Reappraisal of the Paterson Orogen and Savory Basin

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Abstract

Completion of mapping in the Paterson Orogen has resolved several problems associated with the correlation of the Yeneena Group. The westernmost zone is now thought to correspond to a newly defined unit, the Tarcunyah Group, which is Late Proterozoic in age, and from biostratigraphic evidence correlates with Supersequence 1 of the Centralian Superbasin. The Tarcunyah Group is unconformable on the older and more deformed Throssell Group, and the Karara Formation is now included in the Tarcunyah Group. Deposition of the Tarcunyah Group was apparently coeval with older units of the Savory Group, and it is unconformably overlain by younger units of the Savory Group. The Tarcunyah Group, Savory Group, and Officer Basin successions were probably a single tectonic unit. Although this interpretation lessens the mineralization potential of the Tarcunyah Group, it increases the hydrocarbon potential of the area.

KEYWORDS: Paterson Orogen, Savory Basin, Officer Basin, Centralian Superbasin, Late Proterozoic, Yeneena Group, Tarcunyah Group, Throssell Group, Savory Group, mineralization, petroleum potential.

Integration of data emerging from several Geological Survey of Western Australia (GSWA) projects indicates a need to redefine and rationalize the tectonic framework of some of Western Australia's Proterozoic basins. In particular, evidence now available suggests that the Yeneena Group comprises three distinct units called the Tarcunyah, Throssell, and Lamil Groups (Williams and Bagas, in prep.; Fig. 1). The Tarcunyah Group (Bagas and Smithies, in prep.; Williams and Bagas, in prep.) is unconformable on the Throssell Group and is of Late Proterozoic age. It is partly coeval with the Savory Group of the Savory Basin, and is probably part of a greater Officer Basin (Fig. 1). Detailed investigations are required in order to define clearly the components and evolution of this greater Officer Basin, but the combined area of the Officer and Savory Basins would be increased by about 30 000 km^2. This reinterpretation has considerable implications both for mineral exploration, and for evaluation of the petroleum potential of a broad area of the State. There are also ramifications for the understanding of tectonic events associated with the assembly and breakup of the supercontinents of Kanatia and Rodinia (Dalziel, 1995; Myers et al., in press).

Background

For the last two decades there has been controversy about the age of the Yeneena Group as defined by Williams et al. (1976). Chin and de Laeter (1981) reported that the Yeneena Group was deformed at 1132 ± 21 Ma. Over the years, several mining companies have based exploration programs on the concept that the Yeneena Group might be a correlative of the Middle Proterozoic McArthur Group of northern Australia, whereas others have regarded at least the western part of the Yeneena Group to be Late Proterozoic in age. Other geochronological evidence indicated that some mineralization occurred c. 900 to 700 Ma ago and that the age range of the Yeneena Group appeared to be between c. 1000 and 750 Ma, and was therefore Late Proterozoic (Williams, 1990a). By contrast, Williams (1992, p. 89) suggested an age of between c. 1200 and 1000 Ma.

The wide range of suggested dates and proposed correlations not only reflected uncertainties caused by the lack of adequate dating, but also pointed to more fundamental problems in the interpretation of the Paterson Orogen. Disparities in interpreted age could be explained if part of what was previously defined as the Yeneena Group was younger (c. 900 to 700 Ma) than other parts of it. Although the possibility was considered previously (Grey, 1986, 1990; Williams, 1990a), definitive evidence about the stratigraphic relationships and age was lacking. The results of recently completed mapping in the Paterson Orogen, together with preliminary biostratigraphic evidence, now support this interpretation. When examined in the context of parallel developments in interpretations of the Late Proterozoic, it seems likely that the western part of the Paterson Orogen was coeval with the Savory and Officer Basins, and that these areas were probably a single tectonic unit.

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Figure 1. Regional geological setting of the Paterson Orogen. The dashed line on the inset map marks the probable margin of the greater Officer Basin

Various papers in GSWA (1990) such as Williams (1990a,b,c) and Iasky (1990) highlighted the fact that tectonic divisions between the Officer and Savory Basins and the Paterson Orogen were poorly defined and often overlapping, as in the case of the Karara Basin in Williams (1990b) and the Gibson Sub-basin in Iasky (1990). To a large extent this was a result of the prevailing attitude that the Officer Basin was mainly Phanerozoic in age, and of the history and timing of studies carried out in the various areas. Delineation of the Savory Basin (Williams, 1990c, 1992) provided further evidence that a broader overview and redefinition of the various subdivisions, and of links between them, was required. However, the problems could not be resolved until remapping of the Paterson Orogen was completed and the stratigraphic position and relationships of the Karara Formation were correctly determined. Moreover, because the boundary of the Officer Basin was defined by the distribution of Permian rocks, the area designated as the Savory Basin could not at that time be included with the Officer Basin.

Geological mapping at 1:100 000 scale commenced in the Paterson Orogen in 1989. Previously, although components of the orogen were shown to have separate igneous, metamorphic, structural, and palaeogeographic histories (Williams, 1990a), they were considered to be united by a common tectonic history (Williams and Myers, 1990). At about the same time, in a series of publications on the tectonic framework of Western Australia (Myers, 1990, 1993; Myers and Barley, 1992), southwesterly thrusting was identified along the margin of, and within, the Paterson Orogen, and shown as extending into the Officer Basin.

Completion of the mapping of BROADHURST* (Hickman and Clarke, 1994), RUDALL (1:100 000; Hickman and Bagas, in prep.), THROSSELL (Williams and Bagas, in prep.), and CONNAUGHTON (Bagas and Smithies, in prep.) has reinforced the differences noted by Williams (1990a), has confirmed an unconformable relationship between the Tarcunyah and Throssell Groups, and has verified the significance of the thrusting. The Paterson Orogen now includes the Rudall Complex, which has been further subdivided (Bagas and Smithies, in prep.), and the newly defined Throssell, Lamil, and Tarcunyah Groups (Williams and Bagas, in prep.). As discussed below, the Tarcunyah Group is younger than the Throssell Group. The Karara Formation, previously regarded as being younger than the Yeneena Group, is now included in the Tarcunyah Group (Bagas and Smithies, in prep.). Previously the effects of the Miles Orogeny were interpreted as part of the Paterson Orogeny (for example, see Hickman and Clarke, 1994), but recent mapping has demonstrated that the younger Karara Formation is not affected by D_4 folding (Bagas and Smithies, in prep.). The above observations have necessitated a reappraisal of the Paterson Orogen, both in terms of the internal stratigraphic and tectonic framework, and in the wider context of the Late Proterozoic history of Australia.

On a broader front, considerable advances have been made in the last decade with regard to our understanding of Australia-wide Late Proterozoic successions, and rocks of this age have considerable areal extent throughout Western Australia. Mapping of the western Officer Basin (Jackson and van de Graaff, 1981) drew attention to the extensive nature of subsurface Proterozoic successions in this area. This was further emphasized by Iasky (1990) in a summary of the basin, and more recently by Hocking et al. (1994), who recognized two stacked basins comprising the Proterozoic Officer Basin and the Phanerozoic Gunbarrel Basin. Grey (1978, 1995a) pointed out that stromatolite distributions indicated that Late Proterozoic rocks were probably more widespread than had previously been recognized. Discovery of Late Proterozoic tillites (Williams, 1987) confirmed these suspicions and resulted ultimately in the recognition of the Savory Basin (Williams, 1990b, 1992).

Investigations of correlations between the major Late Proterozoic Australian basins (Walter and Gorter, 1994; Walter et al., 1994, 1995; Grey, 1995a) have indicated that deposition commenced in a single large sag basin, the Centralian Superbasin, that included the Officer, Savory, Amadeus, Georgina, and Ngalia Basins, and that subsequent tectonic activity resulted in the formation of separate depocentres in each of these areas. Four major successions were identified (Fig. 2) and referred to as Supersequences 1 to 4 (Walter et al., 1995). Time correlations of the supersequences between individual basins can be documented using a variety of techniques such as lithostratigraphic correlation, sequence stratigraphy, biostratigraphy, and isotope chemostratigraphy. In particular, recent studies have provided a wealth of biostratigraphic data for the superbasin as a whole, most notably from stromatolite and palynological studies of the Amadeus, Georgina, and South Australian Officer Basins, and from comparisons with the Adelaide Geosyncline (Zang and Walter, 1992; Walter and Gorter, 1994; Grey, 1993, 1995a, unpublished data; Walter et al., 1994, 1995).

Abundant fossil material is available from Western Australian basins, and has good potential for correlation with other parts of the Centralian Superbasin, although it has not yet been comprehensively studied. The available stromatolite and palynological data support the new interpretation of the interrelationships between the Paterson Orogen and the Savory and Officer Basins, and indicate that part of the Paterson Orogen, the Tarcunyah Group, is Late Proterozoic in age, and is probably equivalent to Supersequence 1 of Walter et al. (1995). Redefinition of the tectonic framework and time constraints of the western part of the former Yeneena Group will have important consequences for the evaluation of the hydrocarbon potential of the Officer and Savory Basins, currently being investigated by the Interior Basins Petroleum Initiatives team of the GSWA.

Reappraisal of evidence

As data from studies of Late Proterozoic successions in the Paterson, Savory, and Officer Basins has been collated (Fig. 2), reinterpretation of some tectonic boundaries and relationships has

* Capitalized names refer to standard map sheets.

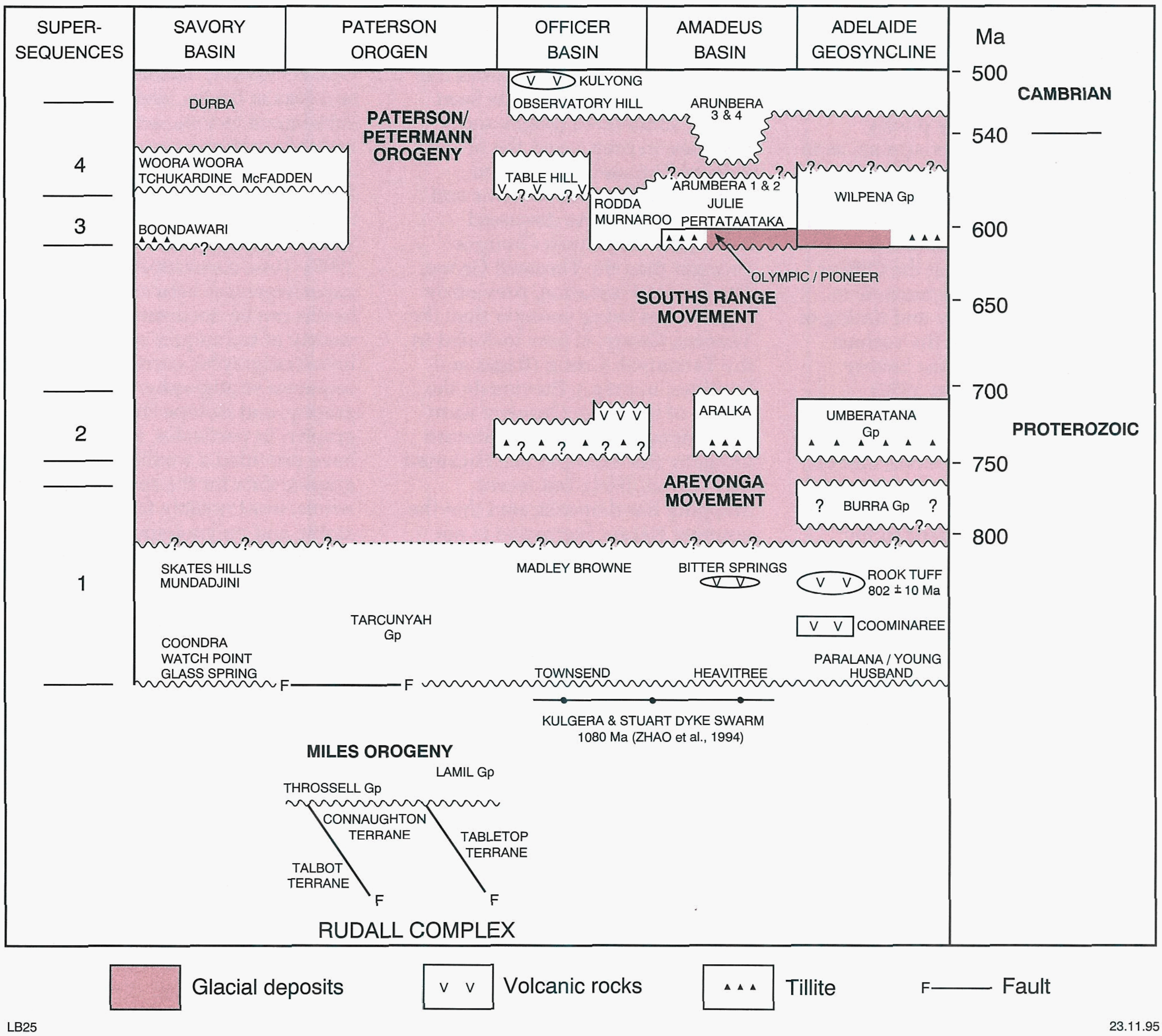

Figure 2. Generalized stratigraphic correlation between the Paterson Orogen and parts of the Centralian Superbasin and Adelaide Geosyncline (modified after Williams, 1992; Walter et al., 1994, 1995; Grey, 1995a)

become possible. Overall trends are now apparent, although determination of precise boundaries will only be possible after more detailed analysis. Below is a brief outline of the evidence already available.

Lithostratigraphy

Broadly similar lithologies are present in the Officer Basin succession, the Tarcunyah Group, and the Savory Group. Evaporites, stromatolitic carbonates, and red beds are present in the Waroongunyah and Waltha Woora Formations of the Tarcunyah Group, the Skates Hills and Mundadjini Formations of the Savory Basin, and the Browne, Neale, and Madley Formations of the Officer Basin. The basal Googhenama Formation of the Tarcunyah Group is lithologically similar to the Coondra Formation of the Savory Basin and to the Townsend Quartzite of the Officer Basin. These lithological similarities are not sufficient in themselves to allow correlation between the basins, but, taken in conjunction with other evidence, are strongly suggestive that similar successions occur in each basin, as in other parts of the Centralian Superbasin (Walter et al., 1995).

Tectonics

The Paterson Orogen contains evidence of at least six major deformation events (Bagas and Smithies, in prep.). The first two deformation events occurred during the Yapungku Orogeny between 2000 and 1760 Ma. The third and fourth deformation events occurred during the newly defined Miles Orogeny approximately between 1300 and 800 Ma. The fifth deformation event may relate to structures in the Blake Fault and Fold Belt that affect the Savory Basin (Williams, 1992; Bagas and Smithies, in prep.). The last deformation event occurred during the Paterson

Orogeny (Bagas and Smithies, in prep.) after the intrusion of the Crofton Granite at c. 620 Ma (Nelson, 1995), and was apparently synchronous with the formation of the Woodroffe Thrust at c. 550 Ma (Maboko et al., 1992; Myers, 1993; Camacho and Fanning, 1995; Myers et al., in press). The Paterson Orogeny appears to be contemporaneous with the Petermann Orogeny in central Australia (Myers, 1990, 1993; Walter et al., 1994; Williams, 1994), which has given ages of 550 and 530 Ma (Maboko et al., 1992) or 560 and 525 Ma (Camacho and Fanning, 1995).

The contact relationship between the Tarcunyah and Throssell Groups is disconformable on CONNAUGHTON and GUNANYA and unconformable on BLANCHE and CRONIN (Bagas and Smithies, in prep.). The major tectonic and metamorphic differences between the two groups are the lack of penetrative foliation in the Tarcunyah Group (this type of foliation is restricted to the Miles Orogeny), and the development of greenschist facies metamorphism in the Throssell Group (Bagas and Smithies, in prep.). This implies that the Tarcunyah Group was deposited after the Miles Orogeny, or has escaped the same degree of deformation and metamorphism that was undergone by the Throssell Group.

On POISONBUSH and WOBLEGUN the Tarcunyah Group is unconformably overlain by the younger units of the Savory Group, of which the oldest is the Boondawari Formation. Elsewhere, the contact relationship between the Tarcunyah and Savory Groups is tectonic. For example, in the northwest Savory Basin the tectonic contacts consist of steep reverse faults that have thrusted the Tarcunyah Group onto several units of the Savory Group (Williams, 1992), in particular onto the Supersequence 1 equivalent (the Mundadjini Formation), as well as the Supersequence 3 or 4 equivalent (the younger Tchukardine Formation).

Age constraints

Geochronological constraints for tectonic events within the Paterson Orogen are very limited, and have been summarized by Bagas and Smithies (in prep.). A maximum possible age for the Tarcunyah Group is c. 1200 Ma, which is the probable age for uplift of the Gregory Granitic Complex (Williams and Trendall, in prep.). Furthermore, the Tarcunyah Group does not display the metamorphism and deformation associated with the Miles Orogeny that is present in the underlying Throssell Group. Galena, probably contemporaneous with the deformation, yielded lead-model ages of between c. 940 and 820 Ma (Bagas and Smithies, in prep.). This provides a minimum possible age of about 800 Ma for the orogenic event, and therefore a maximum possible age for the Tarcunyah Group.

There are two main constraints on the minimum age of the Tarcunyah Group. Firstly, it is overlain by tillites of the Boondawari Formation (Williams, 1992) that have been correlated with the Marinoan glaciation and are equivalent to Supersequence 3 of the Centralian Superbasin (Walter et al., 1994). Secondly, it has undergone gentle folding and faulting during the closing stages of the Paterson Orogeny prior to deposition of, or partly penecontemporaneously with, the upper Savory Group sedimentary rocks (i.e. Tchukardine and McFadden Formations). Perincek (in prep.) suggests that the Tchukardine and McFadden Formations postdate the Paterson Orogeny.

Biostratigraphy

The later Late Proterozoic of Australia has good potential for biostratigraphic correlation using a variety of organisms, and proposed correlations can be substantiated by other dating techniques, such as lithostratigraphy, isotope chemostratigraphy, sequence stratigraphy, and limited geochronology (Walter et al., 1994; Zhao et al., 1994). Late Proterozoic stromatolites have proved valuable for Australia-wide correlations (Walter et al., 1994; Grey, 1995a), and acritarchs, which are mostly planktonic in nature, are also a valuable dating tool, as shown by extensive studies in the Centralian Superbasin (Zang and Walter, 1992; Grey, 1993, unpublished data).

Stromatolites are common in the Tarcunyah Group, but have been only briefly evaluated. More rigorous systematic analysis is required for identifications to be confirmed. Stromatolites from the Savory Basin have been well documented (Walter et al., 1994; Grey, 1995a), whereas those of the Officer Basin have been partially described, but much work remains to be done (Preiss, 1976; Grey and Jackson, 1983; Grey, 1986, 1990, 1995a). In other parts of Australia, Supersequence 1 is characterized by a large number of taxa, of which *Acaciella australica*, *Basisphaera irregularis*, and *Baicalia burra* appear widespread and biostratigraphically significant (Preiss, 1972, 1976; Griffin and Preiss, 1976; Grey and Jackson, 1983; Grey, 1995a, unpublished data; Walter et al., 1995). Specimens of probable *A. australica* and associated Supersequence 1 taxa occur in the Tarcunyah Group, and similar taxa are known from both the Officer and Savory Basins (Grey, 1986, 1995a, unpublished data). Supersequence 3 stromatolites (Walter et al., 1979, 1994, 1995) have more limited correlation value. Although they are present in both the Officer and Savory Basins, they have not been recognized in the Tarcunyah Group.

Palynological observations based on existing preparations indicate that abundant and well-preserved material is present in Officer Basin drillholes in Supersequence 1, particularly in the Kanpa and Hussar Formations, and in the Browne and Madley Formations (Grey, 1995b, unpublished data). Although assemblages are not diverse, they warrant further investigation to establish the ranges of the species observed. Moreover, similar species occur in a Normandy Poseidon drillhole west of the McKay Range (Lake Disappointment – DDH1) that intersects the Tarcunyah Group. Species recorded in a preliminary investigation are consistent with a Supersequence 1 age for the Tarcunyah Group, and it is anticipated that correlations will strengthen as work progresses.

The Thermal Maturation Index (TMI) of organic material from LD–DDH1 indicates a depth of burial consistent with gas formation or possibly with the final phase of liquid-hydrocarbon generation. Burial temperatures are unlikely to have risen above 180°C, and the mid- to dark brown kerogen confirms that the Tarcunyah Group underwent very little metamorphic alteration in this area.

Although distinctive and diverse acritarchs are common in Supersequence 3 in central and South Australia (Zang and Walter, 1992; Grey, 1993, unpublished data) they have not yet been recorded in Western Australia. Supersequence 3 acritarchs have limited stratigraphic distributions and are therefore valuable stratigraphic tools. However, preparations from corresponding units in the Officer and Savory Basin have so far proved barren (Grey, 1995b, unpublished data).

Implications

Regional geology

The separate lines of investigation outlined above have resulted in a convergence of ideas that can be summarized as follows:

1. The Yeneena Group has now been replaced by two older units, the Throssell and Lamil Groups, and a younger unit, the Tarcunyah Group. The relationship between the two older units is presently unclear, but both were apparently deposited before c. 950 Ma, and underwent at least three major phases of deformation and greenschist facies metamorphism. By contrast, the Tarcunyah Group shows one major phase of deformation and is typically unmetamorphosed (Williams and Bagas, in prep.). The Karara Formation is now included in the Tarcunyah Group (Bagas and Smithies, in prep.).

2. The Tarcunyah Group is either in faulted contact with, or unconformably overlies the Throssell Group, indicating a hiatus (Bagas and Smithies, in prep.; Williams and Bagas, in prep.).

3. The Tarcunyah Group was deposited later than c. 1200 Ma, and most probably around 800 Ma (Bagas and Smithies, in prep.). The available biostratigraphic data support a Late Proterozoic age for the Tarcunyah Group, and it is most likely coeval with the oldest Centralian Superbasin depositional succession, Supersequence 1.

4. In places, the Tarcunyah Group is unconformably overlain by younger units of the Savory Group (Supersequences 3 and/or 4 of Walter et al., 1995).

5. Deposition of the western part of the Paterson Orogen, and of parts of the Officer and Savory Basins, was coeval, as can be demonstrated by both lithostratigraphic and biostratigraphic correlations (Walter and Gorter, 1994; Walter et al., 1994; Grey, 1995a, unpublished data). All three areas were subsequently affected by the same tectonic events (Myers, 1993). As a consequence, all three areas should probably be grouped into a single tectonic unit, herein referred to informally as the greater Officer Basin.

6. Tectonic components of the Officer Basin, such as the Gibson Sub-basin and Kingston Shelf (Iasky, 1990), can be traced northwestwards into the Paterson Orogen and Savory Basin, where they apparently correspond to units such as the Karara Basin (Williams, 1990b) and the Trainor Shelf (Williams, 1992). Some rationalization of terminology of the various components will be required in the future.

7. As a result of this new interpretation, some areas formerly included in the Savory and Yeneena Basins will probably need to be redefined as integral parts of the greater Officer Basin. As the tectonic framework becomes better defined, it seems probable that the name Savory Basin may fall into disuse. For the moment the name Yeneena Basin should be restricted to the Throssell and Lamil Groups, but further restriction of the name may become necessary once relationships between the Throssell and Lamil Groups are more clearly understood.

Significance for mineral exploration

Distribution of known mineral occurrences in the Paterson Orogen is shown in Figure 3, and can be summarized as follows:

1. The Rudall Complex and the Throssell Group contain significant mineralization. This includes a variety of base metals and uranium, and minor silver, platinum-group elements (PGE), and rare-earth elements (REE). There is evidence that mineralization in this area is related to hydrothermal activity associated with regional greenschist metamorphism during the Miles Orogeny (Bagas and Smithies, in prep.).

2. The Lamil Group contains important gold deposits and base-metal mineralization. This group is intruded by 620 Ma granitoids that may have been instrumental in the control of gold and other mineralization.

3. The Tarcunyah Group is very sparsely mineralized. This is possibly due to lack of metamorphism and hydrothermal activity.

It is obvious from recent studies that the mineral potential of the Tarcunyah Group appears to be low by comparison with the Thossell and Lamil Groups. However, correlation with Supersequence 1 of the Centralian Superbasin, coupled with the absence of metamorphism, increases the potential for hydrocarbons. Consequently, the Tarcunyah Group should be considered together with other Late Proterozoic units during future evaluation of the hydrocarbon potential of Western Australia.

Implications for regional and global tectonic evolution

Deposition of the Throssell and Lamil Groups probably occurred marginal to the Pilbara Craton sometime between 1790 and 1290 Ma (Bagas and Smithies, in prep.). This was followed by deformation (Miles Orogeny) and associated greenschist metamorphism that occurred sometime between 1290 and 820 Ma. Structures associated with the Miles Orogeny indicate northeast–southwest compression (Bagas and Smithies, in prep.). This compression is interpreted to be at least partly synchronous with the assembly of the supercontinents of Kanatia, and subsequently Rodinia (Myers et al., in press). This event involved the collision of the West Australian Craton and the North Australian Craton, followed by collision with the South Australian

Craton. In the later Late Proterozoic, deposition occurred in a single large sag basin in central Australia, referred to as the Centralian Superbasin (Walter et al., 1995), and may have extended into the southern and western parts of the Paterson Orogen (Tarcunyah Group) at about 800 Ma. Subsequent disruption led to the formation of separate structural basins including the Savory, Officer, Amadeus, Ngalia, and Georgina Basins.

The Tarcunyah Group and the youngest components of the Savory Group (in the northeast part of the Savory Basin) were deformed by the last major event recorded in the Paterson Orogen, the Paterson Orogeny. The orogeny was a compressional event orientated in a northeast–southwest direction, and is probably synchronous with the 560–525 Ma Petermann Orogeny of central Australia (Myers, 1990, 1993; Maboko et al., 1992; Walter et al., 1994; Williams, 1994; Camacho and Fanning, 1995) and the King Leopold Orogeny of the Kimberley region (c. 560 Ma; Shaw et al., 1992).

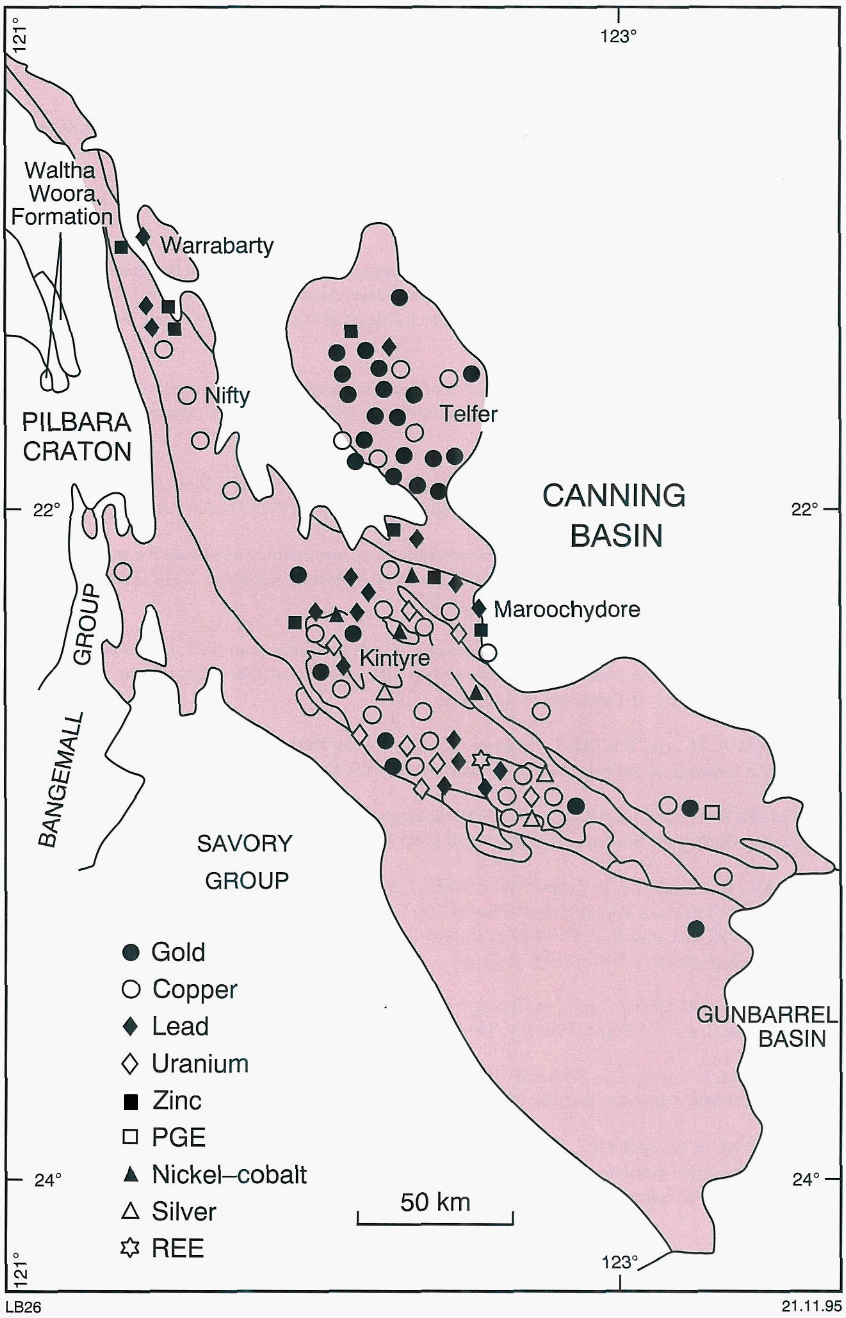

Figure 3. Mineral occurrences in the northwest Paterson Orogen

Conclusions

Revisions to the various tectonic units outlined above require further confirmation, but data collected so far are consistent with a Late Proterozoic age for the Tarcunyah Group. One outcome of this is that the Tarcunyah Group may represent the northeastern margin of the Savory Basin. In addition, it seems likely that the Savory and Officer Basins formed a single depositional unit. While this interpretation lessens the potential for mineralization in the Tarcunyah Group, it will have important consequences for the evaluation of the petroleum potential of the Savory and Officer Basins.

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