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PROGRESS REPORTS ON DETAILED STUDIES IN THE ARLTUNGA NAPPE COMPLEX, N.T., 1971

by

R.D. Shaw and A.J. Stewart (B.M.R.), and
M. Yar Khan and J.L. Funk (A.N.U.)

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59. Map of western part of Arltunga Nappe Complex, showing percentage elongation in east/west direction of deformed quartz grains in Heavitree Quartzite

SUMMARY

General

The Arltunga Nappe Complex is a group of basement-cored nappes, formed by overthrusting and sliding together with subordinate recumbent folding, that lie within a deformed zone along the northern margin of the Amadeus Basin in the centre of Australia, 100 km northeast of Alice Springs. The nappe complex consists of a single large nappe, the White Range nappe, and a group of smaller, related thrust nappes, named the Ruby Gap Nappe in the east, and the Trephina Gorge Nappe in the west, which underlie the White Range Nappe (Fig. 2). The nappe complex formed principally by thrusting in the eastern, southern, and western parts of the complex, whereas in the central and northern parts more ductile deformation under conditions of increased metamorphic grade resulted in folding, strong east-west boudinage, and subvertical flattening, as well as thrusting. Within the zone of more ductile deformation similar tectonic fabrics have formed in both cover and basement rocks. The fold axes of a penetrative generation of north-plunging folds and a strong lineation defined by quartz-grain and pebble elongation both parallel the direction of nappe transport.

Only the two lowest units of the Amadeus Basin sequence, the Heavitree Quartzite and the lower part of the Bitter Springs Formation, are involved in the nappe complex. Major thrust surfaces within the nappe complex probably originated near the basement-cover contact and migrated upwards to join a major decollement in the Bitter Springs Formation. Subsidiary thrust surfaces or slides formed underneath the main faults near the Heavitree - Bitter Springs contact. The thrust slices have subsequently been folded about an east-west axis, and, in the front of the White Range Nappe, rotated.

The present interpretation differs from earlier interpretations in placing greater emphasis on thrusting and sliding rather than recumbent folding as the main mechanism of emplacement of the nappes. The detailed studies have enabled a more comprehensive understanding of the deformation sequence, which varies throughout the complex.

Summary of detailed studies

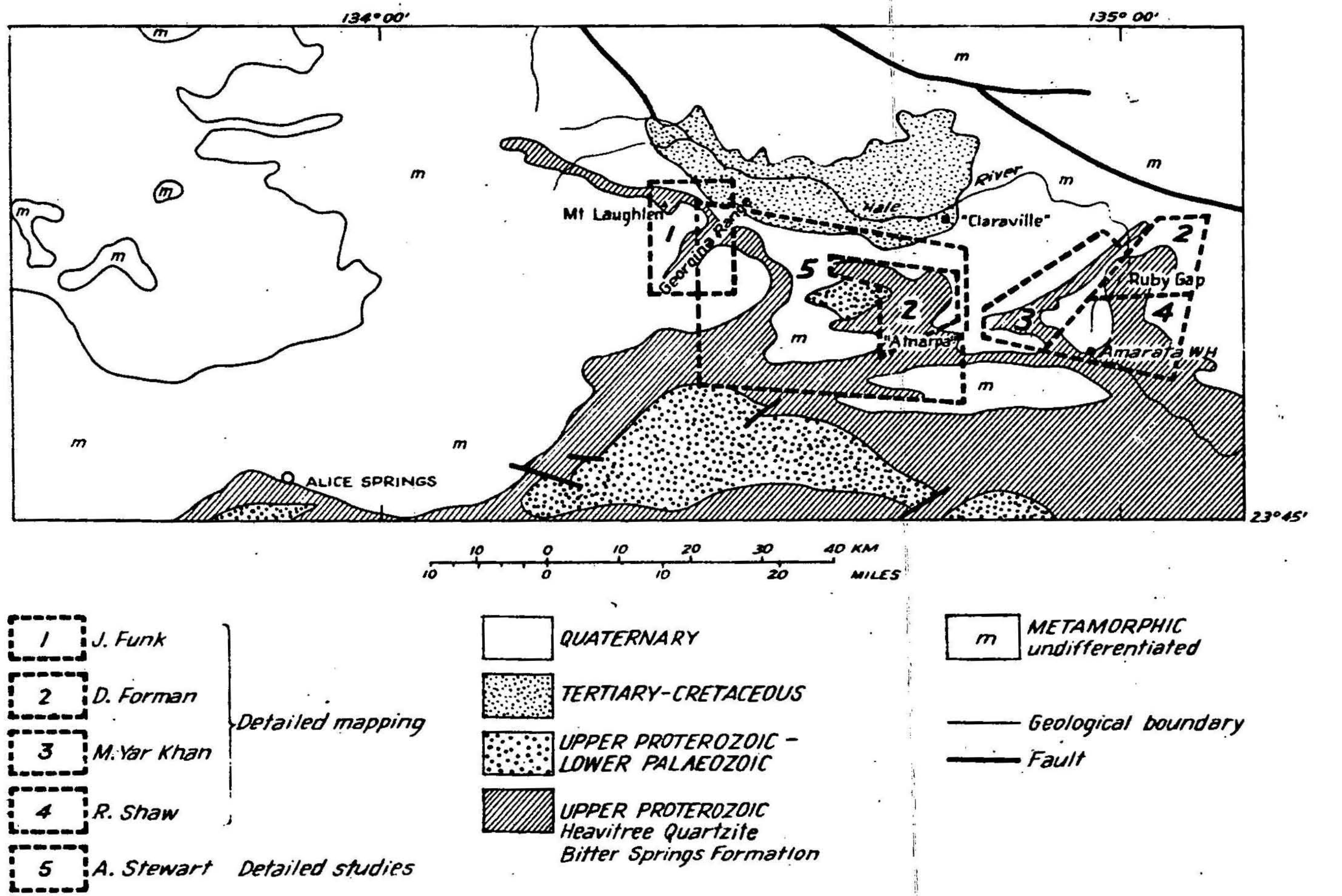
Areas studied by individual authors are shown in Figure 1.

1. Lower Part of Ruby Gap Nappe (R.D. Shaw)

The Ruby Gap Nappe is a thrust nappe. In the Ruby Gap/Amarata Waterhole area thin slices of Heavitree Quartzite and Bitter Springs Formation form an imbricate structure underneath the main thrust surface of the nappe. A quartz-elongation lineation is present near the main thrust zone, and suggests that final movement was north-south.

Fig 1·

LOCATION OF AREAS MAPPED



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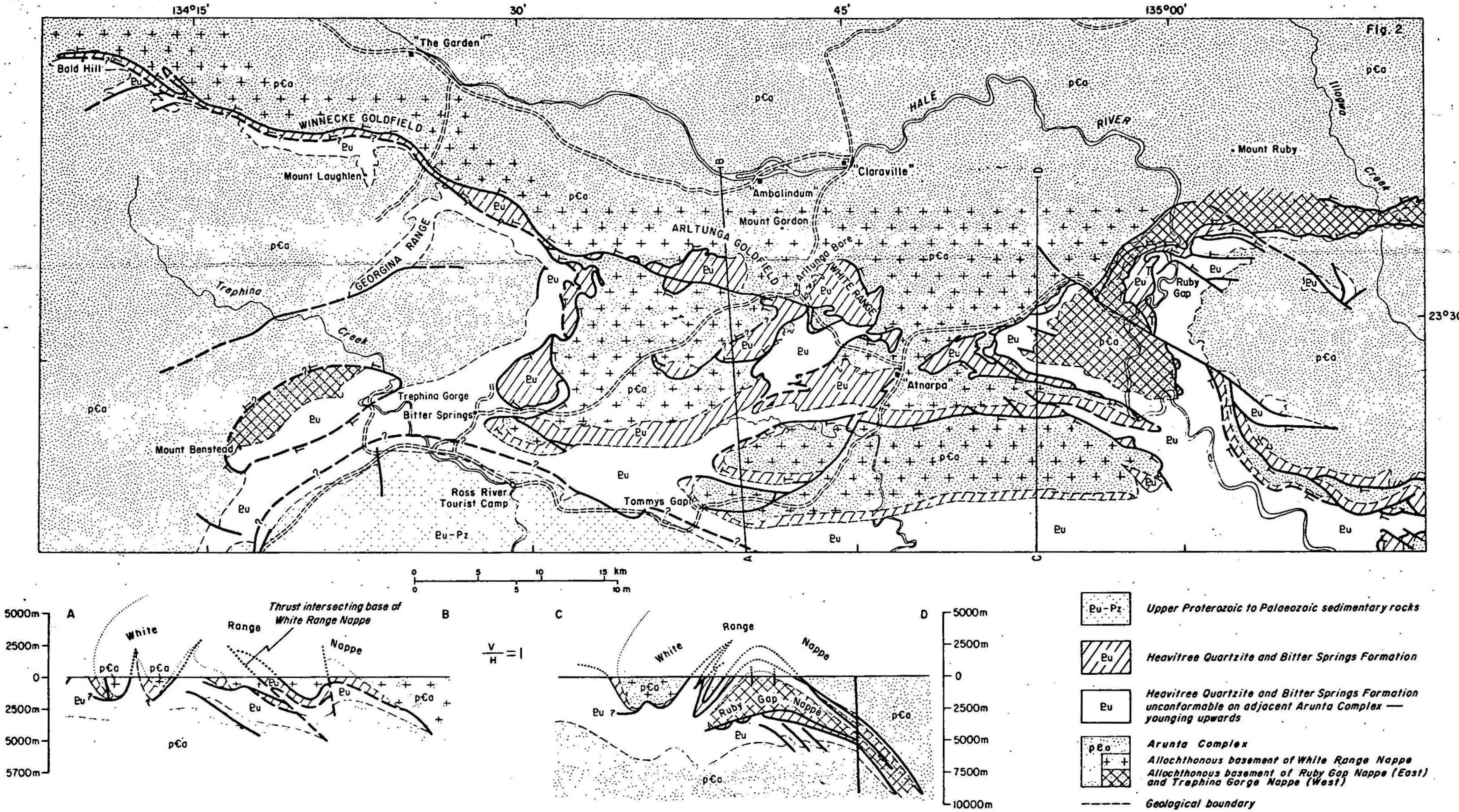

ARLTUNGA NAPPE COMPLEX, NORTHERN TERRITORY

(Modified after Forman 1971)

Fault

Thrust fault (⊢ indicates upper plate)

Cainozoic sediments omitted from map and sections

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2. Upper Part of Ruby Gap Nappe (M. Yar Khan)

Four major thrust slices and a number of smaller slices form an imbricate thrust complex which has been folded about an east-west-trending antiformal axis. The stratigraphy is essentially right-way-up throughout the complex. As fault zones are approached in the southern part of the area, the original quartz grains in the Heavitree Quartzite break down and produce a flinty crush rock; in the northern part of the area, a fine-grained mosaic of polygonal grains forms over a greater strike width. The degree of preferred orientation of the quartz similarly increases northwards. Both features suggest a northwards increase in metamorphic grade.

3. Georgina Gap area of White Range Nappe (J.L. Funk)

Tectonic fish or klippen of retrograded basement rocks, completely surrounded by Bitter Springs Formation, are present in the core of an east-west-trending synform, implying that a period of thrusting of basement over cover took place before folding. The axial planes of two phases of folding parallel the synform; a third is restricted to minor kinking.

4. Deformation processes in the western part of the White Range Nappe (A.J. Stewart)

The southern or front part of the nappe is only slightly deformed, most tectonic transport being due to thrusting, whereas the northern part has deformed in a more ductile manner under conditions of increased metamorphic grade. The more ductile deformation produced homotactic and penetrative mesoscopic and microscopic structures, and involved extensive cataclasis of feldspar and recrystallization of quartz. Quartz c-axes, randomly oriented in the south, form weak crossed-girdles in the north. Carpentarian (1660-1368 m.y.) dates in the southern part of the nappe have been reset to Devonian or Carboniferous in the north.

INTRODUCTION TO THE GEOLOGY OF THE ARLTUNGA NAPPE COMPLEX

by R.D. Shaw and A.J. Stewart (BMR)

General Statement

The distinctive stratigraphy of the cover rocks involved in the Arltunga Nappe Complex has enabled us to reconstruct the geometry of part of an unusual deformed zone of continental proportions at the northern margin of the Amadeus Basin. The deformed zone is some 25 km wide and extends for over 500 km east-west. The Bouguer gravity anomaly gradient over the deformed zone is of such a magnitude (160 mgals) that a warp involving the lower crust is generally invoked to explain it (Marshall & Narain, 1954; Forman in Wells et al., 1970). Basement-cored nappes such as occur in this deformed zone at Arltunga, Ormiston Gorge, and Alice Springs are typical of cordilleran-type mountain belts where continental and oceanic plates interact (Dewey & Bird, 1970), but are not generally known from areas well within an old cratonic shield, as is the case in central Australia. The Amadeus Basin, unlike the ortho-geosynclines of many orogenic belts with their thick flysch sequences, contains a moderately thick sequence (6,000 m) of shelf sediments of the quartzite-carbonate-shale association, and includes negligible volcanic material. The formation of the Arltunga Nappe Complex was accompanied by regional greenschist facies metamorphism that affected both basement and cover rocks, and K-Ar dates determined by Stewart (1971a) indicate that the metamorphism reached a maximum in the Early Carboniferous, during the Alice Springs Orogeny as redefined by Forman (in Wells et al., 1970).

The detailed work reported here has been aimed at (1) establishing sequences of folding and faulting, (2) gathering sedimentary and stratigraphic evidence in order to determine the macroscopic structure, and (3) studying petrographic textures and microfabric in an effort to elucidate the deformational processes involved in the formation of the nappes. The work also begins the 1:100,000 mapping programme in the area.

The areas studied by the various contributors to this report are shown in Figure 1. Shaw describes the results of mapping in 1969 in the lower part of the Ruby Gap Nappe, in the eastern part of the nappe complex. Stewart gives an account of petrographic, petrofabric, and mesoscopic structural studies in the western part of the White Range Nappe, and interprets deformation processes; this work is a summary of part of a Ph.D. thesis submitted to Yale University in 1970. Post-graduate students from the Australian National University, Canberra, are co-operating in the programme, and doing detailed mapping of certain critical areas; Yar Khan has mapped the upper part of the Ruby Gap Nappe (Plate III), and is undertaking petrofabric studies of quartzite deformation; Funk is studying basement-cover relations in the Georgina Gap area of the White Range Nappe (Plate IV).

The detailed mapping was done at a scale of 1:23 250 on enlarged (x2) black and white air-photographs that were originally flown at a scale of 1:46 500 by the Royal Australian Air Force in 1950, and is presented at 1:50 000 scale in Plate 1 (at back of record). The maps Plates I-IV were compiled and drawn by Miss D.M. Pillinger.

For information on access, physiography, and climate, the reader is referred to the comprehensive reports on the regional mapping of the area by Wells et al. (1967), Forman et al. (1967), and Wells et al. (1970). These reports also include bibliographies of investigations up to the time the Arltunga Nappe Complex was first recognized as such, in 1964.

Fold terminology follows Fleuty (1964).

Investigations since 1964

The present detailed studies follow on from regional mapping done in 1964 by D.J. Forman and E.N. Milligan (Forman et al., 1967), during which the presence of a nappe complex was first recognized. From the regional map pattern, Forman (in Forman et al., 1967) interpreted the existence of two nappes, the White Range Nappe and an underlying Winnecke Nappe, collectively named the Arltunga Nappe Complex. He observed that the whole complex had been refolded around east-west-trending axes, the largest fold being the Atnarpa Antiform, which plunges west in the eastern part of the complex, and east in the western part, producing a saddle-shaped depression in the centre of the complex. Later, Forman (in Wells et al., 1970; Forman, 1971) revised this interpretation after detailed mapping in 1969. The Winnecke Nappe was eliminated, its western part now being included in the White Range Nappe, whereas its eastern part was made a separate thrust nappe, the Ruby Gap Nappe (Fig. 2) plus several smaller thrust sheets. Forman (1971) also suggested that the lower and upper surfaces of the Ruby Gap Nappe continued below the White Range Nappe and connected with the corresponding surfaces of the thrust nappe at Trephina Gorge, west of the White Range Nappe (Fig. 2). If this is the case, then the area of cover rocks (Heavitree Quartzite and Bitter Springs Formation) south and southwest of White Range can be interpreted as an outcrop of the upper surface of the 'Ruby Gap-Trephina Gorge Nappe'. However, it is equally likely that the Ruby Gap Nappe and Trephina Gorge Nappe are separate, and that the cover rocks south of White Range are autochthonous. In either case, this area of cover rocks divides the White Range Nappe into two lobes, an eastern and a western; the lobes are clearly evident in the coloured structural relief diagram in Forman (1971). Forman also suggested that the Atnarpa Antiform and other similar east-west structures were the products of rotation rather than folding.

Milligan (in Forman et al., 1967, and in Shaw & Milligan, 1969) suggested that in some places the outcrop pattern could be equally well explained by high-angle faulting or 'laramide-style' tectonics, similar to those described by Prucha et al. (1965) in the Rocky Mountains. Here, a broad zone of dip-slip strike-faulting develops on the flank of a regional monocline. Milligan pointed out that the Heavitree Quartzite and

Bitter Springs Formation all along the southern part of the nappe complex are commonly steeply dipping to overturned, and he suggested that the major faults in this area, e.g., those along the northern flank of the Giles Creek Synform, and in the area southeast of the Ruby Gap Nappe, were also steeply dipping to the north and possibly arcuate in section, i.e., steepening to vertical at depth. South-block-up movement would then produce the observed repetition from north to south of the basement (Arunta Complex) and cover rocks (Heavitree Quartzite and Bitter Springs Formation).

Milligan's hypothesis is untenable, however, as it cannot explain the overturning at the ends of the two western lobes of the Giles Creek Synform; at Tommys Gap, near the end of the southern lobe (Fig. 2), the Heavitree Quartzite dips east at 10° to 25° beneath basement, and the overturning is clearly indicated by upside-down ripple marks and cross-bedding in the basal unit (Buh_1) of the formation; at the western end of the northern lobe, 4 km northeast of Tommys Gap, the Heavitree Quartzite crops out in a well defined synform whose axis plunges east at 55° below the basement, and again overturning of the quartzite is proved by the inversion of cross-bedding. Basal conglomerate of the Heavitree Quartzite dips beneath Arunta Complex in several other places in the Arltunga area (see the section on Results of Detailed Mapping), suggesting that overturning is common. In addition, detailed mapping in the Atnarpa and Ruby Gap Gorge areas has delineated many shallow-dipping thrust sheets, whereas high-angle faults are rare. However, Milligan's belief that, in general, brittle fracture on a large scale played an important role in the formation of the nappe complex has been borne out by the later work.

The first detailed study of the Arltunga Nappe Complex was commenced in September 1968 by Stewart (1969), who examined small-scale structures and made petrographic and petrofrabric studies (Stewart, 1971b) as part of an investigation into the mechanism of emplacement of the nappe. Stewart's investigations also included 35 rock and mineral K-Ar dates on both basement and cover rocks (Stewart, 1971a, 1971b). Detailed mapping was commenced in the winter of 1969 by Forman, Shaw, and Yar Khan, and the data gathered at this time are included in Plate I of this report. In 1970, Shaw and Khan were joined by Funk, and continued the detailed mapping.

Results of Detailed Studies

The biggest problem in understanding the genesis of the Arltunga Nappe Complex has been to determine the relative importance of the parts played by brittle fracture (faulting and brecciation) and ductile flow (penetrative deformation and folding) during the emplacement of the nappes. Forman (in Forman et al., 1967) originally favoured the idea that the nappes were essentially giant recumbent folds with intact limbs although the possibility of major overthrusting was recognized. Proof of the existence of an inverted limb relies on demonstrating (1) that the beds of this limb are inverted, and (2) that they are in undisturbed geometrical concordance with the unconformity surface. During the detailed mapping in 1969, Forman found overturned basal conglomerate of the Heavitree Quartzite in north-plunging reclined folds between White Range and Arltunga Bore, at the northeastern end of the antiform at the Arltunga Goldfield (Fig. 2), and at a locality 3 km west of Arltunga Bore. Thus the lower limb (or base) of the White Range Nappe is overturned in places. Elsewhere, Forman found that the lower limb is thrust out. As a result of the mapping, Forman (1971) suggested that the White Range Nappe had formed by a combination of overfolding and overthrusting. Discontinuity between outcrops of the middle limb can be explained by later folding (around east-west axes) or by later faulting.

The detailed mapping of Shaw, Yar Khan, and Funk has increased and clarified the extent of thrusting in the development of the nappe complex, and casts doubt on interpretations of the White Range Nappe as primarily a fold nappe. In the area of the Ruby Gap Nappe, Shaw has found that retrograde metamorphism of the basement as well as plastic deformation and recrystallization are confined to or adjacent to the main thrust zones. In the area east of Atnarpa, Yar Khan has mapped four major thrust sheets, all of which young upwards; these rocks were previously interpreted by Forman et al. (1967) as being the inverted lower limb of the White Range Nappe. In the Bald Hill-Mount Laughlen-Georgina Gap area, Funk has found that in the westernmost part of the White Range Nappe, the major structures are two large thrust sheets of cover rocks. Primary sedimentary structures show that the beds in these thrust sheets are upright in some places and inverted in others, indicating that the sheets are folded. Funk's mapping of the exposures at Georgina Gap itself limits the northern extent of the syncline beneath the White Range Nappe to the immediate vicinity of the Heavitree Quartzite outcrop between Bald Hill and Georgina Gap (cf. the structural relief diagram in Forman, 1971). The fault along the northern side of the Giles Creek Synform can be interpreted as the surface at the base of a thrust nappe, rather than as the thrust-out middle limb of a large recumbent fold that was subsequently refolded; the overturning of the cover rocks of the synform would be caused by drag along the thrust surface. In the southern part of the western lobe of the White Range Nappe (i.e. between Bitter Springs and Arltunga Bore), Stewart has found that the basement rocks are only slightly metamorphosed and have undergone negligible deformation during the Alice Springs Orogeny; a major fault is present at the western end of this area of basement, and so it seems that this part of the White Range Nappe was also emplaced by thrust faulting.

The main region of penetrative deformation is in the northern part of the White Range Nappe, particularly in the Arltunga Goldfield-White Range area, and here overfolding may well have predominated over overthrusting. Deformation processes in this region are described by Stewart (this report); they show marked contrasts with processes in the southern part of the nappe.

Our correlation of folding episodes, and the inferred sequence of deformation throughout the whole nappe complex, are set out in Table 1. Emplacement of the White Range Nappe began by thrust faulting (sliding), and was accompanied in its later stages by the formation of upright to south-verging east-west folds. The north-dipping penetrative schistosity and retrogression of the central and northern parts of the nappe developed after the early sliding, and were accompanied by the formation of reclined north-south folds with their axial planes parallel to the schistosity. If it is assumed that the schistosity of the deformed zone formed during one episode then the birth of the Ruby Gap Nappe appears to have taken place after that

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of the White Range Nappe, and east-west south-verging folds in the autochthon below the Ruby Gap Nappe, and north-south recumbent folds in the allochthon of the nappe itself probably formed at the same time, during southward sliding. The east-west upright folds and kink bands found throughout the nappe complex formed after the main stages of emplacement in both nappes; the east-west folds in the western part of the nappe complex are tighter than those in the east.

To sum up, the Arltunga Nappes are thought to have formed principally by thrust faulting in the western, southern, and eastern parts of the complex, and by penetrative deformation under conditions of increased metamorphic grade in the central and northern parts. Major thrust surfaces probably originated near the basement-cover contact, migrated upwards, and joined a major decollement in the Bitter Springs Formation; Figure 3 shows the stratigraphic levels where thrust surfaces have formed. Once a large thrust sheet, consisting of a layer of Arunta Complex overlain by Heavitree Quartzite, begins moving over the lower part of the autochthonous Bitter Springs Formation, a series of thin slices of upper Heavitree Quartzite (Buh$_3$) and the immediately overlying Bitter Springs Formation may be stripped away in scraper or bulldozer fashion from the autochthon below the main thrust sheet (Fig. 4a), thus forming subsidiary thrust sheets (each resting on its own thrust fault) beneath the main thrust sheet, e.g. those beneath the Ruby Gap Nappe (Fig. 13). The thrust sheets (both large and small) were subsequently folded about east-west axes, and in the front of the nappe, rotated. We consider that the Giles Creek Synform also formed by sliding, and then rotated bodily as it plunged down into the incompetent sediments of the autochthonous Bitter Springs Formation in front of the earlier formed parts of the White Range Nappe.

DESCRIPTION OF ROCK UNITS

By R.D. Shaw (B.M.R.)

The following is a brief description of the rocks in the area of the Arltunga Nappe Complex; more detailed lithological descriptions of the units are set out in Table 2. Earlier lithological descriptions of the area are included in the reports of Forman et al. (1967) and Wells et al. (1967). Diagrammatic reference sections drawn up for the lower part of the Ruby Gap Nappe are depicted in Figures 5, 6, and 7, and for the Georgina Range in Figure 29. The location of refernece sections is shown in Plate 1.

BASEMENT ROCKS

The Arunta Complex consists of strongly deformed schist and gneiss (pta) which are mainly quartz-rich and calcareous meta-sediments, intruded by mafic and some ultramafic rocks (pGu) and intruded again by granitic rocks (PGg) that range in composition from granite to granodiorite. Large granitic bodies occur in the autochthon west and northeast of the White Range Nappe and in the allochthon of the Ruby Gap Nappe and Giles Creek Synform. The Arunta Complex was regionally metamorphosed to amphibolite facies grade and probably to granulite facies grade in the Middle Proterozoic. K-Ar mineral ages in the southern part of the White Range Nappe were found by Stewart (1971a) to range from 1 660 m.y. to 1 368 m.y. Rb-Sr determinations on five specimens from the Giles Creek Synform define an isochron that indicates an age of about 1 700 m.y. (Rosilind Bennett, B.M.R. pers. comm).

COVER ROCKS

The Arunta Complex is unconformably overlain by the Adelaidean Heavitree Quartzite (Joklik, 1955) which can be readily subdivided into three main units over much of the Nappe Complex.

Buh1 is a basal unit of conglomerate, pebbly sandstone, arkose, and in places siltstone. The unit is up to 70 m thick, but is generally less than 5 m and has a very scattered distribution. Lensic outcrops are common and possibly represented valley fills and lake deposits. Arkosic beds in the Atnarpa Range area are more susceptible to deformation than the overlying quartzite and commonly serve as a horizon of detachment.

Buh2 is a white, blocky quartzite, possibly 150 to 300 m thick, which crops out as prominent strike ridges. Forman has mapped a thin siltstone unit (Buh_{2a}) and a fine-pebble conglomerate unit (Buh_{2b}), in the Arltunga Bore area effectively subdividing Buh_2) into five units.

Buh3 is a unit of platy quartzite about 100 m thick.

The Bitter Springs Formation (Madigan, 1932a, 1932b; Joklik, 1955; Wells et al., 1967) of Adelaidean age, conformably overlies the Heavitree Quartzite. It consists of dolomite, siltstone, shale, and minor amounts of limestone and quartzite. During the present survey, beds near the Heavitree Quartzite boundary containing more than trace amounts of either siltstone or dolomite were included in the Bitter Springs Formation.

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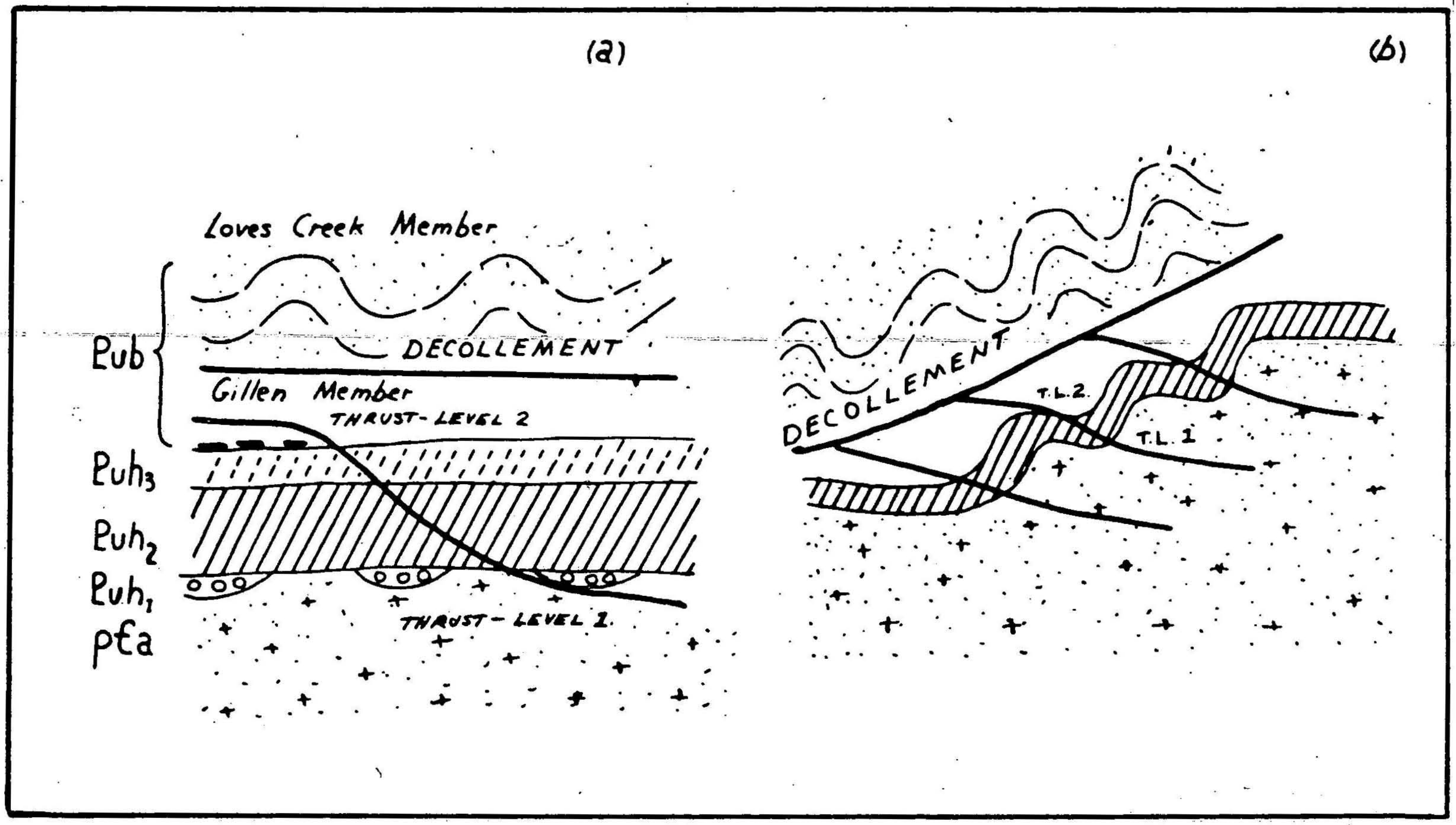
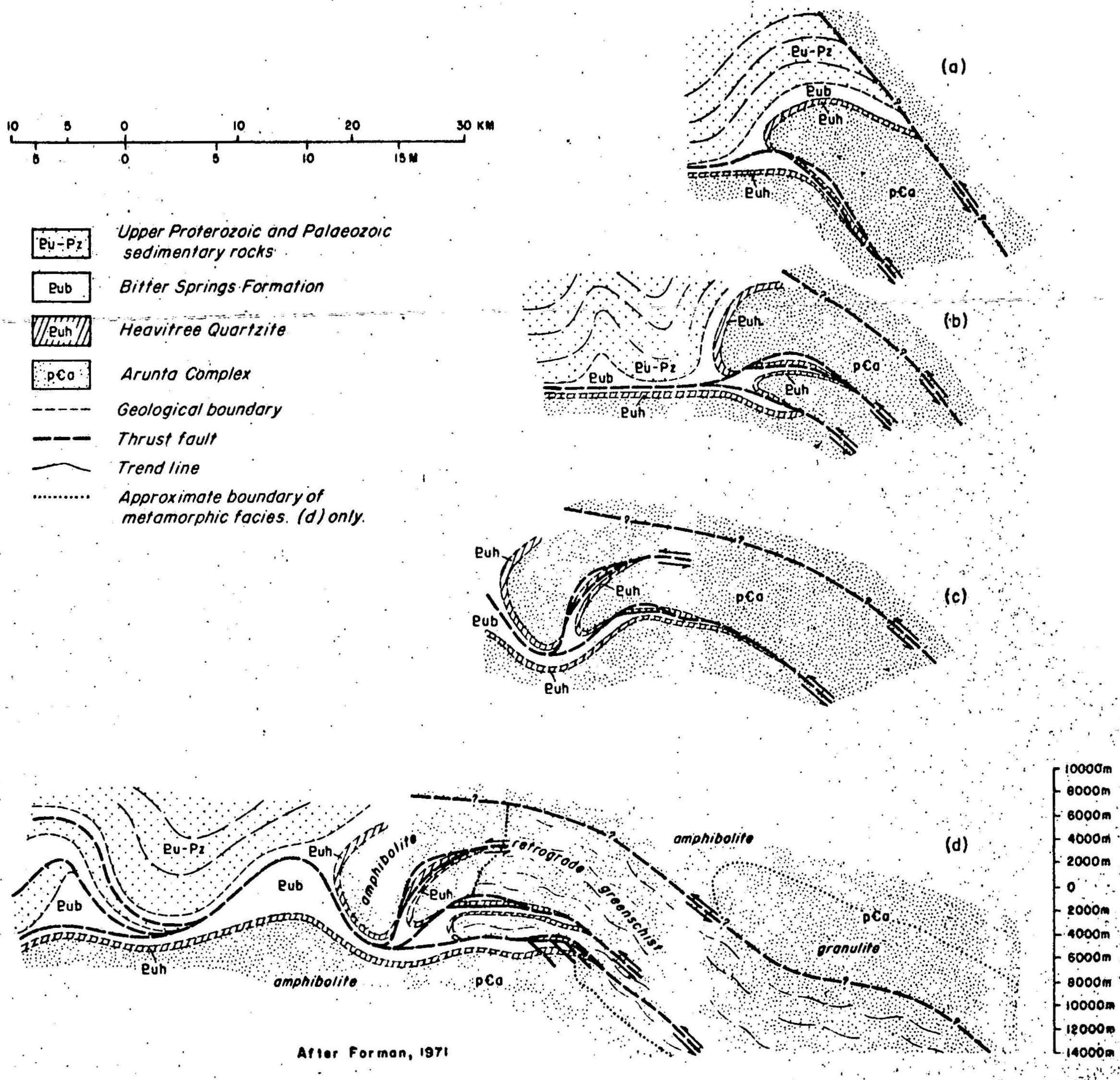


Figure 3. Thrust levels, Arltunga Nappe Complex.
(a) Stratigraphic level of thrusts.
(b) Relationship between thrusts in early stages of development.
Ꝑub - Bitter Springs Formation; Ꝑuh1,2,3 - Heavitree Quartzite;
pЄa - Arunta Complex.

Fig. 4

DEVELOPMENT OF ARLTUNGA NAPPE COMPLEX



After Forman, 1971

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Only the lower of the two members of the Bitter Springs Formation, the Gillen Member (Wells et al., 1967) is preserved within the Nappe Complex. The upper member, the Loves Creek member, was apparently squeezed southwards out of the nappe complex on a decollement probably localized near a salt horizon. The Gillen Member contains halite, anhydrite, and gypsum elsewhere in the Amadeus Basin (Wells et al., 1970). Halite pseudomorphs are common in the siltstone, though none have been noted within the Nappe Complex. Brecciated and plastically deformed gypsum and anhydrite are present in the Ringwood Dome (Wells et al., 1970). Minor laminae of gypsum have been noted in the Gillen Member just downstream from Ruby Gap Gorge by Forman (pers. comm.).

A soft, white to greenish-grey shale, 3 to 7.5 metres thick at the base of the Gillen Member also serves as another horizon of detachment within the Ruby Gap Nappe, and lies at the footwall of many exposed faults.

Metamorphism

The Arunta Complex has been deformed and metamorphosed in at least two separate events. An older, high-grade, metamorphism occurred about 1 700 m.y. ago during the Arunta Orogeny (Forman et al., 1967; Forman, 1968) before the Heavitree Quartzite was deposited. A younger, metamorphism accompanied nappe emplacement during the Alice Springs Orogeny in the Carboniferous (Stewart, 1971a). The younger metamorphism retrogressed mineral assemblages in the basement and produced progressive mineral assemblages in the cover rocks.

Within the nappe complex, and particularly in the southern or frontal part, the older, high-grade metamorphic rocks are substantially preserved. In the south-western part of the White Range Nappe (Stewart, this Record), the old assemblages are indicative of the transition from greenshicst to amphibolite facies and the grade increases eastwards to the middle part of the amphibolite facies. Andalusite and cordierite in the rocks indicate a low-pressure facies series.

Behind the nappe complex to the north, rocks belong to the amphibolite and granulite facies (Forman, 1971, Fig. 4). Typical assemblages of the amphibolite facies are quartz-potash feldspar-garnet-biotite-sillimanite, quartz-potash feldspar-sillimanite-cordierite-biotite, quartz-muscovite-biotite-staurolite kyanite, plagioclase-hornblende-clinopyroxene ± clinozoisite, ± scapolite ± grossularite, plagioclase-biotite-hornblende. Typical assemblages of the granulite facies are hypersthene-diopside-plagioclase ± amphibole ± biotite, quartz-potash feldspar-amphibole-biotite, hypersthene-plagioclase-amphibole ± biotite ± scapolite, biotite-plagioclase-garnet-hypersthene.

The retrograde metamorphism varies in type and amount depending on the structural position of the rocks within the nappe complex. Slight metamorphism has occurred at the front of the White Range Nappe, but metamorphism to the middle part of the greenschist facies is typical of the structurally deeper, rear (or northern) part of the nappe complex. Three distinct types of metamorphism are recognized by the authors.

1. In the front of the White Range Nappe and in the basement core of the Ruby Gap Nappe patchy metamorphism that belongs to the lowest part of the greenshist facies is developed. Chlorite has begun to replace biotite and plagioclase shows alteration to sericite and clinozoisite and, in many places, is completely replaced by them. Original igneous and high-grade metamorphic textures are still preserved.

2. In the rear part of the nappe complex, particularly in the White Range area, retrograde effects, rather than being patchy, are present in nearly every rock. The microstructure is new or shows a high degree of reconstitution. The characteristic minerals are albite and epidote, but biotite* is also present in places, indicating metamorphism to the middle of the greenschist facies.

3. The third-type is of dislocation type rather than a regional type and is typically developed near thrusts, particularly within the Ruby Gap Nappe. The microstructure is partially reconstituted. Quartz grains, particularly those in the matrix, are polygonoized in large part (50% say). Feldspar crystals, though generally unrecrystallized, are commonly fractured or bent. In some cases a schistosity defined by chlorite and sericite is developed. Plagioclase is partially (commonly up to 25%) altered to albite, sericite and clinozoisite; and biotite is partly or completely altered to chlorite and muscovite. Relics of high-grade minerals particularly microcline, are common.

* At the time of writing, Rb-Sr dating of this biotite is still in progress.

Fig 5

DIAGRAMMATIC REFERENCE SECTIONS — AMARATA WATERHOLE AREA
ALLOCHTHONOUS HERVITREE QUARTZITE
(FOR LOCATION SEE PLATE I)

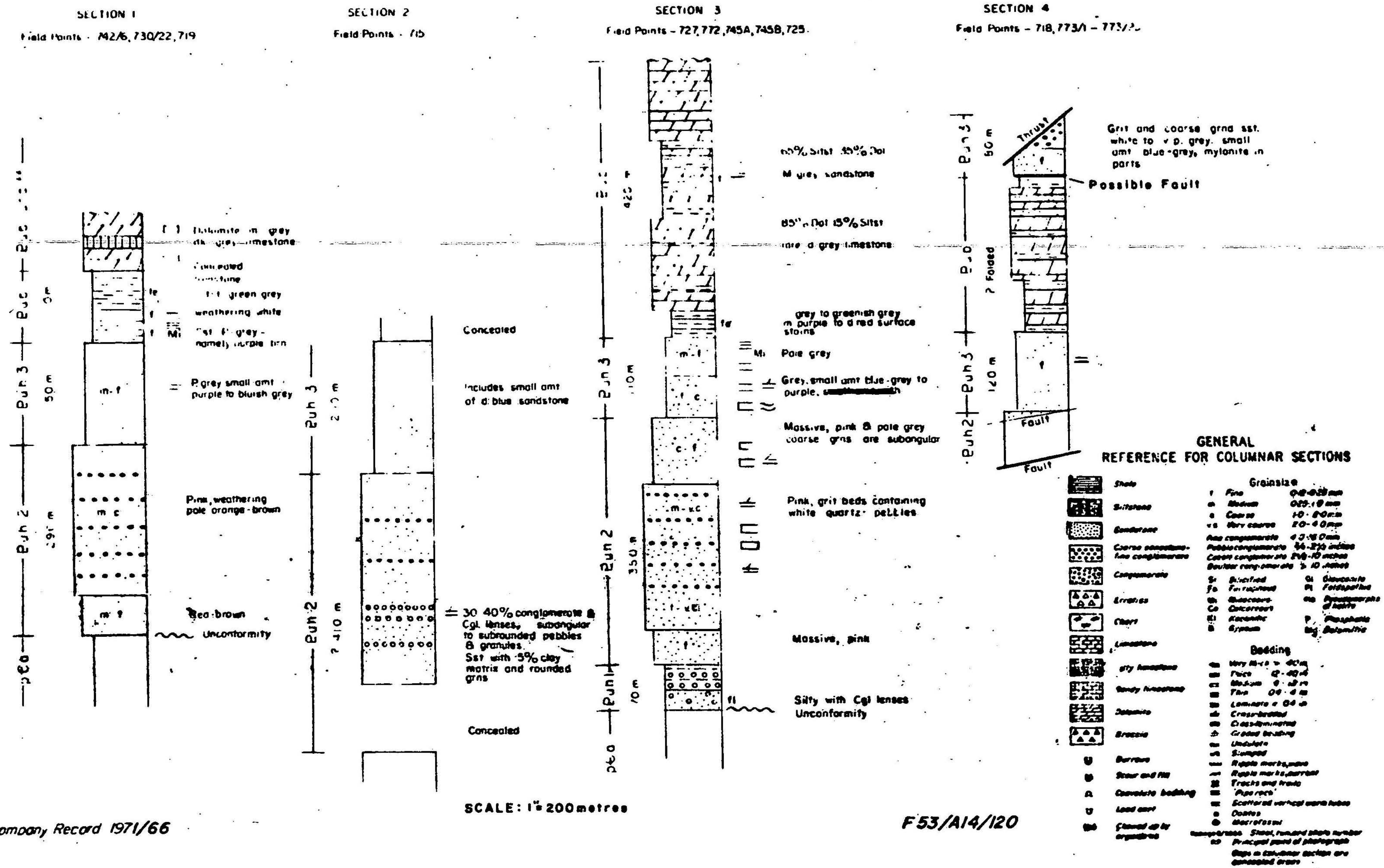

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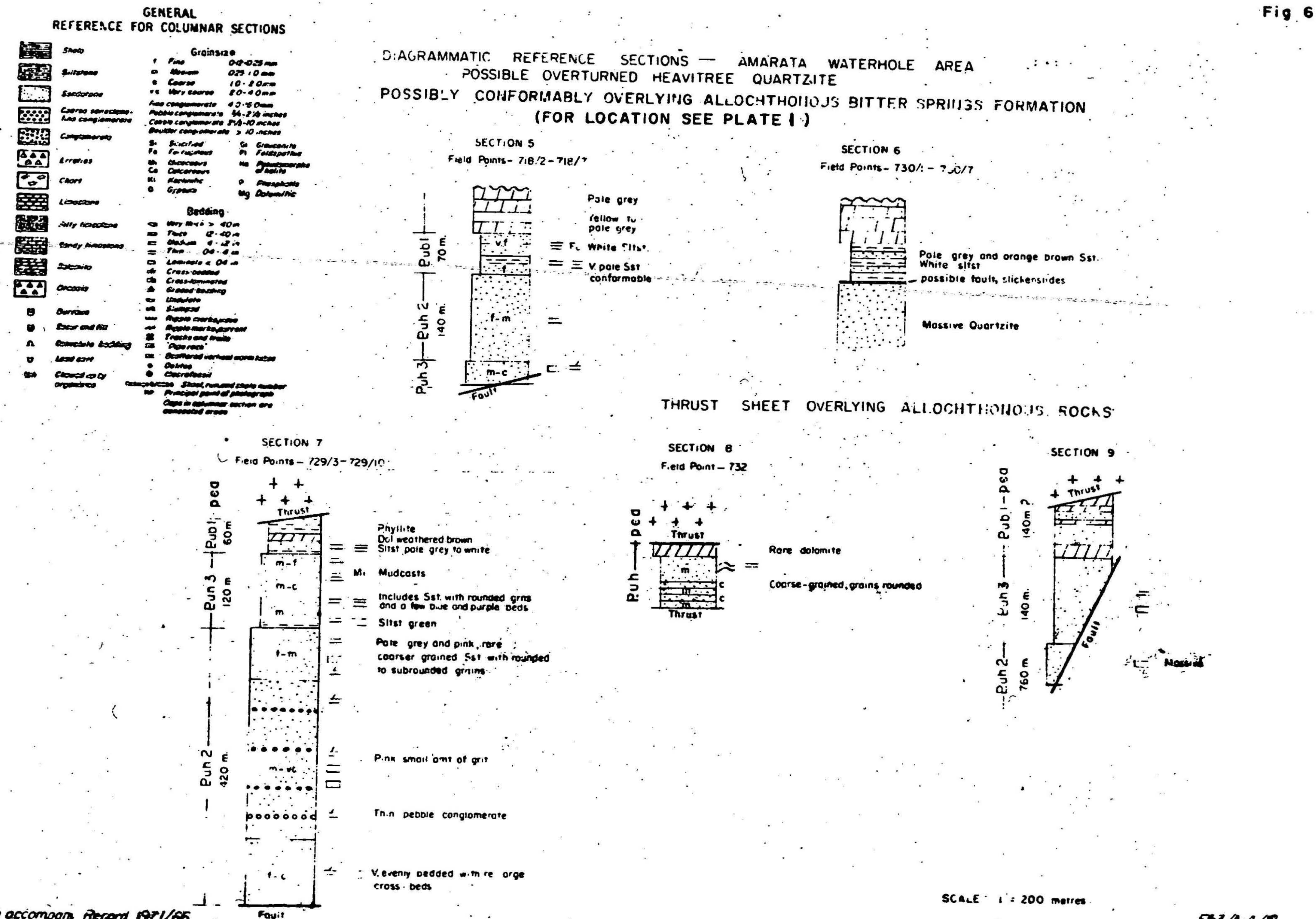
Fig 6



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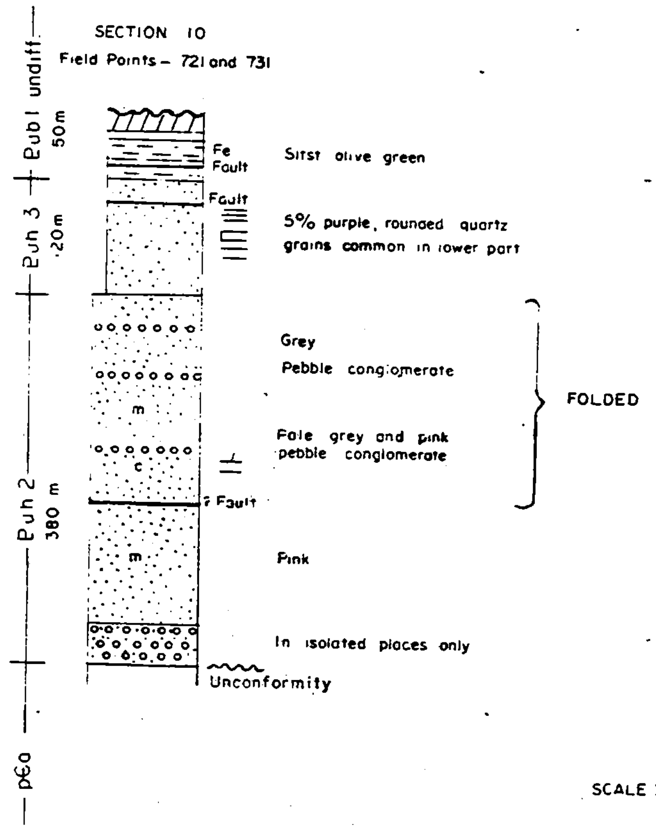
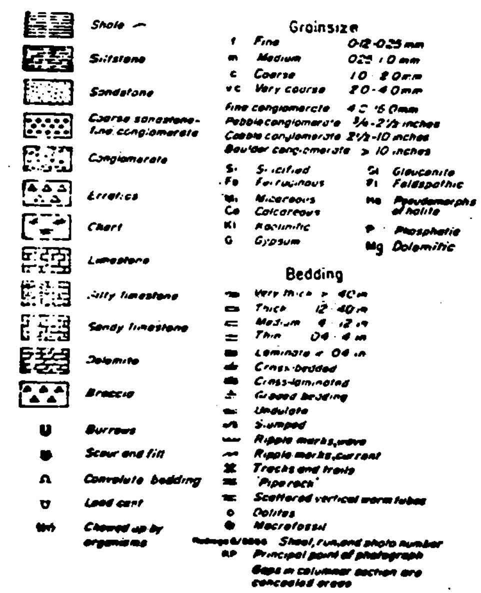
DIAGRAMMATIC REFERENCE SECTIONS — HEAVITREE QUARTZITE OVERLYING THE THRUST SHEET

(FOR LOCATION SEE PLATE 1)



SCALE : 1" = 200 metres



THE 'FRONT' OF THE RUBY GAP NAPPE, AMARATA WATERHOLE AREA, NORTHERN TERRITORY

by

R.D. Shaw (BMR)

SUMMARY

The Ruby Gap Nappe is thought to be a thrust nappe involving the basement as well as the cover rocks of the Amadeus Basin sequence. The basement is significantly deformed only where it is adjacent to major faults.

In the Ruby Gap area thin thrust-slices of Heavitree Quartzite and Bitter Springs Formation that young upwards form an imbricate or shingle block structure underneath the main thrust surface: the Ruby Gap Fault, which lies at the base of the Ruby Gap Nappe (Figure 8). Movement from north to south is suggested by the regional easterly strike of cover units and a quartz-elongation lineation developed in mylonites near the Ruby Gap Fault.

The Amarata Fault (Fig. 8) extends from Atnarpa homestead to south of Amarata Waterhole. The fault lies at the base of the White Range Nappe as interpreted by Forman (1971). The fault truncates at least one low-angle fault and lies on the uppermost part of the Ruby Gap Nappe.

At both the Ruby Gap and Amarata Faults metamorphic rocks of the Arunta Complex are faulted against the Bitter Springs Formation along a large part of each fault, indicating that wedges of basement, and Heavitree Quartzite have been upthrust, to a thrust-level with the Bitter Springs Formation. Thin slices of upper Heavitree Quartzite (and attached Bitter Springs Formation) were progressively stripped off the autochthon by the two main faults.

STRUCTURE

General

The distribution of rock units and main structural features at the front of the Ruby Gap Nappe is shown in Figure 8. An interpretative and diagrammatic cross-section of the Ruby Gap Nappe and overlying thrust structures is shown in Figure 10. The cross-section has been drawn by looking to the west down-structure (Fig. 10; section line Pl. 2). If tectonic transport is assumed to be from north to south then the Ruby Gap Nappe can be interpreted as a moderate sized nappe (i.e. in excess of 15 km from north to south) underlying the much larger White Range Nappe, as interpreted by Forman (1971).

The autochthon of the Ruby Gap Nappe is slightly deformed and consists of the Arunta Complex unconformably overlain by Heavitree Quartzite followed conformably by the lower part of the Bitter Springs Formation.

The allochthonous part of the nappe is composed of Arunta Complex overlying upward-facing thrust sheets of Heavitree Quartzite and Bitter Springs Formation in the northern part of the area (Fig. 13), comparatively slightly deformed autochthonous cover rocks and in most of the southern part of the area. The underlying beds include possibly over-turned beds near the 'front' of the nappe in the southern part (Fig. 12). The Ruby Gap Fault progressively truncates southward a series of low-angle faults. The nose of the Ruby Gap Nappe can be viewed in profile by looking west from a peak immediately east of an S-bend in the Hale River at the 'front' of the nappe is evidenced by inversion of both cross-bedding and the stratigraphic succession.

Beds underneath the Ruby Gap Fault appear to young upwards. Two remnants of partly isoclinally folded and recrystallized Heavitree Quartzite underlie the Ruby Gap Fault and, in turn, overlie Bitter Springs Formation (Section 4, Figure 5, location Pl. 2 and Fig. 12) south of the Star Creek Fault (10c,702) and north of Atniempa Waterhole (10c. 771). As the normal stratigraphic sequence is reversed immediately under the fault it can be assumed that the remnants of Heavitree Quartzite are overturned, having been repeated by folding. Alternatively the repetition of Heavitree Quartzite could have been produced by over-thrusting as depicted in Figure 11(b). Both remnants are undoubtedly upper Heavitree Quartzite and most likely young upwards as do the thrust-sheets of upper Heavitree Quartzite in the Ruby Gap area to the north. The contact of the Heavitree Quartzite with the Bitter Springs Formation is folded in both remnants, an unlikely product of thrust-faulting unless the quartzite remnants were folded after the first thrusting and consequently "strung-out" underneath the Ruby Gap Fault.

The Ruby Gap Fault

The Ruby Gap Fault lies at the base of the Ruby Gap Nappe and is a low-angle fault that truncates a series of low-angle faults in the north. The dip of the fault is best observed in creek banks near locality 773/2, where it dips 20-30° west. Elsewhere dips may reach up to 45°.

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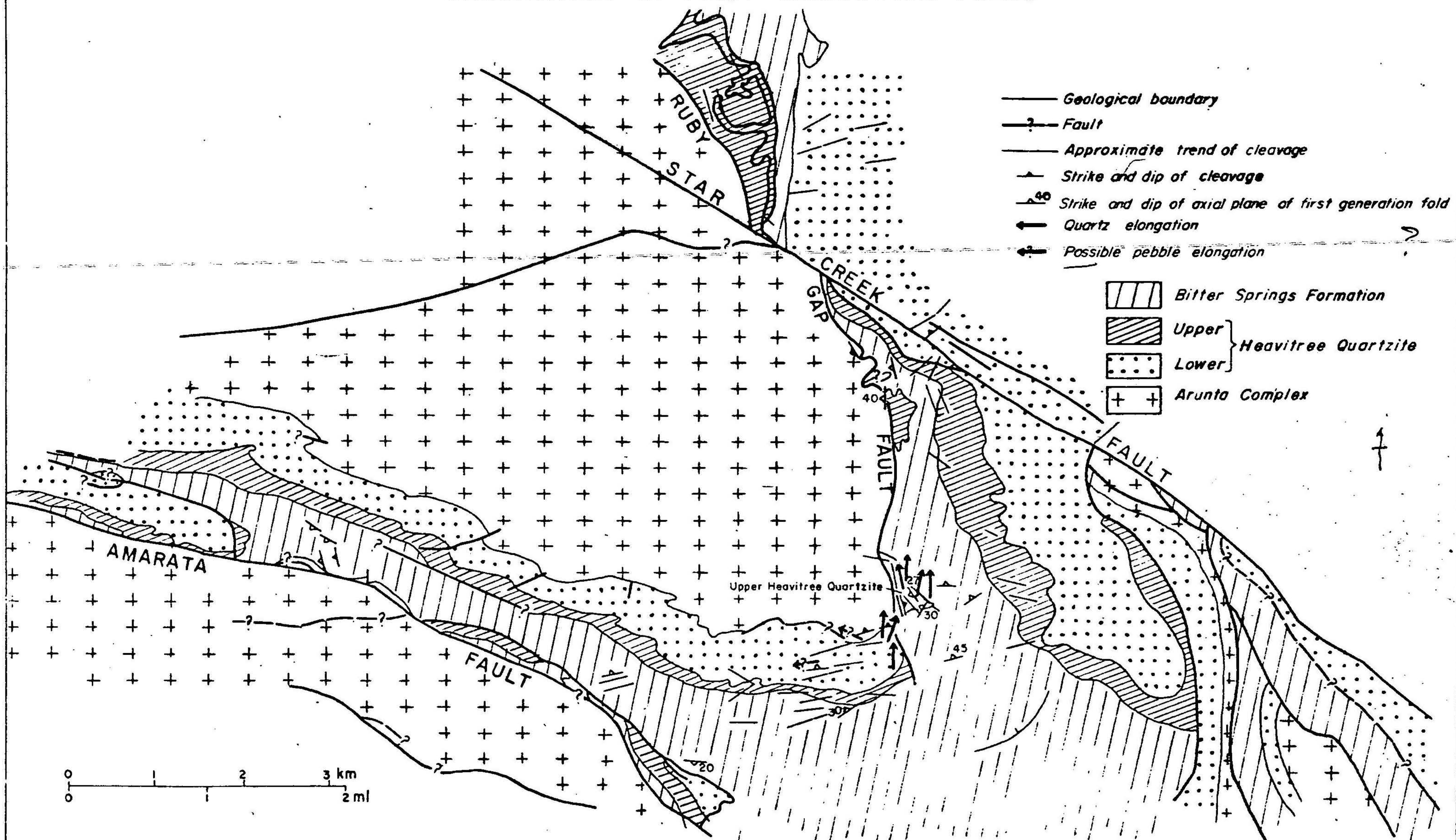
Fig. 8

ORIENTATION OF FIRST GENERATION FOLDS



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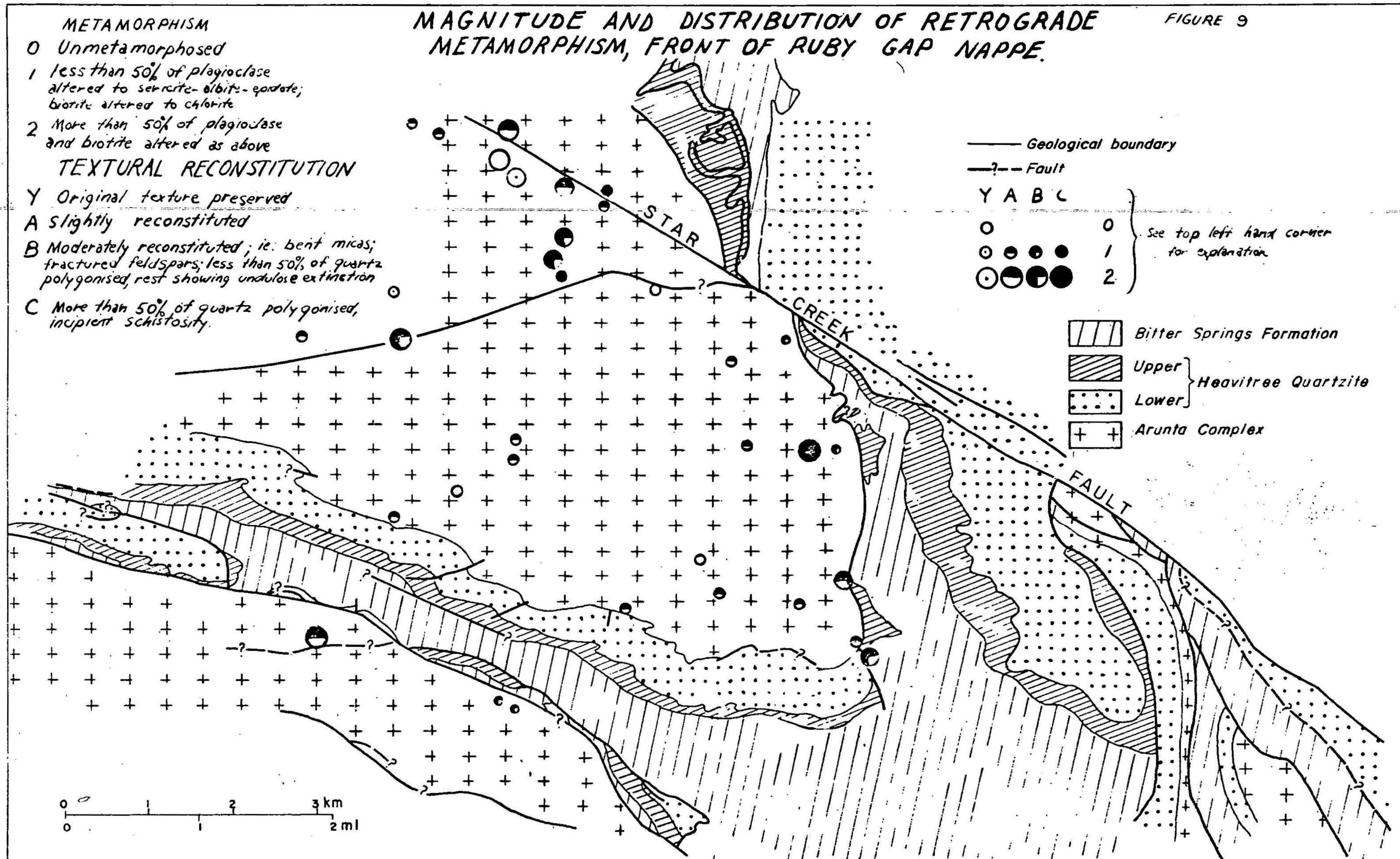

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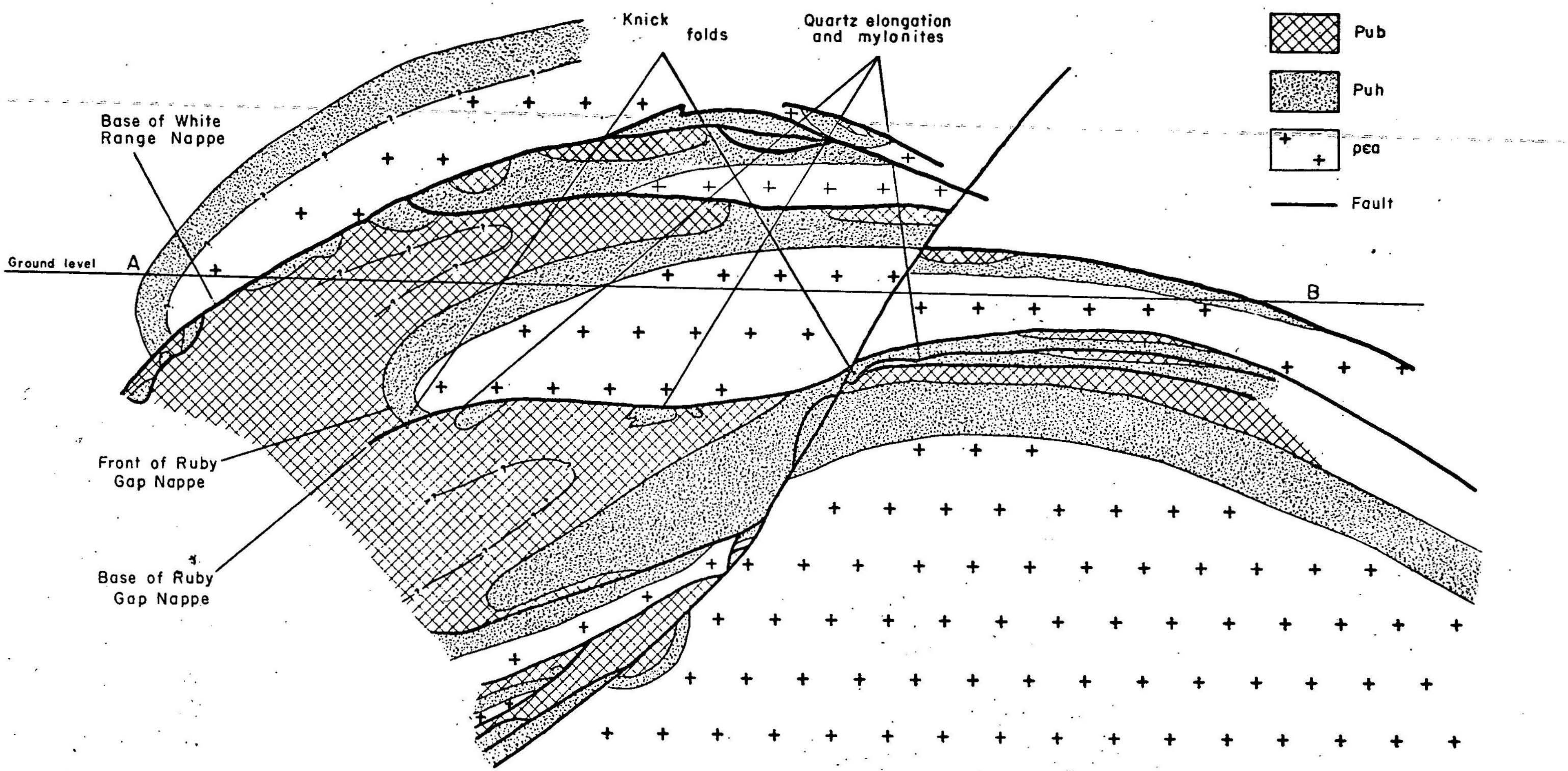
Fig. 10

DIAGRAMMATIC CROSS SECTION – RUBY GAP NAPPE



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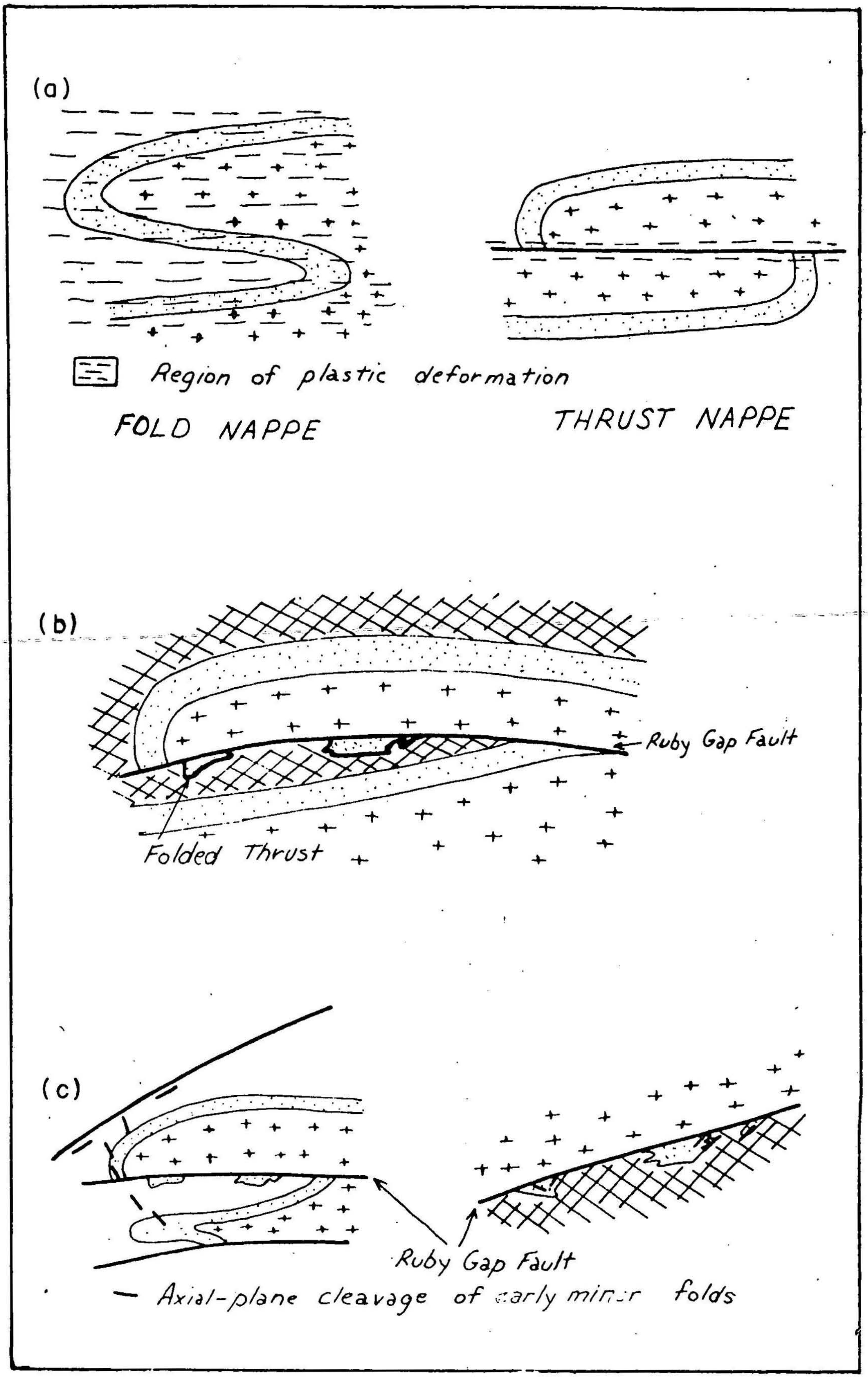

Fig. 11. Interpretation of Ruby Gap Nappe.

(a) Thrust and fold nappe models
(b) Thrust nappe interpretation of front of Ruby Gap Nappe.
(c) Relationship of early minor folds and a possible fold nappe - Westerly view, Northerly view.
(See Figure 8 for reference to rock units).

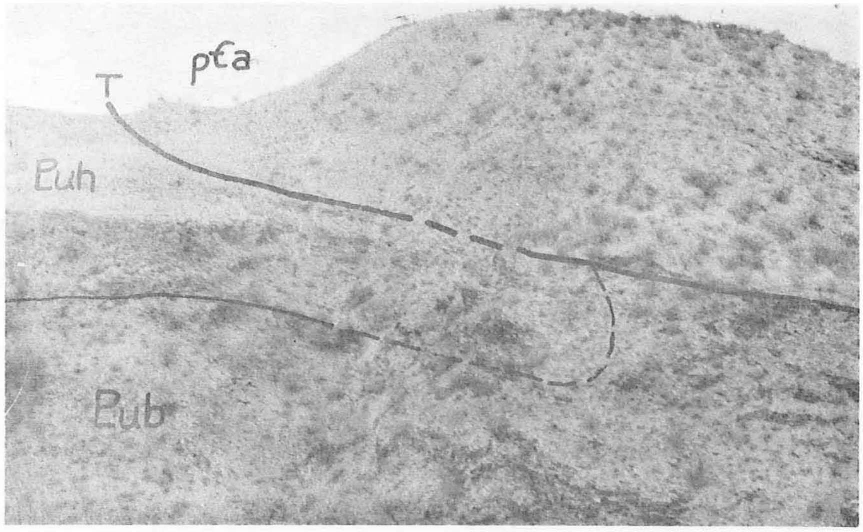

Figure 12. Reverse Fault (T); Arunta Complex (pЄa) overlies Heavitree Quartzite (Buh) and Bitter Springs Formation (Bub) Locality AS773/3. (Neg. No.J624/24)

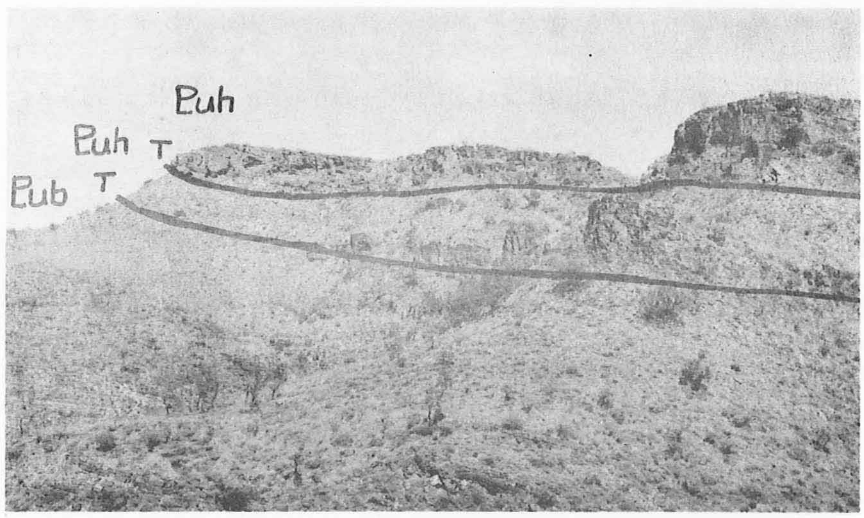

Figure 13. Two-thrust Sheets (T) of upper Heavitree Quartzite (Buh) overlying Autochthonous Bitter Springs Formation (Bub) (Neg. No.J624/27)

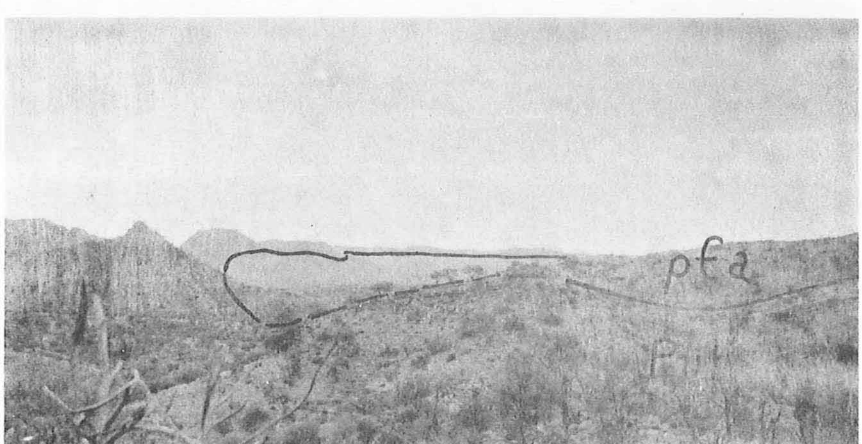

Figure 14. Front of Ruby Gap Nappe, Amarata waterhole area, Heavitree Quartzite cover (Puh) is overlain by Arunta Complex basement (pЄa) in foreground, but overlies basement in the background (i.e. west) (Neg. No.J-624/14)

The elongation of quartz grains adjacent to the Ruby Gap Fault, and the orientation of minor (cleavage) folds in both the autochon and allochthon indicate a consistent movement direction for the Ruby Gap Fault.

Elongation of quartz grains adjacent to the Ruby Gap Fault

Quartz grains in Heavitree Quartzite immediately adjacent to the Ruby Gap Fault are elongated. The quartz-elongation lineation is developed in mylonites both adjacent to the Ruby Gap Fault (specimen 773/3) and upto ½ km east of the fault where the lineation is confined to non-penetrative laminae in quartzite (specimen 790/5). The resultant lineation plunges shallowly northwards as does the lineation defined by the intersection of bedding and cleavage. In detail, fold axes coincident with the bedding-cleavage lineation vary from the quartz elongation by up to 30°. The bedding-cleavage lineation changes orientation by about 90° across the Ruby Gap Fault. The quartz elongation maintains its northerly orientation and is possibly related to late-stage northward or southward movements on the Ruby Gap Fault.

Minor (Cleavage) Folds

Small cleavage-folds mapped in the cover rocks are generally asymmetrical and reclined. Slaty cleavage forms a well defined axial-plane cleavage in the Bitter Springs Formation, but is developed in the Heavitree Quartzite only in zones of intense deformation and then only in the structurally weak beds. Rumples, mullions, or broad crenulations (formed parallel to the intersection planes of bedding and cleavage) are widespread in the Heavitree Quartzite. The crenulations have amplitudes similar to those of ripple marks. The crenulations tend to be discontinuous down-plunge and a spread of orientations up to about 10° is not uncommon suggesting that the lineation has been imprinted on wavy bedding.

Development of cleavage in the autochthon

In the autochthonous Heavitree Quartzite the cleavage is poorly developed. It dips steeply northwards. Small folds and crenulations are more widespread (especially in the upper part of the Heavitree Quartzite) and plunge in a westerly direction.

Development of minor (cleavage) folds in the allochthon underneath the Ruby Gap Fault

Immediately east of the Ruby Gap Fault near its intersection with the Star Creek Fault (Loc. 773/3) the cleavage dips 40° west and parallels the axial planes of recumbent folds developed in Heavitree Quartzite. Folds plunge gently to the north or south approximately parallel to the surface trace of the fault and perpendicular to their plunge in the autochthon. Similar north-plunging folds occur with thrust sheets of Upper Heavitree Quartzite (Buh1) north of the Star Creek Fault.

The Amarata Fault

The Amarata Fault extends from Atnarpa homestead to a point south of Amarata Waterhole. Like the Ruby Gap Fault, it truncates at least one low-angle fault. It lies near the inverted middle limb below a structure interpreted by Forman (in Forman et al., 1967) as a major nappe, the White Range Nappe. As with the Ruby Gap Fault the Bitter Springs Formation is faulted against Arunta Complex along a large part of the fault.

The Star Creek Fault cuts across the Ruby Gap Nappe. It is younger than both the Ruby Gap Structure and the Atnarpa Antiform since it offsets both. The dip varies from vertical to steeply southwest. The block southwest of the fault is thought to have been rotated to produce widespread horizontal beds in the undeformed allothchon above (west of) the Ruby Gap Fault. Such a rotation may explain the odd shaped and relatively large area of outcrop of Arunta Complex interpreted as the core of the Ruby Gap Nappe.

Isolated late-stage warping

A broad anticlinal warp about 600 m across has folded two thrust(?) sheets of Heavitree Quartzite about 1½ km north of where the Star Creek Fault cuts the Ruby Gap Fault. Small warps parallel the larger structure.

Minor Folds related to the Atnarpa Antiform

A series of minor folds possibly related to the Atnarpa Antiform occur along an east-trending ridge of allochthonous Heavitree Quartzite. The folds trend west-southwest and two have west-southwest trending faults in their cores.

INTERPRETATION OF THE RUBY GAP STRUCTURE

The Ruby Gap Structure is interpreted as a thrust nappe complex in which the main direction of transport was from north to south. The thrusts typically developed in the basement, but migrated up section to a position near the contact between the Bitter Springs Formation and the Heavitree Quartzite. As thrusting progressed the Arunta Complex was moved farther and farther over the Bitter Springs Formation. As the large and essentially rigid block of Arunta Complex which forms the allochthon or core of the Ruby Gap Nappe, moved southwards, thin slices of upper Heavitree Quartzite (Buh3) (and attached Bitter Springs Formation) were progressively stripped off the autochthon by the Ruby Gap Fault to produce an imbricate structure. An analagous imbricate structure formed underneath the Amarata Fault.

Figure 11(a) depicts a model of features which might be expected in a thrust nappe as opposed to a fold nappe. In the Ruby Gap Nappe no extensive overturning can be proved nor has a synclinal core been detected beneath the nappe as would be expected in a fold-nappe. Rather, where

Bitter Springs Formation underlies the remnants of Heavitree Quartzite (east of 773/3) it dips consistently west. The most significant evidence for a thrust nappe rather than a fold nappe in the Ruby Gap-Amarata Waterhole area is the lack of plastic deformation and recrystallization of the basement rocks in the core of the nappe.

The retrograde metamorphism of the basement in the core of the Ruby Gap Nappe is a patchy incipient regional metamorphism of the lower greenschist facies and is considered to be of too low a grade to be associated with major fold nappe. In addition dynamic metamorphism is developed adjacent to major faults.

In thin section, most basement rocks show only slight textural reconstitution. Although up to 50% (by volume) of plagioclase grains may be altered to the assemblage sericite - albite - epidote, the original grain shapes are preserved. In contrast, the great majority of rocks contain a predominance of plagioclase and biotite altered to the assemblage sericite - albite - epidote - chlorite.

The remnants of upper Heavitree Quartzite (Buh3) beneath the Ruby Gap Fault can be interpreted (Figure 11(b)) as slices of Heavitree Quartzite sandwiched between two faults, the underlying fault being older and subsequently folded about a north-south axis.

<u>Direction of tectonic transport</u>

The interpretation of the geometry in the Ruby Gap structure depends on the direction of gross tectonic transport. The easterly trend of regional folds and low-angle faults both in the Amadeus Basin as well in the cover-rocks infolded with the basement in the Arlunga Nappe Complex, suggests gross tectonic movement from north to south. Movement from north to south is consistent with an easterly gravimetric trend defined by the very steep regional gravity gradient which occurs north of and parallel to the margin of the Amadeus Basin, (cf. Forman et al., 1967). On the eastern side of the Ruby Gap Nappe, the easterly trend is disrupted by a northwest-trending lineament.

The development of the quartz-alongation lineation in mylonite and its localization near the Ruby Gap Fault strongly suggest major north-south movements on the fault. If such north-south movement is correctly interpreted the geological map pattern suggests sliding of a segment of Arunta Complex rocks over cover rocks. If this is the case then the Ruby Gap Structure can be safely viewed by looking down-structure to the west.

<u>Significance of minor folding</u>

In the Ruby Gap area Forman (1971) has found that the authochthonous rocks are drag-folded about east-west axes and the southern limb of each fold is overturned, whereas the allochthonous rocks above the lowermost thrust are isoclinally folded about north-south axes and display a prominent northerly lineation due to the elongation of quartz grains. The axial-plane schistosity

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of the north-trending folds roughly parallels the dip of the thrusts. Forman considers that both tectonic fabrics were the result of overthrusting from north to south. The east-west drag folds in the autochthon developed at right-angles to this movement and the lineation in the allochthon developed parallel to the direction of movement. Similar north-plunging reclined folds in the inverted middle limb of the White Range Nappe also parallel the penetrative quartz-grain elongation as well as the plunge of extreme pebble elongation (Forman, 1971).

The pattern of folds at the front of the Ruby Gap Nappe suggests the orientation of minor folds is dependent on the degree of strain; north-south folds developed in regions of maximum extension near the Ruby Gap Fault; east-west folds developed at right-angles to the direction of maximum strain in regions of more moderate strain. Nowhere in this area do north-south folds overprint the east-west folds. Rather a penetrative quartz elongation lineation that normally parallels the north-south folds cuts across easterly trending folds (at angles of up to 30 degrees) 400 metres from the Ruby Gap Fault. This fabric is interpreted to represent an intermediate strain-state.

Although the minor cleavage folds away from the Ruby Gap Fault are oriented at right-angles to the direction of movement they are not drag folds on any fold nappe with an east-west axis, as their axial planes cut across the major structure (Figure 11(c)). The orientation of minor folds is more understandable in terms of a thrust nappe rather than a fold-nappe interpretation.

The north-trending folds immediately underlying the Ruby Gap Fault are considered to have developed in a zone of very high strain. Such folds having axes parallel to the maximum principle axes of strain in regions of very high strain have been described by Kvale (1953). Cleavage folds in the southern remnant of Heavitree Quartzite at the southern end of the Fault may have been rotated into a northerly orientation as a result of strain related to thrusting movement or may have formed during quartz-grain elongation at the time of thrusting. The east-trending cleavage folds are considered to have been produced by a milder strain field during early stages of the nappe formation before or during the main period of thrusting but in regions of comparatively mild strain.

GEOLOGY OF THE ATNARPA RANGE AREA

by

M. YAR KHAN (ANU)

INTRODUCTION

Location and Topography

The area extends 19 km eastwards from about 1.6 km east of Atnarpa homestead, covering discontinuous hills and ranges that rise about 200 m above the local plains (Fig. 1 and Pl. 3). As the area apparently has no geographical names, a tentative scheme to facilitate reference will be followed in this report (see Pl. 3). The whole area will be called the Atnarpa Range. The westernmost part, extending nearly east-west for about 5 km, will be referred to as the Western Hill; the valley adjoining this hill eastwards, about 3 km long and 1½ km wide, as the Small Valley; the arcuate range with a northern limb and a southern limb extending eastward from east of the Small Valley as the Eastern Hill Range; and the valley between the two limbs of the Eastern Hill Range as the Large Valley. A vehicle track which runs alongside the northern front of the Atnarpa Range and crosses its northern limb about 17 km east of Atnarpa homestead before entering the Large Valley will also be used for reference to the area.

Summary of Geology

Rocks in the Atnarpa Range form part of the upper limb of the Ruby Gap Nappe and are overlain by basement rocks which form the allochthon of the White Range Nappe. Studies in the Atnarpa Range show that retrograde metamorphism was more associated with local dislocations than with a regional phenomenon. The Atnarpa Range consists of a number of folded thrust sheets with which the deformation is closely associated. The stratigraphic order within the cover rocks in most of these thrust sheets is undisturbed.

BASEMENT ROCKS

In the Atnarpa Range the rocks of the basement Arunta Complex are represented by retrograded equivalents of dominantly quartzo-feldspathic rocks. The quartz is either elongated and highly strained or has recrystallized into a mosaic of strain-free polygonal grains. The feldspars are extensively sericitized and saussuritized leading to the formation of white mica and epidote respectively. Biotite is altered to chlorite. The mineral assemblage of these rocks usually consists of quartz, feldspar, biotite, muscovite, chlorite, and epidote. At a few localities mafic rocks are associated with quartzo-feldspathic rocks and their feldspars and amphiboles are also altered.

STRUCTURE

Thrusts. These are the earliest observed structures in the area. As is evident from Plate 3, several minor thrusts associated with the major ones have produced an imbricate structure. The rock units are piled up over one another in the form of thrust slices so that seven levels of these structural units have been recognized and mapped in the area (Fig. 18). The rocks within most of these thrust slices have been found to be right way up on the evidence of stratigraphy or sedimentary structures or both. A special symbol attached to the strike and dip symbol on the map (pls. 2 and 3) denotes the younging direction of the sequence as determined from sedimentary structures.

The thrusts seem to originate as bedding thrusts, remaining in one detachment horizon for some distance and then cutting upwards in the stratigraphy until they reach another such horizon. It seems that there is one major thrust, which defines the outer boundary of the Atnarpa Range and separates the basement from the cover rocks. The other thrusts are its off-shoots.

The thrust contacts are marked in the southern and central parts of Atnarpa Range by extensive brecciation of the Heavitree Quartzite, giving rise to a flinty crush rock and the pulverization of the soft rocks either in the Arunta Complex or in the cover rocks. These contacts are marked by mylonitization of the rocks in the north and northeastern parts of Atnarpa Range. Slickensides in the southern and central parts and a quartz-elongation lineation in the north and northeastern parts are also associated with these contacts.

Folds. On the macroscopic scale folds are represented by an anticline in the Western Hill and another anticline forming the Eastern Hill Range. The cross-section (AB) in Plate 3 is of the Western Hill anticline, which shows the slight asymmetry of the structure as well as folding of the thrusts. The axial trend and plunge of this structure varies from east to west; in the east the axial trend is northeast and the plunge very gentle. In the west the trend changes to northwest or even west-northwest and the plunge steepens to about 30° (Plate 3). The Eastern Hill Range anticline has a nearly constant west-northwest axial trend and an axial plunge of about 15° to 20° (Plate 3).

On the mesoscopic scale the folds associated with both the macroscopic folds are of concentric to disharmonic type. They are extensively developed in the hinge areas of the major folds in the upper member of the Heavitree Quartzite. The middle limb of these small folds dips steeply or is overturned to the south so that the folds are asymmetric. In the Western Hill anticline their axial planes dip north to north-northwest at moderate angles, and the trend and plunge of the axis varies from N50°E and gently plunging in the eastern part of the structure to N60°W and a plunge of about 30° in the western part. In the anticline of the Eastern Hill Range the axial planes generally dip north at angles not exceeding 45°, and the axes trend

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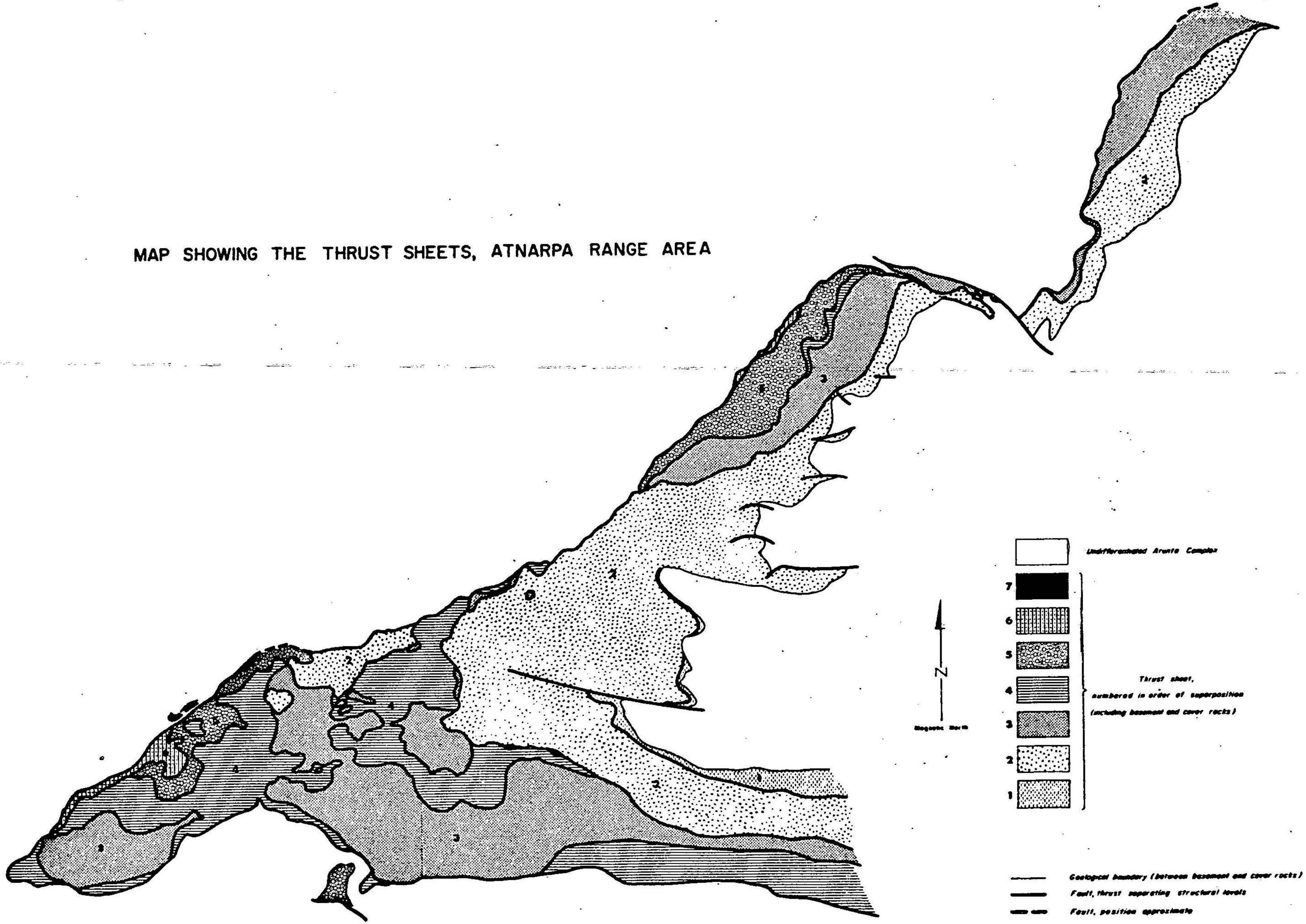
Fig 18

MAP SHOWING THE THRUST SHEETS, ATNARPA RANGE AREA



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west-northwest with a plunge varying generally between 10° and 25°. A crenulation lineation is associated with extensively developed minor folds. On the northern limb of the Eastern Hill Range (in the area between the road and the first major thrust from the south) box folds in conjugate sets are common, whereas the other types of folds described above are absent. The axial trend of these folds varies between northeast and north-northeast. The folds fold the quartz elongation lineation.

Schistosity, Lineation, and Other Structures

In most parts of the Atnarpa Range (represented by the Western Hill, the Small Valley, and the central part and the southern limb of the Eastern Hill Range) sedimentary bedding remains the dominant layering in the cover rocks, and sedimentary structures such as cross-bedding and ripple marks are preserved at many localities in the Heavitree Quartzite. The sedimentary structures are lost where the quartzite is brecciated near the thrusts. In some small zones of intense shearing, especially on the northern front of the Western Hill and in the basal member of the Heavitree Quartzite, the flattening of quartz grains imparts a schistosity to the rocks and with further deformation a streaky lineation also appears owing to the elongation of the grains. The schistosity generally remains parallel to the bedding, and the lineation plunges north to north-northwest except at a few localities where it is distorted by later folding. The rocks of the basement have a coarse foliation in the above-mentioned areas. A streaky north-plunging lineation appears in these rocks also near shear zones, but becomes more widespread in the northern front of the Western Hill. On the northern limb of the Eastern Hill Range the deformation is more penetrative, and the north-dipping schistosity and lineation are widespread in both the cover and the basement rocks. The schistosity and lineation in this area are associated with nearly upright to recumbent isoclinal folds. A crenulation lineation is present in the hinge areas of both the major anticlines, and trends parallel to the axial direction of mesoscopic folds associated with these structures.

Microscopic Structures

Both petrographic and microfabric studies of the Heavitree Quartzite have been made involving the description of textures and the measurement of quartz c-axis orientations. The latter were plotted on equal-area diagrams and contoured using the technique of Kamb (1959). The resulting patterns of preferred orientation were grouped together according to their microfabric types. The microfabric types (Figures 23, 24, 25, 26, and 27) were found to correspond directly to the textural types. (Figure 19)

Type 1 is characterized by the presence of detrital quartz grains with rounded to subrounded outlines, secondary overgrowths, local presence of undulate extinction, absence of deformation lamellae, and absence of dimensional orientation (Fig. 23). This type of texture is present in the western, central, and southern parts of Atnarpa Range in regions away from thrust zones and where other sedimentary structures are preserved. Preferred orientation of the c-axes is completely lacking (Fig. 19A). The major contour interval is 2σ with very small irregular areas of 4σ where σ is the standard deviation from the expected density of a uniform population (Kamb, 1959).

Type 2 is characterized by the presence of subrounded to angular grains in a mosaic-like groundmass of very fine-grained quartz which formed as a result of brecciation and/or recrystallization (Fig. 24). A fair degree of dimensional orientation is present. Undulose extinction and deformation lamellae are present. This type of texture is found in the middle member of the Heavitree Quartzite, particularly where it forms the footwall of a thrust. In the c-axes diagram there is a suggestion of a peripheral girdle, and an increase in the size of the pole-free areas (Fig. 19B). The girdle lies at a high angle to the bedding.

Type 3 is characterized by a high degree of flattening of the quartz grains and strong dimensional orientation (Fig. 25). Some grains show differing orientations of the c-axis in the two adjacent parts in which they tend to finally separate. This type of texture is restricted to narrow shear zones of intense deformation particularly in the northernmost parts of the Western Hill. There is a well defined peripheral girdle in the ac plane of the fabric with an increase in the area of contour interval 4σ, plus two concentrations reaching a maximum value of 10σ situated symmetrically within the girdle (Fig. 19C). This imparts a near-orthorhombic symmetry to the fabric.

Type 4 is characterized by the onset of recrystallization, which produces an aggregate of old, elongate, strained grains and new, polygonal, strain-free grains (Fig. 26). This texture is widespread in the northeastern part of Atnarpa Range, being the northern limb of Eastern Hill Range.

The preferred orientation is weak, but there is a distinct tendency toward the formation of two girdles intersection at a point normal to the mesoscopic lineation (Fig. 19D).

Type 5 is characterized by complete recrystallization, resulting in a network of new, polygonal grains (Fig. 27), with a faint dimensional orientation. This type of texture is present only in narrow zones of very strong deformation within a metre or so of the thrusts in the northern parts of the area.

The preferred orientation is strong, the c-axes forming a new girdle lying about 60° from the foliation (Fig. 19E). The pole-free area is now much larger than the pole occupied area, and the orthorhombic symmetry of the fabric is lost.

CONCLUSIONS

The degree and style of deformation are closely related to the thrusts in the Atnarpa Range but also vary from south to north. In the southern and central parts of Atnarpa Range the rocks have deformed in a brittle fashion along thrust faults, rather than in a plastic fashion. The textural or microstructural type 2 present in the Heavitree Quartzite and the corresponding preferred orientation are related to this type of deformation.

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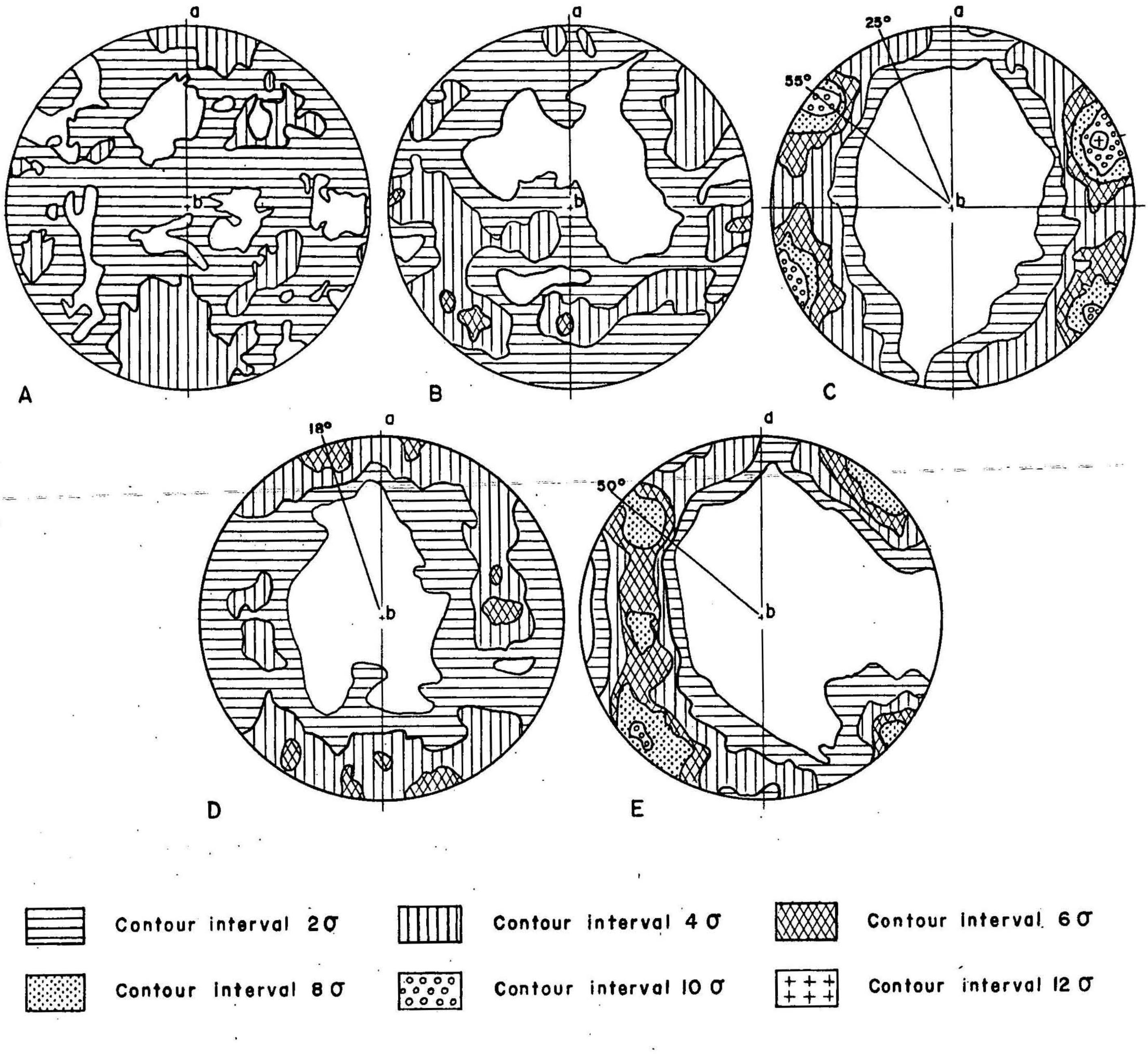

Fig. 19. Preferred orientation of quartz c-axes, Atnarpa Range area, showing preferred orientation types A, B, C, D, and E corresponding to microstructural types 1, 2, 3, 4, and 5 respectively (Specimens 103, 130, 186, 215, and 279 respectively).
ab is the trace of bedding in A and B.
ab is the trace of schistosity in C, D and E; b is the quartz elongation lineation in the schistosity plane.
Number of grains measured: A-300, B-340, C-240, D-300, E-300.

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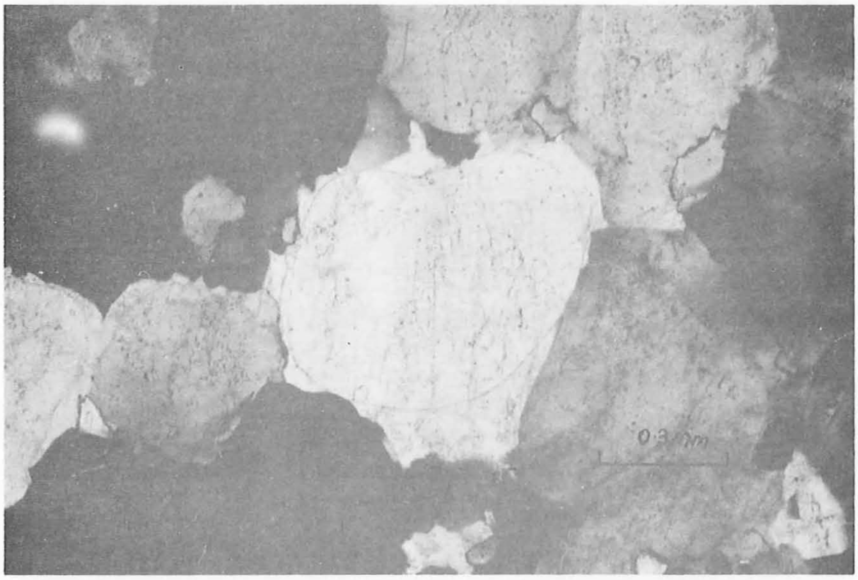

Figure 23. Undeformed detrital quartz grains (crossed-nicols; spec. loc. 103)

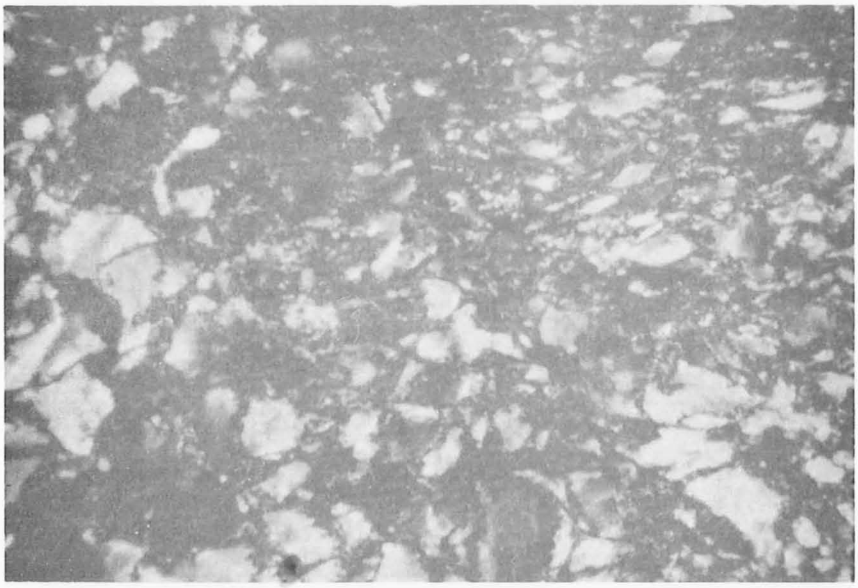

Figure 24. Sub-rounded to angular quartz grains in a mosaic of very fine-grained quartz. (Cross-nicols; spec. loc. 130; scale as above)

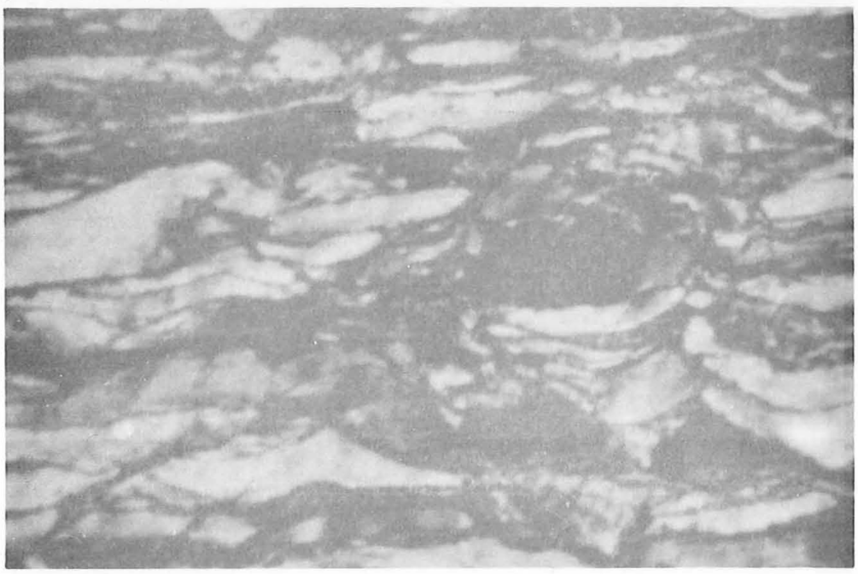

Figure 25. Old deformed quartz grains elongated in the plane of the schistosity (crossed-nicols; spec.loc.186 ; scale as above)

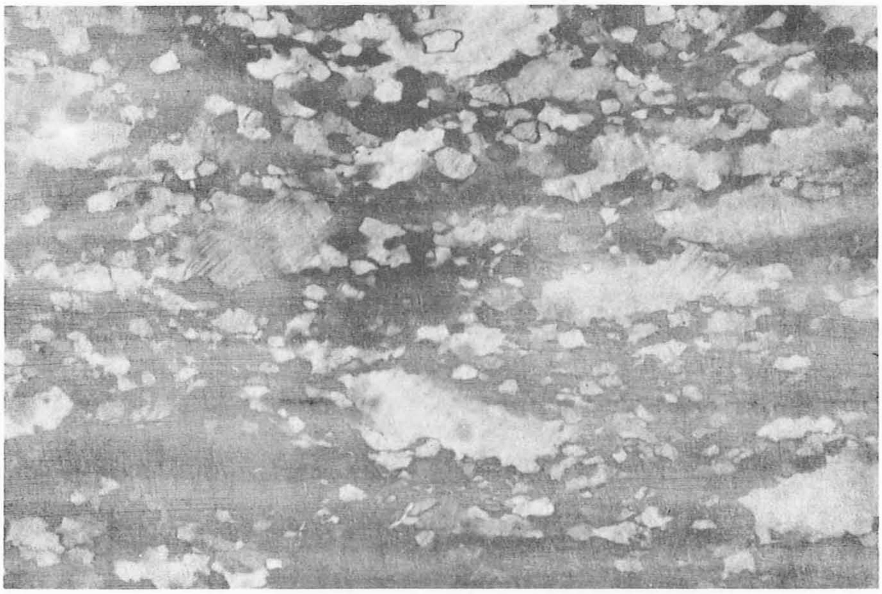

Figure 26. Old, deformed quartz grains with deformation lamellae and new polygonal grains. (Crossed-nicols; spec.loc. 215. Scale as for Figure 22) ANU 579A

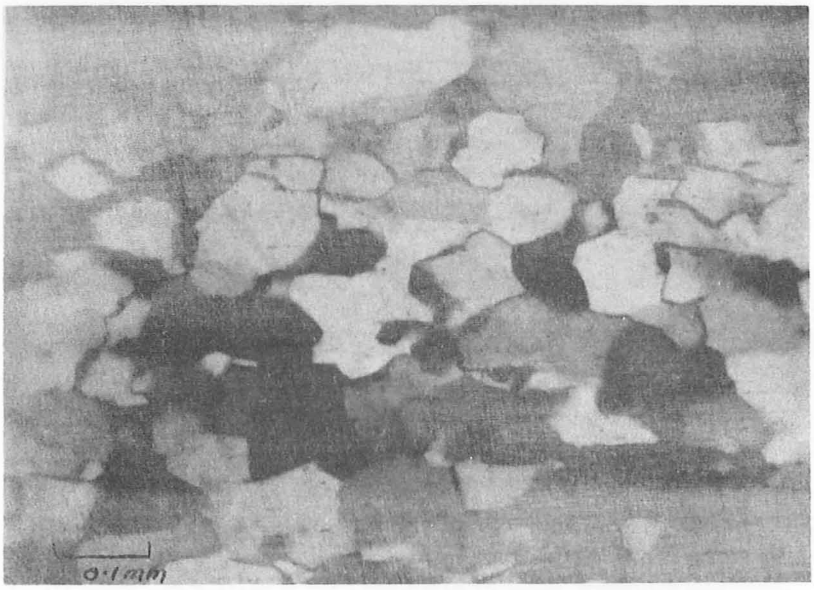

Figure 27. Completely recrystallized polygonal-shaped quartz grains. (Crossed-nicols mag.X136; spec. loc. 279)

Along thrust faults in the narrow belt on the northern part of the Western Hill, the quartz grains are first flattened, thus imparting a schistosity to the rocks which is generally parallel to the bedding; then with increase in deformation a lineation develops due to the elongation of the grains within the plane of the schistosity (microstructural type 3 and the corresponding preferred orientations). In microstructural type (4) the degree of preferred orientation seems to have been subdued by the onset of recrystallization, whereas in type (5) it again increases with complete recrystallization, but the symmetry of the fabric is lost and becomes heterotactic. In areas where the symmetry of the total fabric is near orthorhombic, as well as in areas where the microscopic subfabric is destroyed by complete recrystallization, the symmetry of the movement of deformation should be nearly orthorhombic also.

It is clear that the strain in the rocks increases pregressively northwards. The metamorphism also increase northwards as is shown by the onset of recrystallization; in fact a line can be drawn on the map north of which the recrystallization is clearly manifest and widespread, but as already stated, the effects of metamorphism are more pronounced in zones of narrow thrust slices where the rocks are completely recrystallized. It is likely, though not yet established, that the temperature would have generally increased northwards and that the rocks were more ductile and mobile in the north than in the south.

In the chronology of structural events, thrust faults seem to have developed first with associated development of schistosity and lineation and microscopic subfabrics. This relationship is based on the presence of schistosity and lineation and microstructural and preferred orientation type (3) in the close vicinity of thrust faults in a narrow belt on the northern front of Western Hill, and the change from microstructural and preferred orientation type (4) to type (5) with the proximity of the thrusts on the northern limb of Eastern Hill Range. The folding in the northern limb of the Eastern Hill Range is later than the thrusting, as the schistosity and the quartz-elongation lineations are both folded there by northeast-southwest folds. This is also true in part of the Western Hill where the thrust faults and the quartz elongation lineation are folded by west-northwest trending folds. In other parts of the area it is difficult to show this, as the quartz-elongation lineation is not developed there and the folds may have formed at the same time as the thrusts, although it is suspected that here also the thrusting took place before folding.

The original hypotheses that the movement direction in the Arltunga Nappe Complex was from north to south (or north-northeast to south-southwest) is supported by (1) the north to north-northeast plunging lineation, slickensides of the same trend in rocks which did not undergo a penetrative deformation, and (2) the asymmetric nature of the drag folds with axial planes generally dipping northward and axes trending west-northwest.

PRELIMINARY REPORT ON BASEMENT-COVER DEFORMATION IN THE PART OF THE WHITE RANGE NAPPE BETWEEN MOUNT LAUGHLEN AND THE GEORGINA RANGE

by

J.L. Funk (ANU)

INTRODUCTION

The area described in this chapter is part of the western portion of the White Range Nappe, and centres about Georgina Gap (Fig. 1; Pl. 4), which is situated between Mt Laughlen and the Georgina Range (Fig. 2). The rocks are well exposed, and display an abundance of small structures that record a complex history of deformation; hence, mapping at a scale of 1:23 000 is practicable, and in many places mapping at even larger scales is necessary. This study is not yet complete in extent or detail of mapping, and the results and interpretations presented here are only tentative.

STRUCTURAL GEOLOGY

Outline of the Large-scale Structure

The cover rocks (Heavitree Quartzite and Bitter Springs Formation) form prominent hills that trend generally east to southeast and rise above the closely dissected basement terrain (Arunta Complex). The cover can be divided into two units. The first is an autochthonous, mildly deformed, normal sequence of Heavitree Quartzite and lower Bitter Springs Formation which unconformably overlies the basement. It outcrops at Mt Laughlen and the Georgina Range as a series of gentle warps trending north and northeast respectively. These pass northwards into highly deformed cover rocks that trend east-southeast and constitute the second unit. They are characterized by a strong penetrative schistosity and several generations of folds. The second unit of the cover is considered to be allochthonous, because it is in fault contact with the autochthonous cover rocks to the south, and, along much of the northern contact, the Heavitree Quartzite is separated from the Arunta basement by a thin layer of Bitter Springs Formation (see Pl. 4, cross-sections). The overall structural configuration of the cover rocks appears to be a simple syncline which trends east-southeast and is overturned to the south, but the limbs of this syncline are refolded by smaller folds. Slices of Arunta basement are preserved in the core of the syncline, and are completely surrounded by Bitter Springs Formation.

The strongly deformed cover rocks (the second unit) and the overlying basement rocks were termed the White Range Nappe by Forman (1971), and are so depicted in Figure 2 of this record. However, in the area between Mt Laughlen and the Georgina Range, there is no evidence that the basement north of the cover rocks is allochthonous. The term 'nappe' in this chapter is applied only to the outliers of basement rock in the core of the cover syncline, and to the cover rocks around and north of the basement outliers.

Structural Geometry of the Cover Rocks

In the allochthonous cover rocks there is evidence of at least four generations of folds. The axial planes of all the fold generations are nearly parallel, i.e., they strike east to southeast and dip steeply north. Three of the fold generations are upright to inclined, and the other is inclined to reclined. The sequence of fold generations in the cover rocks is not completely clear, the nowhere has the interference pattern produced by three overprinted fold phases been seen.

A summary of the sequence of deformation in the Georgina Gap area is given in Figure 30. Deformation was probably continuous, and the division into separate episodes is merely a descriptive convenience.

First Folding Phase

The evidence for the earliest phase of deformation is indirect. Within the cover syncline are normal sequences of Heavitree Quartzite through to the Bitter Springs Formation overlain by slices of retrograded Arunta basement. These outcrops of basement rock are interpreted as klippen or tectonic fish, and consist of phyllonite that closely resembles refoliated basement rocks immediately to the north. The klippen must have been emplaced early in the deformational history, since they share with the surrounding rocks the imprint of a strong schistosity and two lineations. The existence of these klippen implies that translation along thrust faults (with associated folding (Fig. 30 (1)) carried basement rock through the Heavitree Quartzite into the highly ductile lower Bitter Springs Formation. Detailed mapping has revealed three distinct thrust faults between repeated sequences of basement and cover rocks. These faults may be 'splays' diverging from one major thrust fault, or they may be three independent faults. The hypothesis of early translation is supported by the occurrence of a narrow layer of Bitter Springs shale along the northern margin of the nappe, i.e., between the Heavitree Quartzite and the basement. The direction of tectonic transport was probably normal to the outcrop pattern, and the southward thrusting was almost certainly accompanied by folding.

Sedimentary structures indicate that all the thrust slices of cover rocks within the nappe young upwards; inverted bedding is restricted to the overturned limbs of second-generation folds. In conclusion, the superposition of basement upon cover involved gliding within the pile for several kilometres, and produced a stack of upright, fault-bounded slabs.

This interpretation of the earliest recognized structural events is by necessity simplified, as at least five gliding or decollement horizons are known in the Heavitree Quartzite (Fig. 28), and many thrust faults may remain unrecognized owing to a lack of marker beds. The structural events described in the above paragraphs represent the first phase of deformation in the development of the White Range Nappe, and virtually all the horizontal translation of the basement and cover of the nappe occurred at this time.

Second Folding Phase

The second-generation folds exhibit two orientations: reclined and inclined to upright. That the two orientations belong to the same phase is demonstrated by the presence of many small folds in both basement and cover rocks in which the pitch of the fold axes varies through 90° in the axial plane (Fig. 30 (2c)). (Occurrences of these folds are indicated on Plate 4 by the overprinting symbol). The variation in the plunge of the fold axes appears to be sinusoidal, and involves a periodic constriction which is similar to boudinage and is probably related to the map-scale extensional features delineated by the cover outcrop along the strike of the nappe.

The presence of large reclined folds is inferred from the detailed mapping of wide zones in which many small reclined folds show a consistent sense of vergence. The presence of large upright to inclined folds is difficult to establish, except where an obvious marker unit is preserved such as the Heavitree-Bitter Springs contact. Elsewhere, as in sections through the thick-bedded middle member that forms two-thirds of the Heavitree Quartzite, folds can only be inferred from systematic reversals in younging directions. Generally, bedding is difficult to recognize owing to transposition by pervasive schistosity; indisputable younging criteria such as current bedding, graded bedding, or sole markings are rare.

The style of folding is the same for both the large and small upright to inclined folds and the reclined folds. Characteristically, the folds are tight to isoclinal, with cleavage almost parallel to bedding on the limbs. There is a marked thickening in the fold cores, and a shape analysis of the folded layers places them in Ramsay's 1C Class of Flattened Parallel Folds (Ramsay, 1967, pp. 336, 387). Large bulk strains are recorded in the fold limbs by the complete transposition of bedding by cleavage, the obliteration of sedimentary structures by recrystallization of the quartz grains, and the high flattening strains indicated by pebbles that have been deformed into oblate ellipsoids whose long axes parallel the lineation. This direct field evidence implies that the folds classified as 1C are very close in shape to the ideal Similar Fold (Class 2 of Ramsay).

Associated with the second-generation folds is a strong, penetrative, axial-plane schistosity, which is termed 'S_1', because no axial-plane schistosity associated with the first-generation folds has been found. In hand specimens the schistosity appears like slaty cleavage, whereas in thin-section it is texturally a mylonite. Associated with the schistosity is a mineral-elongation lineation (usually quartz) that parallels the axes of the reclined folds; genetically it is a bedding-cleavage intersection lineation whose development is directly related to the formation of axial-plane schistosity in the reclined folds. The quartz-elongation lineation maintains a consistently steep, northward plunge along the strike of the nappe.

Third Folding Phase

Third-generation folds are common throughout the area, and characteristically refold the S_1 schistosity and transposed bedding about subhorizontal east-west axes to produce upright folds. The folds commonly 48

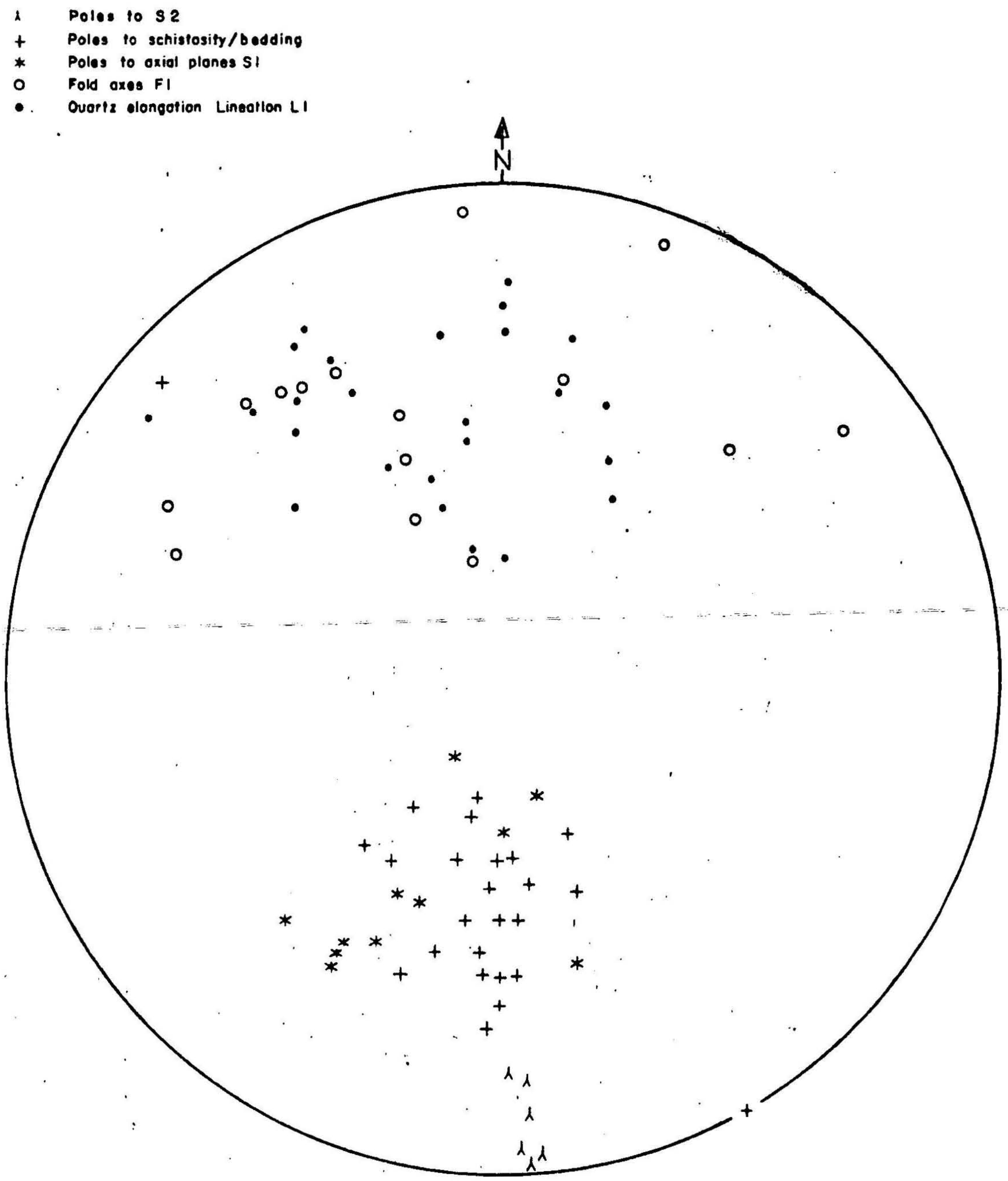

Fig. 28 Equal-area projection of first generation quartz elongations and fold axes, and first and second generation planar elements.

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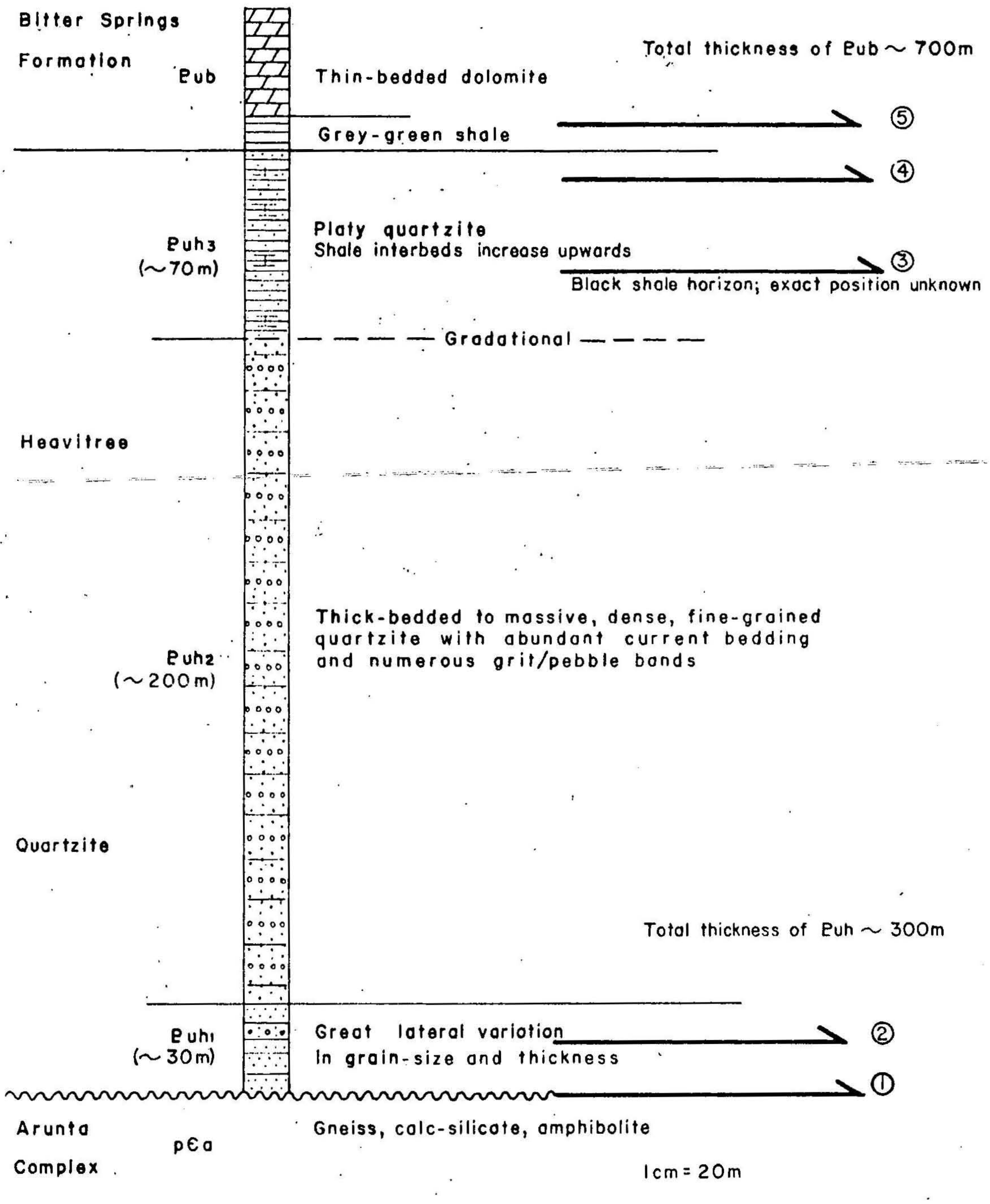
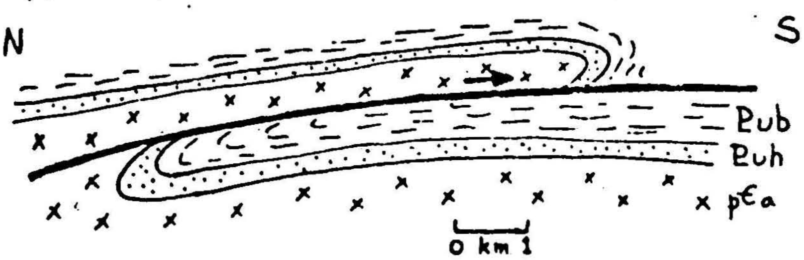
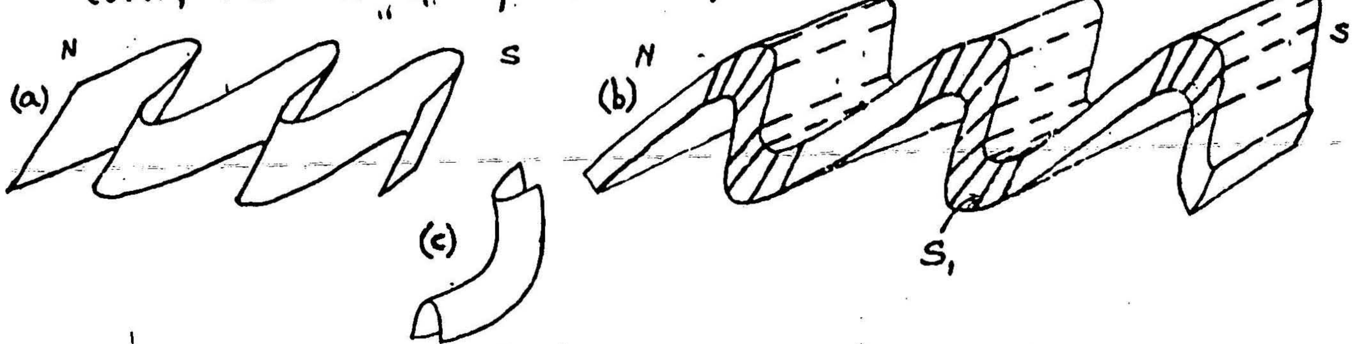


Fig 29 Graphic section of Heavitree Quartzite and lower Bitter Springs Formation, showing positions of thrust surfaces (1,2,3, etc.) (decollement horizons)

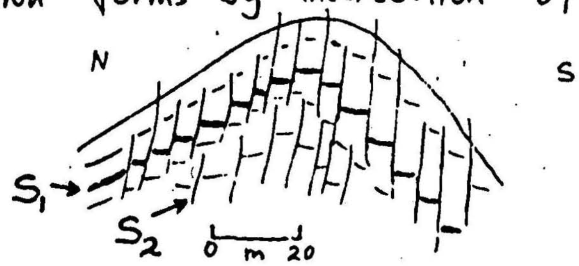
1. Period of nappe emplacement; inferred folding and thrusting.



2. Formation of (a) tight to isoclinal, reclined folds, or (b) tight to isoclinal, upright to inclined folds, or (c) both, simultaneously in some areas, elsewhere one dominates the other. Formation of axial-plane schistosity (S_1) in basement and cover, and down-dip lineation, common to all three types



3. Formation of close to tight upright folds with crenulation cleavage (S_2); S_1 is folded by these folds, and subhorizontal lineation forms by intersection of S_1 and S_2



4. Formation of kinks, sigmoidal quartz veins, fractures, normal faults, and warps at Mt Laughlen and the Georgina Range

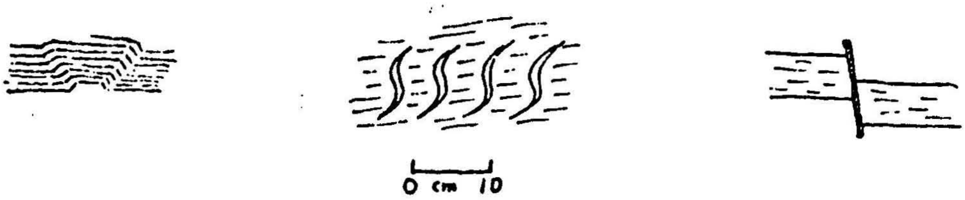


Fig. 30 Sequence of deformation in the Georgina Gap area.

contain an axial-plane crenulation or intersection lineation which parallels the fold axis.

Fourth Folding Phase

The fourth and final phase of deformation consists of various 'brittle' structures that overprint all the previous structures. These include kink folds (in places as conjugate sets), arrays of sigmoidal quartz veins, closely spaced fractures, joints, and small-separation normal faults. The kinks and broad open folds found at Mt Laughlen and in the Georgina Range probably formed during this last phase of deformation. Exact correlation is difficult to establish, however, as the folds are oriented transversely to the structural trend of the nappe; no cleavage or lineation is associated with these folds, and they do not appear to overprint any earlier structures in either the allochthon or autochthon.

The sequence of four folding phases outlined above represents the maximum amount of deformation recorded in the rocks. The intensity of deformation appears to have varied in both time and space, and so it is unlikely that all fold generations would occur at the one locality.

Description of the Basement

Two major lithologies are present in the basement terrain of the area. South of Georgina Gap is a region of monotonous granitoid augen gneiss, bounded on the northwest by a mixed metasedimentary sequence, which also crops out north and east of the nappe. The gneiss-metasediment contact trends north-south, and intersects the south-southeast trend of the nappe in the vicinity of Georgina Gap. Before the Alice Springs Orogeny, the Arunta basement underwent at least three generations of folding, and was metamorphosed to the upper amphibolite facies. Remobilization of the basement began with the first phase of folding in the cover, but climaxed with the coeval development of a penetrative schistosity in the basement and cover associated with the second phase of folding. This S_1 schistosity refoliated the basement in a narrow zone adjacent to the cover rocks of the nappe, and produced folds of the same style and orientation as in the cover. Although the refoliated zone demonstratably cuts across the basement lithologies, the bulk of the refoliated rocks were originally metasediments and orthogneisses, the latter mineralogically similar to the granitoid augen gneiss south of the nappe.

The refoliated basement rocks are classified as blastomylonite if derived from a gneissic parent rock, or phyllonite if derived from a metasedimentary parent. Both consists mostly of biotite and quartz, and the different textures depend on the grain-size and relative proportions of the two minerals present.

Metamorphic grade during deformation

Index minerals in the area are not common, and the general rarity of kyanite, diopside, garnet, and hornblende, either as relics or as new phases, is contrasted with the abundance of epidote, actinolite, and chlorite. The assemblages noted represent a much higher grade for the refoliated basement than that reported in other areas, and is consistent with conditions of the uppermost greenschist to the lower amphibolite facies. The refoliation of the basement is clearly the result of a period of dynamic, retrograde, hydrous metamorphism.

The metamorphic grade of the cover rocks is more difficult to determine, owing to a virtually monomineralic composition. X-ray diffraction study of a sample of the Bitter Springs Formation in contact with the basement found that the slaty recrystallized siltstone was composed entirely of muscovite and quartz.

CONCLUSIONS

Mapping in the Georgina Gap area has substantiated the hypothesis of nappe emplacement by thrust-faulting. Remobilization of the basement, although a continuous process, can be described only at its incipient and final stages of development. During the incipient stage the basement exerted strong control over the growth of the nappes, in that slabs of basement were emplaced into the cover as rigid fault-bounded masses. The basement rock appears to have been transported south in an undeformed and unaltered state like the great areas of allochthonous basement described by Forman (1971). The formation of the S_1 schistosity represents the peak of the basement remobilization, and marks the cessation of the period of horizontal translation and nappe formation. At this stage the basement and cover became welded together and subsequently deformed as a single unit. The development of the refoliated zone was not, therefore, part of the process that mobilized and forced the basement into the cores of the thrust nappes. Age determinations from the new micas parallel to the S_1 schistosity in the Arltunga area (Stewart, 1971a), date the second phase of the deformation as pre-Middle Carboniferous, and place a minimum age on the emplacement of the White Range Nappe. The White Range Nappe must root somewhere in the refoliated basement immediately north of the cover rocks.

DEFORMATION PROCESSES IN THE WESTERN PART OF THE WHITE RANGE NAPPE

A.J. Stewart (BMR)

INTRODUCTION

When Forman and Milligan mapped the Arltunga Nappe Complex in 1964 (Forman, Milligan, & McCarthy, 1967), they observed that much of the Heavitree Quartzite and Bitter Springs Formation in the southern part of the complex was practically unmetamorphosed, and on the supposition that this low grade of metamorphism might have resulted in the preservation of microscopic structures which in many deformed rocks are obliterated by recrystallization, the author made a study of the western part of the White Range Nappe in order to determine the sequence of events and the nature and extent of the deformation processes that led to the emplacement of the nappe, to ascertain the physical conditions that prevailed during the emplacement, and to compare the deformational behaviour of the basement and cover rocks. Much of the material in this chapter is summarized from a thesis submitted to the Graduate School of Yale University (Stewart, 1971b).

In the area studied (Fig. 31), the southern and northern parts of the White Range Nappe differ from each other in a number of ways, and the differences exist in both basement and cover rocks. The basement rocks have undergone retrograde metamorphism throughout the nappe, the degree of retrogression being slight in the southern part of the nappe, and markedly greater both in extent and grade in the northern part: concomitant with this, K-Ar dates in the basement rocks, are re-set from Carpentarian* in the south (1660 - 1368 m.y.) to Middle Palaeozoic (431 - 345 m.y.) in the north. The trends of mesoscopic structures in the southern basement rocks have no obvious relation to the macroscopic form and symmetry of the nappe, but in the northern area the macroscopic and mesoscopic structures are homotactic, i.e., have the same symmetry and orientation. On the microscopic scale, deformation is slight in the southern basement rocks, but substantial in the northern area, where it involved chiefly cataclasis of feldspar and syntectonic recrystallization of quartz; the quartz microfabric of the rocks is homotactic with the macroscopic and mesoscopic structures.

Similar changes are evident in the Heavitree Quartzite cover of the nappe. In the southern area the quartzite is an unmetamorphosed sandstone which is commonly brecciated but shows only very slight microscopic deformation. With increasing distance northwards, the grains are syntectonically recrystallized and become more and more flattened vertically and elongated north-south and to a lesser extent east-west. Mesoscopic folds and penetrative structures are absent in the southern area, but are well developed in the north, where they are homotatic with the macroscopic structure of the

*The use of the term 'Carpentarian', which is the period of time from about 1800 m.y. to about 1400 m.y., follows the proposal of Dunn et al (1966).

nappe and with the mesoscopic basement structures. The quartz microfabric is random in the southern area, but homotactic with the other fabrics in the northern area. Sericite in the northern quartzite gives Carboniferous K-Ar dates (358 - 322 m.y.).

An inferred boundary between the southern and northern parts of the nappe is shown in Figure 31. Its curved shape suggests that it was folded during emplacement of the nappe, and represents, or is parallel to, a folded isograd or geotherm. However, an alternative explanation might be that the rocks were deformed and metamorphosed simultaneously, and the possibility also exists that metamorphism succeeded deformation and affected the most deformed part of the nappe.

DESCRIPTION OF ROCK UNITS

A short description of the major rock-types in the White Range Nappe is given here; detailed descriptions are set out in Stewart (1971b).

BASEMENT ROCKS

Autochthon

The autochthonous basement rocks west of the White Range Nappe consists chiefly of coarse-grained granitic gneiss in which discrete bodies of other rock-types are present (Fig. 32). The largest of these are a mass of melanocratic syenite (R.D. Shaw, pers. comm.) in the north-eastern part of the area, and a lens of interlayered hornblende gneiss and granite in the northwest; a prominent pod of peridotite is situated at the southern end of this lens. Other rock-types include numerous bodies of hornblende amphibolite and quartz diorite in the southern part of the area, and also dykes of basic lamprophyre (vogesite and alnoite). Pegmatite and epidosite are common throughout the area.

Southern Part of Nappe

In contrast to the autochthon, the basement rocks in the southern part of the nappe are chiefly metasediments (Fig. 32). In the southwestern part of the area the rocks include interbedded marble and calc-silicate rock (characterized by epidote, actinolite, and diopside), andalusite-mica schist, and quartzite. These are overlain to the east by quartz-rich plagioclase-biotite gneiss (Fig. 32), which in the eastern part of the area contains abundant sillimanite. Bodies of amphibolite are common throughout the area; the characteristic amphibole in these is hornblende or actinolite in the west, and anthophyllite (generally accompanied by cordierite) in the east.

The abundance of andalusite in the western part of the area and of cordierite in the east indicate that the mineral assemblages belong to the Abukuma or low-pressure facies series (Miyashiro, 1961). The south-western part of the area has transitional greenschist-amphibolite assemblages, and the grade rises eastwards from there to the middle of the amphibolite facies (specifically, the sillimanite-cordierite-muscovite-almandine sub-facies of Winkler, 1967).

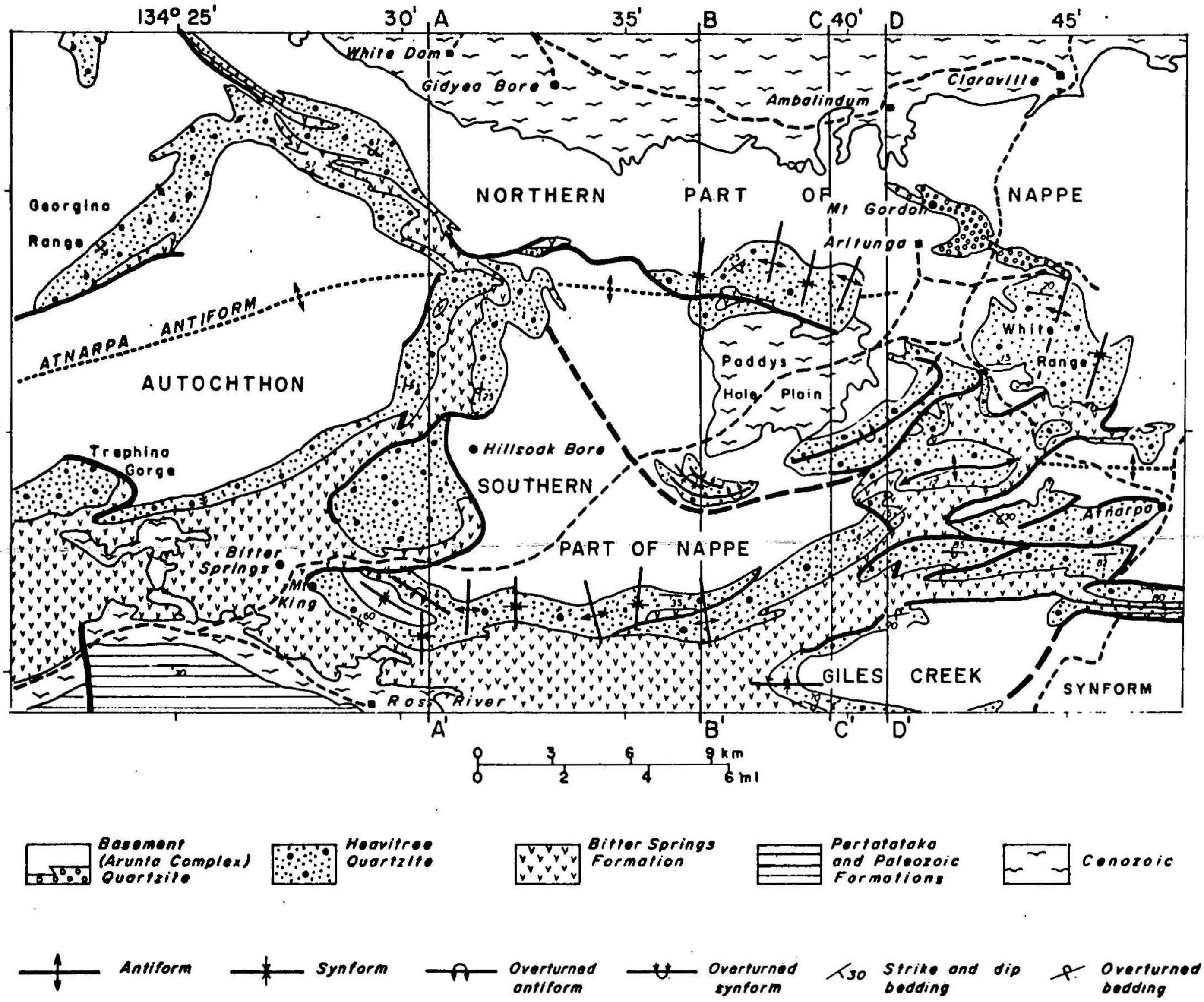


Fig. 31. Geological map of western part of Arltunga Nappe Complex, showing macroscopic fold axes and boundary (thick dashed line) between southern and northern parts of White Range Nappe. Formation boundaries taken from Alice Springs 1:250,000 Geological Sheet (First Edition, 1968), with modifications after Forman, Shaw, and the author. A-A', etc, mark positions of cross sections. (Fig. 37).

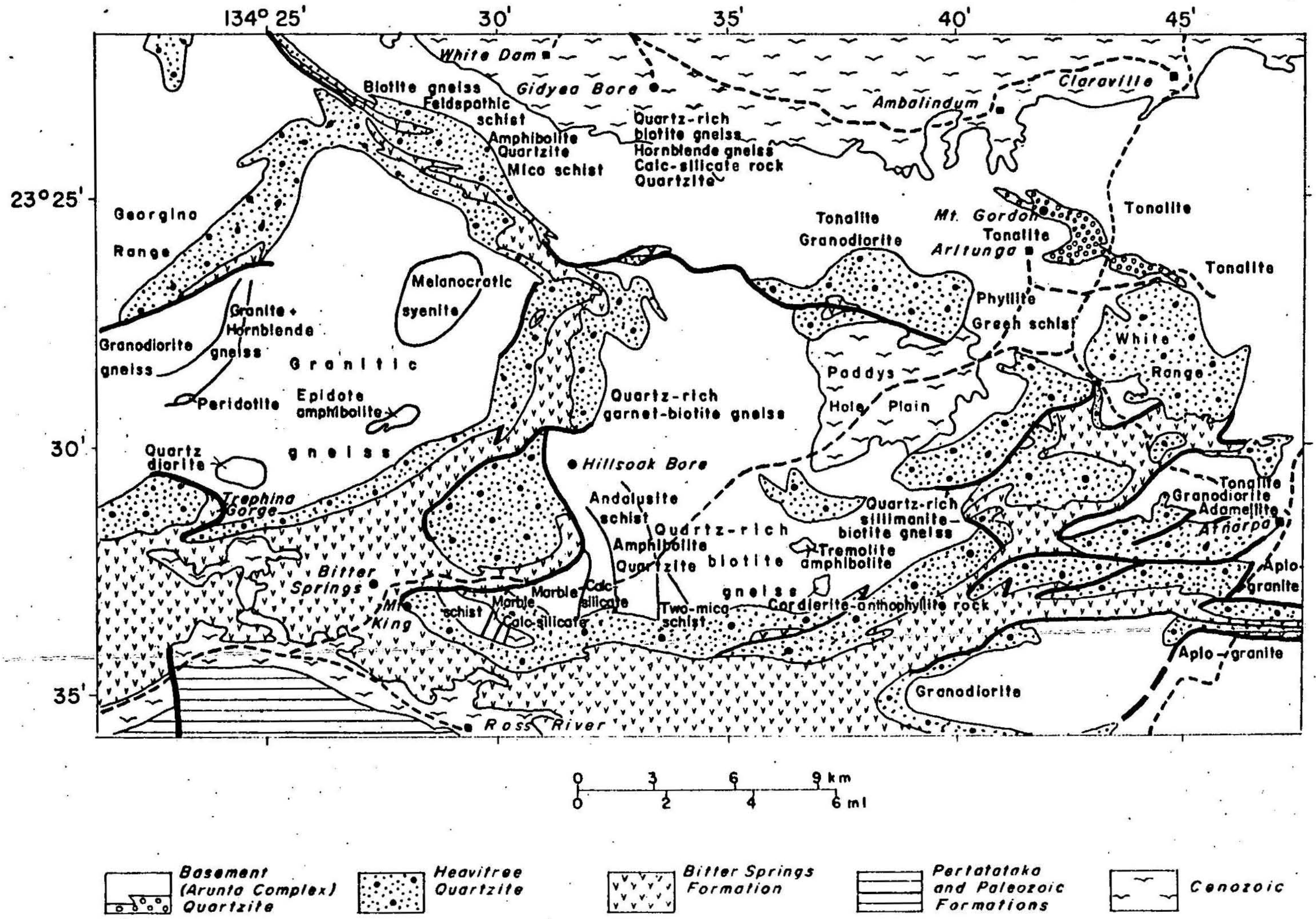


Fig. 32. Geological map of western part of Arltunga Nappe Complex, showing distribution of basement rock-types.

K-Ar dates on hornblende, muscovite, and biotite from the southern part of the nappe are all Carpentarian in age, and range from 1 660 to 1 368 m.y.; details of isotopic dates are set out in Stewart (1971a).

Northern Part of Nappe

The basement rocks in the northern part of the nappe are very heterogeneous. In the western and central parts of the area the major rock-types are quartz-rich biotite gneiss (± garnet), mica schist, hornblende amphibolite, and pegmatite; minor rock-types include epidotized gneiss, quartzite, marble, vein quartz, and epidosite. The eastern part of the area consists mostly of retrogressively metamorphosed tonalite (Fig. 35) and granodiorite, with some greenschist and micaceous quartzite. All the assemblages (before retrogression) were of the amphibolite facies, and compatible with either the moderate high-pressure (Barrovian) or low-pressure (Abukuma) facies series.

K-Ar dates on two hornblende samples from the northern part of the nappe are 2 132 and 1 639 m.y.; on seven biotites the dates range from 1 775 to 370 m.y. (Carpentarian to Late Devonian), and on seven muscovites the dates range from 431 to 345 m.y. (Late Silurian to Early Carboniferous). One muscovite from the large lens of basement quartzite that crops out northwest of White Range gave a K-Ar date of 1 077 m.y.; the significance of this date is discussed elsewhere (Stewart, 1971a).

Retrogressive Metamorphism

As mentioned in the Introduction to this chapter, the basement rocks of the White Range Nappe show widespread, though patchy, retrogressive metamorphism, whose extent and grade increase northwards. In the southern part of the nappe, plagioclase is almost everywhere altered to sericite ± clinozoisite, and in many specimens the alteration is complete. Biotite in parts of the biotite gneiss is altered to chlorite, and ilmenite in amphibolite is rimmed with sphene. Epidotization along fractures is visible in several outcrops of gneiss and amphibolite. Two samples of sericite which had completely replaced plagioclase gave K-Ar dates of 596 and 534 m.y. (Stewart, 1971b), and are interpreted as indicating that the bulk of the sericite formed in Middle Palaeozoic times, and contains either some old (Carpentarian) sericite, and/or excess argon derived from outgassing of biotite in the surrounding rocks. If this interpretation is accepted, then it is possible that the other retrograde effects in the southern part of the nappe also formed in Middle Palaeozoic time, i.e., during the Alice Springs Orogeny.

In the northern part of the nappe, retrograde effects are visible in nearly every thin section examined. Plagioclase + microcline in granitoid rocks and pegmatite have reacted to form albite + clinozoisite + white mica (Fig. 35), biotite is partly or completely altered to chlorite, and quartz is recrystallized to mosaics of small polygonal grains (Fig. 35). In the biotite gneiss of the central part of the area, plagioclase is replaced by sericite, and biotite has reacted to chlorite + muscovite. These white micas all give Middle Palaeozoic K-Ar dates (see previous section), indicating that they formed during the Alice Springs Orogeny. The biotite dates are spread from Carpentarian to Devonian, and Rb-Sr dating is in progress to determine whether the spread arises from only partial recrystallization of the biotite, or from introduction of extraneous argon into completely recrystallized biotite.

The retrograde assemblage in the southern part of the nappe is characterized by chlorite and sericite, and thus belongs to the lowest part of the greenschist facies; at a lithostatic pressure of about 2kb, which corresponds to the total thickness of the pre-orogenic part (pre-Pertnjara Group) of the Amadeus Basin sequence, this assemblage indicates a temperature of about 250°C in the rocks (Turner, 1967). In the northern part of the nappe, the characteristic retrograde minerals are albite and epidote (or clinozoisite) and possibly biotite (see previous paragraph). This assemblage belongs to the middle of the greenschist facies, where the temperature is about 350°C, (Turner, 1967, p.366).

HEAVITREE QUARTZITE

In thin-section, the unmetamorphosed Heavitree Quartzite consists of well rounded grains of quartz cemented by optically continuous overgrowths of silica (Fig. 45). The grains contain numerous inclusions which are commonly arranged in rows and probably represent microcracks, as the rows extend through several grains without interruption; much of the included matter is opaque, dusty material, some of which was identified as hematite, and some as monazite; fluid inclusions were not seen. Small colourless flakes between the quartz grains are probably a clay mineral. Laminae of bimodal sandstone are present in some specimens (Fig. 46). Accessory minerals are chiefly well rounded grains of zircon and tourmaline; a small amount of calcite is present in one sample from the lower part of the middle member.

MACROSCOPIC STRUCTURE

As currently interpreted, the White Range Nappe comprises a western lobe and an eastern lobe, both of which occupy depressions between domal areas of autochthonous rocks, one to the east and one to the west of the nappe, and a third near the centre of the area, viz., the area of autochthonous Heavitree Quartzite and Bitter Springs Formation southwest of White Range (Fig. 36). The two lobes are essentially synformal in east/west cross-section, and their B-axes trend west-northwest. Several other macroscopic fold axes also trend west-northwest or east/west, e.g. the Atnarpa Antiform, which strikes through the centre of the nappe complex, and the Giles Creek Synform, which is the southern part of the eastern lobe of the nappe (Fig. 36). Some minor macroscopic flexures trend at right angles to this direction, e.g., along the southern edge of the western lobe of the nappe and in the range on the northern side of Paddys Hole Plain (Fig. 31).

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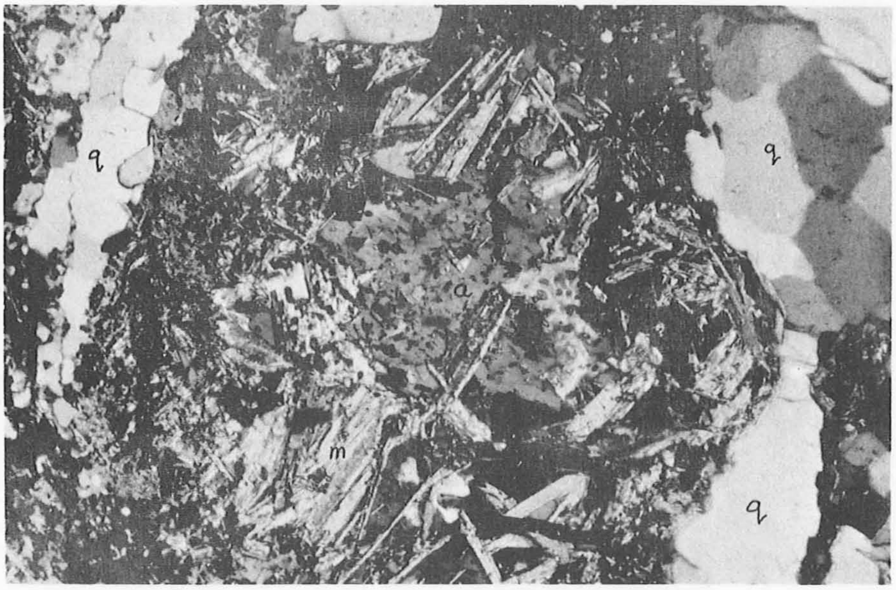

Fig. 35. Photomicrograph of retrogressively metamorphosed tonalite from 4 km northeast of Arltunga, showing coarse white mica (m), albite (a), and recrystallized quartz (q). K-Ar date on white mica = 352 m.y. Crossed nicols. Length of field = 2 mm.

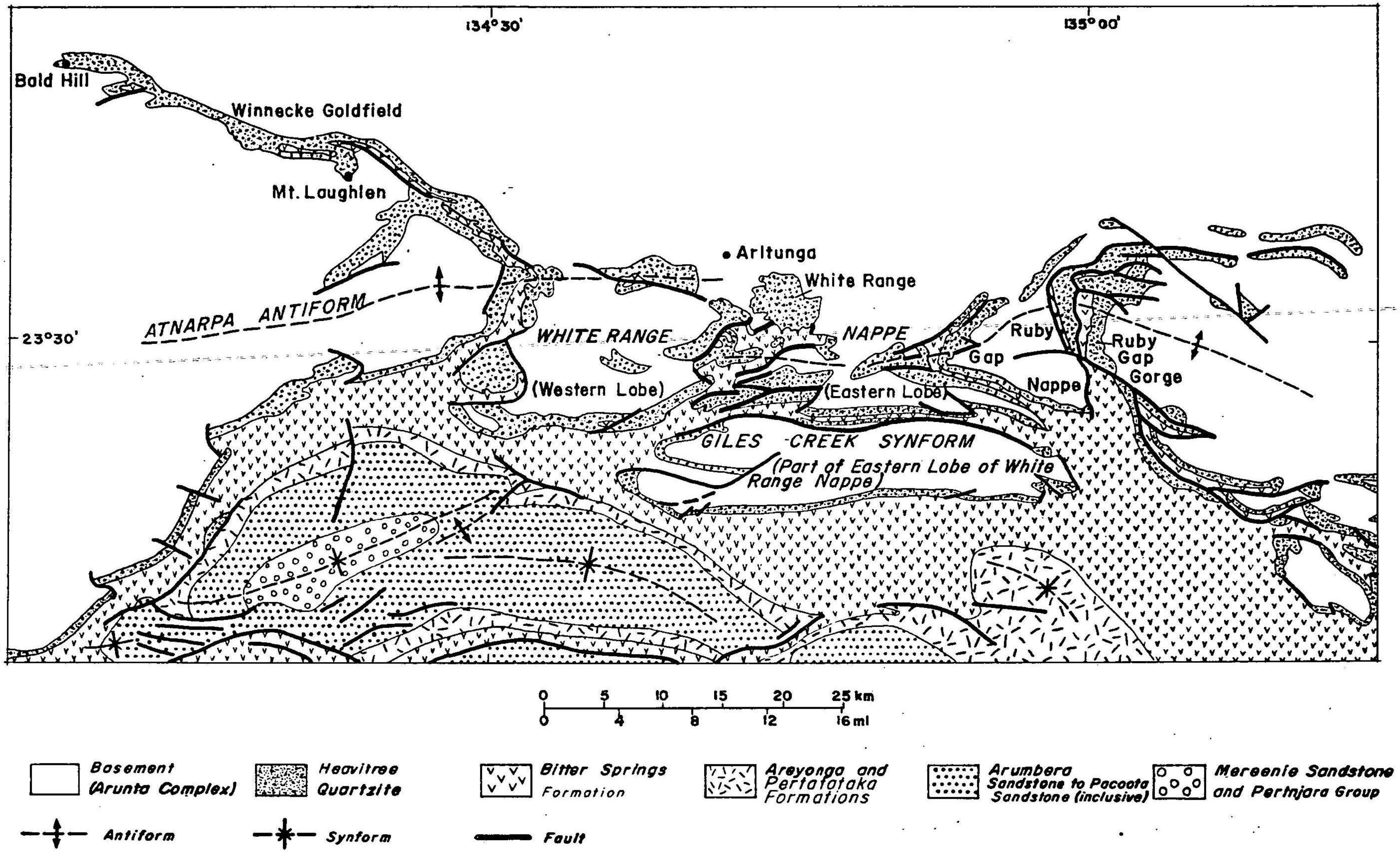

Fig. 36. Geological map of Arltunga Nappe Complex (slightly modified from Bur. Min. Resour. Rept. 113, Pl. 16 after Forman and Shaw, pers. comm.).

Several cross-sections through the western part of the nappe complex are shown in Figure 37.

MESOSCOPIC STRUCTURES

BASEMENT ROCKS IN SOUTHERN PART OF NAPPE

The schist and gneiss in the southern part of the White Range Nappe have a typical metamorphic foliation, lineation, and lithologic layering, and the lineation is invariably in the plane of the foliation. In contrast, the masses of amphibolite in the area are but weakly foliated or massive. The marble and calc-silicate rocks are prominently laminated, and in thin section this is seen to be relict bedding accentuated by metamorphic differentiation.

Poles to foliation in the southern part of the nappe are plotted in Figure 38a; the contoured points form two partial girdles, one with a pi-axis* plunging 30° northwest, the other with a pi-axis plunging 50° east. Linear grain orientations are plotted in Figure 38b, and show a concentration trending northwest/southeast.

Folds** in the southern part of the nappe are of various types, and are most commonly found in the lithologically layered rocks. The hinges of folded pegmatite lenses commonly grade into fold mullions. All fold axes are plotted in Figure 38c, and the poles to their axial planes, where measurable, are plotted in figure 38d. The fold axes show a weak axial concentration with a northwest trend, and it is apparent that most of the axial planes are steep to vertical, i.e., the folds are upright.

BASEMENT ROCKS IN NORTHERN PART OF NAPPE

Mesoscopic structures in the basement rocks of the northern part of the White Range Nappe are noticeably different in style and orientation from those in the southern area, and there is a noticeable paucity of massive rocks. Most bodies of amphibolite, pegmatite, and vein quartz are foliated and lineated concordantly with the surrounding rocks, whereas in the southern area these rock-types are massive.

Foliation in the northern area is characteristically a schistosity; the rocks tend to be flaky and easily cleaved, and litholigic layering is scarce. The rocks are prominently lineated in the plane of the foliation. Poles to foliation and mineral lineations are plotted in Figures 38 e and 38f respectively. The poles to foliation define a single pi-axis, which plunges north-northeast at 30°, and the lineations are concentrated around the same direction.

Folds in the northern part of the nappe are generally small crumples in the schistose rocks, or isoclinal folds in quartz veins. Fold axes and poles to axial planes are plotted in Figures 38g and 38h respectively.

*Pi-axis is used in the sense of Ramsay (1967) to indicate the axis of a great-circle girdle obtained by plotting poles to surfaces.
**Fold terminology in this chapter follows Fleuty (1964).

The fold axes show some concentration around a line plunging gently north-northeast, subparallel to the lineation maximum. Figure 38h shows that most of the folds in this part of the nappe are reclined or recumbent.

HEAVITREE QUARTZITE

Mesoscopic structures in the Heavitree Quartzite include brecciation (with associated quartz veins), foliation and lineation, folds, boudins, mullions, and kink bands. Quartz veins and brecciation are most prominent in the southern part of the nappe, though they are also found in the northern area; the other structures listed are found only in the northern area.

Brecciation

Brecciation is mainly found in the southern part of the nappe, and is particularly common where the quartzite is thinned and overturned. The breccia consists of small angular fragments of quartzite a few centimetres across; bedding is discernible in areas of less disturbed though still fractured rock. Quartz veins are associated with the brecciated quartzite, and commonly occur in swarms. In the northern part of the nappe vein quartz forms irregular masses or 'quartz blows' up to several metres across; some of these consist of a coarse, blebby mixture of quartz and fine-grained green muscovite.

Foliation and Lineation

Foliation and lineation are imparted to the quartzite by the parallel alignment of the flattened ellipsoidal quartz grains in the rock, and of the sericite flakes and aggregates. Pebbles and siliceous concretions in the deformed quartzite are also ellipsoidal, and lie in the foliation plane with their longest axes parallel to the lineation. Except in the ranges on the southern side of Paddys Hole Plain, foliation is in general parallel to bedding. Pi-diagrams of all foliation and lineation measurements in the Heavitree Quartzite are shown in Figures 39a, 39b, 39c. Figure 39a, poles to foliation from non-folded localities, shows a partial great-circle girdle with a pi-axis (π_1) plunging north-northeast at 20°. Figure 39b, poles to folded foliation, shows a great-circle girdle whose pi-axis (π_4) plunges east at 2°. The lineation diagram (Fig. 39c) includes measurements from folded and non-folded areas, and shows a single strong maximum plunging north-northeast at 17°, plus a spread of points along a great circle whose pi-axis (π_5) plunges east-southeast at 20°.

Folds

Three generations of mesoscopic folds are present in the Heavitree Quartzite.

(i) South-verging Folds

These are the earliest folds observed in the Heavitree Quartzite, (Fold Generation 1 in Table 1) and are found only in the ranges on the southern side of Paddys Hole Plain. The folds are open to close flexural-slip folds with east-west subhorizontal axes and vertical to north-dipping axial plans, i.e., the folds verge south. The foliation in the quartzite dips gently north, and transects the bedding on both limbs of the folds.

63

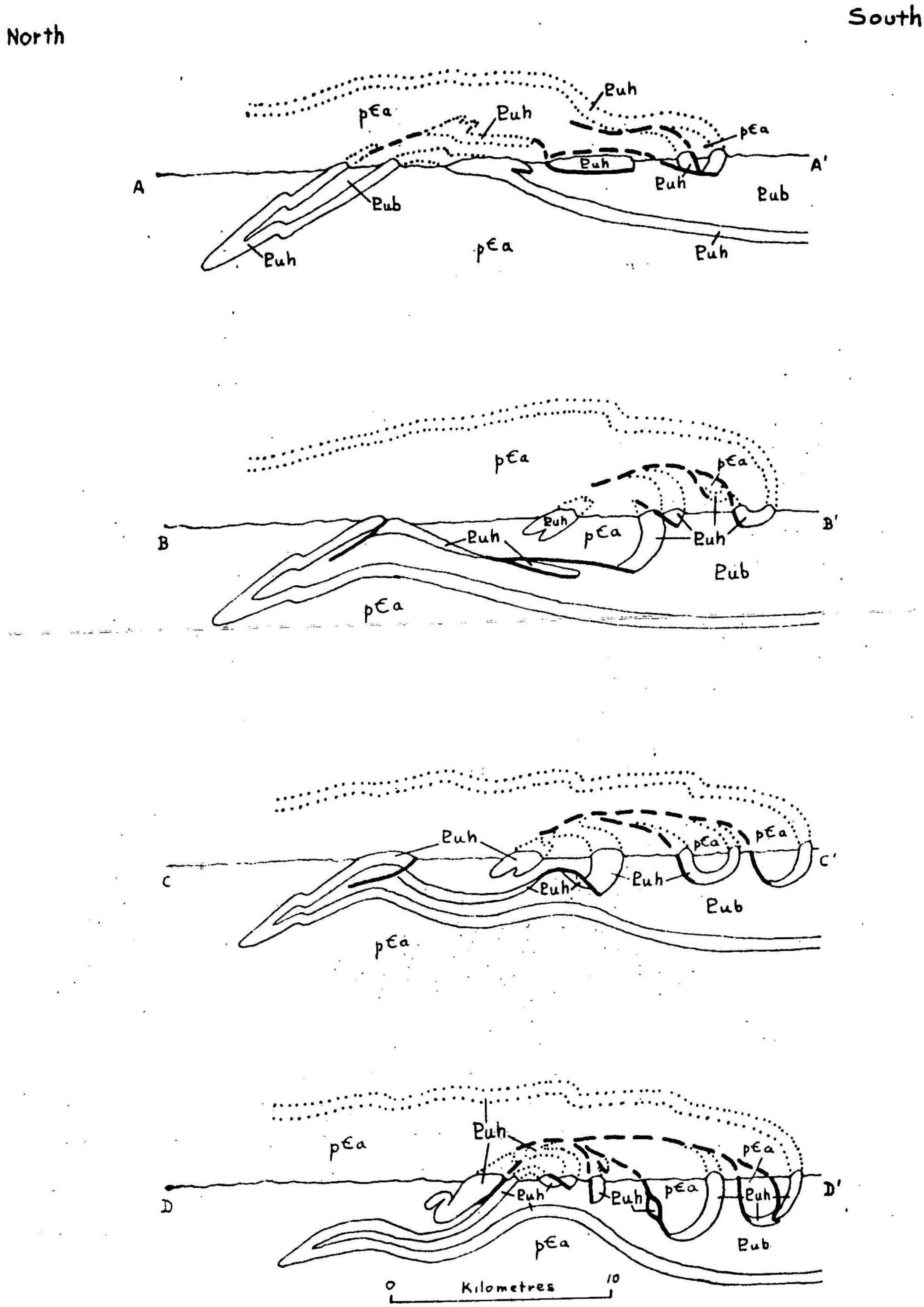

Fig. 37 - Cross-sections through western part of White Range Nappe, Arltunga Nappe Complex, central Australia

pЄa	Arunta Complex	Ꞓuh	Heavitree Quartzite	Ꞓub	Bitter Springs Formation

A.J. STEWART 1972

Position of cross-sections shown in Figure 31.

To accompany Rec. 1971/66

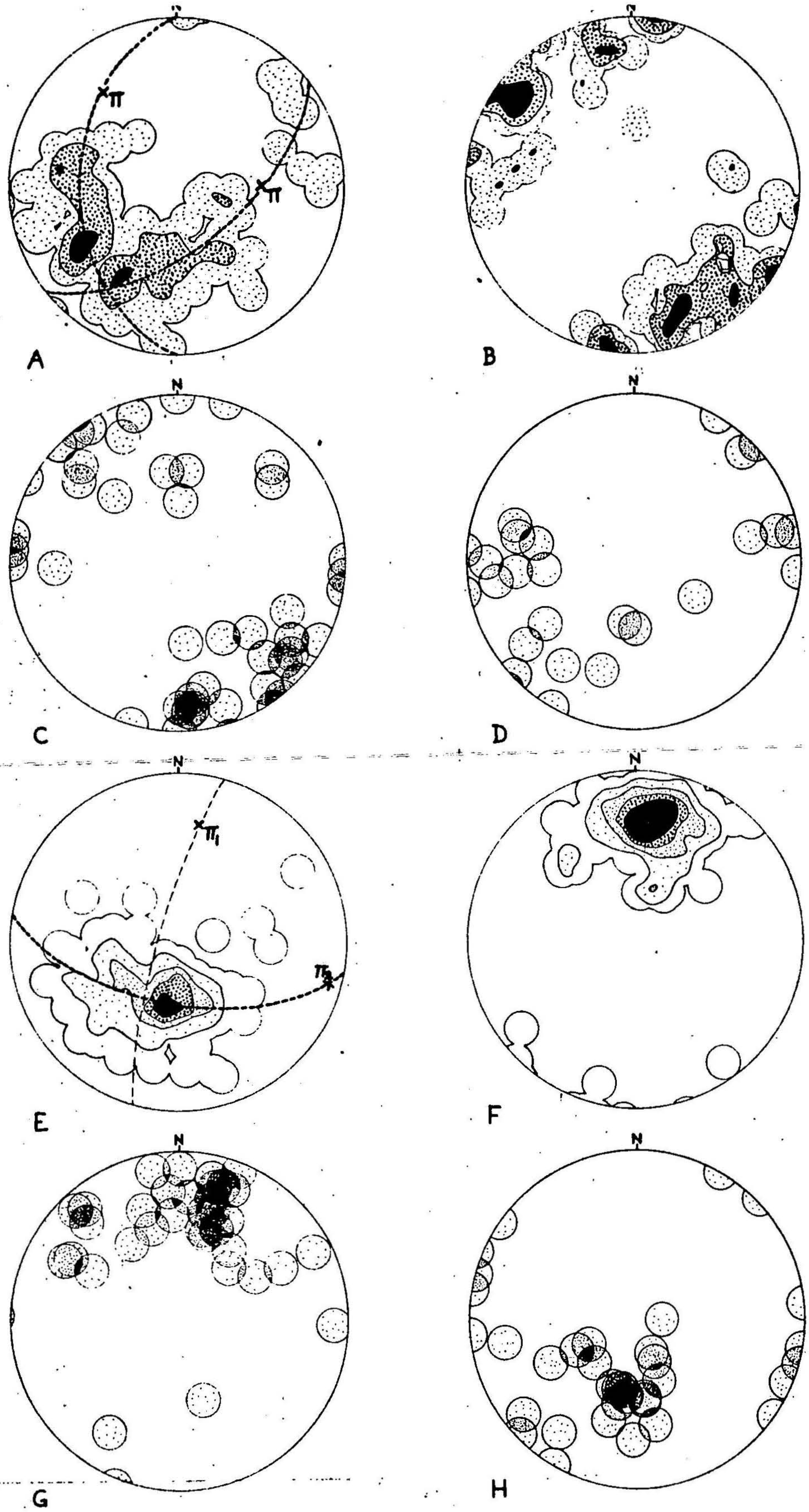

Fig. 38. π-diagrams (equal-area plots on lower hemisphere) of mesoscopic structural elements in basement rocks of White Range Nappe.

Southern Part of Nappe

A. 115 poles to foliation. Contours: 1, 3, 6%, per 1% area.
B. 57 linear grain orientations. Contours: 1.76, 3, 6%, per 1% area.
C. 35 fold axes. Contours: 3, 6, 9, 12%, per 1% area.
D. 21 poles to axial planes of folds in C. Contours: 5, 10, 15%, per 1% area.

Northern Part of Nappe

E. 127 poles to foliation. Contours: 0.8, 3, 6, 9, 12%, per 1% area.
F. 135 linear grain orientations. Contours: .74, 3, 6, 9, 12%, per 1% area.
G. 34 fold axes. Contours: 3, 6, 9, 12%, per 1% area.
H. 28 poles to axial planes of folds in G. Contours: 3.6, 7.2, 10.8, 14.4%, per 1% area.

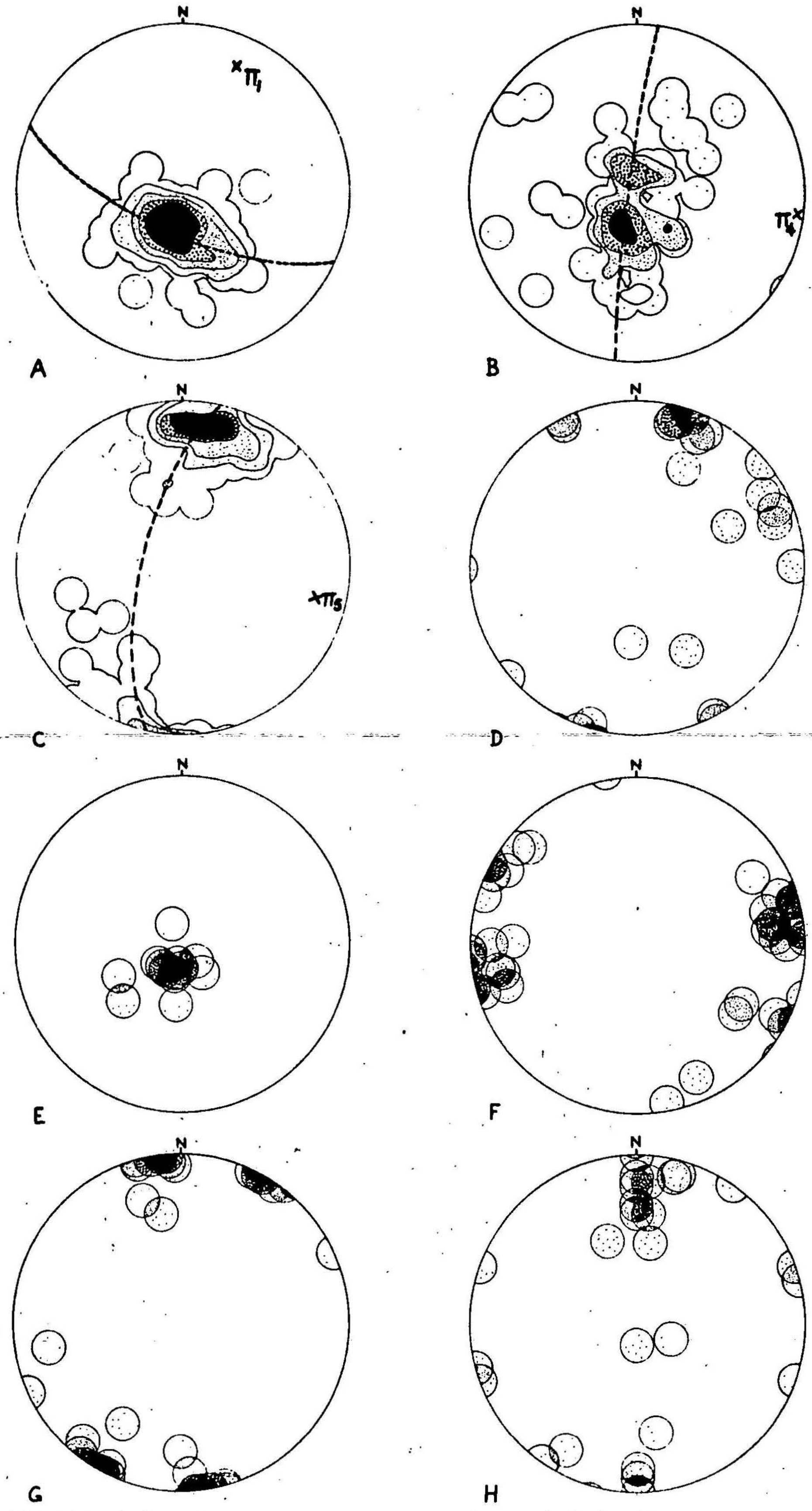

Fig. 39. π-diagrams (equal-area plots on lower hemisphere) of mesoscopic structural elements in metamorphosed Heavitree Quartzite.

A. 133 poles to foliation, excluding measurements from areas affected by late east/west folds. Contours: .75, 3, 6, 9, 12%, per 1% area.
B. 60 poles to foliation from areas affected by late east/west folds. Contours: 1.7, 3, 6, 10%, per 1% area.
C. 134 linear grain orientations from all areas. Contours: .75, 3, 6, 9, 12%, per 1% area.
D. 20 axes of recumbent folds. Contours: 5, 10, 15, 20%, per 1% area.
E. 12 poles to axial planes of recumbent folds of D. Contours: 8, 16, 24, 32%, per 1% area.
F. 29 axes of late east/west folds. Contours: 3.5, 7, 10.5, 14%, per 1% area.
G. 20 poles to axial planes of late east/west folds of F. Contours: 5, 10, 15, 20%, per 1% area.
H. 21 poles to kink bands. Contours: 4.8, 9.6, 14.4, 19.2%, per 1% area.

(ii) Recumbent Folds

The second set of folds in the Heavitree Quartzite (Fold Generation 2 in Table 1) is a group of recumbent folds. These are found only in the northern part of the nappe, coincident with the distribution of lineated quartzite. The size and style of the folds is related to the lithology of the quartzite in which they occur; in the middle part of the formation, i.e., the medium-bedded blocky sandstone, the folds range from 1m to 15m in amplitude and are tight to isoclinal in profile (Fig. 40), whereas in the laminated fine-grained upper beds and the poorly bedded schistose lower beds the folds are only a few centimetres in amplitude and are invariably isoclinal. The axes of all observed recumbent folds are plotted in Figure 39d, and the poles to axial planes are plotted in Figure 39e. Most of the folds plunge north-northeast at about 10^{o}, but there is a considerable spread among the trends, and some folds with east-northeast axes were observed in the White Range. Figure 39e demonstrates the recumbent attitude of the folds, and the coincidence of the maximum in this diagram with that of the poles to foliation (Fig. 39a) confirms the field observation that the foliation is parallel to the axial-plane of the folds.

Boudins and Mullions

Associated with the recumbent folds are numerous boudins and mullions. The limbs of the recumbent folds in the upper beds of the recumbent folds in the upper beds of the quartzite are commonly torn apart into boudins, and the noses of the folds form mullions parallel to the boudins. The boudins and mullions lie in the foliation plane of the quartzite, but their trends differ by up to 30^{o} from the general north-northeast trend of the lineation. In the southern part of the White Range, pinch-and-swell structures in quartzite veins and beds have east-west trending axes, and the lineation in these areas is folded by the swellings.

(iii) Upright Folds

The third set of folds in the Heavitree Quartzite (Fold Generation 3 in Table 1) is a group of east-west trending upright folds. These fold the foliation, lineation, and recumbent folds in the quartzite, and are found only in the northern part of the nappe. As in the case of the recumbent folds, the size and style of the upright folds is related to lithology; folds in the middle beds are open and concentric, with amplitudes and wavelengths of several metres (Fig. 41), whereas folds in the upper beds are tight to isoclinal, concentric to disharmonic, and range up to ½ m in amplitude (Fig. 42). Upright folds are rare in the basal beds, and their place is generally taken by kink bands (Fig. 43). No cleavage was observed in the upright folded rocks.

The orientations of the axes of the upright folds are plotted in Figure 39f, and the poles to their axial planes in Figure 39g. It is apparent that the folds form two sets which are symmetrically disposed with respect to the north-northeast trend of the foliation pi-axis ($_{1}$, in Figure 39a) and lineation maximum (Fig. 39c) in the Heavitree Quartzite.

Kink Bands

Kink bands are common in the Heavitree Quartzite, and are found only in the northern part of the nappe. They occur mostly in the basal schistose beds of the quartzite. There are two sets of kink bands; one set strikes east-west and dips vertically or steeply south, the other set strikes north-south and dips vertically. The east/west bands are generally about 10 cm thick, and some show curvature of the margins which in places grades into folds (Fig. 43). The north/south bands are only about 6 mm thick, and are not as common as the east/west set. At one locality the two sets of bands were observed curving into each other.

Poles to all observed kink bands are plotted in Figure 39h, and the similarity in orientation of the east/west bands to one of the sets of east/west upright folds is evident.

PETROGRAPHIC TEXTURES

BASEMENT ROCKS

In the basement rocks of the southern part of the White Range Nappe, microscopic deformational structures are ubiquitous, but the overall effect on the rock is slight and the total strain is no more than a few percent. Quartz in all the basement rocks shows marked undulatory extinction, deformation lamellae (Fig. 33), and kink bands, and the effects show a progressive increase in intensity with distance northwards across the nappe. Plagioclase (where not replaced by sericite) is commonly cracked and broken, and some grains are bent and kinked as well; microcline shows similar effects. Micas are considerably bent and kinked in some areas, but scarcely affected in others. The other minerals in the southern part of the nappe show little or no strain effects.

In the northern part of the nappe, almost all the strain is recorded in quartz and feldspar. Quartz forms elongate aggregates of small polygonal grains which are generally equant and free of strain (Fig. 35). Plagioclase is broken into subangular fragments which are markedly displaced from their original positions; the fragments themselves are free of strain because they have recrystallized to albite (Fig. 35). Microcline is almo much brecciated, and the fragments are intensely and unevenly twinned. Micas, in contrast to those in the southern area, show relatively mild kinking and bending; the laths of white mica inside albite crystals are unstrained and randomly oriented and apparently are uninfluenced by the cleavage in the albite (Fig. 35). Epidote and clinozoisite show no strain effects. Hornblende shows undulatory extinction at one locality, but generally it is undeformed. Garnet is cracked, but not unusually so.

HEAVITREE QUARTZITE

Microscopic deformation in the autochthonous Heavitree Quartzite is very slight. Specimen 165* from 3 km northwest of Hillsoak Bore shows slight cracking of the grains; specimen 281 from the northern part of the

*Specimen localities are shown in Figure 57.

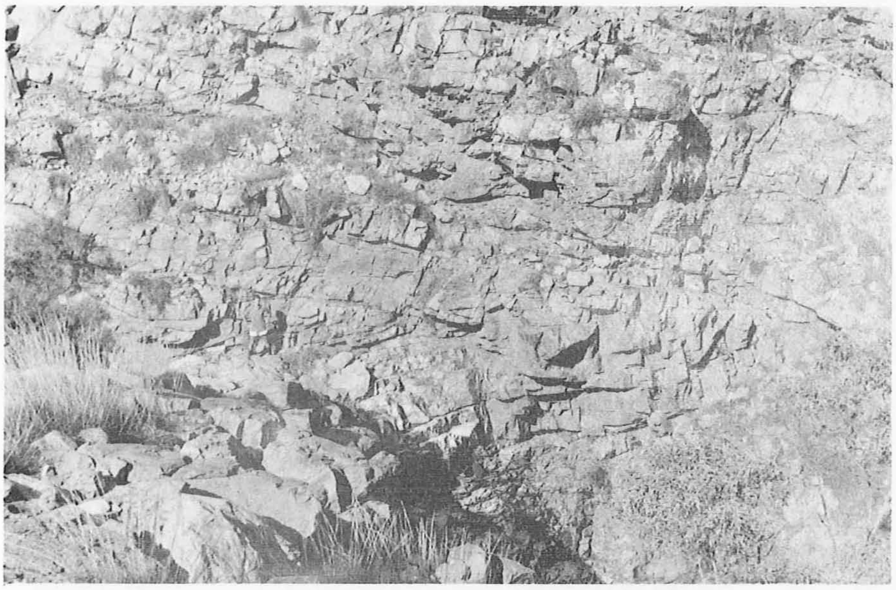

Fig. 40. Recumbent fold in middle beds of Heavitree Quartzite in southern part of White Range. Fold axis trends east-northeast away to observer's right. 8 km southeast of Arltunga.

Fig. 41. Late upright fold in middle beds of Heavitree Quartzite in range on northern side of Paddys Hole Plain. Looking southeast along axis. 5 km southwest of Arltunga.

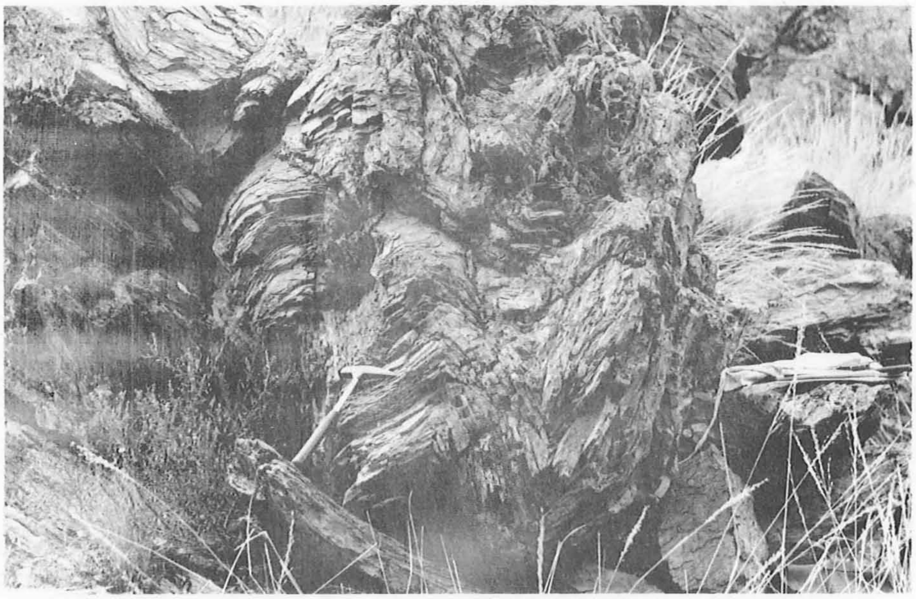

Fig. 42. Late upright folds in upper beds of Heavitree Quartzite, looking northwest up axes. 5½ km southwest of White Dam.

Fig. 43. South-dipping kink bands grading to folds in lower beds of Heavitree Quartzite in range on northern side of Paddys Hole Plain. 8 km west-southwest of Arltunga.

autochthon shows abundant cracks together with displacement of the fragments, and these are associated with thin bands (up to ½ mm wide) of fine-grained xenoblastic quartz (Fig. 44). Undulatory extinction, kink bands, and deformation lamellae are also common, though the grains show no measurable change of shape.

All the quartzite specimens from the southern part of the nappe are strained, but generally the amount of strain is too small to measure. Undulatory extinction is ubiquitous, and commonly forms diffuse kink bands, which in many grains are arranged in two perpendicular sets, both parallel to the c-axis, so that basal sections show a diffuse checkerboard extinction pattern (Fig. 45). Deformation lamellae are abundant (Fig. 46). Incipient recrystallization is also visible in these rocks; aggregates of tiny xenoblastic quartz crystals form thin bands in the rock, and also occur at the margins of large grains (Fig. 46) and along kink band boundaries. The quartzite from directly north of Hillsoak Bore (specimen 167) shows perceptible change of shape of the grains, and fine-grained xenoblastic quartz constitutes about 17% of the rock; in other respects the quartzite here is similar to that along the southern edge of the nappe.

In the northern part of the nappe, the Heavitree Quartzite is considerably deformed and metamorphosed, and the amount of deformation increases northwards (Figs. 47, 48, 49, 50, 51). The quartz grains become increasingly elongated north/south and, with one exception, east/west, and are simultaneously more flattened vertically. Deformation lamellae are present in the ranges of the southern side of Paddys Hole Plain, but are absent farther north. Undulatory extinction increases in intensity northwards (Figs. 47, 48), and forms sharply defined kink bands which tend to lie in the foliation plane of the quartzite (Fig. 49); many are prismatic rather than tabular in shape. Paddle-shaped discs of undeformed quartz up to 20 x 10 x 2 mm in size and with length:thickness ratios far greater than those of the surrounding grains are present in the quartzite (Figs. 49, 50); the c-axes of these paddle-shaped grains are all without exception oriented east/west. Fine-grained xenoblastic quartz around the large grains increases steadily northwards both in grain-size and amount (forming up to 85% of the rock; Fig. 51), and spreads into the interiors of grains along kink band boundaries; in the northernmost parts of the nappe the formation of the fine-grained quartz is preceded by polygonization of the large grains (Fig. 50).

PETROFABRIC ANALYSIS

The orientation of the c-axes in quartz of the basement rocks and Heavitree Quartzite was measured in order to investigate the symmetry relation between the microfabric of the rocks and the macroscopic and mesoscopic structures of the nappe. Two vertical thin sections were cut from each oriented specimen, one striking north/south, the other east/west. Measurements were made on 100 grains per section (except where otherwise noted in the Figure captions), then rotated out of the vertical into a single horizontal point diagram which was contoured by the Schmidt method.

BASEMENT ROCKS

The results of the analysis on the basement rocks in the southern part of the nappe are shown in Figure 52. The diagrams show numerous small weak maxima which are nearly randomly distributed. In the northern part of the nappe the diagrams show weak crossed girdles which are oriented symmetrically across the trend of the lineation in this area, together with two maxima near the intersection of the girdles. The crossed girdles of c-axes are given by large strained quartz grains (Figs. 52C, 52D) and by small polygonal quartz grains (Figs. 52E, 52F).

HEAVITREE QUARTZITE

The orientation of the c-axes in large quartz grains was measured in 15 oriented specimens of Heavitree Quartzite, and the results are shown in Figures 53, 54 and 55. As expected, the c-axes in the autochthon and in the southern part of the nappe are randomly distributed. In the specimens from the northern part of the nappe, where the grains are appreciably deformed, the diagrams show weak crossed girdles oriented symmetrically across the trend of the lineation, plus double maxima near the intersection of the girdles (Fig. 56). The symmetry of the fabrics is orthorhombic, and the orientation of the symmetry axes is constant throughout the area.

The orientation of the c-axes in 400 of the small polygonal quartz grains outside the boundaries of the large grains was measured in each of three specimens of quartzite from the northernmost part of the nappe, and the results are shown in Figures 55D, 55E and 55F. The diagrams show weak cleft girdles with double maxima in the foliation plane, and have the same approximately orthorhombic symmetry and orientation as the diagrams for the large quartz grains.

STRAIN ESTIMATES

BASEMENT ROCKS

The basement rocks of the White Range Nappe were not observed to contain objects of known original shape, and so strain measurements were not attempted. Similarly, the absence of undeformed rocks precludes the estimation of strain from the elongation of mineral aggregates in the mylonitic rocks. The general appearance of the basement rocks suggests that they have undergone about the same amount of deformation as the cover. Along the northern sides of White Range, the range on the northern side of Paddys Hole Plain, and the quartzite ridge in the northwestern part of the nappe, the schistosity of the basement rocks decreases in intensity away from the contact with the Heavitree Quartzite.

HEAVITREE QUARTZITE

As described in the section on Petrographic Textures, the well rounded and equant (though non-spherical) quartz grains of the Heavitree Quartzite have been deformed into ellipsoids, and this allows a rough estimate to be made of the strain in the rock.

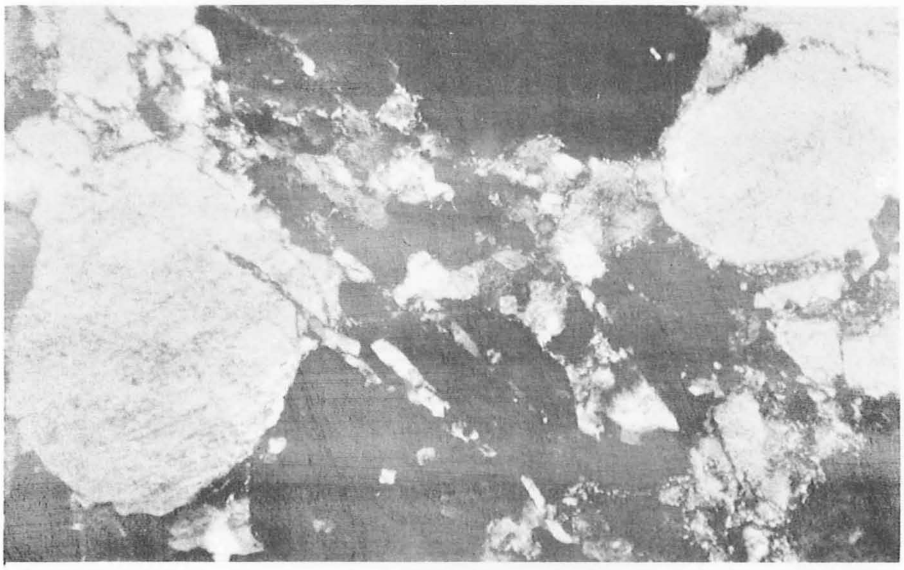

Fig. 44. Photomicrograph of autochthonous Heavitree Quartzite (sp. 281) from 6½ km south-southwest of White Dam, showing quartz grains with cracks, inclusions, and offsets in fracture zone where recrystallization (small grains) has occurred. Crossed nicols. Length of field = 2 mm.

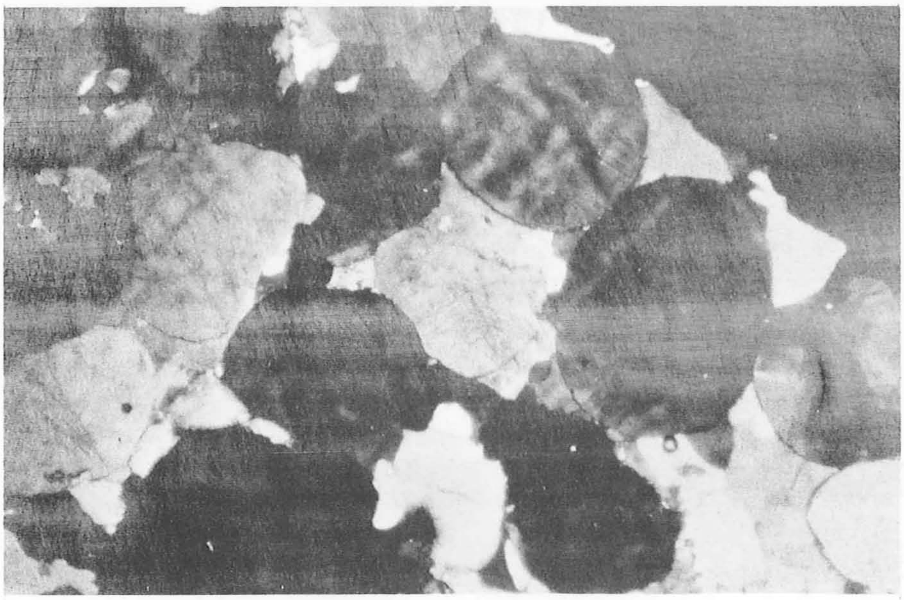

Fig. 45. Photomicrograph of Heavitree Quartzite (sp. 133) from southern edge of nappe, 6½ km east of Bitter Springs, showing 'checkerboard' extinction in quartz grains cut parallel to base, representing cross-sections of diffuse prismatic kink bands parallel to c-axis. Crossed nicols. Length of field = 2 mm.

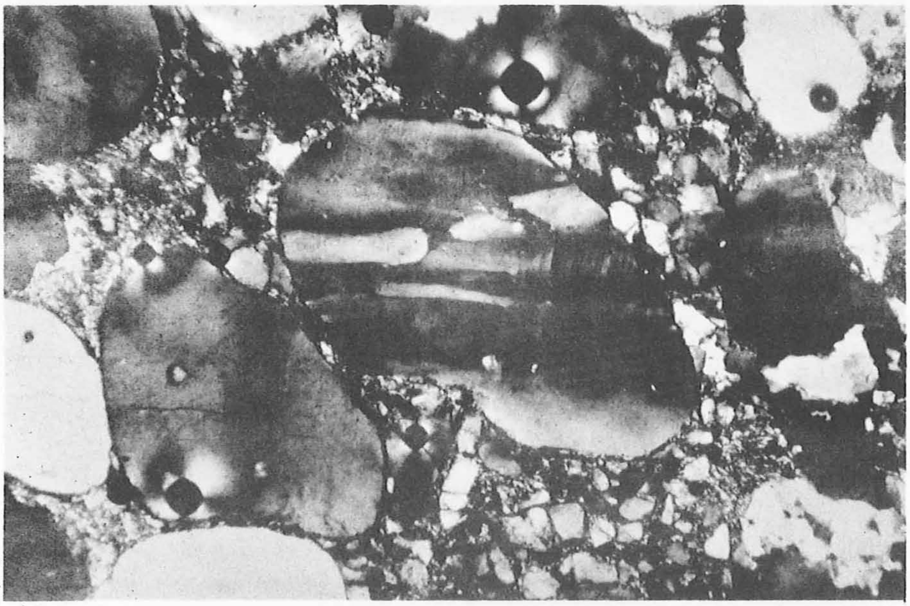

Fig. 46. Photomicrograph of bimodal sandstone in Heavitree Quartzite (sp. 143) from southern edge of nappe (eastern end), 12½ km south-southwest of Arltunga, showing deformation lamellae (thin vertical bands) and kink bands (broad horizontal bands) in central grain, and very small amount of recrystallized quartz indicated by frayed margins of this grain (lower edge) and grains in upper corners. Crossed nicols. Length of field = 2 mm.

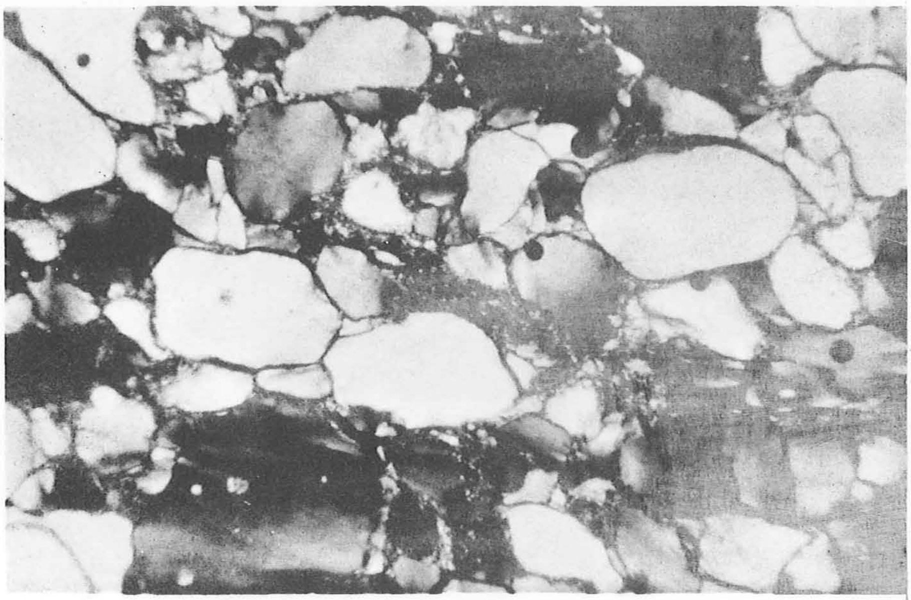

Fig. 47. Photomicrograph of Heavitree Quartzite (sp. 158) from range on southern side of Paddys Hole Plain, 9 km east of Hillsoak Bore, showing slight elongation of grains, undulatory extinction, and small amount of very fine-grained xenoblastic quartz between large grains. Vertical east/west thin section. Crossed nicols. Length of field = 2½ mm.

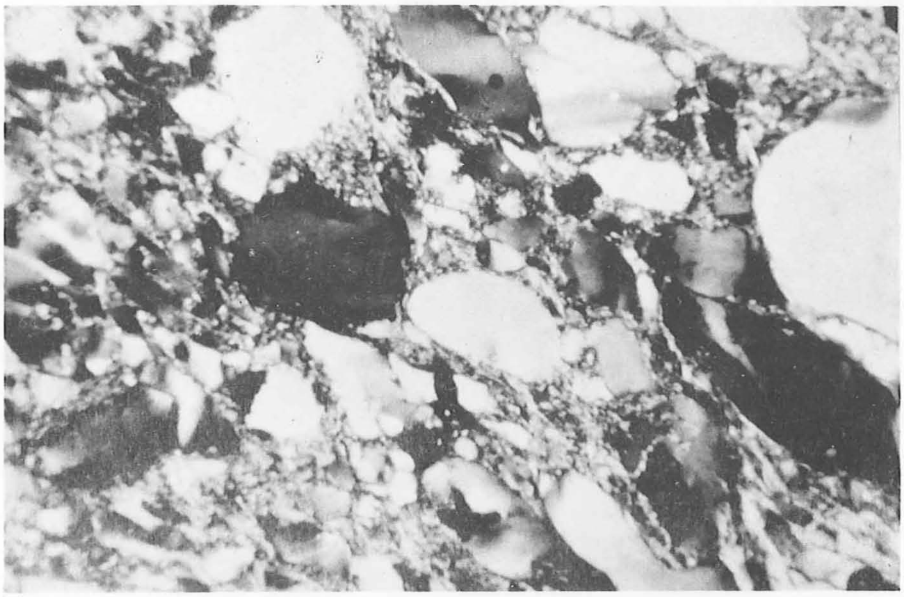

Fig. 48. Photomicrograph of Heavitree Quartzite (sp. 208) from western end of range on southern side of Paddys Hole Plain, 8½ km south-southwest of Arltunga, showing large deformed quartz grains (some broken) with undulatory extinction and kink bands, surrounded by fine-grained xenoblastic quartz, slightly coarser-grained than in Figure 47. Vertical north/south thin section. Crossed nicols. Length of field = 2½ mm.

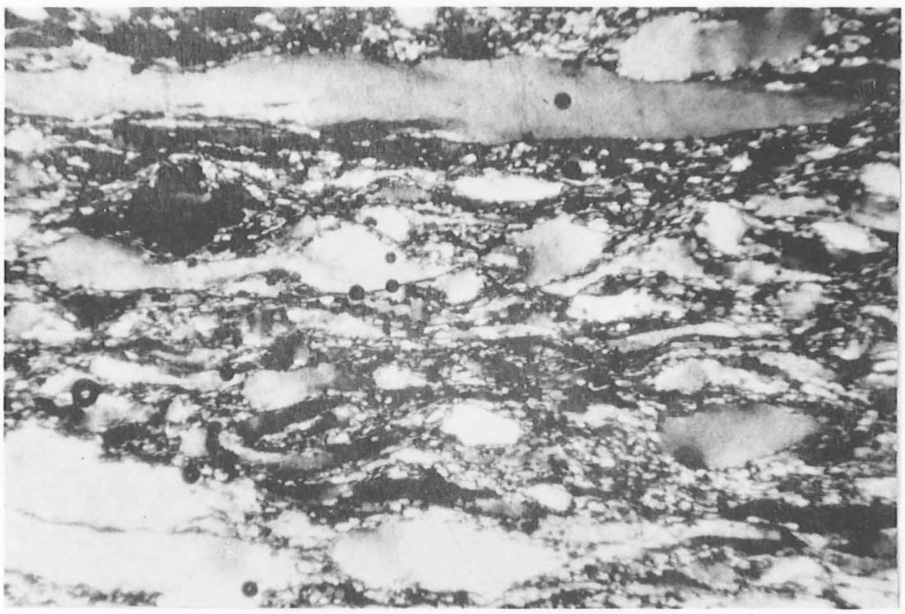

Fig. 49. Photomicrograph of Heavitree Quartzite (sp. 213) from eastern end of range of southern side of Paddys Hole Plain, 5½ km south-southeast of Arltunga, showing deformed quartz grains with serrate margins and kink bands (parallel to schistosity), large elongate quartz grain (part of paddle-shaped disc) at top, and fine-grained xenoblastic quartz, slightly coarser-grained than in Figure 48. Vertical north/south thin section. Crossed nicols. Length of field = 2½ mm.

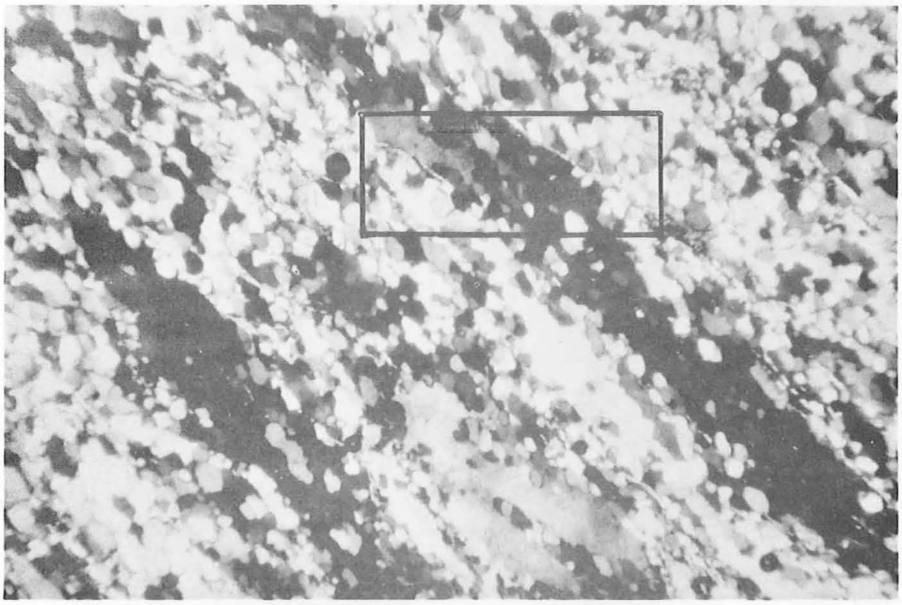

Fig. 50. Photomicrograph of Heavitree Quartzite (sp. 255) from southern part of White Range, 8 km south-east of Arltunga showing polygonization of large elongate grains (in rectangle), and increased recrystallization of surrounding rock; small grains are now polygonal, of larger size than in Figures 48 and 49, and markedly misoriented from each other (in contrast to parts of large grains undergoing polygonization, where degree of misorientation is still small). Vertical north-south thin section. Crossed nicols. Length of field = 2½ mm.

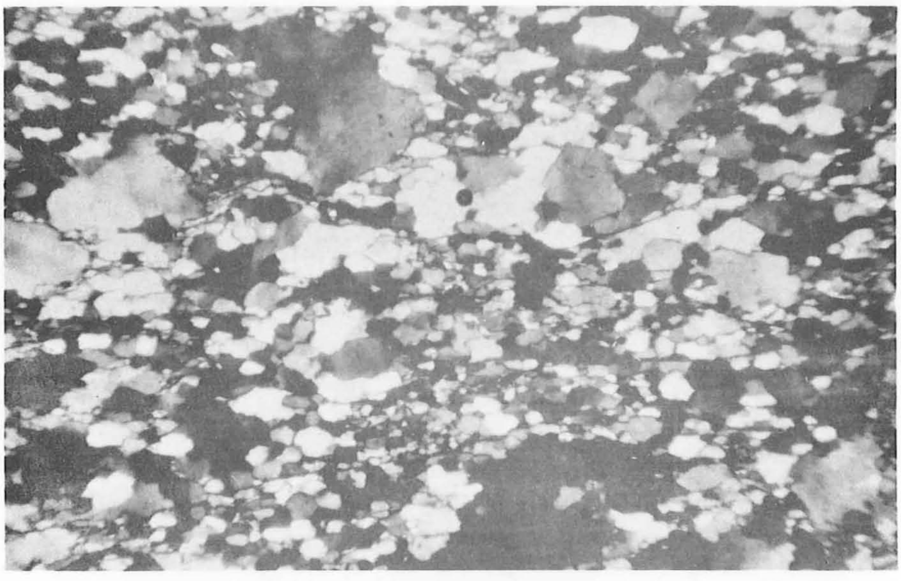

Fig. 51. Photomicrograph of Heavitree Quartzite (sp. 278) from northwestern part of nappe, 5 km southwest of White Dam, showing advanced stage of recrystallization; small grains are at their largest, most abundant, and most polygonal for the area. Vertical north-south thin section. Crossed nicols. Length of field = 2½ mm.

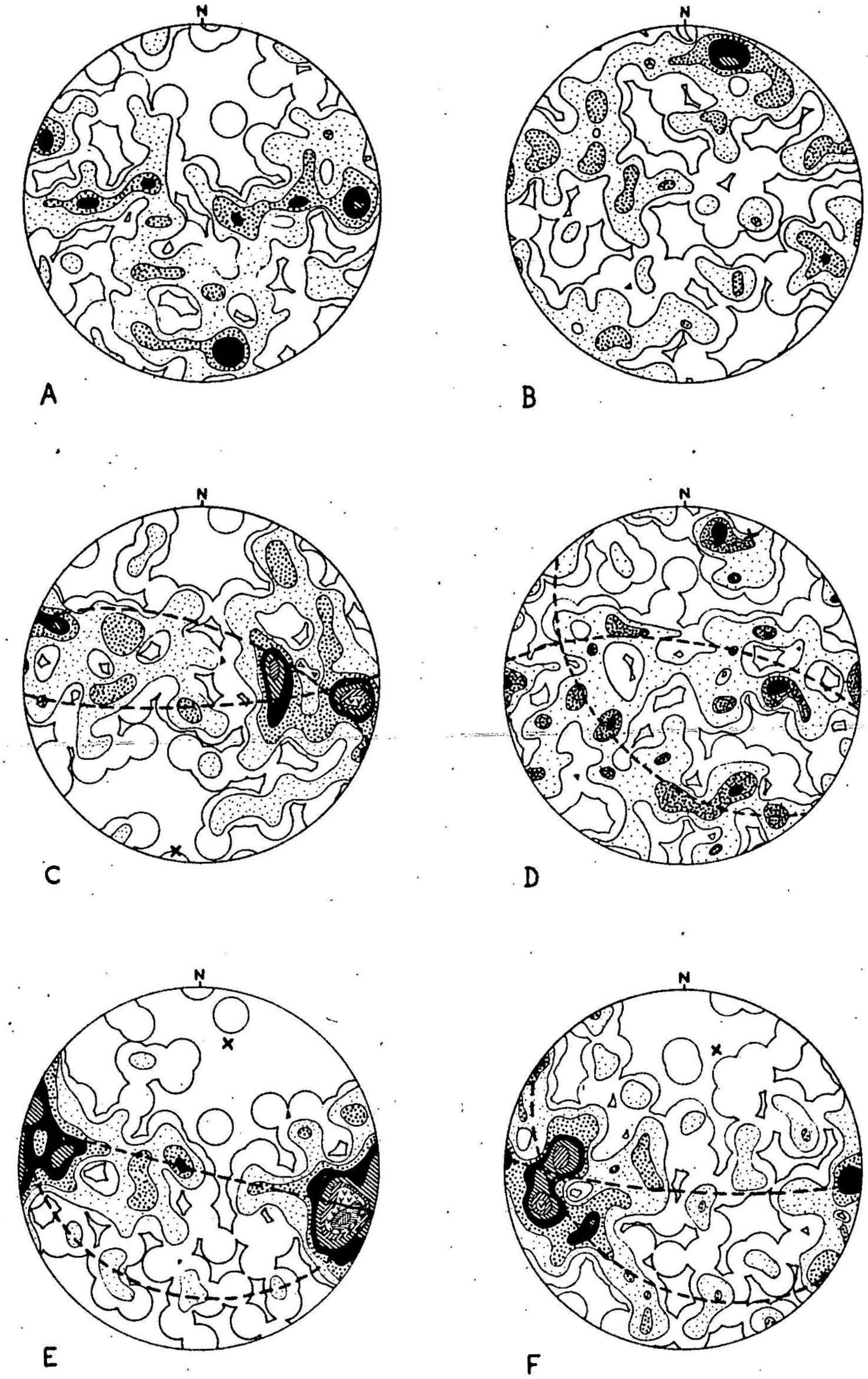

Fig. 52. Equal-area projections (lower hemisphere) of quartz c-axes of basement rocks of White Range Nappe. All diagrams have 200 points, and contours at ½, 1, 2, 3, 4%, ..., per 1% area.

Southern Part of Nappe

A. Adamellite dyke-rock 6 km east of Hillsoak Bore. Maximum concentration = 4%
B. Quartz-rich biotite gneiss, 6½ km east-southeast of Hillsoak Bore. Maximum concentration = 4%

Northern Part of Nappe

C. Metamorphosed tonalite, 3 km west of Arltunga. Quartz forms large strained grains. Maximum concentration = 6%
D. Quartz-rich biotite gneiss, 3 km south of Gidyea Bore. Quartz forms large strained grains. Maximum concentration = 3%
E. Metamorphosed granodiorite, 3 km west of Arltunga. Quartz forms small polygonal grains. Maximum concentration = 8%
F. Metamorphosed tonalite, 4 km northeast of Arltunga. Quartz forms small polygonal grains. Maximum concentration = 6%.

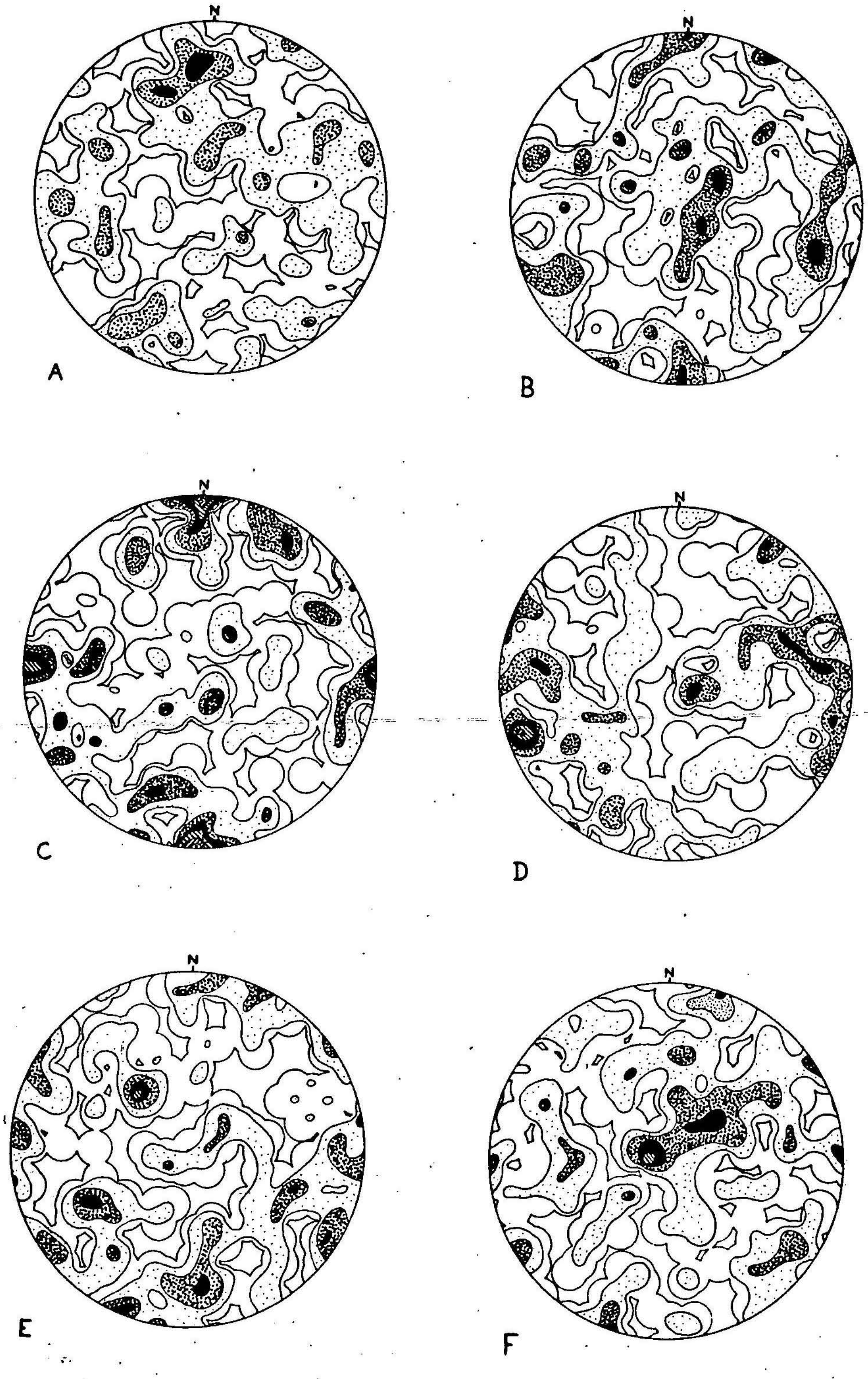

Fig. 53. Equal-area projections (lower hemisphere) of c-axes of large quartz grains in Heavitree Quartzite. All diagrams have 200 points, and contours at ½, 1, 2, 3%, ..., per 1% area.

A. Specimen 129 from southern edge of nappe, 5 km east-southeast of Bitter Springs. Maximum concentration = 3%.
B. Specimen 133 from southern edge of nappe, 6½ km east of Bitter Springs. Maximum concentration = 3%.
C. Specimen 135 from southern edge of nappe, 13 km east of Bitter Springs. Maximum concentration = 6%.
D. Specimen 143 from southern edge of nappe, 12½ km south-southwest of Arltunga. Maximum concentration = 5%.
E. Specimen 165 from autochthon, 3 km northwest of Hillsoak Bore. Maximum concentration = 4%.
F. Specimen 167 from western side of nappe, 1½ km north of Hillsoak Bore. Maximum concentration = 4%.

To accompany Record 1971/66

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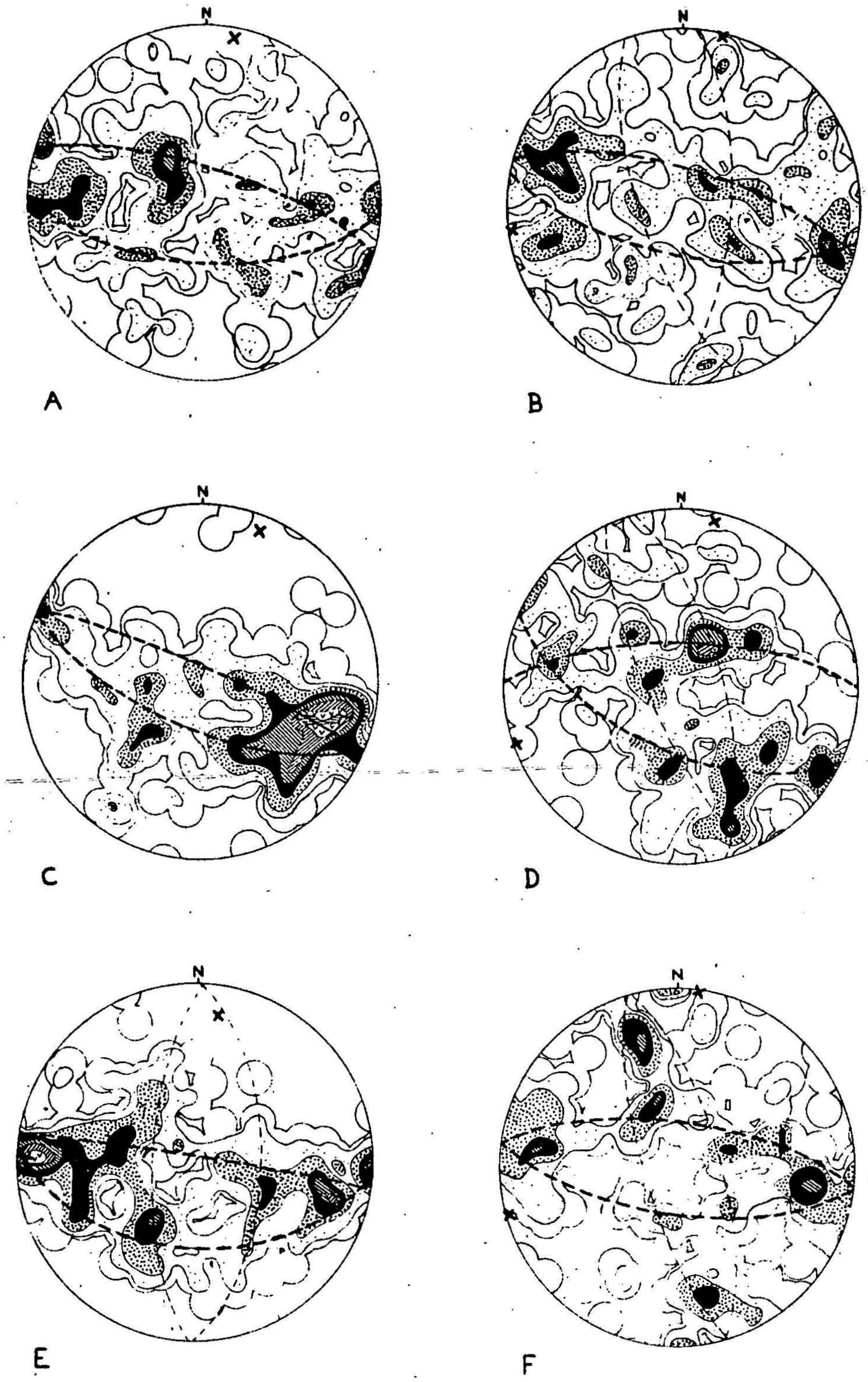

Fig. 54. Equal-area projections (lower hemisphere) of c-axes of large quartz grains in Heavitree Quartzite (continued). All diagrams have 200 points, and contours at ½, 1, 2, 3%, ..., per 1% area.

A. Specimen 158 from range on southern side of Paddys Hole Plain, 9 km east of Hillsoak Bore. Maximum concentration = 4%.
B. Specimen 208 from range on southern side of Paddys Hole Plain, 8½ km south-southwest of Arltunga. Maximum concentration = 4%.
C. Specimen 213 from eastern end of range on southern side of Paddys Hole Plain, 5½ km south-southeast of Arltunga. Maximum concentration = 7%.
D. Specimen 220 from northern part of White Range, 5½ km east-southeast of Arltunga. Maximum concentration = 6%.
E. Specimen 255 from southern part of White Range, 8 km southeast of Arltunga. Maximum concentration = 6%.
F. Specimen 191 from range on northern side of Paddys Hole Plain, 9 km west-southwest of Arltunga. Maximum concentration = 4%.

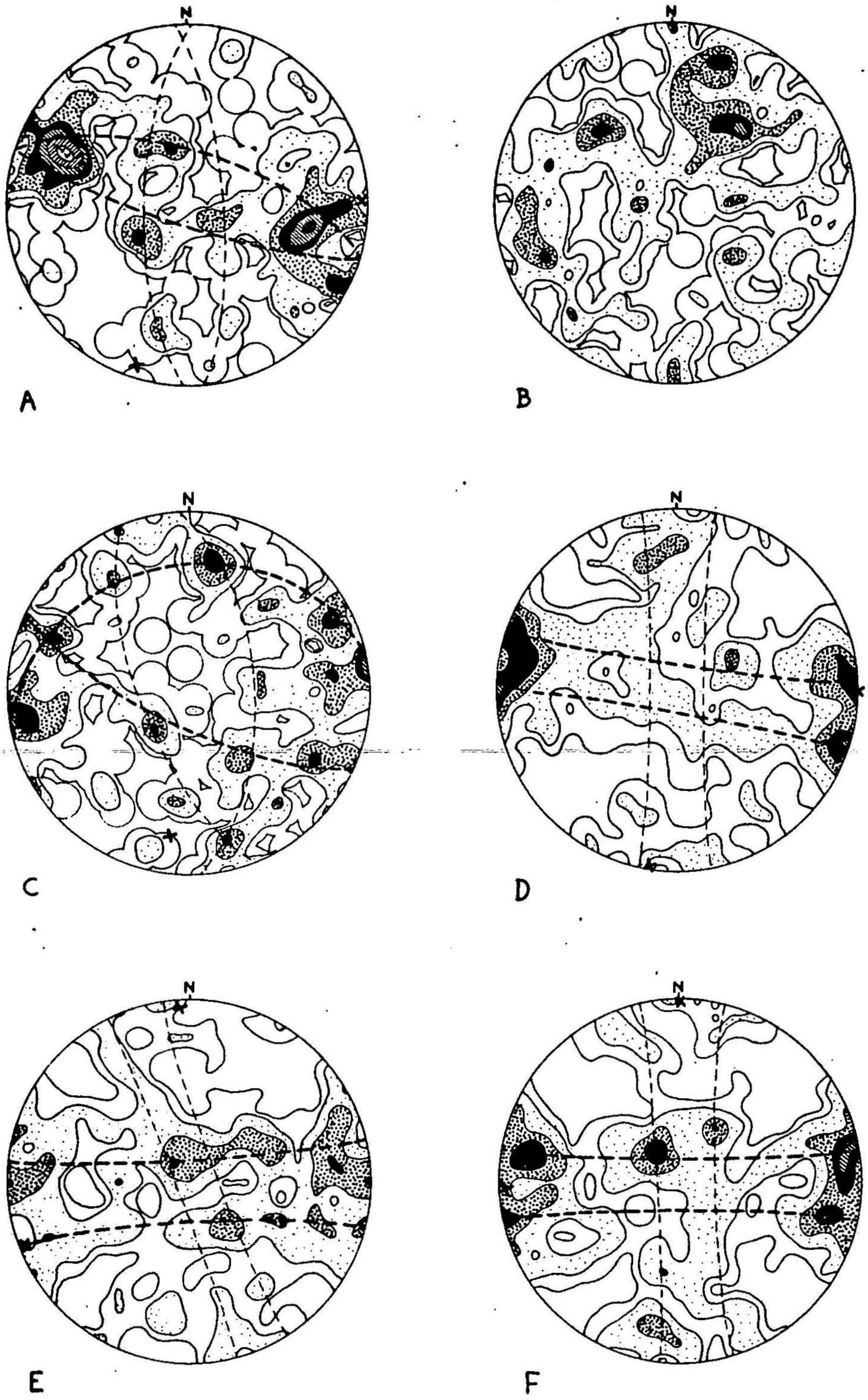

Fig. 55. Equal-area projection (lower hemisphere) of c-axes of quartz grains in Heavitree Quartzite. A, B, and C: large quartz grains, diagrams have 200 points and contours at ½, 1, 2, 3%, ..., per 1% area. D, E, and F; small polygonal quartz grains, diagrams have 400 points and contours at ½, 1, 2, 3%, ..., per 1% area.

A. Specimen 193 from range on northern side of Paddys Hole Plain, 5 km southwest of Arltunga. Maximum concentration = 6%.
B. Specimen 281 from autochthon in northwestern part of area, 6½ km southwest of White Dam. Maximum concentration = 4%.
C. Specimen 278 from northwestern part of nappe, 5 km southwest of White Dam. Maximum concentration = 4%.
D. Specimen 193; maximum concentration = 4%.
E. Specimen 220; maximum concentration = 3%.
F. Specimen 255; maximum concentration = 4%.

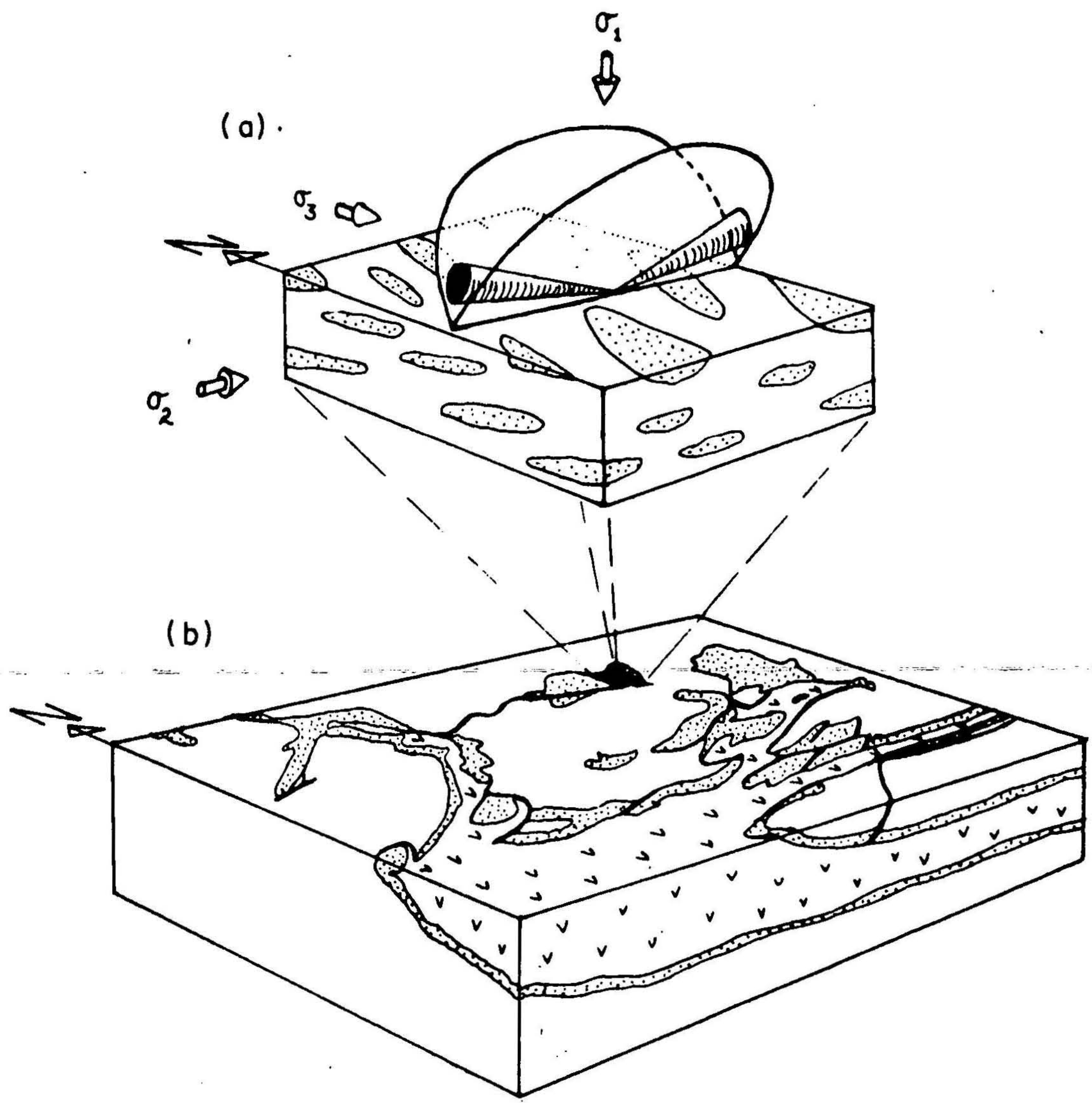

Fig. 56. (a) Perspective sketch of block of foliated and lineated Heavitree Quartzite, showing orientation of crossed girdles of quartz c-axes and maxima near intersection of girdles, and relation of these to macroscopic structure of western part of White Range Nappe (b). Geographic orientation of both diagrams the same. Orientations of principal stresses (σ_1, σ_2, and σ_3) also shown. Full explanation in text.

Throughout the greater part of the southernmost ridge of quartzite the quartz grains show no perceptible change of shape, but at the eastern end of the ridge (specimen 143) there is a faint suggestion of deformation visible in thin section (Fig. 36), and the method of Dunnet (1969) was used to try and measure this. The results of the analysis (presented in detail in Stewart, 1971b) indicate that the range of initial shapes of the grains exceeds the maximum estimated strain ratio, and so the existance of tectonic deformation is not proved; the apparent strain could be the result of an initial preferred orientation that formed during deposition.

The method of Cloos (1947) was used to estimate strain in the northern part of the nappe, except that logarithmic means of the axial ratios of the grains were used instead of Cloos' arithmetic means. The results of the analysis are shown in Figures 57, 58, and 59. It can be seen that there is a fairly steady increase (0 to 71%) in the amount of north/south elongation of the grains, and a similar increase (0 to 53%) in the vertical shortening. As expected, the east/west elongation of the grains is much less than the north/south elongation at the same locality, and it appears to reach a maximum at about 25 or 30%. In the northwestern part of the nappe the east/west elongation is negative, i.e. shortening occurred, and the grains are rod-shaped.

The undeformed quartz grains in the Heavitree Quartzite are not spherical, and the strain estimates obtained by the Cloos method cannot be regarded as accurate. Taken overall, however, the differences between the estimated amounts of strain from specimen to specimen may not be too inaccurate.

DISCUSSION OF RESULTS

GEOMETRIC RELATION BETWEEN MACROSCOPIC STRUCTURE, MESOSCOPIC STRUCTURES, AND MICROSCOPIC FABRIC IN WHITE RANGE NAPPE

The macroscopic axes and symmetry planes of the White Range Nappe trend west-southwest/east-southeast (or perpendicular to this direction), and the overall symmetry of the nappe is essentially orthorhombic. The synoptic diagrams of Figures 38A-D show that the various mesoscopic structural elements in the basement rocks of the southern part of the nappe are geometrically unrelated to the macroscopic structure, in that all the trends but one are northwest/southeast, and the exception, the east-trending pi-axis in Figure 38A, has a much steeper plunge than the B-axis of the nappe. In contrast, in the northern part of the nappe (Figs. 38E-H) the trend of the mesoscopic structures is uniformly north-northeast, i.e., perpendicular to the macroscopic B-axis of the nappe, and the symmetry of the mesoscopic fabric is orthorhombic.

A similar relation to that noted for the basement rocks exists in the Heavitree Quartzite; penetrative mesoscopic structures are absent in the southern part of the nappe, but are prominent in the northern area, and their trends here are north-northeast (Figs. 39A-H); further, the late upright folds and kink bands are symmetrically disposed around this direction. Again, the symmetry of the mesoscopic fabric is orthorhombic.

In the microfabrics of both basement rocks (Fig. 52) and Heavitree Quartzite (Figs. 53, 54, and 55) we find a similar relation; quartz c-axes are randomly oriented in the southern part of the nappe, but form crossed girdles or cleft girdles with a constant orientation throughout the northern area. The symmetry of the microfabric in both basement and quartzite is in detail triclinic but approximately orthorhombic, and is thus essentially homotactic with the mesoscopic fabric and macroscopic structure of the nappe (Fig. 56).

The overall consistency in symmetry and orientation of the three sets of structures in the northern part of the nappe indicates that they all formed during the same deformational episode, and also that basement and cover deformed together as a single tectonic unit.

INTERPRETATION OF MICROFABRIC

Directions of Principal Compressive Stresses

The pattern of quartz c-axes found in both basement and Heavitree Quartzite, namely, two crossed girdles which intersect in or near the plane of the foliation and at right angles to the lineation, accompanied by one or two pronounced maxima near the intersection of the girdles, is one of the commonest found in quartz-bearing tectonites. The long-held supposition that σ_1 (the maximum principal compressive stress) symmetrically bisects the crossed girdles (Fig. 56) was confirmed by

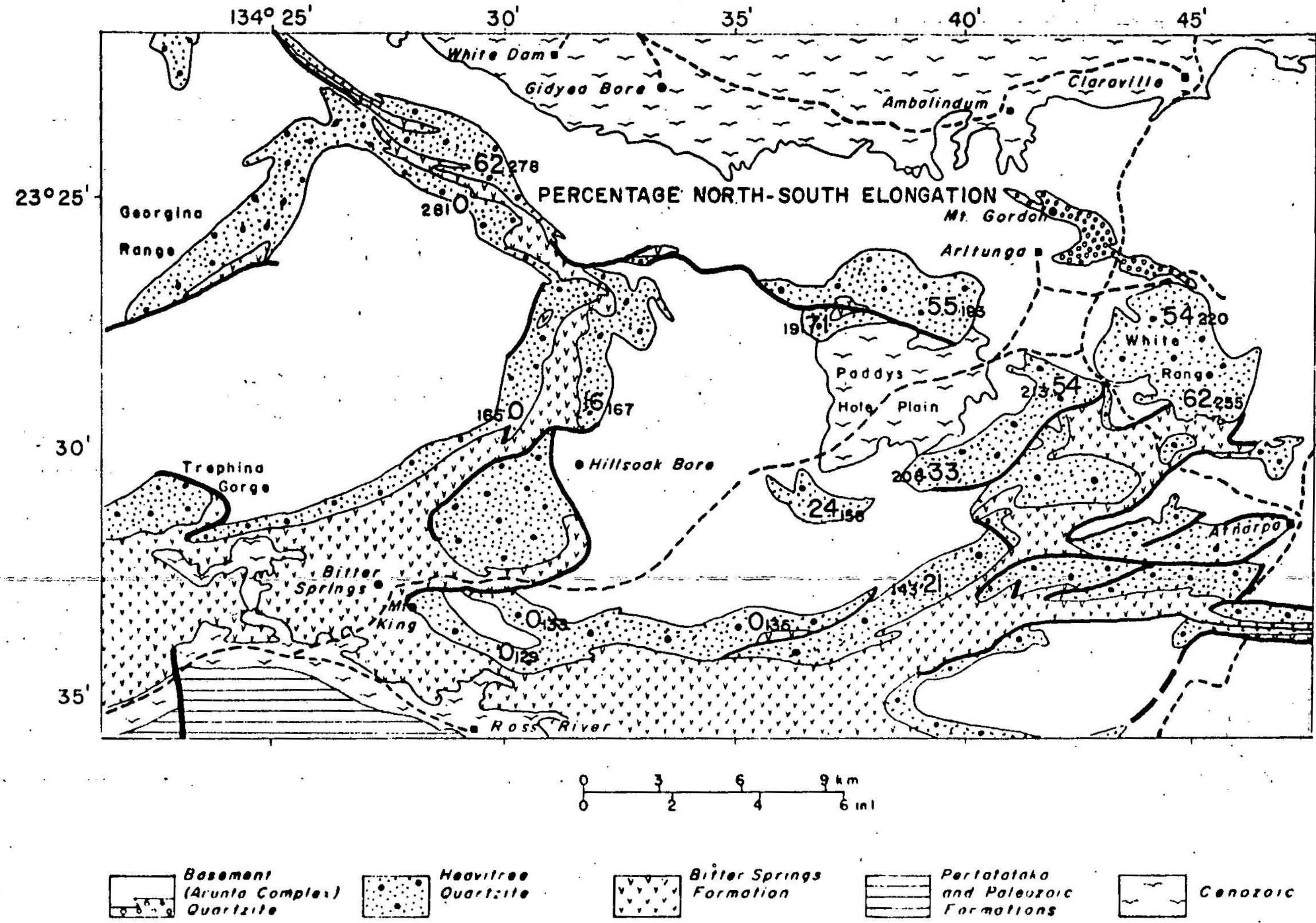

Fig. 57. Map of western part of Arltunga Nappe Complex, showing percentage elongation in north/south direction of deformed quartz grains in Heavitree Quartzite.

To accompany Record 1971/66

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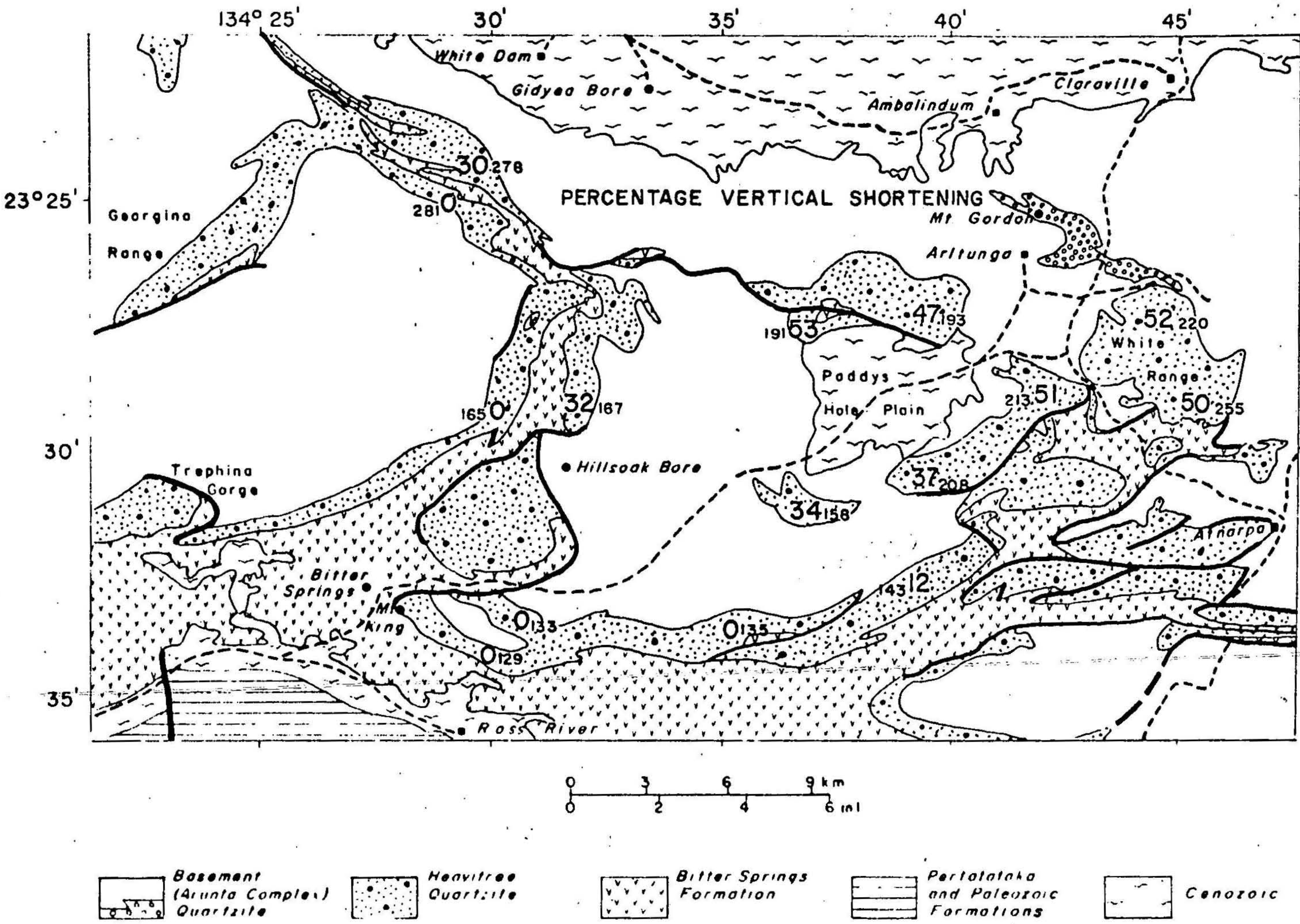

Fig. 58. Map of western part of Arltunga Nappe Complex, showing percentage vertical shortening of deformed quartz grains in Heavitree Quartzite.

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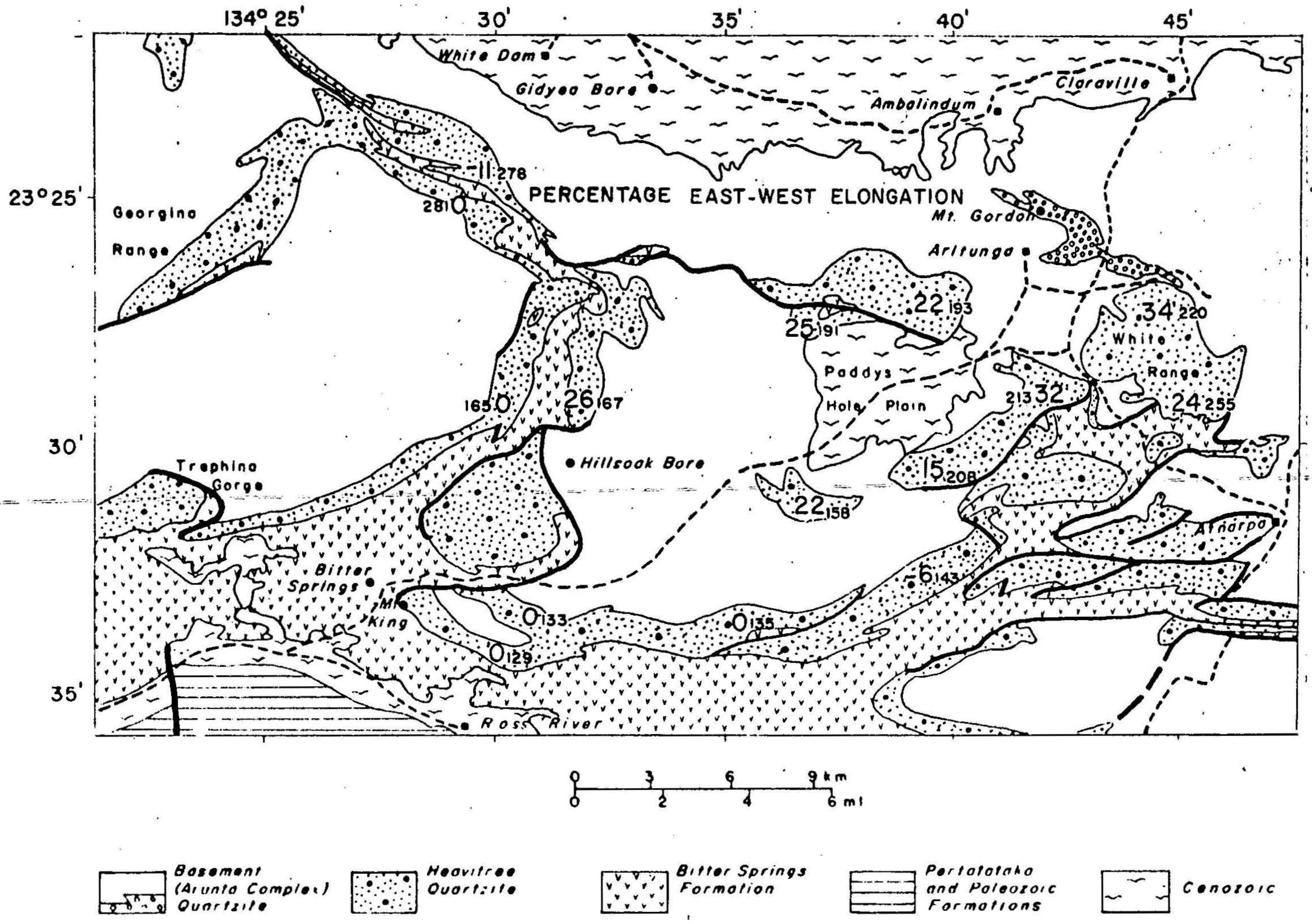

Fig. 59. Map of western part of Arltunga Nappe Complex, showing percentage elongation in east/west direction of deformed quartz grains in Heavitree Quartzite. Parentheses enclose specimen numbers.

Sylvester & Christie (1968) in a study of deformed quartzites in California, where the flattening direction was indicated by boudins and distorted fossils. If this case is generally applicable, then it appears that the basement and Heavitree Quartzite in the White Range Nappe deformed by shortening (flattening) of the rocks in a direction parallel to σ_1, accompanied by elongation (spreading) at right angles to this direction, thus forming the foliation and lineation in the rocks (the lineation being the direction of maximum elongation).

The orientation of stress directions deduced from an analysis of quartz deformation lamellae in the southern portion of the northern part of the nappe (Stewart, 1971b) is in agreement with that derived from the crossed girdles of c-axes. In addition, it indicates that σ_2 was oriented east/west in the plane of the foliation, with σ_3 north/south, coincident with the lineation in the rocks. In the southern part of the nappe the analysis suggests that the principal compressive stresses were approximately equal in magnitude. Histograms (figured in Stewart, 1971b) in which the angle between the c-axis and the pole to lamellae in the same grain is plotted against frequency (in per cent) have pronounced maxima in the 10° to 30° range, indicating that most of the visible lamellae are sub-basal.

Origin of Crossed-Girdle Orientation of Quartz C-Axes

One of the mechanisms by which randomly oriented lattices of crystal aggregates acquire a preferred orientation during deformation is syntectonic recrystallization (Sylvester & Christie, 1968; Ave'Lallement & Carter, 1970). Another mechanism is intragranular flow (slip and twinning), provided that enough independent slip systems are present to keep grain boundaries together (von Mises, 1928). In an earlier account of the area, I thought that syntectonic recrystallization had been the only orienting mechanism in the White Range Nappe (Stewart, 1971b), as it appeared that only one slip mechanism, sub-basal slip, had operated in these rocks, and this mechanism moves the quartz c-axis towards σ_1, not away from it (Fig. 56). However, it is possible that there are several other slip systems in the quartz that are not visible under the petrographic microscope, and so intragranular flow may have been an important deforming and orienting mechanism (G. Lister, A.N.U., pers. comm.).

In the Heavitree Quartzite on the southern side of Paddys Hole Plain, the quartz grains are appreciably flattened and their c-axes weakly oriented, but they do not appear to be recrystallized (except at their edges); they probably achieved their deformed state and weak preferred lattice orientation by intragranular flow, and there is abundant evidence of slip in these grains (Figs. 46, 47, and 48). In the northern part of the nappe, the deformed quartz grains show clear evidence of recrystallization, and this was probably the important deforming and lattice orienting mechanism in this area. In addition, both deformation and the degree of preferred orientation are considerably greater in the northern area compared to the southern area, and so it appears that in the White Range Nappe as a whole syntectonic recrystallization was the most effective deforming and orienting mechanism; in the southern part of the nappe, conditions were cooler, and the principal deforming and orienting mechanism was the less effective one of intragranular flow.

The various thin sections of Heavitree Quartzite taken from south to north across the White Range Nappe provide a series of 'snapshots' of the steps in the deformation process, particularly syntectonic recrystallization. The steps appear to have been the following:

1. Before deformation, the rock consisted of an aggregate of quartz grains with random orientation of the c-axes (Fig. 45).

2. Deformation took pleace by intragranular flow, forming undulatory extinction, deformation lamellae, and kink bands (Figs. 46, 47, and 48). This was the principal deforming mechanism in the southern part of the nappe, and 30 to 40% vertical shortening (with corresponding north-south and east-west elongations) was achieved.

3. Diffusion (i.e., dislocation motion) began, as evidenced by the serrate grain boundaries and kink band boundaries (Fig. 49). In the southern area this step was followed by a limited amount of growth and spread of very fine-grained quartz from these sites into the interiors of the large deformed grains. In the northern area, the intial dislocation motion was followed by polygonization of the large grains into a mass of subgrains which are slightly misoriented from each other (Fig. 50). These subgrains are considerably larger than the tiny grains of the very fine-grained quartz in the southern area.

4. Recrystallization then ensued in the northern part of the nappe by growth (enlargement) (Fig. 51) of those subgrains with the most stably oriented lattices, which in this area was apparently those whose c-axes had the largest east/west directional component. These grains grew at the expense of those with unfavourably oriented c-axes, and the end product is an aggregate of grains comparable in size to the original grains and in which the c-axes are now preferentially oriented in an east/west direction. It is presumably the solution, diffusion, and precipitation of material from unfavourable to favourable sites which gradually accomplishes the change in shape of the original grains.

5. The cycle then repeats, involving the various steps of intragranular flow, suturing, polygonization, and selective grain growth.

We thus end up with an aggregate of grains in which the degree of preferred orientation of the lattices can be quite pronounced. The large paddle-shaped grains of quartz (Fig. 49) may have formed by successive accumulations of quartz on to those grains whose c-axes were oriented east/west from the start.

RELATION BETWEEN SOUTHERN AND NORTHERN PARTS OF WHITE RANGE NAPPE

The differences between the southern and northern parts of the White Range Nappe can be summarized as follows:

Southern Basement Rocks

1. Mesoscopic structures not related to macroscopic structure.

2. Microscopic deformation slight; microfabric random.
3. Retrogressive metamorphism slight, i.e., patchy in extent and low in grade.
4. K-Ar dates all Carpentarian.

Northern Basement Rocks

1. Mesoscopic structures homotactic with macroscopic structure.
2. Microscopic deformation considerable; microfabric homotactic with mesoscopic and macroscopic structures.
3. Retrogressive metamorphism ubiquitous, and higher in grade.
4. Most K-Ar dates re-set; white micas are Silurian to Carboniferous, biotites range from Carpentarian to Carboniferous, hornblendes are Carpentarian or older.

Southern Heavitree Quartzite

1. No penetrative mesoscopic structures; brecciation common.
2. Microscopic deformation slight; microfabric random.
3. Progressive metamorphism (recrystallization) just discernible.
4. No K-Ar dates determined.

Northern Heavitree Quartzite

1. Mesoscopic structures homotactic with macroscopic structure.
2. Microscopic deformation considerable; microfabric homotactic with mesoscopic and macroscopic structures, and with corresponding structures in basement.
3. Recrystallization considerable.
4. K-Ar dates Carboniferous

The fundamental phenomenon indicated by all these changes is an increase in temperature from south to north across the nappe, and approximate 'calibration points' are given by the greenschist facies assemblages, namely, about 250°C in the south and 350°C in the north. The transition between the two different parts of the nappe is inferred to be near the position shown in Figure 31.

The relationship between metamorphism and deformation during emplacement of the White Range Nappe is not easy to determine; to put it concisely, did the deformation cause the retrogressive metamorphism, or did the metamorphism allow the deformation to take place? To put it another way, what caused the rise in temperature of the rocks in the northern part of the nappe? Two possible heat sources suggest themselves, namely, a rise in the geothermal gradient, or the heat produced by the mechanical work done during the penetrative deformation of the rocks. Though some writers (Ambrose, 1936 & De Lury, 1944) have maintained that the latter can cause regional metamorphism, it is not generally held to be the case (Goguel, 1948;

Turner & Verhoogen, 1960), most geologists preferring to believe that some sort of upsurge of heat is the prime cause of metamorphism (Fyfe, Turner and Verhoogen, 1958; Sutton, 1965; Winkler, 1967). The root of the White Range Nappe is located in a belt of rocks which have been retrogressed to greenschist facies assemblages, and this retrograde belt extends east and west far beyond the limits of the Arltunga Nappe Complex (Forman and Shaw, 1971). It has been suggested that the belt of retrogressed rock is the expression of a 'deformed zone that dips northward through the crust into the mantle' (Forman, 1971), and the nappe is envisaged as forming in this deformed zone during overthrusting of the crust and mantle from north to south (relatively). It might be argued that the linear character of the retrogressed zone supports the notion that deformation during overthrusting caused the retrogression, but that this is not so is indicated by the situation in the autochthonous rocks west of the White Range Nappe, and in the basement rocks in the southern part of the Nappe. Here, the rocks underwent retrogression during the Middle Palaeozoic (probably; the argument depends on the assertion that the Early Palaeozoic age (534 and 596 m.y.) of sericite in this area is caused by excess argon in what is actually Middle Palaeozoic sericite - see above), but they show no mesoscopic structures that can be related or attributed to the Alice Springs Orogeny. Thus, there are areas in this linear retrogressed zone which have not undergone deformation while they were being retrogressed, and so the retrogression could not have been caused by deformation in these areas.

A similar conclusion can be reached by considering the sequence of events during the emplacement of the White Range Nappe. The argument depends on putting the emplacement (by sliding) of the Giles Creek Synform late in the sequence of events, which is not how Forman (1971, and Fig. 4 in this report) shows it. However, the basement rocks of the Giles Creek Synform are substantially more retrograded than the rocks in the southern part of the western lobe of the White Range Nappe, and this indicates to me that the rocks of the Giles Creek Synform spent more time in the warm root zone of the nappe complex than did the rocks of the western lobe. Hence, they moved out of the root zone and formed the Giles Creek Synform at some time later than the emplacement of the western lobe. If this emplacement history is accepted, then the entire sequence of events comprises essentially a period of early thrust-faulting (sliding), then a period of penetrative deformation, then a final period of sliding again. This sequence suggests that the rocks underwent a rise and fall in temperature, the response of the rocks changing as the temperature changed. If the mechanical work done by the moving rocks were the cause of the heat that caused the retrograde metamorphism, then we might expect the highest temperatures and most ductile deformation to persist until the end of the emplacement, rather than being confined to the middle of the emplacement, as appears to be the case. Conversely, if the rocks had never been warmed up, we might expect the nappes to have been emplaced entirely as thrust nappes, and show no region of substantial penetrative deformation and retrogression.

Thus it appears that deformation was not necessary for retrograde metamorphism of the rocks to start, though there is no doubt that deformation assisted in completion of the process; the most retrogressed rocks are also the most deformed rocks.

The problem remains: what warmed the rocks that consequently retrogressed? One possibility might be the heat contained in the deeper crust and mantle rocks that were brought up to a higher level during the southward thrusting. A rough calculation shows that, on a 'normal' geothermal gradient of 20°C/km, granulite facies rocks moving from a depth of 25 km (in Carboniferous times) to a depth of 10 km would undergo a fall in temperature of about 150°C, while the cooler rocks below the thrust would undergo a corresponding rise in temperature. Other problems remain, however. If simply thrusting up the deeper, hotter rocks provided enough heat to cause retrogression, why are Carboniferous nappes not present all along the retrogressed zone? (Unless it is just that they have not been found). I am left with the feeling that the marked retrograde metamorphism, penetrative deformation, and existence of new mesoscopic structures in the northern part of the White Range Nappe indicate that that region is fundamentally different from the other parts of the nappe, and from the autochthonous rocks west of the nappe. Though some may say that this is merely pushing the problem out of sight, I believe that this difference was caused by a rise in the geothermal gradient in that area.

If this view is accepted, then a possible sequence of events that led to the emplacement of the western lobe of the White Range Nappe may have been as follows:

SEQUENCE OF EVENTS

1. In the later part of Devonian time, retrogressive metamorphism began to affect part of the deeper basement rocks below the northern part of the Amadeus Basin.

2. Movement of the nappe started at or about the end of Devonian time, when the first and mildest effects of retrogression had reached the upper part of the basement. The nappe began as a gentle upwarp or anticline in the basement and Heavitree Quartzite, and was accompanied by brecciation of pegmatite and quartzite plus a very small amount of microscopic deformation in all the rocks. Because the rocks were relatively cool (ca. 250°C), further movement took place by sliding of the nappe along a fault (or tectonic slide) that sliced through the southern limb of the anticline, thus emplacing the southern part of the nappe as a relatively rigid block in which old structures, minerals, and K-Ar dates were preserved more or less intact.

3. The sliding accounted for about 20 per cent of the north/south displacement of the nappe, and might have gone on to account for all of it, as in the Ruby Gap Nappe and the Blatherskite Nappe at Alice Springs (Stewart, 1967). That it did not, and was instead succeeded by macroscopic recumbent folding, was because of the continued rise of the geotherms in the root zone

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of the nappe, so that eventually the rocks became warm enough (ca. 350°C) to deform penetratively. Thus the northern part of the nappe was emplaced over the underlying Bitter Springs Formation as a large recumbent anticline of retrogressively metamorphosed basement and progressively metamorphosed Heavitree Quartzite. The penetrative deformation involved principally the cataclasis of feldspar and syntectonic recrystallization of quartz; old mesoscopic structures in the basement were largely obliterated, and a new foliation and lineation formed in both basement and Heavitree Quartzite. As the southern part of the nappe became impeded by the mass of Bitter Springs Formation squeezed out of the syncline below the nappe, it was over-ridden by the warmer retrograding rocks of the northern part. The mass of quartzite and its accompanying south-verging folds which crops out along the southern side of Paddys Hole Plain was emplaced at this stage, and represents part of the lower limb of the nappe that was dragged up and folded by the continuing motion of the northern part of the nappe against the back of the slower moving (or stationary) southern part.

4. The origin of the north-northeast trending recumbent folds in the northern part of the nappe can probably be ascribed to the geometry of the conduit through which this part of the nappe flowed. As outlined earlier, the western lobe of the nappe occupies a synformal depression between two domes. These dome and basin structures might be the result of later east/west stress, but it seems at least equally likely to me that a structure as large as the White Range Nappe would have a non-cylindrical shape from the start (cf. Fig. 3 in Forman, 1971). If so, then the western part of the nappe flowed along a channel between two antiforms or domes, and these would to some extent prevent the nappe from spreading sideways (i.e. east/west) as it flattened vertically, thus resulting in the formation of folds (in this case recumbent folds) with their axes more or less parallel to the direction of flow or tectonic transport.

5. The emplacement of the northern part of the nappe over the southern part caused the north-dipping, cross-cutting foliation in the quartzite on the southern side of Paddys Hole Plain, and also caused the macroscopic boudinage of this quartzite and the mesoscopic boudinage in the White Range and the range on the northern side of Paddys Hole Plain.

6. The southward translation of the nappe removed the rocks from the warm region in the root zone, and so cooling and stiffening of the rocks ensued and microscopic deformation ceased. Residual stresses caused the late upright folding of the Heavitree Quartzite around east/west axial planes, and also the two sets of kink bands. Final cooling was accompanied by the filling of cracks with vein quartz, quartz-muscovite aggregates, and probably the auriferous reefs at White Range.

QV

EPILOGUE

The Arltunga Nappe Complex is an unusual structure. Basement-cored nappes of this general type are usually found in cordilleran-type or collision-type mountain belts, where there has been extensive movement and interaction of lithospheric plates (Dewey & Bird, 1970). However, the evidence shows that the Arltunga Nappe Complex formed far inland from the edge of the Australian continent, in a cratonic platform composed of rocks that are very much older than the reconstituted tectonites of the nappes; in Middle Palaeozoic time, when the nappes formed, the Arltunga area was separated by 1 000 km of Proterozoic rocks from the northern and southern margins of the continent, by 2 000 km of Archaean and Proterozoic rocks from the western margin. So, there is no evidence that the Arltunga Nappe Complex formed at or near the edge of a continent that subsequently became incorporated into the interior of a larger continent, after collision of the sort that may have occurred along the Ural Mountains in Russia, or along the Himalaya Mountains between India and Tibet.

Other major differences between the Arltunga nappes and basement-cored nappes elsewhere in the world are:

1. Brittle fracture phenomena (thrust faulting, sliding, and brecciation), indicative of a low-temperature environment, predominate over ductile mechanisms (folding, intragranular flow, and syntectonic recrystallization), indicative of a warmer environment.

2. Regional metamorphism is patchy, local in extent, and of very low grade.

3. There is no associated magmatic activity, neither volcanic nor plutonic.

These phenomena can probably be ascribed to the fact that the Arltunga Nappes formed within a cool and dry cratonic basement beneath a relatively thin sedimentary cover. The ultimate cause of the formation of the nappes may have been movements in the earth's mantle, but if so, the very large negative Bouguer gravity anomaly south of the Arltunga nappes suggests that the movements, rather than involving subduction of a cool lithospheric slab into a hot asthenosphere to a depth of several hundred kilometres, led instead to a general thickening of the continental crust, either by the pushing together of an imbricate mass of thrust slices, or by folding and flowage, or by some other mechanism. Deep seismic profiling of the crust-mantle boundary may help to elucidate this problem, and the Geophysical Section of the Bureau of Mineral Resources has this investigation on its programme.

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TABLE 1 - SEQUENCE OF DEFORMATION

Fold generation	Western part of White Range Nappe (J.L. Funk)	Central part of White Range Nappe (A.J. Stewart)	Upper Part of Ruby Gap Nappe (M. Yar Khan)	Lower Part of Ruby Gap Nappe (R.D. Shaw)
	North-south sliding	North-south sliding		
1	Lineation implying folding episode possibly associated with continued sliding	East-west, south-verging folds, associated with north-south sliding		
2	North-south reclined folds with northerly dipping axial plan schistosity. East-west folds inclined (south-verging) to upright	North-south reclined and recumbent folds with northerly dipping axial plane schistosity. North-south sliding (Giles Creek Synform)	North-south reclined and recumbent folds with northerly dipping axial-plane schistosity	East-west south-verging folds in autochthon and concurrent north-south recumbent shallow folds with west and north dipping axial-plane schistosity in allochthon associated with thrusting
3	East-west upright folds and crenulations (late, minor)	'East-west' upright folds (2 sets) and kink folds, and east-west kink bands	East-west upright to south-verging folds and related large macroscopic fold (eg Atnarpa Antiform post-date thrusting)	East-west minor and macroscopic warps (post-date thrusting
4	Kink bands concentric folds, broad-warps tension gashes (post-dates thrusting)	North-south kink bands	Kink bands and box folds	Kinks associated with thrust faults.

TABLE 2 - LITHOLOGICAL DESCRIPTION OF STRATIGRAPHIC UNITS

Stratigraphic Unit	Western Part of White Range Nappe (J. Funk & A.J.S.)	Central Part of White Range Nappe (A.J.S. & D.J.F.)	Ruby Gap Nappe (R.D.S. & M.Y.K.)
ARUNTA COMPLEX	<u>Northern part</u> (i.e. allochthon) Quartzofeldspatchic gneiss, amphibolite, marble and calc-silicate rock together with their mylonitic and retrograded equivalents <u>Southern part</u> (i.e. autochthon) Granitic gneiss, melanocratic syenite, lens of hornblende gneiss and granite in northwest with pod of peridotite at southern end, numerous hornblende amphibolite and quartzdiorite in south, dykes of basic lamprophyre	<u>Southern part</u> Marble, calc-silicate rock, andalusite-mica schist and quartzite overlain by quartz rich plagioclase biotite gneiss (± sillimanite); numerous bodies of amphibolite some with cordierite + anthophyllite <u>Northern part</u> (a) <u>Western and central part</u> quartz-rich biotite gneiss (± garnet), mica schist, hornblende amphibolite, pegmatite and minor amounts of epidotized gneiss, quartzite, marble, vein quartz and epidosite (b) <u>Eastern part</u> - retrogressively metamorphosed tonalite and granodiorite together with small amounts of greenschist and micaceous quartzite	<u>Allochthon and northwestern part of Allochthon</u> muscovite, biotite and hornblende bearing gneisses mainly of tonalitic and granodioritic composition but including minor amounts of granitic composition; subordinate amounts of tremolite and hornblende amphibolites, a few of which are quartz-bearing <u>Allochthon</u> Biotite gneiss (± sillimanite), amphibolite clac-silicate rock, small amounts of marble
HEAVITREE QUARTZITE — Basal Member (Buhi)	?Coarse-grained to medium-grained sandstone <u>Thickness</u> - 30 metres (est)	Coarse-grained pebbly sandstone, and conglomeratic sandstone containing stretched pebbles and cobbles and boulders of quartzite up to 10 cm across and 65 cm long	Clayey, pebble sandstone (commonly fledspathic or arkosic), and conglomerate - all generally chocolate-brown or green. Pebbles subrounded to subangular and consist of vein quartz and small amounts of gneiss. Pebbles up to 2.5cm across. Fragments of vein quartz up to 15cm long in northern part of Western Hill, Atnarpa area. Maximum thickness: 3 metres

TABLE 2 (Continued)

Stratigraphic Unit		Western Part of White Range Nappe	Central Part of White Range Nappe	Ruby Gap Nappe
	Basal Member			in Atnarpa Range area
HEAVITREE QUARTZITE	Middle Member (Buh_2)	Thick-bedded to massive, fine-grained quartzite with abundant current-bedding and numerous grit and pebble bands Thickness 200 metres (est)	Medium-grained blocky sandstone. Includes a thin siltstone unit (Buh_{2a}) and a fine-pebble conglomerate unit (Buh_{2b}) in Arltunga Bore area	Blocky white quartzite; cross-bedded, medium to coarse-grained sandstone; minor amounts of very coarse-grained sandstone, pebbly sandstone and conglomerate containing sub-angular white vein quartz granules and some pebbles. In general grainsize decreases upwards. Cross-beds are more abundant in lower part. Thickness 200-400 metres (est)
	Upper Member (Buh_3)	Platy quartzite; shale interbeds increase upwards (one black shale horizon) Thickness 70 metres (est)	Fine-grained laminated quartzite	Fine-grained, platy quartzite, typically laminated to thin bedded, but some thick beds occur in lower part. Ripple marks common. It is characterized by a few distinct reddish-brown, purple and bluish-grey beds, some of which consists of coarse rounded quartz grains. Thickness 100-200 metres (est)
BITTER SPRINGS FORMATION	Transitional Unit (Bub)			Siltstone and dolomite interbedded with quartzite. Greyish-grey siltstone which weathers to a characteristic white colour, several beds heavily iron-stained

TABLE 2 (Continued)

Stratigraphic Unit	Western Part of White Range Nappe	Central Part of White Range Nappe	Ruby Gap Nappe
BITTER SPRINGS FORMATION (Gillen Member)	Thin unit of grey-green shale overlain by thin-bedded dolomite		Lower part Dolomite, siltstone, shale, and minor amounts of limestone and sandstone Upper part Dark reddish-brown siltstone and olive-grey shale; subordinate dolomite in thin irregular bands. Junction with Buh marked by dark-brown ferruginous layer, 1-1.5m thick at some localities. Preserved Thickness 60-90 metres (est)

GEOLOGY OF THE ARLTUNGA NAPPE COMPLEX, NORTHERN TERRITORY

To accompany Record 1971/66

F53/A14/155

PLATE 2

LOCATION OF SPECIMENS IN THE AREA OF THE ARLTUNGA NAPPE COMPLEX, NORTHERN TERRITORY

To accompany Record 1971/66

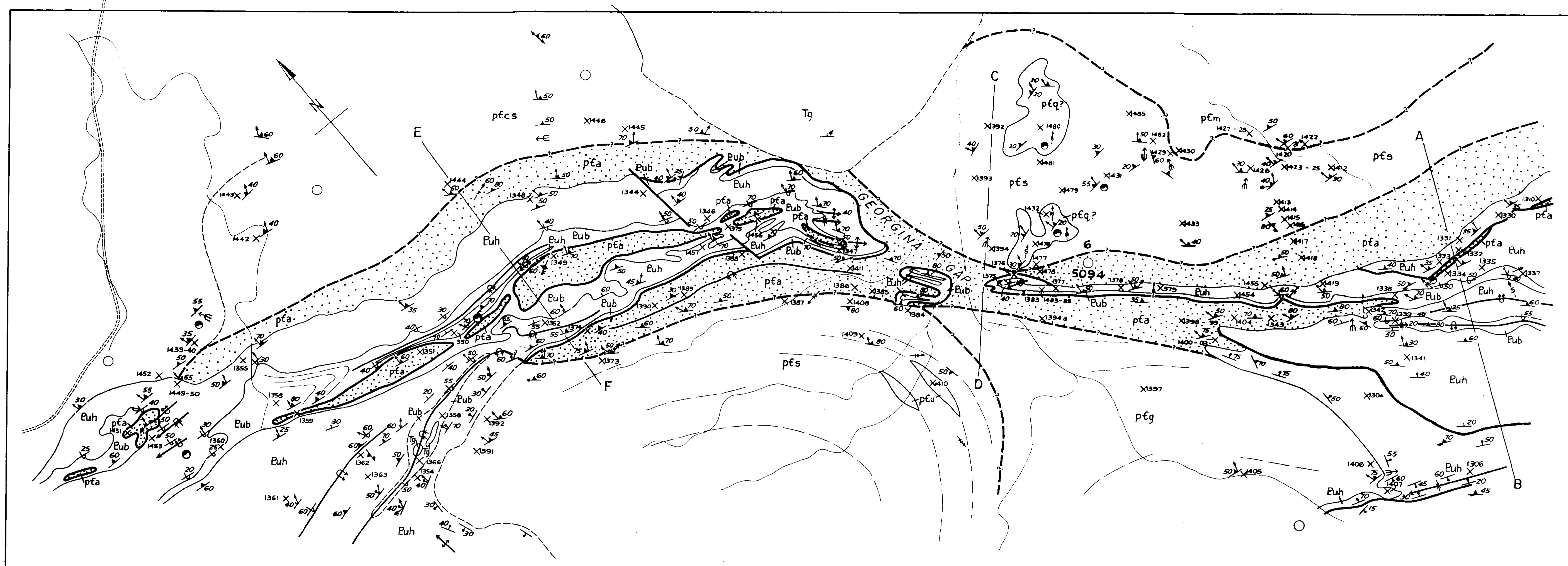
F 53/A14/156

PLATE 3


GEOLOGY OF THE ATNARPA RANGE AREA
NORTHERN TERRITORY
1:15 000
km
MI
MAP AREA IN RELATION TO 1:250 000
NAPPERBY
ALCOOTA
HUCKITTA
HERMANNSBURG
ALICE SPRINGS
ILLOGWA CREEK
HENBURY
RODINGA
HALE RIVER
LOCALITY MAP
N
N.T.
CAINOZOIC
QUATERNARY
Qa
Alluvium, river gravel
PRECAMBRIAN
UPPER PROTEROZOIC
Bitter Springs Formation
Ꝑub
Siltstone, shale, quartzite and dolomite
Heavitree Quartzite
Ꝑuh
Quartzite, sandstone, pebbly sandstone
Ꝑuh3
Platy quartzite
Ꝑuh2
Quartzite, sandstone
Ꝑuh1
Conglomerate, siltstone, pebbly sandstone, arkose
p€a
Basement igneous and metamorphic rocks
p€g
Granite
p€qt
Quartzo-feldspathic rocks
p€u
Mafic rocks
Geological boundary, position accurate
Position approximate
Concealed
Anticline, showing plunge
Position approximate
Syncline, showing plunge
Position approximate
Plunge of fold showing 'S' vergence, crenulation parallel to fold axis
Plunge of fold showing 'Z' vergence, crenulation parallel to fold axis
Plung of fold showing 'M' vergence, crenulation parallel to fold axis
Plunge of fold showing strike & dip of its axial plane
Plunge of minor antiform
Plunge of minor synform
Locality of superposed folds
Fault, position accurate
Position approximate
Inferred
Inclined (measured)
Fault containing mylonite or breccia
Fault with slickensides
Strike and dip of strata, measured
Strike and dip of overturned strata
Strike and dip of vertical strata
Strike and dip of upright strata
Strike and dip of strata with plunge of lineation
Strike and dip of strata parallel to foliation with plunge of lineation
Strike and dip of strata parallel to foliation with horizontal lineation
proved direction of younging based on sedimentary structures, indicated by dot. For arrowheads applicable to other types of lineation see under 'Lineation' below
Trend line
Strike and dip of foliation, measured
Vertical foliation
Foliation with plunge of lineation (both measured)
Foliation with horizontal lineation
Trend and plunge of lineation (undifferentiated, measured)
Trend and plunge of lineation (mineral elongation)
Trend and plunge of lineation (slickensides)
Trend and plunge of lineation (crenulation)
Horizontal lineation
X 206
Specimen locality
Dyke or vein, q-quartz
Water bore with windpump
Road
Vehicle track
Atnarpa homestead
Yd
Yard
Photo centre: wing point
Hole Creek
Creek
SMALL VALLEY
LARGE VALLEY
EASTERN HILL RANGE
ATNARPA RANGE
WESTERN HILL
"Atnarpa"
A
A1
B
B1
1000m
V/H = 1
To accompany Record 1971/66
F53/A14/157

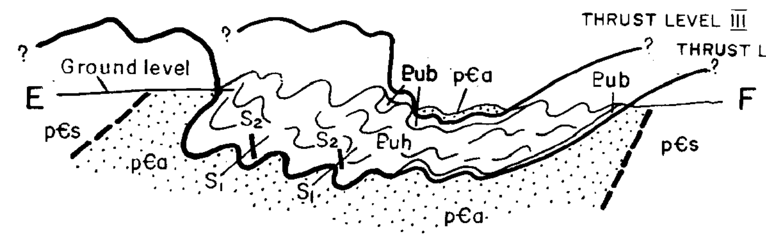
GEOLOGY OF THE GEORGINA GAP AREA, N.T.

Geology by J. Funk, Australian National University



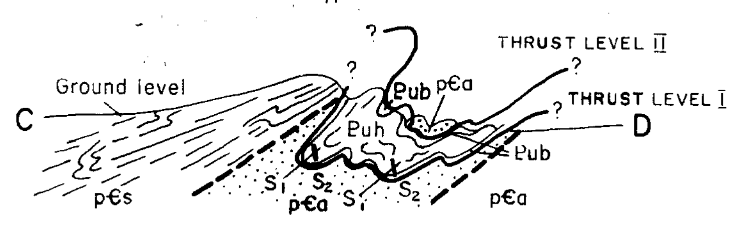
DIAGRAMMATIC Cross section E-F

$\frac{V}{H} = 1:1$



DIAGRAMMATIC Cross section C-D

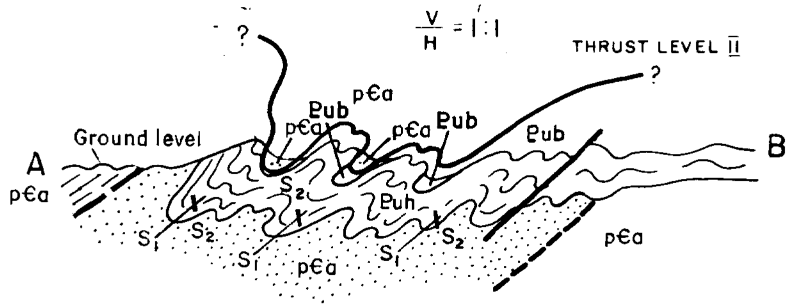
$\frac{V}{H} = 1:1$



S_1 - schistosity; S_2 - crenulation cleavage

DIAGRAMMATIC Cross section A-B

$\frac{V}{H} = 1:1$



- Tg *Tertiary gravels, silicified sandstone*
- Eub *Bitter Springs Formation*
- Euh *Heavitree Quartzite*
- p€a *Retrograde mylonitic rocks*
- p€q *Quartzite, possibly Euh*
- p€a *Undiff. metamorphic rocks (cross-section)*
- p€u *Amphibolite*
- p€g *Granitic gneiss*
- p€s *Biotite-muscovite schist*
- p€m *Marble, calc-silicate*
- p€cs *"Curled" schist*

- *Lineation (bedding-cleavage intersection)*
- *Lineation (mineral elongation)*
- *Lineation (crenulation)*
- *Strike and dip of foliation*
- *Vertical foliation*
- *Measured foliation, number of ticks indicates whether 1st, 2nd or 3rd generation in a sequence of folding episodes*
- *Foliation with plunge of lineations (crenulation and mineral elongation)*
- *Foliation with plunge of lineation (mineral elongation)*
- *Foliation with horizontal lineation (mineral elongation)*
- *Strike and dip of overturned strata with plunge of lineation (mineral elongation)*
- *Strike and dip of strata*
- *Strike and dip of strata-proved direction of younging indicated by dot*
- *Strike and dip of overturned strata-proved direction of younging indicated by dot*
- S *Schistosity (cross-section)*
- S2 *Crenulation cleavage (cross-section)*
- *Plunge of folds, showing "S", "Z" and "M" vergence as indicated; style of arrowhead indicates lineation type paralleling fold axis*
- *Plunge of minor antiform*
- *Plunge of minor synform*
- *Locality where superposed folds (i.e. interfering folds of differrent ages), have been observed*
- ×1444 *Sample locality*
- 6 / 5094 *Air photo centre point, Alice Springs, 1950 set.* ○ *Wing point*
- *Geological boundary, position accurate*
- *Geological boundary, position approximate*
- *Fault, position accurate*
- *Fault, inferred*
- *Antiform, showing direction of plunge*
- *Synform*
- *Overturned antiform*
- *Overturned synform*
- *Trend line*

0 1 2 km
0 1 mile

To accompany Record 1971/66

F53/A14/128