Volume 1

Report following 1:20,000 Scale Mapping of the Helen Springs and Renner Springs Tenement Areas (Northern Territory)

by

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for

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KEY POINTS

- Two areas totalling 300 km^2 have been mapped at a scale of 1:20,000.
- The main units of interest are folded and faulted Proterozoic sedimentary rocks.

Geological Discoveries and Interpretations

- There are previously undocumented angular unconformities within the Proterozoic successions.
- There is evidence for reactivations of some faults.
- There is evidence that some faults were active during Proterozoic sedimentation.
- There is evidence for relatively recent (≤ Cretaceous) fault movements.
- Previously undocumented hydrothermal silica, iron and “clay” alteration, hydrothermal brecciation, and evidence of hydrothermal dissolution of dolomite have been documented.
- There is evidence for the passage of multiple hydrothermal fluids through the Proterozoic successions.
- A possible impact structure has been recorded.

Mineralisation

- The regional and local scale distribution of manganese is structurally controlled.
- There is evidence for a deep-seated, NNW-trending structure controlling the distribution of hydrothermal manganese mineralisation at Renner Springs and Bootu Creek.
- There is evidence for local structural and stratigraphic (lithological) control on the movement of hydrothermal fluids, including the fluid(s) that deposited manganese.
- Manganese mineralisation styles have been characterised.
- Prospective stratigraphic units and areas have been recognised and documented within the mapped areas.
- The maps and revised understanding of the stratigraphy, structure and controls on manganese mineralisation should provide a framework for further manganese exploration within and without the mapped areas.

1
INTRODUCTION

In February 2009 the author was requested by OM (Manganese) (OMM) to initiate a sub-regional mapping program on selected parts of the company's tenement holding in the Bootu Creek area in the Northern Territory. Following discussions, United Photo and Graphic Services were contracted to fly a set of 1:20,000 scale aerial photographs over the area shown in Figure 1.1.

On 24 April 2009 the air photos were flown (Fig. 1.1). All negatives were scanned and orthorectified using ground and aerial control points. Two digital photo mosaics have been compiled (Fig. 1.2). Contact prints were first available on the 11 June 2009 and mapping commenced immediately thereafter.

Four areas were nominated for mapping (Fig. 1.2); two have been mapped (Renner Springs, Helen Springs; Fig. 1.3). Figures 1.4 and 1.5 indicate the amount the ground covered in each area. Most of the mapped areas have sufficient ground cover for a first pass sub-regional map, though some parts are essentially air photo interpretation. The maps cover an area of 300 km^2 (Renner Springs 208 km^2, Helen Springs 92 km^2).

A total of 51 days was spent mapping (excluding travel etc.) which equates to an average field mapping rate of about 6 km^2 per day.

Following field work, photo overlays were re-drawn on to final overlays and colour checked. They were then scanned, orthorectified and compiled into a geopositioned orthomosaic (raster image) by Survey Graphics Ltd. The maps were drafted in MapInfo by Jennifer Pretty (OMM). Digital copies of the maps are available in Appendix I.

All field data have been copied into a spreadsheet (App. II) and this was used to compile descriptions in the geological legend and other graphic data (e.g., bedding dips; App. I).

Lithological descriptions are based solely on field observations. No thin sections have been made or described. No stratigraphic or sedimentological sections have been measured. All thickness estimates are derived from the maps without allowance for topography.

This report contains the following.

1) The geological maps, associated structural measurements and lithological descriptions (Apps I, II).
2) A library of 352 digital field photographs sorted by mapping unit (App. III).
3) Summary descriptions of the stratigraphic successions and lithologies in the areas mapped, including an interpretation of the outcrop of the main Proterozoic stratigraphic units.
4) An outline of the main structural components of the areas mapped.
5) Comments on the tectonic and depositional history of the areas mapped.
6) Descriptions of the alteration and mineralisation styles in the areas mapped.
7) A discussion of possible controls on the distribution of manganese mineralisation at local and regional scales.
8) Definition of areas prospective for manganese mineralisation.
9) Recommendations for further work.

A review of previous work and maps has not been made and most background geology is derived from Hussey et al. (2001a, b). This report does not contain:

- detailed descriptions of lithologies and textures;
- geological cross sections;
- descriptions at a prospect level;
- integration of geological and geophysical data; nor
- designation of specific targets.

Mapping at a scale of 1:4000 was also undertaken on selected prospects by Joe Drake-Brockman (see Volume 2).

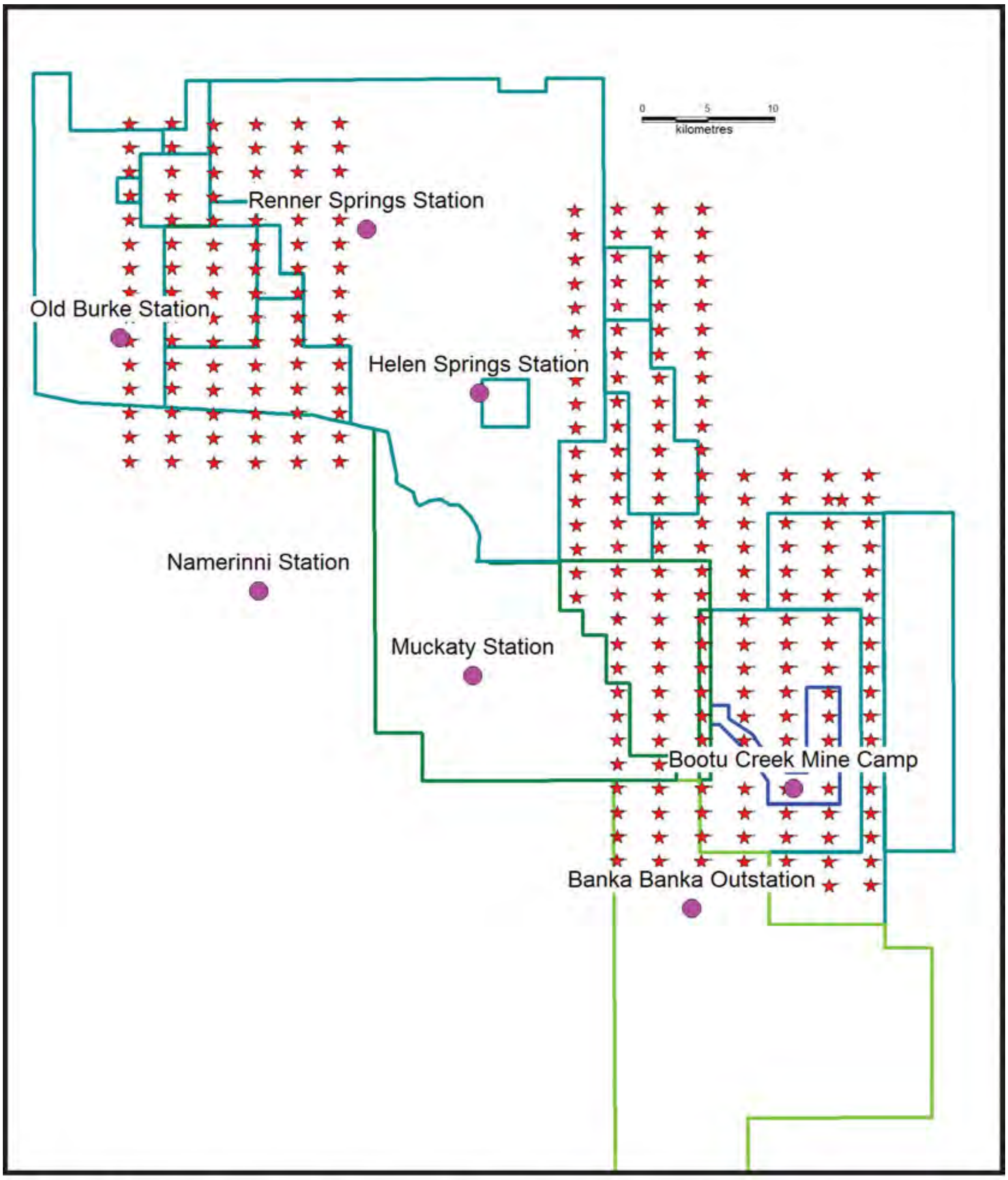

Figure 1.1: 1:20,000 aerial photograph centres and OMM tenement boundaries.

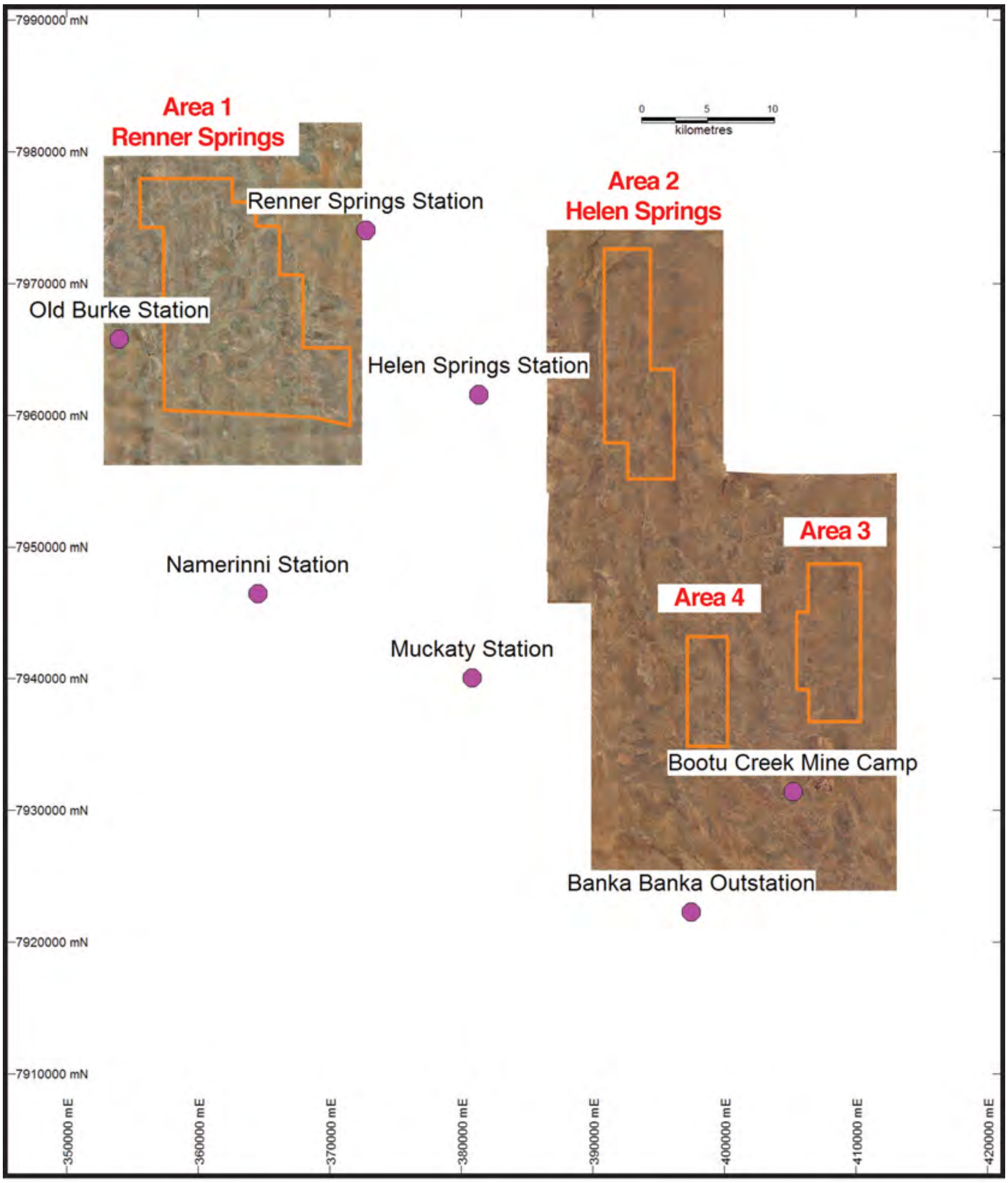

Figure 1.2: 1:20,000 aerial photograph mosaics and requested mapping areas.

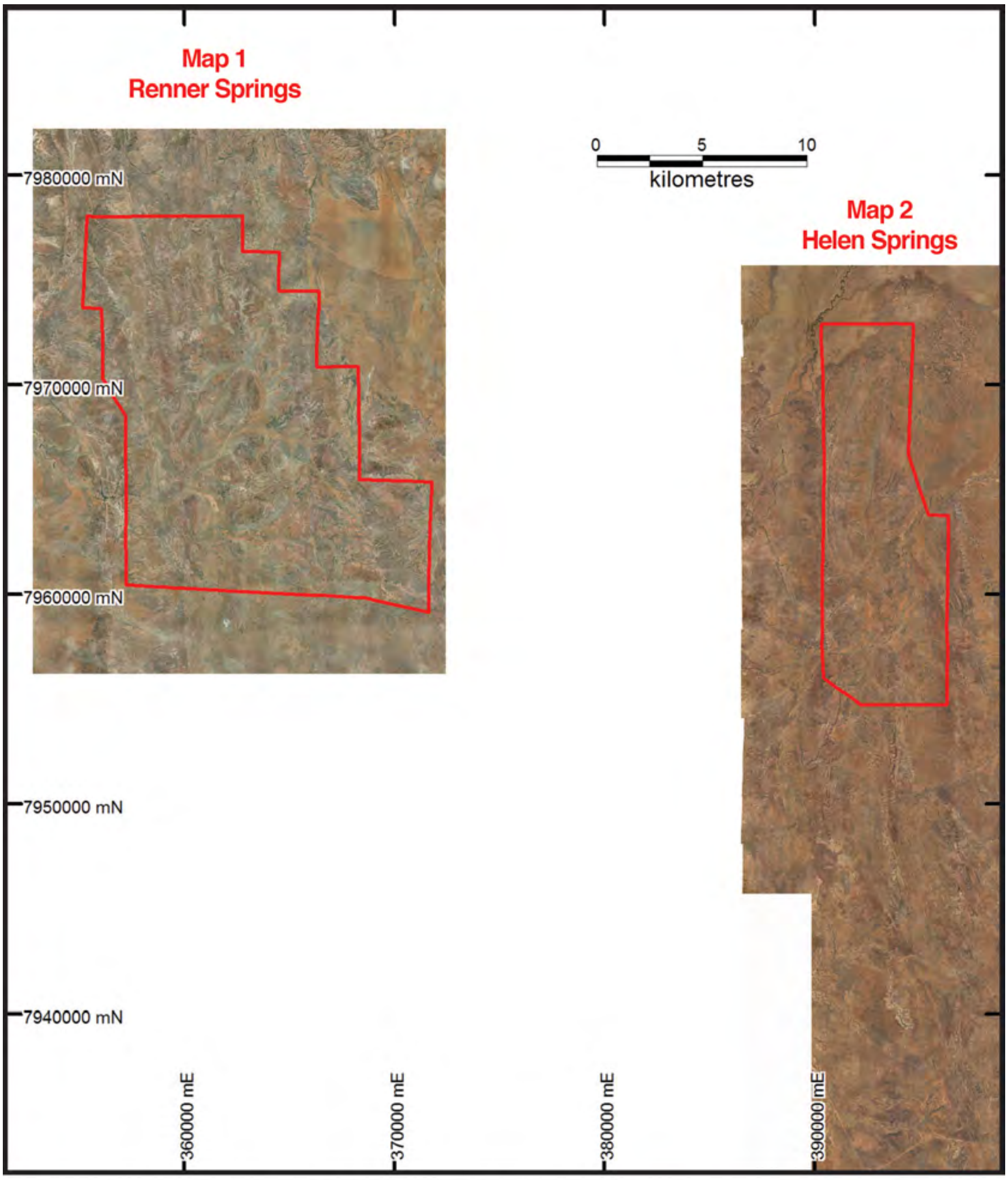

Figure 1.3: 1:20,000 aerial photograph mosaics and outlines of areas mapped.

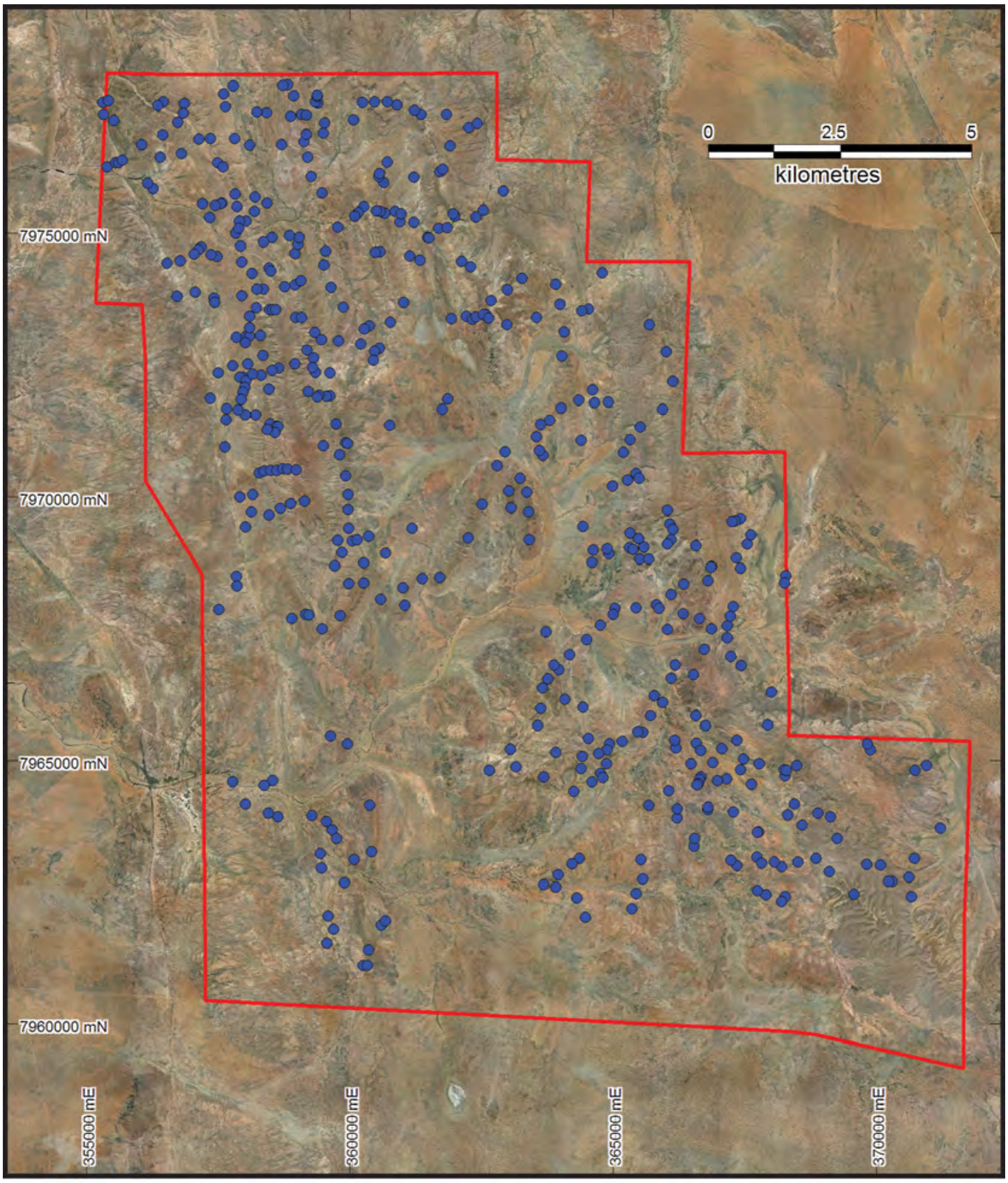

Figure 1.4: Outline of Renner Springs mapped area showing field locations (blue dots; App. II).

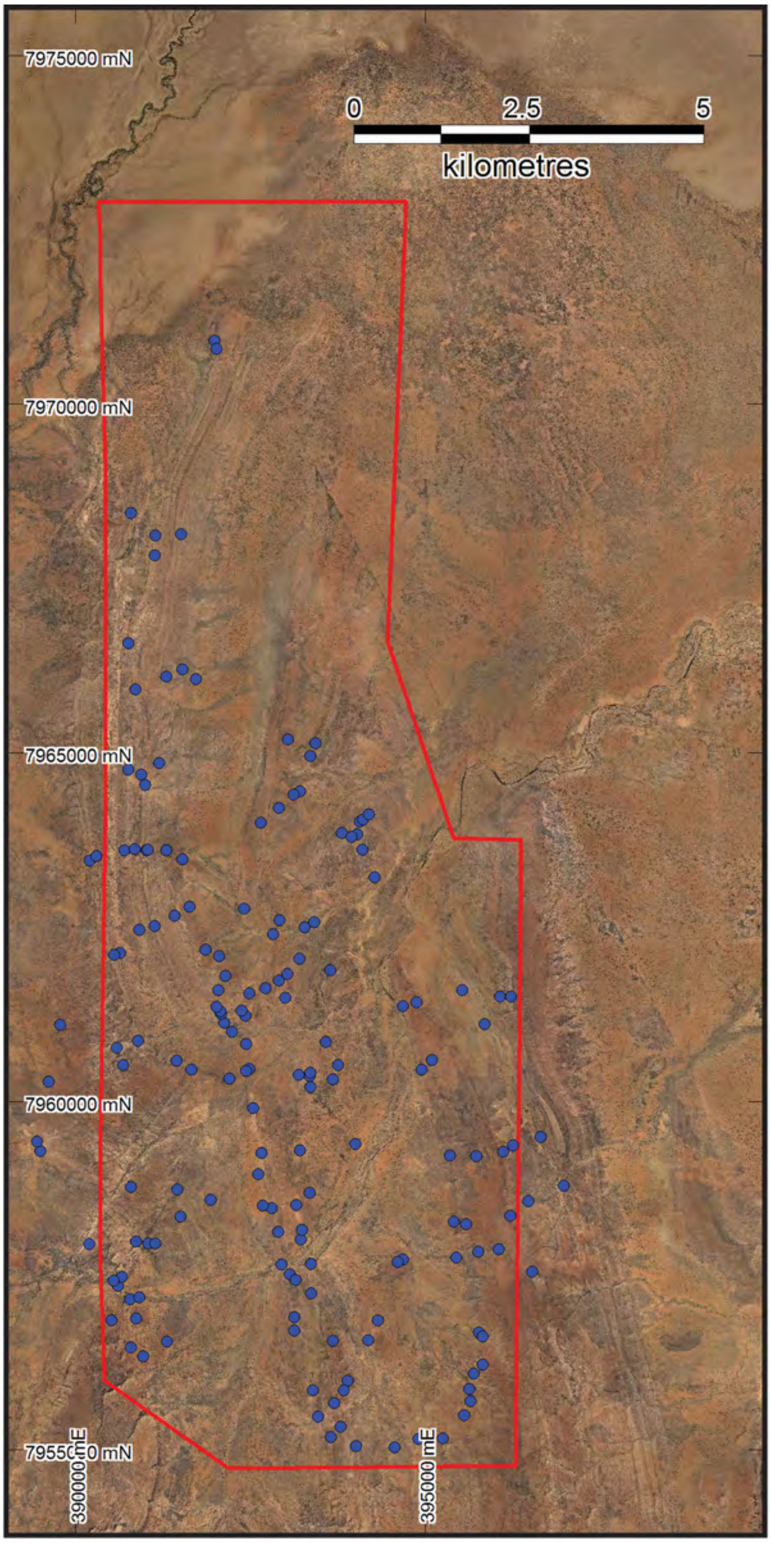

Figure 1.5: Outline of Helen Springs mapped area showing field locations (blue dots; App. II).

2
BACKGROUND GEOLOGY

The mapping areas are in the Tomkinson Province in the Northern Territory. This province comprises Paleoproterozoic to Mesoproterozoic (*ca* 1800–1430 Ma) siliciclastic sedimentary rocks, dolomites and basalts that have been folded and faulted. The succession is of low metamorphic grade. Figure 2.1 shows the locations of the mapped areas over the 1:250,000 scale geology map of Hussey et al. (2001a).

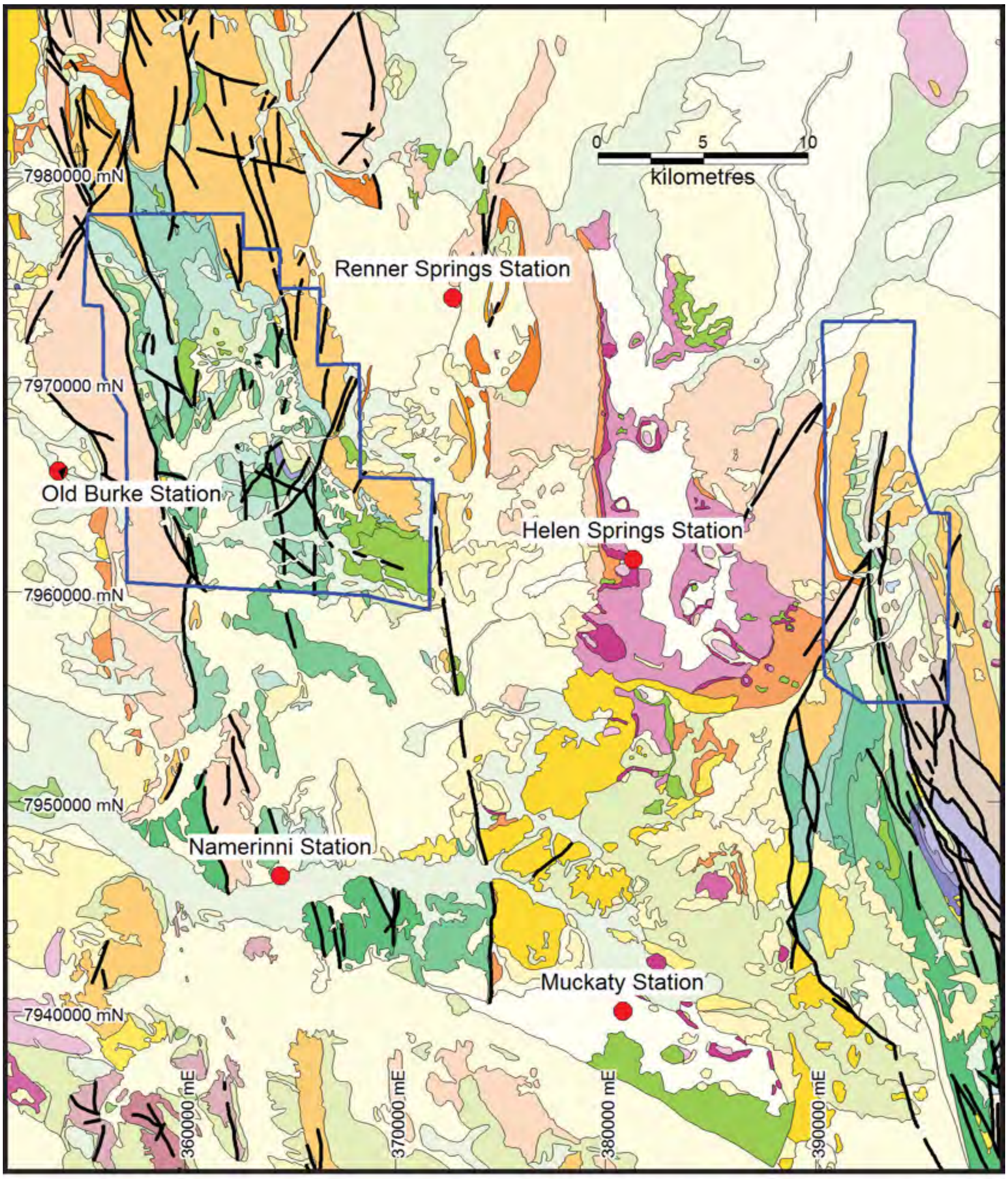

Figure 2.1: Outlines of the areas mapped at 1:20,000 scale over the 1:250,000 scale map of Hussey et al. (2001a).

2.1 Stratigraphic Divisions

The rocks in the Tomkinson Province have been divided into three groups, namely:

- the Tomkinson Creek Group (*ca* 1805–1710 Ma);
- the Namerinni Group (*ca* 1660–1610 Ma); and
- the Renner Group (*ca* 1550–1430 Ma; Figs 2.2, 2.3, 2.4).

The Groups are separated by unconformities[1] but also have internal unconformities. The parts of the succession covered by the maps and the stratigraphic distribution of manganese are indicated in Figures 2.2, 2.3 and 2.4.

2.2 Depositional Settings

Depositional settings are described in detail in Hussey et al. (2001b). In summary they are as follows.

Tomkinson Creek Group
Fluvial to shallow marine, intertidal to supratidal including evaporite environments.

Namerinni Group
Fluvial, deltaic, shallow marine, intertidal to supratidal including evaporite environments.

Renner Group
Fluvial to shallow marine, subtidal, intertidal and supratidal.

Broadly, these depositional settings have been supported by the 1:20,000 scale mapping. Importantly, most of these successions were probably once redbeds, but subsequent alteration has removed much of their original red colouration.

[1] The word "unconformity", when used herein alone, means a significant time break. Its physical nature (e.g., angular unconformity, nonconformity, disconformity) is not relevant to its definition.

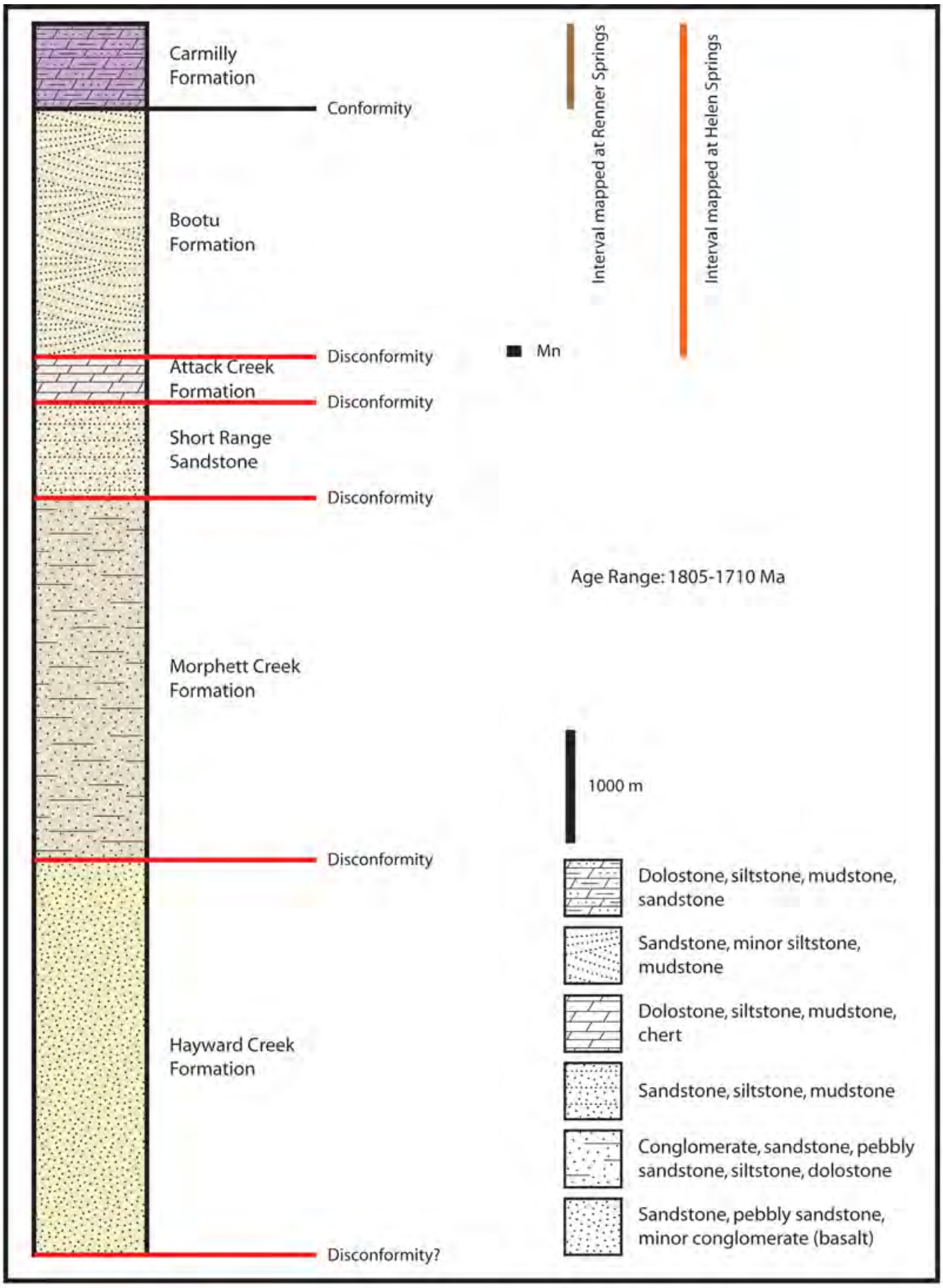

Figure 2.2: Summary stratigraphic column of the Tomkinson Creek Group on the Helen Springs 1:250,000 scale map (cumulative maximum thicknesses; lithologies, thicknesses and ages after Hussey et al., 2001b) showing:

a) the approximate stratigraphic position of manganese mineralisation; and

b) the approximate stratigraphic intervals mapped in each area.

Unconformable contacts between formations are shown where recorded in Hussey et al (2001b).

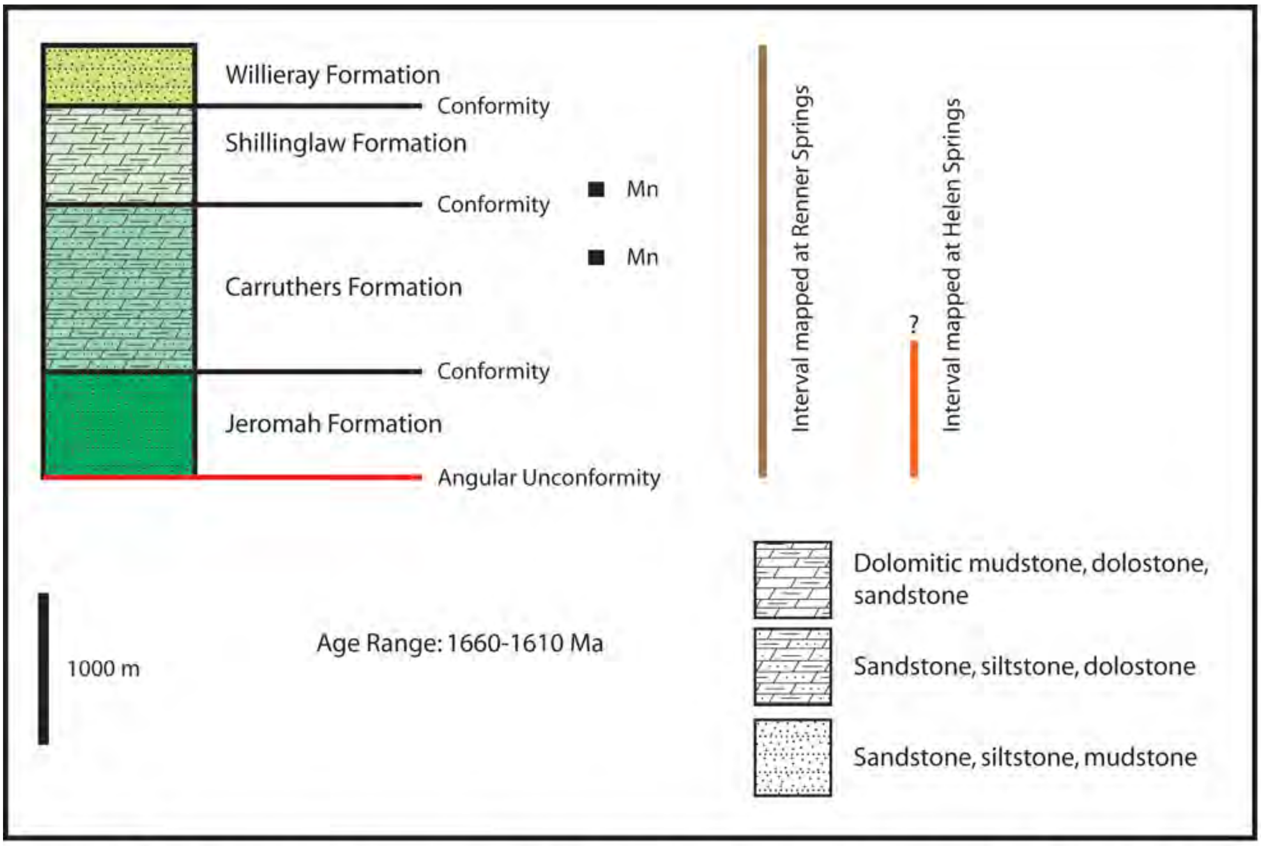

Figure 2.3: Summary stratigraphic column of the Namerinni Group on the Helen Springs 1:250,000 scale map (cumulative maximum thicknesses; lithologies, thicknesses and ages after Hussey et al., 2001b) showing:

a) the approximate stratigraphic position of manganese mineralisation on the Helen Springs 1:250,000 scale map; and

b) the approximate stratigraphic intervals mapped in each area.

The unconformable contact is recorded in Hussey et al (2001b).

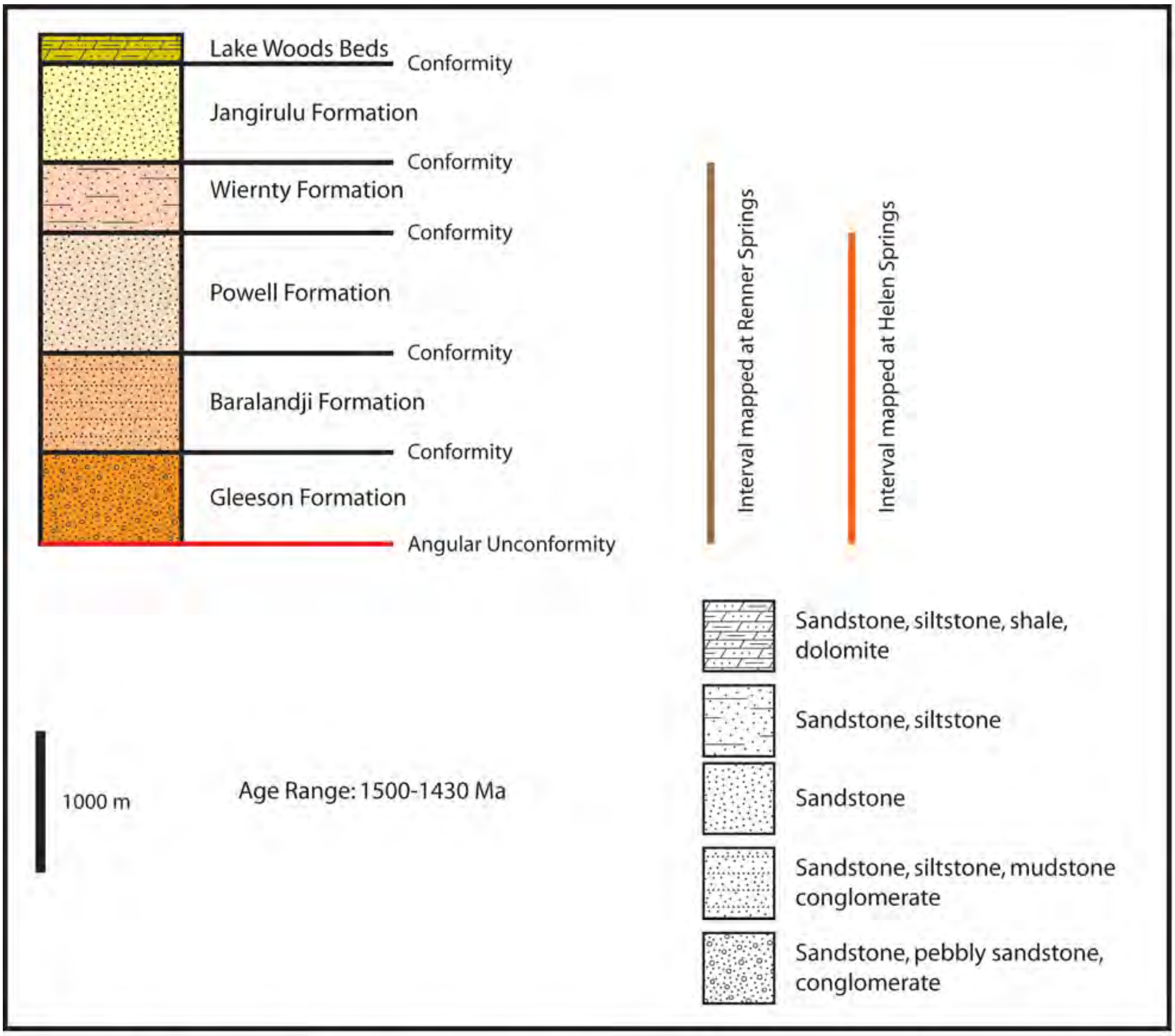

Figure 2.4: Summary stratigraphic column of the Renner Group on the Helen Springs 1:250,000 scale map (cumulative maximum thicknesses; lithologies, thicknesses and ages after Hussey et al., 2001b) showing the approximate stratigraphic intervals mapped in each area.

2.3 Tectonic Settings

The time period covered by the rocks in the Tomkinson Province was one of convergence and collision of the West Australian, North Australian and South Australian Cratons (e.g., Betts and Giles, 2006; Walter and Veevers, 2000). The Tomkinson Province is in the Northern Australian Craton and formed as a succession of intracratonic basins. According to Giles (2002) between 1800 Ma and 1670 Ma (approximately the period of deposition of the Tomkinson Creek Group) the area was one of intermittent lithospheric extension, transient shortening, and elevated heat flow in the overriding plate of a complex subduction zone and accretionary system. The Namerinni Group probably formed in a similar setting. The Renner Group was deposited in an intracontinental setting during a period of orogenesis in eastern Australia (Betts and Giles, 2006).

Before 1300 Ma the West Australian Craton (Pilbara and Yilgarn Cratons) and the North Australian Craton were joined along the Paterson Orogen (Betts and Giles, 2006; Bodorkos and Clark, 2004). Between about 1300 and 1100 Ma the combined West and North Australian Cratons collided with the South Australian Craton during the Albany-Fraser and Musgravian Orogenies (Giles et al., 2004). These major continental collisional events resulted in intracratonic deformations and probably drove fluids through older intracratonic basins.

The Tomkinson Creek, Namerinni and Renner Group basins have not been reconstructed and their detailed tectonic settings and development are unknown. Some comments about the tectonic implications of the recent mapping are made in Section 5.

3
STRATIGRAPHIC UNITS

3.1 Rock Descriptions

Rock descriptions in this section are of least altered lithologies. Alteration and mineralisation is described in Section 6.

3.2 Mapping Divisions

All mapping units are descriptive and comprise either a dominant lithology or a distinctive suite of lithologies (see notes in App. I). Rock colours are not an integral part of any mapping unit definition because they are too subjective and impossible to describe accurately, however, mapping units do have distinctive colours. Divisions at a mapping unit scale are pragmatic and boundaries represent a mappable contact at the scale of mapping.

Mapping units are grouped interpretively into a hierarchy of stratigraphic units. In the published lithostratigraphic framework these are groups, formations and members. The group divisions of Hussey et al (2001a, b) have been retained (Tomkinson Creek, Namerinni, Renner Groups) but the formations and members have not. Groups have been divided using an alphanumeric system whereby:

- 1, 2, 3 etc. denotes units separated by an unconformity (mapped of inferred); and
- a, b, c etc. denotes lithostratigraphic units separated by boundaries of unknown stratigraphic significance.

The Namerinni Group has been divided into four numbered units in the Renner Springs area and three in the Helen Springs area. These units have been named packages (Figs 3.1–3.6). An unconformity was discovered in the Renner Group at Helen Springs but, because this boundary could not be mapped across the entire area, the Renner Group has not been divided into packages.

3.3 Correlations of Proterozoic Rocks

Most mapped units correlate at group level with the mapping of Hussey et al. (2001a) but some do not. Correlations of mapping units and the Northern Territory Geological Survey's (NTGS's) lithostratigraphic units are given in the map legend in Appendix I.

Correlations of mapping units and packages within a mapped area is locally problematic. This is because:

- there is commonly significant Cretaceous to Recent sedimentary cover resulting in non-continuous exposure (Figs 3.7, 3.8);
- there is a strong bias towards exposure of similar looking sandstones; and
- some lithologies are strongly altered.

The Bootu Formation of the Tomkinson Creek Group crops out only in the Helen Springs area. Its designation as Bootu Formation is based on previous mapping, cursory examination of the Bootu Formation elsewhere and because these rocks are distinctly different from rocks placed in the Namerinni and Renner Groups in this area.

Packages 1 and 2 of the Namerinni Group are correlated between the two areas but this must be regarded as provisional, and further mapping and other work is needed to confirm this. Package 3 at Helen Springs is a poorly exposed unit that could correlate either with Packages 3 or 4 at Renner Springs or be unrelated.

The Renner Group is divided differently in the two areas with more detail at Helen Springs. A broad correlation of this group, however, is shown in the map legend in Appendix I.

3.4 Proterozoic Succession at Renner Springs

Figure 3.1 is a summary of the Proterozoic succession at Renner Springs and Figures 3.2 and 3.3 show the exposure and outcrop of the succession respectively.

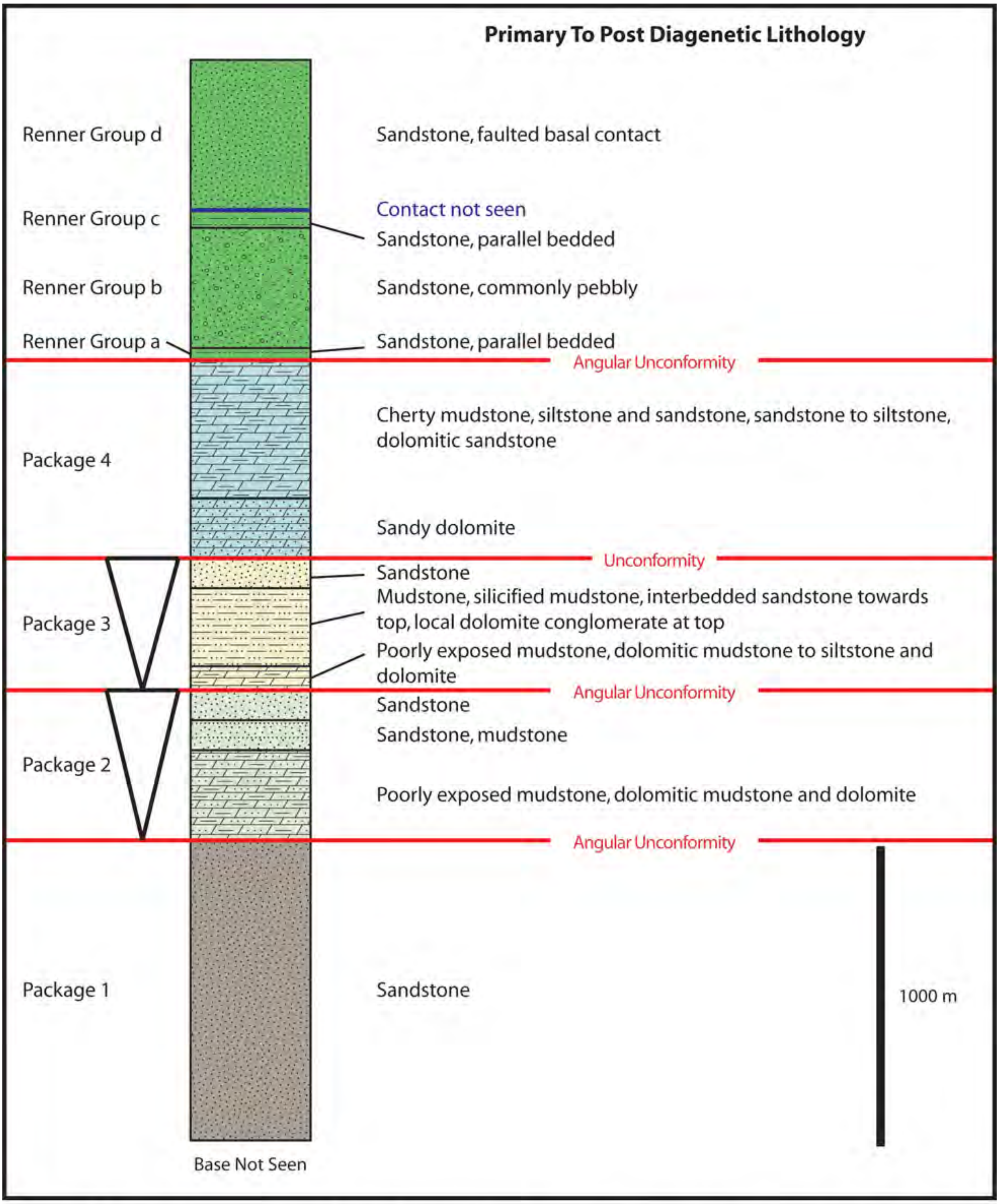

Figure 3.1: Summary stratigraphic column of Packages 1-4 (Namerinni Group) and the Renner Group at Renner Springs. Thicknesses are approximate and have been calculated from the 1:20,000 scale maps without allowances for topography. Units that vary laterally in thickness are shown at their thickest. Lithologies are simplified. Packages 2 and 3 coarsen upwards.

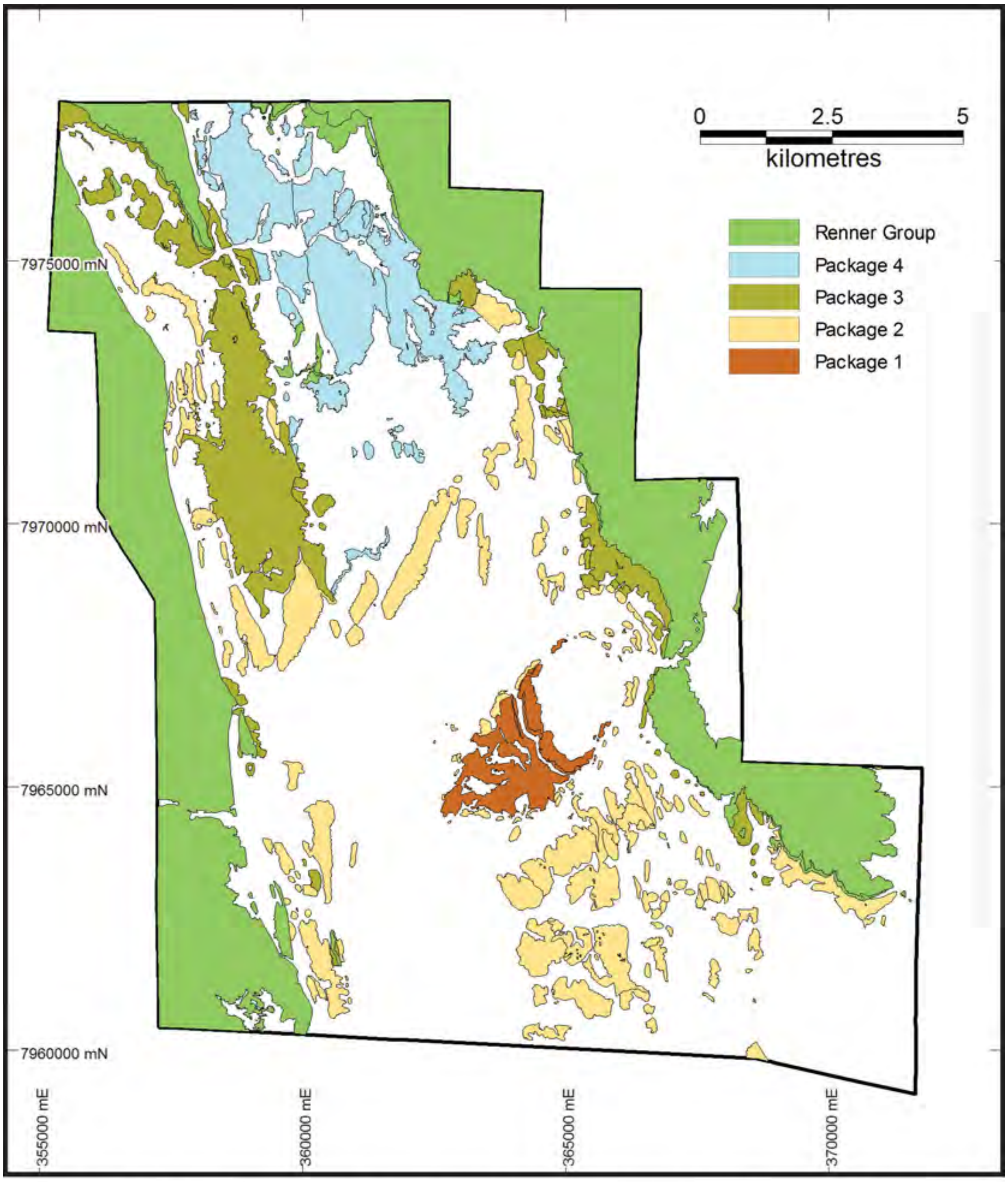

Figure 3.2: Major Proterozoic stratigraphic units mapped at Renner Springs.

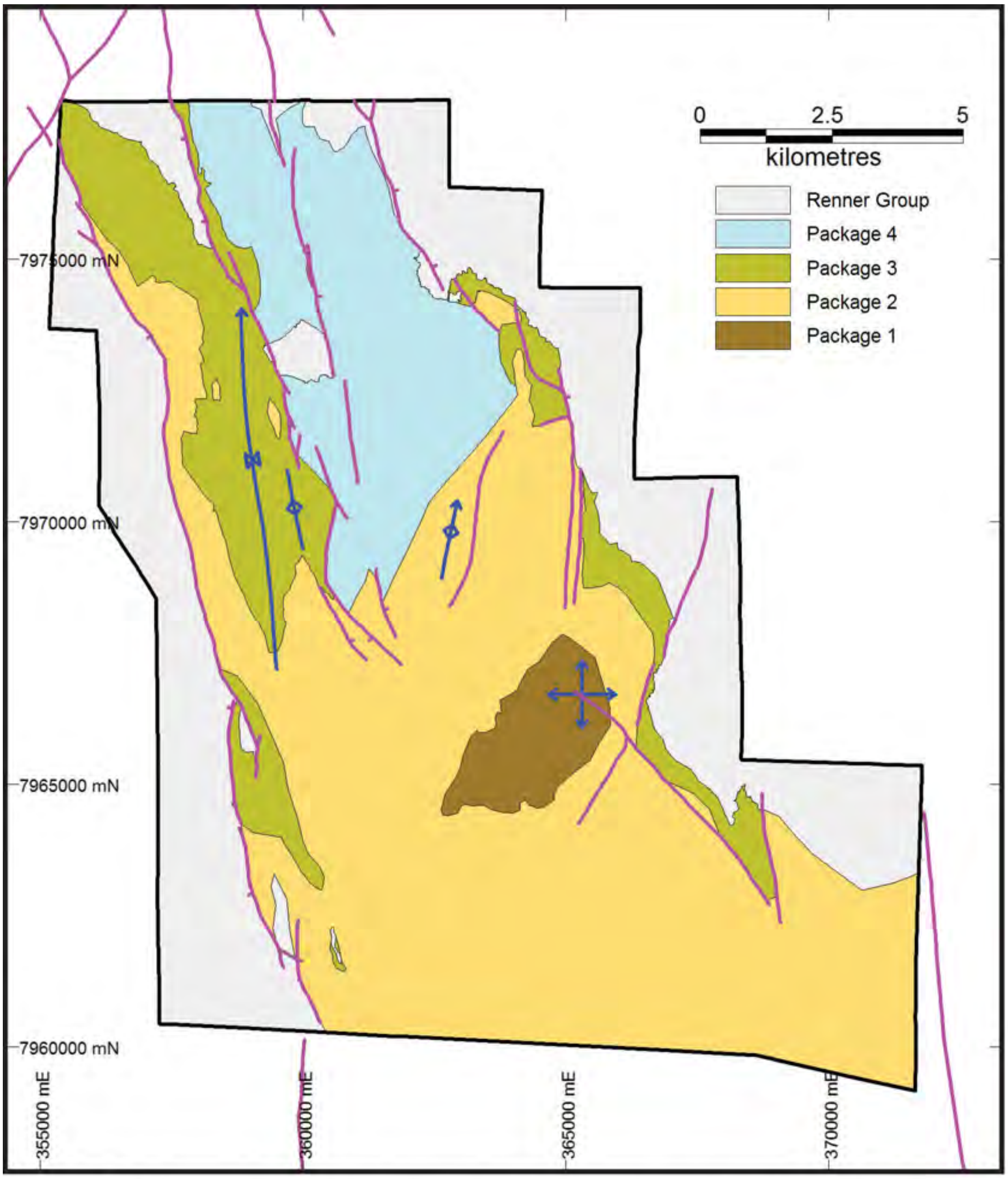

Figure 3.3: Interpreted outcrop of major Proterozoic stratigraphic units at Renner Springs. Major faults in mauve with downthrown side indicated where known. Major fold axes in blue. See Figure 4.1 for names.

3.4.1 Renner Springs Package 1

The exposed parts of Package 1 are entirely sandstone (Fig. 3.1), though the unit probably contains interbedded fine-grained rocks that are not exposed. The exposed part of the package is estimated to be about 1000 m thick and its base is not seen. Package 1 forms a distinctive elongate range of hills southwest of the Burke Creek Dome (Figs 3.2, 4.1). The sandstone is coarse- to medium-grained, parallel very thinly to thinly bedded and medium cross bedded.

The lowest exposed stratigraphic unit contains abundant ripple marks and has been mapped, in part, as the Carmilly Formation (Tomkinson Creek Group; Fig. 2.2) by the NTGS. The rest of Package 1 has been mapped as the Jeromah Formation (Namerinni Group; Fig. 2.3) by the NTGS. No evidence of an unconformity between these two units was observed.

3.4.2 Renner Springs Package 2

Package 2 is the most widespread unit of the Namerinni Group at Renner Springs (Fig. 3.3). Exposure is dominated by the upper part of the succession which is almost entirely sandstone. The unit is interpreted to overlie Package 1 with an angular unconformity, though no exposure of the contact was observed.

Rare exposures of the lower part of the succession include mudstone, siltstone and dolomitic rocks including massive dolomite. Halite pseudomorphs were recorded at one location (Photos 5 RN2M to 8 RN2M) and silicified stromatolites were recorded at another (Photos 17 RN2MXSi to 20 RN2MXSi). The succession is interpreted to coarsen upwards from mudstone and dolomite (some ferruginous or silicified) to mudstone with interbedded sandstone to sandstone. The top sandstone unit typically forms a prominent escarpment. The package is estimated to be about 500 m thick.

3.4.3 Renner Springs Package 3

Package 3 overlies Package 2 with an angular unconformity and is about 450 m thick. It comprises an upward coarsening succession that can be divided into three parts (Fig. 3.1). The lower few tens of metres of the succession is poorly exposed. This part of the package probably comprises mudstone, dolomitic mudstone to siltstone and dolomite, including silicified stromatolites (Photos 1 RN3MD to 5 RN3MD) and halite pseudomorphs. This horizon has been extensively altered and is discussed further in Section 6.

The middle part of the succession is dominated by parallel laminated to thinly bedded mudstone and very fine-grained sandstone. The proportion of sandstone increases stratigraphically upwards and there are distinct sandstone lenses towards the top of the unit. Silicified stromatolites have been recorded in the lower part of this unit (Photos 1 RN3M, 11 RNSM to 13 RN3M). The mudstones are commonly silicified and textures associated with compaction and soft sediment folding suggest silicification was "early" (pre-, syn-diagenesis; Photos 5 RN3M to 10 RN3M, 24 RN3M to 32 Rn3M).

In one area there is well exposed, 40 m thick, conglomerate unit in the transition zone between the middle and top of the succession. This is a massive cobble to boulder conglomerate dominated by clasts of dolomite, sandy dolomite, sandstone and siltstone (Photos 1 RN3DC to 19 RN3DC). Beds are up to 2 m, and possibly 5 m, thick and the succession fines upwards into pebbly sandstone. It is interpreted to be a mass flow deposit. Importantly, the clasts all appear to have been lithified prior to erosion suggesting that they were probably derived from a pre-Package 3 succession – possibly the lower part of Package 2.

The upper part of Package 3 is a sandstone unit that is preserved in the NW of the mapped area. Elsewhere, this part of Package 3, if present, lies beneath the Renner Group.

3.4.4 Renner Springs Package 4

Package 4 is a minimum of about 650 m thick and has an inferred erosive (unconformable) contact with Package 3. It can be divided into a lower unit dominated by sandy dolomite with lesser massive dolomite, and an upper unit comprising cherty mudstone, cherty siltstone, cherty fine-grained sandstone, fine-grained sandstone to siltstone and dolomitic sandstone. Stromatolites were recorded at one location in the upper succession (Photo 01 RN4MSDCt) and possible gypsum pseudomorphs were recorded in massive dolomite in the lower succession (Photos 03 RN4MSDCt to 04 RN4MSDCt).

3.4.5 Renner Springs Renner Group

The Renner Group overlies Package 3 and 4 with an angular unconformity and is faulted against Package 2 on the western side of the area mapped. It has been divided into four lithostratigraphic units (a–d).

Unit a is a 30 m thick, laterally discontinuous and commonly poorly exposed succession of mostly parallel bedded sandstone that grades up into Unit b over a few metres. Unit b comprises up to 400 m of cross bedded very coarse-grained granular sandstone that is commonly pebbly. In the central north of the mapped area, between the Dolomite Dam and Mount Shillinglaw Faults (Fig. 4.1), Unit b has thinned to about 50 m and Unit a is missing. This suggests that there was either significant palaeotopography on the basal Renner Group unconformity surface, faulting contemporaneous with sedimentation or both.

Unit c overlies Unit b with a sharp contact between the Dolomite Dam and Mount Shillinglaw Faults (Fig. 4.1). It comprises about 50 m of mostly thinly parallel bedded sandstone. Its stratigraphic significance is unknown because it is recorded only in a relatively small outlier without any overlying Renner Group rocks.

Unit d is the NTGS Powell Formation. Its relationship to Units a–c is unknown because it has a faulted against other Renner Group rocks. Unit d is about 500 m thick and comprises coarse- to medium-grained sandstone. Locally it contains a distinctive granule quartz conglomerate horizon(s).

3.5 Proterozoic Succession at Helen Springs

Figure 3.4 is a summary of the Proterozoic succession at Helen Springs and Figures 3.5 and 3.6 show the exposure and outcrop of the succession respectively.

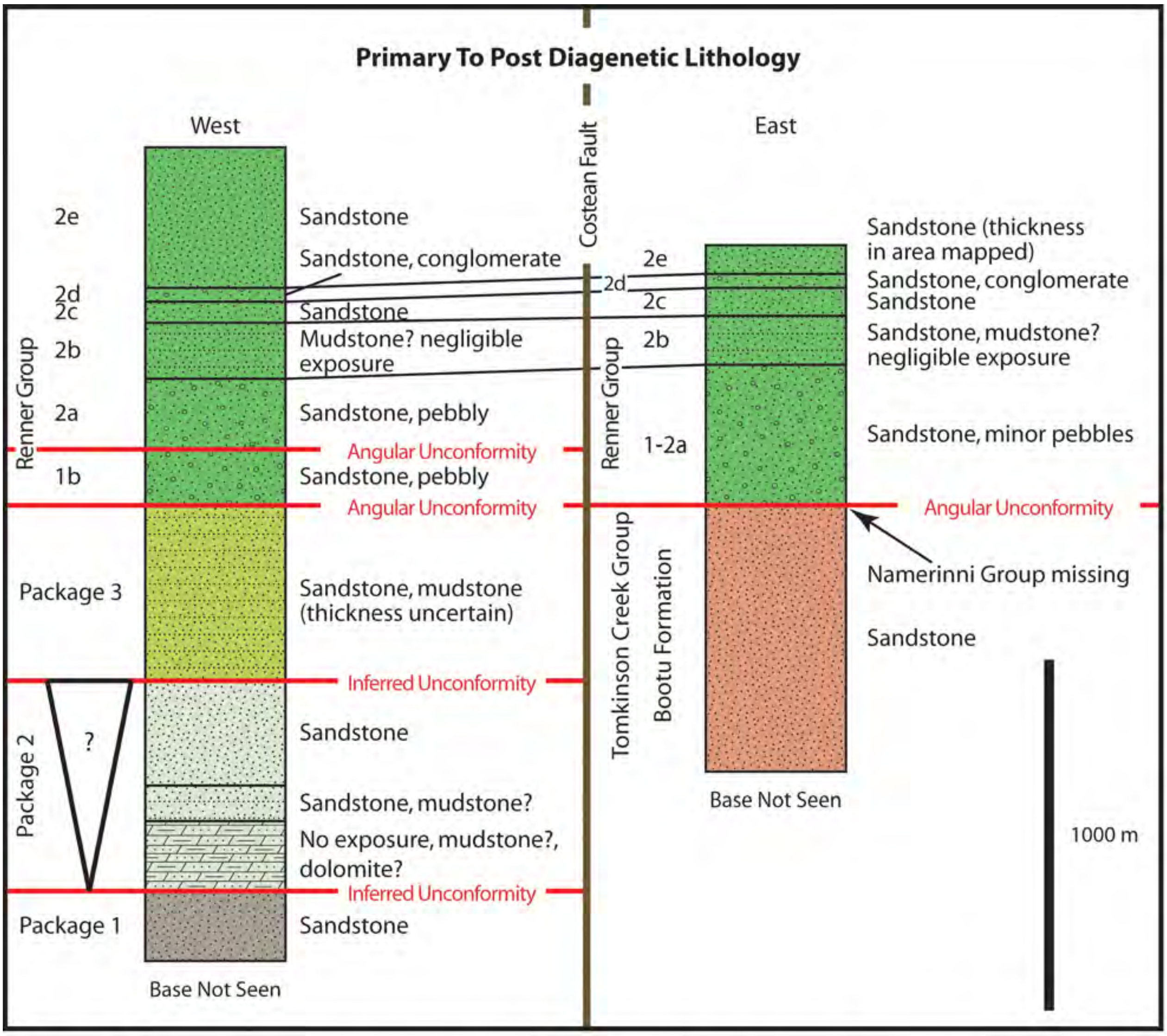

Figure 3.4: Summary stratigraphic column of Tomkinson Creek Group, Packages 1-3 (Namerinni Group) and the Renner Group at Helen Springs. Thicknesses are approximate and have been calculated from the 1:20,000 scale maps without allowances for topography. Units that vary laterally in thickness are shown at their thickest. Lithologies are simplified. Package 2 probably coarsens upwards.

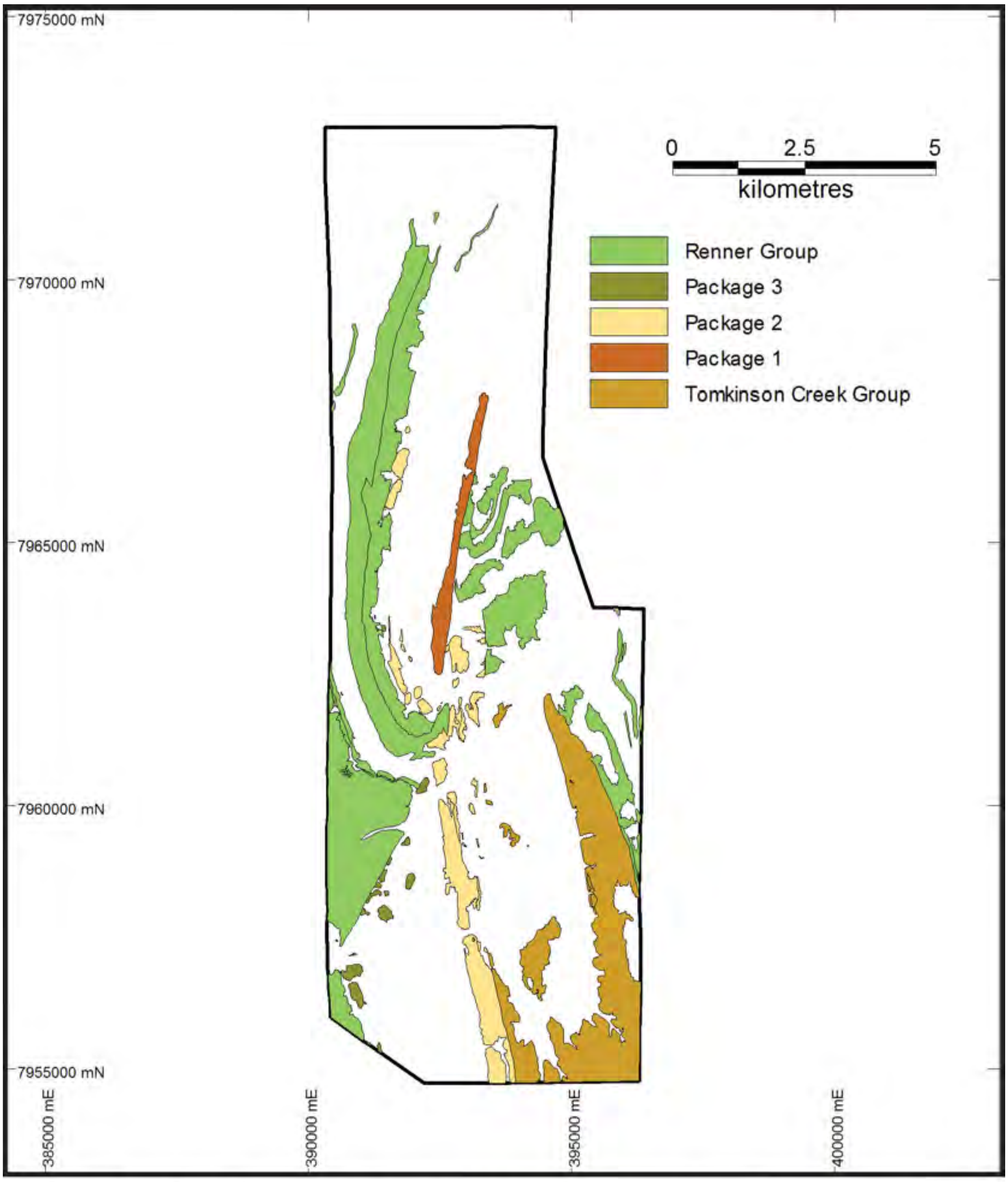

Figure 3.5: Major Proterozoic stratigraphic units mapped at Helen Springs.

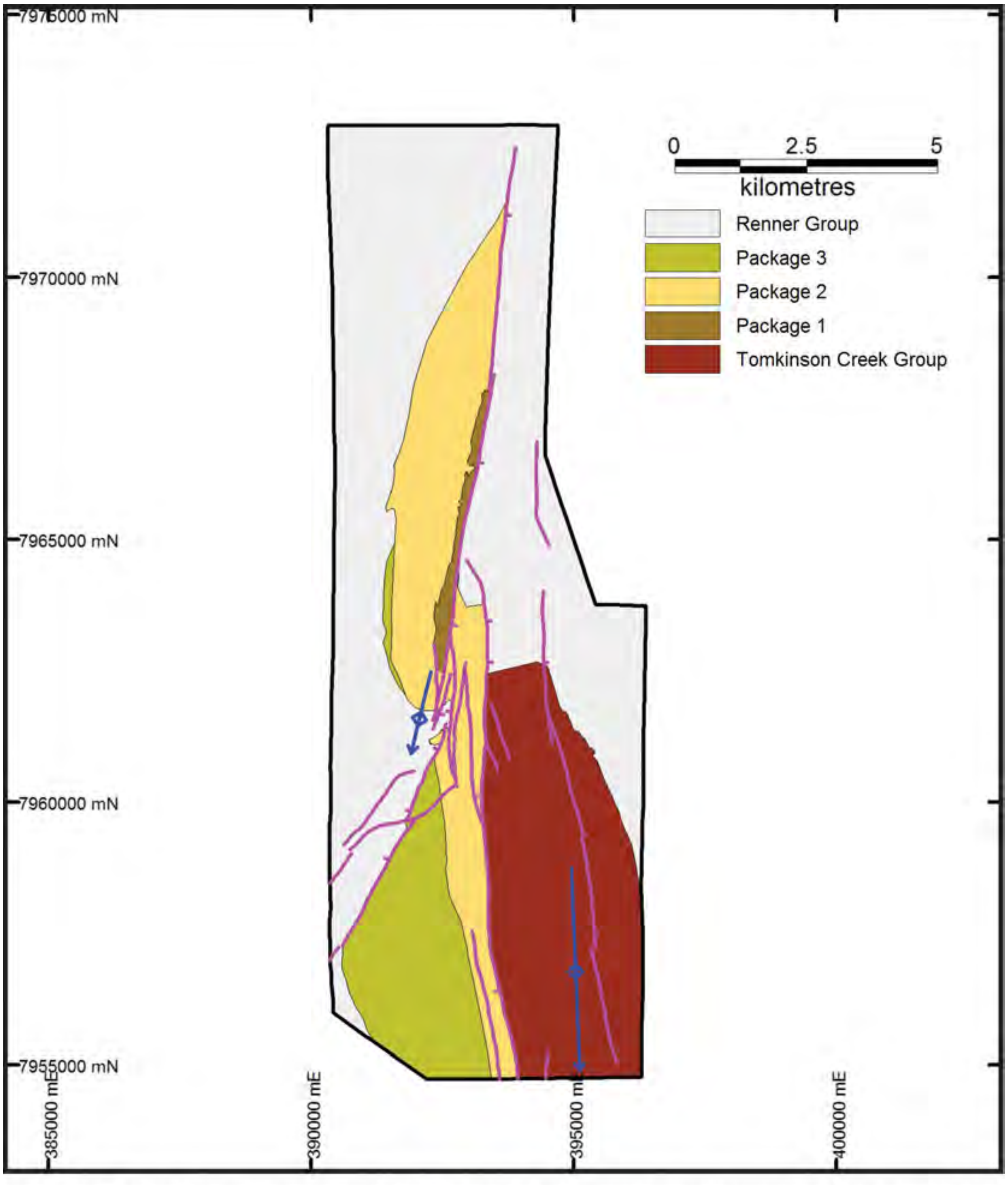

Figure 3.6: Interpreted outcrop of major Proterozoic stratigraphic units at Helen Springs. Major faults in mauve with downthrown side indicated where known. Major fold axes in blue. See Figure 4.3 for names.

3.5.1 Helen Springs Tomkinson Creek Group (Bootu Formation)

The Bootu Formation is recorded only at Helen Springs. It can be divided into a lower 250 m of ferruginous sandstone overlain by about 500 m of very coarse- to medium-grained sandstone (Fig. 6.2). The upper sandstone is commonly cross bedded and locally contains pebbles and mud flakes.

3.5.2 Helen Springs Package 1

Package 1 is about 200 m of coarse- to medium-grained sandstone. It crops out as a NNE-trending ridge on the eastern side of the White Nose Bore Fault (Fig. 4.4) and its base is not seen. This unit has been mapped as Bootu Formation by the NTGS but it is lithologically unlike the Bootu Formation in this area and more like Package 1 at Renner Springs.

3.5.3 Helen Springs Package 2

Package 2 probably comprises an upward coarsening succession (Fig. 3.4) but only the top of the unit is well exposed. Rare exposure of mudstones are mostly strongly altered. The exposed top half of the succession is a coarse- to medium-grained sandstone unit that thins northwards across the mapped area from about 300 m to < 100 m. The reason for the thinning is uncertain, it is either primary or has resulted from erosion at the base of Package 3, or both. Locally, the upper sandstone unit contains a pebble to boulder conglomerate unit horizon that may be a stratigraphic marker (Photos 1 HN2S, 7 HN2S to 8 HN2S).

3.5.4 Helen Springs Package 3

Package 3 is poorly exposed and its contact with Package 2 is not seen. This contact is inferred to be an unconformity. The exposed parts of Package 3 are dominated by wavy parallel thinly bedded sandstone that is commonly ferruginous.

3.5.5 Helen Springs Renner Group

East of the Costean Fault (Fig. 4.4) the Renner Group unconformably overlies the Bootu Formation, but west of the Costean Fault the Renner Group unconformably overlies Package 2 and is faulted against Package 3. This relationship attests to pre-Renner Group movement on the Costean Fault and significant pre-Renner Group erosion.

West of the Costean Fault there is an angular unconformity in the lower part of the Renner Group dividing it into Units 1 and 2. This unconformity may exist to the east of the fault but has not been mapped out. A dip discordance of 5–10° is recorded across this unconformity in the closure of the Pale Sun Anticline (Fig. 4.4). This discordance seemingly decreases to concordance northwards along the western limb of the Pale Sun Anticline. Immediately east of the closure of the Pale Sun Anticline the succession is truncated at the confluence of the White Nose Bore and McKinlay Faults (Fig. 4.4). Importantly, Unit 1 terminates against a fault that is overstepped by Unit 2 in this area. These relationships suggest that the White Nose Bore and McKinlay Faults were active during sedimentation of the lower part of the Renner Group.

Unit 1a is only mapped in a small area in the east. It comprises about 30 m of distinct parallel bedded sandstone and may be a stratigraphic equivalent of Unit a at Renner Springs.

Units 1b and 2a comprise sandstone, pebbly sandstone and local conglomerate. Both include fining upward channel successions and overall Unit 1b is coarser grained. Unit 1–2a is a grouped unit that covers Units 1a (where not mapped) to 2a. Unit 1b is about 100–150 m thick and Unit 2a is about 200 m thick.

Unit 2b is about 150 m thick and is very poorly exposed. It is probably dominated by fine-grained sedimentary rocks that overlie Unit 2a with a sharp contact.

Unit 2c is about 50 m thick and comprises very coarse- to medium-grained sandstone. It probably has a gradational contact with Unit 2b.

Unit 2d comprises a 30 m thick, poorly exposed ferruginous sandstone, ferruginous granule conglomerate with local coarser conglomerate. Its stratigraphic status is unknown because it may be an alteration horizon rather than a primary sedimentary unit. The distinctive granule conglomerate may be a stratigraphic marker because a very similar rock has been found in Unit d at Renner Springs which is a broad stratigraphic equivalent.

Unit 2e includes the NTGS Powell Formation. It is about 400 m thick and comprises coarse- to medium-grained sandstone.

3.6 Phanerozoic Rocks and Sediments at Renner Springs and Helen Springs

Figures 3.7 and 3.8 show the distribution of Phanerozoic rocks and sediments at Renner and Helen Springs respectively. Fifty four percent of the Renner Springs and seventy percent of the Helen Springs areas are covered by Cretaceous to Recent sediments and sedimentary rocks. Further, the Namerinni Group and parts of the Tomkinson Creek Group are more extensively covered than the Renner Group.

3.6.1 Cambrian Rocks

Basalt and sedimentary rocks of the Cambrian Kalkarindji Province crop out immediately west of the Helen Springs mapping area. While not mapped, exposures were visited and photographs are included in Appendix III.

3.6.2 Cretaceous to Tertiary Rocks and Sediments

Mostly flat lying to very shallow dipping (<10°) clastic sedimentary rocks have been mapped unconformably overlying Proterozoic rocks. These are most abundant in the Renner Springs area. By correlation with the NTGS maps these are classified as Cretaceous. Over some Proterozoic rocks the Cretaceous sedimentary rocks have a sharp basal contact (Photos 1 RS CcS to 4 RS CcS). Elsewhere there is a well-developed basal palaeosol. (Photos 7 RS CcS, 8 RS CcS).

The Cretaceous rocks comprise boulder conglomerate dominated by sandstone clasts that are commonly > 50 cm across (Photos 3 RS CcS, 1 HS CcC, 1 RS CcC to 7 RS CcC), coarse- to medium-grained sandstone and siltstone, and less common shale. The conglomerates are mostly only a few metres thick and developed immediately above the basal unconformity. However, at Mount Willieray, in the SE corner of the Renner Springs area, massive boulder conglomerates are at least 100 m thick.

All the Cretaceous rocks have been affected by at least one period of lateritic weathering which is probably Tertiary in age. This results in them being strongly weathered and ferruginous, though the original iron may have been present prior to lateritisation, particularly in the shales. Reworked laterite granule to cobble conglomerates are common over Cretaceous sandstones (Photo 01 RS TC).

While the massive basal boulder conglomerates may have formed on a marine platform, the thick boulder conglomerate at Mount Willieray cannot be explained this way. More probably this is a fault-controlled alluvial fan containing mass flow conglomerates.

Cumulatively, therefore, there is evidence for syn- to post-Cretaceous fault movements in the areas mapped, summarised as follows.

1) At least one possible fault-controlled alluvial fan deposit.
2) Local gentle tilting of the deposits.
3) Local probable fault offsets of the deposits.

Figure 3.9 shows the regional distribution of Cretaceous (and Cambrian) rocks and major faults. Between the Renner and Helen Springs mapping areas there is a 15-km-wide N-trending graben bounded by a NNW-trending fault in the west, a N–NNE-trending fault in the east and a NW-trending fault in the south (see Fig. 6.10). This graben contains relatively common Cretaceous rocks and a distinct domain of Cambrian rock (mostly basalt). Immediately south of Muckaty Station there is a significant mapped exposure of Cretaceous rocks that abuts a major WNW-trending fault to the south. This distribution, accompanied by the evidence from recent mapping, suggest that major basement faults have been reactivated during and after the Cretaceous and probably also during the Cambrian.

3.6.3 Quaternary Sediments

These sediments are part of the current drainage system and are undivided. They include alluvium, colluvium and screes around hills.

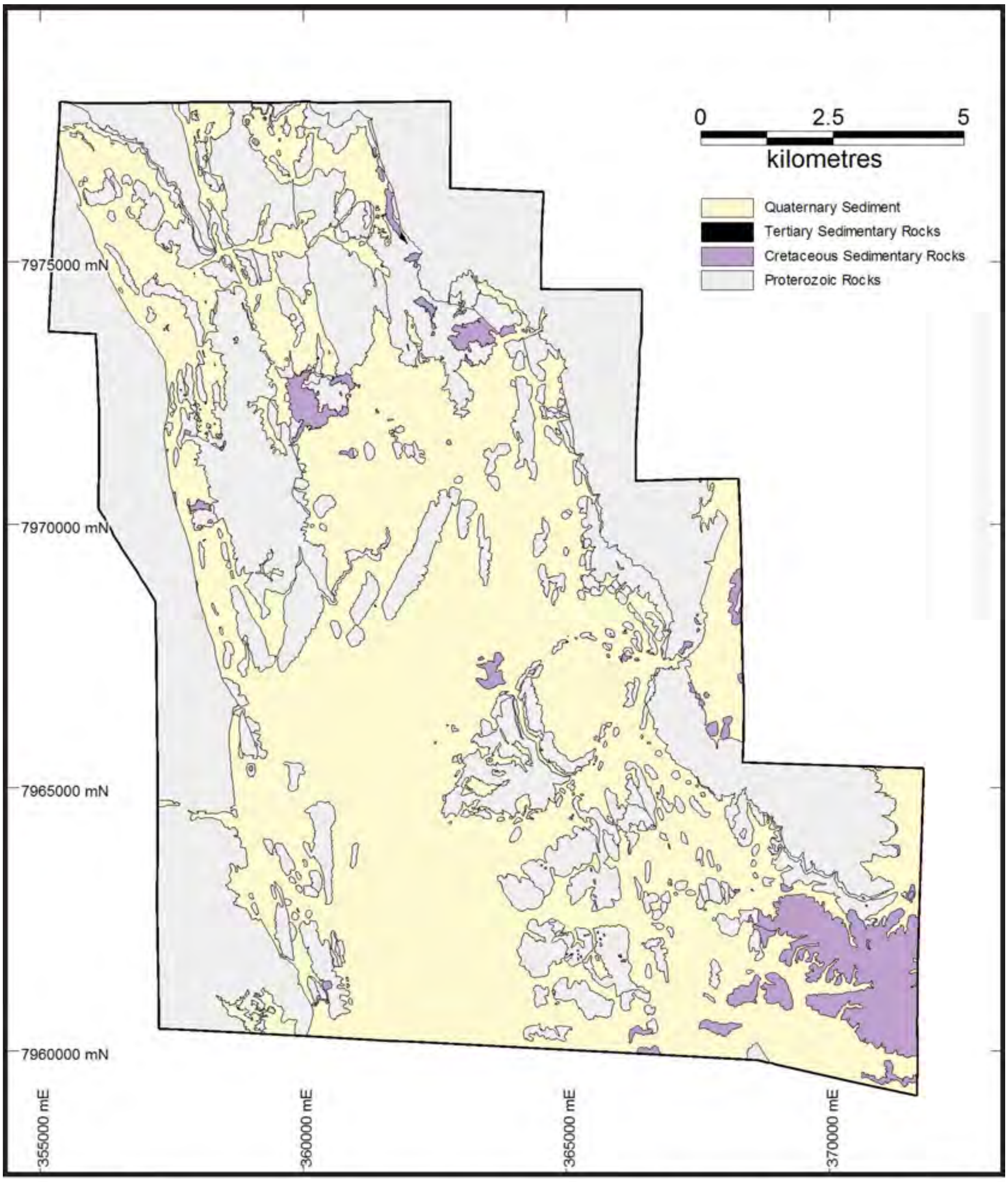

Figure 3.7: Phanerozoic sediment and sedimentary rock cover at Renner Springs.

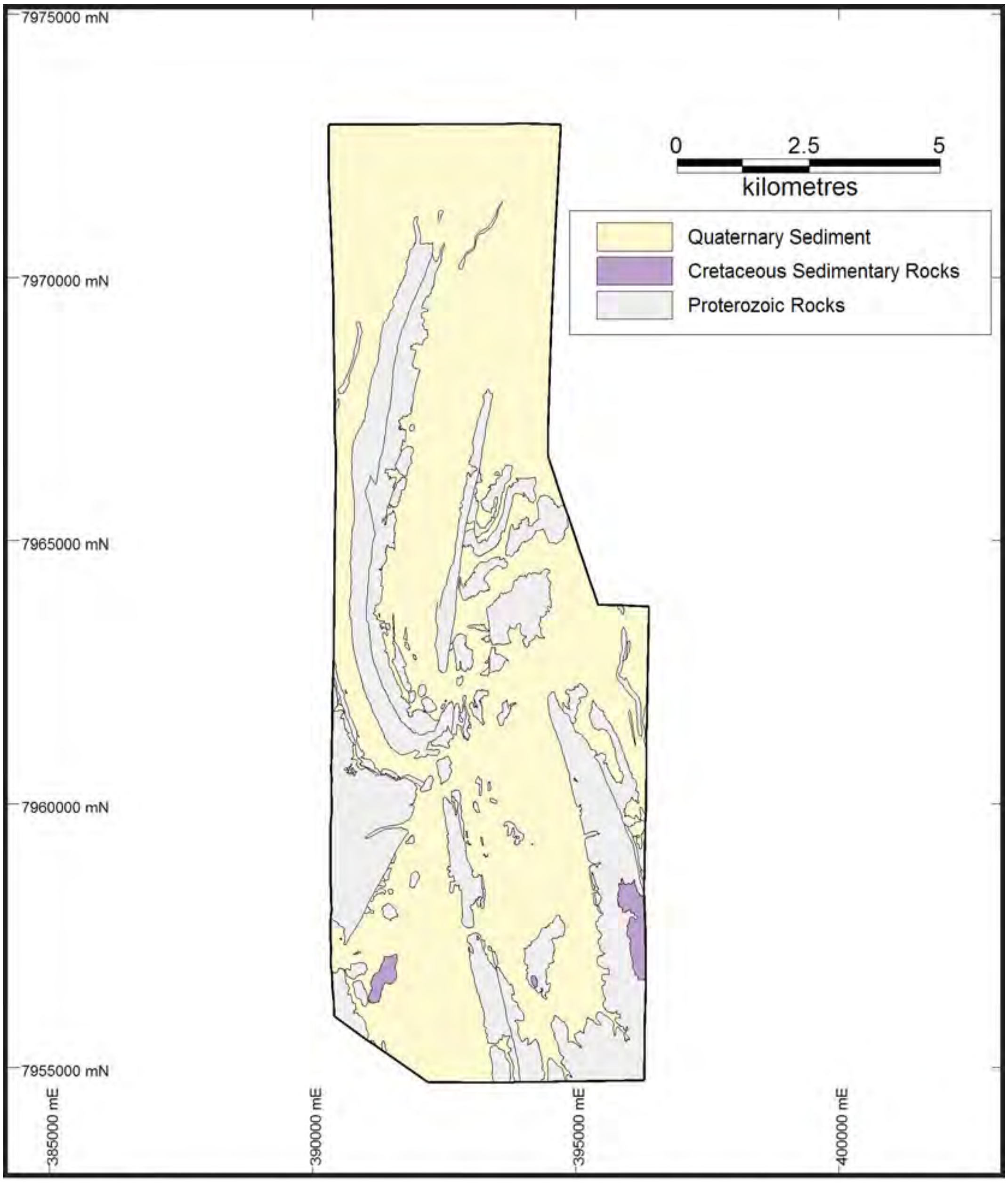

Figure 3.8: Phanerozoic sediment and sedimentary rock cover at Helen Springs.

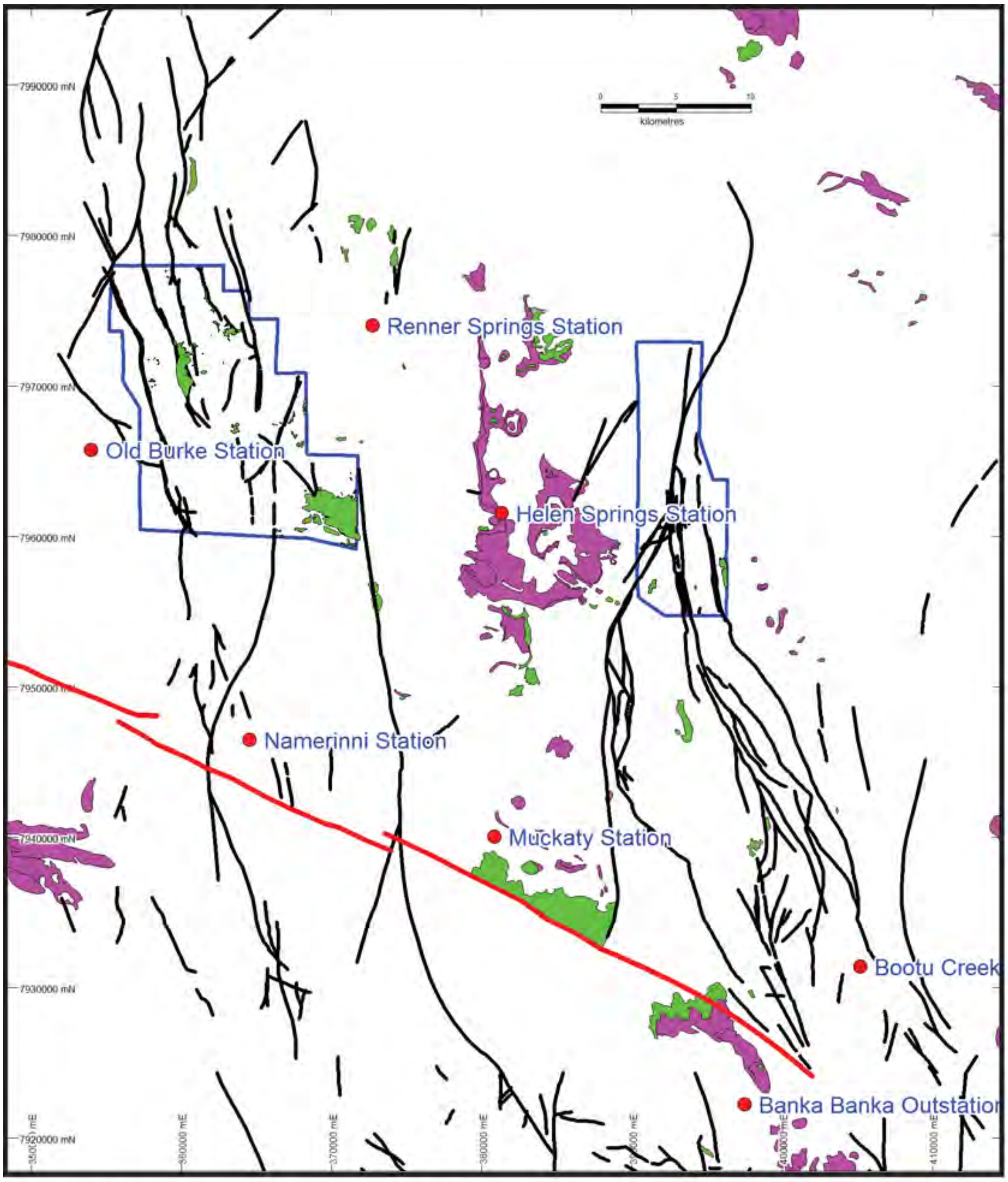

Figure 3.9: Regional distribution of Cambrian (mauve) and Cretaceous rocks. Regional scale faults shown in black. 1:20,000 scale mapped areas in blue. Red lines are a mapped and inferred WNW-trending major structural contact. Data from 1:20,000 maps, Hussey et al., 2001a and NTGS open file sources.

4
STRUCTURE OF PROTEROZOIC ROCKS

Figures 4.1 to 4.5 summarise the major structural components of the Proterozoic rocks in the Renner Springs and Helen Springs areas.

The successions in both areas are gently to openly folded. Average bedding dips at Renner Springs and Helen Springs are 25° and 32° respectively. The successions are also cut by a probable conjugate set of NNW-trending and N–NNE-trending regional scale faults (Fig. 6.10). In detail, folding and faulting can be very complicated and there are abundant minor folds on the limbs of major folds, particularly in finer grained lithologies. Penetrative cleavages are not developed, though locally there are domains of close-spaced fractures particularly, but not always, close to faults. This section discusses major structures only.

The abundance of angular unconformities in succession attest to multiple generations of folding and faulting. Much of this is probably sequential tightening of folds and multiple reactivations of faults. Discussion of structure at this level is beyond the scale of mapping.

4.1 Renner Springs

The Namerinni Group at Renner Springs is exposed in the core of a NNW-trending faulted anticline in the Renner Group (Fig. 4.2). The succession is also segmented by mostly NNW-trending faults that down throw away from the major anticline axis; *i.e*, to the west in the west and to the east in the east. The central part of the area is also cut by NNE-trending faults that define a 4 km wide corridor in which the oldest rocks are exposed, named the Burke Creek Corridor (Fig. 4.1). Many of the faults have probably been active several times. For example, the Gleeson Fault was probably active prior to and after deposition of the Renner Group (Sect. 6.1.1).

North of the Burke Creek Corridor most major and minor folds are upright, have NNW- to N-trending axial traces and plunge to the north, though towards the boundary of the corridor axial traces trend to the NNE (Fig. 4.1). The half wavelength of major folds in this area is about 3 km and minor folds typically have half wavelengths of 10’s to 100’s m. South of the Burke Creek Corridor there are no defined major folds but the few minor fold axes recorded trend NNW to N.

The main geological structure within the Burke Creek Corridor is the Burke Creek Dome (Figs 4.1, 4.3). This 3 km diameter, almost perfectly symmetrical dome is evident in both the Namerinni and Renner Groups. The origin of this structure is uncertain. All other folds in the areas mapped, and regionally, are strongly elongate, and, while there has been some cross folding, symmetrical dome and basin structures are not recorded elsewhere. An alternative interpretation is that the Burke Creek Dome is an impact structure. If so it has probably been affected by some of the NNE-trending faults in the Burke Creek Corridor which would suggest it is not “recent”.

4.2 Helen Springs

The Helen Springs area is cut by major NNE-trending and N–NNW-trending faults (Fig. 4.4; see also Fig. 6.10). Three of these structures (McKinlay, Costean, White Nose Bore Faults) coalesce in the centre of the area. As noted in Section 3.5.5, some of these faults were active prior to, probably during and after deposition of the Renner Group. For example, the Costean Fault had a pre-Renner Group west-block-down throw and a post-Renner Group east-block-down throw. Two major folds have been mapped out (Pale Sun Anticline, Mount Hall Anticline). Both are south plunging faulted anticlines (Fig. 4.5). As at Renner Springs, major faults downthrow away from anticlinal closures (Fig. 4.5). Minor folds, recorded in the Renner Group only, trend NNW to NNE and all plunge to the north.

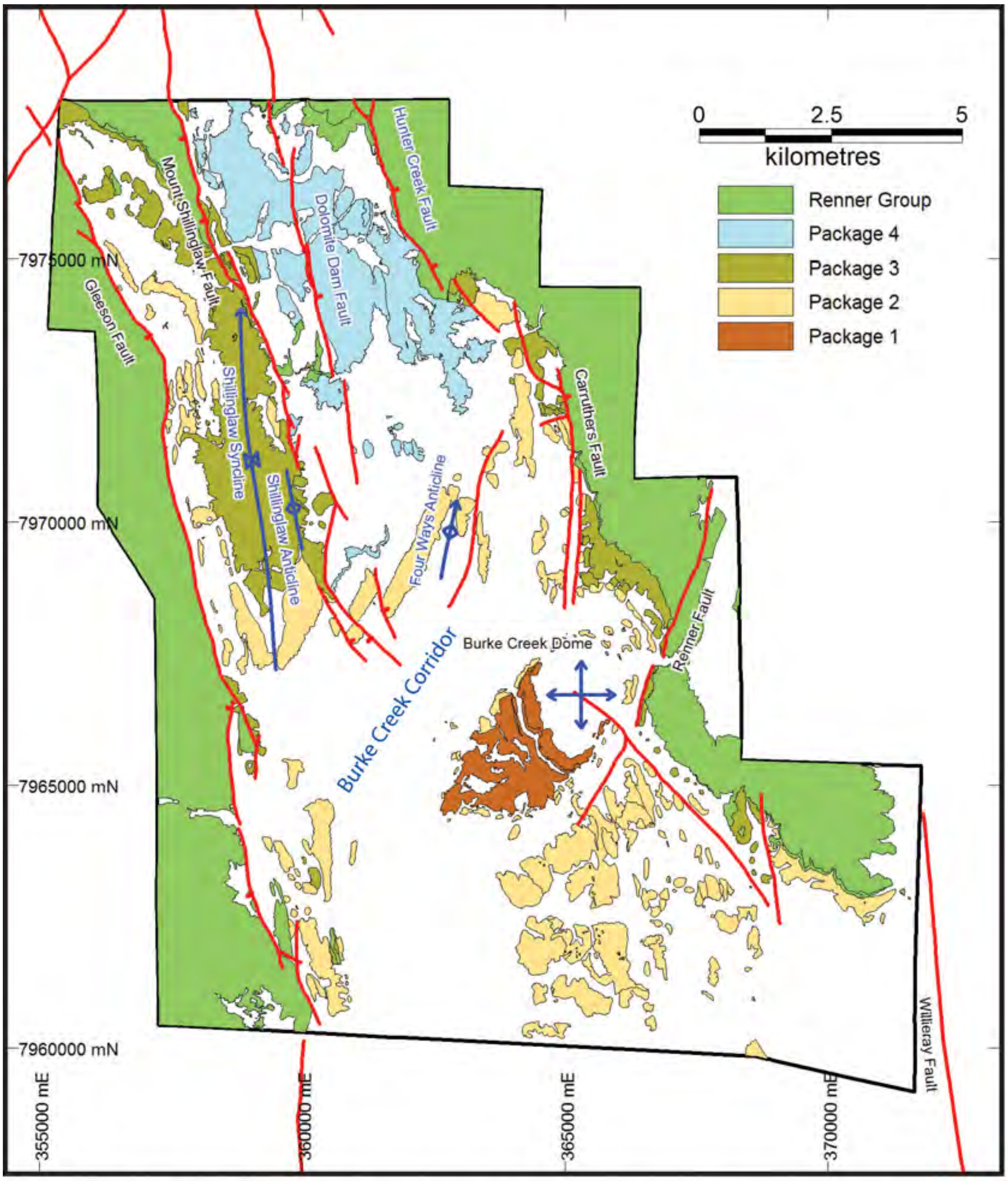

Figure 4.1: Major Proterozoic stratigraphic units at Renner Springs showing:
1) Regionally significant faults (red) with downthrown side indicated where known (faults outside mapped area are after Hussey et al (2001a).
2) Major fold axes (blue).
Names in black are after Hussey et al. (2001a, b). Names in blue are new.

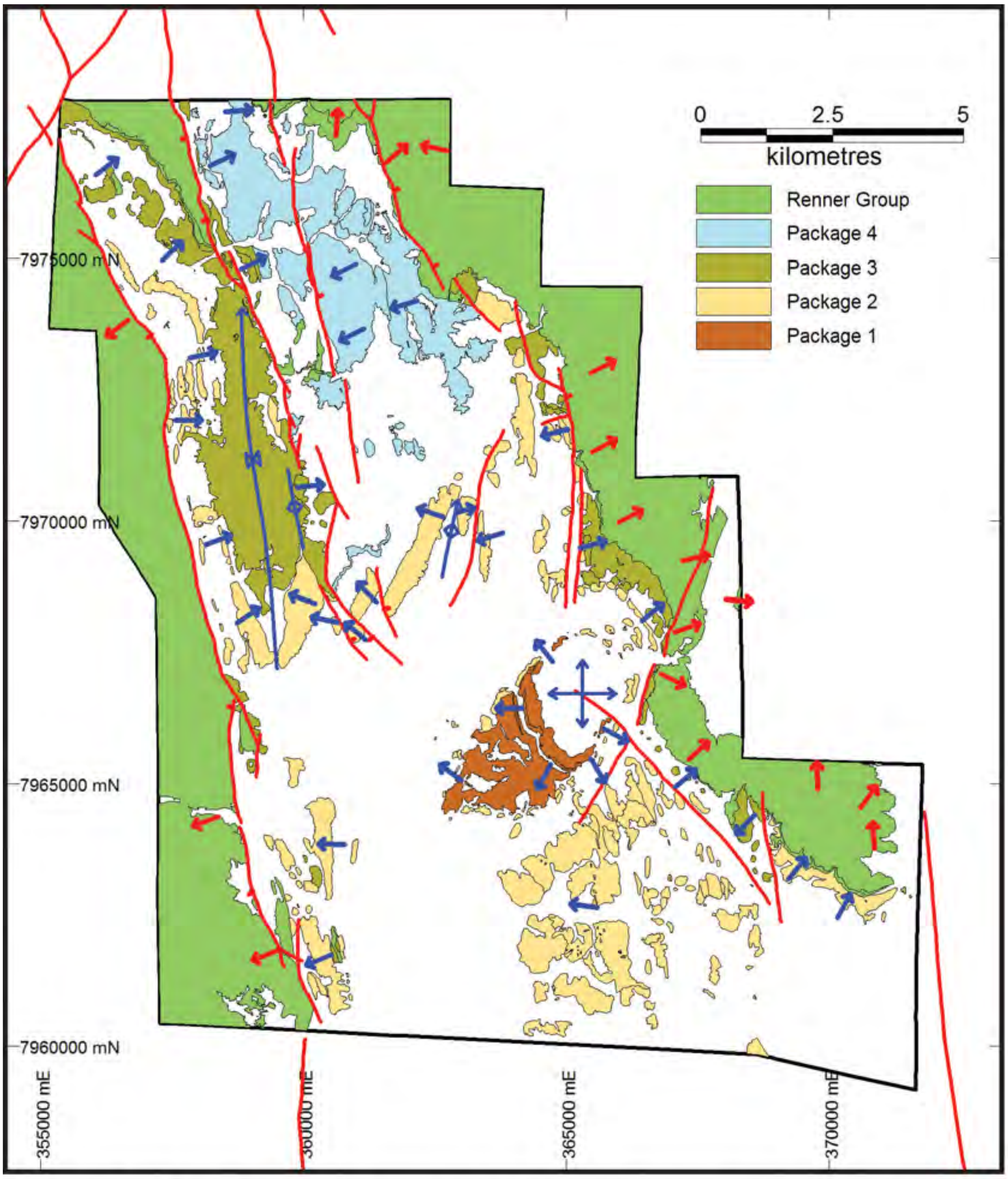

Figure 4.2: Major Proterozoic stratigraphic units at Renner Springs showing:
1) Regionally significant faults (red) with downthrown side indicated where known (faults outside mapped area are after Hussey et al (2001a).
2) Major fold axes (blue).
3) Dominant bedding dip directions. Blue = Packages 1-4. Red = Renner Group.

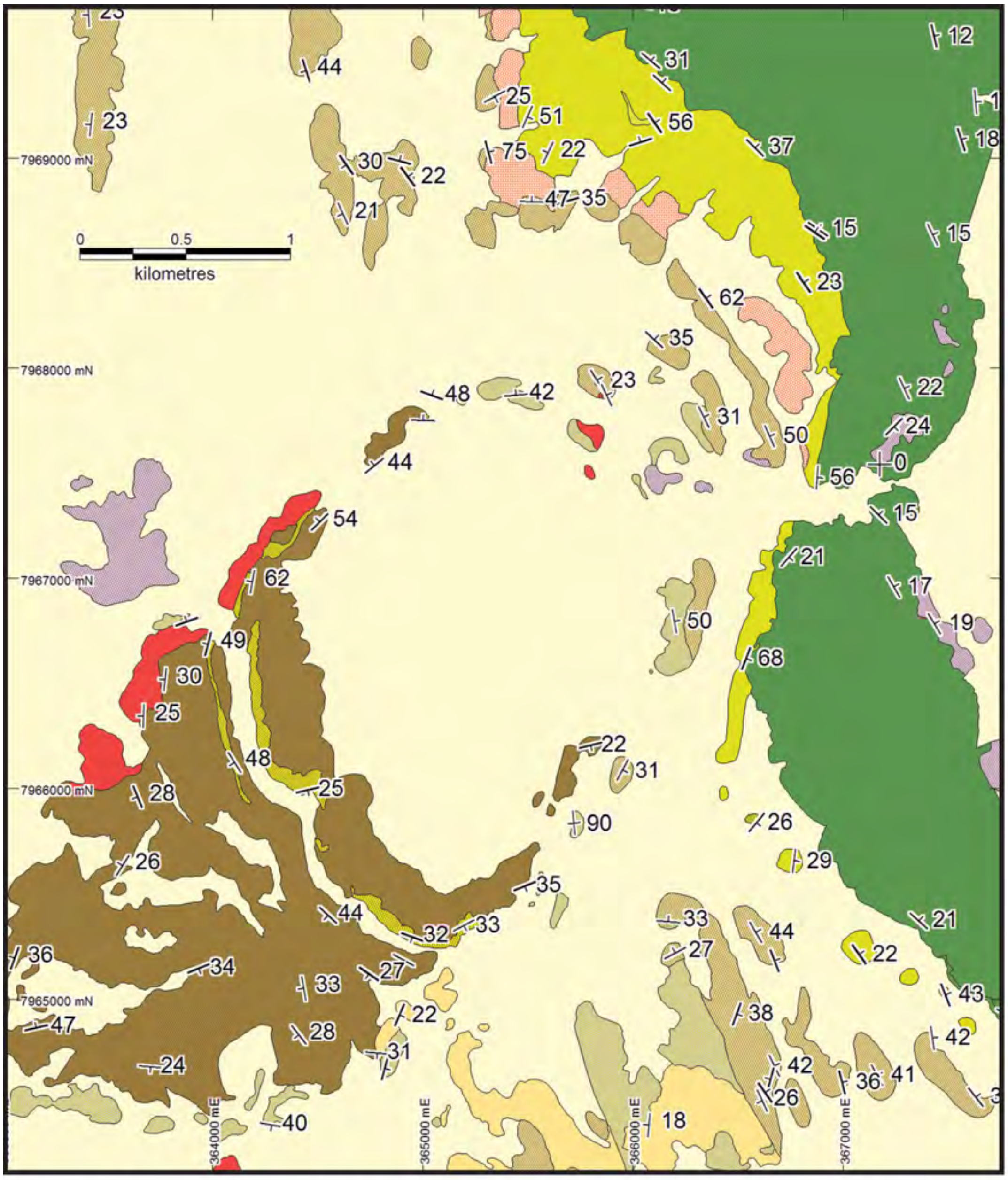

Figure 4.3: Bedrock geology of the Burke Creek Dome (see App. I) showing the symmetrical dome structure.

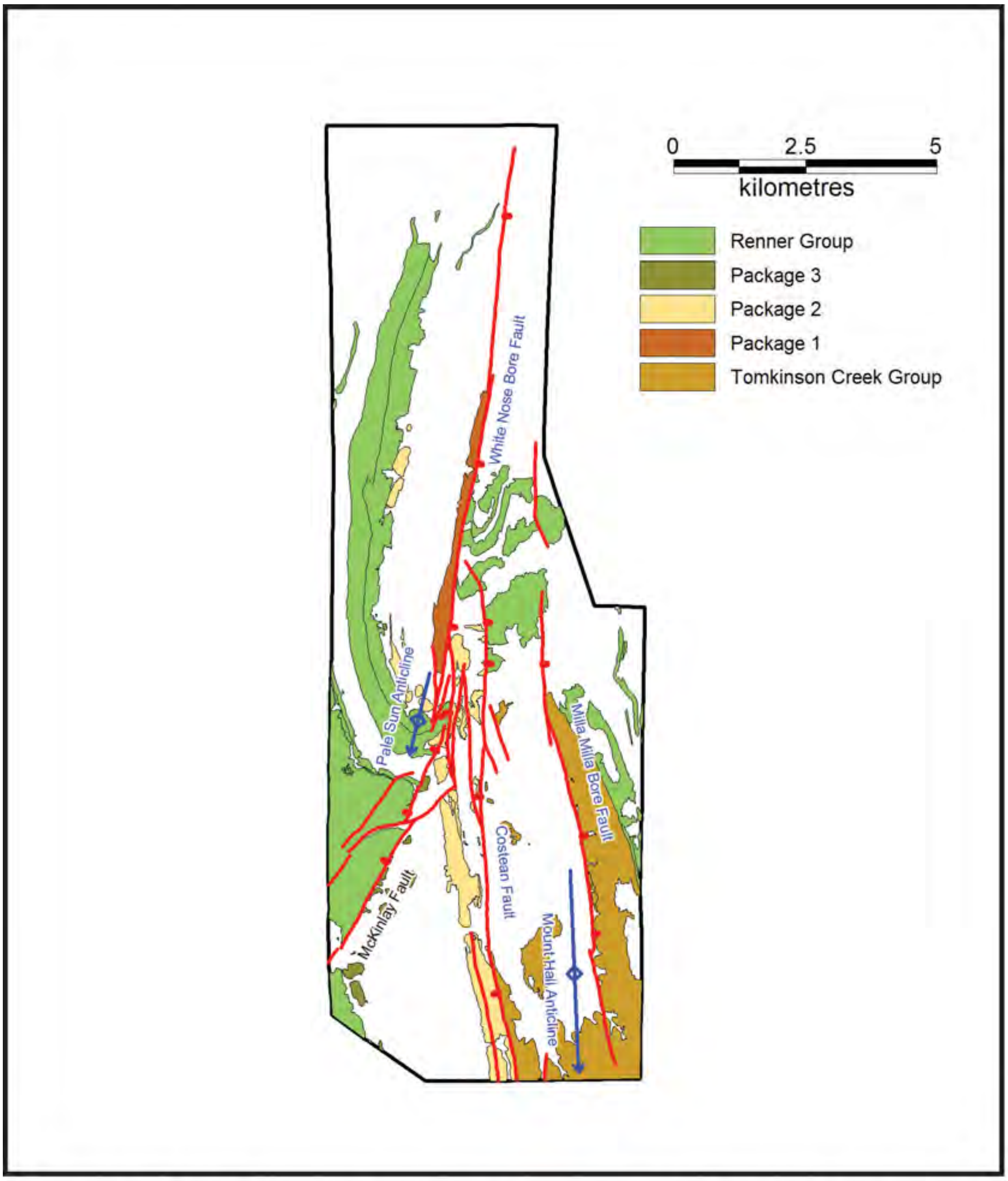

Figure 4.4: Major Proterozoic stratigraphic units at Helen Springs showing:
1) Regionally significant faults (red) with downthrown side indicated where known.
2) Major fold axes (blue).
Names in black are after Hussey et al. (2001a, b). Names in blue are new.

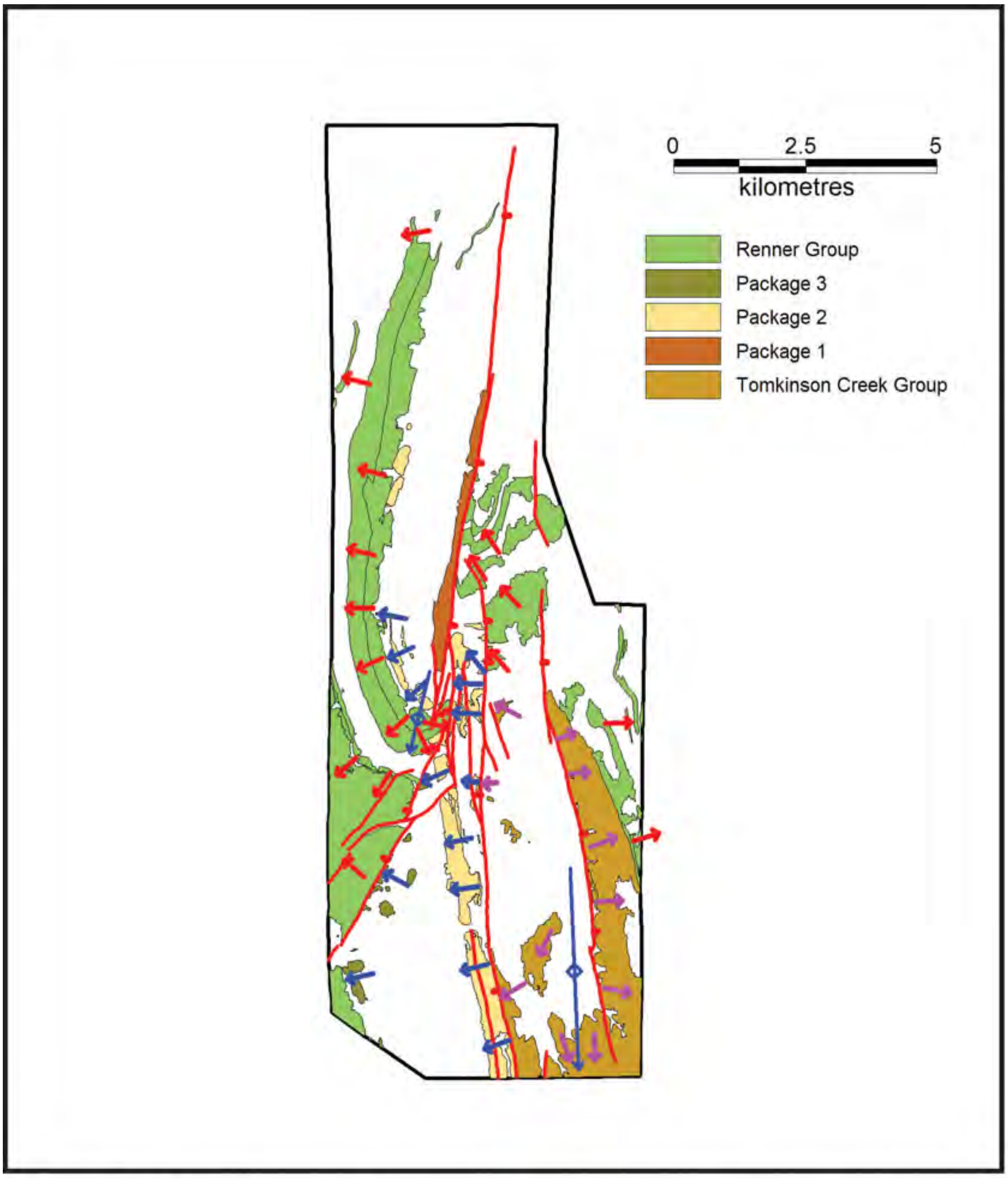

Figure 4.5: Major Proterozoic stratigraphic units at Renner Springs showing:
1) Regionally significant faults (red) with downthrown side indicated where known.
2) Major fold axes (blue).
3) Dominant bedding dip directions. Mauve = Tomkinson Creek Group. Blue = Packages 1-4. Red = Renner Group.

5
DEPOSITIONAL AND TECTONIC SETTINGS

An analysis of depositional and tectonic settings is beyond the scope of this project, however the following points should contribute to a better understanding.

5.1 Namerinni Group

- Packages 2 and 3 at Renner Springs are both upward coarsening (upward shallowing) cycles.
- Packages 1 and 4 at Renner Springs are incompletely exposed or preserved but could also be parts of upward coarsening cycles.
- Overall there is an upward decrease in siliciclastic sandstone.
- Broadly the lithologies in each package are similar but are present in different proportions.
- Packages are separated by angular unconformities or erosion surfaces.
- The points above suggest that the cycles reflect episodic rapid deepening followed by gradual relative sea-level fall in a broader regime of relative sea-level rise.
- The presence of angular unconformities between cycles is evidence of semi-continuous deformation during sedimentation. Relative sea-level rises and falls may, therefore, have been driven tectonically rather than eustatically which is more consistent with a convergent than a divergent margin.

5.2 Renner Group

- There may have been a significant palaeotopography on the basal Renner Group unconformity.
- Some faults were probably active during deposition of the Renner Group.
- Deformation of the Renner Group involved major reactivations of earlier faults and probably tightening of earlier folds.

5.3 Phanerozoic

- There is evidence that basement faults were reactivated, possibly during the Cambrian and probably during and after the Cretaceous.

6
ALTERATION AND MINERALISATION

6.1 Proterozoic Rocks

Proterozoic rocks have been extensively altered and some have been strongly weathered. Textures suggest that much, if not all, the alteration is hydrothermal, though care must be taken not to confuse alteration with weathering. There have been several alteration "events" whose relative and absolute timing and extent are uncertain.

Table 6.1 is a summary of recorded macroscopic alteration. Alteration is divided into silica, iron. "clay" and manganese. Figures 6.1 and 6.2 summarise the stratigraphic positions and types of alteration at Renner Springs and Helen Springs respectively. Figures 6.3 and 6.4 show the areal distribution of the mapped alteration facies at Renner Springs and Helen Springs respectively.

6.1.1 Silica

Silica alteration is divided into four types:

- diagenetic,
- "flooding" immediately below Cretaceous deposits (silcretisation; see Sect. 6.2),
- hydrothermal "flooding", and
- associated with hydrothermal brecciation.

Diagenetic silicification is common in mudstones and dolomitic rocks. It ranges from complete silicification to selective silicification. The latter is important because it results in alternating beds or laminae of silica and precursor rock that may be dolomite or dolomitic. Many of the exposed silicified stromatolites were probably silicified at this stage.

Hydrothermal silica "flooding" is restricted to sandstones. It comprises complete or selective silicification, mostly without extensive brecciation or quartz veining (e.g., Photos 1 RN1SSi to 4 RN1SSi). In detail though the rocks are fractured and micro-veined. This style of alteration has been recorded in Package 1 at Renner Springs and at the top of the uppermost sandstone in Package 2 also at Renner Springs.

Silicification associated with brecciation and veining ranges from steeply-dipping, cross-cutting quartz vein and hydraulic breccia complexes (e.g., Photos 1 RN2MXSi to 7 RN2MXSi, 21 RN2S to 27 RN2S, 1 RN2SXSi to 2 RN2SXSi, 14 RN3M to 23 RN3M) to bedding parallel silicification and hydraulic brecciation (e.g., Photos 8 RN2MXSi to 29 RN2MXSi). This style is common in the southern half of the Renner Springs area and is associated with WNW-trending quartz vein complexes (Fig. 6.5). It is also associated with the Gleeson Fault in the northern part of the Renner Springs area (Fig. 6.5) where it probably pre-dates Unit d of the Renner Group. However, a WNW-trending quartz vein complex cuts Unit b of the Renner Group in the southwest of the Renner Group area. Bedding parallel silicification, veining and brecciation is common towards the base of Package 2 where it includes calcite. Preferentially silicified beds may have been dolomitic.

Silica flooding of sandstones in Package 1 at Renner Springs is probably related to the silicification associated with brecciation.

6.1.2 Iron

The nature of many pre-alteration rocks is unknown because of extensive alteration. However, cumulative observations suggest that many of the Proterozoic successions were redbeds. Therefore, pink to red colouring is not necessarily an indicator of post-diagenetic iron alteration, rather, it may represent a lack of alteration. All exposed iron-altered rocks are strongly weathered (now iron oxyhydroxide) so the alteration mineralogy is unknown, though it is probably hematite.

Post-diagenetic iron alteration falls into two types: ferruginous “flooding” and ferruginous alteration associated with brecciation. The age and origin of ferruginous flooding can be problematic because:

a) locally, some of the primary succession may have been moderately ferruginous; and
b) iron staining of Proterozoic rocks can be derived from overlying lateritised Cretaceous rocks.

Ferruginous flooding has been recorded in Packages 2 and 3 at Renner Springs (Fig. 6.1) and in all three Groups at Helen Springs (Figs. 6.2). It affects mudstones, cherty mudstones and sandstones. Ferruginous alteration associated with brecciation has been recorded in Package 2 and the Renner Group at Helen Springs. Typically, breccias show hydraulic textures and have a ferruginous sandstone matrix (e.g., Photos 2 HN2S to 6 HN2S, 011 HN2S to 15 HN2S, 1 HR2cSXFe to 8 HR2cSXFe, 1 HR2dSFe to 3 HR2dSFe).

6.1.3 Bleaching of Sandstones

Many massive quartz arenites, particularly in the Renner Group are bleached. While commonly this is due to weathering (e.g., Photo 21 RRbS) it is also due to alteration (reduction?). Bleaching occurs in two settings.

1) Adjacent to faults where the rocks are strongly fractured, particularly in the Renner Group (e.g., Photos 1 HR2eS to 3 HR2eS, 1 RRbS to 4 RRbS, 1 RRdS).
2) Within the body of the sandstone unit where, in places, alteration fronts are visible (e.g., Photos 6 HR2eS to 8 HR2eS, 8 RRbS to 20 RRbS).

6.1.4 Bleaching of Dolomites

In Package 4 (Renner Springs) crystalline and sandy dolomite locally show strong bleaching (Photos 7 RN4DS to 8 RN4DS, 5 RN4MSDCt to 7 RN4MSDCt). Bleached and unbleached dolomite have a sharp contact. Observations elsewhere show that this style of bleaching, without volume loss, is associated with hydrothermal fluids related to manganese mineralisation.

6.1.5 Dissolution and “Clay” Alteration

Figure 6.3 shows a significant area of “clay” alteration in the NE of the Renner Springs area. This alteration affects mostly Package 4 and lesser Package 3 rocks. Most rocks in the area comprise strongly weathered sandstone and siltstone interlaminated or interbedded with more clay rich laminae or beds (Photos 01 RN4MSCy to 23 RN4MSCy). These rocks comprise essentially quartz and clay. Commonly these rocks show complex breccia textures (Photos 1–3, 6–8, 11–14, 16 RN4MSCy).

Observations of this style of weathering, alteration and brecciation elsewhere suggest it is related to dissolution, volume reduction and possibly phyllosilicate alteration of a dolomitic precursor. In this case the precursor was probably a sandy dolomite.

Table 6.1: Summary of post-diagenetic alteration and mineralisation records in the areas mapped. Hydrothermal alteration and mineralisation are coloured.

	Contact	Silica	Iron	Other Alteration	Manganese
Quaternary					
	Unconformity				
Cretaceous, Tertiary		Si (silcrete)	Fe (marine? & laterite)	Clay (laterite)	
	Unconformity				
Cambrian					
	Unconformity				
Renner Group		Si (vein breccia)	Fe alteration Fe brecciation	Bleaching, reduction	
	Unconformity				
Namerinni Group P4				Dissolution, Clay alteration	Mn
	Unconformity				
Namerinni Group P3 (Renner Springs and Helen Springs)		Si (with Fe?)	Fe alteration	Dissolution, Clay alteration	Mn
	Unconformity				
Namerinni Group P2 (Renner Springs and Helen Springs)		Si (flooding) Si (brecciation)	Fe alteration Fe brecciation		Mn
	Unconformity				
Namerinni Group P1 (Renner Springs and Helen Springs)		Si (flooding)			
	Unconformity				
Tomkinson Creek Group			Fe alteration		Mn

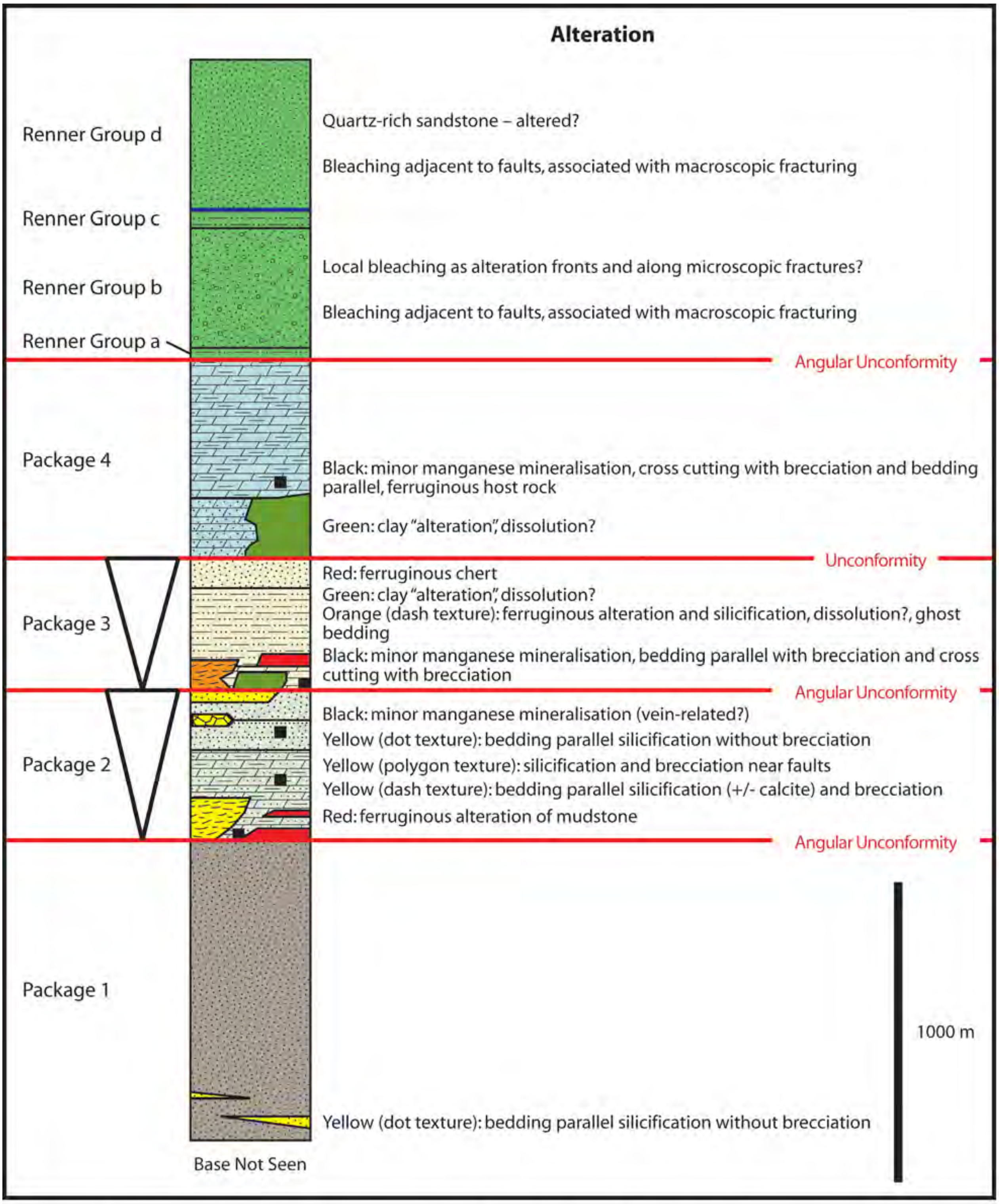

Figure 6.1: Summary stratigraphic column of Packages 1-4 (Namerinni Group) and the Renner Group at Renner Springs showing alteration. See Figure 3.1 for "primary" lithologies". Alteration graphics are schematic.

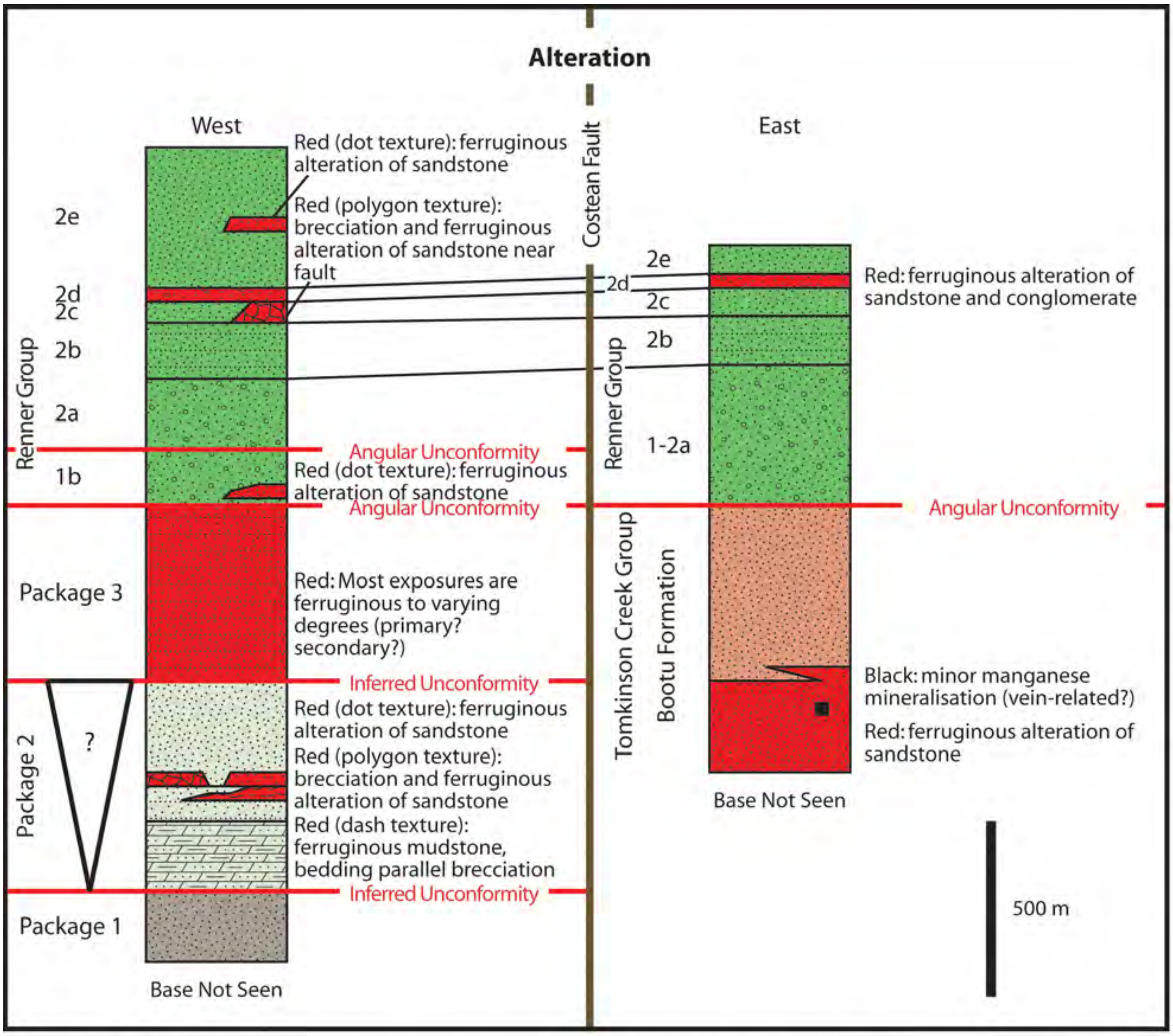

Figure 6.2: Summary stratigraphic column of Tomkinson Creek Group, Packages 1-3 (Namerinni Group) and the Renner Group at Helen Springs showing alteration. See Figure 3.4 for “primary” lithologies”. Alteration graphics are schematic.

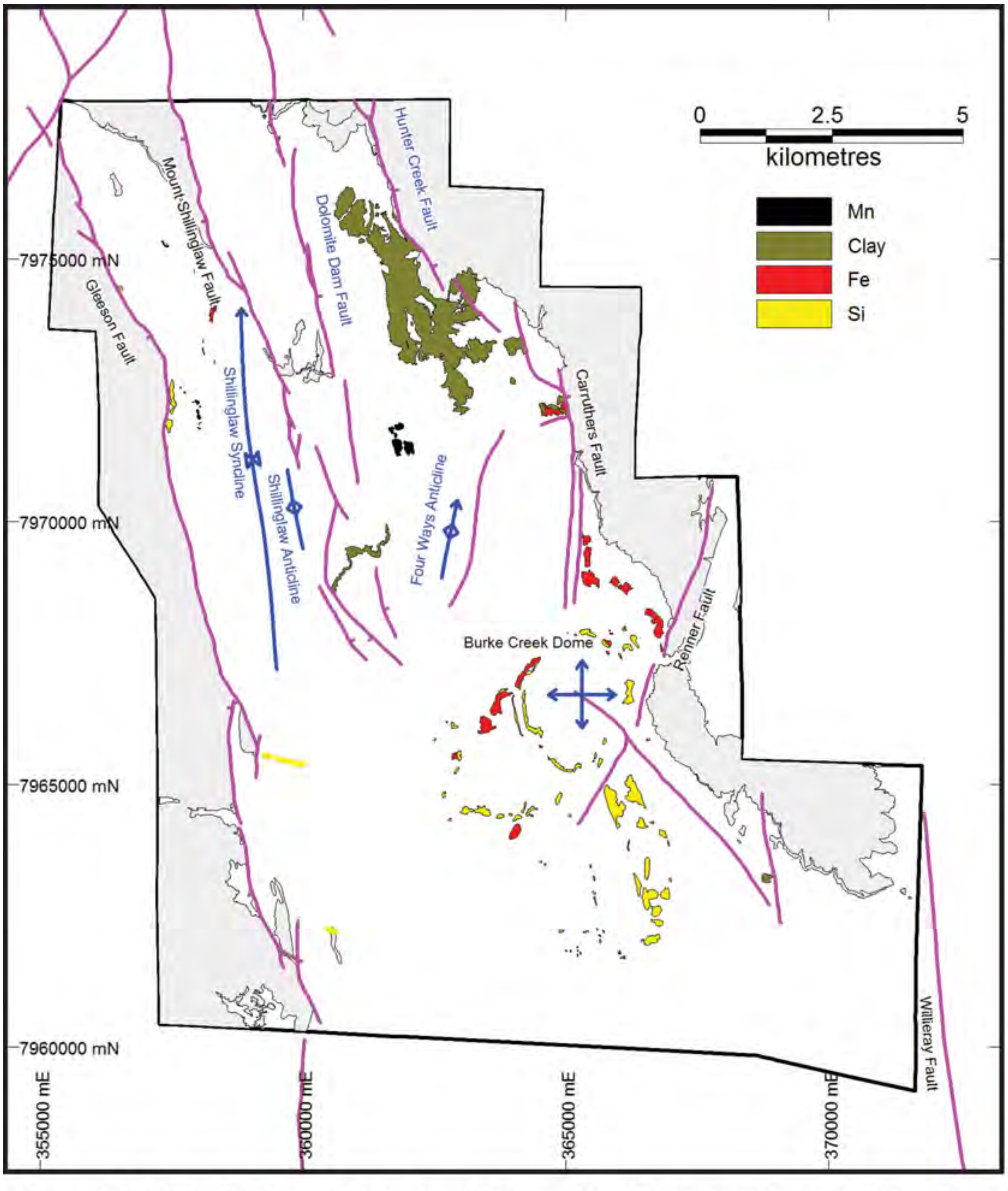

Figure 6.3: Distribution of altered and mineralised Proterozoic mapping units at Renner Springs. Renner Group in grey. Major faults showing known downthrown sides in mauve. Major fold axes in blue.

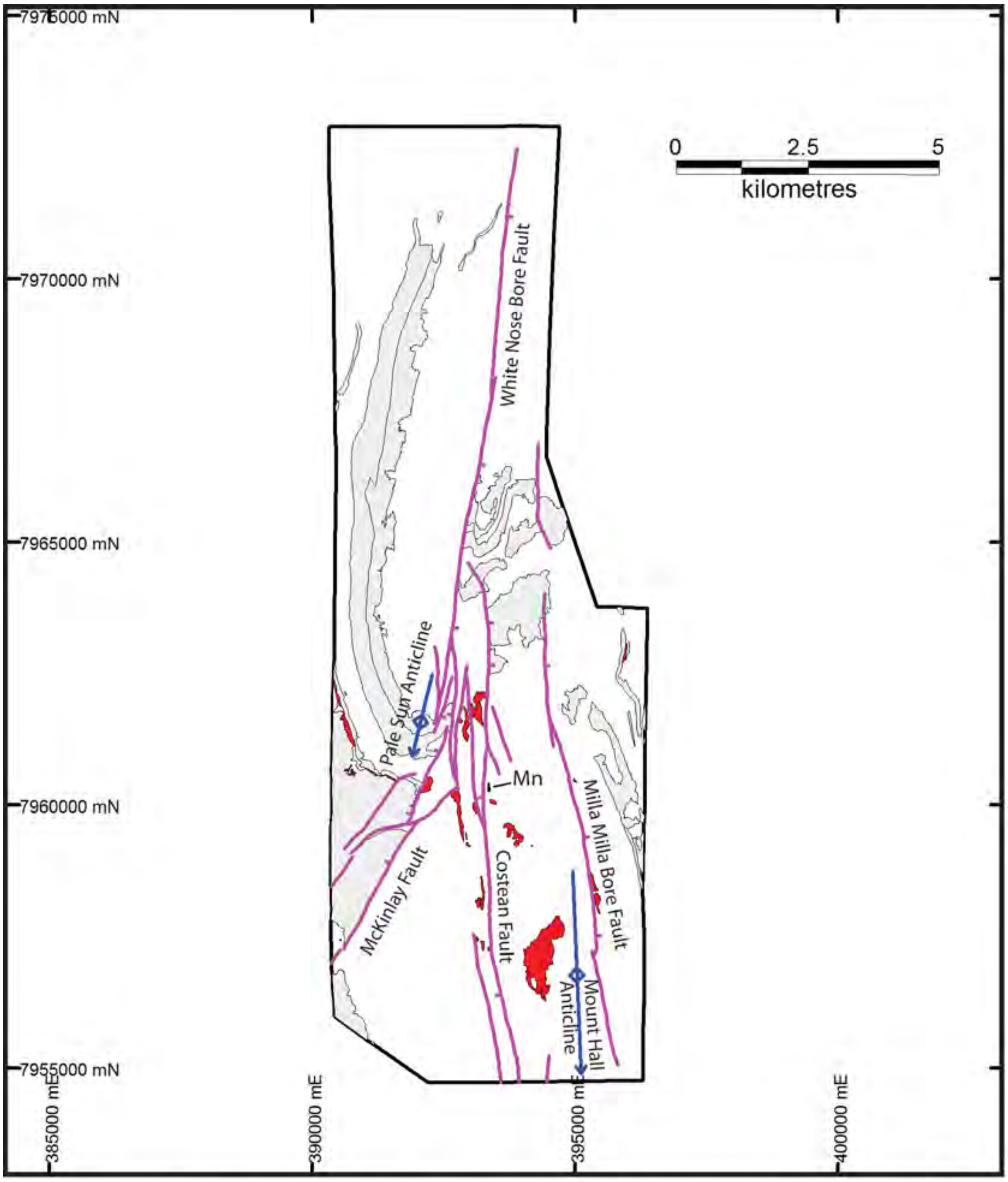

Figure 6.4: Distribution of iron-altered (red) and manganese mineralised (black, annotated) Proterozoic mapping units at Helen Springs. Renner Group in grey. Major faults showing known downthrown sides in mauve. Major fold axes in blue.

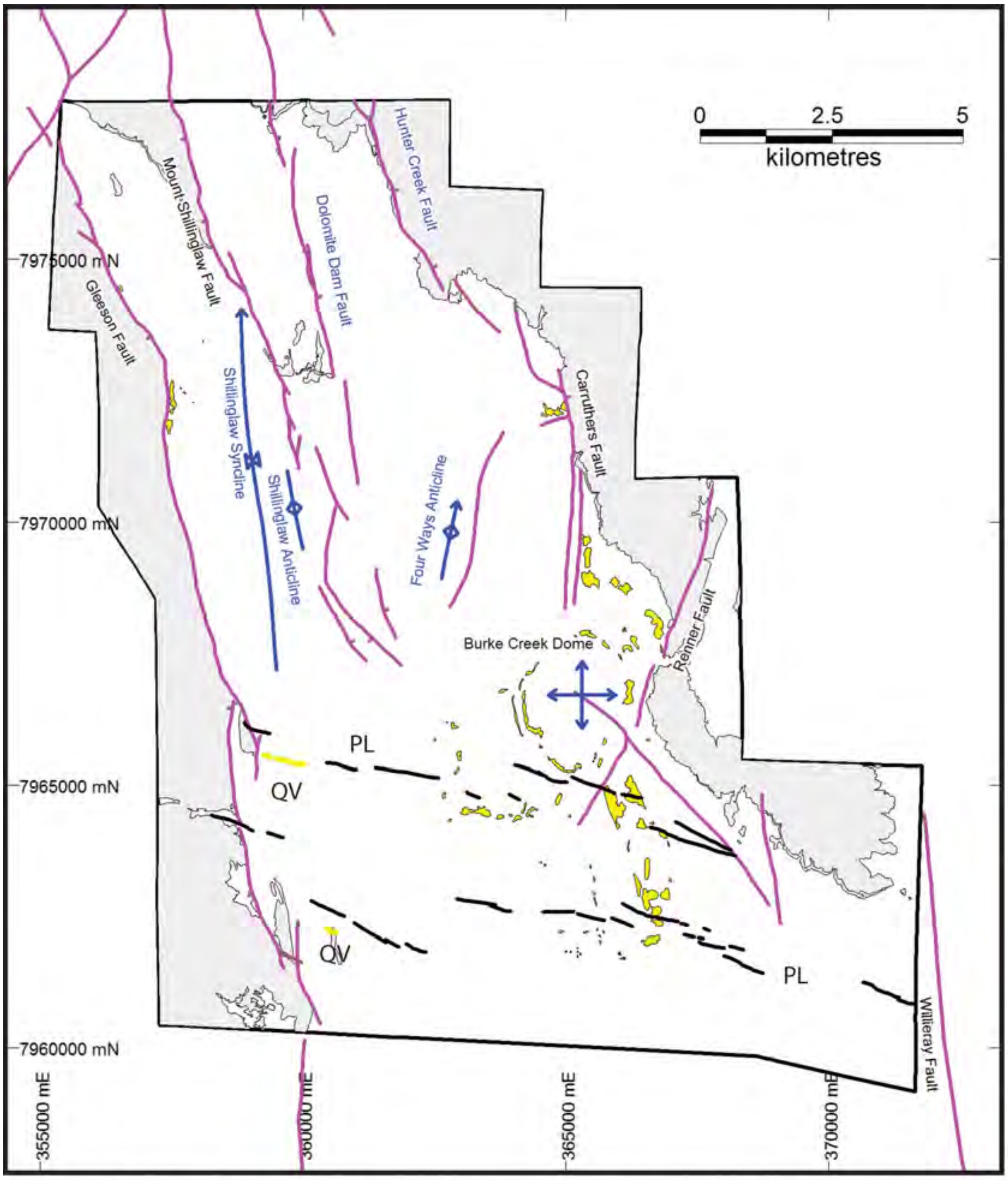

Figure 6.5: Distribution of Proterozoic mapping units that include post-diagenetic silicification at Renner Springs (yellow). QV (yellow) = mapped quartz veins that may be more extensive and marked by a suite of WNW-trending air photo lineaments (thick black, PL). Renner Group in grey. Major faults showing known downthrown sides in mauve. Major fold axes in blue.

6.1.6 Dissolution "Clay" Iron and Silica Alteration

The basal few tens of metres of Package 3, for about 5 km north of the Renner Fault, at Renner Springs comprises a ferruginous, variably silicified mudstone that is locally brecciated (Mapping Unit RN3MXSiFe; Photos 1 RN3MXSiFe to 6 RN3MXSiFe). This unit has a sharp lower contact with the silicified top sandstone of Package 2 and a gradational upper contact into mudstones. Observed textures suggest this complex unit resulted from a combination of dissolution (and associated brecciation), hydraulic brecciation and iron and silica alteration. The precursor rock is unknown but, given its stratigraphic position, it is likely to have been dolomitic.

6.1.7 Manganese

At Helen Springs manganese mineralisation is recorded in the Tomkinson Creek Group only (Fig. 6.2; Photos 1 HTSFeMn to 7 HTSFeMn). At Renner Springs it is recorded in Packages 2 (Photo 1 RN2Mn), 3 (Photos 1 RN3MXBMn to 20 RN3MXBMn, 1 RN3MXMn to 15 RN3MXMn) and 4 (Photos 1 RN4MSFeMn to 4 RN4MSFeMn, Tab. 2; Fig. 6.1). The largest and most areally extensive manganese mineralisation occurs within the basal few tens of metres of Package 3.

Manganese is mobile in the supergene environment and the origin of manganese staining and coatings in surface rocks is problematic. Experience elsewhere has shown that relatively small amounts of "primary" manganese can result in significant weathering-related stains. Further, manganese mineralogy in exposed "primary" manganese rarely survives and deducing a meaningful hydrothermal paragenesis from Australian surface manganese is essentially impossible.

Manganese occurs mostly in breccias and as veins in fractures. In breccias manganese forms the matrix and clasts are remnants of local country rock. The clasts include sandstone, siltstone, silicified mudstone, silicified stromatolites and chert – essentially quartz-rich rocks. Manganese may also contain minor barite.

Manganese exposures can be divided into three types.

1) Massive, structureless, cross-cutting breccias ranging from about 1 m to 10 m across (e.g., Photos 1 HTSFeMn to 7 HTSFeMn, 1 RN3MXMn to 15 RN3MXMn, 1 RN4MSFeMn to 4 RN4MSFeMn). The proportions of country rock fragments in these bodies varies. Where seen, contacts with country rocks are sharp. This is the style of mineralisation at Helen Springs.
2) Bedding parallel breccias (e.g., Photos 1 RN3MXBMn to 20 RN3MXBMn). This type is more common than massive manganese breccia and is exposed as either individual “beds” or groups of “beds” with a strike length of up to 200 m. Exposed “beds” are 1 m to ≥ 5 m thick. Preservation of bedding is variable and defined by alignments of quartz-rich clasts.
3) Bedding parallel replacement (e.g., Photo 02 RN2Mn)? This style is only visible in costeans in strongly weathered rocks and its origin is problematic. It is either a clast free variant of 2 (above) or is true replacement.

Allowing for the effects of weathering, the manganese deposits are interpreted to have formed as hydrothermal deposits as follows.

- Massive cross cutting manganese breccias originated as structural breccias (tension gashes) that were probably enhanced by dissolution of any dolomite present. These probably represent cross-cutting fluid feeders.
- Bedding parallel breccias represent zones of bedding parallel fluid movement. These formed in dolomitic rocks by a combination of hydraulic brecciation and dissolution of dolomite. The quartz-rich clasts are the non-dissolved residue.
- Manganese replacement of dolomitic rock, without dissolution, may have occurred also but this is poorly documented.

Figures 6.6 and 6.7 show that manganese exposures at Renner Springs are aligned in a NW-trending corridor that coincides with a zone of NW-trending fractures. Figure 6.8 (see also Joe Drake-Brockman 1:4000 maps) shows that most of the manganese exposures in the NW of the Renner Springs area are elongate NW to NNW, parallel to the strike of local bedding. This elongation reflects mostly the dominance of bedding replacement manganese, though the long axis of the single largest cross-cutting manganese body in Prospect R6 (Fig. 6.7) is also oriented NW. Combined, these data suggest that the tensional direction at the time of manganese mineralisation was oriented NW to NNW, resulting in cross cutting tension gashes and enhancing fluid access to lithologically suitable beds striking the same orientation.

In summary, manganese mineralisation at Renner Springs appears to be controlled by a series of tension gashes (feeders) that align as a NW-trending corridor within a zone of NW-trending fractures. Mineralisation post-dated Package 4 (at least) and formed in dolomite-bearing parts of the succession in Packages 2, 3 and 4. Manganese propagated parallel to bedding in some dolomite bearing units cut by feeders. The basal few tens of metres of Package 3 contains the largest and most areally widespread manganese deposits.

Table 6.2: Summary of manganese prospects at Renner Springs (see Fig. 6.7 for locations). See Joe Drake-Brockman report for detailed mapping, descriptions and recommendations.

Prospect Number	Stratigraphic Unit	Mapping Unit	Comments	Photo Numbers in Appendix III
Prospect R1	Package 3 (lower)	QuA, RN3M, RN3MD	Single exposure of Mn recorded.	
Prospect R2	Package 3 (lower)	QuA, RN3M, RN3MD, RN3MXBMn	Bedding parallel Mn recorded.	11 RN3MXBMn.to 20 RN3MXBMn
Prospect R3	Package 3 (near base)	QuA, RN3MXBMn, RN3MXMn	Bedding parallel Mn and more massive Mn parallel to bedding strike.	
Prospect R4	Package 2	RN2S	JDB only.	
Prospect R5	Package 3 (near base)	QuA	JDB only.	
Prospect R6	Package 3 (near base)	QuA, RN3MXBMn, RN3MXMn	Bedding parallel Mn and more massive Mn crossing bedding.	1 RN3MXMn to 15 RN3MXMn, 1 RN3MXBMn to 10 RN3MXBMn
Prospect R7	Package 4	RN4MSDCt	30 cm thick? Mn horizon, not in situ.	
Prospect R8	Package 4	RN4MSDCt. RN4MSFeMn	Ferruginous Mn-stained sandstone to siltstone, cross-cutting Mn pods.	1 RN4MSFeMn to 4 RN4MSFeMn
Prospect R9	Package 2	RN2Mn	Bedding parallel Mn.	1 RN2Mn to 4 RN2Mn
Prospect R10	Packages 2, 3	Several	Relatively large area enclosing minor Mn exposures and one Mn drill intersection.	

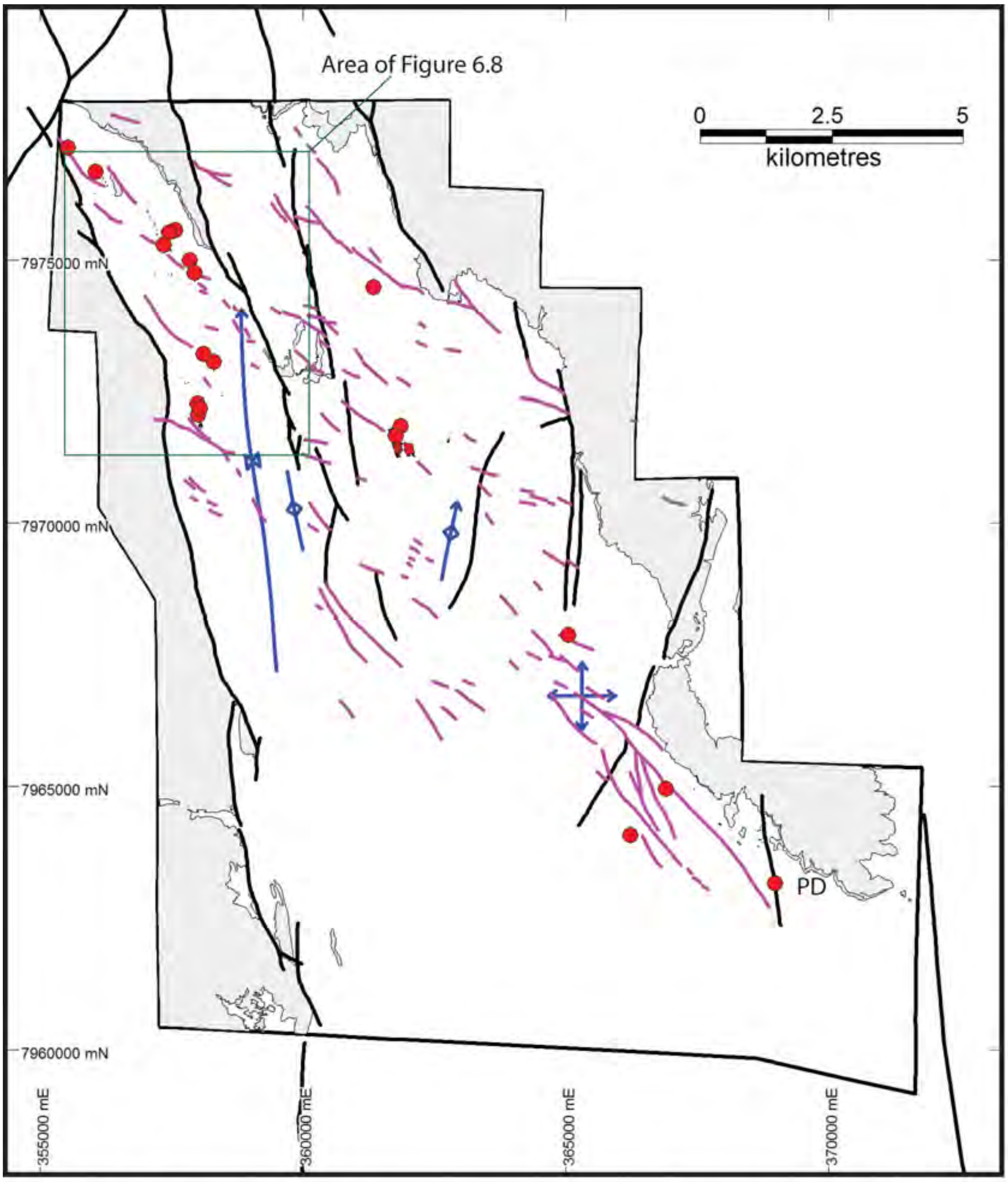

Figure 6.6: Distribution of manganese at Renner Springs (red). Manganese includes: all Mn-bearing units mapped at 1:20,000 and 1:4000 (by Joe Drake-Brockman);

manganese locations too small to map at 1:20,000 (red dots); and

a public domain manganese location not recorded during mapping (PD).

Mauve lines are a suite of NW-trending faults and air photo lineaments. Renner Group in grey. Major faults in black. Major fold axes in blue.

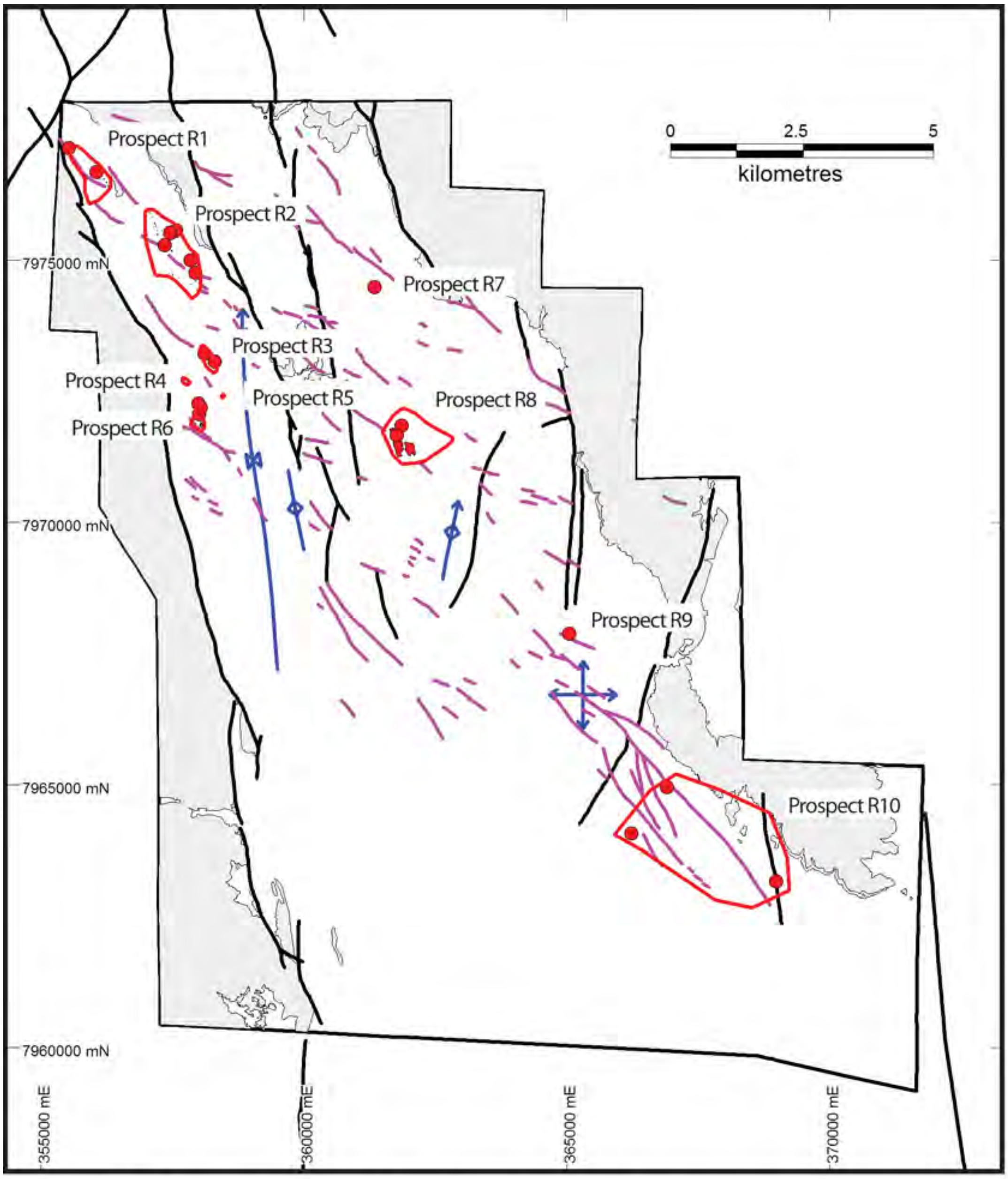

Figure 6.7: Copy of Figure 6.6 showing the 10 named prospects at Renner Springs.

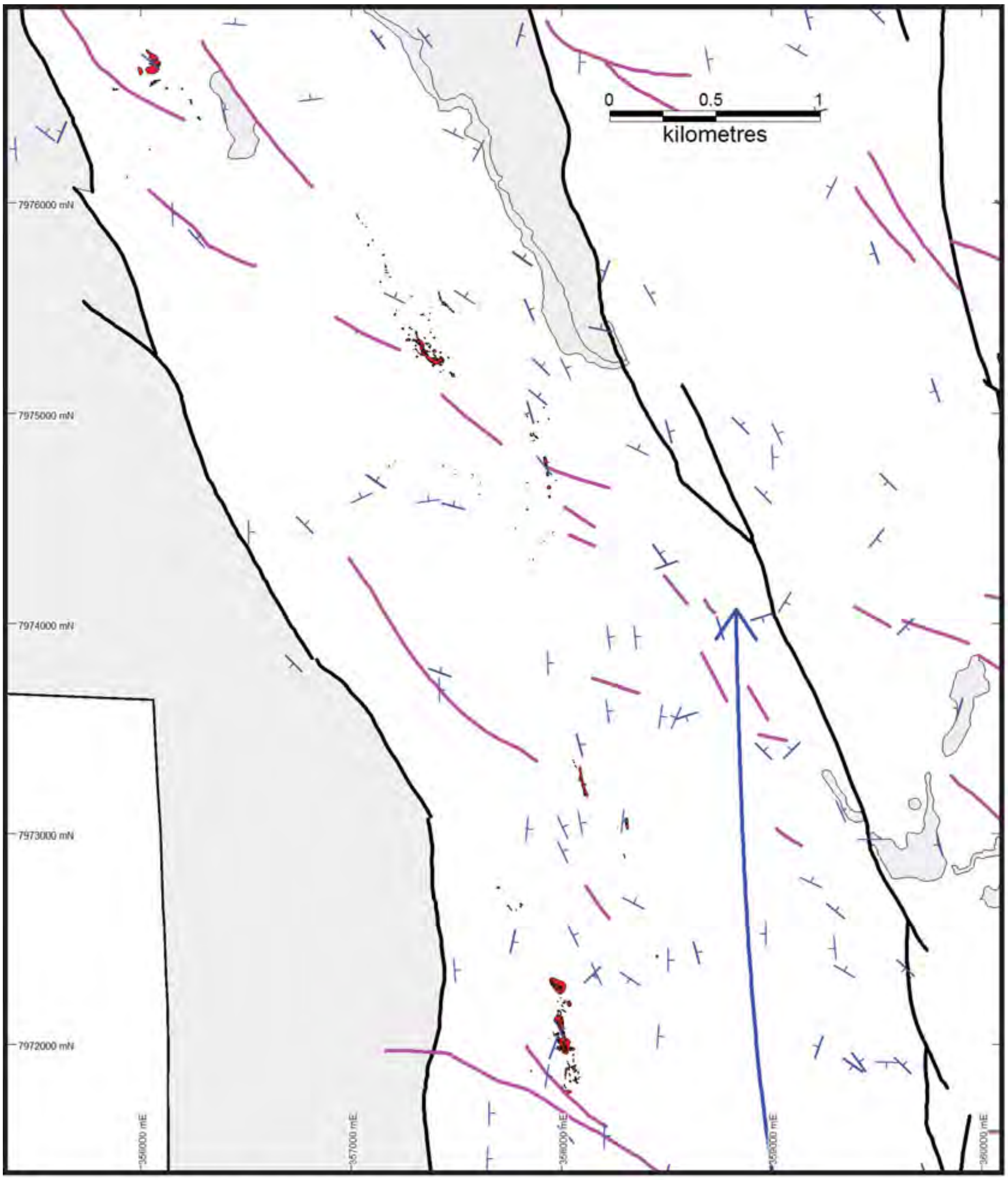

Figure 6.8: Mapped manganese in the inset area in Figure 6.6. (red; mapped at 1:20,000 and at 1:4000 by Joe Drake-Brockman) and measured bedding dip directions from the 1:20,000 mapping (blue strike and dip symbols). Mauve lines are a suite of NW-trending faults and air photo lineaments. Renner Group in grey. Major faults in black. Major fold axes in blue.

6.1.8 Timing of Alteration

Table 6.1 shows that all Proterozoic rocks are affected by alteration, though manganese is not recorded in the Renner Group. Where seen together, manganese post-dates iron flooding and silicification associated with hydrothermal fracturing. Experience elsewhere has shown that dolomite bleaching, dolomite dissolution, "clay' alteration and manganese mineralisation are probably related. The bleaching (reduction) of the Renner Group sandstones and silicification of sandstones at the very top of Package 2 may also be related to this event. At Woodie Woodie hematite mineralisation always precedes manganese where they are seen together, as it does here.

The following points summarise hydrothermal events.

- Hydrothermal fracturing and associated silicification controlled by WNW-trending fractures (Fig. 6.5) cut the Namerinni Group at Renner Springs. Only one quartz vein complex has been recorded extending into the lower Renner Group. Thus, this significant event could either pre-date the Renner Group, with a local post-Renner Group reactivation, or post-date the lower Renner Group.
- Assuming iron and associated brecciation is one event, which is unlikely, it post-dates the Renner Group.
- Dolomite bleaching, dolomite dissolution, "clay' alteration, manganese mineralisation, bleaching of the Renner Group sandstones and silicification of sandstones at the very top of Package 2 could be the effects of one major fluid event. Iron alteration may have been an early part of this event. Fluid assess was via NW–NNW-trending fractures and post-dates the Renner Group. The absence of manganese mineralisation in the Renner Group may reflect a lack of suitable rocks (dolomite) or an absence of suitable geochemical traps in this part of the succession.

6.2 Phanerozoic Rocks

Some rocks immediately beneath the Cretaceous cover have been silcreted and brecciated and the few Cretaceous shales mapped are ferruginous. Lateritisation in the Tertiary locally concentrated iron from the Cretaceous deposits

6.3 Stratigraphy, Structure, Tectonics, Alteration and Mineralisation

Figure 6.9 shows that the alignment of manganese deposits at Renner Springs extends to the Bootu Creek area and a manganese "corridor" can be defined. This corridor cross cuts the dominant fault directions and fold axes (Fig. 6.10). However, stepping out to a more regional scale (Figs 6.10, 6.11) it is apparent that the orientation of the corridor is not anomalous, rather it is the orientations of the faults and fold axes that are anomalous. The corridor, therefore, probably reflects the presence of a deep NW-trending basement structure that has been reactivated, allowing fluids to move upwards into the Tomkinson Creek, Namerinni and Renner Groups. WNW–NW-trending sinistral basement shearing would open WSW–W-trending tension gashes (hydrothermal silica event?) and WNW-trending dextral basement shearing would have opened NNW-trending tension gashes (manganese event?) and may have reactivated NNW-trending faults.

In the manganese event fluids could have risen from the deep seated NW–NNW-trending structure via tension gashes and reactivated faults. As they encountered successive lithologies they altered them in a style dependent on local lithology and probably local redox conditions. Beds of suitable lithology (dolomite) were dissolved and locally mineralised, and quartz-rich beds (sandstones) probably formed barriers that forced fluids laterally, parallel to bedding. In detail, therefore, each manganese deposit will be different depending on local lithologies, the orientations of pre-existing fractures, bedding strike, local stress and local redox conditions.

At Renner Springs the basal few tens of metres of Package 3 is extensively altered and locally manganese mineralised. The horizon, which is bounded by the top sandstone of Package 2 and overlying siliciclastic mudstones, appears to have formed a major bedding-parallel fluid conduit, probably due to the presence of dolomite. The dolomitic basal part of Package 4 has also been "clay"-altered in places. The basal part of Package 2 may also have been a bedding-parallel fluid conduit but many of the dolomitic rocks were probably silicified, and therefore non reactive, prior to the ingress of the manganese fluid.

The manganese deposits at Helen Springs lie well outside the manganese corridor discussed above (Fig. 6.9). However, recorded iron mineralisation in the Namerinni Group is common close to the Costean Fault (Fig. 6.4) and at the junction of the Costean and McKinlay Faults suggesting that these may have focussed fluids. The Costean Fault in particular may have been under tension during the manganese event.

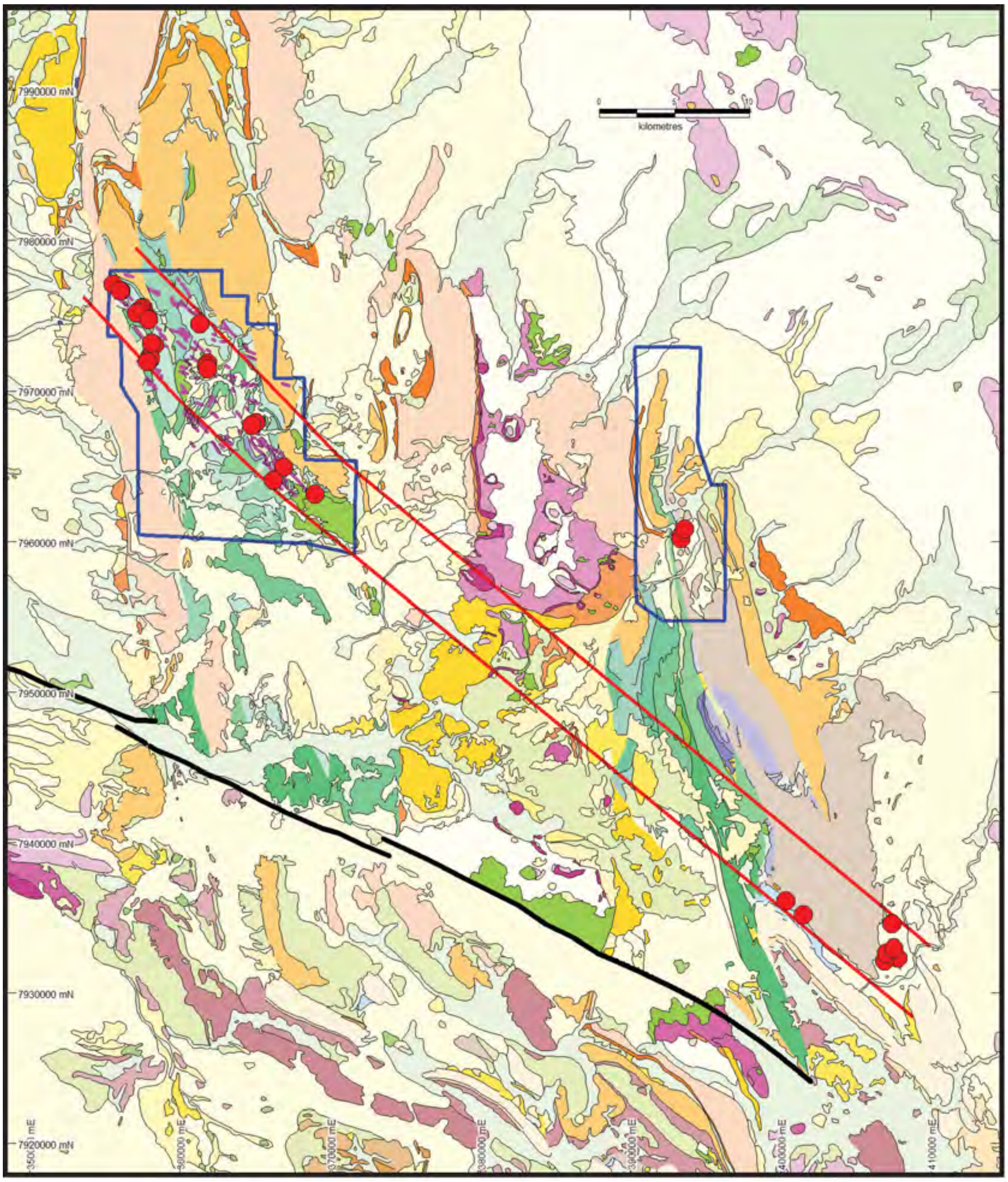

Figure 6.9: Regional distribution of manganese locations (red dots) defining a NW-trending mineralised corridor (red lines). Black lines are a mapped and inferred WNW-trending major structural contact. Mauve lines are a suite of NW-trending faults and air photo lineaments mapped at Renner Springs. 1:20,000 scale mapped areas in blue. Base map after Hussey et al., 2001a.

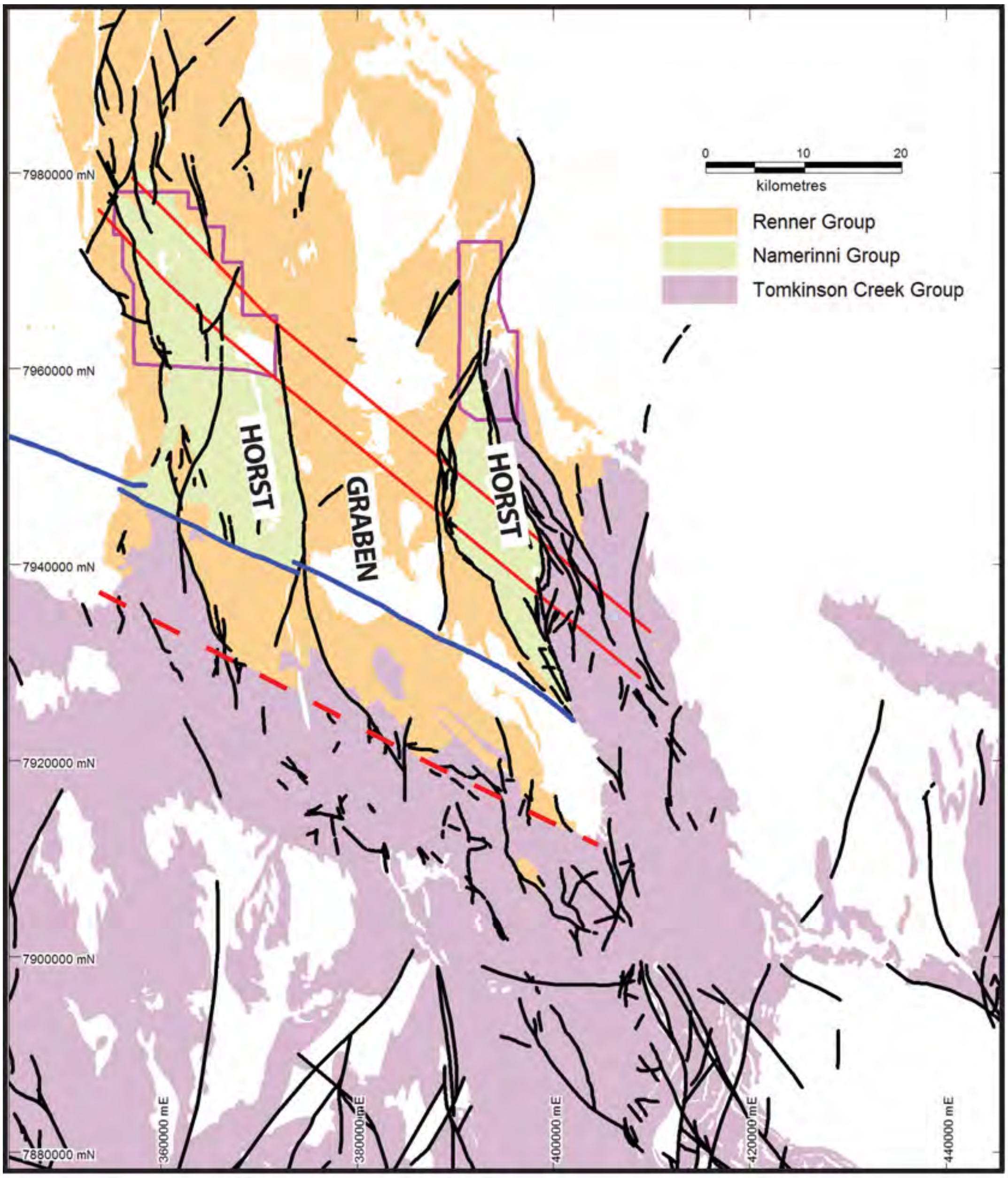

Figure 6.10: The manganese corridor defined in Figure 6.9 (red lines) in a greater regional context. Black lines are major faults. Blue lines are a mapped and inferred WNW-trending major structural contact. Dashed red line is a second WNW-trending lineament marking the southern edge of the outcrop of the Renner Group. 1:20,000 scale mapped areas in mauve. Base map after NTGS open files sources.

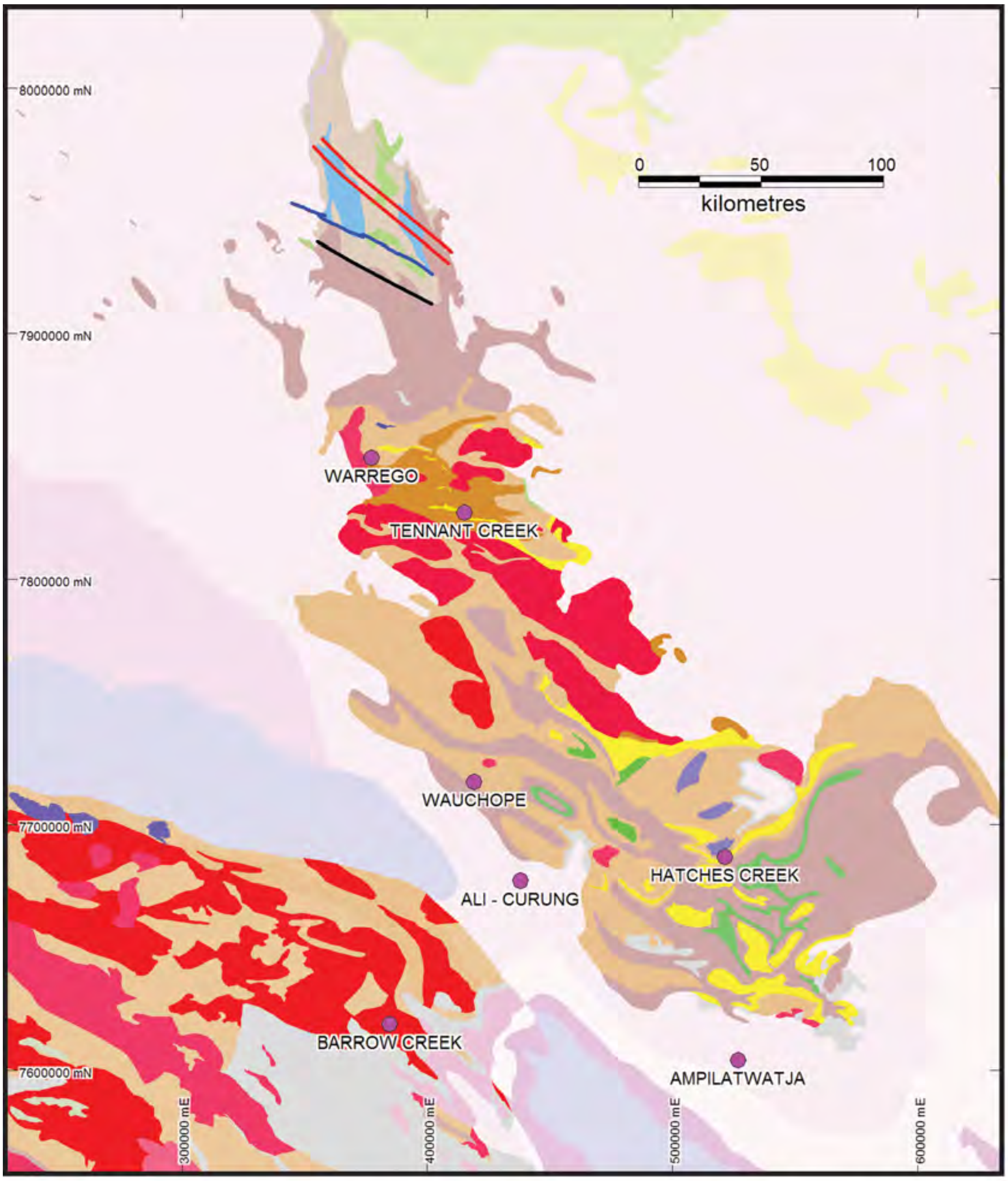

Figure 6.11: Summary geological map of the Renner Springs to Barrow Creek area showing:
1) The manganese corridor (red lines; see Figs 6.9, 6.10).
2) The inferred WNW-trending major structural contact (blue line; see Figs 6.9, 6.10).
3) The WNW-trending lineament marking the southern edge of the outcrop of the Renner Group (black line; see Fig. 6.10).
Base map after NTGS open files sources.

6.4 Prospective Areas for Manganese

6.4.1 Renner Springs

Figure 6.12 summarises the alteration in Proterozoic rocks at Renner Springs and shows the boundaries of the regional manganese corridor and the NW-trending fracture set. While the regional corridor was defined using known manganese exposures only, it also encloses most of the NW-trending fracture set and manganese-related alteration facies. Based on available data, therefore, the area inside the regional manganese corridor must be considered more prospective for manganese mineralisation than the area outside. Within the corridor there are two prospective domains (Fig. 6.12).

1) The lowest few tens of meters of Package 3.
2) The “clay” alteration domain affecting mostly Package 4. Importantly, this domain is probably more widespread than mapped because is passes under an extensive area of Cretaceous to Quaternary cover southwest of the main exposure.

6.4.2 Helen Springs

Figure 6.13 summarises the alteration in Proterozoic rocks at Helen Springs. The following areas are considered prospective for manganese.

1) The outcrop of the ferruginous lowest part of the Tomkinson Creek Group, particularly adjacent to the Costean Fault.
2) The unexposed lower parts of Cycle 2 adjacent to the Costean Fault.
3) The basal part of Package 3, assuming it is the same as Package 3 at Renner Springs.

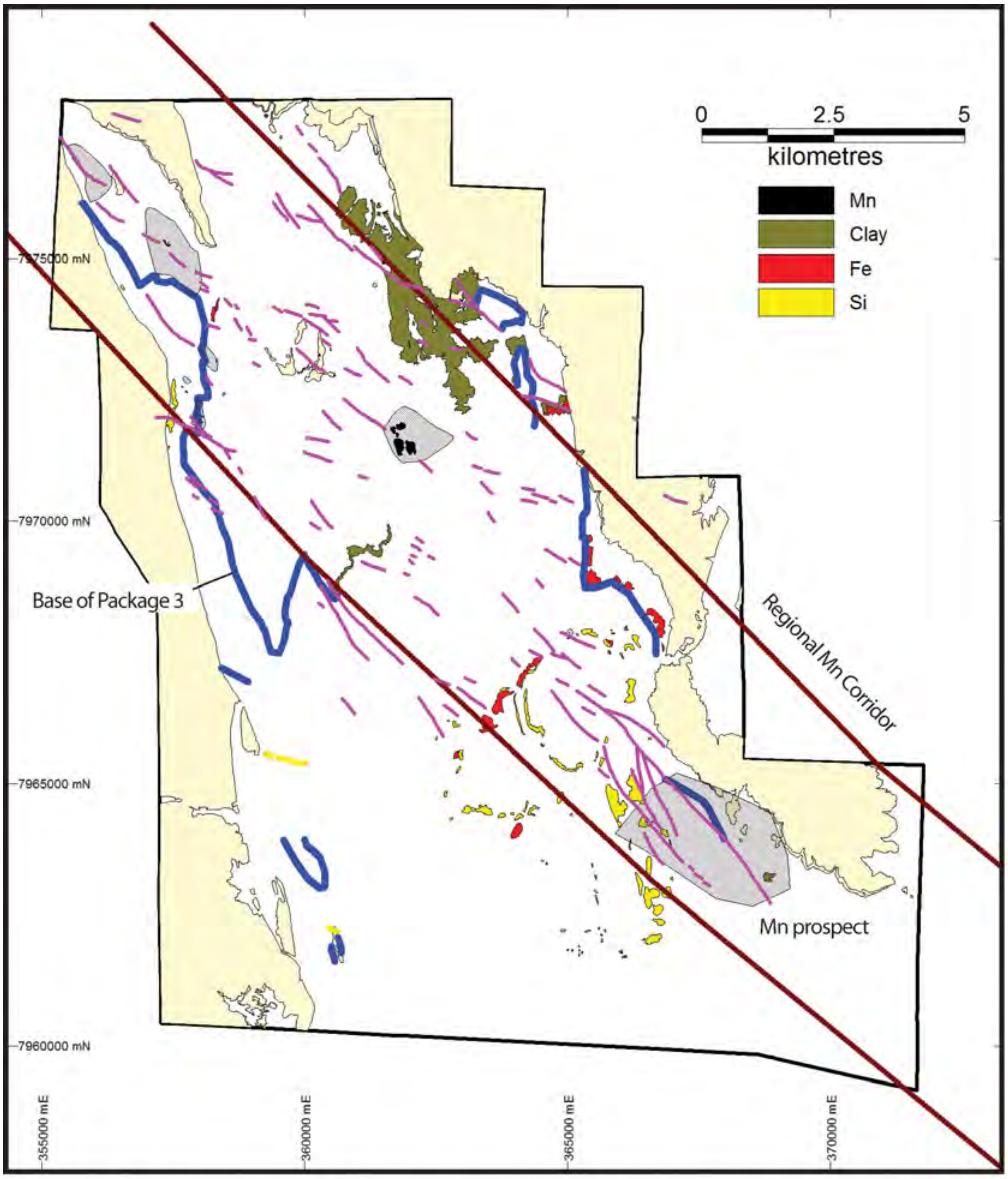

Figure 6.12: Summary of alteration and mineralisation at Renner Springs showing the regional manganese corridor, the zone of NW-trending fractures (mauve) and the base of Package 3. Grey areas are manganese prospects. Renner group is light yellow.

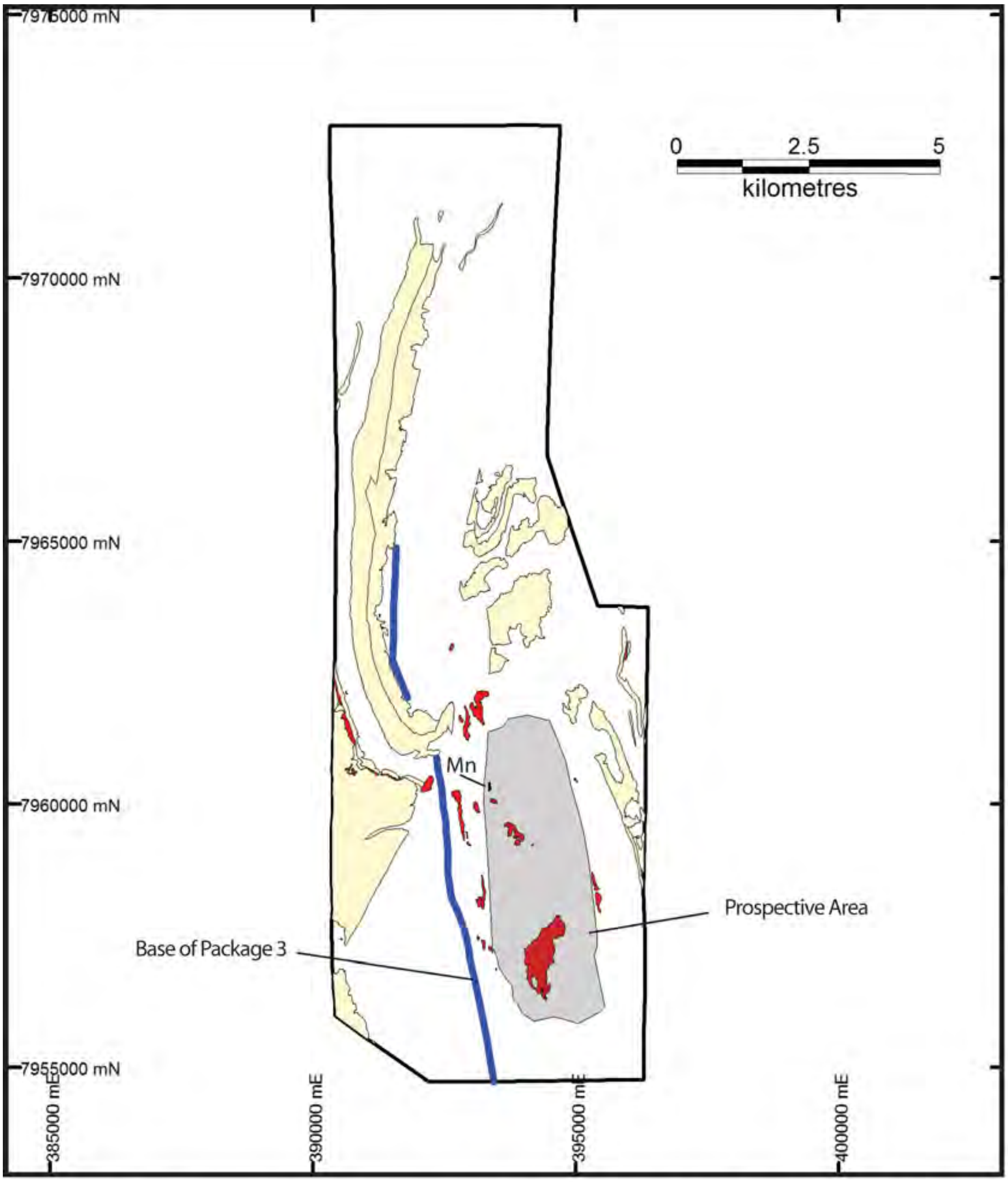

Figure 6.13: Summary of alteration and mineralisation at Helen Springs showing the base of Package 3. Iron alteration is red, manganese is black (annotated). Renner Group is light yellow. Shaded area is the prospective area in the Tomkinson Creek Group

7
RECOMMENDATIONS

- The 1:20,000 scale maps are a basis for further interpretation. All geophysical data should now be reviewed in detail using these maps. This should result in:
  - ➢ better definition of the distribution of stratigraphic units, faults and alteration domains under cover;
  - ➢ characterisation of the geophysical signatures of mineralised and prospective horizons and areas; and
  - ➢ recognition of anomalous domains worthy of further exploration.

- The mapping has shown that there are extensive areas of alteration not previously recorded. Some alteration, particularly “clay”, is probably related to manganese mineralisation and, because these domains are significantly larger than manganese deposits, they should be easier to map out. If the clay domains at Renner Springs are first characterised, it should be possible to map their regional extent using remote sensing. This would results in:
  - ➢ a better understanding of the regional context of the Renner Spring, Helen Springs and Bootu Creek manganese deposits; and
  - ➢ the location of other altered domains, should they exist.

- The proposed regional scale controls on manganese mineralisation should be followed up with a review of the regional geology and geophysics with the intent of locating the main basement structures where they underlie prospective lithologies.

- Follow up petrographic studies on all alteration facies are needed. Particularly using drill hole material if available.

- The hydrothermal brecciated and silicified rocks in the southern half of the Renner Springs area (Fig. 6.5) should be tested for gold mineralisation.

- The regional Cretaceous deposits should be reviewed for their iron and manganese potential.

8
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APPENDICES

APPENDIX I
MAPS, MAP LEGEND, SELECTED MAP DATA, MAP INTERPRETATIONS
(on accompanying DVD)
AND NOTES

I Notes

I.I Map Code Construction

Map codes are constructed using abbreviations for the following components (in the following order):

- mapping area (Proterozoic rocks only) →
- stratigraphic unit →
- lithology →
- brecciation →
- mineralisation and/or alteration.

I.II Stratigraphic Divisions

- The primary divisions in each area are the NTGS lithostratigraphic groups (Tomkinson Creek Group, Namerinni Group, Renner Group). There are some differences at this level with the NTGS 1:250,000 scale map (see legend).
- Stratigraphic divisions within groups use an alphanumeric system whereby:
  - ➢ 1, 2, 3 etc. denotes units separated by an unconformity (mapped of inferred); and
  - ➢ a, b, c etc. denotes lithostratigraphic units separated by boundaries of unknown stratigraphic significance.

I.III Correlations With NTGS Lithostratigraphic Units

Correlations of Proterozoic mapping units with NTGS lithostratigraphic units are given in brackets at the end of each mapping unit definition in the legend.

I.IV Stratigraphic Unit Abbreviations

Cretaceous to Quaternary Rocks and Sediments

Qu	Quaternary (active sedimentary systems)
T	Tertiary
Cc	Cretaceous

Proterozoic Rocks

Renner Springs Area

RR	Renner Group (not divided)
RRd	Renner Group
RRc	Renner Group
RRb	Renner Group
RRa	Renner Group
RN4	Namerinni Group, Package 4
RN3	Namerinni Group, Package 3
RN2	Namerinni Group, Package 2
RN1	Namerinni Group, Package 1

Helen Springs Area

HR	Renner Group, not divided
HR1-2a	Renner Group, Units 1a to 2a (not divided)
HR2e	Renner Group, Unit 2
HR2d	Renner Group, Unit 2
HR2c	Renner Group, Unit 2
HR2b	Renner Group, Unit 2
HR2a	Renner Group, Unit 2
HR1b	Renner Group, Unit 2
HR1a	Renner Group, Unit 1

HN3	Namerinni Group, Package 3
HN2	Namerinni Group, Package 2

HN1	Namerinni Group, Package 1
HTB	Bootu Formation (Tomkinson Creek Group)

Lithologies

The dominant exposed lithology or lithologies are used in the code. Where more than one lithology is indicated they are listed in order of apparent decreasing abundance. Definitions are based on field observations only. More specific definitions are given in the legend.

C	Conglomerate
S	Sandstone (and siltstone)
M	Mudstone (siltstone, muddy siltstone, claystone, shale)
D	Dolomite (mostly crystalline)
DS	Sandy (quartz grains) dolomite
Ct	Chert (mostly silicified mudstone)
A	Alluvium, colluvium, talus, calcrete (not divided)
T	Transported Tertiary rocks and sediments (undivided).

Brecciation

X Brecciated (post-lithification), degree and areal extent varies

Mineralisation and/or Alteration

Cy	Clay rich
Si	Silica
Fe	Iron, ferruginous
Mn	Manganese (origin varies: hydrothermal alteration?, remobilised hydrothermal alteration? [weathering]).

II Digital Files

Folder: Maps (Mapinfo)

Maps and graphic structural data.

RS HS Geol Poly V4 1 Col V1

Geology polygons have been coloured and textured as follows.

- Relatively unaltered rocks coloured by stratigraphic unit.
- Conglomerate (first lithology in code) – coarse rectangular “dot” pattern.
- Sandstone (first lithology in code) – fine dot pattern.
- Mudstone, chert (first lithology in code) – solid colour.
- Dolomite (first lithology in code) – brickwork pattern.
- Brecciation – coarse “dot” pattern.
- Mn alteration – greyscale.
- Clay “alteration” – fine cross hatch pattern.
- Fe alteration – orange, brown.
- Si alteration – yellow.

RS HS Lineaments V4

RS HS Measured Bedding Black Halo

RS HS Measured Bedding Black

RS HS Measured Bedding Blue

RS HS Minor Fold Axes V4

RS HS Photo Dips V4

RS HS Quartz Veins V4

Folder: Selected and Intepreted

Folder: Bedrock Interpretation (Mapinfo)

Interpreted outcrop of Proterozoic units.

HS P1

HS P2

HS P3

HS TCG

RS P1

RS P2

RS P3

RS P4

Folder: Prospective (Mapinfo)

Prospective areas and stratigraphic horizons.

HS Base of P3

HS Tomkinson

RS Base of P3

Folder: Units Extracted (Mapinfo)

Major mapped stratigraphic units.

HS All Package 1

HS All Package 2

HS All Package 3

HS All Renner Group

HS All Tomkinson Group

RS All Package 1

RS All Package 2

RS All Package 3

RS All Package 4

RS All Renner Group

RS HS All Cretaceous

RS HS All Cy

RS HS All Fe

RS HS All Mn

RS HS All QuA

RS HS All Si Proterozoic

RS HS All Tertiary

Folder: 20K Map Legend (PDF)

Map legend.

OMM MGS 2010 1 Map Legend V1_8.pdf

APPENDIX II
FIELD DATA
(on accompanying DVD)

This appendix contains all field data and a summary description of each location (file: *OMM MGS 2010 1 App II Field Data.xls*).

APPENDIX III
FIELD PHOTOGRAPHS
(printed summary and on accompanying DVD)

This appendix is a record of 352 relevant field photographs. Some are referred to in the text. Photos are available as printed and digital contact sheets and as high resolution digital images. The photographs have not been edited.

- Photographs are grouped hierarchically in folders, first by mapped area (where relevant) then by mapping unit.
- Photographs are named after the main stratigraphic unit illustrated.
- All field photos are in JPEG format.
- Photo locations are available in the IPTC Image metadata (Photoshop).
- Brief descriptions are available in the IPTC Content metadata (Photoshop).

Printed Contact Sheets (following pages)

01 RS QuA.jpg

02 RS QuA.jpg

Quaternary

01 RS TC.jpg

Tertiary


01 HS CcC.jpg


01 RS CcC.jpg


02 RS CcC.jpg

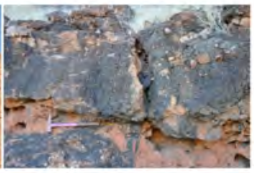

03 RS CcC.jpg


04 RS CcC.jpg


05 RS CcC.jpg


06 RS CcC.jpg


07 RS CcC.jpg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04 RS CcS.jpg


05 RS CcS.jpg


06 RS CcS.jpg


07 RS CcS.jpg


08 RS CcS.jpg


01 RS CcSi.jpg

Cretaceous

01 HS Cambrian.jpg

02 HS Cambrian.jpg

03 HS Cambrian.jpg

04 HS Cambrian.jpg

05 HS Cambrian.jpg

06 HS Cambrian.jpg

Cambrian

Renner Springs: Renner Group (A)

28 RRbS.jpg

29 RRbS.jpg

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02 RRdS.jpg

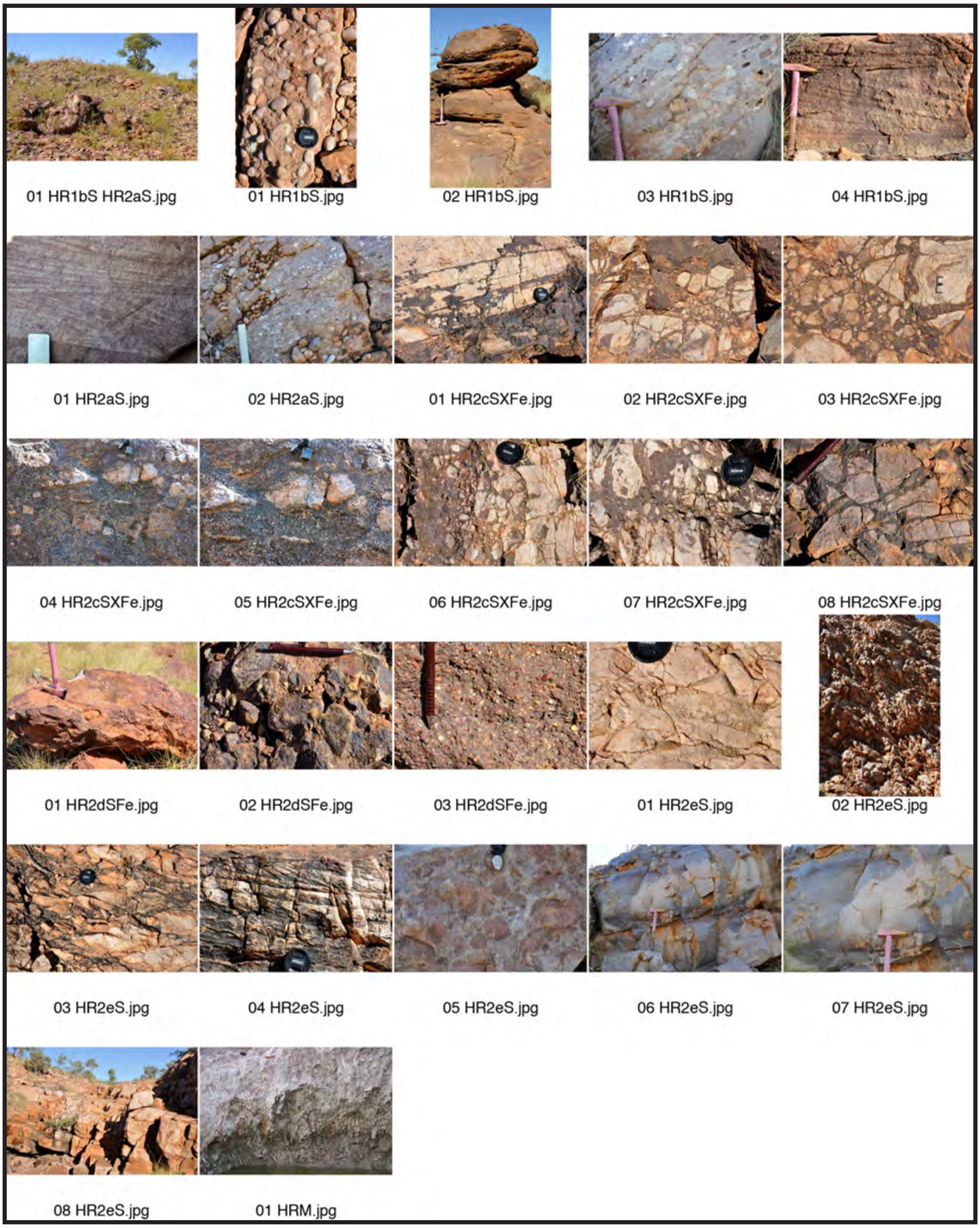
03 RRdS.jpg

04 RRdS.jpg

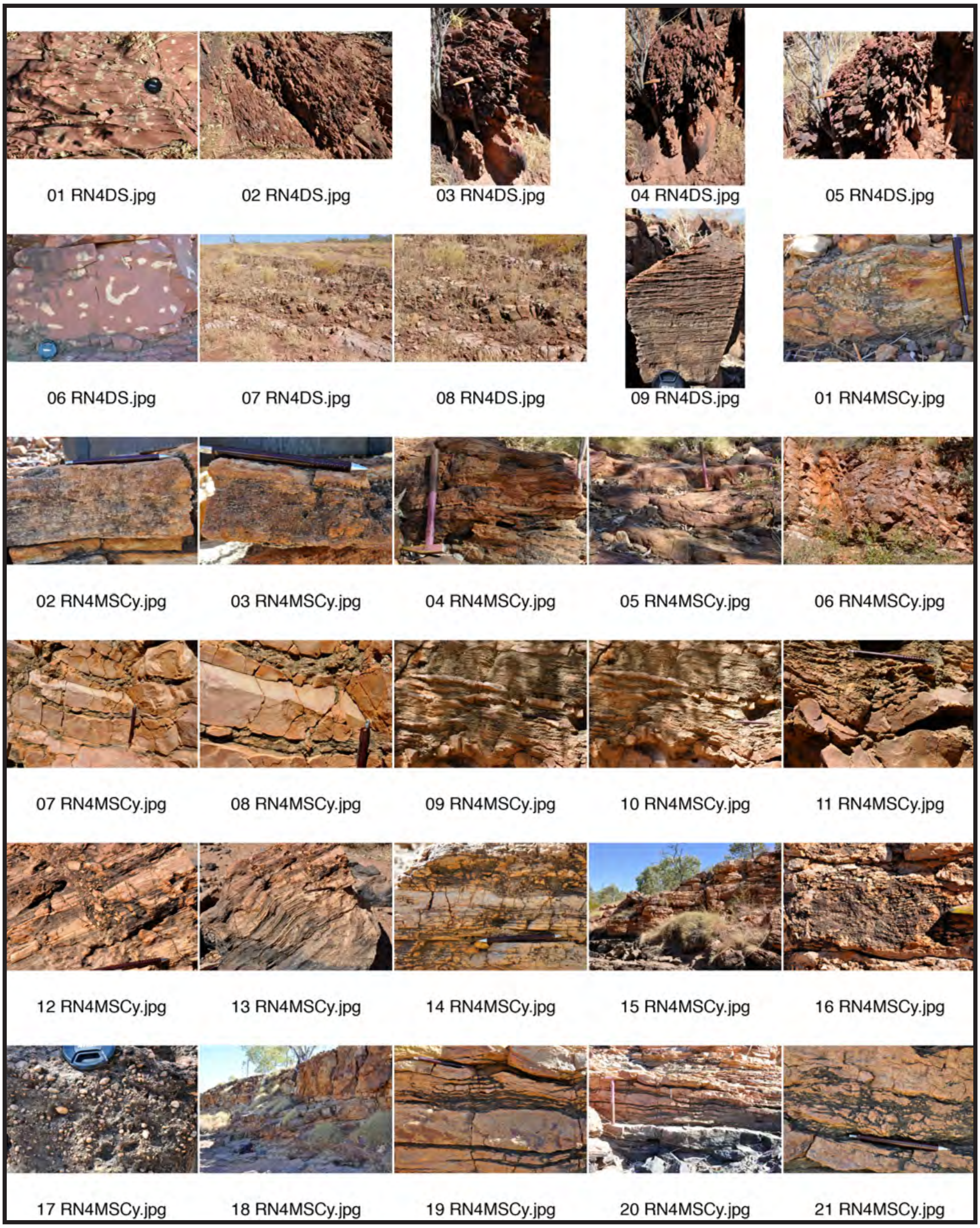
05 RRdS.jpg

06 RRdS.jpg

Renner Springs: Renner Group (B)

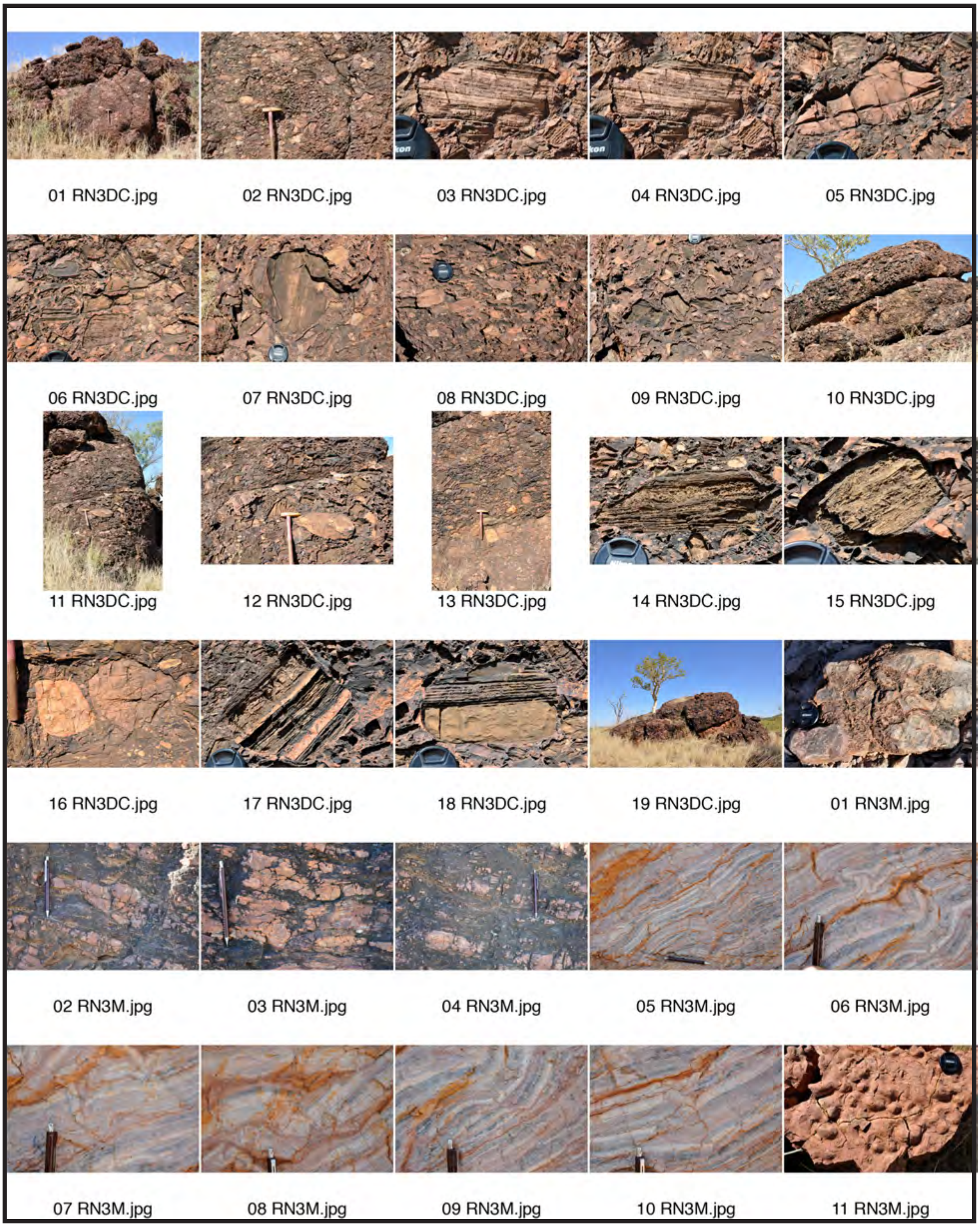


Helen Springs: Renner Group



Renner Springs: Package 4 (A)

Renner Springs: Package 4 (B)



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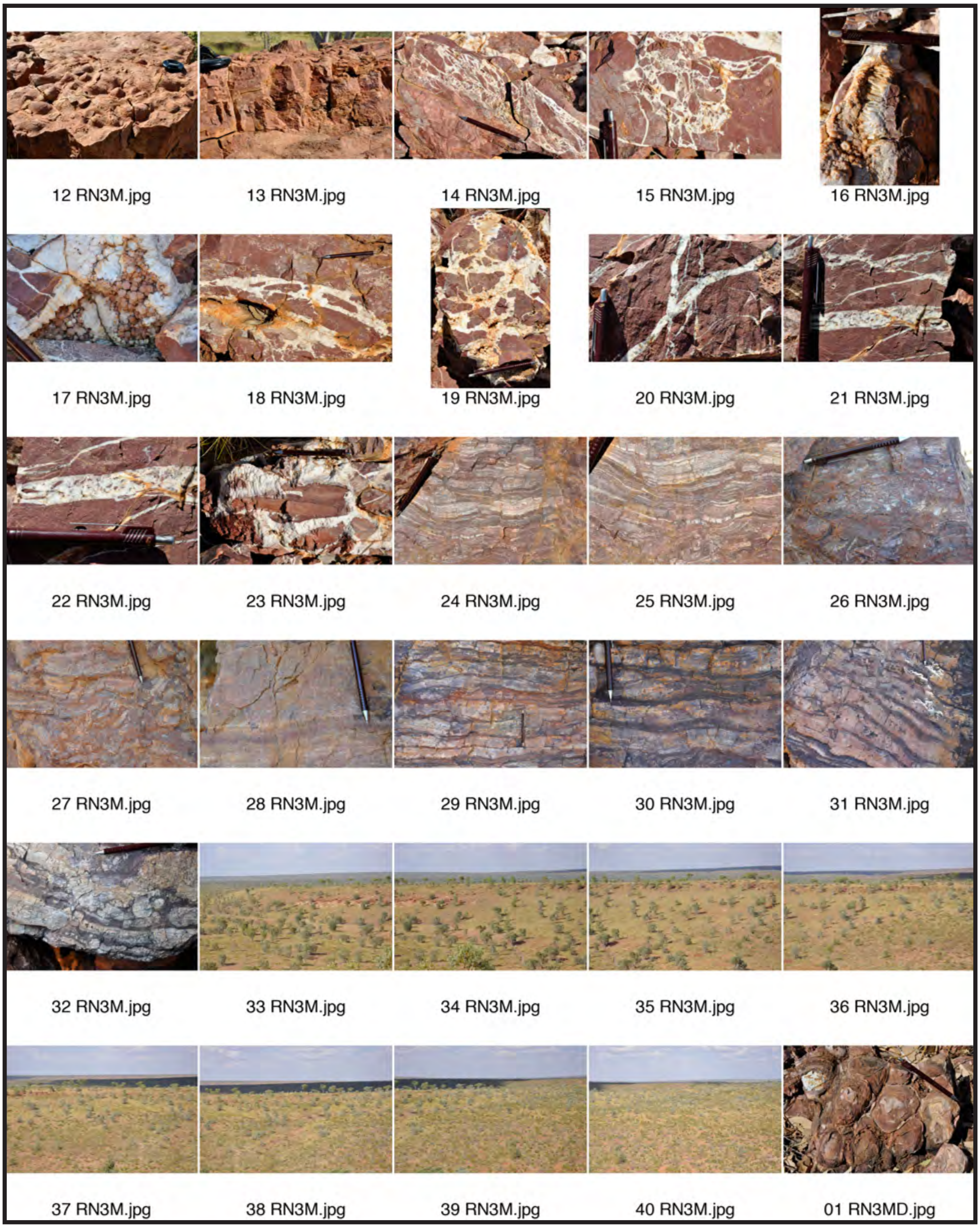

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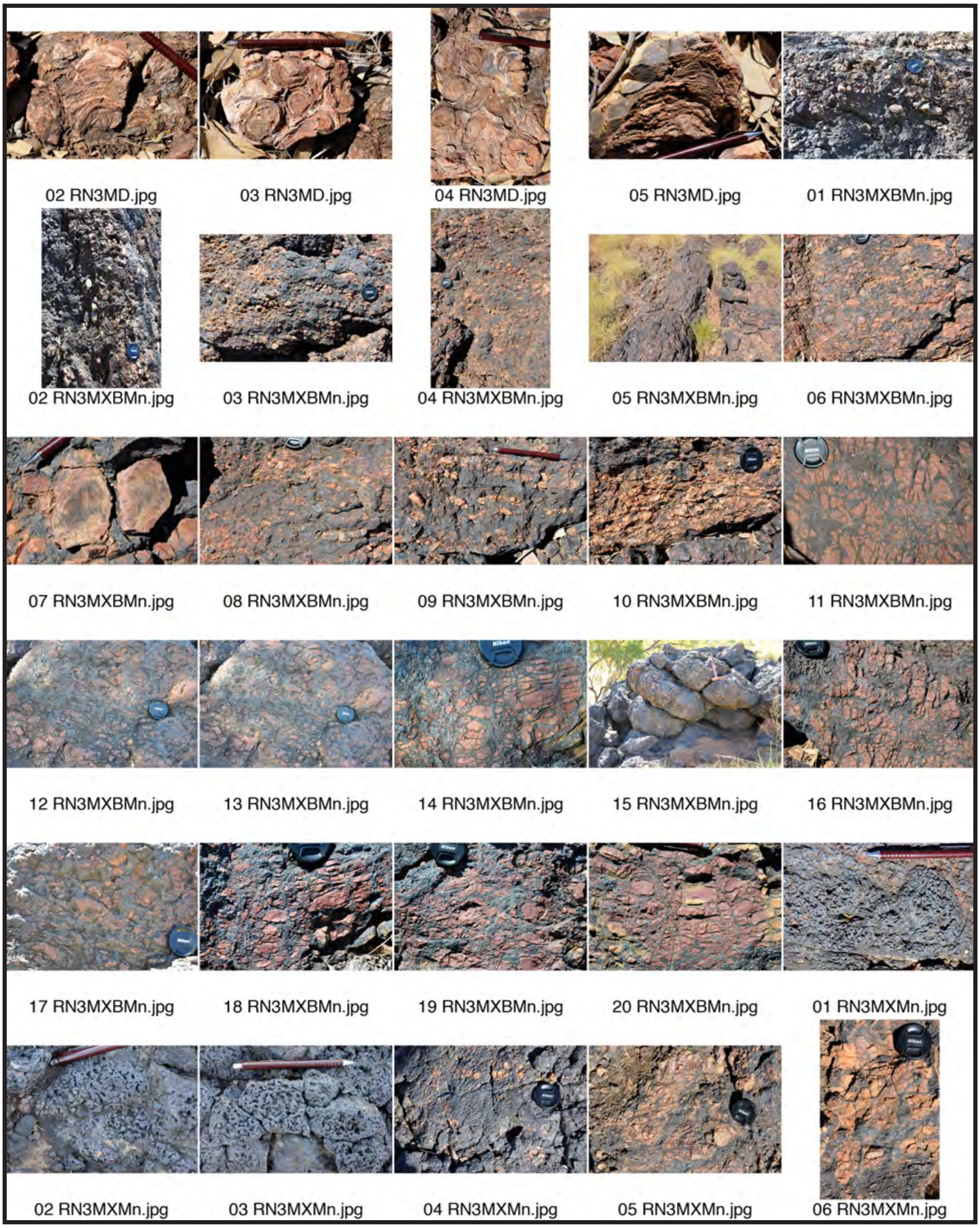

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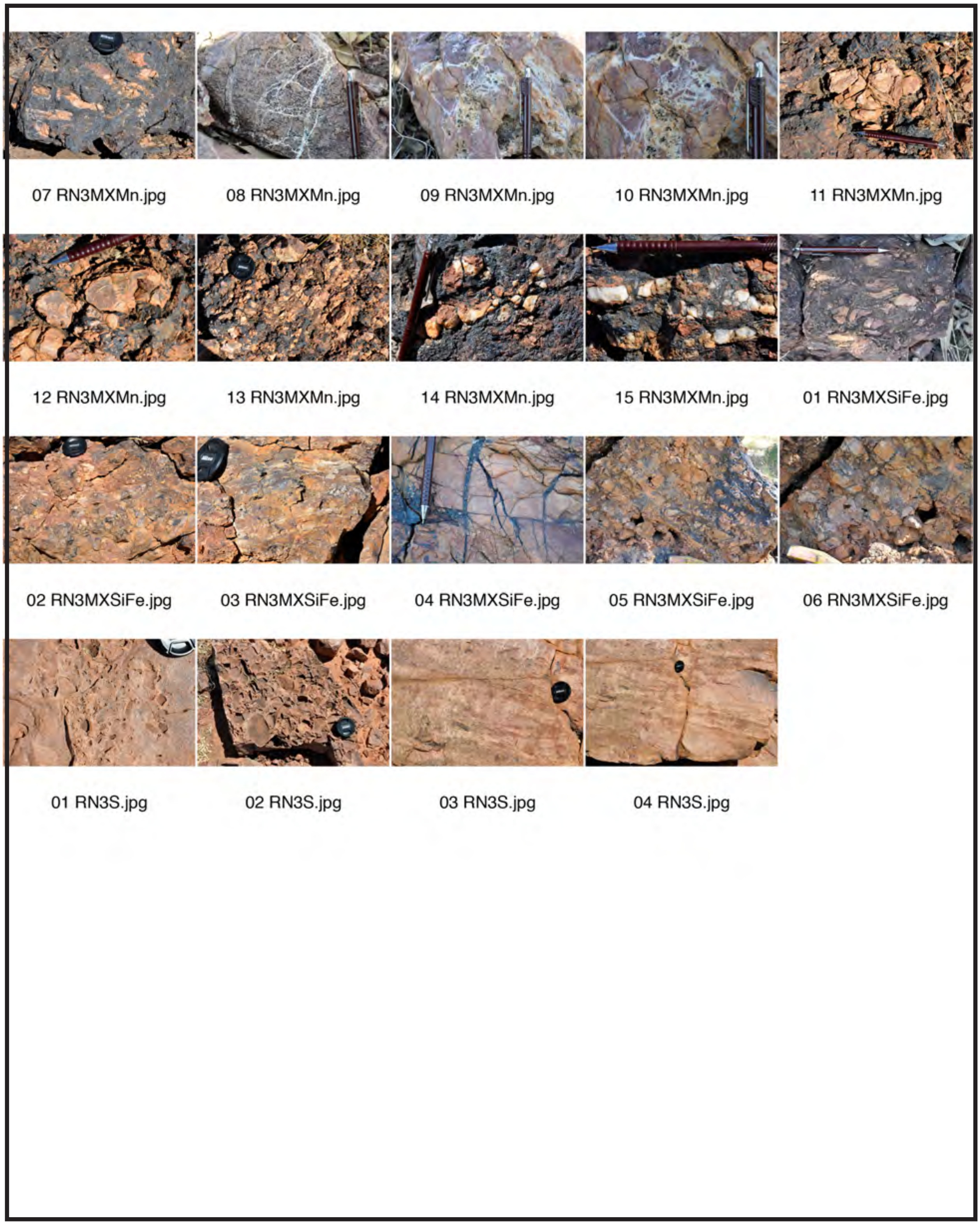

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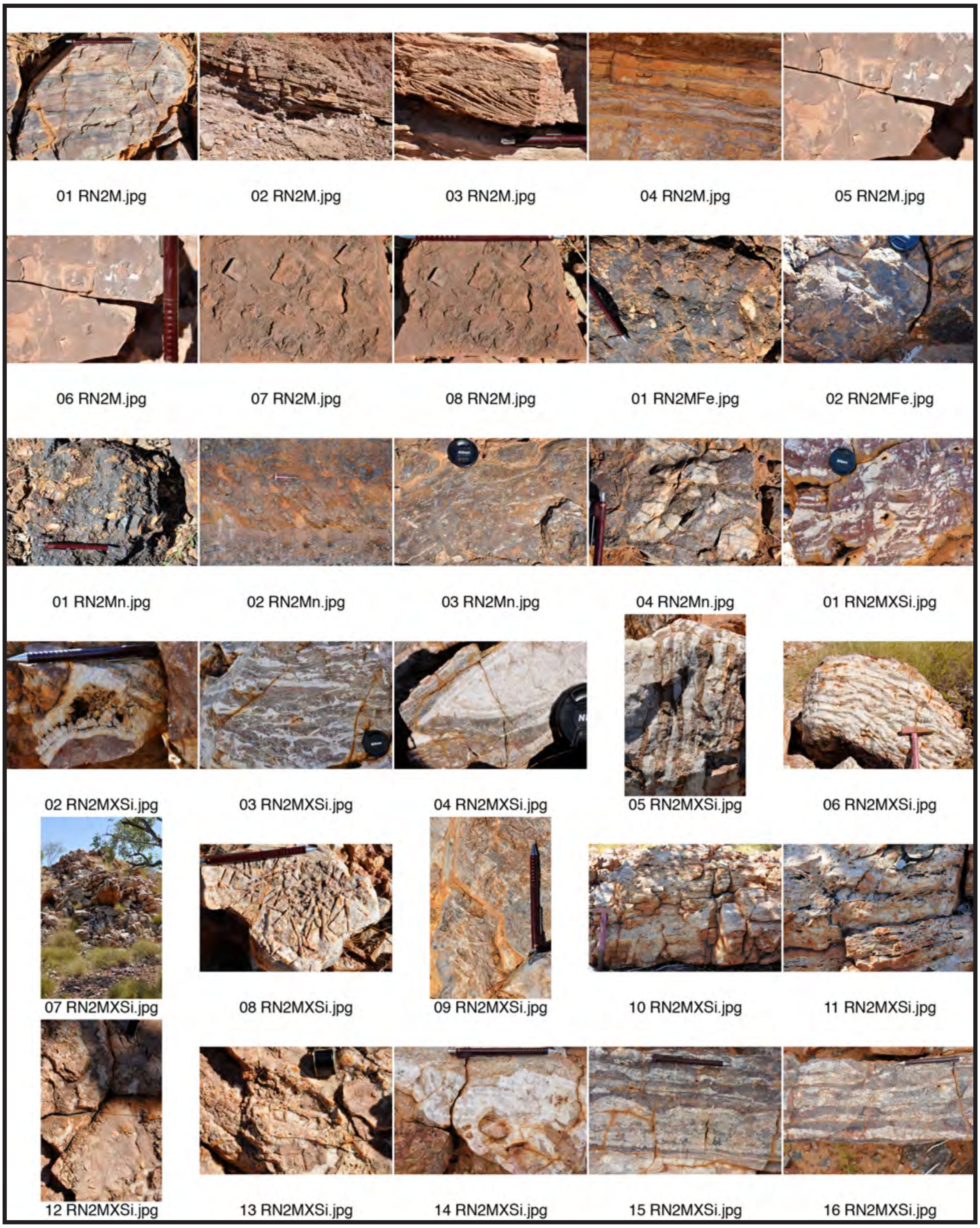

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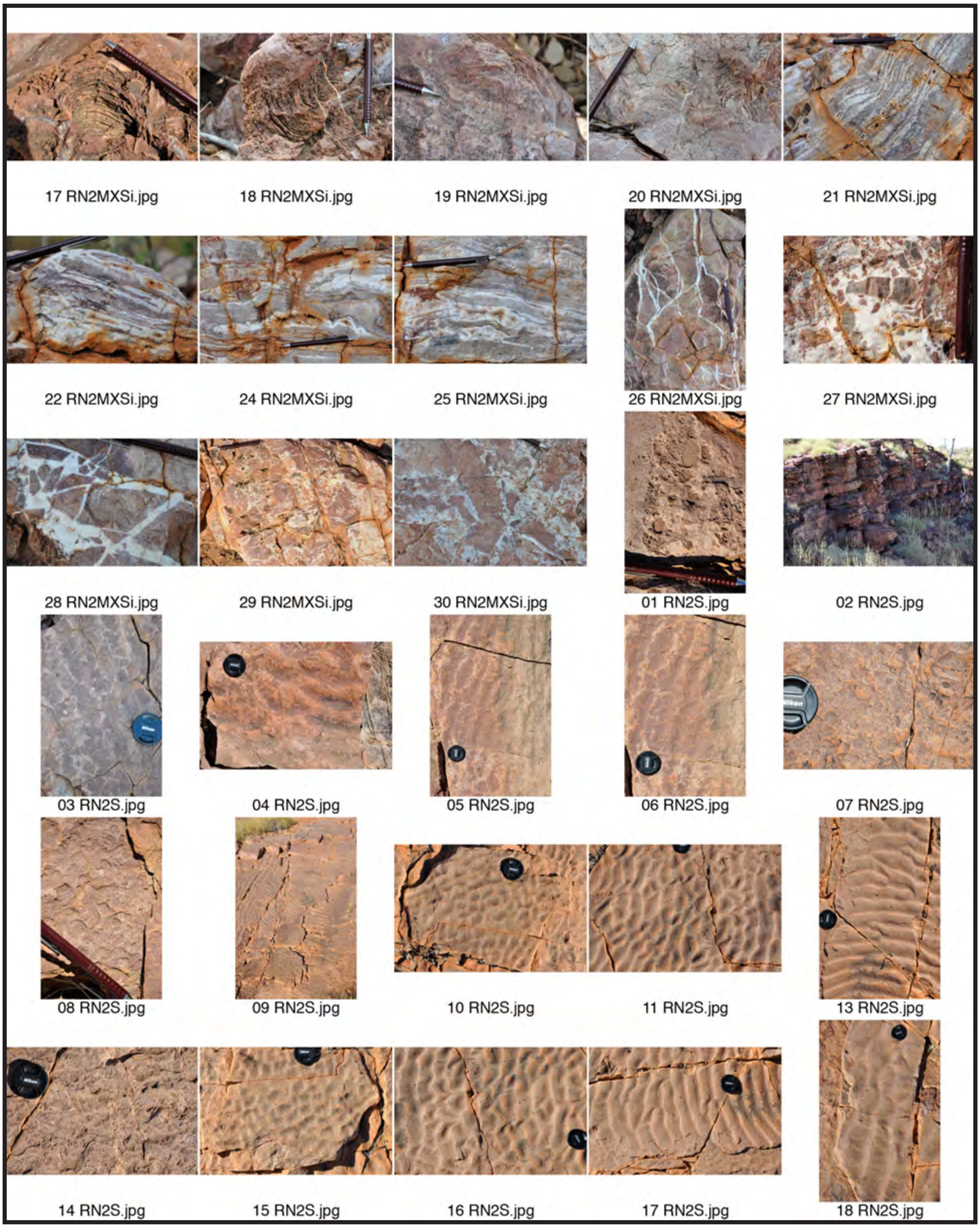

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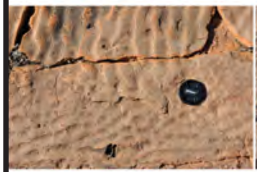

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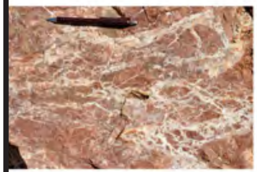
23 RN2S.jpg



24 RN2S.jpg

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27 RN2S.jpg

01 RN2SXSi.jpg

02 RN2SXSi.jpg

Renner Springs: Package 2 (C)


01 RN1S.jpg


01 RN1SSi.jpg


02 RN1SSi.jpg


03 RN1SSi.jpg


04 RN1SSi.jpg

Renner Springs: Package 1


01 HN3M.jpg


02 HN3M.jpg

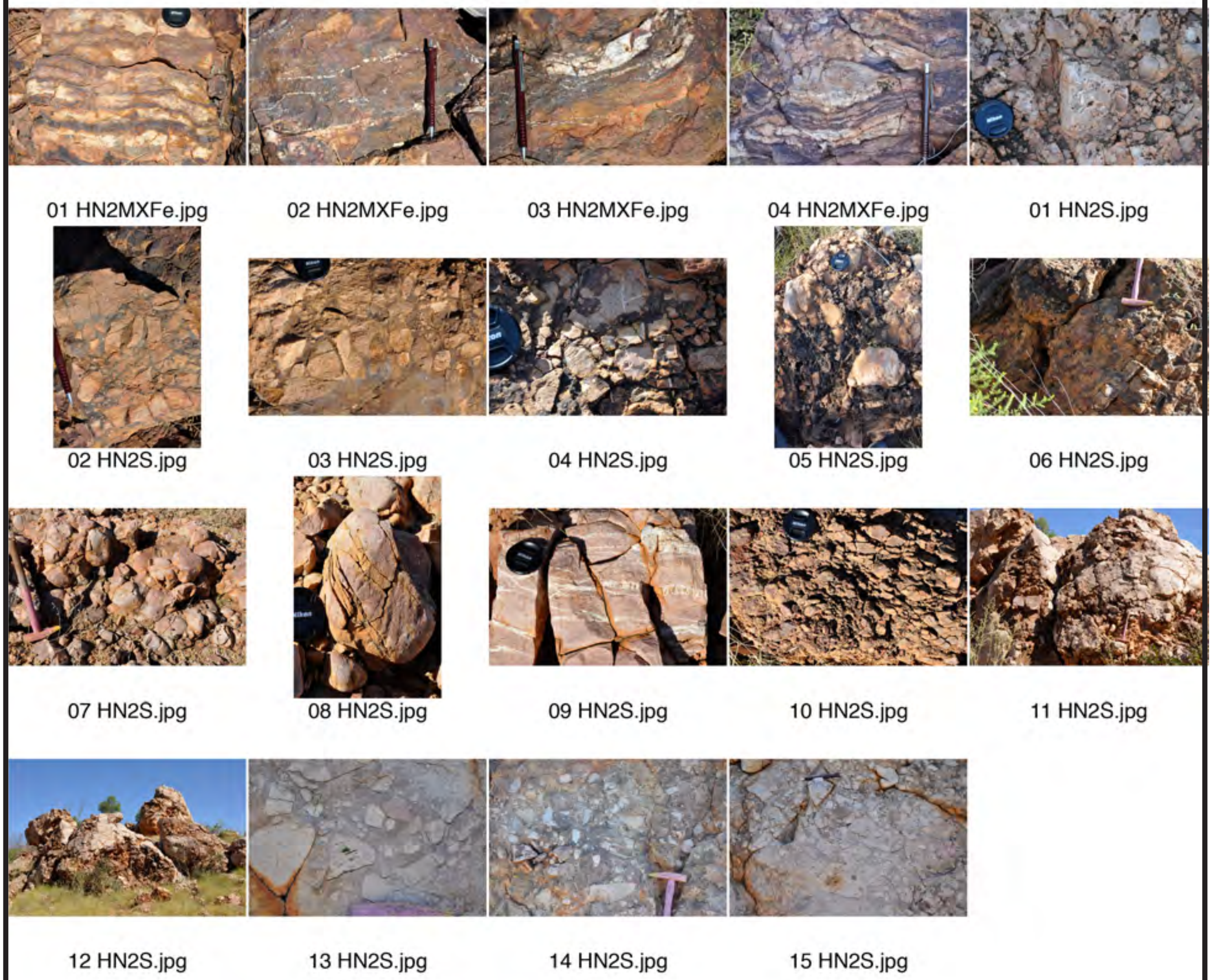

03 HN3M.jpg


04 HN3M.jpg

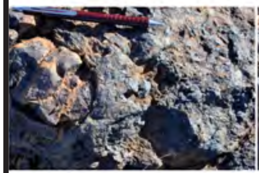

01 HN3S.jpg


02 HN3S.jpg

Helen Springs: Package 3



Helen Springs: Package 2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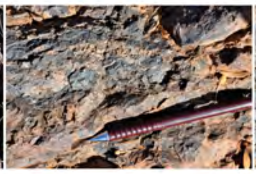
03 HTSFeMn.jpg


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05 HTSFeMn.jpg


06 HTSFeMn.jpg


07 HTSFeMn.jpg

Helen Springs: Tomkinson Creek Group, Bootu Formation