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TECTONIC EVOLUTION OF THE PRECAMBRIAN GAWLER PROVINCE IN SOUTHERN AUSTRALIA

BY

R.W.R. RUTLAND[1]

A.J. PARKER[2]

and

G.M. PITT[2]

1. Department of Geology and Mineralogy, University of Adelaide.
2. Geological Survey, Regional Geology Division.

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CONTENTS

FIGURES

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G.S. No. 6176
D.M. No. 75/79

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INTRODUCTION

In South Australia the Gawler Province (Fig. 1) displays a history of early Proterozoic orogenic evolution, and transitional tectonism leading to deposition of the Gawler Range Volcanics (ca 1500 Ma) on a relatively stable platform. A fragmentary record of platform deposition on the resulting Gawler Craton provides the link with the Adelaide 'Geosyncline' (mainly <1000 Ma) which was folded to form the Delamerian Foldbelt in the Delamerian Orogeny (ca 500 Ma).

In northern South Australia the interval between 1500 Ma and 1000 Ma was a period of intense orogenic reactivation of the early Proterozoic orogenic complexes in the Musgrave domain of the Musgrave-Fraser Province (Fig. 2). The evolution of the Musgrave domain should be compared with the Fraser and Albany domains and the southern part of the Arunta domain.

In this chapter, ages by the Rb/Sr method previously published with $\lambda^{87}Rb = 1.39 \times 10^{-11}y^{-1}$ have been recalculated using $\lambda^{87}Rb = 1.42 \times 10^{-11}$. Thus these ages need to be increased by about 2% if 1.39 is substituted in the decay constant.

THE GAWLER PROVINCE

Introduction

The principal outcrop of the Gawler Province is in the Gawler orogenic domain (Fig. 3). However, although the area of basement rock as shown in figure 3 is extensive, it is generally of very low relief and commonly blanketed by a thin superficial cover. Thus the geology is relatively well known only in the area of higher relief between the Gawler Range Volcanics and the NW shore of Spencer Gulf (Fig. 4). There, a series of early Proterozoic metasedimentary rocks (the Hutchison Group) and granitic gneisses (the Lincoln Complex) have been highly metamorphosed and tightly interfolded to form a major north to northeast trending orogenic belt. Recent work has shown that Archaean gneisses forming the basement to the early Proterozoic metasedimentary sequences are widespread in the less well exposed areas in the W and NW of the domain. Some of the granitic gneisses of the Lincoln Complex may represent reworked Archaean gneisses.

In the southern part of the Musgrave domain, overprinting by later Musgravian events is weak and therefore this part is also included within the Gawler Province. Again however exposure is very poor and little attention has yet been paid to its early Proterozoic history.

Early Proterozoic rocks of the Gawler Province also reappear in a major inlier, the Willyama orogenic domain, east of the main part of the Delamerian Foldbelt. This domain is divided by an area of relatively poor outcrop into the Olary sub-domain in South Australia (Fig. 5) and the Broken Hill sub-domain in New South Wales (Fig. 6). However the tectonic development of both these sub-domains is so similar to that of the Gawler domain that it is convenient to consider them together.

Smaller inliers of the Gawler Province are also found within the Delamerian Foldbelt both near Adelaide (Talbot, 1963; Mills, 1973) and, more extensively, in the Mt. Painter domain (Coats and Blissett, 1971) and in the Peake and Denison Ranges (Ambrose and Flint, 1978) (Fig. 3).

Archaean basement rocks

Several occurrences of Archaean basement rocks have recently been described from the Gawler domain (Cooper and others, 1976; Webb and Thomson, 1977; Daly and others, 1978). In the past these have been grouped together with younger gneissic rocks and several different hypotheses have been put forward for their origin and relationship to the metasediments. On Eyre Peninsula all the gneissic rocks were originally allocated to the Flinders 'Series' by Tilley (1921) who regarded them as intrusive into the metasedimentary Hutchison Group. Johns (1961) however suggested that the gneisses, the Flinders "Group" of his revised terminology, represented a higher grade of metamorphism, with local granitization, of the metasediments, whereas Whitten (1966) suggested that they, the Flinders "Gneiss" of his terminology, represented basement to the overlying metasediments. This latter view has been supported by Coin (unpublished Ph.D. thesis, 1976) and by Glen and others (1977) although these authors noted that, because of the strong tectonism, no major stratigraphic unconformity had been demonstrated between the two groups.

Cooper and others (1976) dated some of the granitic gneisses in the Eyre Peninsula at 1816 $\pm$ 10 Ma with an initial ratio of 0.7043 $\pm$ 0.0008. They regarded the rock as a granite intrusion and the date as the date of intrusion. They suggested that if the date represents a metamorphism, only about 10 Ma could have elapsed between intrusion and metamorphism. It must be presumed therefore that the dated event provides a minimum age for the associated Hutchison Group metasediments.

However, Cooper and others (1976) also showed that some granulite facies gneisses (?pre Hutchison Group metasediments) and associated augen gneisses at Cape Carnot (Fig. 4) on the southern end of Eyre Peninsula are of Archaean age. They regarded a date of 2587 ± 130 Ma with an initial ratio of 0.7015 ± 0.0043 as the most meaningful interpretation of their data for the augen gneisses (regarded as anatectic) but they were unable to evaluate any effect of the subsequent Proterozoic metamorphism. Webb and Thomson (1977) obtained further evidence from granites in the south and similar rocks 400 km to the north in the Lake Harris-Tarcoola region. Their isochrons suggest dates between 2400 and 2300 Ma and provide a minimum age for the paragneisses which the granites intrude and a maximum age for the overlying quartzites of the Hutchison Group.

Cooper and others (1976) note that the Archaean rocks at Cape Carnot include sillimanite-corderite gneiss with up to 20% sillimanite. Basic granulites are interpreted as original dolerite intrusions. Daly and others (1978) showed that a large area of paragneisses in the Tarcoola region are also sillimanite and cordierite bearing. They contain an iron formation which is a well layered quartz-magnetite-diopside-hypersthene-amphibole gneiss. Thin calcite layers containing minor mafic minerals are also present. The date of 2417 ± 59 Ma from the sequence is inferred to be the metamorphic age and the low initial ratio of 0.7036 ± 0.0015 is interpreted to indicate that the material had not resided in the crust for more than 100-150 Ma.

Thus these late Archaean metasediments appear to represent a relatively mature sedimentary sequence, unlike the main greenstone belts of the Eastern Goldfields sub-province of the Yilgarn orogenic domain, in either sedimentary character or their high grade of metamorphism. They are more similar in these characteristics to the older gneisses of the Wheat Belt sub-province in Western Australia. However, south-east of Tarcoola, Forbes and others (1977) record an occurrence of relict pillow structures in basic hornfels intruded by the Glenloth Granite (2318 ± 55 Ma).

The iron formations are similar to, and were previously correlated with, those of the Middleback Ranges in the Hutchison Group (Whitten, 1966). However Daly and others (op. cit.) report that initial isotopic ratios for units of the Hutchison Group suggest that their deposition could not have occurred prior to ca. 2000 Ma. Also the older iron formations are feldspathic whereas Hutchison Group iron formations are not and trace element compositions are distinct (Whitehead, 1978).

It therefore seems clear that part of Tilley's Flinders 'Series' is indeed Archaean, at least in the sense that it forms an older basement, metamorphosed and intruded by granite, before the deposition of the Hutchison Group. That part is now assigned to the Sleaford Complex[1] while the remaining granite gneisses, those derived from pretectonic granite intrusions or from reworked Archaean basement or from migmatized early Proterozoic metasediments (such that their original identity is no longer distinguishable), are assigned to the Lincoln Complex[1]. It appears that the Hutchison Group has its principal development in the eastern part of the Eyre Peninsula but that westwards it has been largely removed by subsequent erosion to expose its reworked Archaean basement. It can be reasonably inferred that the quartzites at the base of the Hutchison Group were deposited on a major unconformity (Parker, unpublished Ph.D. thesis, 1978) although evidence of a structural contrast across the unconformity has not yet

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1. Thomson B.P. (Compiler), in prep., Geological Map of South Australia, 1:1 000 000, scale, Geol. Surv. S. Aust.

been presented. It is possible that much of the structure in the Archaean rocks is the consequence of the Proterozoic deformation episodes which also affected the overlying Hutchison Group. In any case it is clear that the Archaean rocks particularly of southern Eyre Peninsula do not represent a stable Archaean craton like the Pilbara and Yilgarn orogenic domains in Western Australia. Instead they represent part of the reworked basement to the early Proterozoic sequences.

Granitic gneisses in the Broken Hill area are interlayered with the metasediments and have taken part in all the deformation episodes that affect the metasediments. These gneisses have been dated at about 1660 Ma (Pidgeon, 1967; Shaw, 1968) which is interpreted as the age of the Willyama metamorphism. The relatively low initial ratios however suggested a maximum primary age for the rocks of little more than 1800 Ma, although the uncertainties involved in making such inferences were emphasised by Pidgeon. In the Olary subdomain, granitic rocks consist of granitic to adamellitic intrusives of 1500-1550 Ma age, and semi-concordant granodioritic gneisses which, like the granite gneisses of Broken Hill, have the same metamorphic history as their enclosing metasediments. Stratigraphically interlayered with, and underlying the granodioritic gneiss bodies is a quartzofeldspathic gneiss sequence probably comparable to the lower parts of the Hutchison Group of Eyre Peninsula. These appear to be part of the Willyama sequence and there is no evidence to suggest they are Archaean. In fact their correlation with the lower gneisses of Broken Hill, and their low initial strontium ratios support their interpretation as part of the Willyama Complex. Thus the Archaean rocks that must have been basement to the Willyama sedimentation are not present or not recognised as such, due to lower to middle Proterozoic metamorphism and anatexis (cf. Lincoln Complex). In both the Broken Hill and Olary areas dated events ca. 1600 provide a minimum age for the metasediments.

The Lower Proterozoic sequences

Lower Proterozoic sedimentation throughout the Gawler Province is notable for its relatively shallow water, mature and uniform character over wide areas (Glen and others, 1977). Details of the sedimentation and stratigraphy are most readily established for the higher parts of the sequence where the metamorphic grade is generally low and the deformation less severe (e.g. Tuckwell, 1978). In the lower part of the sequence highly complex superposed deformations and high grade of metamorphism make it difficult to correlate locally established successions over wide areas.

In the Gawler domain, quartzites (the Warrow Quartzite) dominate the base of the succession immediately above the Archaean crystalline basement. Sedimentary facing criteria have not been firmly established but a base has been inferred from structural evidence (Parker, op. cit.), from the presence of local quartz "pebble" bands near the supposed base of the quartzite (M. Fanning, pers. comm., 1978), and from a general similarity of the total succession with other early Proterozoic sequences throughout the world. The quartzites are locally calc-silicate rich at the base whereas higher up they are intercalated with pelitic schists.

Immediately overlying the quartzites is a sequence of mixed chemical and semi-pelitic metasediments ranging from massive dolomite and associated banded iron formation and chert to quartzo-feldspathic gneisses and schists. There are numerous conformable amphibolite sills throughout this part of the sequence but their origin is obscure. Their massive, uniform lithology and their chemical affinity to quartz tholeiites suggests an igneous, possibly intrusive, origin although amphibolitic dykes have only been recorded in the Middleback Ranges west of Whyalla (Furber and Cook, 1976) where they may be related to younger tectonic features. The chemical/ semi-pelitic part of the sequence is well developed in the Middleback Ranges where it is locally known as the "Middleback Group" (Miles, 1954) and where iron ore has been mined for over half a century. The underlying leucogneiss unit in that area is locally known as the Gneiss Complex, but is considered at least in part to be a granitized equivalent of the basal (Warrow) quartzites that are so well developed to the west and southwest. The composition of the iron formations is dominantly quartz hematite at the surface but below the weathered zone ranges from quartz-magnetite to quartz-magnetite-amphibole (grunerite-actinolite) $\pm$ talc, calcite, sulphide and diopside. Feldspar is absent. The weathering of the orebody was, at least, partly Precambrian since clasts of the ore are found in the Corunna Conglomerate (see below; N. Lemon, pers. comm., 1978).

The metasedimentary sequence above the iron formation horizons has mostly been eroded away, but where part of it is locally preserved, it is of pelitic to semi-pelitic character and generally of slightly lower metamorphic grade.

Deformation and igneous intrusion have greatly modified the apparent thickness of the succession in the Gawler domain, but it is estimated to be of the order of 1500 to 2000 m thick.

In the Broken Hill mine area it has been shown that the lower part of the succession was inverted during the first deformation so that the major (F_2) fold structures are downward facing (Laing and others, 1978). The 'Mine Sequence' which was regarded as a stratigraphic succession facing northwest is now interpreted as containing both limbs of a downward facing antiformal structure separated by a syn-metamorphic slide. Within the mine area therefore the principal stratigraphic units are as follows. The numbers correspond to local lithological units (Fig. 7).

Top 5. Pelitic and psammopelitic sillimanite gneiss (without metavolcanics)

4. Psammopelitic sillimanite gneiss (ca. 1000 m thick) containing units of mine sequence - Banded Iron Formation, amphibolite, Potosi gneiss, Lode horizon (with lead lodes stratigraphically above zinc lodes).

Base 3. Granite gneiss (pre-F_1 granite or meta-volcanic).

The 'lode horizon' and its associated 'Potosi' and 'Parnell' gneisses can be traced throughout the Broken Hill sub-domain. The 'Potosi' and 'Parnell' gneisses apparently represent meta-volcanic rocks (especially meta-dacites) closely associated with Banded Iron Formation and with the Broken Hill mineralisation, while the stratigraphically overlying sillimanite gneisses are generally regarded as mature non-volcanogenic meta-sediments. In contrast, Stanton (1976) interprets the whole environment as of volcanic island arc character (see also Rutland and others, 1978).

Some feldspathic metasediments east of Broken Hill (the Thorndale gneisses which are possibly several thousand metres thick), appear to lie stratigraphically below the mine sequence, while to the northwest, major synclinal structures carry lower grade metasediments stratigraphically above the mine sequence. Tuckwell (1978) has divided these younger metasediments into the Wookookaroo Beds (up to approximately 4000 m thick) below, and the Bijerkerno Beds (up to 1500 m thick) above, separated by a prominent calc-silicate unit. The Wookookaroo beds commonly show graded bedding in peliti-psammite beds and were probably deposited by traction and turbidity currents. Psammitic beds are commonly feldspathic or calcareous. By contrast the Bijerkerno beds are well laminated and consist of suspension deposited fine grained muds and quartz rich sediments. The sediments are often carbonaceous and the psammites are relatively pure quartzites.

No major stratigraphic breaks have been observed anywhere in the Broken Hill succession. Unit 5 of the mine sequence probably corresponds to the lower part of the Wookookaroo Beds. It is notable however that the granitic gneisses and amphibolites are confined to the high grade part of the sequence although structural studies suggest that the whole succession has been involved in the same deformation episodes. Tuckwell (1978) has suggested that the mafic intrusive activity may have preceded deposition of the higher part of the succession and that a major tectonic or stratigraphic break may be present.

Three distinct areas within the Olary subdomain (Fig. 5) are recognised on metamorphic, lithological and deformational grounds (Forbes and Pitt, 1979). Regional mapping has shown that specific stratigraphic units can be traced through both the Old Boolcoomata and Kalabity areas. The Old Boolcoomata area is, as a rule, more mobilised and gneissic than the less penetratively deformed Kalabity area. The recognition of a sequence, in the former area, depends on the validity of interpreted isoclinal F_2 folds which often lack exposed closures. Grades of deformation and metamorphism can vary from limb to limb resulting in schistose, gneissic or migmatoid variants of any particular unit or sequence of units. The consistency of local and regional sequences, erected on this basis, however, supports the assumed structure.

The interpreted sequence of the Old Boolcoomata area is therefore broadly as follows:

Top 4. Interlayered schist and quartzite.

3. Knotted aluminosilicate and/or muscovitic schist, with ubiquitous tourmaline and garnet. Fibrolite often appears to be later than both kyanite and andalusite. The andalusite is often retrogressed to corundum plus pyrite. Chiastolite is developed locally in an upper, carbonaceous member. Calc-silicate and calc-albitic marker beds are present at the top and base - the "Ethiudna Calc-silicate Group" of Campana and King (1958).

2. Layered, often magnetitic and/or feldspathic, gneisses, containing one to three thin, but laterally persistent, iron formations which display a ± sulphide ± magnetite ± hematite ± baryte ± quartz ± albite mineralogy.

1. A thick, lower sequence of quartzo-feldspathic gneisses, which may be migmatoid or anatectic, containing lenticular

Base. semiconcordant granodiorite gneiss bodies near the top.

There are no indications of an Archaean basement to the succession and preliminary estimates give a thickness of some 4-6000 m. Nevertheless this succession appears to correspond very closely to that described from Broken Hill.

The Kalabity area is stratigraphically equivalent, but less penetratively deformed and kyanite has not been observed. However, the local development of fibrolitic sillimanite indicates that the metamorphic grade is not necessarily very much lower.

The structure of the Kalabity area is that of a broad north-closing anticlinal arch. Relative to the Old Boolcoomata succession, Unit 4 is similar, while Unit 3 is a very thick, more homogeneous carbonaceous metapelite up to 1.5 km thick with ubiquitous (now retrogressed) chiastolite and andalusite porphyroblasts. Iron formations equivalent to those of Unit 2 at Old Boolcoomata are thicker and more massive and are directly associated with calc-silicate, calc-albitic and albitic horizons at the base of Unit 3. Thus the correlation of Units 2 and 3 is clear but there appear to be significant differences in thickness and facies between the two areas. Possibly the Kalabity area represents the more distal facies. Unit 1 is represented by psammopelitic schists and gneisses which occupy the core of the anticline and which are intruded by late-tectonic granitoids, while granodiorite gneiss bodies like those of the Boolcoomata area are absent.

The origin of albite-rich units in both areas is controversial. Acid volcanics are believed to have made some contribution, in the form of tuff or of clastics reworked from the original extrusives (cf. Vernon, 1961; Stanton, 1976). Evaporites and related sediments are possibly also important to the origin of both calc-silicate and albitic rock-types, but this is not proven.

The Mutooroo area is of notably higher grade (upper amphibolite) than the other two areas described above, consisting of undifferentiated coarser grained sillimanite-kyanite-garnet schists and gneisses. Local occurrences of "Aplite", "augen gneiss" and "Q.M." (quartz-magnetite iron formation) lithologies like those of Broken Hill have been recorded, but have not allowed a stratigraphic succession to be established. However it seems likely that these rocks are equivalent to the lower-grade successions to the north. A notable feature, not present in the other areas, is the presence of conformable amphibolites, regarded as of igneous origin.

These summaries of recently acquired stratigraphic evidence give support to the general conclusions of Glen and others (1977) regarding the stratotectonic unity of the Gawler Province. It appears that the whole province was characterised by relatively shallow water sedimentation on an older continental crust. An increase in thickness appears to accompany a change from more proximal to more distal environments from west to east.

The lower part of the sequence with its banded iron formations and amphibolite sills is similar throughout the province and invites analogy with the Hamersley Group in Western Australia (Whitten, 1966). The available isotopic data place the sequence between 2400 Ma and 1800 Ma approximately so that it could indeed be approximately the same age as the Hamersley Group. Unlike the Hamersley Group however it has suffered strong deformation and metamorphism.

The probable metavolcanics (e.g. Potosi Gneiss) in the lower part of the sequence are well developed only in the Broken Hill sub-domain and appear to be genetically associated with the major stratiform base metal sulphide mineralisation of that region (see e.g. Both and Rutland, 1976; Stanton, 1976; Laing and others, 1978).

Deformation and Metamorphism

Deformation and metamorphism is also similar in character throughout the Gawler province (Glen and others, 1977). The earliest prominent schistosity in the high grade rocks is a layer-parallel schistosity (S_1) which in the Broken Hill region is known to be associated with stratigraphic inversion of the high grades in the Broken Hill Mine area. In the low grade rocks S_1 is an axial plane schistosity and there is evidence of metamorphic crystallisation prior to its development

(Glen, unpublished Ph.D. thesis, 1978). There is less strong evidence for porphyroblast development in the high grade rocks prior to S_1 (Parker, 1978) and correlation of S_1 between the high and low grade rocks is not firmly established (e.g. Glen, 1978).

The second deformation was also accompanied by high-grade metamorphism and produced tight to isoclinal folds with local transposition in the high grade rocks. F_2 folds are the major structures of the Broken Hill Mine area for example (Fig. 8) and they played an important part in localizing the Pb-Zn orebody (Laing and others, 1978). The ages of the F_1 and F_2 deformations in the Gawler Province are not easily separated. The isotopic dates reflect an age of metamorphism associated with one or both of these deformations. It can be concluded only that F_1 is not younger, and F_2 is not older, than these dates. The two deformations are bracketed in the Gawler domain between about 1816 (± 10) Ma given by Cooper and others (1976) for the Kirton Point gneiss (which antedates both F_1 and F_2) and about 1650 ± 35 Ma for the syn F_2 Middle Camp Granite on east-central Eyre Peninsula (N.B. the post-F_2 Carpa Granite in the same area gives an age of 1677 ± 125 Ma).

The third deformation appears to be significantly younger throughout the province and is associated with the intrusion of late tectonic granites. These are dated at ca. 1520 in the Broken Hill domain. In the Gawler domain regional F_3 folds deform Carpa Granite equivalents but are unconformably overlain by the basal Gawler Range Volcanics dated at 1525 ± 15 Ma (see below).

The F_3 deformation has produced major north-northwest to northeast trending upright folds throughout the province and is generally accompanied by retrogressive metamorphism and the development of ductile shear zones. For example, in the Gawler domain a major mylonite zone was developed (Fig. 9) and in the Broken Hill subdomain retrograde schist zones were initiated. The axial trends and plunge directions of F_3 folds are somewhat variable throughout the province reflecting in part the effects of the weak overprinting F_4 deformation and in part the variable nature of F_3 strain (as is also evidenced by the production of local F_3 shear zones). F_3 folds generally do not have strong axial planar fabrics by contrast with F_2 folds (Fig. 10). They also have influenced the localization of orebodies and in the Gawler domain the iron ores of the Middleback Ranges lie in an F_3 synform.

Glen and others (1977) note that the province was characterised by a high geothermal gradient and that there is general correlation between metamorphic grade and height in the structural succession. In the NW part of the Broken Hill subdomain, Glen (1978) observed that metamorphic boundaries were subparallel to bedding and folded by D_1 folds. He considered that there was some modification of the metamorphic boundaries by this and subsequent deformations, but that the major metamorphism in that area antedated the D_1 deformation. Consequently, he concluded that the basal rocks of the local succession were higher grade and more penetratively deformed than the upper succession. Similar relations may well hold elsewhere in the province for the M_0/M_1 metamorphism but it is clear that metamorphic boundaries are not always bedding parallel and that subsequent metamorphism can be locally more important. In the higher grade parts of the Broken Hill region sillimanite growth locally continued into the F_3 deformation and isograds clearly transgress the early formed structures. In the Olary subdomain the iron formations (Unit 2) are present in both higher and lower grade regions. Likewise in the Gawler domain amphibolite facies iron formations of the Middleback Ranges can be traced south into granulite facies terrain. Furthermore, metamorphic boundaries in that domain locally transgress major D_2 fold structures thus necessitating post M_1 modification of the original, perhaps bedding parallel, metamorphic boundaries. Superimposed metamorphism is also important in the Olary subdomain where fibrolite overprinting andalusite has already been noted.

Late Tectonic History of the Gawler Province

Following the F_3 deformation there was a major disruption to the parallelism of tectonic events in the Gawler, Willyama and Musgrave domains. In the Gawler domain the eruption of the Gawler Range Volcanics, the synchronous deposition of the predominantly clastic Moonabie Formation, Tarcoola Beds and Corunna Conglomerate and the subsequent co-magmatic intrusion of the post-tectonic granites define a major tectonic episode which represents the transition from orogenic to cratonic character (cf. Tectonic Map of Australia and New Guinea, G.S.A. 1971). In the Kokatha and Tarcoola areas, the Gawler Range volcanic complex locally rests directly on Archaean rocks, demonstrating that uplift and erosion of the entire Hutchison Group took place prior to its deposition. On eastern Eyre Peninsula, this uplift had already begun by F_3 time since the metamorphic conditions during F_3 indicate uplift of at least 4-6 km after F_1 and F_2 (Parker, 1978).

The volcanics are relatively flat lying and undeformed and form a large basin-like feature surrounded by a ring of post-tectonic granites approximately in the centre of the Gawler domain (Fig. 3). They were erupted subaerially in a continental environment and consist essentially of acid ignimbrites with minor lavas and agglomerates (Blissett, 1975). In the Kokatha area, Branch (1978) recognizes several phases of volcanic activity (collectively called the Chitanilga Volcanic Complex by Blissett, 1975) initiated by the development of large stratovolcanoes at 1525 ± 15 Ma* on a folded Archaean basement. This initial phase was dominated by basaltic and andesitic flows with some acid ignimbrites but the subsequent premonitory caldera, caldera formation and post-caldera phases are dominated by the eruption of thick rhyodacite to dacite ignimbrites. The recognition of the calderas themselves is tenuous because of the outflow of a thick sheet of dacite during the so-called caldera phase. However there are several circular features tens of kilometres across with volcanic units gently dipping towards their centres suggestive of a caldera origin (Crawford, 1963a). The age of the thick sheets of dacite (Chandabooka Dacite and Yardea Dacite) is 1511 ± 36 Ma*. The caldera phase is succeeded by thin rhyodacites and breccias and the whole sequence is intruded by the Hiltaba Granite suite at 1478 ± 38 Ma* and by rhyodacite dykes at 1457 ± 22 Ma*.

The relationship between the volcanics of the Gawler Ranges and clastic sediments is not clearly established in that area. However in the Moonabie Range 50 km southwest of Whyalla (Fig. 4), volcanics which have been likened to those of the Gawler Ranges (C. Giles, pers. comm., 1978) are interlayered with volcanoclastic sediments of the Moonabie Formation (Fig. 11). Overlying the Moonabie Formation is a sequence of fluvio-marine conglomerates and sandstones, the Corunna Conglomerate sequence, and both sequences have been intruded by the Charleston Granite dated by Rb-Sr methods at 1455 ± 39 Ma

*radiometric ages determined by A.W. Webb (Australian Mineral Development Laboratories) and quoted by Blissett, A.H., 1977: Gairdner, South Australia - 1:250 000 geological atlas series. Geol. Surv. S. Aust.

(N.B. K-Ar gives an anomalous age ca. 1560 Ma). Deposition of the Moonabie Formation and Corunna Conglomerate is largely controlled by fault graben which are believed to have been developed by reactivation of F_3 structures since they parallel F_3 fold trends. F_4 deformation features are present in both the basement and Middle Proterozoic sediments and local K-Ar dates ca. 1470 are common in the basement (Parker, 1978). This date is believed to represent the cessation of tectonic activity in the Gawler domain. Subsequent volcanism, the Roopena Volcanics and Beda Volcanics, and Adelaidean sedimentation took place on a stable cratonic platform, the Stuart Shelf (Fig. 3). It is significant to this point that Rb/Sr and K/Ar Delamerian ages (ca. 490 Ma) have not been recorded in either Olarian basement or Adelaidean cover rocks of the Gawler domain west of the Torrens Hinge Zone.

In contrast, tectonic events in the Willyama domain continued through to Delamerian time and Delamerian K/Ar ages are obtained from basement rocks. Adelaidean rocks resting on the Willyama domain are strongly deformed and they show large thickness changes across faults believed to be extensions of retrograde schist zones. In fact the retrograde schist zones are believed to have been intermittently reactivated from F_3 time through to Delamerian time. Furthermore, Berry and others (1978) have recorded five deformations in basement rocks north of Olary in the Willyama domain, and they identify the F_4 and F_5 deformations with deformation of the Adelaidean sediments. Consequently the final development of a stable craton in the Willyama area did not take place until ca. 490 Ma. This also applies to the other, smaller, basement inliers east of the Torrens Hinge Zone.

RWRR:AJP:GMP:ZV

R.W.R. RUTLAND A.J. PARKER G.M. PITT

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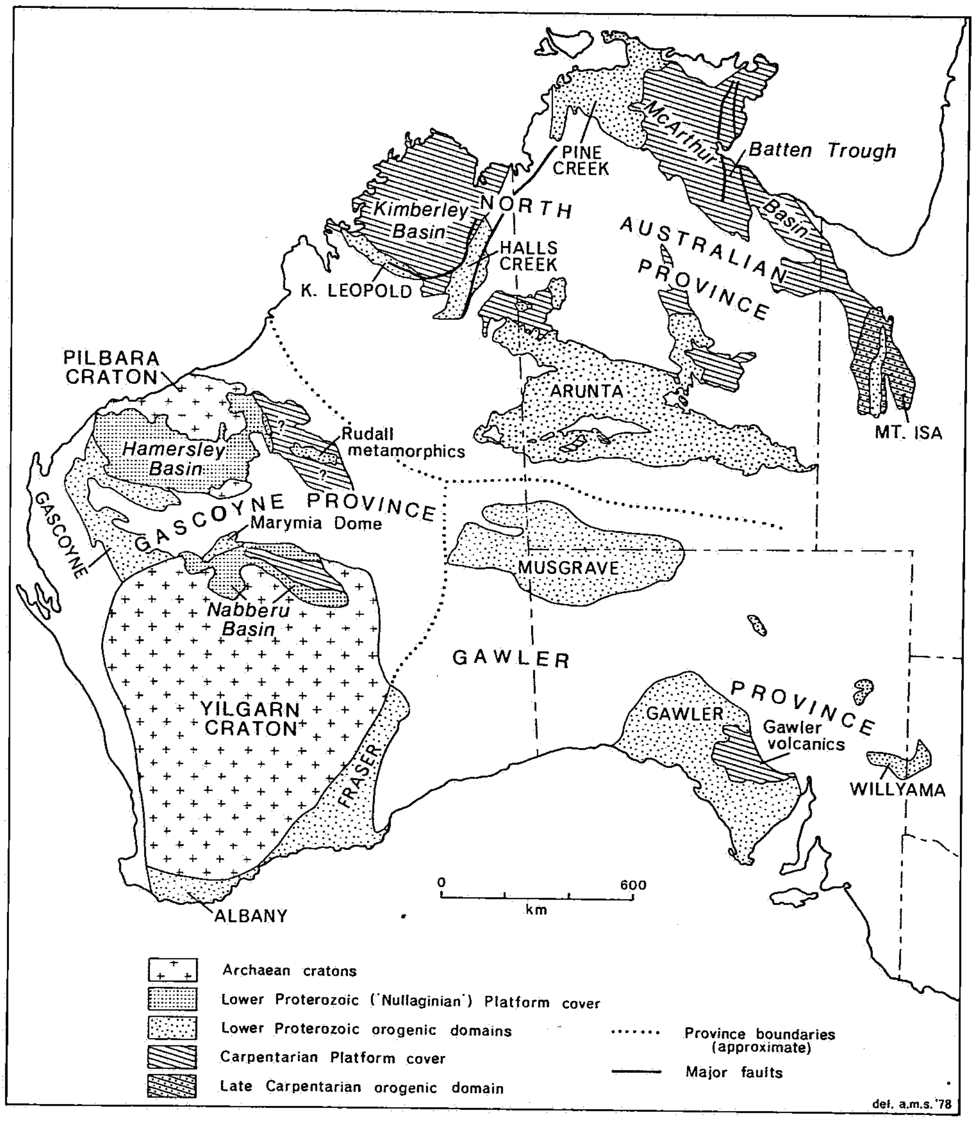

Fig. 1. Principal tectonic elements of the early and middle Proterozoic chelogen (2400-1400 Ma, excluding reactivation features 1400-1000 Ma). The three Proterozoic provinces are areas of Lower Proterozoic orogenic domains (e.g. Gawler, Willyama and Musgrave) separated by areas of younger orogenic basement (Fig. 2). The earlier Archaean provinces formed stable cratons during the development of the early and middle Proterozoic chelogen.

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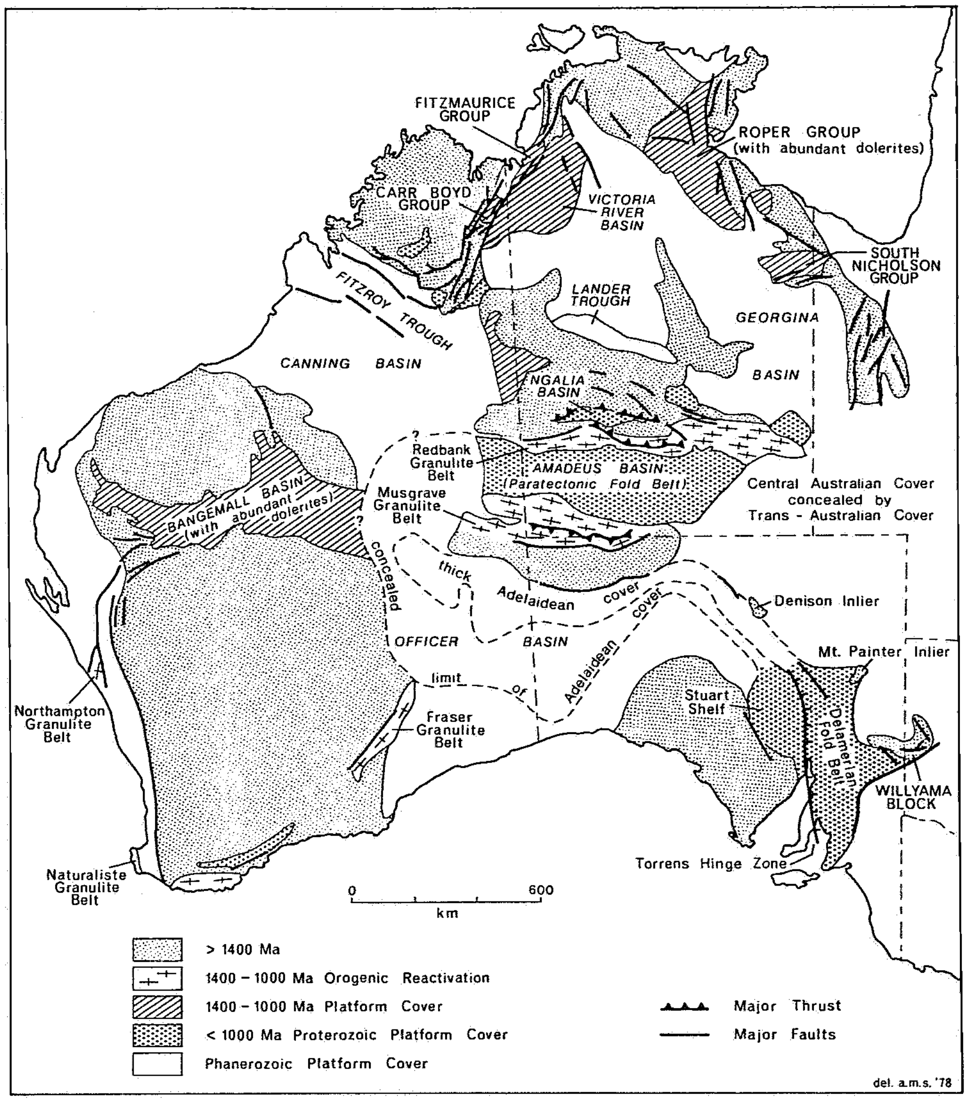

Fig. 2. Features of the reactivation of the Proterozoic chelogen during the period 1400-1000 Ma in relation to the distribution of the Central Australian Platform Cover.

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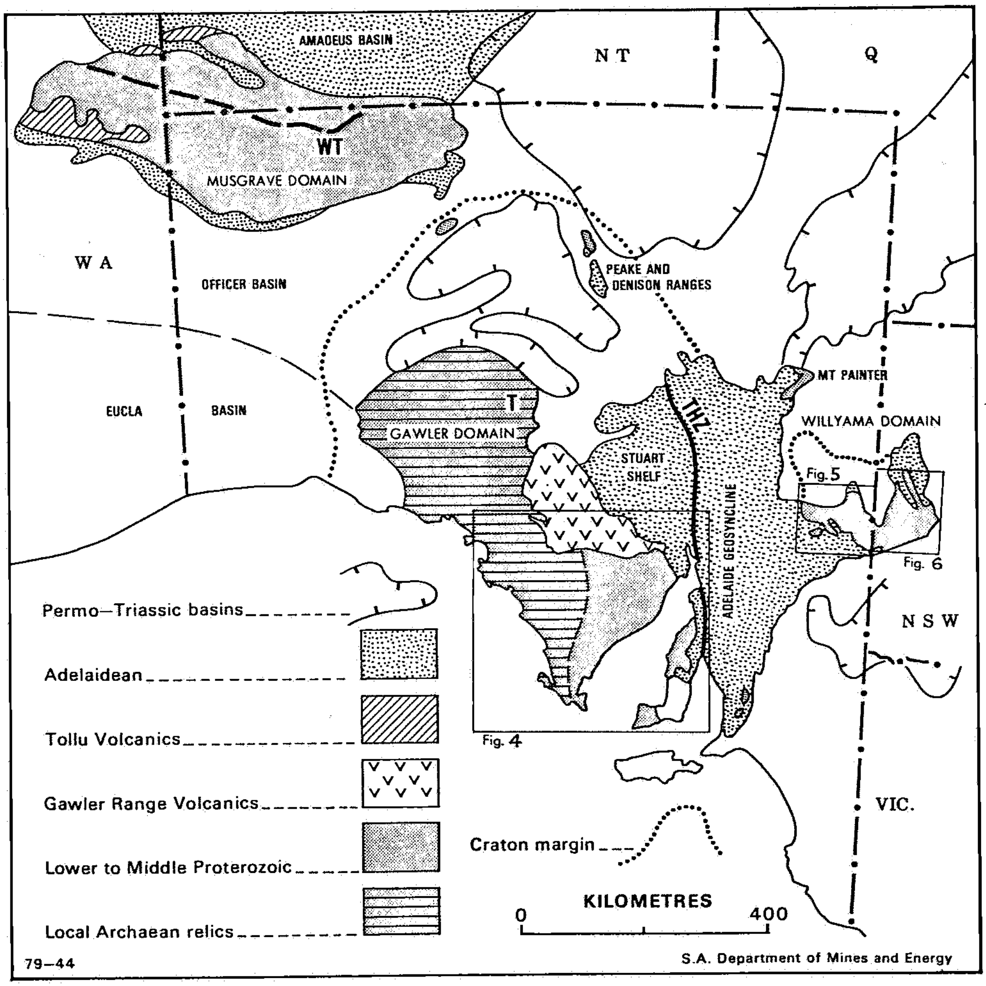

Fig. 3. Principal areas of outcropping Precambrian in South Australia, and the proposed margins of the concealed extensions to the Gawler and Willyama domains as defined by aeromagnetics. T-Tarcoola area; THZ-Torrens Hinge Zone; WT-Woodroffe Thrust. The location of Figures 4, 5 and 6 are indicated.

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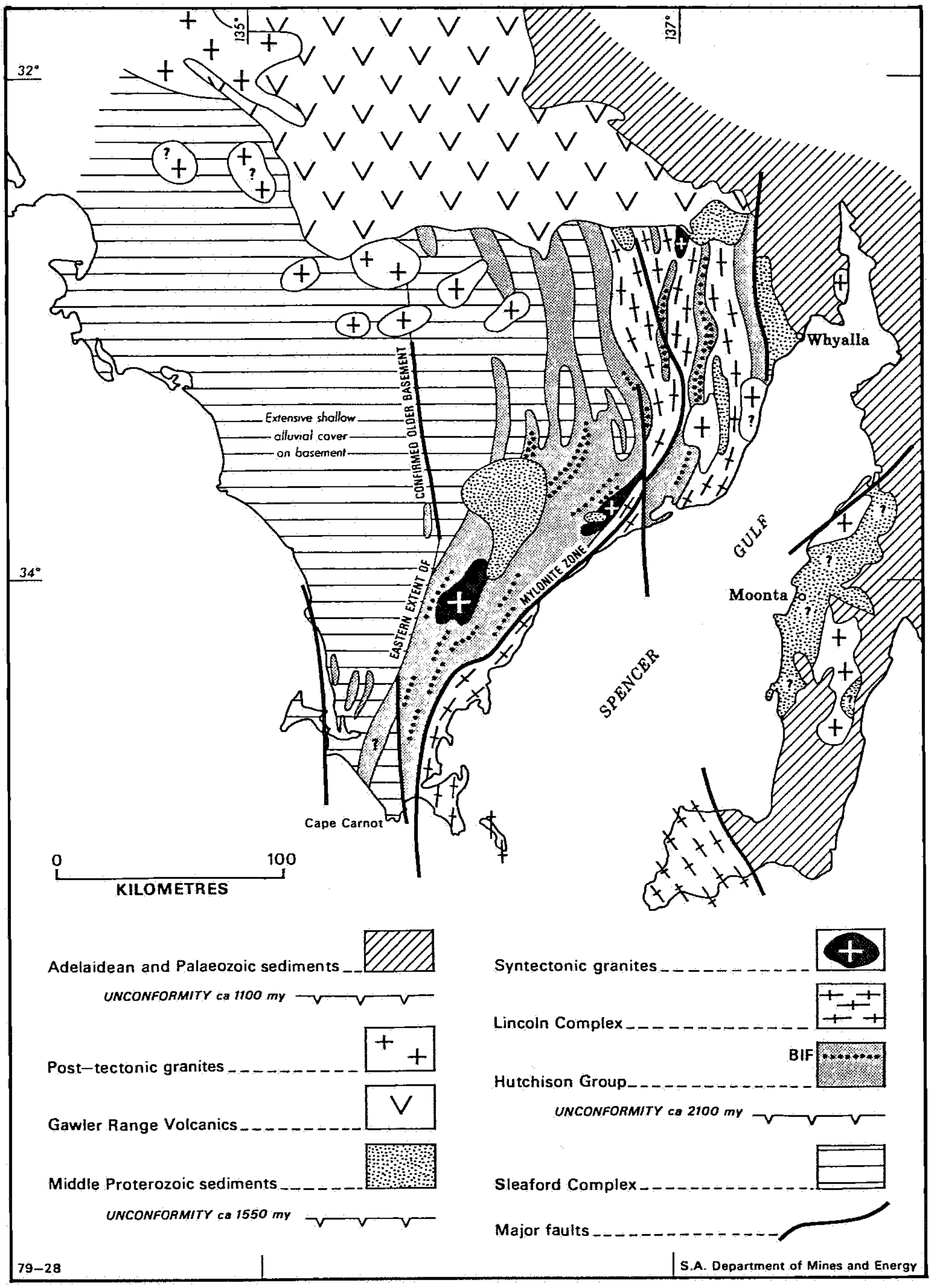

Fig. 4. Regional geology of the southern part of the Gawler domain on Eyre Peninsula (W. of Spencer Gulf) and Yorke Peninsula (E. of Spencer Gulf). Archaean ages for the Sleaford Complex have only been confirmed by geochronology at Cape Carnot and on western Eyre Peninsula. To the east the Sleaford Complex has been reworked during the Proterozoic Olarian Orogeny and yields ca. 1700 Ma ages. S14237.

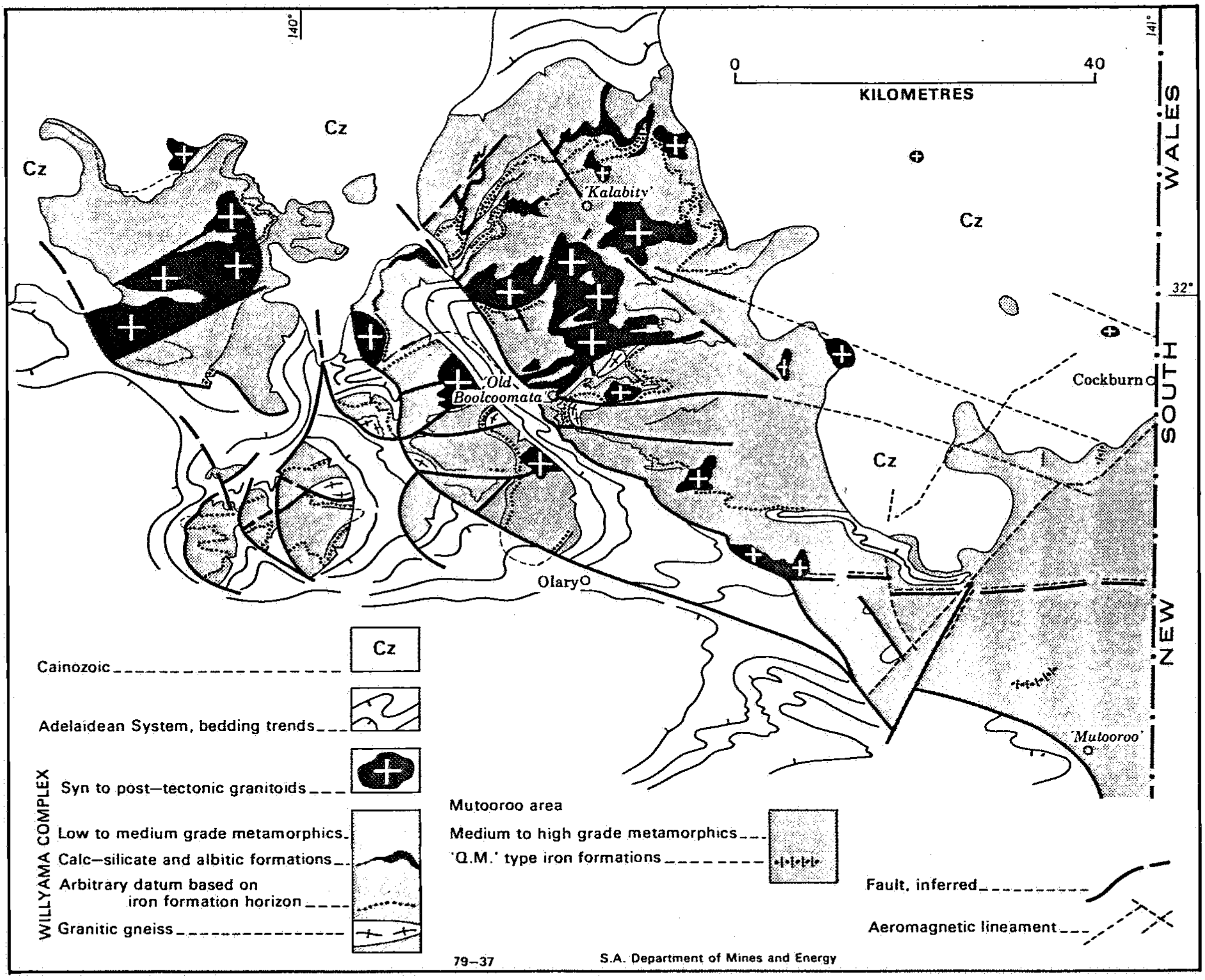

Fig. 5. Regional geology of the Olary subdomain. A complex system of curved, branching shears determines the relative distribution of Willyama Complex and Adelaidean rocks. As a consequence, individual fault-blocks or inliers of Willyama Complex are bounded to the west by shears and to the east by unconformably overlying Adelaidean rocks. This pattern is maintained throughout the Willyama Domain. S14238.

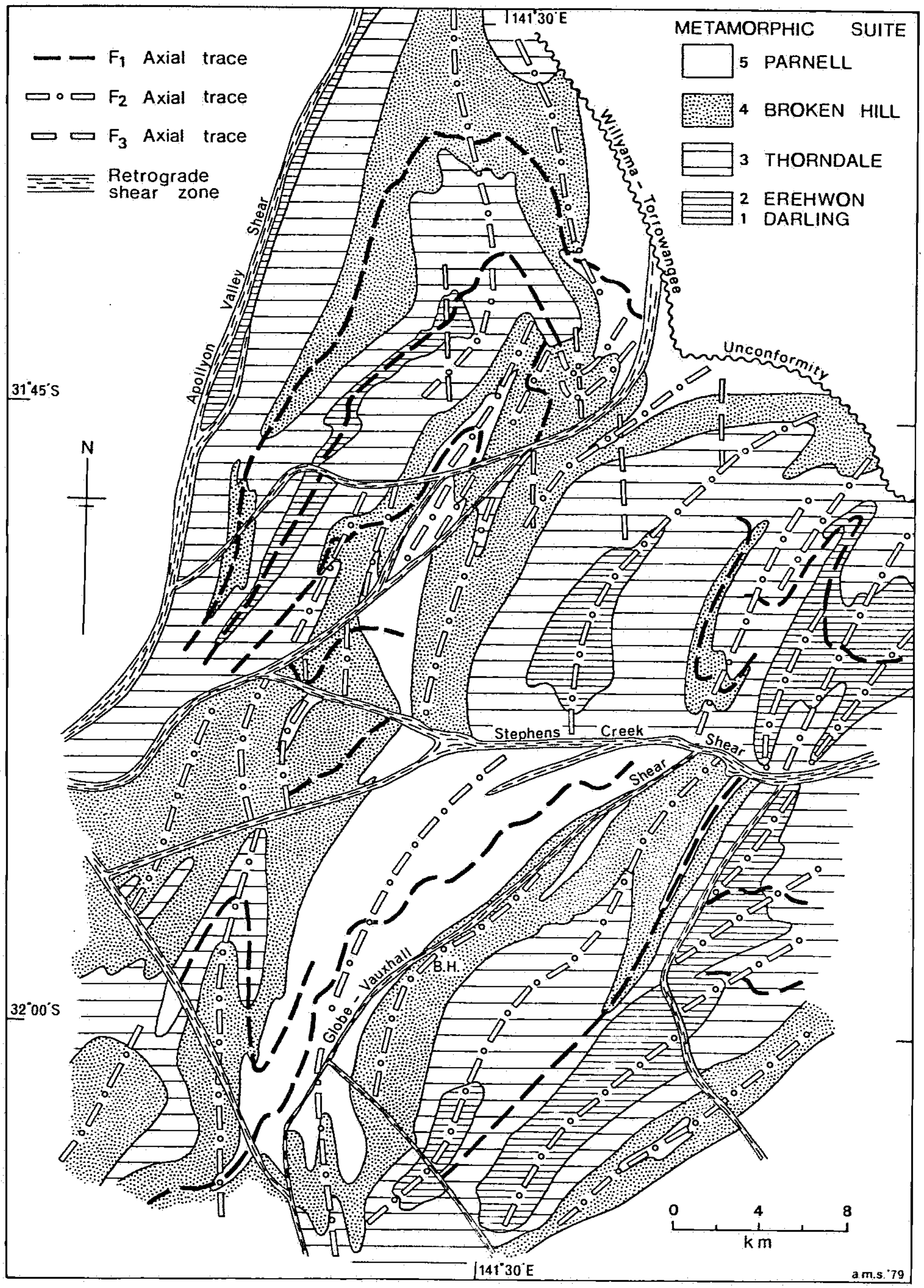

Fig. 6. General geology of the Broken Hill subdomain in the Willyama orogenic domain, showing inferred axial traces of superposed folds of three generations. Redrawn from map prepared by N. Archibald as part of the Broken Hill Lode Horizon research programme at the Department of Earth Sciences, Monash University. Unpublished geological information from the N.S.W. Geological Survey is included.

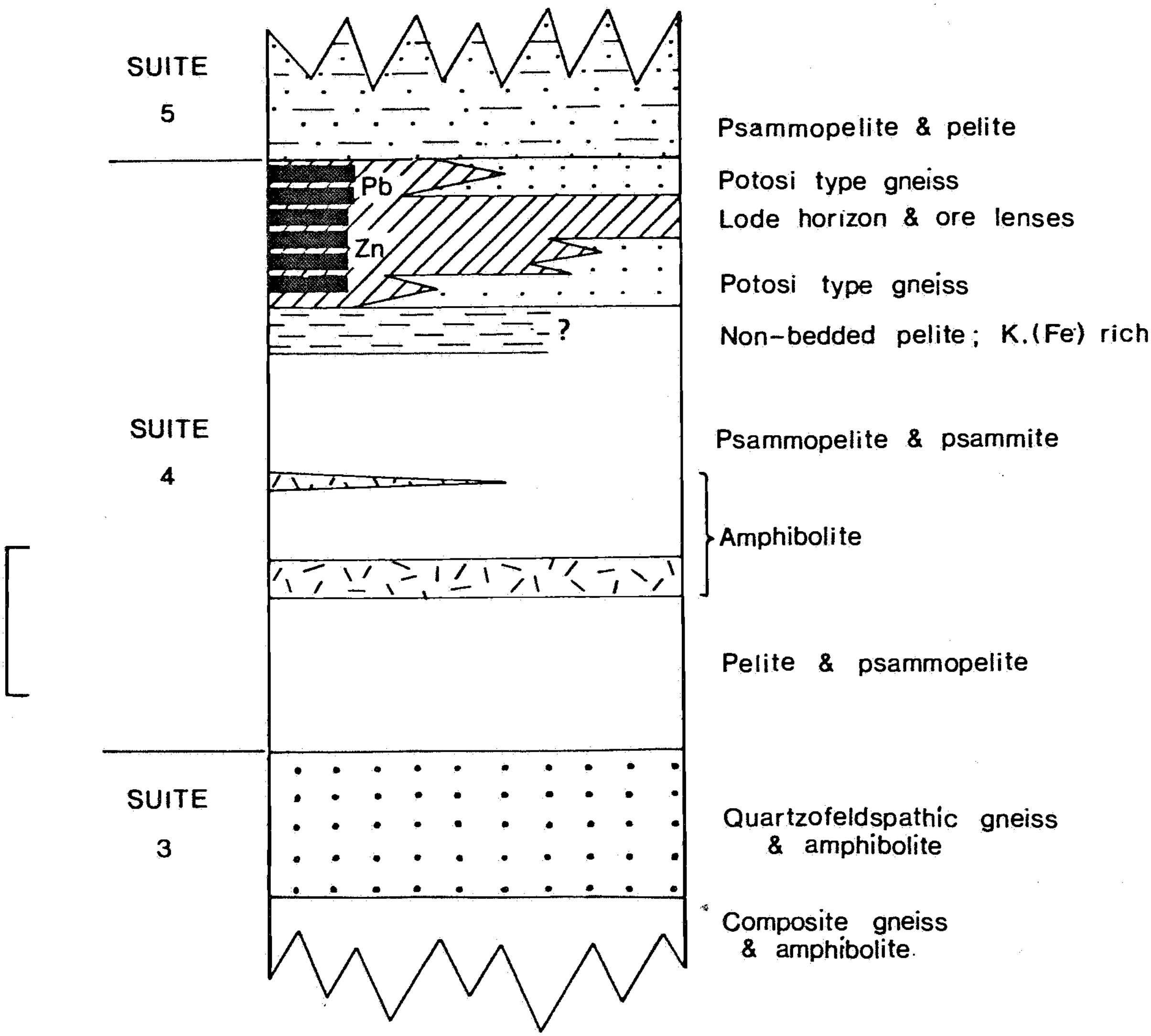

Fig. 7. Composite stratigraphic section of the Broken Hill mine sequence in the mines area. Bar scale is approximately 100 m. From W.P. Laing in unpublished report GS1979/062, Geological Survey of New South Wales.

S.A.D.M.E. S14240.

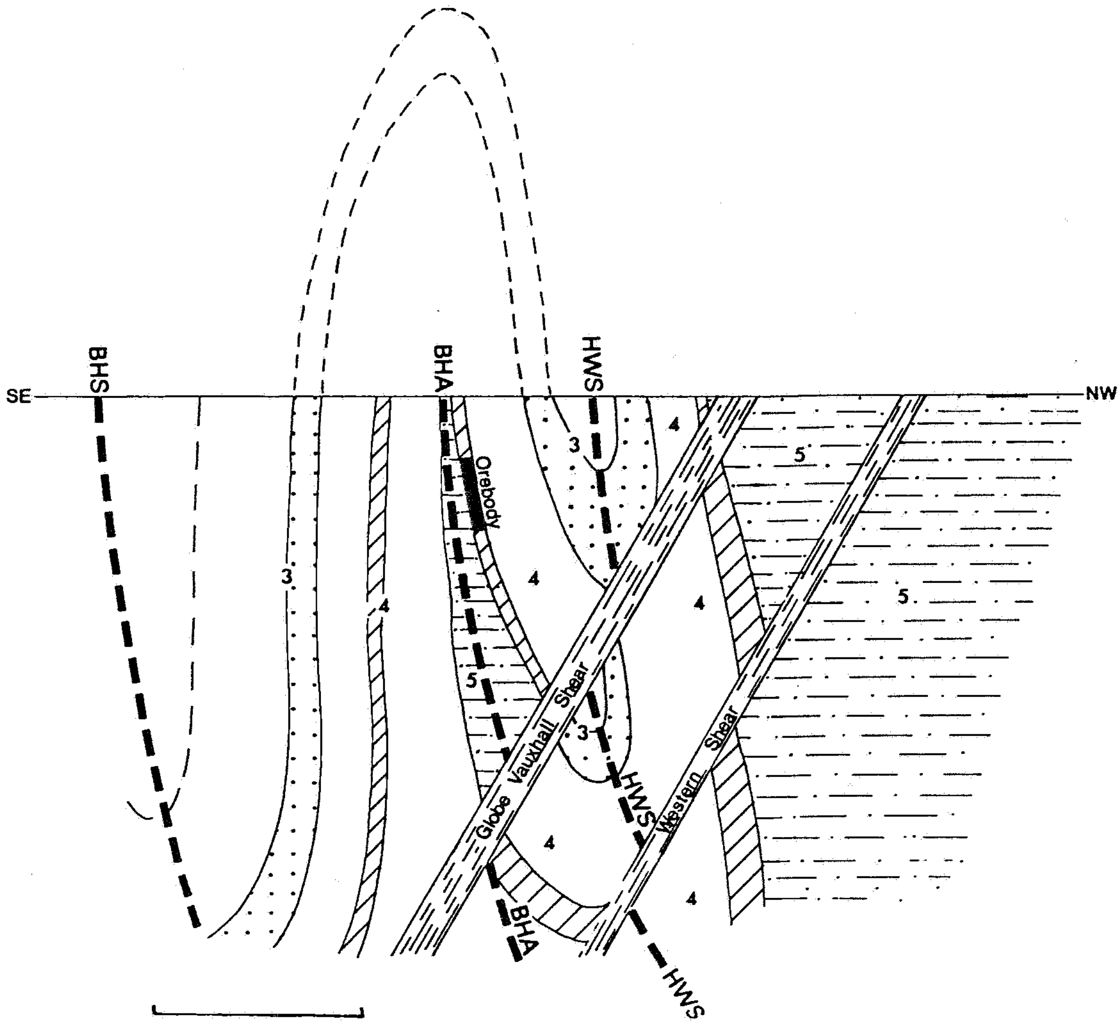

Fig. 8. Schematic geological cross section through the Broken Hill Mine area showing the approximate location of the main orebody. Numbers refer to the rock suites as outlined in Figure 7, and the principal fold structures - Broken Hill Synform, Broken Hill Antiform, and Hanging Wall Synform - are major F_2 features deforming an inverted (by F_1) mine sequence. The bar scale is approximately 1 km. From W.P. Laing in unpublished report GS1979/062, Geological Survey of New South Wales.

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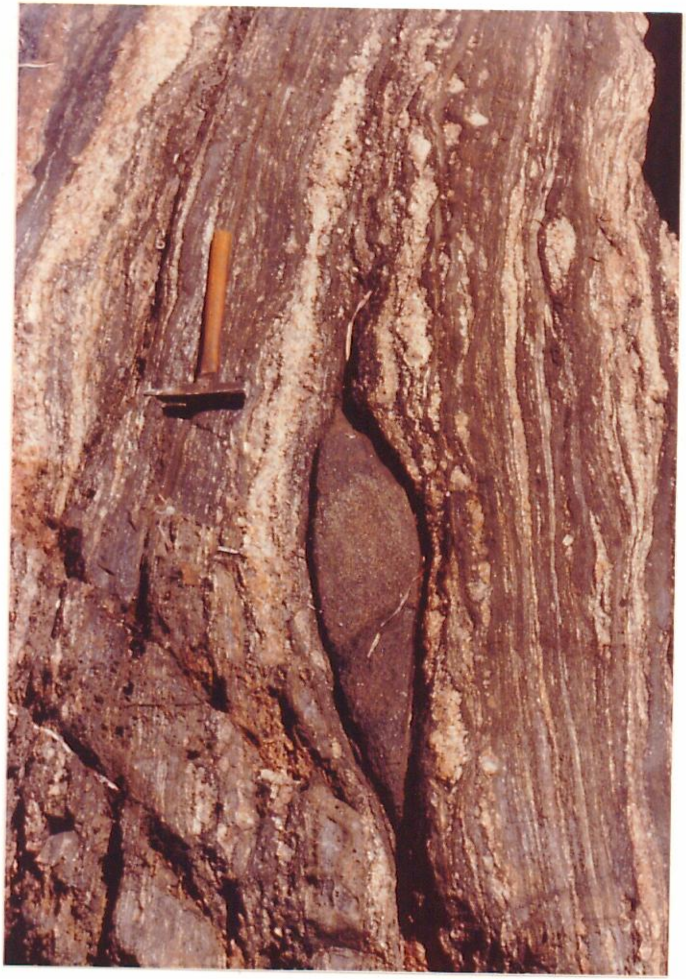

Fig. 9. Boudinaged amphibolite pod within strongly mylonitic gneisses north of Pt. Neill on eastern Eyre Peninsula. The amphibolite was formerly a sill within well banded granite gneisses transitional to the granulite facies. S.A.D.M.E. Neg. 30874.

Fig. 10. Open F_3 folds and crenulations (sub vertical axial planes) superimposed on overturned, tight to isoclinal F_2 folds within schists of the Hutchison Group. The strong schistosity is developed axial planar to the F_2 folds. F_4 crenulations (not visible here) are present in the same outcrop but their axes are oblique to F_2 and F_3 axes.

S.A.D.M.E. Neg. 30875.

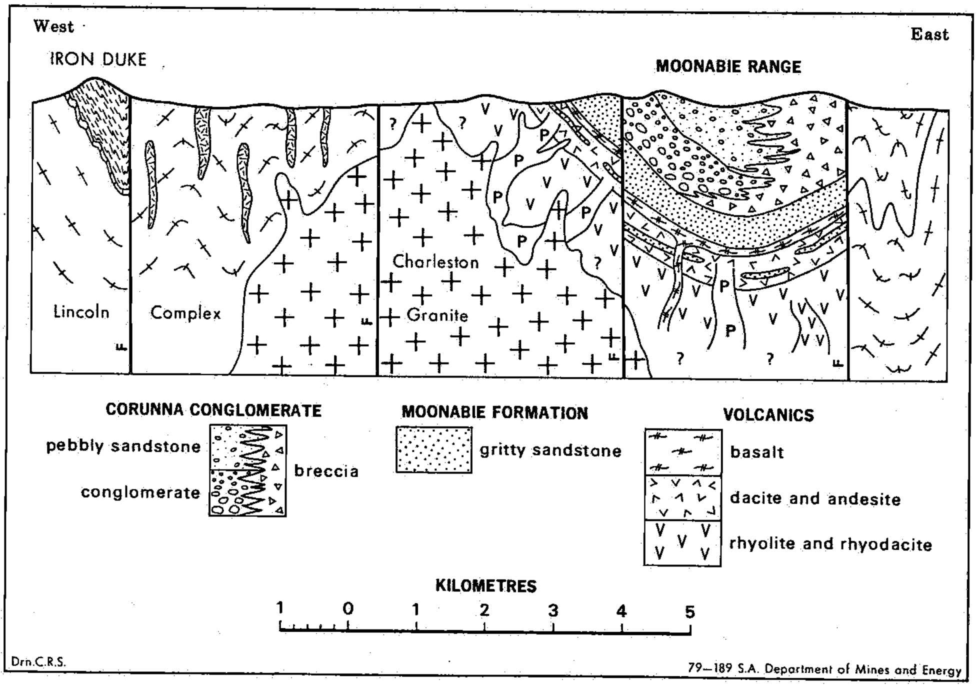

Fig. 11. Schematic geological cross section through the South Middleback (Iron Duke) and Moonabie Ranges 50 km southwest of Whyalla on Eyre Peninsula. Iron formations, schists and dolomites of the Hutchison Group outcrop in a tight F_3 synform at Iron Duke, and are underlain by a series of gneisses and amphibolites of the Lincoln Complex. The volcanics rest unconformably on these older rocks, are fed by massive feeders (P), and are interbedded with the Moonabie Formation. They are considered to be equivalents to the Gawler Range Volcanics. The overlying Corunna Conglomerate is represented by sandstones and conglomerates with a western provenance in the west but these interfinger to the east with a talus breccia that has an eastern provenance. Reproduced with permission of N. Lemon and the Broken Hill Proprietary Co. Ltd. S14242.