figure No.23 Syn Nathan and Roper Group deposition features



Scale 1:750,000

Distribution of Nathan Group and Roper Group rocks. Roper Group unconformity has been labelled with the underlying McArthur Group Formation. Grey arrows indicate the direction of increasing age of the unconformable relationship. These increase to the north, south and west away from the HYC area.

siltstone to very fine-grained sandstone, minor thin beds of dolomitic siltstone and light purple mudstone, uniform laminated light green to light purple micaceous siltstone to muddy siltstone, minor glauconitic fine-grained sandstone and siltstone". It is the strongest conductive unit in the AEM imagery. Although the "red-brown" colours might indicate an oxidised sequence the presence of glauconite suggests diagenetic alteration from biotite under reducing conditions - possibly increasing its exploration potential. In the southern part of the Abner Range outlier a thick sandstone member is locally developed at the top of the Formation - this is:

  - **The Kilgour Sandstone Member (-Prg)** - The local development of this unit suggests that the Roper Group of the Abner Range was forming in a sub-basin.

- **The Crawford Formation (-Prr)** - Described as "Ridge-forming: red-brown, fine-grained, micaceous sandstone and siltstone with minor mudstone beds, glauconitic sandstone, feldspathic sandstone; planar, trough and hummocky cross-beds, mudstone intraclasts and clast imprints, mudcracks". It has a characteristic high radiometric signature and also a significant magnetic character in the tilt image.

- **The Abner Sandstone (-Pra)** - Has often been split into its component members in the interpretation but is sometimes not sub-divided. From base to top the Members are:

  - **The Arnold Sandstone Member (-Prax)** - "Ridge-forming: pseudo-karstically weathered, strongly jointed quartzarenite; medium-grained, well sorted, predominantly 10-30 cm thick cross-bed sets".

  - **The Jalboi Member (-Praj)** - "Recessive: interbedded red mudstone, ferruginous quartz sandstone, granule matrix-supported conglomerate, clean medium-grained quartz arenite, very fine-grained micaceous quartzarenite with synaeresis cracks and hummocky cross-beds".

  - **The Hodgson Sandstone Member (-Prah)** - "Ridge-forming: pseudo-karstically weathered, strongly jointed quartzarenite, medium-grained, well sorted, rare thin quartz granule beds; planar and trough cross-beds".

- **The Corcoran Formation (-Pro)** - "Recessive: interbedded pale purple and pale green mudstone, siltstone and fine-grained sandstone; mudstone intraclasts and clast imprints, mudcracks, convolute sandstone beds". The unit has a low radiometric signature. The base to the formation is sometimes formed by a separate sandstone member:

  - **The Munyi Member (-Prom)** - "Fine to coarse grained sandstone and mudstone; Basal and near basal thin granule conglomerate beds"

- **The Bessie Creek Sandstone (-Pre)** - A good white sandstone ridge marker "Ridge-forming: pseudo-karstically weathered, strongly jointed quartzarenite; feldspathic and ferruginous in places; predominant planar cross-beds, ripple marks". Has a very low radiometric signature.

- **The Velkerri Formation (-Prv)** - This is the highest Roper Group Formation recognised in the interpretation (although it is not formally recognised in the maps) and is described as "Flaggy, fine-grained sandstone and siltstone, commonly micaceous".

Regionally, the main Roper Group depocentre is recognised as lying west of the exposed McArthur Group which thickens in the opposite direction to the east so there does not seem to be a simple rift-sag relationship between the two. The sequence in the Abner Range seems to be thicker and has the locally developed Kilgour Sandstone Member - this area was an upstanding block during upper McArthur sedimentation. The situation seems to have reversed during Roper Group sedimentation but could still de accounted for in dextral strike slip on the Central Transfer and Mallapunyah Faults as illustrated in **Figure 23**. The outlier to the west of HYC may have developed in a similar setting.

Post Roper Group - Pre Cambrian Deformation

Elements of post Roper Group deformation have been depicted in **Figure 24**. To the west of the study area the main structural grain of the Roper Group is approximately E-W but gradually rotates to N-S under the influence of the N-S faults associated with the Batten Fault Zone. There is relatively little shortening with dips less than 15 degrees common. However, close to the main faults (including the Emu Fault) beds can be sub-vertical and the dip slip components on faults increase to the east indicating inversion of the Trough was still ongoing. The following features have been noted:

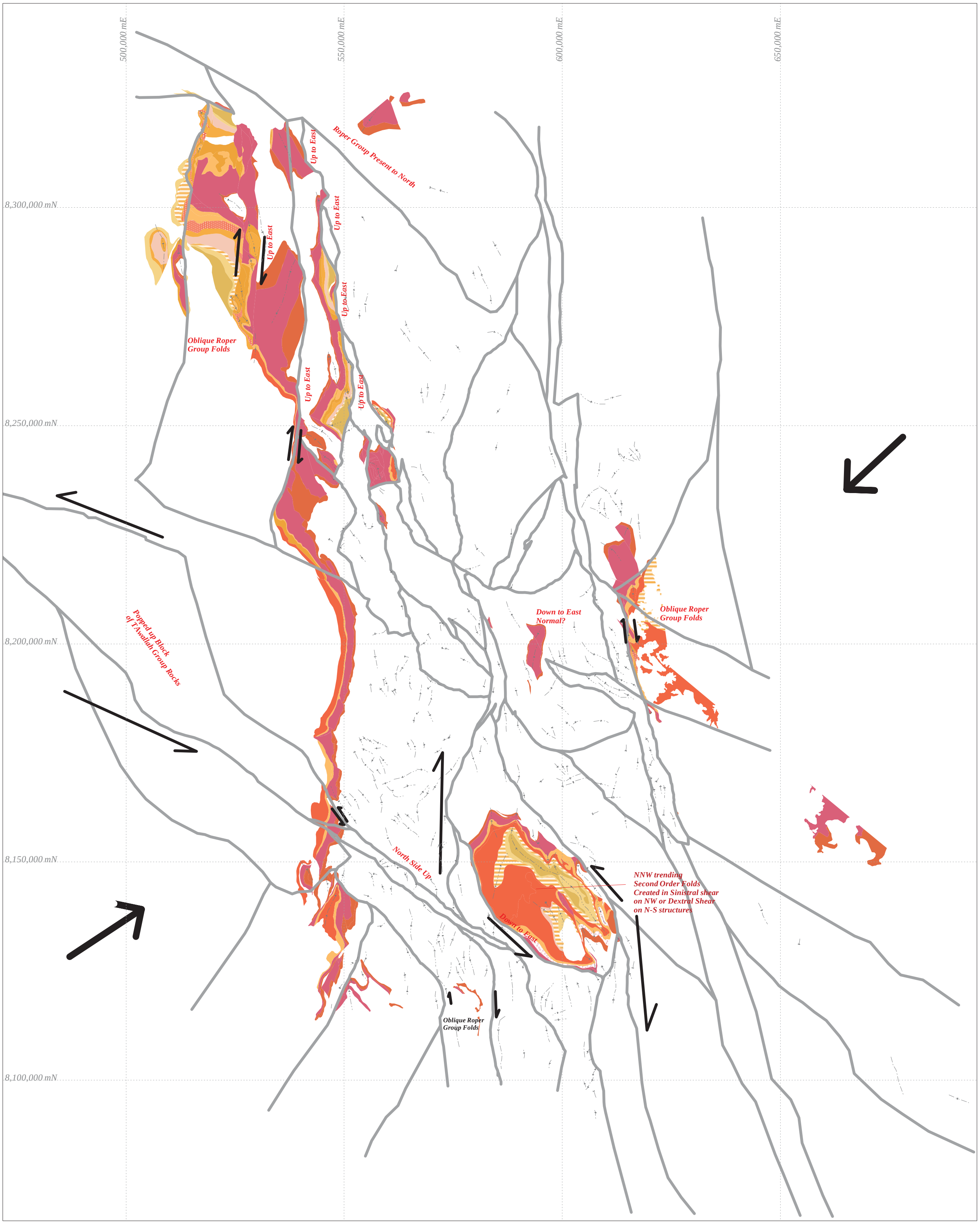
- There is a clear dextral component on the N-S trending faults as second order, en echelon folds are developed.
- The N-S faults accommodate ongoing inversion of the McArthur Group; faults to the west have a east-side-up component whilst the Emu Fault has a west-side-up component.
- A reversal of the dextral shear on WNW faults invoked to create the Roper Group pull-apart basin of the Abner Range. Sinistral shear on WNW structures now creates NW trending folds in the Abner Range and reverse faults on its NE and SW margins.
- The Mallapunyah Fault does not significantly offset the Roper Group, however, this may be apparent with the sinistral fault slip vector lying close to the intersection of the fault and the gently west dipping bedding.

These features suggest a NE-SW directed shortening direction was in operation (**Figure 24**).

4 Target Selection and Conclusions

The interpretation resulting from this report shows that basin and sub-basin development is far from simple and that both the NW and NNW trending fault systems have played an important role during deposition, mineralisation and deformation. The WNW trending Mallapunyah and Central Transfer zones are fundamental structures (**Figure 25** gravity image). WNW trending structures could be interpreted as the main orientation controlling gross early basin formation in a sinistral shear system with the E-W Murphy and Urapunga Ridges left as upstanding highs with extensional faults forming their margins (see **Figure 25**). This would also be compatible with the early extensional history of more E-W segments Mallapunyah Fault and Central Transfer during early McArthur Group deposition. This system was briefly reversed to a dextral control during the deposition of the River Sequence around McArthur River and HYC mineralisation. Formation of the HYC sub-basin involved the interaction of these faults with

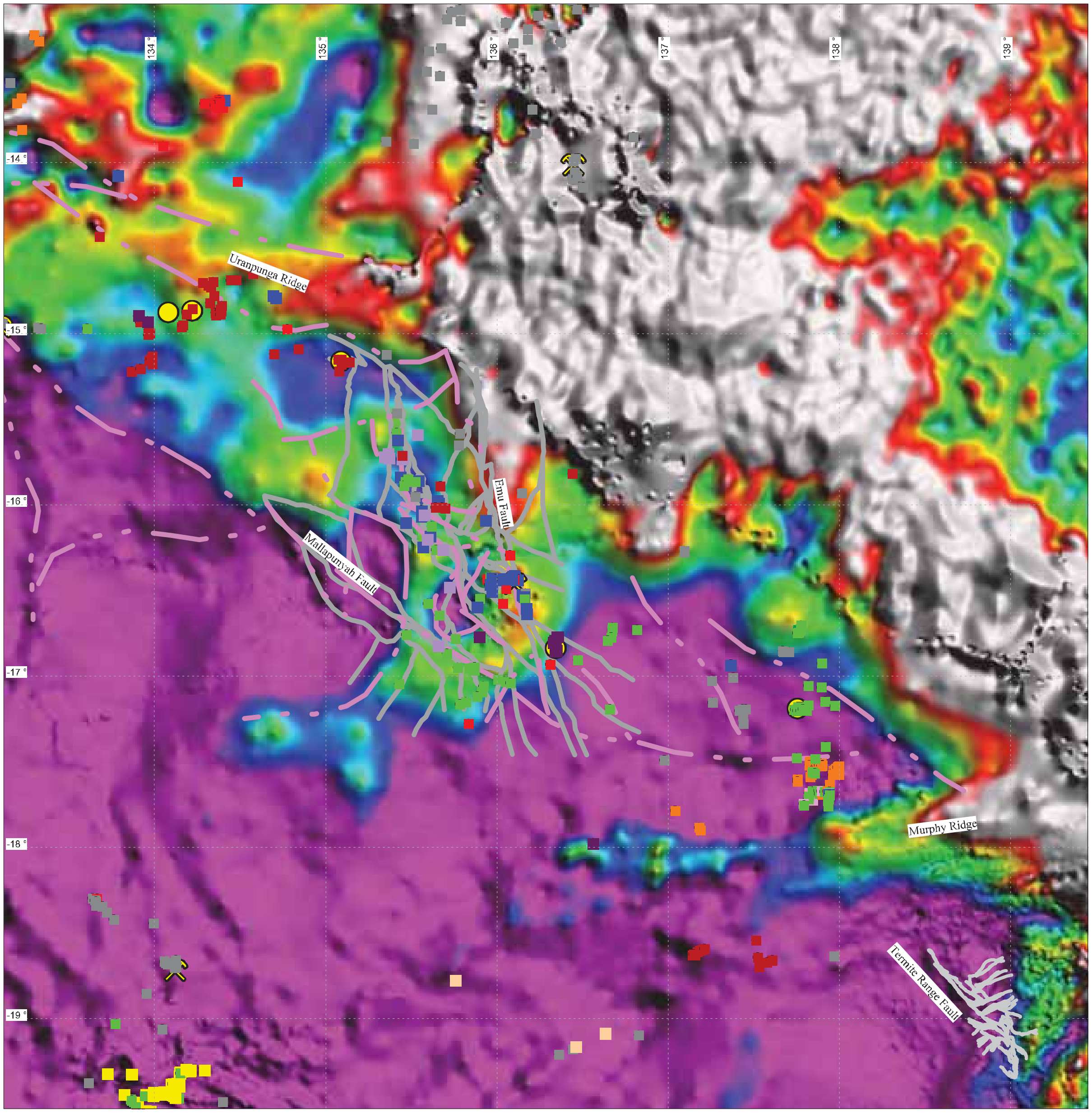
Figure No.24 Structural model for Post Roper Group deformation



Scale 1:850,000

Figure No.25 Bouger Gravity Image

Scale 1:4,000,000



Bouger gravity image showing the interpreted block boundaries around McArthur River and the main fault from the interpretation around Century. The Malapunyah Faultis a fundamental structure with associated gravity gradient.

Solid Geology

the Emu, Tawallah and Hot Spiring Faults, all of which are also implicated as having an early history (although this is harder to prove for the Emu Fault). In order to identify prospective areas for further exploration it is necessary to define the main structural block bounding zones from interpreted major structures and changes in the interpreted geology. The interpreted blocks are presented in **Figure 26** along with known deposits and mineral occurrences. There seem to be two main clusters of deposits:

- Cu only occurrences to the south of the Central Transfer and west of the Emu Fault - this is likely to be misleading - the Gorge Prospect lies in this domain and the interpreted early history of the Mallapunyah Fault should mean this structure is also prospective for Pb-Zn.
- Pb-Zn deposits which seem to transfer from the Emu Fault in the south via the Central Transfer Zone to the Four Archers Fault System in the west. These deposits also seem to be coincident with more complex zones of smaller structural blocks.

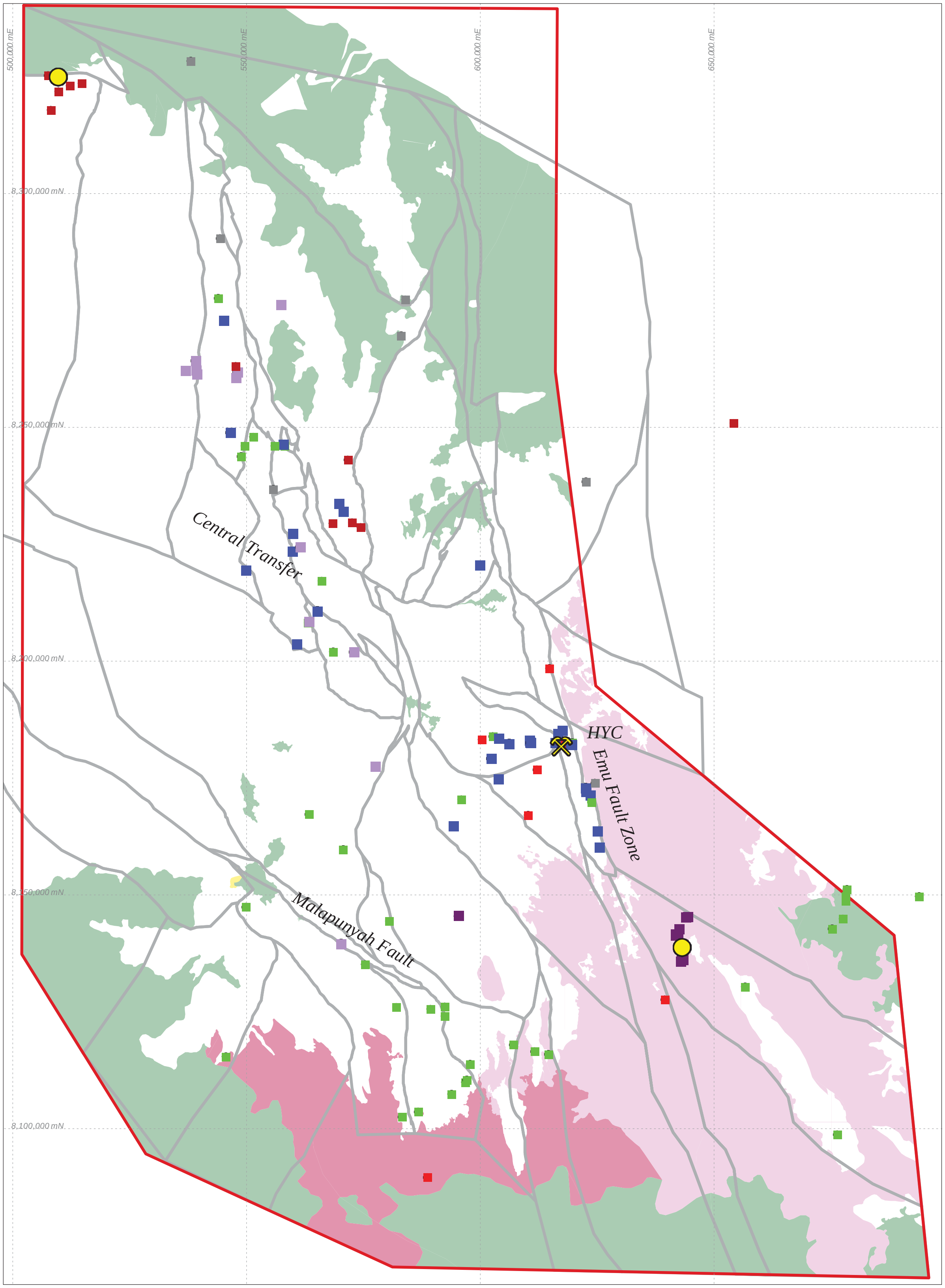
It is highly likely that a significant deposits will lie within 1-2km of these defined block boundaries (note that some of the boundaries are under Cretaceous or Cambrian cover and so their absolute position is not as well constrained or any small scale block complexities that cannot be resolved under cover.

A number of parameters have been tagged to the polygons in this interpretation enabling them to be mapped. These may aid the understanding of lithology distribution and help select target areas. They are presented below along with other compilations that may be useful:

- **Distribution of recessive units (Figure 27)** - This diagram shows the distribution of recessive units from the Tawallah to Roper Group stratigraphy relative to the interpreted block architecture. Selected target areas are superimposed which include those related to recessive lithologies in interesting structural settings. The target descriptions are listed in **Figure 32**.
- **Shale as primary lithology (Figure 28)** - This only contains the Barney Creek Formation and the Mallapunyah Formation. The definitions are from the published mapping. From the Google Earth appearance of the Mallapunyah Formation it doesn't seem likely that a large proportion of it would be shale dominant.
- **Lithologies with evidence for evaporites (Figure 29)** - Initially units were tagged for those that had evidence for evaporites in the their description fields in the published geology. However, so many units have such evidence that it is probably of limited use. The Colourmap table can be queried to see which units were selected.
- **All interpreted faults with mineral occurrence data (Figure 30)** - This diagram better illustrates the interaction of the NNW Batten Trough structures and the zone of WNW structures associated with the Central Transfer and Mallapunyah Faults. It also gives a better appreciation of the Central Transfer continuing to the SE as a more cryptic zone of structures but which still define a zone, as well as the lozenge shaped blocks that are formed through the interaction of the two trends - one of these being the HYC sub-basin. It could be argued that the Pb mineralisation is associated with two separate rhomb shaped blocks.
- **Block Dip Summary (Figure 31)** - A summary of the general dip direction of the defined structural blocks to help give an overall appreciation of the architecture. This illustrates that there is a change from generally SW and W dipping blocks to the south of the Central Transfer to East dipping blocks to the north.

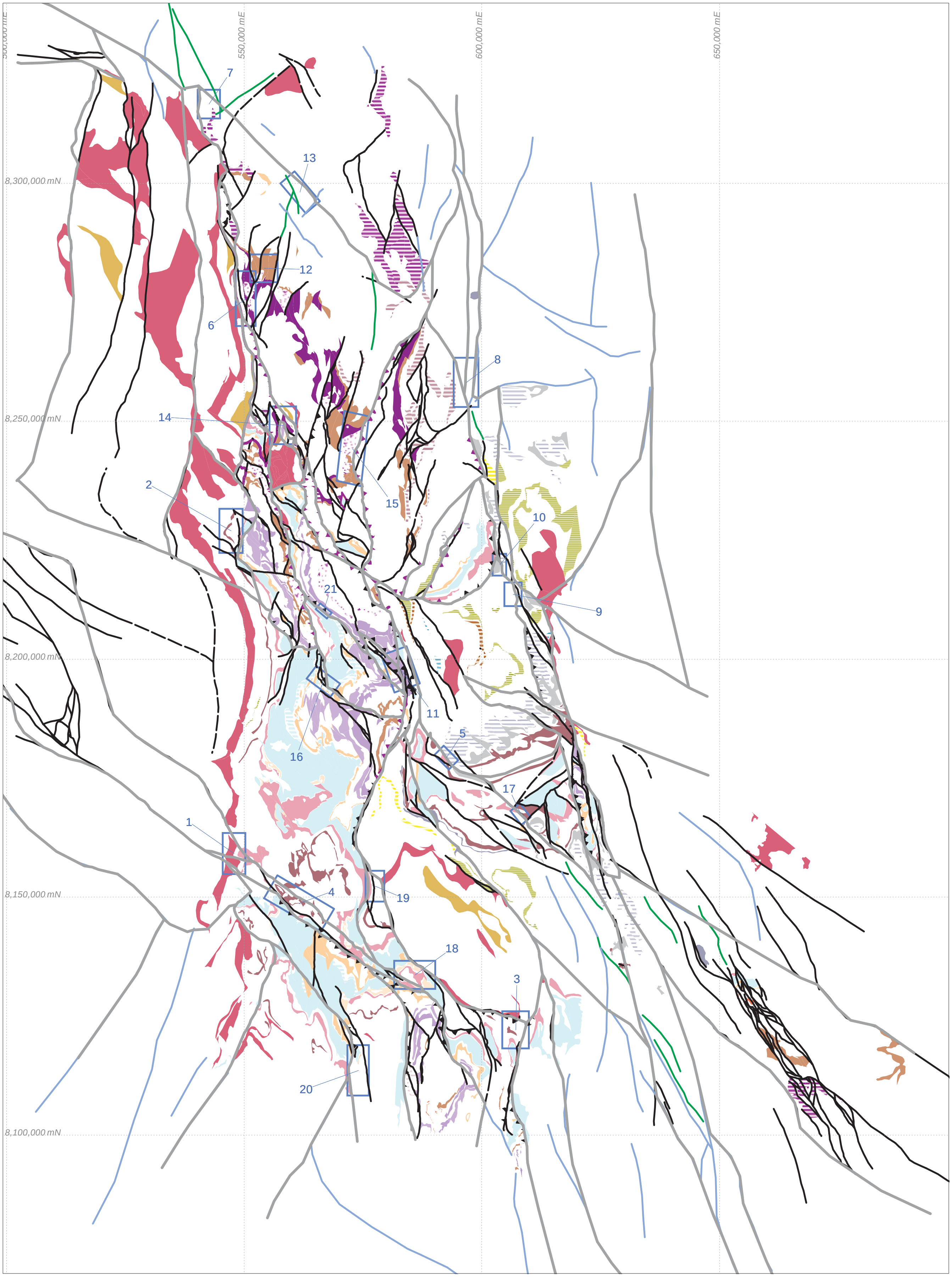
Figure No.26 Interpreted structural block boundaries with mineral occurences and deposits

Scale 1:1,200,000



Mineral occurrence collours, Blue (Pb), Red (Zn), Dark Red (Fe), Green (Cu), violet (Ba), Dark Purple (Diamonds)

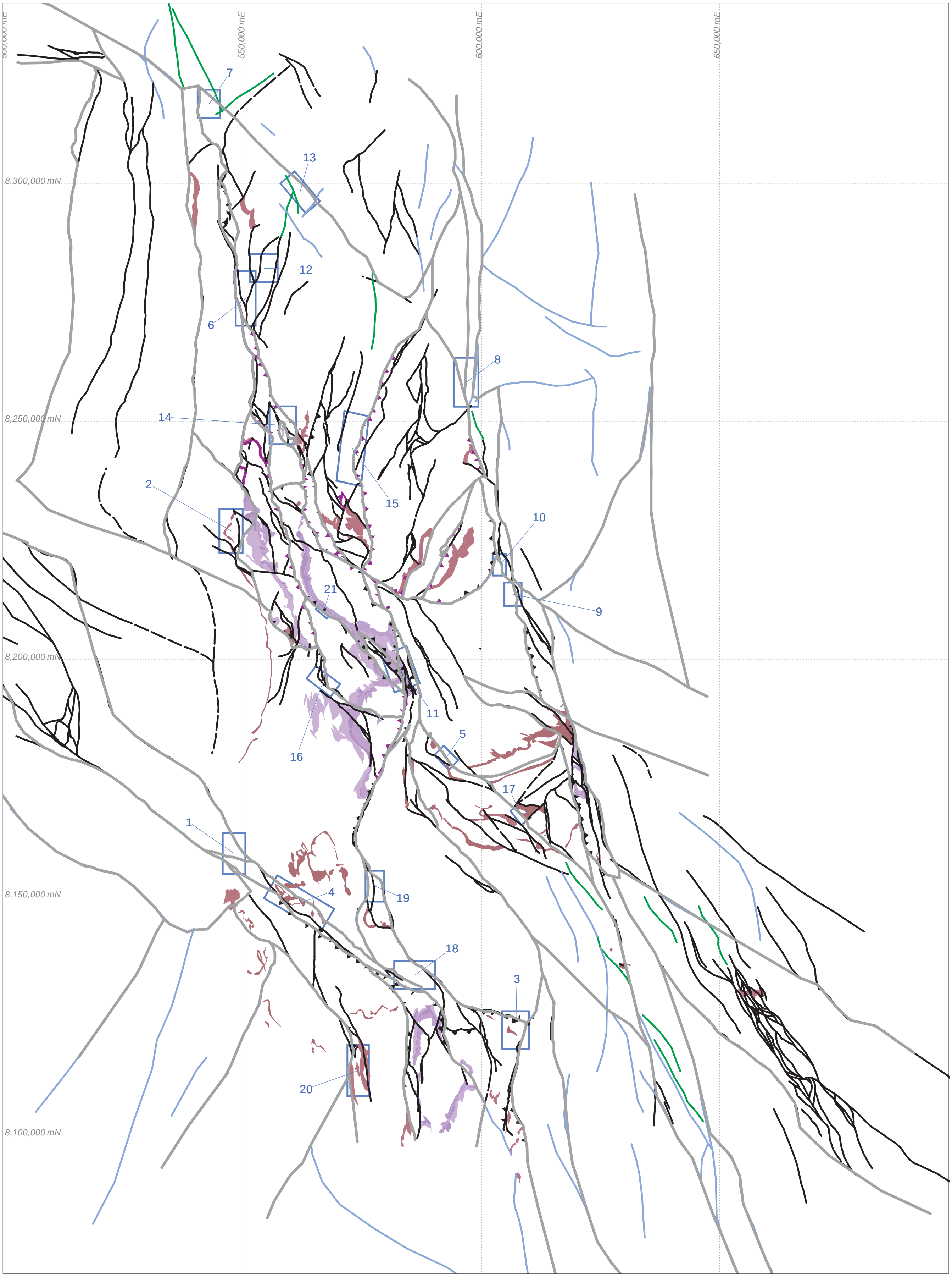
Figure No.27 Distribution of recessive lithologies and target areas



Scale 1:750,000

See Figure 32 for target descriptions

Figure No.28 Distribution of units with shale as primary lithology

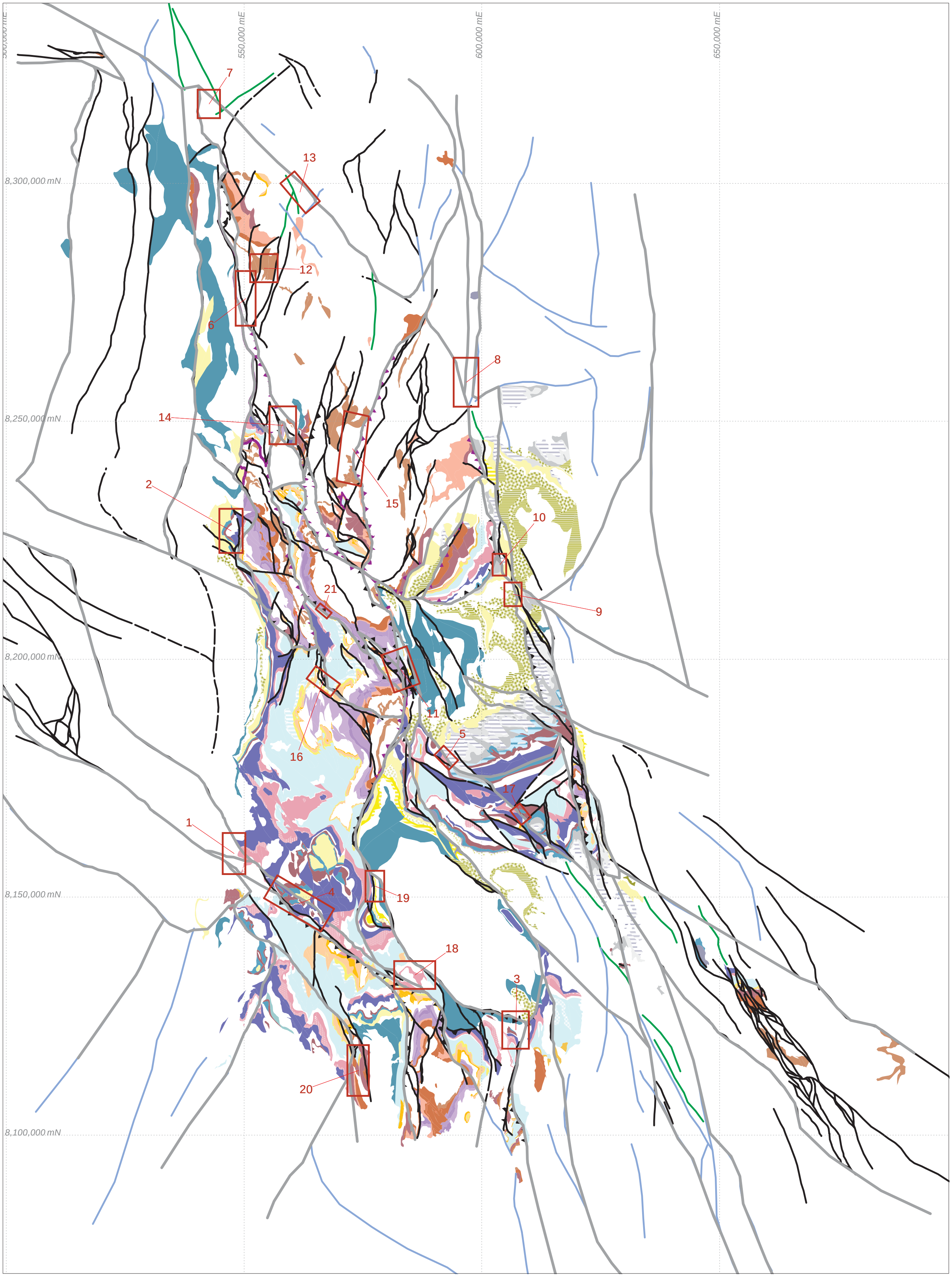


Scale 1:750,000

A query of units with shale as primary lithology only selected the Malapunyah Formation and the Barney Creek Formation. Target areas are supperimposed.

See Figure 32 for target descriptions

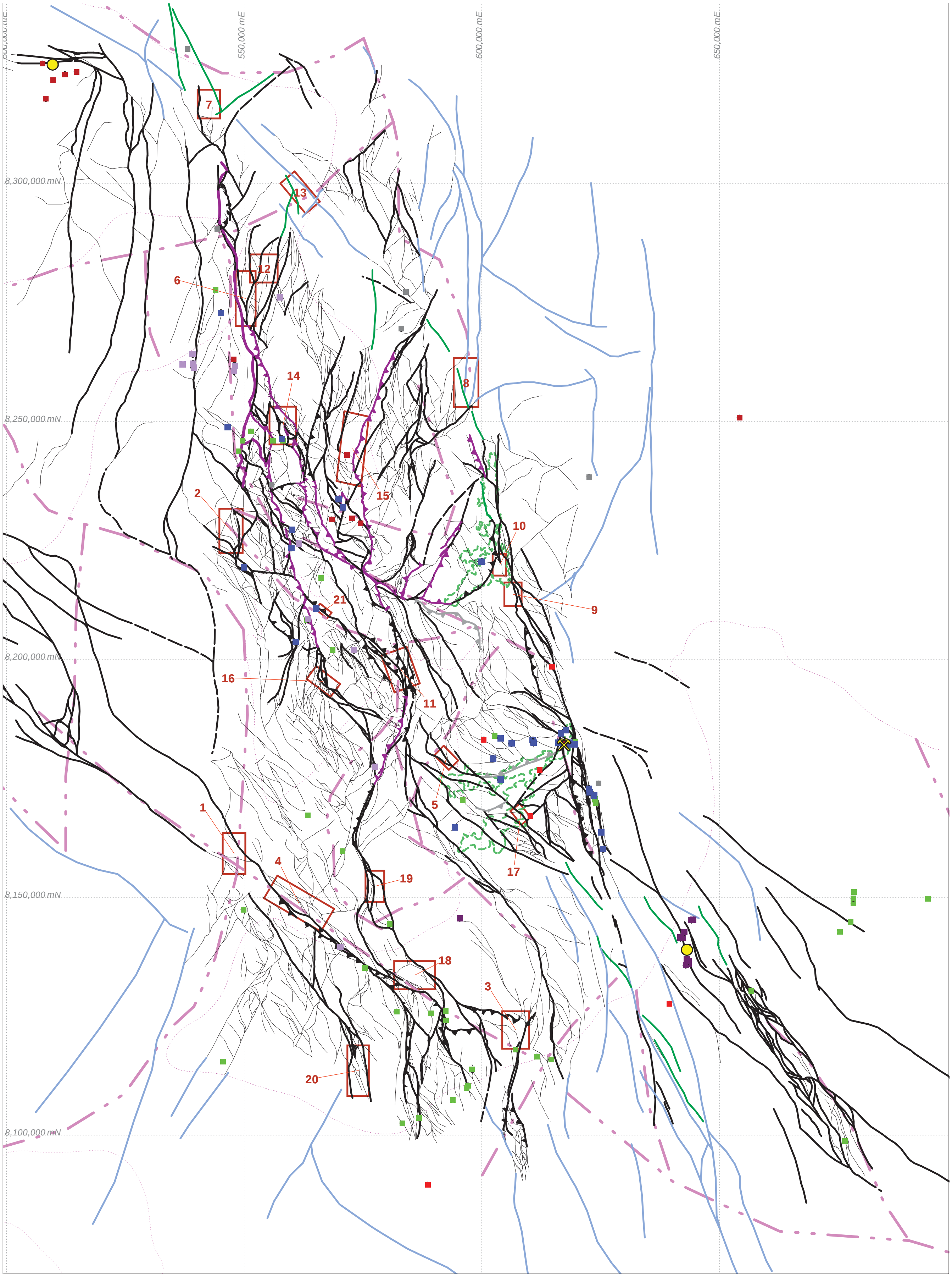
Figure No.29 Distribution of lithologies with evidence for evaporites - target areas superimposed



Scale 1:750,000

See Figure 32 for target descriptions

Figure No.30 All interpreted faults with deposits and target areas



Scale 1:750,000

See Figure 32 for target descriptions

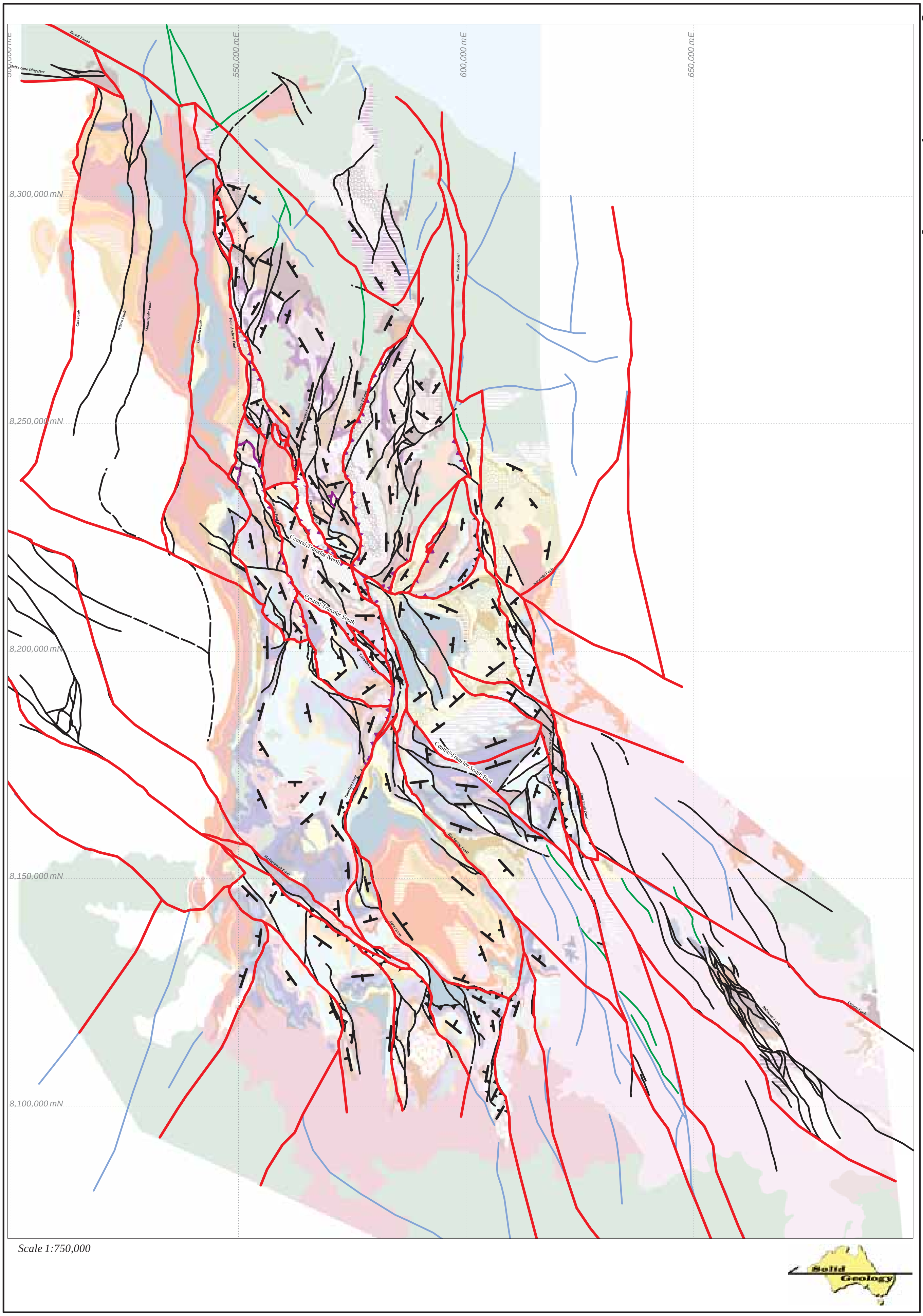


Figure No.31 Summary of internal dips of structural blocks

Figure No.32 Target descriptions

Target_N	Target_Name	Target_Type	Host_Unit	Rank	Target_Description
1		Recessive lith on Fault	Mainoru Formation	3	If the Mainoru Formationwhich is recessive and conductive is prospective then wherethe Malapunyah Fault Crosses it seems the most likely target area
2		Barney Creek Sequence	Barney Creek Formation	2	Barney Creek Sequence within the Central Transfer Zone with locally thickened Teena Dolomite
3		Barney Creek Sequence	Barney Creek Formation	2	Contains Gorge Prospect - likely to be sub-basin developed to terminate Malapunyah Fault to the SE
4		Barney Creek Sequence	Barney Creek Formation	1	Thickened Barney Creek Sequence against Malapunyah Fault Which seems to bound thickness change, may also be slight releasing bend on Malapunyah in dextral shear
5		Recessive lith on Fault	Caranbirini Member	1	Potential rapid thickness change of Caranbirini Member across SE trending fault - similar setting to HYC on Hot Spring Fault
6		Recessive lith on Fault	Aquarium Formation	3	Thickened Tawallah Group in north against major fault.
7		Recessive lith on Fault	Aquarium Formation	2	Major fault interaction with thickened Aquarium Formation - under cover
8		Fault Interaction	?	2	Interaction of Emu Fault strand, with strike change, with southern marginal fault to Urapunga Ridge - host lithology unclear - under cover
9		Fault Interaction	Caranbirini Member	1	Linkage structure on Emu Fault - smae position in Caranbirini Member as HYC - target at depth below Hotspring Member
10		Fault Interaction	Caranbirini Member	1	Interaction of Emu Fault with significant NE structure and change in strike to new strand of Emu Fault.
11		Fault Interaction	Mallapunyah Formation	3	Complicated splay intersection of Tawalah and Central Transfer with thickened Mallapunyah Fm as recessive unit
12		Recessive lith on Fault	Wollogorang Formation	3	Locally thick Wollogorang Formation? On faulted zone but away from block boundary.
13		Fault Interaction	?	3	Under Cover - Interaction of NNE faults with potential growth fault for Tawallah Group on
14		Recessive lith on Fault	Aquarium Formation	2	Aquarium Formation and Wollogorang Fm in complex fault setting on major block bounding faults with Pb-Zn
15		Recessive lith on Fault	Wollogorang Formation	2	Wollogorang Formationand Aquarium Fm intersect block boundary with change in fault strike and potential thickness change across fault.
16		Recessive lith on Fault	Tooganinie Formation	3	Possible secondary linkage from Central Transfer to Tawallah Fault with basal Tooganinie unit present intocating thickening.
17		Barney Creek Sequence	Barney Creek Formation	1	Thick Barney Creek Formation against fault localising thickness changes
18		Recessive lith on Fault	Myrtle Shale	3	Potential linkage Basin between Mallapunyah Fault and the Tawallah Fault. Similar High Rad Emmerugga signature to around the Emu Fault.
19		Recessive lith on Fault	Donnegan Member	2	Bend in fault margin which affects Hot Spring Member thickness - target in Donnegam Membr at surface and Barney Creek Fm at depth
20		Shale lith on Fault	Mallapunyah Fm	3	Thicker mallapunyah Fm beside block bounding fault.
21		AEM conductor	Mallapunyah Fm	1	Anomalous conductor beside fault in normally unconductive Mallapunyah

The WNW trending Mallapunyah Fault and Central Transfer Zone had a much more important role to play during deposition, mineralisation and deformation than has perhaps previously been appreciated - the gravity data indicates they are fundamental structures and coherent with the gross structural architecture at Century. The Batten Trough must have been a failed rift which was subsequently inverted - the Geoscience Australia seismic line was poorly positioned to make any conclusion about the Batten Trough as a whole. The extent of the McArthur Group to the east of the Emu Fault needs to be better constrained - is there a structural basin margin further to the east?. The Tawallah Group is mapped 150km east of the Batten Trough and the passive margin that may be associated with Isa Block extension could be 500km to the east making the Batten Trough an intracratonic rift, although extensional zones associated with passive margins can approach that width in some circumstances.

Further work is required to:

- Constrain the thickness of cover in the uninterpreted areas of the map
- Add information from stratigraphic drilling to constrain the geology east of the Emu Fault and add the information for the Glyde Sub-Basin.
- Augment the deposit and mineral occurrence data with drilling results from company web sites (Sandfire Resources, Brumby Resources and others).

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