Bureau of Mineral Resources, Geology & Geophysics

RECORD

Record 1990/5

ASPECTS OF STRUCTURAL GEOLOGY OF THE GILES LAYERED BASIC/ULTRABASIC COMPLEX AND ASSOCIATED FELSIC GRANULITES, TOMKINSON RANGE, MUSGRAVE BLOCK, CENTRAL AUSTRALIA

T.C.Pharaoh

ASPECTS OF STRUCTURAL GEOLOGY OF THE GILES LAYERED BASIC/ULTRABASIC COMPLEX AND ASSOCIATED FELSIC GRANULITES, TOMKINSON RANGE, MUSGRAVE BLOCK, CENTRAL AUSTRALIA

T.C.Pharaoh

Deep Geology Research Group,
British Geological Survey.

In collaboration with the Division of Petrology and Geochemistry,
Bureau of Mineral Resources, Geology and Geophysics
Canberra, A.C.T. 2601

edited by: A.Y. Glikson, BMR

drafted by: D. Pillinger, BMR

Bureau of Mineral Resources, Geology and Geophysics

Record 1990/ 5

LIST OF CONTENTS

SUMMARY

This record summarises structural investigations of parts of the Giles layered basic/ultrabasic complex in central Australia conducted during 2 weeks of fieldwork in July, 1988, as well as the results of interpretation of aerial photographic and aeromagnetic data. While the nature of the relationships between the Giles Complex and the associated felsic granulites remains uncertain, occurrences of mafic and hybridised granulite contaminated with quartzofeldspathic blebs and veins recognised at a number of localities are interpreted as an assimilation/rheomorphic phenomenon along marginal zones of the layered intrusions. The actual contact between mafic and felsic granulites is mostly modified by mylonitic deformed zones, sometimes overprinted by brittle deformation. Photogeological interpretation suggests that the emplacement of the Ewarara body postdated the regional F_2 folding in the felsic granulites, whereas the emplacement of other layered bodies may have predated this deformation. Further (?F_3) folding and shearing in deformed zones of increasingly brittle aspect led to disaggregation of the basic/ultrabasic bodies. Major WNW-trending deformed zones such as the Mann Fault can clearly be recognised on the aeromagnetic map and a number of other lineaments with NW trend have also been identified. The observations and interpretations are discussed with reference to published structural and isotopic data for the Giles Complex, giving rise to a tentative tectonic synthesis followed by recommendations for further structural studies in connection with the ongoing project.

1. INTRODUCTION

The area investigated forms part of COOPER 1:250k Sheet (Daniels, 1971), whereas the Giles Complex extends into parts of the adjacent MANN 1:250k Sheet (Thomson et al., 1962) and SCOTT 1:250k (Daniels, 1972). Parts of the complex are also found in the area covered by the WOODROFFE 1:250k Sheet in the central Musgrave block. An extensive literature is available on the petrological features of the Giles Complex, particularly in South Australia, as a result of studies by workers from the University of Adelaide (Nesbitt and Kleeman, 1964; Nesbitt and Talbot, 1966; Nesbitt et al., 1970; Goode and Krieg, 1967; Goode and Moore, 1975; Goode, 1978. With the exception of the publications by Nesbitt et al. (1970) and Goode (1978) limited information is available on the structural history of the complex.

This report summarises structural observations made on the Giles Complex and associated country rocks in the vicinity of Wingelinna, Western Australia, during a 2 week period in July, 1988. The visit was made in collaboration with a BMR field party led by Dr. A.Y. Glikson. The field investigations were restricted to bodies of the complex in the Tomkinson Ranges of Western Australia adjacent to the border with South Australia, including the Hinckley Range, Michael Hills, Bell Rock range, Mount West and Latitude Hill. The field observations have been augmented by structural interpretations of the 1:20k aerial photographic coverage over most of the Tomkinson Range in South Australia and Western Australia compiled at 1:80k (Plate 1) and of aeromagnetic data for the PETERMANN RANGES 1:1M sheet (Plate 2). The field observations and interpretations from the air photo and aeromagnetic coverage are integrated with published isotopic data and structural descriptions in a tectonic synthesis.

2. FIELD OBSERVATIONS

2.1 Introduction: Field observations were located using 1:20k colour aerial photography flown in May 1987 and provided by the Australian Survey Office, Canberra. The locality reference numbers as used by the field party are of the form: X (Run No.);Y (Photo frame No.);Z (Locality). The scheme of nomenclature used for deformation phases throughout this report is comparable to that presented by Nesbitt et al. (1970) and is summarised in Table 1. The structural history of this region is mainly established in granulite facies felsic gneisses which contain composite gneissose banding recognised throughout the region and referred to here as S_{1F}. On the outcrop scale, it is locally possible to recognise an earlier fabric which is deformed by intrafolial F_{1F} folds and is transposed to S_{1F}. Further studies are required to determine whether this fabric, defined as S_0, is of sedimentary or tectonic origin. The regional structure is dominated by E-W trending F_{2F} folds of the S_{1F} banding, whose limbs have been modified by severe attenuation (D_{2F} deformed zones). The folds are themselves transected by several generations of ductile shear zones and strain discontinuities of deformation chronology is less easily applied to the layered bodies and associated mafic granulites of the Giles Complex because of the ductility contrast with the felsic granulites and because the Giles Complex bodies do not appear to share the early structural history of the latter. As a result, fold structures affecting the mafic rocks are given the terminology F_{1M} etc, which is not considered equivalent to the early folds which affected the felsic granulites.

2.2 Felsic Granulites: For the purposes of this report, the felsic granulites are divided into two series: [1] banded gneisses and [2] gneissose granitoids. The former have a more complex tectonic history, and were examined in the vicinity of Latitude Hill, Mount West and the North Hinckley Range. The latter were examined east of Bell Rocks and in the Champ de Mars valley. The classification of the granulites in the field uses criteria such as the presence of dark bluish-grey quartz and of feldspars with a waxy green or brown appearance in hand specimen.

2.3 Banded gneisses: This series displays a strong composite mineralogical banding (regional S_{1F}), often associated with a mineral lineation, which is the dominant fabric in the felsic granulites of the region. Quartzofeldspathic granulites are the most abundant and are probably derived from felsic protoliths with some mafic volcanic protoliths (Gray, 1977; 1978), while quartzitic (metasedimentary), intermediate and mafic (?lavas or intrusive sheets) enclaves have been mapped in South Australia (Thomson, 1962;1964). Early intrafolial folds, frequently similar and adpressed [Fig. 1a, 1c] have been recognised north of Mount West (31.32.8-10), close to the contact with layered gabbroic rocks, and are comparable to the early structures in felsic granulites in South Australia described by Nesbitt et al. (1970). It is possible that the intrafolial folds are deforming an earlier tectonic fabric, as recognised by Nesbitt et al. (op. cit.). The intrafolial folds are cut by thin, less deformed sheets of granitic composition coplanar with the axial surfaces of the intrafolial folds, giving rise to a strong composite gneissose banding (Fig. 1b). A later generation of thicker, less deformed granitic sheets discordant to the composite banding, recognised in the vicinity of Latitude Hill (34.128.6) and in the North Hinckley Range (25.142.10), is also metamorphosed in the granulite facies.

2.4 Gneissose granitoids: More homogeneous felsic granulites, frequently displaying relict igneous features such as xenoliths and porphyritic textures, are derived from felsic intrusive suites. Examples include the porphyritic granite east of the Bell Rocks Range (29.120.11, 30.202.17) and coarsely porphyritic (rapakivi) granite [Fig. 2a] in the Champ de Mars valley south of the Hinckley Range (28.134.1 and 28.138.11-12). Fabrics are of variable intensity in these infracrustal protoliths. None of these larger granitic bodies displays a clearly intrusive relationship with the layered bodies of the Giles Complex. As noted above, the banded series is crosscut by strongly discordant, less deformed granitic sheets, while bodies of the Giles Complex are also intruded by granite sheets, some several metres thick (see later section). These granitic sheets may be of more than one generation and further petrological, geochemical and isotopic studies are required to define their relationship to each other and to the larger granitic bodies. Some or all of these granitic suites may be cogenetic.

2.5 Emplacement of the Giles Complex: Most of the contacts between the layered complexes and the felsic granulites examined by the author are demonstrably tectonic in nature, and have been modified by ductile deformation with or without subsequent superimposed brittle deformation. It has thus not proved possible to demonstrate an intrusive relationship between the major layered bodies and their presumed host rock in Western Australia. The only exception to this situation is north of Mount West (32.50.10-15), where the boundary between the felsic and mafic granulites consists of a wide and diffuse zone of hybridisation (Fig. 2d, Fig. 3a,b). Internally the layered bodies are well preserved, however, including primary igneous features such as mineralogical grading and trough-cross bedding, as for example in the Hinckley Range. In places distinctive 'marginal facies' are developed in mafic granulites adjacent to, although usually tectonically separated from, felsic granulites. In the marginal zone of the layered intrusions north and east of Mount West (at 32.50.1-5 and 31.32.8), in the vicinity of Latitude Hill (34.127.5-6) and along the eastern margin of the Bell Rocks Range (29.170.11 and 30.202.17) the mafic granulites contain irregular patches and lenses of quartzofeldspathic material. These can become enlarged to form stringers and veinlets, e.g. at Mount West (32.50.1-5) and grade into areas exhibiting complex hybridisation textures and more continuous veins of intrusive felsic material. These distinctive textures are believed to represent the marginal facies of the layered bodies, the felsic material probably generated by rheomorphic melting of the felsic granulites by the mafic magma. Such contact effects die out rapidly into the interior of the mafic bodies, although recrystallisation of the igneous texture to mafic granulite can be recognised over a considerably greater distance. Intrusive sheets of granitic composition several metres thick intrude the mafic granulites at the western end of the Hinckley Range. Similar contaminated mafic granulite and quartz-plagioclase intergrowth and rheomorphic veining have been described at the western end of the Hinckley Range by Daniels (1974) and along the southern (upper) contact of the Mount Davies body, by Nesbitt and Talbot (1966) and Nesbitt et al. (1970).

2.6 Deformation of the Giles Complex: As presently exposed, most of the layered mafic-ultramafic bodies in the Tomkinson Range exhibit steeply dipping igneous layering. In places, e.g. on the eastern side of the Bell Rocks Range and at Mount Davies (Nesbitt and Talbot, 1966) magmatic way-up structures suggest overturning (Plate 1). The majority of the layered bodies have tectonically truncated contacts, as will be described below. Many of the bodies exhibit obscuration of igneous textures, granulation of the igneous mineralogy and recrystallisation to granulite facies. The localisation of these effects to the margins of the bodies reflects the concentration of strain at such boundaries and is believed to be a predominantly rheological effect. A metamorphic foliation (S_{1M}) is only rarely developed in the mafic granulites (although see Fig. 4a) because of the sparse occurrence of hydrosilicate minerals. All of these effects are attributed to deformation of the Giles Complex bodies subsequent to emplacement, and under subsolidus conditions, as has been invoked in the Wingelinna Hills body (Ballhaus and Glikson, in press).

2.7 Ductile Deformation Zones: Zones of ductile deformation frequently truncate the major layered bodies, and less frequently occur internally. The contact between the porphyritic granite (Pog) of Daniels (1971) and mafic granulites on the eastern margin of the Bell Rocks gabbro is typical of such zones, which have been examined at a number of localities. The contact (at 29.170.10 and 30.202.17) has the form of a NW trending, strongly asymmetric ductile shear zone with a steep dip to NE, and is marked by an intense mylonitic LS-tectonite fabric (Fig. 4b). The latter becomes gradually less penetrative upon transition into the granite so that original granulite facies mineralogy can be recognised a few tens of metres from the contact. By contrast, this new fabric is absent in mafic granulites a few metres from the contact. The mylonitic fabric is relatively fine-grained, does not appear to have suffered blastomylonitic annealing, and is associated with a strong, steeply plunging mineral lineation. Shear criteria such as tails on porphyroblast 'fish' (Choukroune et al., 1987) indicate displacement of the granite westward over the mafic granulites. Further into the granite, the ductile fabric is reworked by a zone of brittle deformation (29.170.11, Fig. 5d), while zones of pseudotachylite are extensively developed in the adjacent mafic granulite (29.170.8). The pseudotachylites presumably record late movements on the fault under brittle conditions. Comparable mylonite zones were examined west of the Mount West body (31.32.8-10), on the southern periphery of the Hinckley Range (25.126.12, Fig. 4c) and in the Latitude Hill area (34.127.5-12), the majority of which have a NW trend, steep dips and reflect thrusting of gneissose granite or banded felsic granulite over the adjacent mafic rocks (Plate 2).

The Hinckley Fault (Nesbitt et al., 1970) in Western Australia appears to split into a number of discrete, narrow mylonite zones which transect the mafic rocks of the Hinckley Range massif. The zone of deformation associated with this particular structure is not as wide as that outlined on the MANN sheet at the western border of South Australia. The movement on the main strand of the fault zone (as depicted on Plate 1) could not be determined, but spatially associated narrow mylonitic zones consistently show steep, south side-up displacements. Augen in the deformed rapikivi granite in the Champ de Mars valley at 28.134.1 also demonstrate steep, south side-up displacement. Although pseudotachylite veining is found throughout the region it is particularly abundant in the Hinckley Range, where it is possible to see early generations of pseudotachylite which have been sheared and lineated by subsequent movements.

Only two of the zones investigated, at Latitude Hills (34.128.5) and in the Champ de Mars valley (28.138.17), appear to have significant apparent transcurrent displacements as indicated by gently plunging lineations. Folding of mylonite fabrics has been observed at several localities. In most cases, e.g. east of Bell Rocks (30.202.19) and west of Mount West (32.50.15, Fig. 4d), this folding is internal to the mylonite zones and reflects rotation of early formed fabrics by subsequent movements. In the Champ de Mars valley (28.138.17) the whole mylonite zone (which must have had an original gentle dip to north) has been folded by post-kinematic deformation.

2.8 Ductile-Brittle Transition: Irregular vein networks of pseudotachylite are commonly developed, while spaced brittle fracturing and banding is occasionally found e.g. east of Bell Rocks (29.170.12) and at Latitude Hills (34.127.5-6), indicating that the history of movement in these zones is complex and continued into the brittle regime at upper crustal levels. Such veins have not been observed in the Blackstone, Cavenagh, Jameson and Murray Ranges however (A.Y.Glikson, pers. comm. 1989).

As described above, movements on the Hinckley Fault appear to have involved sub-vertical displacements. In the Hinckley Range, abundant pseudotachylite veining of a number of generations testifies to seismic movements of this zone under a brittle, upper crustal regime. The widespread distribution of pseudotachylite throughout the region investigated suggests that many of the early, ductile deformation zones described above may have been reactivated at this time. A study of pseudotachylites of the Giles Complex is in progress (Glikson et al., in press).

3. AIR PHOTO INTERPRETATION

3.1 Introduction: The scope of this study has been extended to areas not visited in the field, including parts of the Giles Complex in South Australia, through structural interpretation of aerial photographic coverage. The interpretation was compiled on a 1:80 k scale base map photographically enlarged from the 1:250 k maps by Thomson (1962) and Daniels (1971). Structural features identified on the 1:20 k aerial photographs were located on a survey at 1:80k.

3.2 Early deformation (D_{2F}): The present regional structure of the western part of the Musgrave Block is dominated by major scale east-west trending open to tight modified concentric folds (F_{2F}) on steeply dipping axial planes which deform the composite banding of the felsic granulites described earlier. The folds are clearly recognisable on 1:20 k scale air photographs and are indicated on the aerial photo interpretation presented (Plate 1). Many of the folds exhibit steep plunges and are thus of neutral vergence. They are frequently associated with steeply dipping, coplanar deformation zones which attenuate their limbs e.g. as seen southeast of the Ewarara body, north-east of Gosse Pile and at Mount Aloysius (Plate 1) and which reflect adpression of the folds during ductile deformation (D_{2F}). Most of these zones have an east-west trend but on Mount Aloysius the trend of the folds and limb attenuation zones is north-westerly.

The east-west trending deformation zones transect the felsic granulites and may continue into or define the margins of truncated layered intrusions of the Giles Complex. It is also possible to identify the West Kalka and Nmbunja Gneiss Zones described by Goode (1978) from the aerial photographs. The age and trend of these zones appears to be comparable to that of the D_{2F} attenuation zones described above, basically concordant with the D_{2F} fold structures. A major E-W trending synformal fold deforms igneous layering in the northern part of the Michael Hills intrusion (Plate 1) as recognised by Daniels (1974). Following the scheme of nomenclature outlined in the introduction, this is an F_{1M} fold. The similar trend to regional F_{2F} structures described above suggests that it was probably formed during the D_{2F} deformation.

3.3 Post D_{2F} intrusive bodies: The photo-interpretation presented (Plate 1) suggests that some of the intrusions were emplaced subsequent to the regional F_{2F} folding. The most spectacular example of this is the Ewarara body, which trends south-west and transects the structure of the east-trending compositional banding in the felsic granulites produced by F_{2F} folding. The Ewarara body shows no sign of any internal fabric apart from a gently dipping igneous layering (Goode and Krieg, 1967) and is undeformed. A body of granite lying in the core of the F_{2F} synform to the south-east of Ewarara mapped by Thomson (1965) and the body of anorthosite to the south-west of Teizi Soak also appear to transect the west-trending F_{2F} regional folding in the felsic granulites. These bodies exhibit a spaced, north-west trending fabric on the aerial photographs (Plate 1) which is believed to record D_3 or later deformation (see next section).

3.4 Younger folds (F_{2M}): The igneous layering of Michael Hills intrusion is deformed by a system of folds (?F_{2M}) whose axial traces have a NW-SE trend (Plate 1) as recognised by Nesbitt and Talbot (1966). To the north of Michael Hills, south of 'The Bald One' hill, this generation of folds appears to interfere with the E-W trending F_{1M} fold described above, producing a basinal interference fold (Plate 1). Another possible fold of this generation appears to refold the F_{2F} fold mapped south-west of Papakuna Soak by Thomson (1965). Folds of this generation do not produce a fabric recognisable on the aerial photographs, although the weakened axial zone of the fold at the eastern end of the Michael Hills has provided a locus for the emplacement of late north-west trending dykes (Plate 1). The north-west trending fabric observed in the post-F_{2F} bodies described above is probably a manifestation of this same deformation.

Later cross-folding has been invoked to explain the warping of the Kalka and Mount Davies bodies (Nesbitt et al. 1970). This generation of folds also seems to be associated with deformation zones, this time with a north-west trend and dextral displacement, although these tend to be discretely spaced and have a more brittle aspect than those of earlier deformations. Deformed zones with a north-west trend appear to truncate both the western and eastern ends of the Michael Hills body. According to Fig. 1 of Goode (1978), the fabric of the Hinckley Fault is cut and displaced up to 1km by NW-trending brittle spaced fractures with dextral displacement but this may simply represent reactivation of an earlier structural trend.

3.5 Ductile deformation zones: The early D_{2F} deformation zones described above are transected by straighter and younger mylonitic zones such as the Scarface Lineament and Hinckley Fault (Nesbitt et al., 1970) which are more strongly discordant to the igneous layering and compositional banding. The east-west trending fault which defines the southern side of the Champ de Mars valley, passing just north of 'The Bald One' hill, is another such example. The main strand of the Hinckley Fault can be followed as a photolinear WNW trend through the

Hinckley Range (Plate 1). The fault is presumed to pass through Numbunja Pass (Plate 1) so that the Numbunja Gneiss Zone probably contains later mylonitic fabrics in addition to the blastomylonitic textures recognised by Goode (1978). A north-west trending symmetrical shear zone passing along Teizi Creek deforms composite banding in the felsic granulites and the Teizi anorthosite body (Plate 1), which is sinistrally displaced a distance of about 6 km apparently on two discrete fractures. The deformation of the felsic granulites observed in these zones SE of Wandu Hill and east of Bell Rocks may be related to similar north-west trending shear zones, although these effects may also be due to even later brittle deformation (see later section). The combined effect of these shear zones of different ages has led to considerable disruption of the original intrusive bodies of the Giles Complex, giving rise to the present pattern of tectonically separated, lozenge-like bodies.

3.6 Younger brittle features The photo-interpretation (Plate 1) shows numerous north-east trending sub-vertical brittle fractures displacing the igneous layering on Mount Davies and at the eastern end of the Hinckley Range with a sinistral sense, while north-west trending fractures displace layering in the Michael Hills intrusion with a dextral sense. As noted above, some of these fractures are co-planar with the axial traces of north-west trending cross-folds. Sub-vertical fractures with a north-west trend offset the Hinckley Fault south of Kalka (eg see Fig.1 of Goode, 1978) with apparent dextral horizontal displacements approaching 1 km. These 2 fracture sets can be interpreted as a conjugate set produced by compression from the north. Two swarms of mafic dykes follow north-west and north-east trends, comparable to those of the brittle fractures. The north-west trending swarm (most abundant) has an en-echelon pattern and is compatible with P Max in a north-north-west orientation. The orthogonal north-east trending set well developed in the Michael Hills and the west Hinckley Ranges was emplaced with P Max orientated north-east. These swarms correspond to the late, unrecrystallised olivine dolerite dyke suites (Type C and D) described by Nesbitt et al. (1970).

4. INTERPRETATION OF AEROMAGNETIC DATA

The available aeromagnetic data, summarised on the PETERMANN RANGES 1:1M Sheet G52 (BMR, 1977), provide useful additional information on the patterns of tectonic lineaments affecting the central and western parts of the Musgrave Block. A partial interpretation of the data is presented in Plate 2. Geological information from this interpretation is from published sources, principally Thomson (1962), Daniels (1971) and 1:1M scale geological maps published by the geological surveys of South Australia and Western Australia.

The most obvious feature visible in the data are west-north-west trending magnetic lineaments associated with the Mann Fault and Davenport Shear, which juxtapose blocks of granulite and amphibolite facies gneiss (Forman, 1972; Collerson et al., 1972). The Hinckley Fault is associated with a less distinct linear feature on a comparable trend. The trace of the Woodroffe Thrust is less clearly visible in the data. The edge of the Musgrave block is clearly demarcated by the contrast between the low frequency anomalies associated with late Proterozoic-Palaeozoic sediments of the Officer Basin in the south, and the high frequency anomalies associated with the block itself. At the western end of the block, distinctive magnetic anomalies associated with the Tollu volcanics persist for some distance to the west, indicating that the the sediments of the Canning Basin are rather thin in this area.

A number of linears with a north-northwest and northwest trend cut across the western end of the Musgrave Block, and apparently transect the west-north-west trending structures. One lineament, which runs from Baggaley Hill to the Murray Range, passes just to the west of the Bell Rocks Range, appears to cause significant displacement of the margins of the Musgrave Block. Bending of the high frequency anomalies associated with the Giles Complex bodies suggests that the zone has a dextral displacement of about 30km. This lineament could be the cause of the reorientation of structures in the north-west trending zone from Mt West to Mt Aloysius and the reason for the major re-entrant in the anomaly pattern in the southern part of the block. It should however be noted that this lineament transects the lopolithic 'Blackstone Sheet' proposed by Nesbitt et al.(1970) without achieving much disruption of the putative structure.

It has been inferred that the Tollu Volcanics are occupying large cauldron-subsidence structures above a contiguous layered basic lopolith consisting of the Bell Rock, Blackstone and Cavanagh Range outcrops (Daniels, 1974), although the aeromagnetic data provide little supporting evidence for this hypothesis. More detailed examination of the digital geophysical databases by image analysis may shed more light on these problems.

5. REVIEW OF EARLIER STRUCTURAL WORK

5.1 Tectonic history of the felsic granulites: Nesbitt et al. (1970) recognised two generations of folding in the felsic granulites. F_1 folds predate emplacement of the gabbros and are intrafolial similar folds developed within the compositional banding. F_2 folds are more open folds, associated with only a weak axial-plane foliation and postdate emplacement of the major layered intrusive bodies. Refolding of F_1 by F_2 can be recognised (Nesbitt et al., op cit, Figs. 2G,H). Moore and Goode (1978) calculated that the felsic granulites formed at about 1000°C and 10-11kb, equivalent to about 30-35km depth.

5.2 Emplacement of the Giles Complex: Intrusive relationships have been described at the margin of the Ewarara intrusion (Goode and Krieg, 1967) and elsewhere (Nesbitt and Kleeman, 1964; Nesbitt et al., 1970). A low angle of discordance to the foliation in the felsic granulites has been deduced for many of the bodies which are therefore interpreted as a series of large sills (or lopoliths) emplaced into the felsic granulites while their banding was essentially sub-horizontal (Nesbitt et al., 1970; Goode, 1978). The southern (upper) contact of Mount Davies has a thin chill zone, displays rheomorphic effects and postdates the earliest recognisable folds in the felsic granulites (F_{1F}). This zone is now structurally overturned about an east-west axis (F_{2F}) as is also the Gosse Pile body.

By contrast, the Ewarara body cuts the composite banding in the felsic granulites at a high angle, and the gentle dip of its internal layering (Goode and Krieg, 1967; Goode and Moore, 1975) suggests that the body was emplaced subsequent to regional scale F_{2F} folding of the composite banding (S_{1F}) in the felsic granulites (Nesbitt et al., 1970). An early suite of mafic dykes (Type A dykes of Nesbitt et al. (1970)) exhibits granulite facies recrystallisation and predates deformation of the Giles Complex.

5.3 Pressure-temperature estimates: Nesbitt et al. (1970) and Goode and Moore (1975) described several features of the Kalka, Ewarara and Gosse Pile bodies which suggested crystallisation under high pressures. These included: [1] Subsolidus reaction of olivine and plagioclase to produce orthopyroxene and clinopyroxene and spinel symplectite in double corona textures in the Ewarara and Kalka intrusions, indicating pressures of 8-13 kb; [2] Spinel exsolution in pyroxenes of all 3 bodies; [3] High Al and Cr contents in both orthopyroxenes and clinopyroxenes; [4] Dominance of orthopyroxene (rather than olivine) as an early crystallising phase in the chill at Ewarara, suggesting pressures of 10-12 kb; [5] High $K_D^{Mg/Fe}$ for coexisting pyroxene pairs suggesting a liquidus temperature possibly as high as 1400°C and high pressure; [6] Thin chilled margins suggesting the felsic granulites were at high temperature when the layered bodies were emplaced. Goode and Moore [1975] concluded that Ewarara, Gosse Pile, Kalka and the Teizi anorthosite crystallised at pressures of 10-12kb (35-40km), close to the base of the crust. Mount Davies, Hinckley and the upper part of Kalka lack double reaction coronas and were thought to be transitional. The Blackstone sheet lacks high pressure features and grades up into volcanic rocks of the Bentley Supergroup. Nesbitt et al. (1970) claim that the sequence Michael Hills, Mount West and Bell Rocks represents a crustal section 11.5km thick (equivalent to 3-4kb). From a detailed study of coronas and symplectites in the Wingelinna Hills intrusion, Ballhaus and Berry (in press) suggest crystallisation pressures of about 6.5 kb, assuming isobaric cooling, equivalent to emplacement at about 20 km depth during high grade metamorphic conditions.

5.4 Early deformation zones: Curvilinear deformation zones such as the Nmbunja and West Kalka gneissic belts transect the Kalka intrusion and contain blastomylonitic fabrics according to Goode (1978). The mafic and ultramafic blastomylonitic gneisses developed soon after crystallisation of the intrusion under lower crustal conditions (Goode and Moore, 1975) and may be restricted to the high pressure bodies (Goode, 1978). The maximum principal elongation occurred parallel to the lineation, apparently while the foliation had an almost horizontal attitude (Goode, op cit.), locally giving up to 400% elongation of plagioclase inclusions within orthopyroxene. The effect of these high temperature shear zones was to disrupt the layered bodies soon after their emplacement (e.g. Fig. 1 of Goode, 1978).

5.5 Post-emplacement folding: The regional structure of the western part of the Musgrave Block is dominated by major scale east-west trending modified concentric folds on steeply dipping axial planes which deform the composite banding of the felsic granulites described earlier (regional F_{2F}). According to Nesbitt et al. (1970) and Goode (1978) these folds postdate emplacement of most of the Giles Complex bodies. Many of the Giles Complex bodies display megascopic folding of the igneous layering e.g. in the eastern part of the Michael Hills (Nesbitt and Taylor, 1966), Mount West and Latitude Hills intrusions (Plate 1), which Nesbitt et al. (1970) have attributed to a third phase of folding.

5.6 Significance of the Hinckley Fault: The Musgrave Block provides a deep section through the crust as a consequence of differential uplift on seismic faults which is considered to have taken place during the Petermann Ranges Orogeny at about 600 Ma (Forman, 1972; Collerson et al., 1972). According to Nesbitt et al. (1970) and subsequent interpretations (e.g. Goode, 1978) all of the layered bodies exhibiting high-pressure features and assemblages lie on the northern side of the Hinckley Fault. These authors therefore infer uplift of the northerly block during the Petermann Ranges Orogeny, while the Hinckley Fault is perceived as a significant structure on the regional scale.

5.7 Upper crustal development during emplacement of the Giles Complex: Nesbitt et al. (1970) consider that the Skirmish Hill Volcanics (equated with the Tollu Group of Bentley Supergroup) are genetically related to the Giles Complex, the former containing evolved lavas fed from open-system magma chambers of the latter at deeper crustal levels. Nesbitt and Talbot (1966) have suggested that the Bell Rock, Blackstone and Cavenagh bodies are part of one large sheet, which forms a synform with the Skirmish Hill volcanics in its core. The age of this folding is presumably the same as the regional scale folding (F_{2F}) found at lower crustal levels. On the other hand, Daniels (1971;1974) has suggested that the Tollu volcanics of the Bentley Supergroup at Mummawarrawarra Hill are older than, and are intruded and contact-metamorphosed by, small high-level dolerite dykes which he correlated with the Giles Complex.

6. REVIEW OF ISOTOPIC EVIDENCE

The felsic granulites of the Musgrave-Mann metamorphic assemblage have yielded Rb-Sr isochron ages as old as 1614±168 Ma (Webb, 1985). Gray and Oversby (1972) found that U loss in granulites at Mount Aloysius at about 1200 Ma was compatible with granulite facies metamorphism at that time. Gray (1978) interpreted the Rb-Sr isotopic data in the north-western part of the block in terms of granulite facies metamorphism at about 1200 Ma, ages in the order of 1600-1300 dating the formation of the protolith. According to Webb (1985) the Rb-Sr isotopic data indicate thermal events at c. 1.7-1.6 Ga, interpreted as a period of high grade metamorphism of supracrustal protoliths with short crustal residence histories, and at 1.12 Ga, associated with the formation of granites.

Other gneiss complexes within the Musgrave Block have also yielded 1600 Ma ages, although usually with somewhat larger errors. Webb (1985) reports an Rb-Sr isochron of 1693±322 for the Wataru Gneiss in the western part of the Musgrave Block, while gneisses in the Kenmore Park region in the east of the block yielded ages of 1620-1350 Ma (Compston and Arriens, 1968).

Only indirect radiometric evidence is currently available for the age of emplacement of the Giles Complex. Nesbitt et al. (1970) reported model Rb-Sr ages of 1100 and 970 Ma for granitic veins intruding the mafic granulites in South Australia. The Tollu Volcanics, which are inferred to have close genetic relationship (e.g. a similar Sr_i) to the Giles Complex by Nesbitt et al. (1970), have yielded an (uncorrected) Rb-Sr isochron age of 1060±140 Ma (Compston and Nesbitt, 1967). Fletcher and Myers (pers. comm. to A.Y.Glikson, 1988) have obtained a Sm-Nd mineral isochron age of 1291±21 Ma and an Rb-Sr biotite-whole rock pair of 1295±45 Ma for the least deformed gabbro in the Fraser Complex, which lies to the SW of the Giles Complex in Western Australia. This event has been interpreted as the age of granulite facies metamorphism of the tectonically interleaved plutonic and supracrustal rocks. If the analogy suggested by Glikson et al. (1988) is correct, the Giles Complex could be of a similar age. Detailed Sr and Nd isotopic studies of the Kalka intrusion by Gray and Goode (1981) indicate massive contamination of the basic magma by felsic country rock.

The Kulgeran granite suite, representing a widespread felsic magmatic event, was emplaced into the Musgrave-Mann metamorphics at 1140-1100 Ma (Wilson et al., 1960; Thomson, 1977). The Ernabella adamellite which is deformed by the Woodroffe Thrust has yielded an Rb-Sr age of 1099± 27 Ma (Arriens and Lambert, 1969).

Pseudotachylites from the Woodroffe Thrust Zone exhibit a range of ages (1550-1780 Ma), with large errors, which are not significantly different from the ages for the granulite facies rocks (Webb, 1985). Although other interpretations are possible, Webb (1985) suggests from the @ 1050 Ma K-Ar ages for mylonitic rocks that it is most likely that the pseudotachylite-forming event occurred later than 1000 Ma so that the isotopic systems are retaining the 'original' age of the granulites. K-Ar hornblende and biotite ages in the range 1000-500 Ma represent cooling and/or resetting by movements on the Woodroffe Thrust.

7. TECTONIC SYNTHESIS

The structural history of the Giles Complex in the Tomkinson Ranges is summarised in Table 1. Formation of the Musgrave-Mann metamorphic assemblage by granulite facies metamorphism of supracrustal protoliths occurred at some time between 1.7 and 1.1 Ga. The assemblage exhibits a strong composite banding, as well as probable earlier transposed fabric(s). These banded gneisses are intruded by less deformed (late- or post-tectonic) plutonic suites.

The age of emplacement of large volumes of mantle-derived melt which gave rise to the layered mafic-ultramafic bodies of the Giles Complex is not well constrained either by field criteria or radiometric data. The intrusive relationship is most clearly demonstrated at Ewarara, where emplacement appears to postdate regional F_{2F} folding. The same appears to be true for the Mt. Davies body which appears to transect an F_{2F} fold on its southern side, although Nesbitt et al. (1970) have claimed that the body was emplaced prior to this fold phase. The northern margin of the Michael Hills is affected by an east-west trending synform which suggests that emplacement of this body may predate regional D_2.

Emplacement and crystallisation of some large, early bodies e.g. Kalka and Mount Davies was followed almost immediately by the development of ductile extensional zones. The Ewarara body contains evidence of high pressure assemblages (Goode and Moore, 1975) which indicates that granulite facies conditions continued at least until the end of D_2. Emplacement of a second generation of dykes recrystallised in the granulite facies and picritic plugs also probably occurred at about this time.

A critical question is whether the present steep attitude of the mylonite zones observed above is a primary feature, or whether this is the result of post-movement rotation. In South Australia, published field observations and the author's photointerpretation allow at least three generations of ductile deformation zones to be recognised.

Uplift of the bodies with high pressure assemblages e.g. Ewarara, Kalka and Gosses Pile, most of which lie on the north side of the Hinckley Fault, is believed to have taken place during the Petermann Ranges Orogeny (Forman, 1972) when granulite facies gneisses were thrust northward over lower grade gneisses on the Woodroffe Thrust. South of the latter, a number of west-north-west-trending mylonitic fault zones such as the Davenport Shear, Mann Fault (Collerson et al., 1972) and Hinckley Fault (Nesbitt et al., 1970) are likely to have been (re-)activated, chopping the Musgrave Block into a number of slices with differential uplift of the metamorphic rocks. The Hinckley Fault represents a third generation of ductile deformation within the area investigated. The presence of abundant pseudotachylite associated with these late faults suggests that differential uplift occurred under seismic conditions.

The mylonite zones observed in this study appear to belong to the second and third generations recognised above (summarised in Table 1). Blastomylonitic fabrics, comparable to those described from the Nmbunja and West Kalka Gneissic Zones, have not been recognised by the author. It is probable that the original attitude of most of the deformation zones was steeply dipping or sub-vertical, close to their present attitude. The anomalous north-west trend of the mylonite zones in the area from Mount West to Mount Aloysius is worthy of comment. This is in marked contrast to the east-west trend of the D_2 shortening zones and late structures such as the Hinckley Fault. It is believed that this reflects reorientation of this block by later, more brittle faulting. Late swarms of unrecrystallised olivine dolerite dyke suites (Type C and D of Nesbitt et al.,1970) apparently postdate the Hinckley Fault.

8. RECOMMENDATIONS FOR FURTHER WORK

8.1 Isotopic studies: The continuing absence of high precision isotopic ages for the crystallisation of the Giles Complex and for critical events in the origin and structural history of the felsic granulites are major problems. These should be addressed by U-Pb and/or Sm-Nd isotopic studies as soon as possible.

8.2 Petrological, geochemical and isotopic studies of minor intrusions: Minor intrusive bodies, both mafic (e.g. dykes) and felsic (e.g. granitic sheets) appear to have been emplaced over a longer period than the major bodies of the Giles Complex and provide useful time markers in the evolution of the complex and its felsic granulite host. It is suggested that more detailed studies are made of minor intrusions whose structural age is well known.

8.3 Structural studies of intrusive discordances: Detailed studies of the structural relationships at Ewarara and on the south side of Mount Davies are required to confirm the published descriptions. Studies of the possible fold interference patterns in the north of the Michael Hills and near Papakuna Soak should be a high priority.

8.4 Structural studies of mylonite zones: Detailed studies are required of the fabrics in the various generations of deformed zones, in particular the supposed high-T blastomylonitic fabrics described by Goode (1978) and the mylonitic fabrics associated with the Hinckley Fault.

8.5 Geothermometry and geobarometry: Such studies are required throughout the complex, but particularly to investigate the P-T history of the igneous bodies on the southern side of the Hinckley Fault, to examine whether these bodies really were emplaced under lower P than the bodies on the northern side of the fault.

8.6 Geophysical data acquisition and analysis: Mapping of the Giles Complex bodies and the deformation zones which separate them would be facilitated by the acquisition and analysis of higher precision aeromagnetic data than those which are currently available.

9. Acknowledgements

I gratefully acknowledge the invitation by A.Y.Glikson to join the BMR Giles field party and the assistance of members of that party during the fieldwork. The work was completed in Canberra in the course of a scientific exchange between the British Geological Survey (BGS) and the Bureau of Mineral Resources, Geology and Geophysics.

10. REFERENCES

Arriens, P.A. and Lambert, I.B. 1969. On the age and strontium isotopic geochemistry of granulite facies rocks from the Fraser Range, Western Australia, and the Musgrave Ranges, Central Australia. geol. Soc. Aust. Sp. Publ. , 2, 377-388.

Ballhaus, C. and Glikson, A.Y. 1989. Petrology of the North Hinckley Intrusion, Giles Complex, Western Australia. J. Petrol. [in press].

Choukroune, P., Gapais, D. and Merle, O. 1987. Shear criteria and structural symmetry. J. Structural geology, 9, 525-530.

Collerson, K.D., Oliver, R.L. and Rutland, R.W.R. 1972. An example of structural and metamorphic relationships in the Musgrave Orogenic Belt, Central Australia. J. geol. Soc. Aust. , 18, 379-393.

Compston, W. and Nesbitt, R.W. 1967. Isotopic age of the Tollu volcanics, W.A. J. geol. Soc. Aust., 14, 235-238.

Daniels, J. 1971. Cooper, W.A. 1:250,000 Geological Sheet, Explan. Notes. geol. Surv. W. Aust.

Daniels, J. 1972. Scott, W.A. 1:250,000 Geological Sheet, Explan. Notes. geol. Surv. W. Aust.

Daniels, J.L. 1974. The Geology of the Blackstone Region, Western Australia. Geological Survey of Western Australia Bulletin, 123.

Forman, D.J. 1972. Petermann Ranges, N.T. 1:250,000 Geological Sheet, Explan. Notes. Bur. Miner. Resour. Geol. Geophys. Aust.

Glikson, A.Y., Ballhaus, C., Goleby, B.R., Stewart, A.J. and Warren, R.G. 1988. Major thrust faults and the vertical zonation of the middle to upper Proterozoic crust in central Australia. NATO ASI Meeting, Ontario, Canada [in press].

Goode, A.D.T. 1978. High Temperature, High Strain Rate Deformation in the Lower Crustal Kalka Intrusion, Central Australia. Contrib. Mineral. Petrol., 66, 137-148.

Goode, A.D.T. and Krieg, G.W., 1967. The geology of the Ewarara intrusion, Giles Complex, central Australia. J. geol. Soc. Aust., 14, 185-194.

Goode, A.D.T. and Moore, A.C. 1975. High pressure crystallization of the Ewarara, Kalka and Gosse Pile Intrusions, Giles Complex, central Australia. Contrib. Mineral. Petrol., 51, 77-97.

Gray, C.M. 1977. The geochemistry of central Australian granulites in relation to the chemical and isotopic effects of granulite facies metamorphism. Contrib. Mineral. Petrol., 65, 79-89.

Gray, C.M. 1978. Geochronology of granulite-facies gneisses in the western Musgrave block, central Australia. J. geol. Soc. Aust., 25, 403-414.

Gray, C.M. and Compston, W. 1978. A Rb-Sr chronology of the metamorphism and prehistory of central Australian granulites. Geochim. Cosmochim. Acta., 42, 1735-1748.

Gray, C.M. and Goode, A.D.T. 1981. Strontium isotopic resolution of magma dynamics in a layered intrusion. Nature, 294, 155-158.

Gray, C.M. and Oversby, V.M. 1972. The behaviour of lead isotopes during granulite facies metamorphism. Geochim. cosmochim. Acta, 36, 939-952.

Moore, A.C. and Goode, A.D.T. 1978. Petrography and origin of granulite-facies rocks in the western Musgrave Block, central Australia. J. Geol. Soc. Aust., 25, 341-358.

Nesbitt, R.W., Goode, A.D.T., Moore, A.C. and Hopwood, T.P. 1970. The Giles Complex, Central Australia: a stratified sequence of mafic and ultramafic intrusions. Spec. Pub. geol. Soc. S. Afr., 1, 547-564.

Nesbitt, R.W. and Kleeman, A.W. 1964. Layered intrusions of the Giles Complex, Central Australia. Nature, 203, 391-393.

Nesbitt, R.W and Talbot, J.L. 1966. The Layered Basic and Ultrabasic Intrusives of the Giles Complex, Central Australia. Contr. Mineral. and Petrol., 13, 1-11.

Thomson, B.P., Mirams, R.C. and Johnson, J. 1962. Mann, S.A. 1:250,000 Geological Sheet, Explan. Notes. geol. Surv. South. Aust.

Thomson, B.P. 1965. Geological atlas of South Australia, Sheet Davies, 1:63,360 series.

Thomson, B.P. 1977. The Musgrave Block, S.A., N.T., W.A. Chapter 17. In: C.L. Knight (Ed), Economic Geology of Australia and Papua New Guinea; Aus. Inst. Min. Metall. Mono. 5, 451-460.

Thomson, B.P. 1980. Geological Map of South Australia, 1:1 M scale. S. Aust. Dept. Mines and Energy.

Webb, A.W. 1985. Geochronology of the Musgrave Block. Min. Resour. Rev. S. Aust. Dept. Mines and Energy, 23-37.

Wilson, A.F., Compston, W., Jeffery, P.M. and Riley, G.H. 1960. Radiometric ages from the Precambrian rocks in Australia. J. geol. Soc. Aust., 6, 179-195.

Table 1 - Tectonic history of Giles Complex in the Tomkinson Ranges

REGIONAL EVENTS	THIS REPORT	PREVIOUS USAGE
LATE BRITTLE DEFORMATION	Olivine dolerite dykes Conjugate NW & NE fracture sets	Type C & D dykes
SEISMIC UPLIFT	Pseudotachylite veining Movements on Hinckley and Mann Faults etc.	Hinckley Fault
D_3	NW trending folds (F_{2M}) in Michael Hills and elsewhere	Warping of Mt Davies body and Michael Hills by cross folds (F_3)
	?Late granite bodies (with NW trending fabric)	
D_2	Emplacement of Ewarara body F_{2F} limb attenuation zones F_{2F} folds and folding in north Michael Hills F_{1M}	Type B dykes & plugs F_2
?EXTENSION	Flat-lying blastomylonitic gneiss belts	Nmbunja & Kalka Gneissic Zones
GRANULITE FACIES METAMORPHISM	Early recrystallised dykes ?Emplacement of early bodies e.g. Michael Hills?	Type A dykes Emplacement/crystallisation of Giles Complex
	?Late/post-tectonic granites	
D_1	Composite banding (S_{1F}) in banded series Intrafolial folds (F_{1F})	Composite banding in Musgrave-Mann metms. Intrafolial folds(F_1)
	?Early gneissose fabric	?Early fabric
?Early Proterozoic	Protolith of banded series	Felsic volcanic and sedimentary protoliths

Table 2 - Mylonite zone attributes

RELATIVE AGE	EARLY D_2	Late D_3	LATER Post D_3-D_4
EXAMPLES	Nmbunja, Kalka Gneissic Zones	Gosse Pile Mt Aloysius	Hinckley Fault Champ de Mars and Mann Fault
FABRICS	Blastomylonites	Mylonites	Mylonites and pseudo-tachylite
DISCORDANCE TO LAYERING	Low angle	Variable	Variable
GEOMETRY	Curvilinear-deformed by F_3	Coplanar with F_3	Straight ?Cut F_3
ORIGINAL ATTITUDE	? Sub-horizontal	Steep	Steep
DISPLACEMENT	? Extensional	Compressional	Compressional

ENCLOSURES

A. PLATES

Plate 1: Structural interpretation of 1:20k scale air photographic coverage for the Tomkinson Ranges. Outcrop pattern, geological boundaries, structural and younging observations compiled from Thomson et al. (1962), Thomson (1965), Daniels (1971) and Goode (1978), in addition to the author's own observations. Trend of shear zones and folds beneath the Cenozoic-Recent cover is speculative. Compare sections A-B with equivalent profile of Thomson [1964].

Plate 2: Partial structural interpretative of 1:1M Aeromagnetic sheet PETERMANN RANGES [BMR, 1977]. Geological data from same source as Plate 1 plus 1:1M scale geological map by the Geological Surveys of South Australia and Western Australia.

B. FIGURE CAPTIONS

Fig. 1. Fabrics in felsic granulites at the northern end of Mt. West.

a. 31.32.8 Folds [F_{2F}] of composite fabric of gneissose banding [S_{1F}] and granitic veins.

b. 31.32.8 Composite banded gneiss with granitic veins discordant at low angle to early fabric.

c. 31.32.8 Complexly deformed gneissose foliation and veins.

d. 31.32.8 Anatectic textures in migmatitic gneiss.

Fig. 2. Contacts between mafic and felsic granulites.

a. 28.138.11 West end of Champ de Mars. Porphyritic 'rapakivi' granite with tectonic fabric.

b. 32.50.5 Mafic dyke (contacts parallel to hammer handle on right hand side) with streaky (granulite facies?) recrystallisation in the interior.

c. 34.127.5 North side of Latitude Hills intrusion. Blebs of quartz and feldspar within mafic granulite adjacent to the contact with felsic granulites.

d. 32.50.10 Western contact of Mt. West intrusion. As c.

Fig. 3. Contacts between mafic and felsic granulites (cont.)

a. 32.50.10 Western contact of Mt. West intrusion. Quartzo-feldspathic blebs larger in size and coalescing into veinlets.

b. 32.50.10 As a.

c. 25.126.12 Irregular vein-like networks of felsic material intruding mafic granulite at the southwestern periphery of Hinckley Range.

d. 25.128.1 The western end of Hinckley Range.

Fig. 4. Contacts between mafic and felsic granulites (cont.)

a. 25.126.11 Southwestern periphery of Hinckley Range. F_{2M} fold deforming S_{1M} foliation in mafic granulite.

b. 30.202.17 East of Bell Rocks Range. Mylonite developed from felsic granulite.

c. 25.126.12 South-western periphery of Hinckley Ranges. Mylonite developed from felsic granulite.

d. 32.50.15 Western contact of Mt West. Folded lineated mylonite fabric close to mafic/felsic contact.

Fig. 5. Pseudotachylite veins and brittle structures.

a. 30.202.15 Pseudotachylite vein cutting weakly banded felsic granulite.

b. 29.184.4 Leucogabbro near 'The Bald One' Hill. Strong fabric, with ductile shears and pseudotachylyte veins.

c. 27.76.40 North of Mt. Hinckley summit. Pseudotachylite vein network.

d. 29.170.11 East of Bell Rocks Range. Late brittle shears reworking earlier ductile deformation zone.

Figure 1

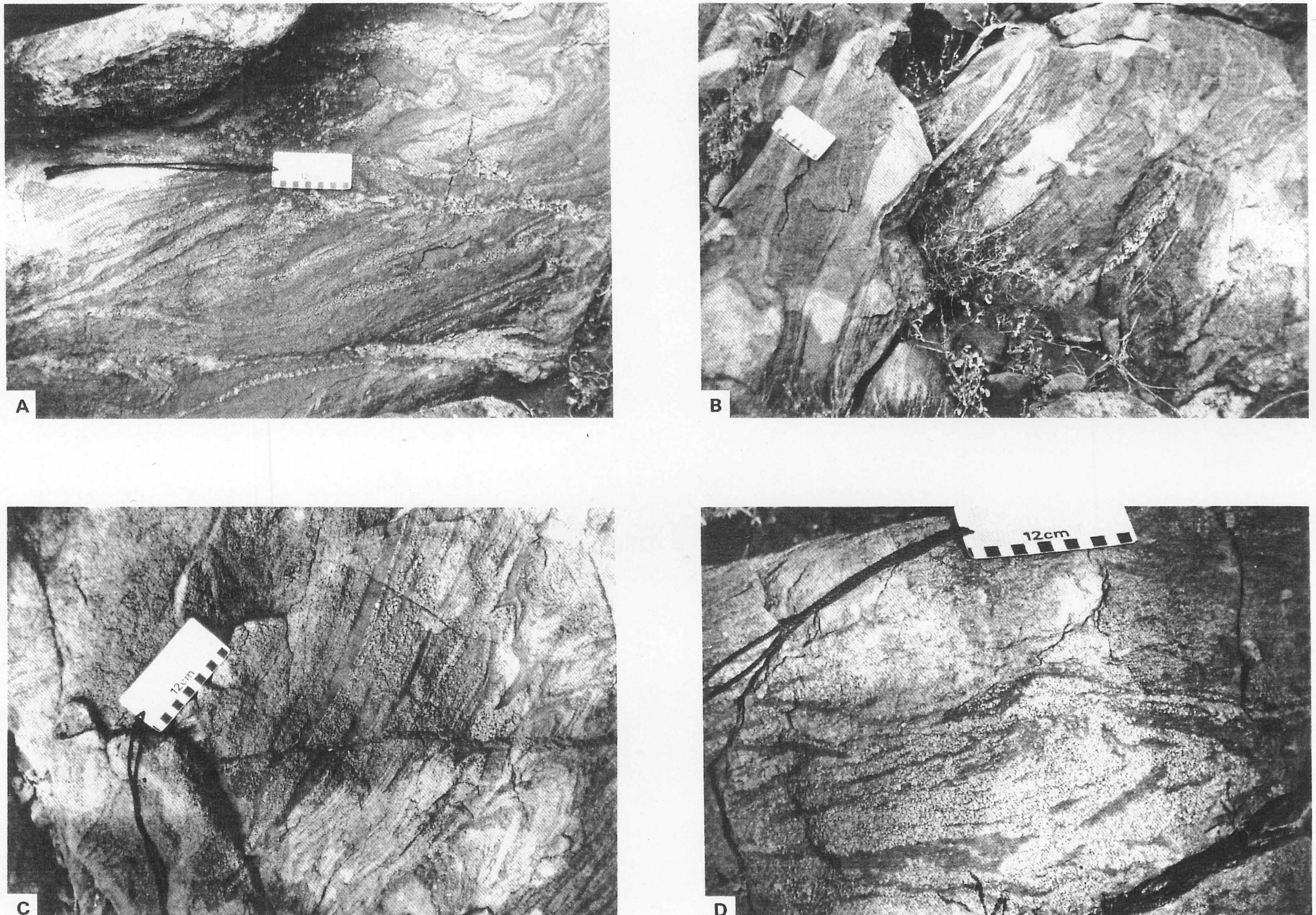


Figure 2

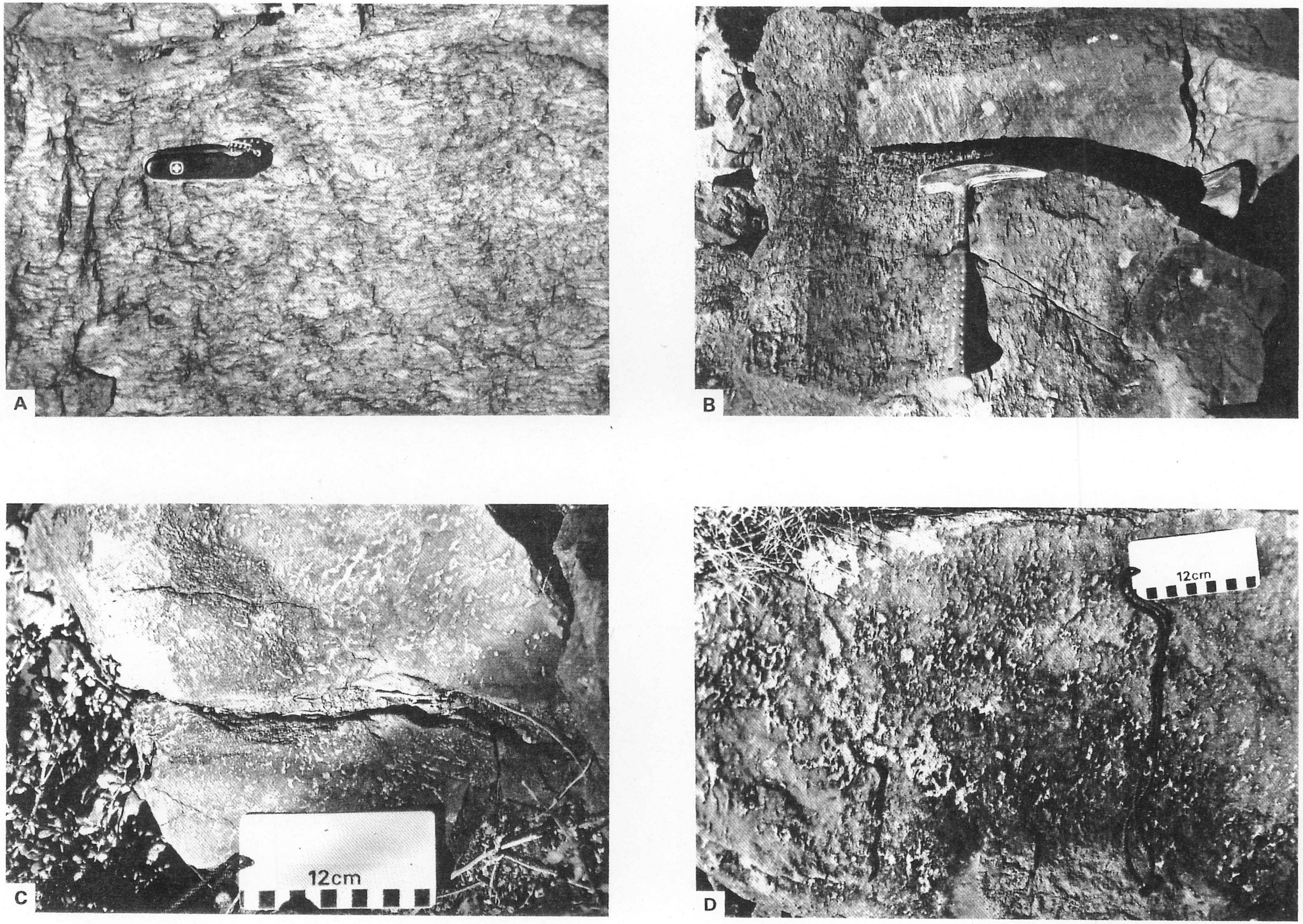


Figure 3

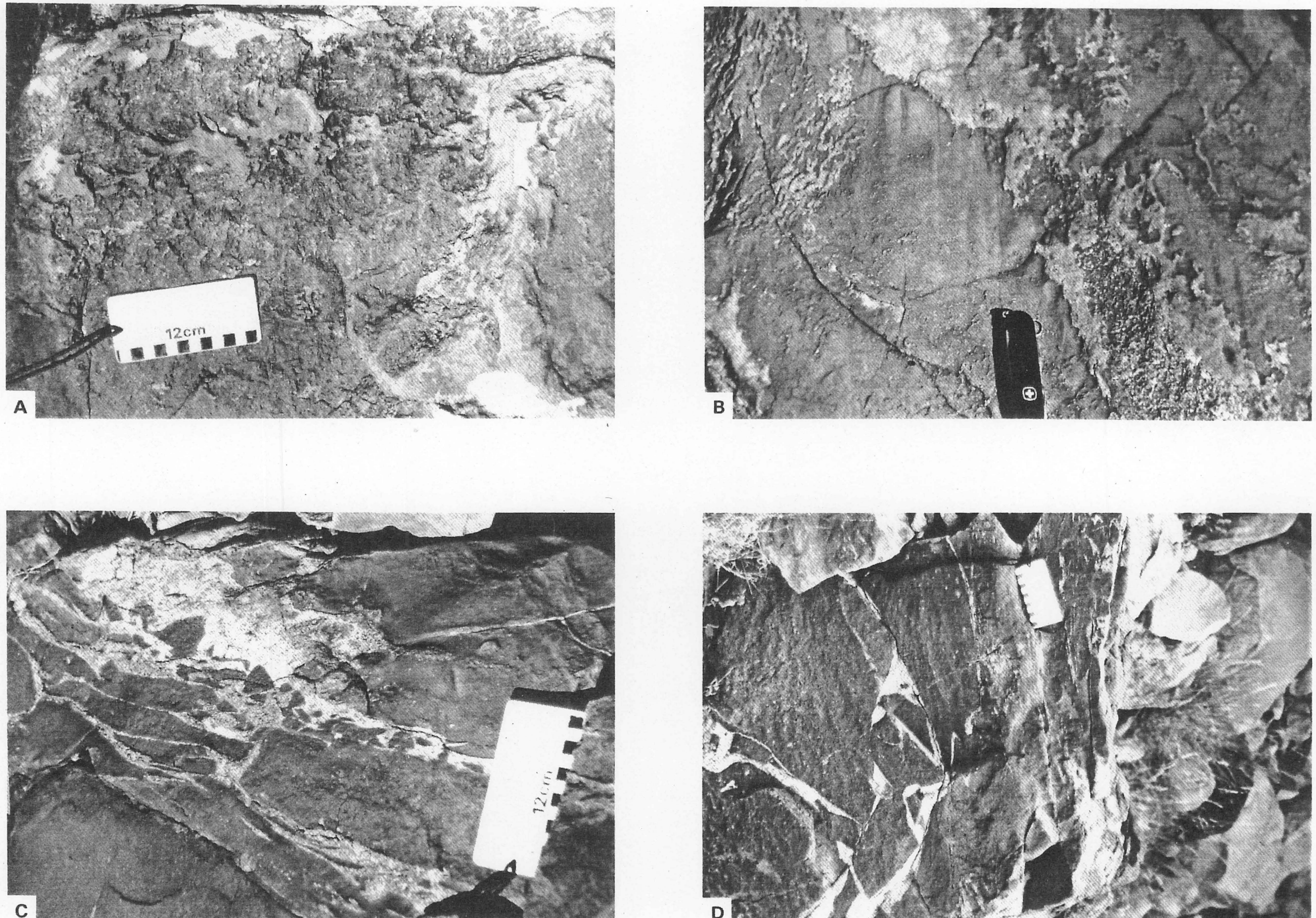


Figure 4

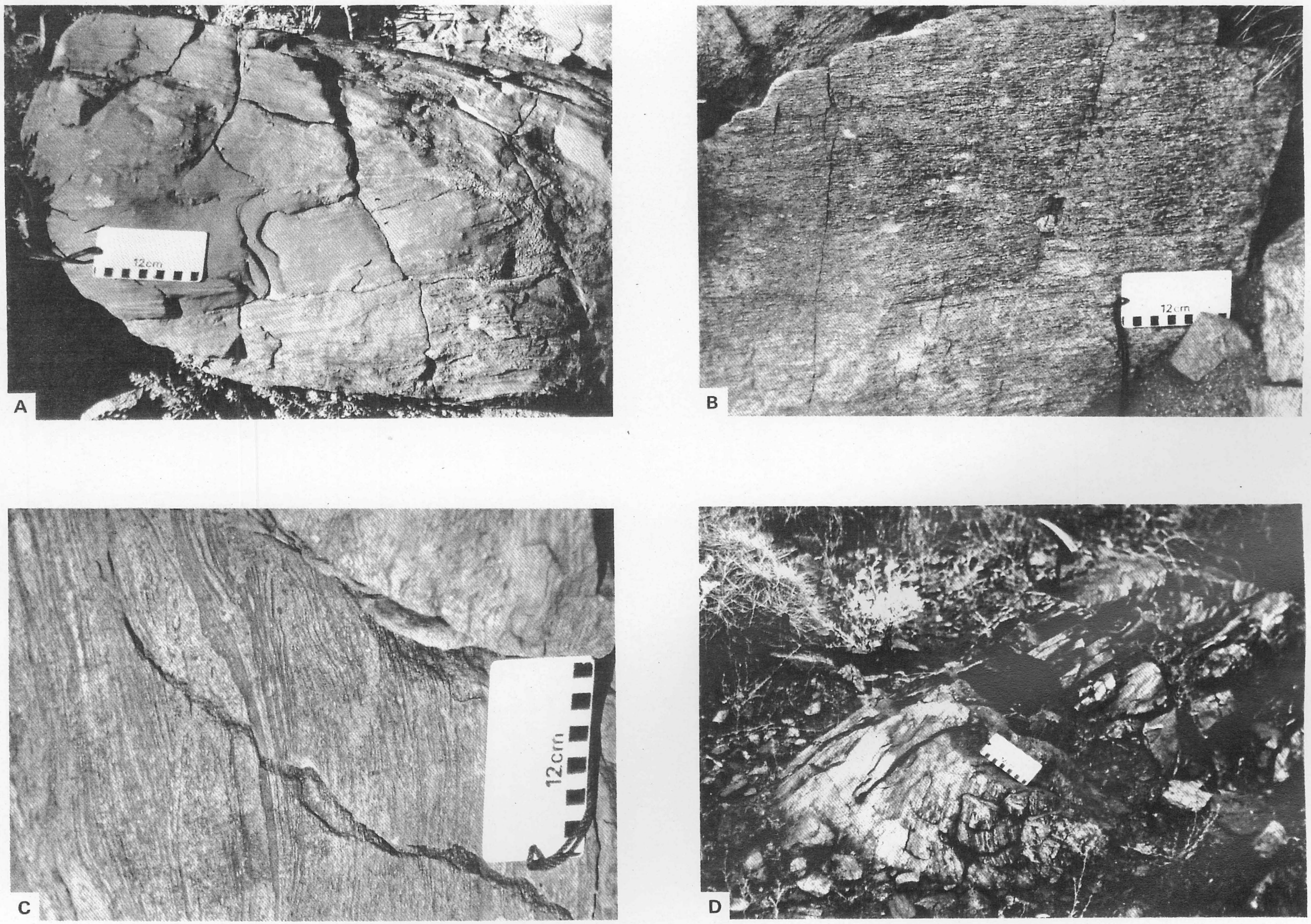


Figure 5

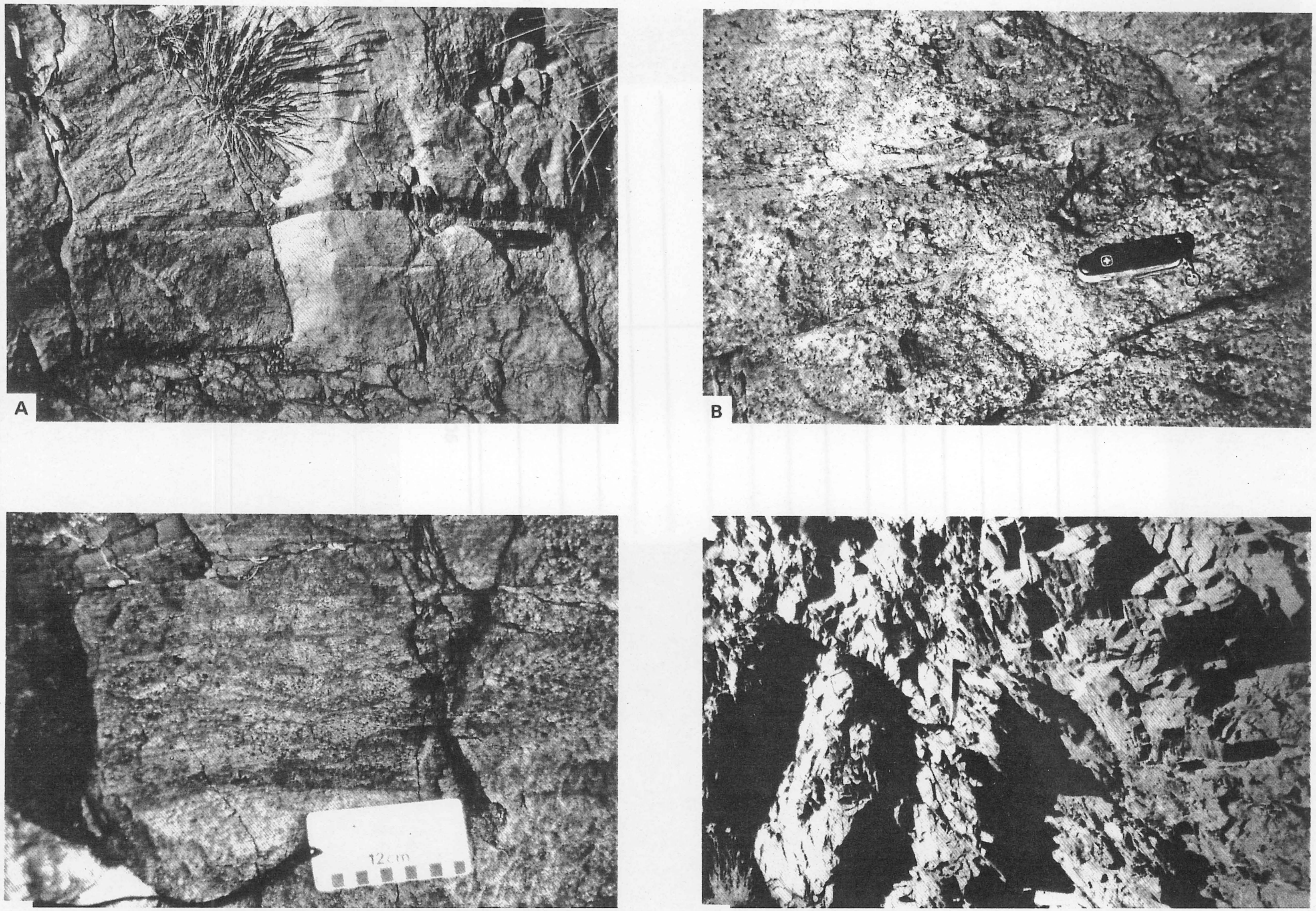


PLATE 1

ROCK TYPES/FABRICS

MAP LOCALITY

area outside airphoto coverage

- Gabbro
- Felsic gneiss, granite etc
- Bentley Supergroup volcanics and sediments

area covered by 1:20 000 scale photography

- Layered mafic/ultramafic bodies (igneous layering)
- Mafic granulites and contaminated marginal facies of the above (foliation trend)

area covered by 1;20 000 scale photography

- Felsic granulites, some gneissose granite and anorthosite (foliation trend)
- Gneissose granite, rapikivi granite
- Granite
- Anorthosite
- Foliation trend in granite and anorthosite bodies
- Jasper zone developed on ultramafic and mafic rocks

STRUCTURAL INTERPRETATION OF THE TOMKINSON RANGES

by T.C. PHARAOH, 1989

SCALE 1:100 000

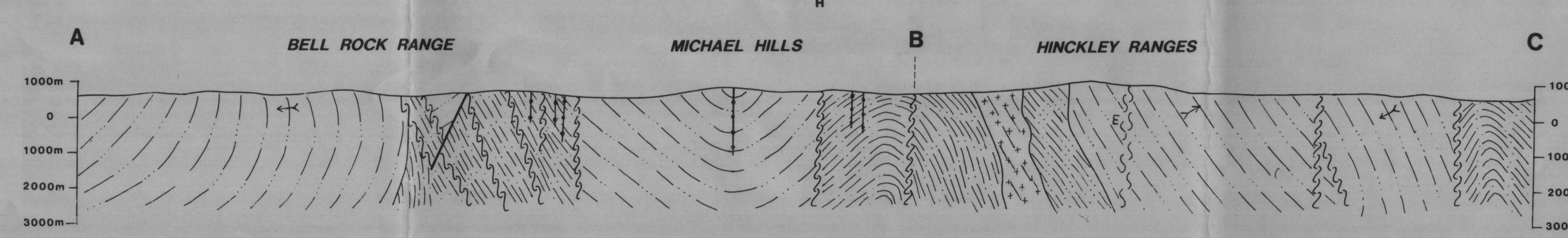
0 1 2 3 4 5 6 7 8 9 10Kms

Transverse Mercator Projection
Numbered lines are 10 000 metre intervals of the Australian Map Grid, Zone 52

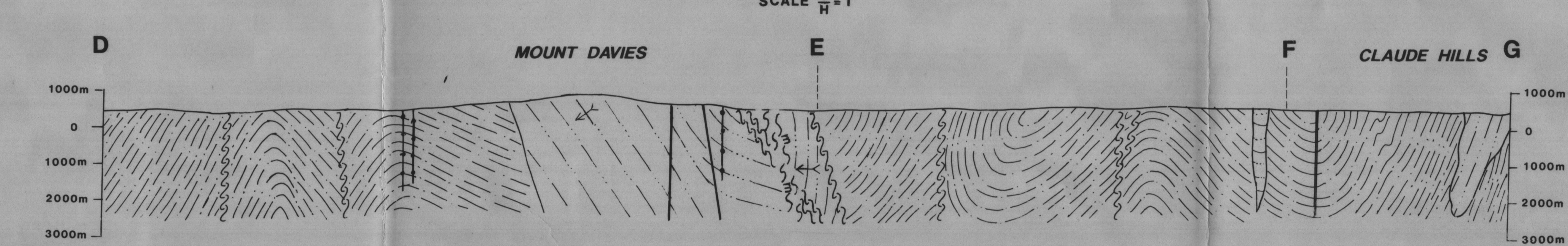
- Geological boundary, approximate, concealed
- Fault or brittle fracture
- Fault showing relative horizontal movement
- Late mylonite zone (eg Hinckley Fault)
- Early deformed zone
- Concealed traces of above
- Antiform
- Synform
- Dolerite dyke
- Strike and dip of foliation
- Vertical foliation
- Strike and dip of banding
- Vertical banding
- Top of bed
- Plunge of mineral elongation (lineation)
- Dip of mylonitic fabric (u - up, d - down)

MAP INDEX SHOWING 1:100 000 AND 1:250 000 SHEETS

SECTION
SCALE $\frac{V}{H} = 1$

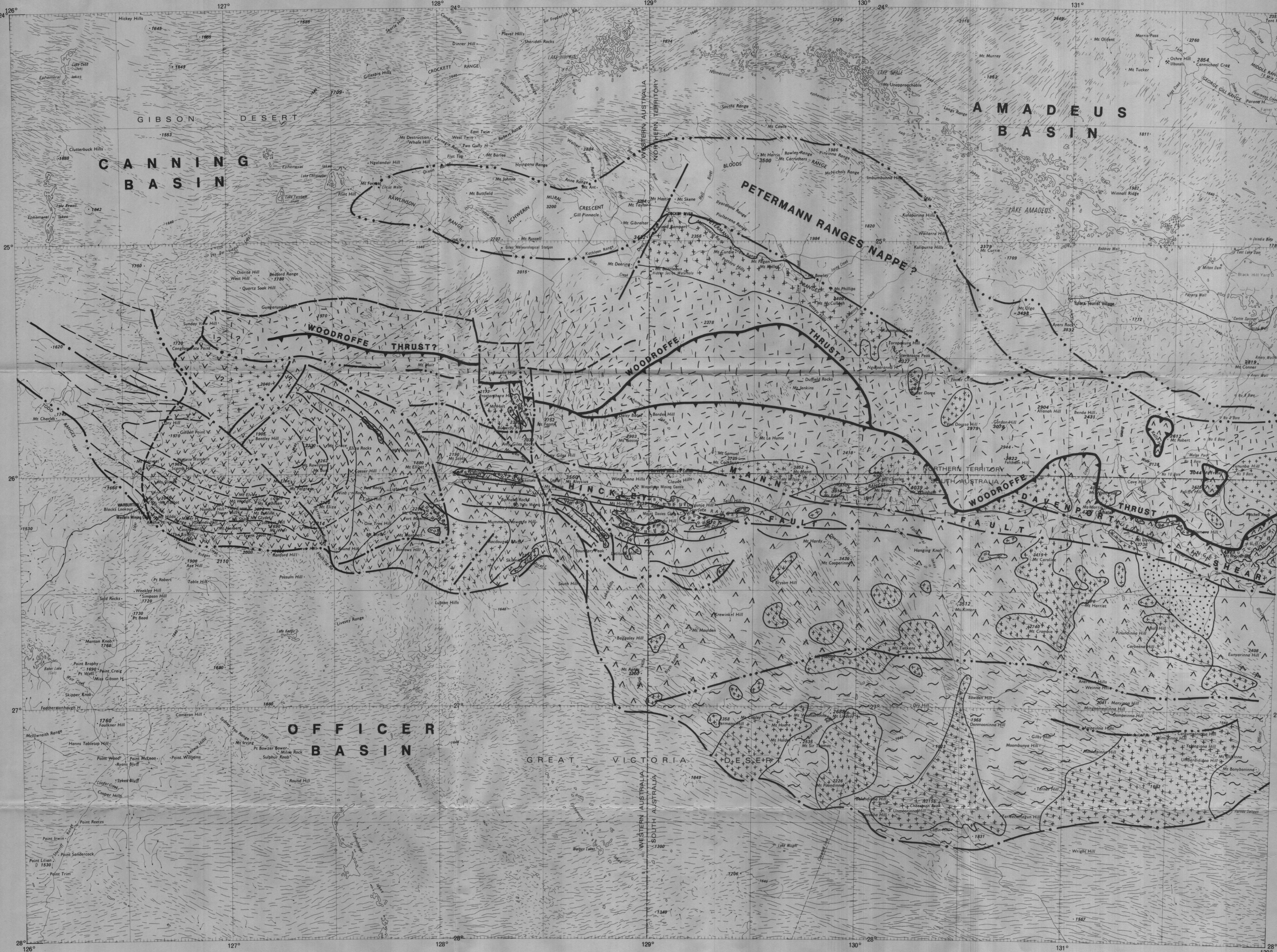


SECTION
SCALE $\frac{V}{H} = 1$



Compiled 1988–1989 by T.C. Pharaoh British Geological Survey,
D.M. Pillinger BMR
Incorporates data by B.P. Thomson (1964) Dept of Mines, SA
J.L. Daniels (1971–1974) GSWA
A.D.T. Goode (1978) Univ of Adelaide,
C.J. Ballhaus, Univ of Tasmania, A.Y. Glikson (1988)
Drawn by D.M. Pillinger

Compiled by the Bureau of Mineral Resources, Geology and Geophysics, Department of Primary Industries and Energy. Issued under the authority of the Minister for Primary Industries and Energy
Base map supplied by the Australian Survey and Land Information Group, Department of Administrative Services



PARTIAL STRUCTURAL INTERPRETATION OF THE 1:1 000 000 SCALE PETERMANN RANGES AEROMAGNETIC SHEET

(G52, BMR 1979)

by T.C. PHARAOH, 1988

SCALE 1:1 000 000

0 50 100Kms

- Outline of major bodies of the Giles Complex
- Exposed volcanic rocks and sediments of the Bentley Supergroup
- Levenger arkose (p€?-€)
- Amphibolite facies and lower grade gneisses, including some retrograded granulites and granites
- Wataru granitic gneiss
- Granulite facies gneisses, including some amphibolite facies gneisses and granite
- Granites, mostly of Kulgeran Suite

DOMAIN BOUNDARY LINEAMENTS

- Lineament, 1st order
- Lineament, 2nd order
- Lineament, 3rd order

INTRA-BOUNDARY LINEAMENTS

- Lineament associated with layered intrusive body
- Other lineaments
- Geological boundary
- Thrust fault
- Eastern limit of Permian sediments forming thin cover at western end of Musgrave Block

MAP LOCALITY

Geological data compiled from: Geological Map of South Australia 1:1 000 000 scale
Geological Map of Blackstone Region WA. 1:500 000 SCALE (Forman, 1971)
Drawn 1989 by D.M. Pillinger

Compiled by the Bureau of Mineral Resources, Geology and Geophysics, Department of Primary Industries and Energy. Issued under the authority of the Department of Industries and Energy
Base map supplied by the Australian Survey and Land Information Group, Department of Administrative Services