THE UNIVERSITY OF ADELAIDE

THE STRUCTURAL GEOMETRY OF THE ONKAPARINGA GORGE REGION, SOUTHERN ADELAIDE FOLD BELT, SOUTH AUSTRALIA.

by C. MATTHEWS

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by

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Abstract.

The Onkaparinga Gorge, situated on the Onkaparinga River southwest of Clarendon contains exposed middle Adelaidean rocks of the southern Adelaide Fold Belt. The structural geometry displayed exists as the result of a Cambro-Ordovician compressional deformation, the Delamarian Orogeny. Folds are gentle in competent strata and close to tight and west vergent in fine grained incompetent strata. The majority of faulting is thrusting oriented subparallel to bedding with one high angle thrust, the Onkaparinga Fault that cross-cuts all other tectonic elements. Low angle thrusting caused the repetition of competent beds and the duplexing or imbrication of incompetent units. Total displacement calculated by the addition of all minimum displacements measured on individual thrusts is in the order of 1.8 kilometres.

Strain patterns indicate that thickening of bedding has ocurred in the Sturt Formation diamictite with considerable shortening and volume loss due to compaction. The style of deformation in the Belair Subgroup is one of stretching parallel to bedding. The difference in strain patterns in the two above mentioned formations suggests that there is a structural discontinuity between the Belair Subgroup and the Sturt Formation.

Evidence from geological mapping and subsequent stereographic projections of field data indicates that thrusting subparallel to bedding has been the major deformational influence at the levels of the Sturt and Tapley Hill Formations with folding less influential. This evidence may support the the existence of a roof thrust zone at this level but such features can also be attributed to other deformational models. Two models of tectonic evolution can explain the current structural geometry in the Onkaparinga Gorge. The first model associates the thrusting observed with fold development during compression. The second model proposes a two part deformation of thrusting followed by folding of the thrusted strata during continued compression.

1.Introduction.

The Adelaide Fold Belt: The Structure Controversy.

The Cambro-Ordovician Delamarian Orogeny caused compressional deformation and resultant structures can be seen in the Onkaparinga Gorge, south of Adelaide (fig 1) where Adelaidean rocks of the Burra Group, Belair Subgroup and Umberatna Group (Mawson and Sprigg 1950; Thomson 1964) outcrop. The Adelaidean sequence of the southern Adelaide region has limited exposure because of the existence of extensively developed Permian and Tertiary cover sequences and a high level laterite soil profile. Because of this it is necessary to seek key exposures in order to investigate the geology of the Adelaidean rocks. The Onkaparinga Gorge is one such place where the mid-Adelaidean is well exposed.

The purpose of this thesis is to produce a detailed geological map and construct a structural geometry of the lower-middle Adelaidean rocks in the Onkaparinga Gorge, south of Adelaide.

told us 3 times.

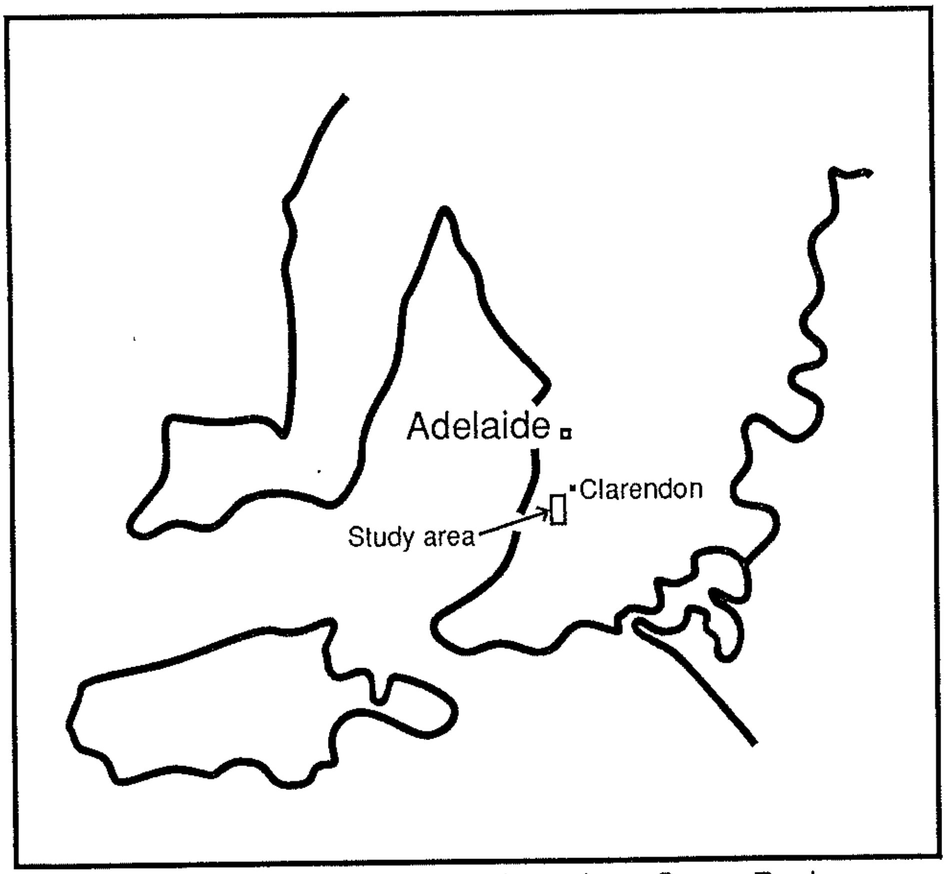


Figure 1. Locality map of Onkaparinga Gorge Region.

The structural geometry of the Adelaide Fold Belt has been discussed for nearly 150 years. Insight into the geological configuration was provided by Jukes (1850 in Howchin 1904) who considered that "The south-easterly dip here would put the clayey slates *under* the metamorphic gneisses". Selwyn (1859) described "great anticlinal and synclinal undulations".

Ralph Tate in 1879 amplified the geological enigma remarked on by Jukes, describing the "strata composing the Mount Lofty Range as dipping south-east and younging to the east" and further commenting that "It is remarkable that the apparently less metamorphosed strata occupy the lowest position". However he still supported the theory that the geometry of the Fold Belt was one of a monoclinal fold.

Brown (1883) said that the general dip of the area is to the south-east with about twenty (?) kilometres of extent, "giving an immense apparent thickness of the fold belt". Brown went on to say that the occurrence of dykes and granites suggests that igneous rocks may underly the sediments of the whole area. A crucial observation was made when he said that "faulting and strata inversion must have taken place to account for the apparent thickness of the fold belt".Tate (1893) still supported the "vast monocline" theory but did note the highly developed metamorphism of the upper strata.

Howchin (1904) described low angle thrusting of the Sturtian tillite over the Tapley Hill Formation in the Onkaparinga Gorge: "The slates are horizontal then they dip 20 degrees to the south-east and finally pass under the tillite at a 30 degrees contact dip. The occurrence of tillite above slate means the old beds broke and slid over the newer in a thrust plane of a quarter of a mile exposure". He also described other extensive thrusts and likened the front of the Mount Lofty Ranges to a staircase of stepped thrusts.

Sprigg (1946) attempted to sum up the structural geology of the Adelaide area. He described a regional domed anticlinorium with the whole structure greatly disturbed by faulting. Major faulting documented in the paper fell under three headings, one of them being "low angle overthrust":

" The extent of override is not long in any one case....locations include Glen Osmond, Waterfall Gully, Morialta, Torrens Gorge...Low angle cleavage planes, upper limbs of overfolds glide over the lower limbs. Such zones are marked by quartz veins and tension gashes." Sprigg also mentioned structures he described as imbricates and noted that the overriding segments were gently folded while the overridden segments were "overfolded". Places where such structures were documented are Torrens Gorge, Sturt Gorge and Brownhill Creek.

Wilson (1952a) noted that in the Adelaide area folding and faulting are more intense than further north, for example around the Riverton-Clare region. He noted that in the north faulting does not appear to "cut upsection" as it does in the south.

Talbot (1963) studied structures in Burra Group sediments of the Torrens Gorge area and recognised two general fold styles: 1) those with slaty cleavage parallel or sub-parallel to the axial planes of the folds (called B2 in the paper) and ;2) folds with crenulation cleavage (B3). He noted hinge thickening in folds and small thrust zones in the overturned west limbs of folds. Sometimes the west limbs did not show thrusts but were simply attenuated.

It was Jenkins in a brief abstract in 1986 who revived the debate on the enigma outlined by Tate (1879). Jenkins (1990) was a followup paper that formed a "tectonic reappraisal" of the Adelaide Fold Belt. By particular reference to Sprigg (1946) Jenkins described two kinds of faulting in the Adelaide Fold Belt:

1) Zones of strongly foliated rock, brecciation, small zones of attenuated isoclinal folds, rotated intersection lineations that in turn define south-east north-west stretching lineations, and thrusting with an easterly dip of a relatively low 20-45 degrees.

2) Imbricate thrusting in the central ranges. "Rafts" of Stonyfell Quartzite enveloped by phyllites, staircase mode of faulting with associated folds of leading antiforms and trailing synforms where overturned limbs are either attenuated or broken. These all combine to describe an antiformal thrust stack. Jenkins went on to state that the oblique intersection between the main antiform structure and the thrust pattern suggest that the entire sedimentary prism represents an allochthon over a detachment surface.

The main structural focus of Jenkins (1990) was the Stonyfell Quartzite and the older Adelaidean Burra Group. Supposedly, the central Burra Group shows the greatest degree of deformation with the Stonyfell being cut by shear zones and displaced in a dextral shear sense (Sprigg 1946: "repeated dip faults in the Stonyfell Quartzite"). The western edge of these Stonyfell "Islands" are shear bounded antiforms with the main body being horizontal and the eastern margins being synformal.

Jenkins drew attention to other observations with regard to thrusting and metamorphism and cited Offler and Fleming (1968) who described an increasing metamorphic grade from west to east with chlorite grade at Marino, biotite grade at Coromandel, andalusite-staurolite at Meadows through sillimanite grade in the Kanmantoo Complex further east finally to migmatite grade partial melting at Palmer. A conclusion drawn from this was that thrusting followed a thermal event in the south-east and thrust sheets were emplaced "hot".The younger rocks are the most metamorphosed and appear to be ramped over the older, hence Ralph Tate's enigma.A reason for the structural enigma of younger rocks ramping over older will be proposed in a tectonic model of the Onkaparinga Gorge geometry in relation to other areas in the southern Adelaide Fold Belt.

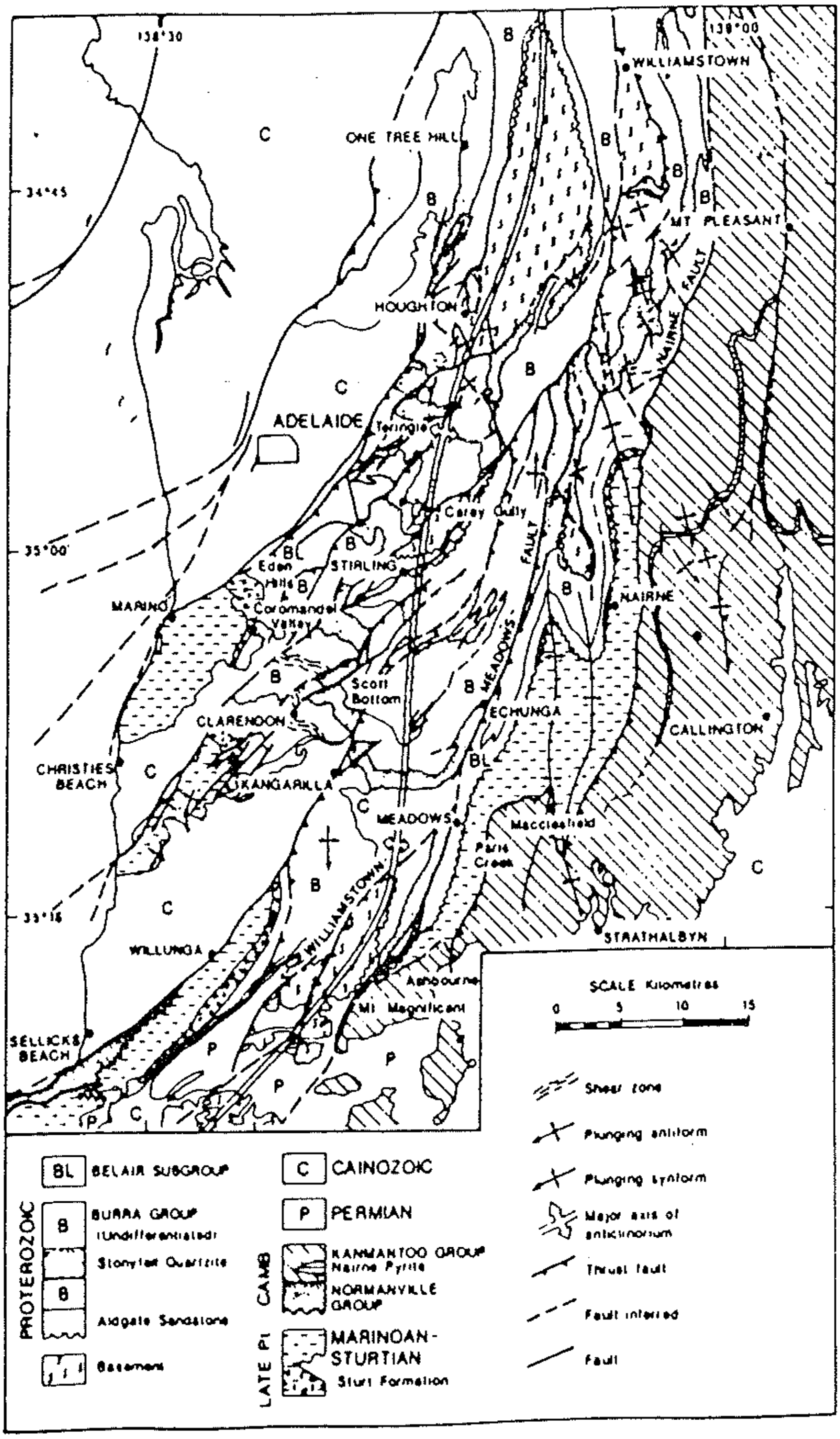


Figure 2. Regional Geology Southern Adelaide Fold Belt

(from Jenkins, 1990)

2. Stratigraphy.

2.1: Mid-Adelaidean Stratigraphy: History of Burra and Umberatana Group descriptions.

The Burra and Umberatana groups of rocks represent the older to middle Adelaidean time sequence.Stratigraphy corresponding to the Burra Group was first proposed by Wilson (1952a) who described units in the Rhynie-Clare region of the northern Mount Lofty Ranges. The Burra Group was first defined by Thomson et al (1964). It conforms chronologically to the Torrensian Series of Mawson and Sprigg (1950). The base of the Burra Group is defined as being of earliest Torrensian age. The Umberatana Group was also defined by Thomson et al (1964) and included the Sturtian and Marinoan diamictite sequences and all sediments in between. This group also conforms chronologically to the Sturtian and parts of the Marinoan series of Mawson and Sprigg (1950) with one exception only, the Belair Subgroup. Thomson placed this Subgroup in the topmost echelon of the Burra Group whereas Mawson and Sprigg linked it with the rocks subsequently placed in the Umberatana Group, claiming that it was related to the Sturtian Glacial sequence.Most formations described in the north of the state have correlatives in the southern Adelaide Fold Belt except for the Belair Subgroup which only has documented outcrop in the mid and southern Mount Lofty Ranges.

2.2 - Onkaparinga Gorge Stratigraphy (FIG 3).

a) Burra Group.

The lithology included as part of the Burra Group outcrops in the northernmost part of the mapped area on the eastern side of the Onkaparinga Fault. Identification as Burra Group was based on the presence of dolomite in outcrop. Dolomite has never been documented in the Belair Subgroup stratigraphy (Mawson and Sprigg 1950, Thomson 1964). It followed that these rocks are likely to be part of the Burra Group. This identification is important for the nature of displacement on the Onkaparinga fault. The displacement was found to be reverse (see Chapter 3 for geometric description).

b) Belair Subgroup.

The sediments and phyllites interpreted as belonging to the Belair Subgroup outcrop in the greater part of the mapped area. The subgroup is characterized by the existence of several thick units of feldspathic coarse arenites. Quartz grains are subrounded and the existence of feldspar in the sediments suggests that weathering (chemical or physical) was not sustantial before deposition. The source of the sediments must have been proximal. These units contained cross bedding of scales up to 30 cm and ripple marks on exposed bedding planes. Flat lamination is present in parts of the feldspathic quartzite. Conglomeratic lenses were also observed in coarse sandy units. Outcropping between the quartzites are medium and fine grained sandstones and shales.These rocks are laminated with cross bedding rare or absent.

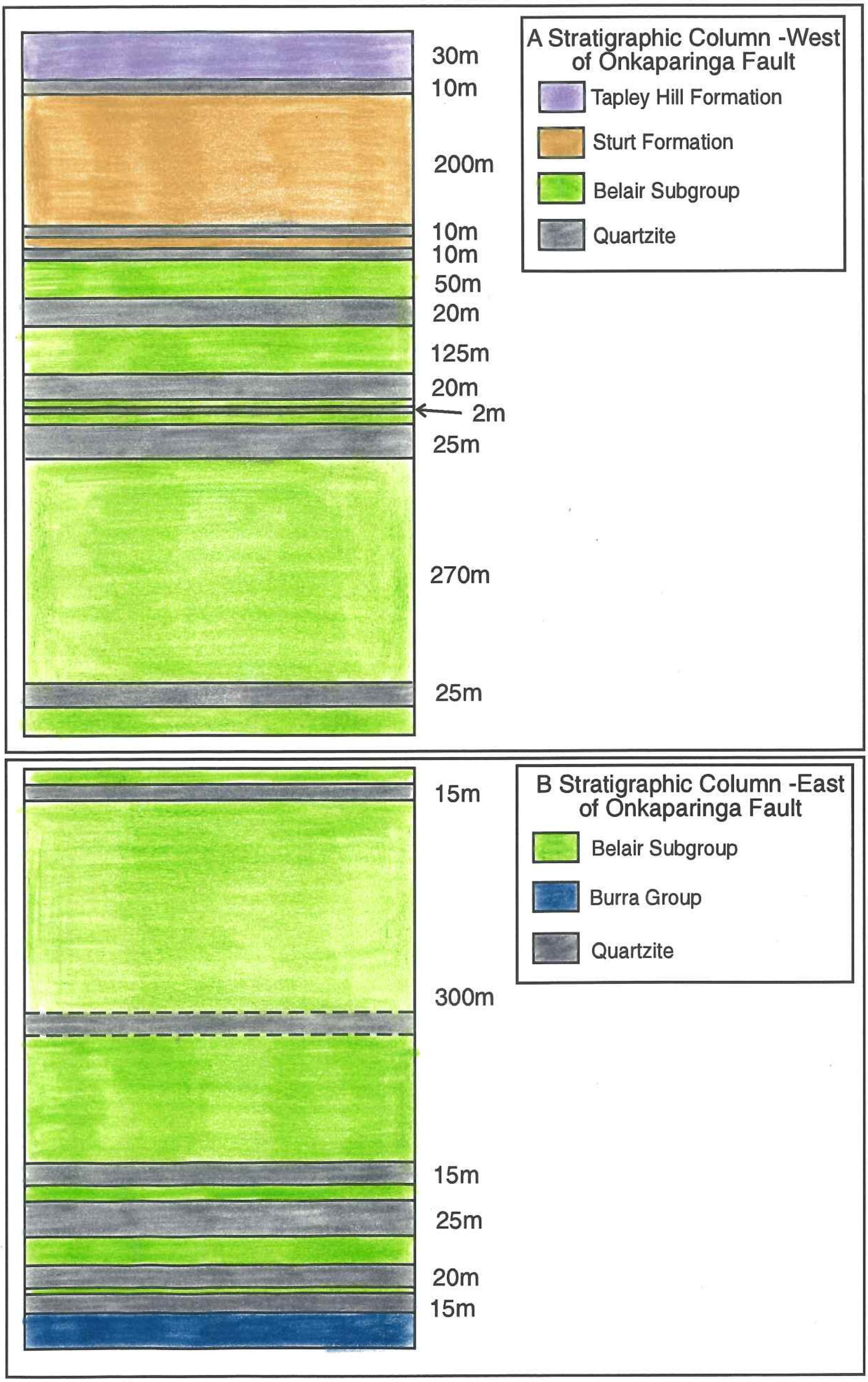


Figure 3. Stratigraphic Columns.

c) Sturt Formation.

The lower boundary of diamictites of the Sturt Formation with the underlying Belair Subroup is a sharp continuous contact, not tectonic or unconformable. The stratigraphic lower boundary of the diamictite is taken at the first appearance of clasts in a fine grained matrix with slaty cleavage. Clast types observed included quartz, anorthoclase, potassium feldspar and in some cases granite. Isolated conglomeratic lenses were found at some levels while other shale units contained no clasts. Quartzite units occurred sporadically in the diamictite, three were observed.

In a large proportion of the diamictite bedding was absent. In some parts bedding could be observed with thin (1cm max) beds that appeared to have coarse sharp basal contacts grading up to finer grained strata at the top. These beds give an indication of cyclic sedimentation. Modern temperate glacial settings show strong seasonal effects where summer temperatures are above freezing and large volumes of meltwater produce fluviodeltaic sediment pulses recorded in sediment couplets which Mackiewiz et al (1984) labelled as "cyclopels". Sedimentary structures such as these have been observed in modern temperate glacial settings in Alaska (Phillips, Smith and Powell 1991) and were called graded couplets. Sturtian sandstones in close proximity to these graded couplets displayed very large scale (70 cm) cross bedding with steeply dipping (65-80 degrees) foresets. Both of the above mentioned sedimentary characteristics may occur in glaciomarine sedimentary environments, a suggestion that the Sturt Formation is at least in part depositionally related to a glacial climate.

d) Tapley Hill Formation.

A two metre thick unit of white feldspathic quartzite occurs at the upper boundary of the Sturt Formation and the overlying Tapley Hill Formation. The section appears continuous from the diamictite through the quartzite into the dark grey slates that characterise the Tapley Hill Formation. The exposure of the boundary is poor being largely covered by the Onkaparinga River (see plan maps). Fine grained beds of the Tapley Hill Formation show cyclic alternation of slightly coarser and finer grained laminations at times. Medium-fine grained sand units are interspersed with the slates. Reduction spots of pyrite were observed indicating reducing diagenetic processes, perhaps reflecting a deep water anoxic setting.

2.3 Stratigraphic Evolution.

The Belair Subgroup represents a depositional environment that possibly consisted of marginal marine and shallow marine conditions with occasional transgressive facies. Feldspathic quartzites occur frequently in the section. The presence of feldspar in the sediments suggests that the source was proximal and/or that chemical weathering was at a minimum during erosion of the original sediments.

Feldspathic sedimentation continues up to the conformable contact with the overlying clast-rich diamictite. The diamictite may represent a tectonically active depositional period when high relief caused debris flows. Some sedimentological evidence suggests that the diamictite may be related to a temperate-cold glaciomarine environment. Marginal marine and shallow marine conditions may have existed during this time period with the diamictite interbedded with feldspathic quartzite.

The upper stratigraphic limit of the Sturt Formation is marked by a two metre thick unit of arkosic sandstone which passes conformably into fine grained slates. The Tapley Hill Formation marks a transgressive phase. The conditions of deposition seem to have been anoxic or reducing with reduction spots of pyrite observed in slaty layers.

Overall, the stratigraphic boundaries between units in the Onkaparinga Gorge are difficult to interpret because of the bedding planar nature of thrusting. Coats (1967) described the overefolded contact of the Belair Group and overlying Sturtian diamictite in the Sturt Gorge as being "sharp and sedimentary". This interpretation disagrees with Sprigg (1946) and Jenkins (pers. comm. 1993) who described the contact there as being "overthrusted". In the Onkaparinga Gorge the contact is sharp and appears to be disconformable,with no apparent low angle unconformity (Coats 1967). The description of the contact in the Sturt Gorge as being overthrusted is not concerned with the sedimentological characteristics of the contact which formed long before thrusting. Thrusts were mapped in the Onkaparinga Gorge stratigraphically above and below the Belair Subgroup/Sturt Formation. The contact is repeated in section by the Black Snake Thrust that is located 10 metres below the contact (see plan maps).

No evidence was found of an unconformable contact between the Burra Group and Belair Subgroup in the Onkaparinga Gorge area. However the exposure of the boundary is poor with the Onkaparinga River essentially "following" the contact (see plan maps).

No strata could be correlated on either side of the Onkaparinga Fault. Because of this fact two stratigraphic columns have been constructed, one for each side of the fault (fig 3). The columns are drawn with repetitions of strata removed. Strata thicknesses were taken from down plunge projection results (fig 5).

3.Methods and Results.

3.1 Field Mapping

The field study of the Onkaparinga Gorge region comprised detailed geological mapping on 1:10,000 aerial photographs. The map is divided into three zones, numbered 1,2,3. Outcrop structures were recorded as sketches and photographs. Mappable markers were common, usually in the form of units of medium to coarse quartzites. The abundance of these coarse units was found to be augmented by repetition of strata due to thrusts. The general form of the mapped area is one of gentle folding in competent strata with close to tight west vergent folding and thrust planes present in less competent strata. The trends of the fold axes in zone 3 are relatively parallel but have been displaced along thrusts that follow bedding planes. This layer parallel nature of thrusting is well exposed in plan because the gentle (20 degrees to the south-southeast) plunge of the structure elongates the section (fig. 4 from Dahlstrom 1969A). The down plunge projection reveals the open nature of the folds. The plan map section is very narrow and it would require extremely tight folding on a regional scale to enable the observation of folding on map scale here.

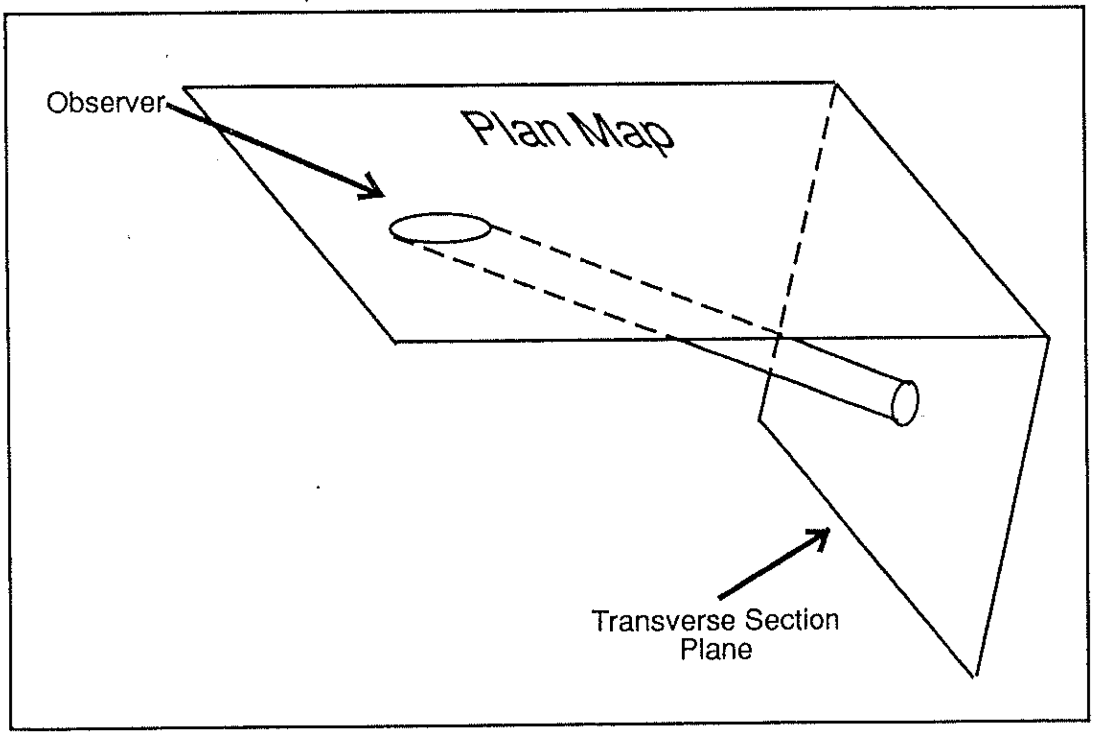


Figure 4. Section elongation in plan of shallowly plunging structures and down plunge projection viewing. After Dahlstrom 1969A.

Four separate thrusts were mapped on which repetition was recognised; The Black Snake, Gold Mine, Sundews and Torana Thrusts. Each of them is associated with but not restricted within arenite units. In zones where competent strata (quartzites or coarse arenite) outcrop, layer parallel thrusting has occurred. In outcrop some thrusts ramp up through bedding planes causing strata to be repeated in section.

A particularly thick sequence of three quartzites situated approximately in the geographical centre of the mapped area was found to be the focus of a major thrust (the Torana Thrust) in the region. The trajectory of the river infact follows the thrust, an observation similar to that made in other parts of the region by Sprigg (1946). The three quartzites themselves have been repeated by thrusting and demonstrate a hanging wall ramp and cut off geometry (plates 1, 3 and 7, fig 6). Further to the west above the Torana Thrust there is a highly complex zone of thrusting contained in a fine grained unit. It is depicted on the map as a duplex (Boyer and Elliott 1982) zone of repetition with considerable shortening and thickening. Plates 4 and 5 show this area in outcrop. Outcrops investigated stratigraphically below the Torana Thrust showed no evidence for repetition of strata by thrusting. Stratigraphically above the Torana Thrust cut off and duplex zone numerous bed-planar thrusts were observed with three instances of certain strata repetition.

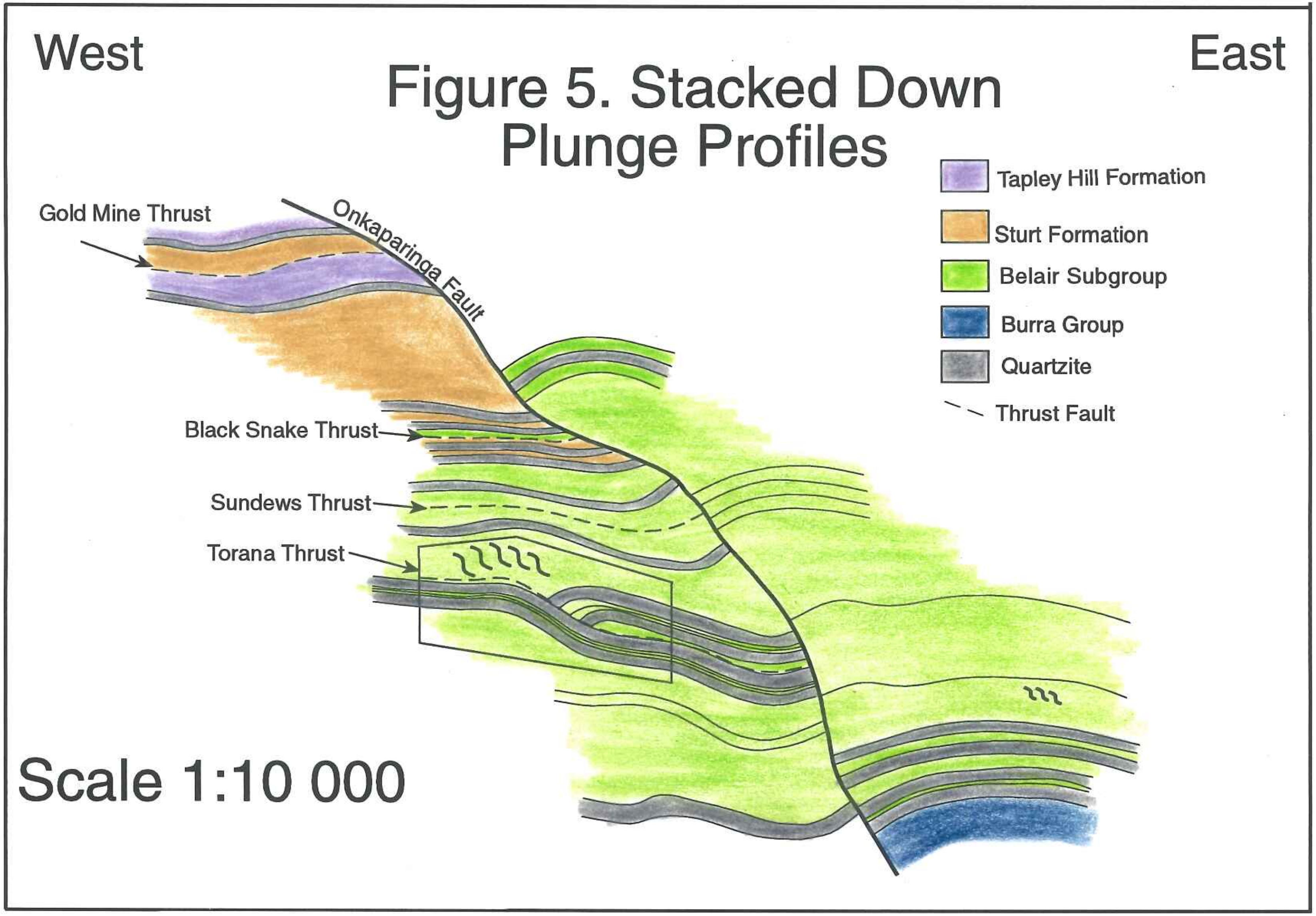
The most prominent structure on the map is a high angle fault (The Onkaparinga Fault) that cross cuts all other tectonic elements. It may be noted that the strike of the Onkaparinga Fault is sub-parallel to the trends of the axial planes of folds in the region suggesting that the development of this fault and the regional folds may be related. The nature of displacement on the Onkaparinga Fault was found to be reverse sense when outcrop of Burra Group (see section on stratigraphy) was obseved on the eastern side of the Onkaparinga Fault but not on the west side. The quartzites directly succeeding the Burra Group constitute the Mitcham Quartzite (Mawson and Sprigg 1950). Strata mapped on the eastern side of the Onkaparinga Fault show an antiformal shape suggesting that a reverse sense of movement has occurred. The antiformal shape is consistent in amplitude as one continues along the line of the Onkaparinga Fault, meaning that the fold is approximately cylindrical. The magnitude of dip of the Onkaparinga Fault varied from 60 to 77 degrees to the east.

Recognition of stratigraphic units repeated by thrusting was based on lithological evidence such as grain size and composition, as well as on the basis of the corresponding thickness of quartzite units. Measurement of thicknesses of the quartzites around the Torana Thrust (fig 6) was done by suspending a fifty metre tape with weight from the top of the quartzites to the base.

3.2 Down Plunge Projections

From geological mapping it was observed that the structures in the area plunge at around 20 degrees towards south-south west. Due to the low angle nature of the plunge the plan map shows a section that is elongated considerably (fig 4). The down plunge projection (Mackin 1950; Stockwell 1960) is a simple method for the construction of profile sections perpendicular to shallowly plunging structures. The folds seen appear close or even tight in plan but in profile are infact gentle. The trend and plunge of structures in the Onkaparinga

Figure 5. Stacked Down Plunge Profiles



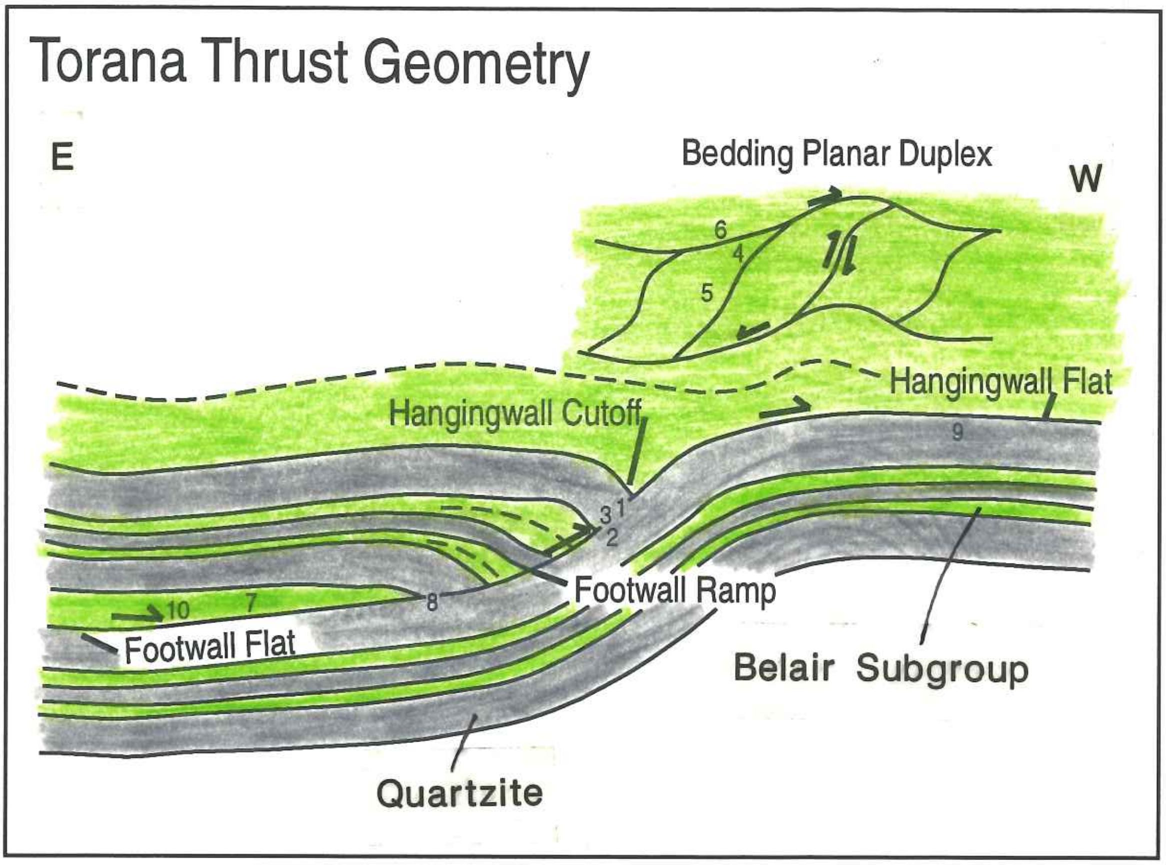


Figure 6. Torana Thrust Geometry. Numbers indicate plate locality for plates 1-10.

Gorge show slight variation as one passes upsection from the north. For this reason the mapped area was divided into three zones. The boundaries of the projection profile planes in each zone are parallel to the trend and perpendicular to the plunge of the structures. The three projection profiles were then stacked to produce the cross section of the area (fig 5).

The Onkaparinga Fault can be seen to dominate the profile structure, dipping steeply to the east. The nature of displacement along the fault is reverse, a fact suggested by the existence of characteristically Burra Goup dolomite at the lowest stratigraphic level mapped on the east (down) side of the fault. The magnitude of displacement could not be measured because no correlative strata could be recognised on either side of the fault (see section 2.3).

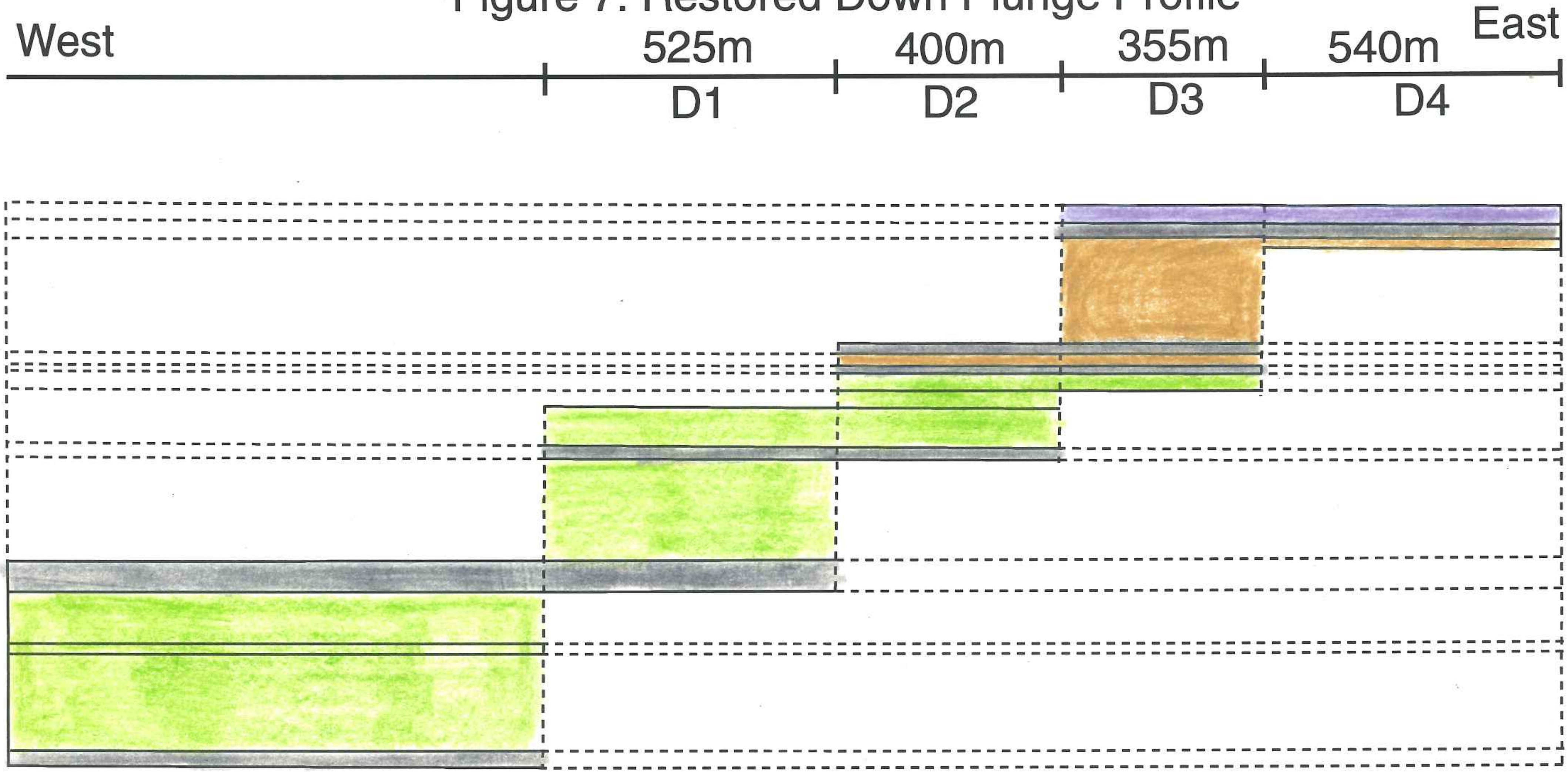
The quartzites around the Torana Thrust display strata repetition with hanging wall cut off and footwall ramp geometry (fig. 6). Thrusts further up section have resulted in strata repetition and these are labelled on the plan map. Other movement horizons mapped could not be identified as having resulted in repetition of strata. Six separate movement horizons (Tanner 1987) were mapped in the Sturt Formation but due to the massive nature of this unit minimum displacements could not be quantified. Examination of thin sections from the Sturt Formation diamictite showed a shear sense throughout consistent with that of the movement horizons mapped as thrusts: southeast over northwest. These movement horizons therefore show reverse displacement but the massive nature of the diamictite does not allow magnitudes to be measured by recognition of displaced strata. The geometry displayed at the Torana Thrust was not observed in the thrusts higher upsection. It is probable that there are cut offs similar to that observed on the Torana Thrust to the west and east of the Onkaparinga Gorge.

The bed-planar nature of thrusting is expressed in the form of duplex-type structures in two places. The boundary thrusts of these systems are parallel to bedding. The more prominent of the two is situated above the Torana Thrust on the western side of the Onkaparinga Fault (fig 6). The position of the other duplex much lower in the section on the eastern side of the Onkaparinga Fault suggests that thrusting in bedding plane directions was quite extensive through the Belair Subgroup.

3.3 Restored Sections.

The stacked down plunge profiles were restored using the methods outlined by Dahlstrom (1969B). No thrusts resulting in significant recognisable strata repetition could be found on the eastern side of the Onkaparinga Fault so the restored section (fig 7) is concerned only with the outcrop west of this fault. Minimum displacements were measured on the four individual thrusts where repetition was recognised and on the basis of conservation of bed length in outcrop the section length and thickness could be restored. The minimum displacements measured on the four thrusts are considerable, the smallest being 355 metres. The total minimum displacement was measured as 1820 metres. This means that the uppermost

Figure 7. Restored Down Plunge Profile



Total Minimum Displacement = 1820m

Scale 1:10 000

horizon studied, the Tapley Hill Formation, has been displaced at least 1.82 kilometres northwest relative to the lowest underlying stratigraphic level.

3.4 Stereoplot. (fig 8)

During field mapping four kinds of measurements were taken throughout the Onkaparinga Gorge area:

1) Bedding

2) Cleavage

3) Intersection Lineations

4) Stretching or slip lineations

The measurements were plotted on Stereoplot 11 computer program (Mancktelow 1989).

1) Bedding.

Stereoplots of bedding were separated into those measured in quartzite units and those measured in units other than quartzite. These data show that in zone 1 and 2 the most competent strata (quartzites) have responded differently to deformation compared to the less competent strata (units other than quartzite). Bedding of quartzite units is evenly distributed with approximately equal numbers of readings plotting on east and west limbs with the magnitude of dip similar for both limbs. The magnitude of dip of quartzite strata is relatively low in most cases. Units other than quartzite show different spatial distribution. A majority of readings are of shallow easterly dip, the rest mainly being of steeper westerly dip. The more competent units have been folded in a more upright manner than the finer grained strata, which show folding with westerly vergence. Zone 3 bedding of quartzites and non-quartzites plot similarly with two limbs of a fold not clearly defined. Eleven separate movement horizons (Tanner 1987) were mapped in zone 3 with three recognisable repetitions of strata. From mapping and subsequent stereoplot work it can be said that thrusting has been the major deformational influence in zone 3 with folding minimal. The possible existence of a roof thrust zone at a level around the Sturt Formation or Tapley Hill Formation in the stratigraphic section was proposed by Jenkins; 1990. Although the above mentioned observation may support the existence of a rather flat lying thrust zone at the level proposed by Jenkins, it does not discount other models of structural geometry.

2) Cleavage.

A majority of cleavage readings in all three zones plot in close grouping with a mean strike and dip of 040/35 east. This cleavage is the regional slaty cleavage that occurs in all strata consistently except for the competent coarse grained units. Cleavage in coarse grained strata dips steeper by up to 40 degrees than the "regional" cleavage (plates 21 and 22). Bedding

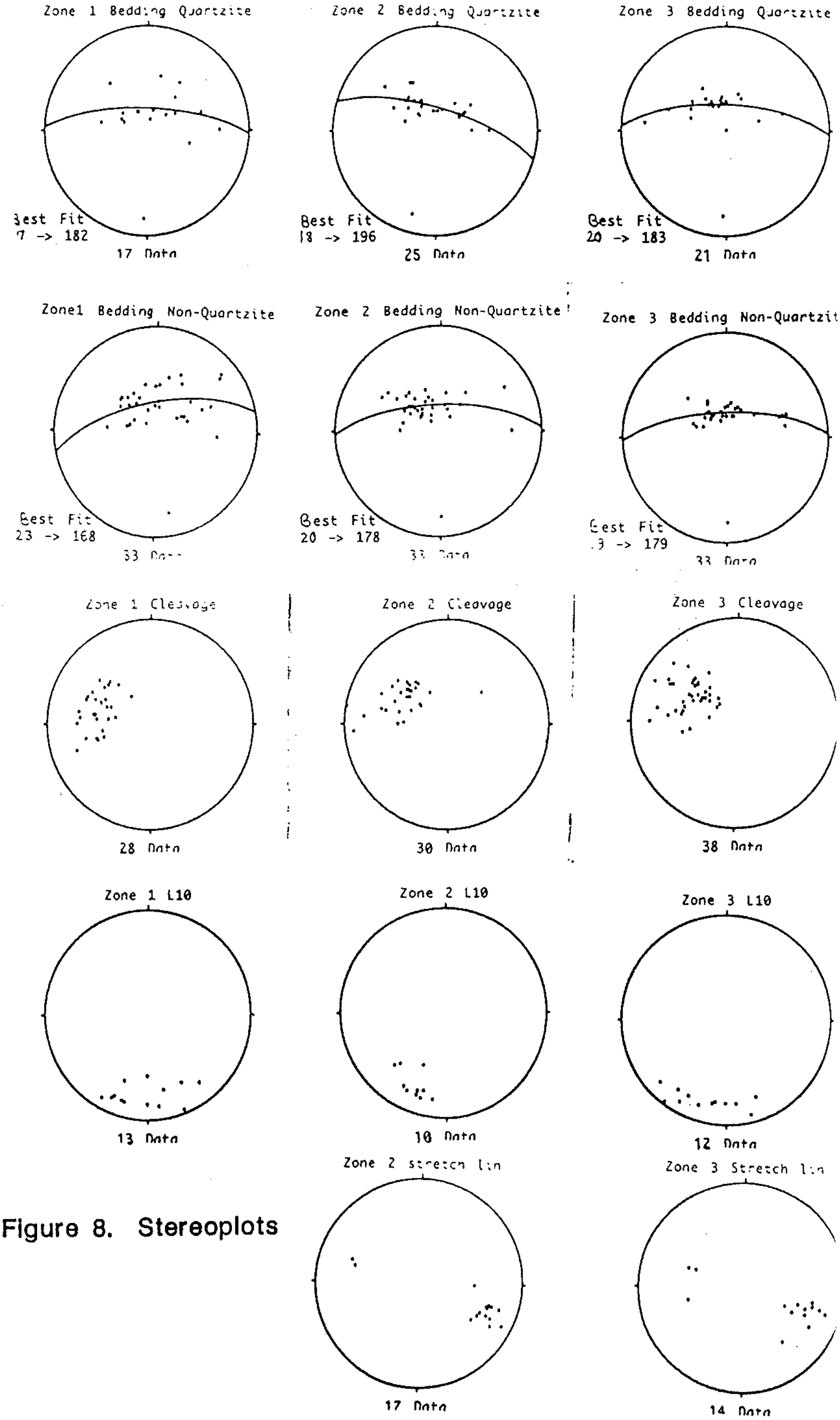


Figure 8. Stereoplots

readings in units other than quartzites plot in close proximity to regional cleavage values throughout the area suggesting that to a certain extent bedding planes in finer grained less competent strata have been deflected towards alignment with cleavage (plate 22).

Nine separate outcrops were found that contained two cleavages, the first being the regional slaty cleavage, usually plane parallel to bedding in these outcrops. The second cleavage has a steeper dip and strikes more northerly than the regional cleavage. Great circles of best fit of cleavage were plotted for zones 2 and 3. The poles to these great circles dubiously define the trends and plunges of fold axes. The majority of cleavage readings however plot in close grouping and do not clearly define the two limbs of a fold. It is evident that the regional cleavage and the possible second steeper cleavage have not been significantly deformed subsequent to their development.

3) Intersection Lineations.

Stereoplots of intersection lineations between bedding and cleavage show considerable variation for zones 1 and 3. From these results it can be seen that fold axes generally plunge shallowly (15-20^{o}) towards south-southwest.

Zone 3 intersection lineations show trend variation between 170 and 230 with similar plunges. The variation in trend was found to be due to a bending of intersection lineations that in turn form SE-NW stretching lineations (Jenkins 1990). Fig 8 is a sketch from the field notebook of the outcrop seen in plate 6 with readings labelled to show how the lineation is bent. Note also how a new lineation is defined that trends east-southeast.

Zone 1 intersection lineations show trend variations between 150 and 220 with small variation in plunge. The zone is dominated by the Mitcham Quartzite which is folded gently. Intersection lineation readings come from units other than quartzite in the zone which contain west verging folds with overturned west limbs. No movement horizons were mapped in zone 1 so it can be deduced that the variation in trend of intersection lineation is not due to rotation during a low angle deformation. In a regime where the folds are non-cylindrical trends of intersection lineations vary considerably (Stockwell 1960). As can be seen on the plan map the folds on the east side of the Onkaparinga Fault are approximately cylindrical (Wilson 1967) in nature so intersection lineation variation in trend would not be due to an irregular (conical) style of folding.

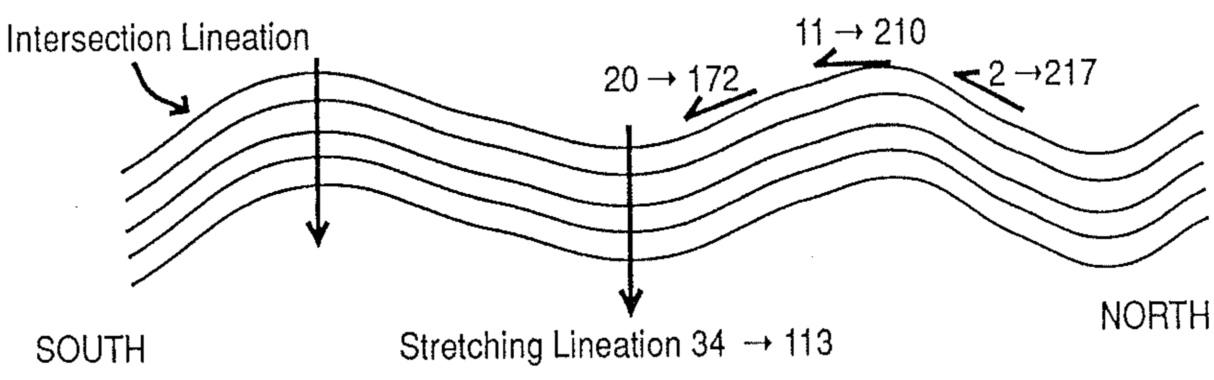


Figure 8a Intersection Lineation Bend, Belair Subgroup.

4) Quartz Fibre and Stretching Lineations.

Trends and plunges of these lineations form two groupings. Stereoplots are shown for zones 2 and 3 because zone 1 contains no major slip horizons (only four isolated measurements). The majority of readings show plunges of 20-30^{o} towards east-southeast. The rest of the readings show plunges of around 50^{o} towards west-northwest. The principle plane strain direction (XZ direction) can therefore be identified as approximately 110-290. The two groupings may be considered as limbs of a fold with a shallow east limb and steeper west limb. This style of west vergent folding accords with fold styles in finer grained bedding in the region. The apparent folded nature of the lineations suggests one of two things: 1) The deformation that resulted in the creation of quartz fibre and stretching lineations occurred *before* the folding episode in the Onkaparinga Gorge, or 2) Folding and "slipping" occurred simultaneously in the same deformational episode.

3.5 Photographic Study.

Fig 6 is an enlargement of a part of the stacked profiles (fig 5) depicting the Torana Thrust geometry. Some of the most descriptive pictures that show structural geometry related to compression in the Onkaparinga Gorge come from the area surrounding and including the Torana Thrust. The locations of plates 1-10 are labelled on the cross section. The locations of all plates can be found on the plate locality map (see appendices). Overlays outline structural features.

Plate 1 : Hangingwall cutoff of a quartzite unit repeated over itself by the Torana Thrust, Belair Subgroup. The cutoff is marked by fault breccia in the hangingwall and footwall (see plate 3).

Plate 2 : The top of the footwall quarzite seen in plate 1 with polished quartz sheets and striations.The lineations trend towards east-southeast. This structure formed as a result of movement of the hangingwall over the footwall as the Torana Thrust propagated.

Plate 3 : Fault breccia in hangingwall quartzite above Torana Thrust, Belair subgroup. The geological hammer rests on a line that is the Torana Thrust.

Plate 4 : Intense zone of thrusting parallel to bedding planes in hangingwall over a link thrust in the bedding planar duplex above the Torana Thrust, Belair Subgroup. The lithology is medium and fine grained sandstone.

Plate 5 : Thrusting in bedding planar duplex zone above the Torana Thrust, Belair Subgroup. Note the intense folding of strata between the link thrusts.

Plate 6 : (Also see fig 8) Bending of intersection lineation in medium grained sandstone beds in the bedding planar duplex above the Torana Thrust, Belair Subgroup. The rotation shape itself defines a stretching lineation that trends towards east-southeast.

Plate 7 : Superbly exposed hangingwall cutoff in fine grained arkose over a sandstone dyke that has acted as a slip horizon as part of the Torana Thrust, Belair Subgroup. Note the tension gashes in the footwall sandstone dyke.

Plate 8 : Demonstration of how bedding planes have become thrust planes in the Torana Thrust area, Belair Subgroup. The compass sits on the thrust plane, above it is quartzite, below is medium-fine grained sandstone.

Plate 9 : Fold in quartzite as a result of flexural slip parallel to bedding, directly below the Torana Thrust, Belair Subgroup.

Plate 10 : Bedding planar duplex in fine grained strata, Belair Subgroup. Note the gentle folded nature of the overlying unit and the very low angle of the link thrusts of the duplex that possibly indicate the mechanism of duplex formation in this outcrop was flexural slip (Tanner 1992).

Plate 11 : Competence contrast between slate and fine sandstone expressed as difference in angle of cleavage dip in adjacent beds of the Tapley Hill Formation. The fine sandstone beds are cleaved at a higher angle than the surrounding slate.

Plate 12 : Hangingwall cutoff and footwall ramp geometry in medium and fine grained strata, Belair Subgroup.

Plate 13 : Superb boudinage (pinch and swell) structure contained in a medium grained sanstone bed in amongst shale units, Belair Subgroup. Note the bend of slaty cleavage around the pinch and swell structure as well as the prominent quartz sheets that have formed in the bedding planes of the sandstone. The overall shape of the sandstone outcrop can be seen to be in s-fabric style. East is to the left.

Plate 14 : Bedding planar decollement (detachment) structure at contact of quartzite and overlying finer grained unit, just below the Black Snake Thrust, Belair Subgroup.

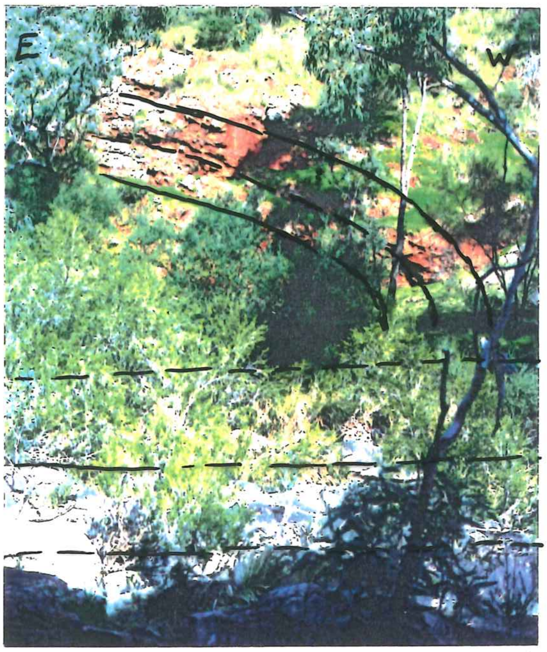
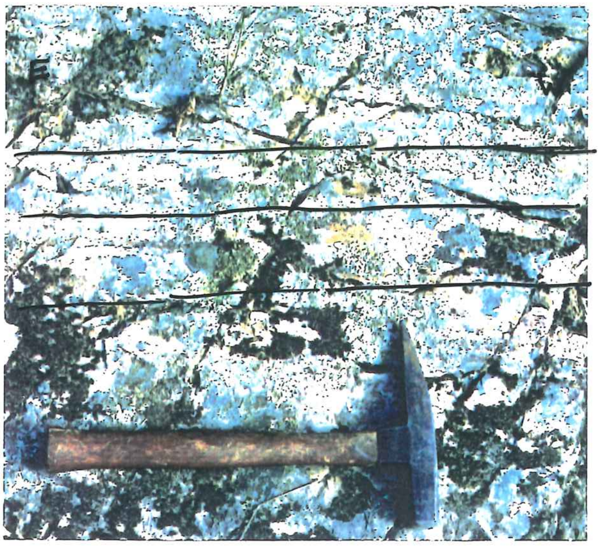


PLATE 1



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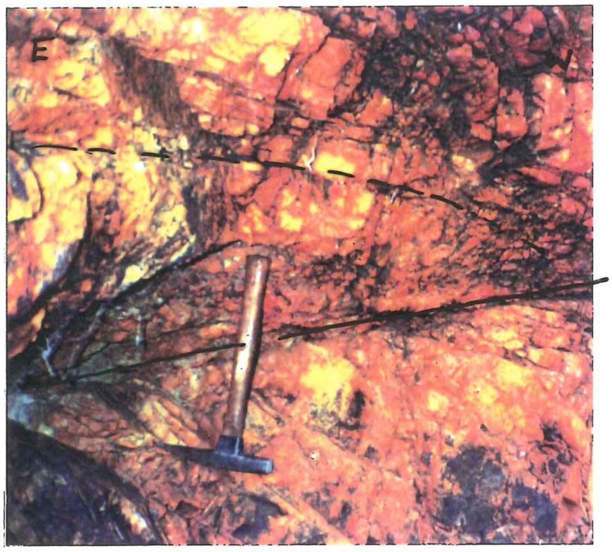

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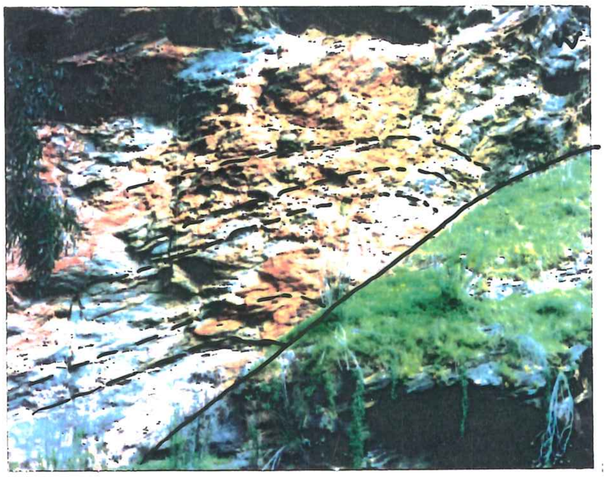

PLATE 4

PLATE 5

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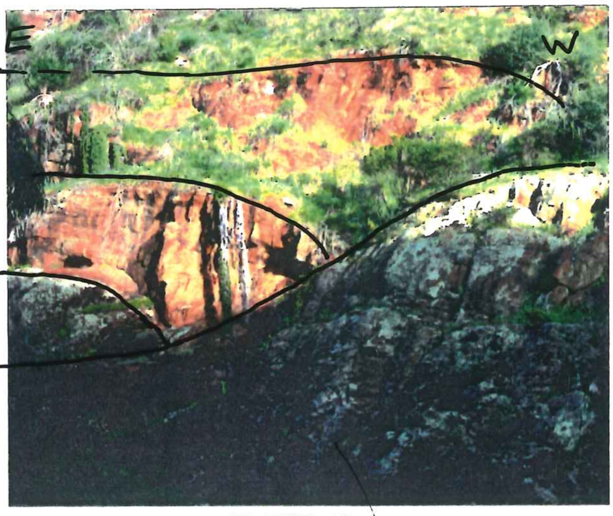
PLATE 9

PLATE 10

PLATE 11



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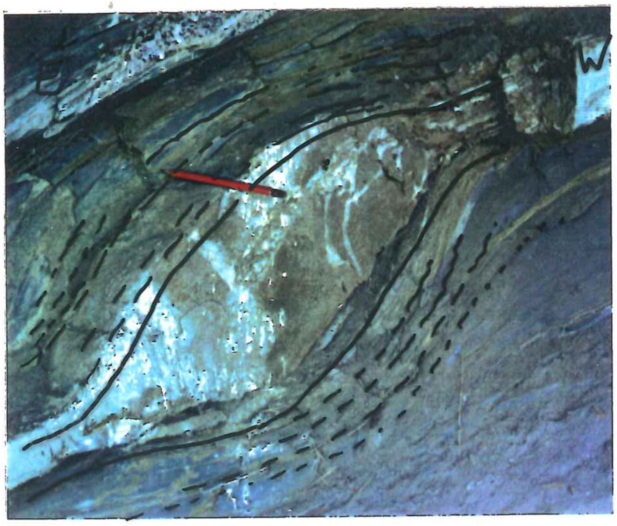
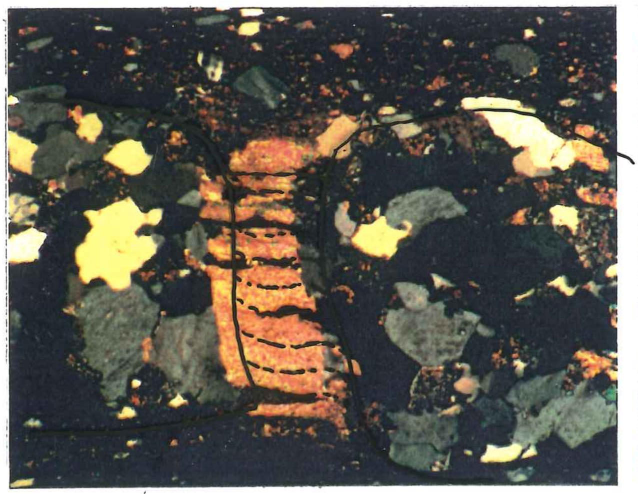


PLATE 13

PLATE 14

PLATE 15

PLATE 16



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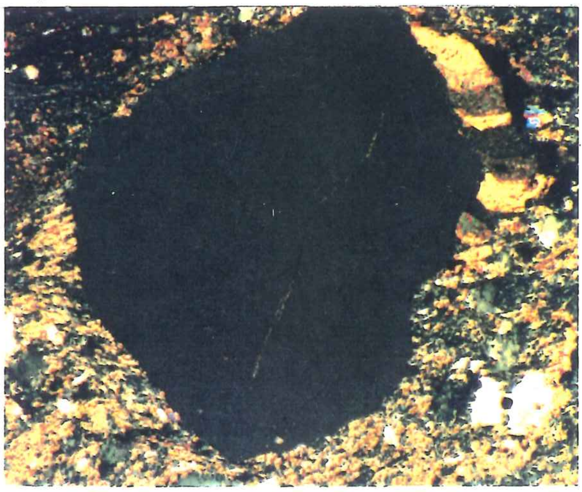

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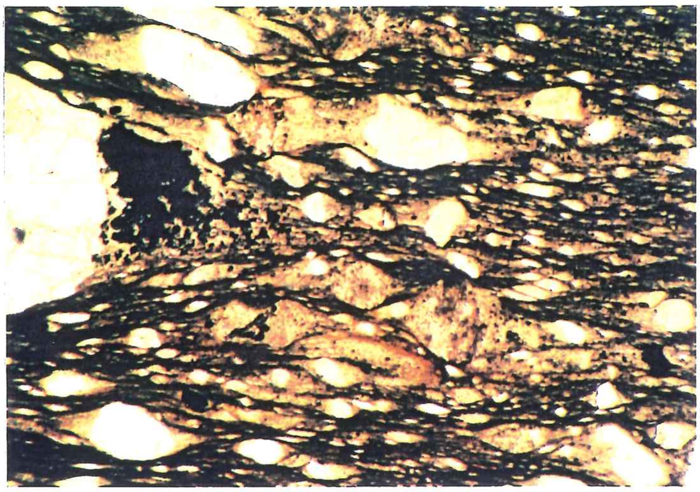

PLATE 19

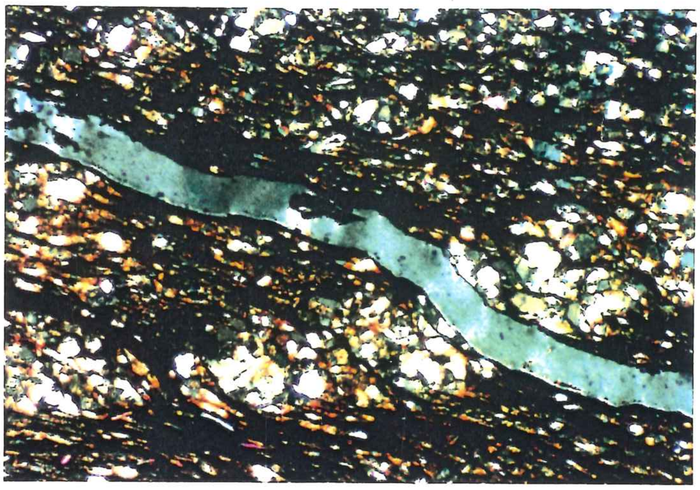

PLATE 20

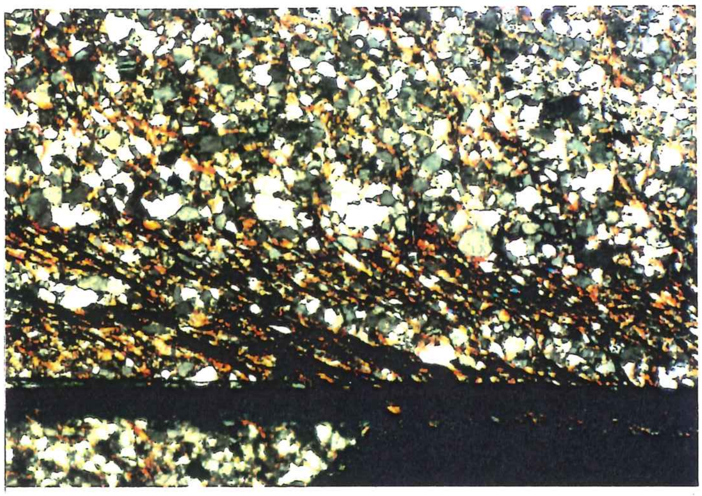

PLATE 21

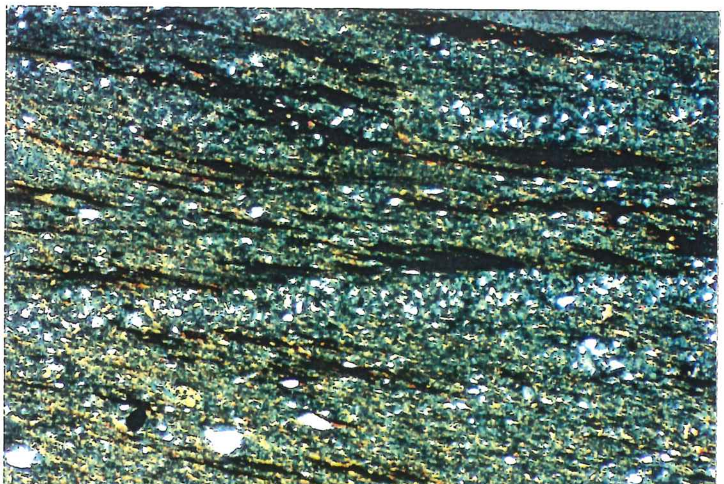

PLATE 22

Plate 15 : Hangingwall cutoff of fine sandstone against the high angle Onkaparinga Fault, Belair Subgroup. Note the steepness of cleavage in the footwall to the right of the fault.

Plate 16 : Abrupt cessation of quartzite outcrop against the Onkaparinga Fault, Belair Subgroup. The quartzite is infact the lower unit of the three quartzite package repeated by the Torana Thrust (fig 6).

Plate 17 : Pulled apart clast of quartz grain aggregate in Sturt Formation diamictite. Opening direction is marked by veins of calcite.

Plate 18 : Pressure shadows filled with calcite around a quartz clast in the Sturt Formation diamictite.

Plate 19 : Pressure shadows around clasts in Sturt Formation diamictite. Orientations of most shadows are aligned with cleavage planes.

Plate 20 : Competence contrast between layers in fine sandstone, Belair Subgroup. Penetrative cleavage in coarser layers is at a higher angle than that in the finer layers. The fracture that dominates the photograph accentuates the contrast.

Plate 21 : Cleavage duplex (Tanner 1987) in fine grained layer of sandstone, Belair Subgroup. Note also how cleavage steepens in the overlying coarser layer.

Plate 22 : Low angle cleavage-bedding relationship common in the region, Belair Subgroup. The cleavage is either parallel or sub-parallel to bedding in the fine grained strata here.

3.6 Strain Analysis.

Introduction.

The restoration of deformed cross sections purely on the basis of section length is not sufficient to describe shortening in orogenic terranes. Three dimensional strain analysis allows for changes in volume to be measured and the style of deformation to be discussed.

The key concept for visualising strain in three dimensions is the strain ellipsoid. The axes of the ellipsoid are inclined to the x,y and z coordinate directions of three dimensional space (Ramsay and Huber 1983). The three axes are the three principal axes of finite strain of semi-axis lengths $1+e1 \geq 1+e2 \geq 1+e3$. Extensions e1,e2 and e3 are the principal longitudinal strains. The three principal planes of finite strain are the XY, YZ and XZ sections. The individual strain ellipses on them are the principal strain ellipses with strain ratios $Rxy = (1+e1/1+e2)$ etc. The strain ratios are related by :

$$Rxz = Rxy.Ryz$$

Two methods of strain analysis were undertaken to measure the ratios described above:

1) Rf Ø′ (Dunnet 1969).
2) Fry method (Fry 1979).

Results

Samples taken from the field were cut in sections taken as XZ and YZ for thin section, and the sections photographed. The shapes of grains were measured, digitised and plotted using the instrain program (McEachran 1989, Erslev 1989) for RfØ´ and Fry method strain measurement. The two methods give values for Rxz and Ryz, the strain ratios in XZ and YZ sections.

Appendix 1 displays the data measured and calculated for all samples. Fig 9 shows locations of strain data samples and the orientations of the strain ellipses for the XZ plane strain direction (format of presentation after Reks and Gray 1983). From strain calculation it can be seen that different units in the Onkaparinga Gorge area have responded differently to deformation. The Sturt Formation strain data show that thickening has occurred at high angles to bedding and that significant shortening (5-36%) resulted. Strain data for other units (quartzite and sandstone) show that flattening has occurred at low angles to bedding with small amounts of lengthening (1-4%) associated. There seems to be a systematic variation in the orientations of the ellipses as one passes up the stratigraphic section. The lithological difference between the Belair Subgroup and overlying Sturt Formation would result in a competence contrast. However, the strain ellipses for the XZ direction should still be of similar orientation with variations in intensity depending on the lithological competence. The XZ strain ellipse patterns may have regional significance with respect to deformation in the southern Adelaide Fold Belt. Strain patterns in neutral suface folding show different orientations of the long axis of the XZ section strain ellipse for different parts of the fold (Colmann-Sadd 1978). In the hinge zone of a syncline (fig 10) there will be stretching parallel to bedding in the lower parts of the pile and stretching or thickening perpendicular to bedding in the upper parts. This scenario is unlikely on the scale observed in the Onkaparinga Gorge however, usually occurring on smaller scales. A more likely scenario is that the XZ strain orientations reflect a structural discontinuity around the level of the Belair Subgroup and the Sturt Formation boundary. XZ strain patterns in the Belair Subgroup samples show that flattening parallel to bedding (possibly associated with shearing) has occurred. XZ strain patterns in the Sturt Formation samples show flattening perpendicular to bedding possibly reflecting a pervasive strain that is uniform throughout and not contained in one discreet plane. This strain pattern may indicate that some form of detachment and subsequent buckling of the overlying rocks has occurred.

When values of Rxy and Ryz were able to be calculated (ie in samples where XZ and YZ sections were cut and digitised), they were plotted on a Flinn plot (Flinn 1962). From this plot (fig 11) it can be seen that all samples where Rxy and Ryz were calculated lie in the "oblate" field of apparent flattening. Flattening produces lengthening perpendicular to the principle compressional direction and shortening parallel to it. From thin section photographs a measure of the amount

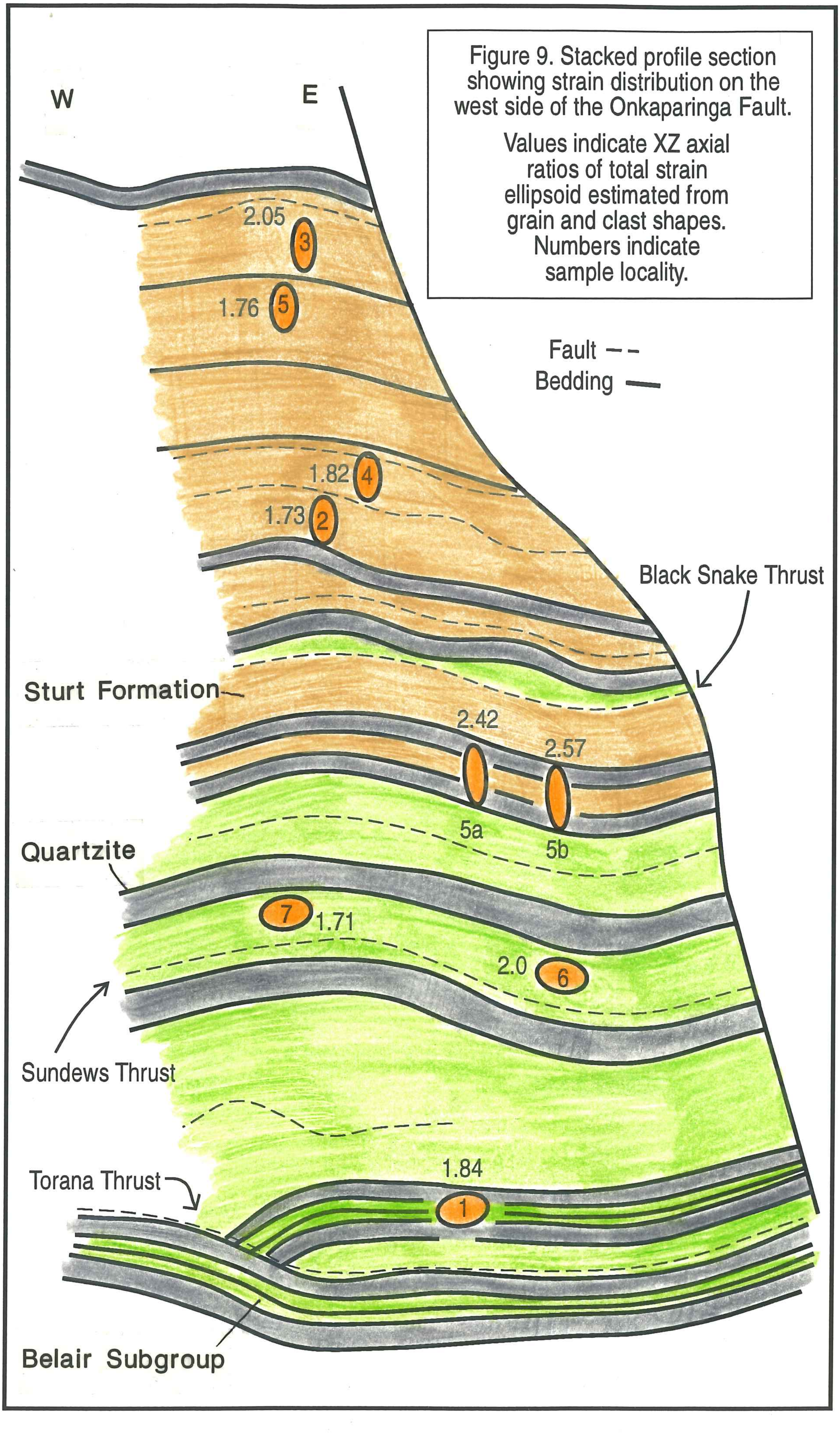

Figure 9. Stacked profile section showing strain distribution on the west side of the Onkaparinga Fault.

Values indicate XZ axial ratios of total strain ellipsoid estimated from grain and clast shapes. Numbers indicate sample locality.

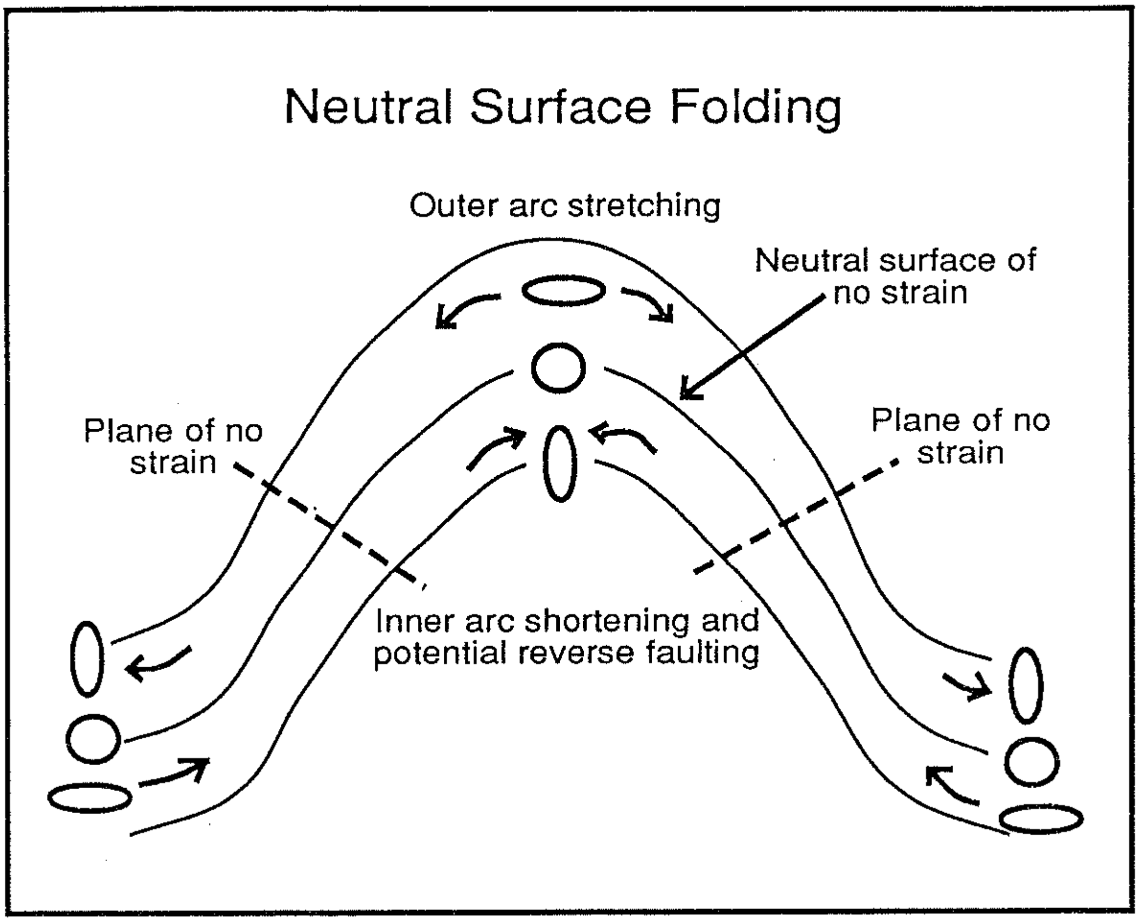

Figure 10. Strain distribution in folds developed by neutral surface folding.

of extension perpendicular to compression was found using length measurements of diamictite clasts that were pulled apart with calcite veins forming in the fractures (plate 17).

Using the approximation that the axis $1+e1= L_1 - L_0/L_0$ (length change in direction of 1+e1), values of 1+e2 and 1+e3 were calculated. The change in volume due to compaction in flattening can be expressed in the equation:

$$1+dV = (1+e1)(1+e2)(1+e3)$$

where the values of (1+e1, 1+e2, 1+e3) are normalised to 1+e2. 1+dV for the sample with pulled apart clasts was calculated to be 0.63 indicating that dV= -0.37 ie a 37% *volume loss* due to compaction during deformational flattening in the Sturtian Diamictite. ?

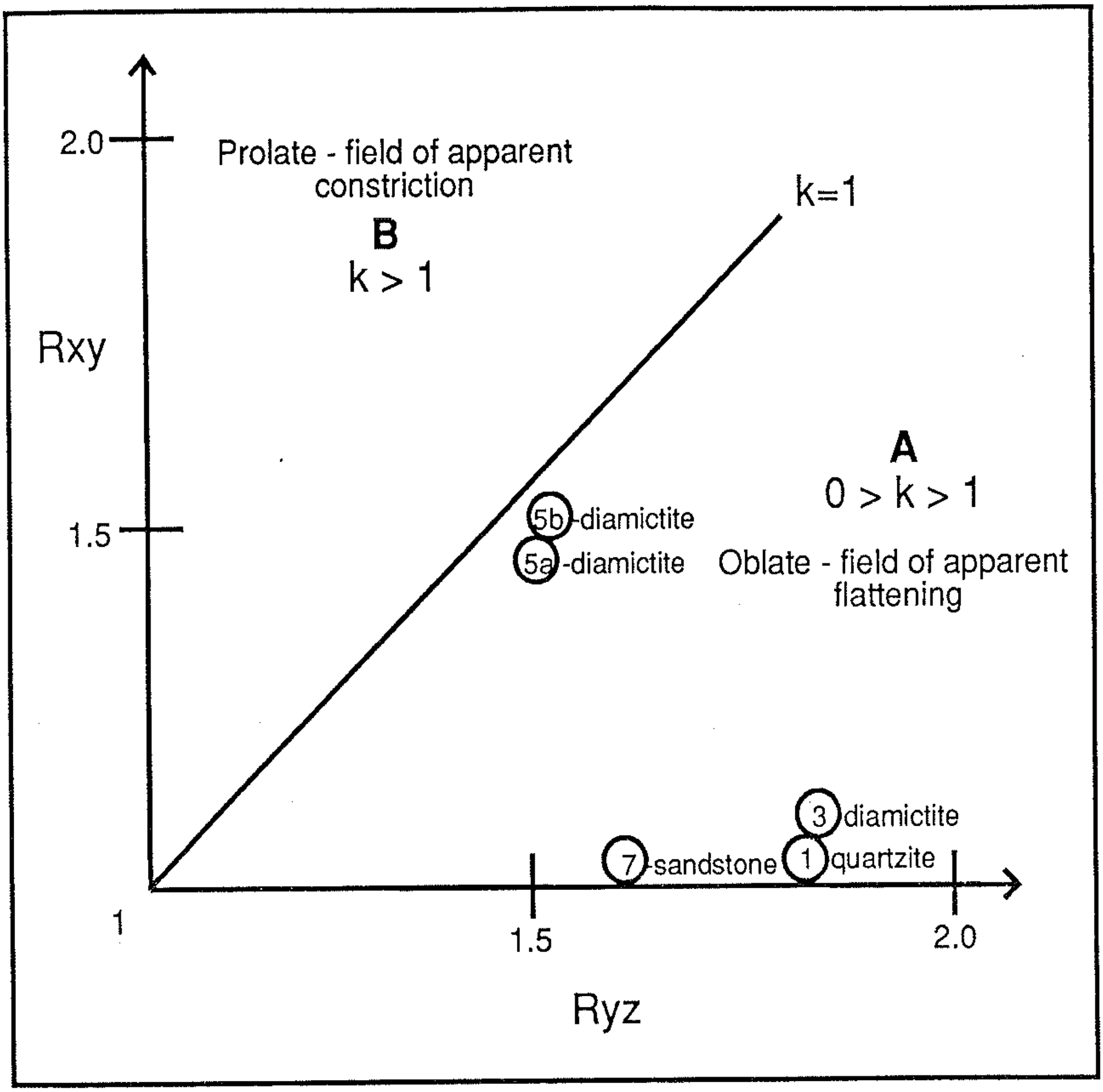

Figure 11. Flinn Plot of strain data.
All samples plot in the flattening field

4.Tectonic Models for evolution of the Onkaparinga Gorge Structural Geometry.

Two tectonic models have been proposed for the structural evolution of the Onkaparinga Gorge area, the first proposing that thrusting occurred as a result of congestion during folding. Due to the narrow nature of the field area it is unclear as to whether the Onkaparinga Gorge is in a hinge or limb zone of a fold. The second model proposes thrusting that produced a stack of bedding planar imbricates or duplexes (Tanner 1989) that were later folded during ongoing deformation. The verification of either model requires continued research in the areas surrounding the Onkaparinga Gorge region to outline the extent of the thrust mapped and their setting with respect to regional geological structures.

4.1Model 1: Deformation development through folding (Fig 12).

Tanner (1989) discussed flexural slip as a mechanism for formation of thrust horizons during fold development. The mechanism involves the slip of upper beds of the limbs of the fold over the lower beds towards the fold axis during folding. In folds where one limb is steep or overturned, this limb may not slip towards the hinge but lock, with all displacement being taken up on the shallow limb. The slip sufaces that form during flexural slip folding were defined as "movement horizons". These horizons are commonly marked by quartz fibre sheets or veins. The thicknesses between such horizons depends on the spatial position in question. The steep limb of an asymmetric fold will contain more movement horizons than the shallow limb. In rocks that contain competent strata interlayered with finer grained units the movement horizons are contained in the finer strata at a small distance below the base of the competent unit. In areas where movement horizons cannot occur on regular intervals such as in thick quartzite units slip is taken up on a few surfaces where abnormally thick quartz sheets or veins form. Internal duplexes form in association with movement horizons. Link thrusts in duplexes that form in flexural slip regimes usually dip at a lower angle than the 30^{o} dip of link thrusts in the classic duplex model of Boyer and Elliott (1982). Plate 10 may show a duplex structure from such a setting. Roof and floor thrusts are parallel to bedding. Small scale cleavage duplexes (Tanner 1989) are common (plate 22). Other thrust characteristics that can occur in flexural slip horizons include low angle thrusts, ramps and imbricates.

In proximal sediments, such as diamictites where bedding thickness changes considerably and sedimentary contacts are not flat planar, obstacles arise when movement of units on the limbs of folds occurs during flexural slip. These obstacles may become "sticking points" and compressional faulting is initiated. This leads to duplex formation (Knipe 1985).

Quartz fibre lineations in flexural slip regimes are commonly perpendicular to fold axes and develop as bedding rotates *on the limbs* of growing folds (Tanner 1992).

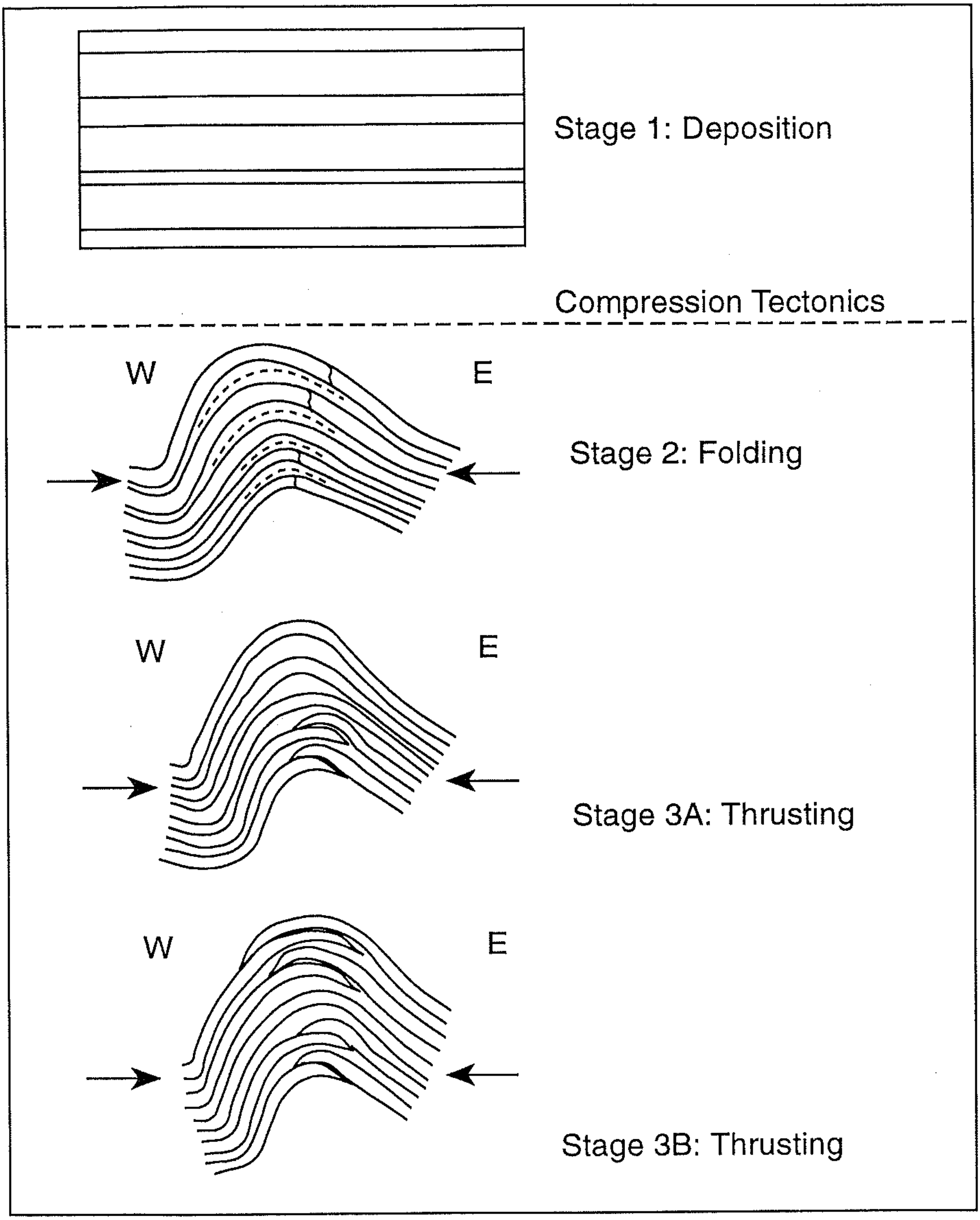

Figure 12. Model 1- Thrusting due to fold development

The flexural slip mechanism can be used to explain the existence of slip horizons on limbs of folds. The concept of neutral surface folding (Davis 1984) can explain the existence of thrust faults in the cores of folds. When rocks are buckled in neutral surface folding outer layers undergo layer parallel stretching and the iner arc of the fold hinge experiences layer parallel shortening (fig 10). The middle of the folded layer experiences no layer parallel strain, this is the neutral surface.

Colman-Sadd (1978) documented neutral surface folding in Mesozoic and Cainozoic sediments of southwest Iran. Normal faults were found on the crests of anticlinal folds where strata is broadly and concentrically folded. Anticlinal fold cores contained thrusts that repeated Jurassic beds. This "congestion" in the anticlinal cores was attributed to lateral shortening caused by a regional maximum principal stress tangential to the surface and perpendicular to the fold axis.

The folds in the Onkaparinga Gorge are gentle. However, the area is small compared to the amplitude of the regional structure (fig 2). It can be seen in the plan map of the Onkaparinga Gorge that thrusting has occurred in the region and that it has been oriented in bedding planes. Strata have been certainly repeated on four separate occasions. The area is near the hinge zone of the regional domed anticlinorium (Jenkins 1990) that lies to the east. A method for the evolution of the structural geometry of the Onkaparinga Gorge could be inner arc shortening in a large anticlinal structure that caused sufficient congestion in the core of the fold to result in strata repetition at four stratigraphic levels.

The Onkaparinga Fault trends sub-parallel to fold axes and cleavage steepens as one nears it. The fact that the Onkaparinga Fault cross cuts all other structural features proves that it post-dates them, and may represent a late stage steepening of the fold axis of the regional antiform during continued compression. Thrusts that formed during inner arc shortening may be reactivated when the folding becomes more tight and bedding planes with associated bedding planar thrusts are steepened with continued buckling of layers.

4.2 Model 2: Thrust then folding (fig 13).

A two stage deformation may be outlined to explain the geometry of the Onkaparinga Gorge area.

1)Stage 1 appears to be the development of a low angle slaty cleavage with associated stretching lineations. Steinhardt (1991) described features of the southern Fleurieu Peninsula: "A very pronounced mylonitic foliation and stretching lineation with constant orientation...majority of kinematic indicators show SE over NW movement in Palaeoproterozoic, Adelaidean and Kanmantoo rocks." The direction of thrusting corresponds with stretching lineations further north. This lineation can be traced over the whole fold belt (Mancktelow 1990). The low angle thrusting with strata repetition observed in the Onkaparinga Gorge may have occurred in this initial stage of deformation (fig 13). Again the size of the study area places restrictions on theories postulated. The extent of the thrusts mapped could not

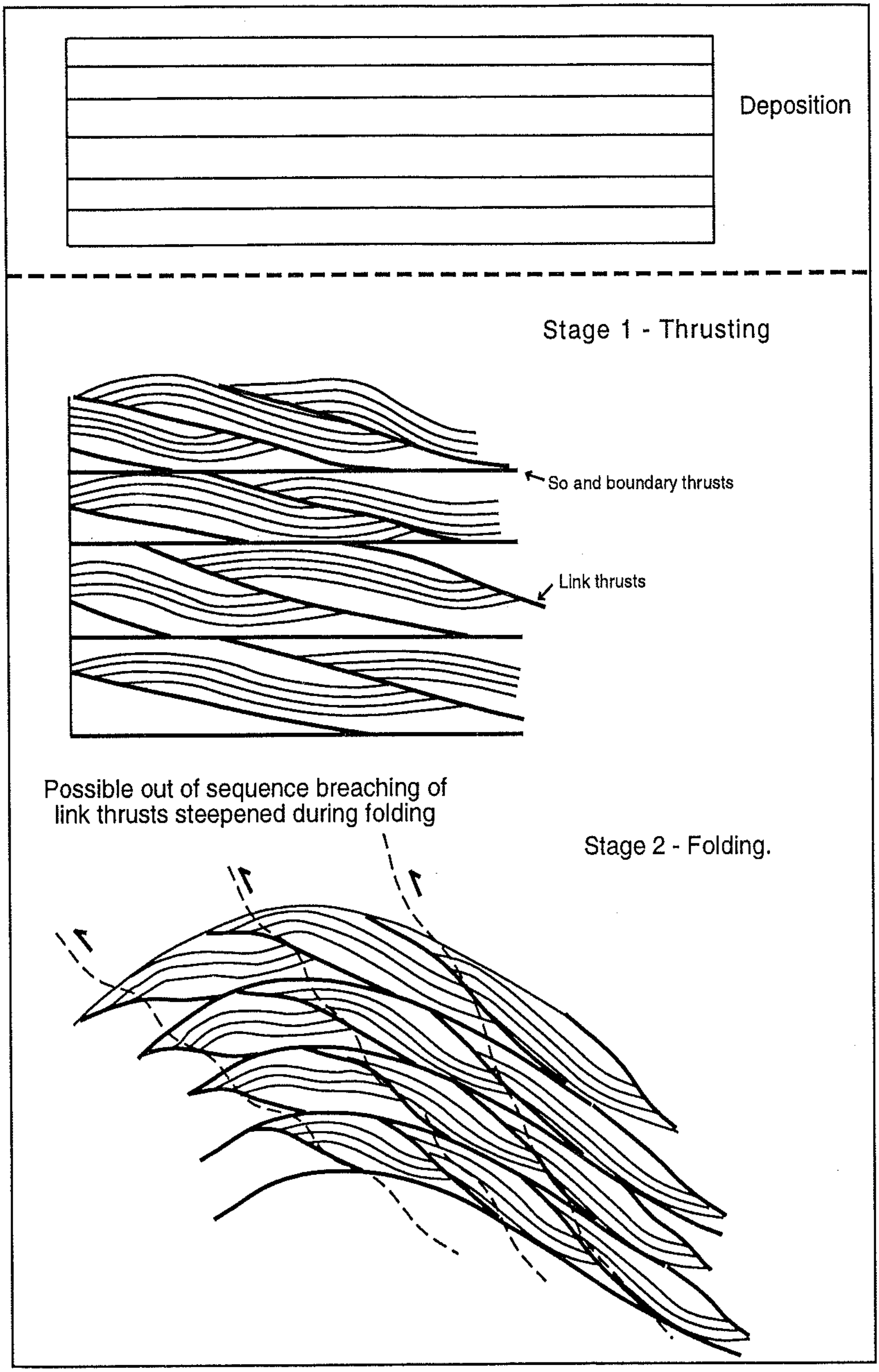

Figure 13. Model 2- Thrusting then fold development

be determined in this study. However, extensive imbrication and duplexing has been mapped in several areas in the southern Adelaide Fold Belt and the thin slice observed in the Onkaparinga Gorge may be part of a wider stack of imbricated or duplexed strata.

2) Stage 2 - The low angle thrust development may have caused considerable thickening to have occurred in the western part of the region that is now the southern Adelaide Fold Belt. The southern Fleurieu Peninsula is a zone where thrusting has been the dominant form of deformation. This thrust zone may have become a partly separate domain over which the second stage of deformation was able to evolve. Buckling of layers overlying the southern Fleurieu thrust zone as the deformation continued may have resulted in the formation of a second cleavage, steeper than the first and axial planar to the more upright buckle fold in the cover rocks. A problem with this theory is that this second stage would fold the stage 1 slaty cleavage. No conclusive evidence was found for a folded slaty cleavage in the Onkaparinga Gorge

Imbricates or duplexes from stage 1 with boundary thrusts oriented largely in bed planar directions possibly had some of their link thrusts reactivated out of sequence, (a process described as breaching by Butler 1987) and connected at high angles to bedding. This is a possible mechanism for the formation of the Onkaparinga Fault. The reactivation may have been facilitated by the steepening of link thrusts on the limbs of folds associated with continued compression. The steepening may have been such that the link thrusts were subparallel to the axial plane of the regional antiform.

It must be stressed that stages 1 and 2 outlined above are not necessarily discreet stages and may have occurred with considerable overlap in time period. The two models proposed can both explain the current structural geometry exhibited in the Onkaparinga Gorge.

4.3 The possible existence of a Roof Thrust (Jenkins 1990).

Jenkins (1990 p407) proposed the existence of a roof thrust zone at about the level of the Sturt and Tapley Hill Formations that overlies a zone of imbricate thrusting. It was postulated that thrust faults propagated southwards and may have been rotated into flatter orientations as increasingly intense compressive movements from the southeast generated "flake tectonics".

The plan map of the Onkaparinga Gorge shows more thrusts exist in zone 3 (the zone that contains the Sturt and Tapley Hill Formations). Stereographic evidence (fig 8) suggests that bedding is more flat lying in zone 3 with all strata type measurements plotting similarly. XZ strain patterns (fig 9) reflect a structural discontinuity around the contact of the Belair Subgroup and overlying Sturt Formation. The above mentioned evidence, especially the XZ strain patterns support the possible existence of a detachment surface or roof thrust at around the level of the base of the Umberatana Group.

5. Conclusions.

The structural geometry of the Onkaparinga Gorge area can be outlined in terms of 1) gentle folding in abundant competent strata and open to tight west vergent folding in finer grained less competent strata and 2) two styles of reverse faulting at very low and high angles. The high angle reverse fault (Onkaparinga Fault) postdates the low angle thrusts because it cross cuts them. The antiformal nature of strata to the east of the Onkaparinga Fault and the record of only one orogenic episode in the area suggests that The Onkaparinga Fault is genetically related to the other deformational features and does not represent an activation later in the geological time scale.

The plan map and down plunge projection show the bedding planar nature of thrusting (the first style of reverse faulting). Such action resulted in the repetition of strata (usually coarse grained) and duplex/imbricate structure formation in finer grained strata. Such thrusts are marked by stretching lineations and S-surfaces in cleavage. Minimum displacements on the four individual thrusts that resulted in strata repetition are in the order of 350-600 metres. The total minimum displacement, a combination of all recognised individual minimum displacements is 1820 metres. The development of these structures may be associated with stage 1 outlined above (section 4.2). Stereoplots of bedding and cleavage show a different response to compression in competent quartzites to that in less competent units with cleavage in competent strata dipping steeply compared to that of less competent strata. Stereoplots of quartz fibre and stretching lineations that mark thrust planes plot on the two limbs of a west vergent fold indicating either that the thrusts were folded after formation or that thrusting occurred simultaneously with folding. Strain patterns from shortening show a different response in the Sturt Formation to that in the Belair Subgroup, indicating that a structural discontinuity may exist between the Umberatana Group and underlying rocks.

The possible existence of a roof thrust zone in the southern Adelaide Fold Belt at around the level of the Sturt Formation or Tapley Hill Formation level (Jenkins 1990) was investigated. More movement horizons (thrusts?) and less fold influence was found at the stratigraphic levels described above. The level in the section that these abundant movement horizons outcrop may simply indicate that because of the incompetent nature of the Sturt Formation (generally fine grained matrix with clasts) and overlying Tapley Hill Formation (slates) there has been less displacement with folding and more tectonic compaction and shortening at this particular level. The structural discontinuity described above lends support to the existence of a roof thrust

The second style of reverse faulting seen was high angle faulting (the Onkaparinga Fault) that cross cuts (and therefore postdates) preexisting low angle thrusts. Folds that exist in the Onkaparinga Gorge have axial planes that trend sub parallel to the general trend of the Onkaparinga Fault and have folded the thrusted repetitions and duplex structure that formed during stage 1 of a possible two stage deformation. The displacement on the

Onkaparinga fault is reverse as demonstrated on the map and low angle thrusts are cut off by it. Cleavage around the Onkaparinga Fault is steep (55-70^{o}).

The style of deformation observed in the Onkaparinga Gorge (mainly thrusting sub-parallel to bedding) can be attributed genetically to resultant stuctures formed during the flexing of the regional antiform. Thrusting may have occurred on the limbs of the fold by the flexural slip mechanism or in the hinge zone of the fold by the inner arc shortening mechanism of neutral surface folding. The resultant structures can also be attributed to a low angle thrusting episode (unrelated to folding described above) that caused the imbrication or duplexing of strata that was later folded due to continued compression. Steepening of link thrusts in preexisting imbricates or duplexes as the fold flexed may have resulted in them being reactivated out-of-sequence and breaching to form reverse faults that would cross cut bedding planes at high angles.

References

1) Boyer S E 1986: Styles of folding within thrust sheets: examples from the Appalachian and Rocky Mountains of USA and Canada. *J. Struct. Geol.* 8 325-339.

2) Boyer SE and Elliott D 1982: Thrust Systems. *AAPG Bulletin* 66 1196-1230.

3) Brown 1883: Annual Report *Government Geological Parliamentary Paper* p10.

4) Butler RHW 1987: Thrust Sequences. *Jour. Geol. Soc. London* Vol 144 619-634.

5) Coats R P 1962: A Sturtian Unconformity. *SADME* Rept.Bk. 55/8 GS. 2384 DM. 1556/62.

6) Coats R P 1967: The "Lower Glacial Sequence" - Sturtian Type Area. *The Geological Survey of South Australia Quarterly Notes* no 23 1-3.

7) Colman-Sadd S P: 1978: Fold development in Zagros simply folded belt, SW Iran. *AAPG* Bulletin 62 no26 984-1003.

8) Dahlstrom C D A 1969A: The upper detachment in concentric folding. *Bulletin of Canadian Petroleum Geology* 17 no3 326-346.

9) Dahlstrom CDA 1969B: Balanced Cross Sections. *Canadian Journal of Earth Sciences* 6 743-757.

10) Davis GH 1984: Structural Geology of Rocks and Regions. *John Wiley and Sons (publ).*

11) Dunnet D 1969: A technique of finite strain analysis using elliptical particles. *Tectonophysics* 7 117-136.

12) Erslev E 1989: INSTRAIN - an integrated analysis program for the MacIntosh. *Rockware inc.*

13) Flinn D 1962: On folding during three dimensional progressive deformation. *Q. J. Geol. Soc. London* 118 385-428.

14) Fry N 1979: density distribution techniques and strained length methods for determination of finite strains. *Jour. Struct. Geol.* 1 221-229.

15) Howchin W 1904: The geology of the Mount Lofty Ranges part 1: The Coastal District. *Trans. Royal Soc. S. Aust.* 28: 253-280.

16) Knipe RJ 1989: Deformation mechanisms - recognition from natural tectonites. *Jour. Struct. Geol.* 11 no1/2 127-146.

17) Jenkins RJF 1986: Ralph Tate's Enigma and the regional significance of thrust faulting in the Mount Lofty Ranges. In 8th Aust. Geol. Conv. Adelide 1986, *Abstr. Geol. Soc. Aust.* 15:101.

18) Jenkins RJF1990: The Adelaide Fold Belt: A tectonic reappraisal. In JB Jago and PS Moore (eds), The Evoution of a Late Precambrian and Early Palaeozoic Rift Complex: The Adelaide Geosyncline. *Geol. Soc. Aust. Spec. Pub.* 16:396-420.

19) Jukes 1850: In Howchin (1904).

20) McEachran 1989: Digitise TM: Digitising software for the MacIntosh, version 1. Rockware Inc.

21) Mackin J H 1950: Down structure method of viewing geologic maps. *J. Geol.* 58 no1 55-72.

22) Mancktelow NS 1989: Stereoplot: A plotting program for orientation data for the MacIntosh.

23) Mancktelow NS 1990: The structure of the southern Adelaide Fold Belt. In JB Jago and PS Moore (eds), The evolution of a late Precambrian and Early Palaeozoic Rift Complex: The Adelaide geosyncline. *Geol. Soc. Aust. Spec. Pub.* 16:215-229.

24) Mawson D and Sprigg R C 1950: Subdivision of the Adelaide System. *Aust. J. Sci.* 13: 69-72.

25) Offler R and Fleming PD 1968: A synthesis of folding and metamorphism in the Mount Lofty Ranges, South Australia. *Jour. Geol. Soc. Aust.* 15: 245-266.

26) Phillips AC, Smith ND, and Powell RD 1991: Laminated sediments in prodeltaic deposits, Glacier Bay, Alaska. Geol. Soc. America Spec. Paper 261. 61-73.

27) Ramsay JG and Huber MI 1983: The techniques of modern structural geology volume 1: Strain Analysis. *Copyright 1983 Academic Press Limited.*

28) Reks IJ and Gray DR 1983: Strain patterns and shortening in a folded thrust sheet: An example from the southern Appalachians. *Tectonophysics* 93 99-128.

29) Selwyn A R C: "Geological Notes" *Parl. Paper no20* 1860 p14.

30) Sprigg R C 1946: Reconnaissance Geological Survey of portion of the Western escarpment of the Mount Lofty Ranges. *Trans. Roy. Soc. S. Aust.* 70(2) :313-347.

31) Stockwell C H 1960: The use of Plunge in the construction of cross-sections of folds. *Proc. Geol. Ass. Canada* 3 no2 :97-121.

32) Talbot J L 1963: The structural geometry of rocks of the Torrens Group near Adelaide, South Australia. *J. Geol. Soc. Aust.* 11:33-48.

33) Tanner PWG 1989: The Flexural Slip mechanism. *Jour. Struct. Geol.* 11 no6 635-655.

34) Tanner PWG 1992: Morphology and geometry of duplexes formed during flexural slip folding. *Jour. Struct. Geol.* 14 no10 1173-1192.

35) Tate R 1879: "Presidential Address" *Trans. Proc. Phil. Soc. Adelaide* vol *ii*: 1878-9.

36) Tate R 1893: Inaugral Address Australian Association for the Advancement of Science, Adelaide 1893. *Aust. Ass. Ad. Sc.* vol *v* p45 *et seq* .

37) Thomson B P *et al* 1964: Precambrian rock groups in the Adelaide Geosyncline: A new subdivision. *Q. Geol. notes, Geol. Surv. S. Aust.* 9: 1-19.

38) Wilson A F 1952a: The Adelaide System as developed in the Riverton-Clare region, Northern Mount Lofty Ranges, South Australia. *Trans. Roy. Soc. S. Aust.* 75:131-149.

39) Wilson G 1967: The geometry of cylindrical and conical folds. *Proc. Geol. Ass.* 78 part 1 :179-209.

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Above all other acknowledgements comes the thanks that go to my father for help beyond all family commitment.

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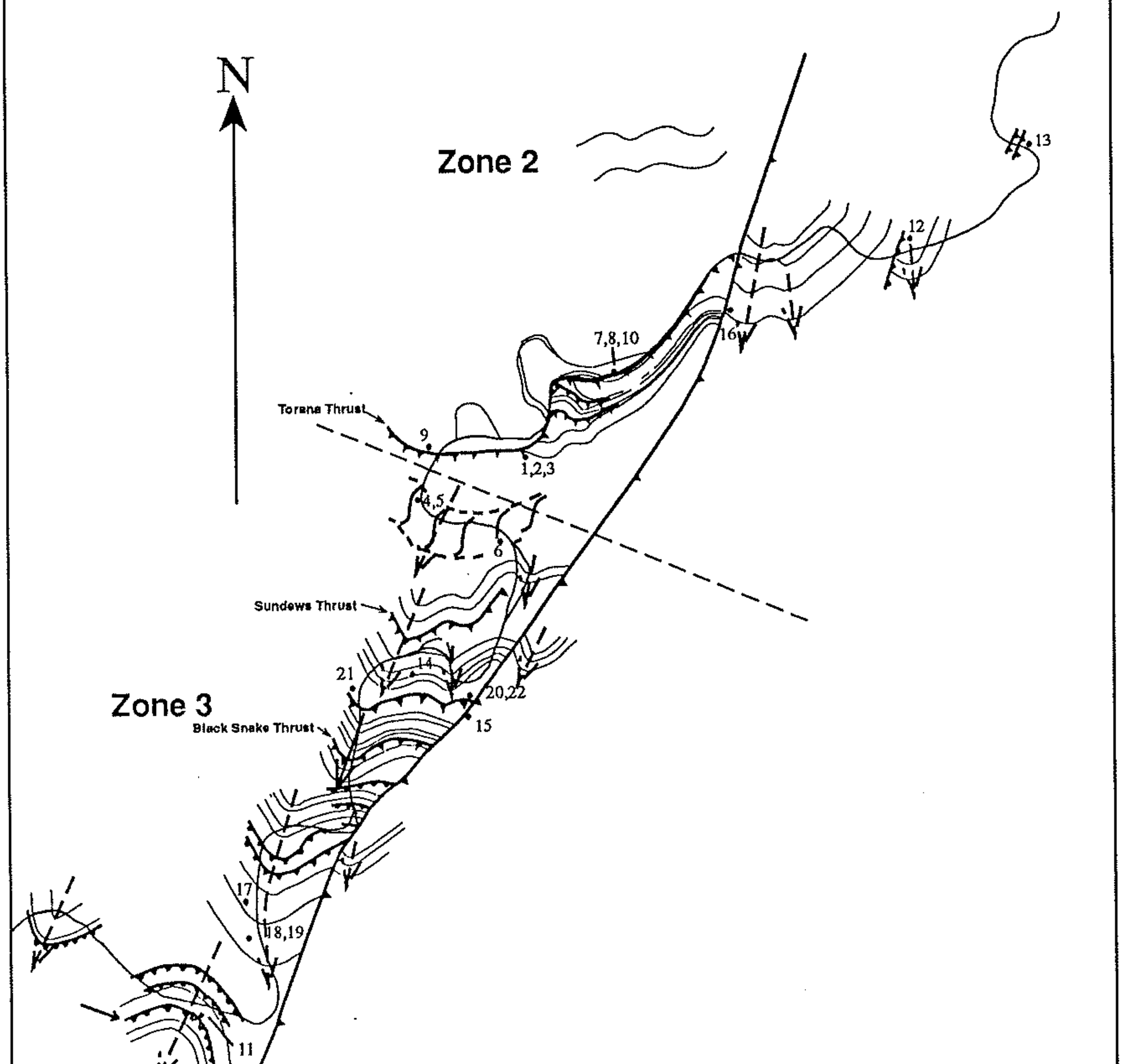
When problems arose during the year it was friends outside the university who provided assistance to me when it seemed that I could not continue. Darren Zaza, Russell Seaman, Michael Foord, Mary Jane and Ben Pearson were there when thieves removed my transport and enabled me to get to the field and finish mapping. Mark Gamcheff helped invaluably with the production of the thesis when the crunch came.

Finally, I would like to thank the Department of Mines and Energy for assistance during the year.

Appendix 1 - Plate Locality Map



Appendix 2: Strain Data
Strain Plot Results: RfØ
Fry Method

<u>Onkaparinga Gorge Strain Data</u>

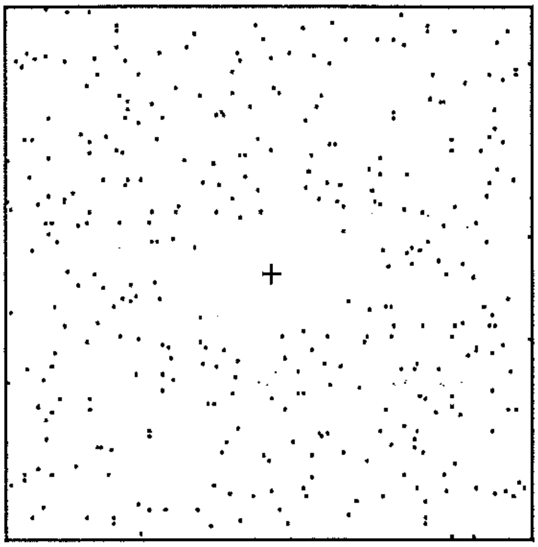
Sample	Locatior	R(XZ)	R(XY)	R(YZ)	Unit/Marker	R(XZ)(e2=1)	R(YZ)(e2=1)	1+e1	1+e3	1+dv	angle	(bedding-strain ellipse	dL
1	N-3	1.84	1.022	1.8	Quartzite	1.8	1.761	1.022	0.568	0.581	-5	1.022	2.222
2	21-6	1.73			Diamictite								
3	17-7	2.05	1.139	1.8	Diamictite	1.8	1.580	1.139	0.633	0.721	90	0.633	-36.728
4	20-8	1.82	#DIV/0!		Diamictite	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!
5	18-9	1.76	#DIV/0!		Diamictite	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!
5a		2.42	1.513	1.6	Diamictite	1.6	1.058	1.513	0.945	1.430	85	0.948	-5.249
5b		2.57	1.521	1.69	Diamictite	1.69	1.111	1.521	0.900	1.368	85	0.902	-9.794
6	13-2*	2	#DIV/0!		Fine SS	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!
7	14-6*	1.71	1.043	1.64	Arenite	1.64	1.573	1.043	0.636	0.663	4	1.038	3.842
8	N-3	1.84	1.022	1.8		1.8	1.761	1.022	0.568	0.581		1.022	2.222

INSTRAIN 2.5: INTEGRATED STRAIN ANALYSIS

Project: sample 1 Fry
Data File: data 1
Number of Objects: 78 defined by 4 points each.

Sample ID: sample 1
Surface Orientation: Xz

Fry (1979) Method



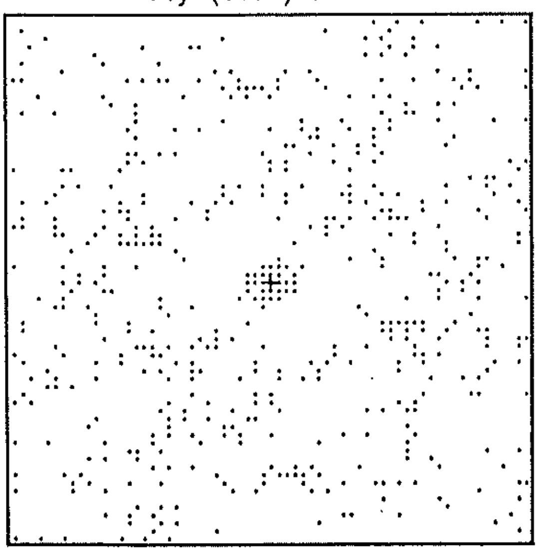
Mean Object Ellipse: X/Y = 1.958 Phi = 5.53
Average error: 16.36 %

INSTRAIN 2.5: INTEGRATED STRAIN ANALYSIS

Project: sample 2 Fry
Data File: data 2
Number of Objects: 254 defined by 4 points each.

Sample ID: sample 2
Surface Orientation: XZ

Fry (1979) Method

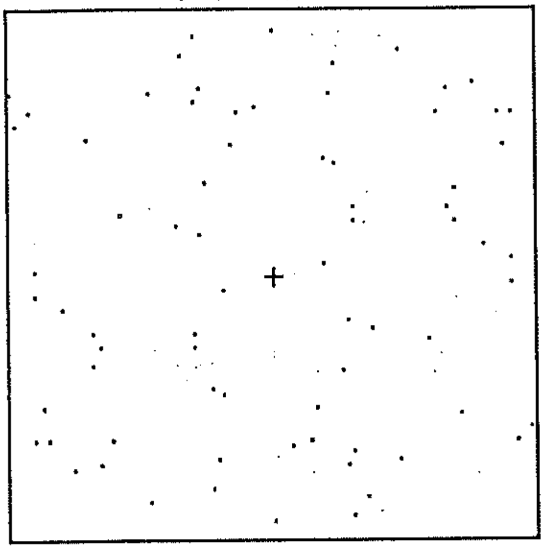


Mean Object Ellipse: X/Y = 1.282 Phi = -30.00
Average error: 25.96 %

Project: sample 3 Fry
Data File: data 3
Number of Objects: 58 defined by 4 points each.

Sample ID: sample 3
Surface Orientation: XZ

Fry (1979) Method



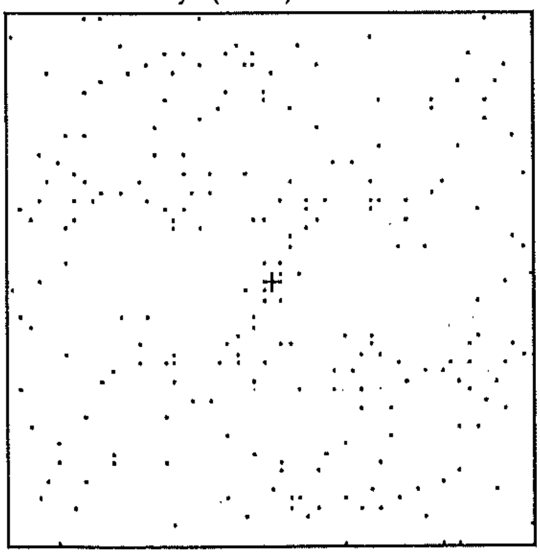
Mean Object Ellipse: X/Y = 2.138 Phi = 0.44
Average error: 17.01 %

INSTRAIN 2.5: INTEGRATED STRAIN ANALYSIS

Project: sample 4 Fry
Data File: data 4
Number of Objects: 227 defined by 4 points each.

Sample ID: sample 4
Surface Orientation: XZ

Fry (1979) Method

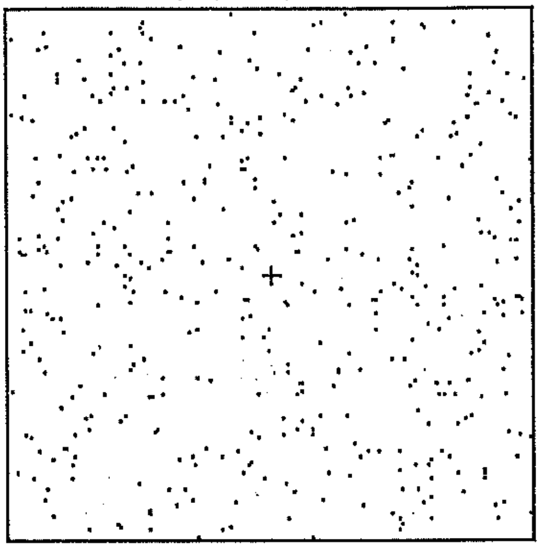


Mean Object Ellipse: X/Y = 2.069 Phi = -10.98
Average error: 26.90 %

Project: sample 5 Fry
Data File: data 5
Number of Objects: 97 defined by 4 points each.

Sample ID: sample 5
Surface Orientation: XZ

Fry (1979) Method



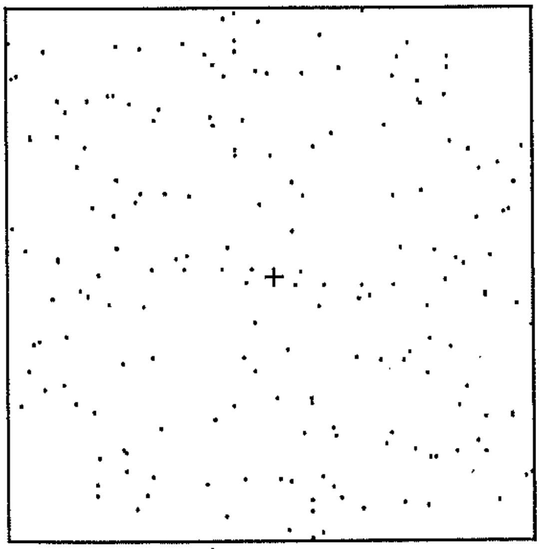
Mean Object Ellipse: X/Y = 2.186 Phi = 0.41
Average error: 37.84 %

INSTRAIN 2.5: INTEGRATED STRAIN ANALYSIS

Project: sample 6 Fry
Data File: data 6
Number of Objects: 58 defined by 4 points each.

Sample ID: sample 6
Surface Orientation: XZ

Fry (1979) Method



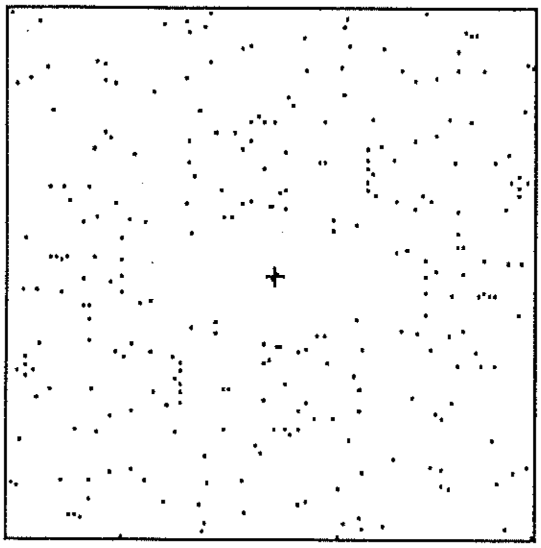
Mean Object Ellipse: X/Y = 1.795 Phi = 56.41
Average error: 45.93 %

INSTRAIN 2.5: INTEGRATED STRAIN ANALYSIS

Project: sample 7 Fry
Data File: data 7
Number of Objects: 90 defined by 4 points each.

Sample ID: sample 7
Surface Orientation: XZ

Fry (1979) Method

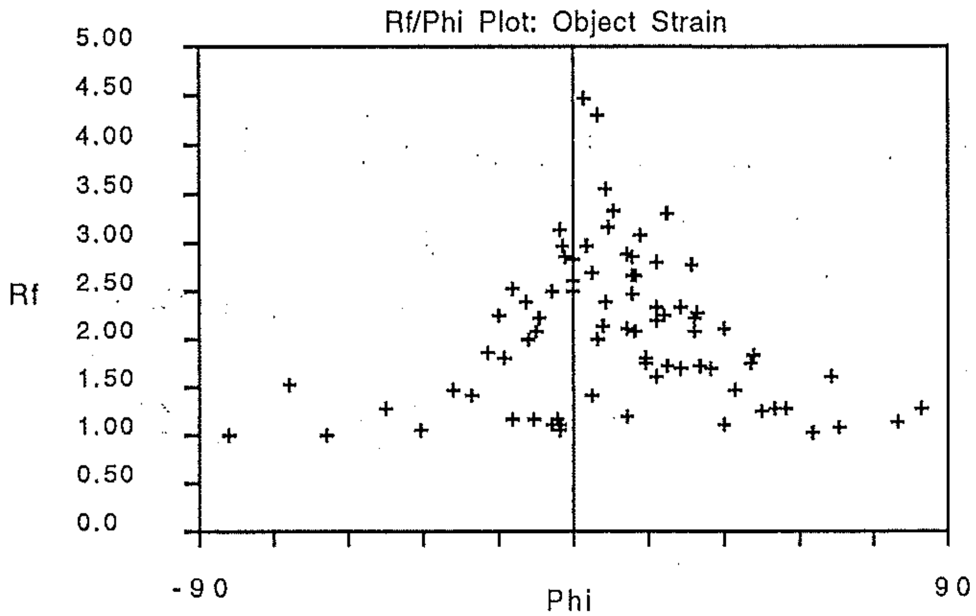


Mean Object Ellipse: X/Y = 1.678 Phi = 0.35
Average error: 18.55 %

INSTRAIN 2.5: INTEGRATED STRAIN ANALYSIS

Project: Rf-phi sample 1
Data File: data 1
Number of Objects: 78 defined by 4 points each.

Sample ID: sample 1
Surface Orientation: XZ



Ellipticity Range: 1.002 to 4.461

MEANS (+/- 1 STD)

Phi (degrees) : 9.998 +/- 29.168
X/Y (n = 78)
Arithmetic 2.069 +/- 0.780
Harmonic 1.795

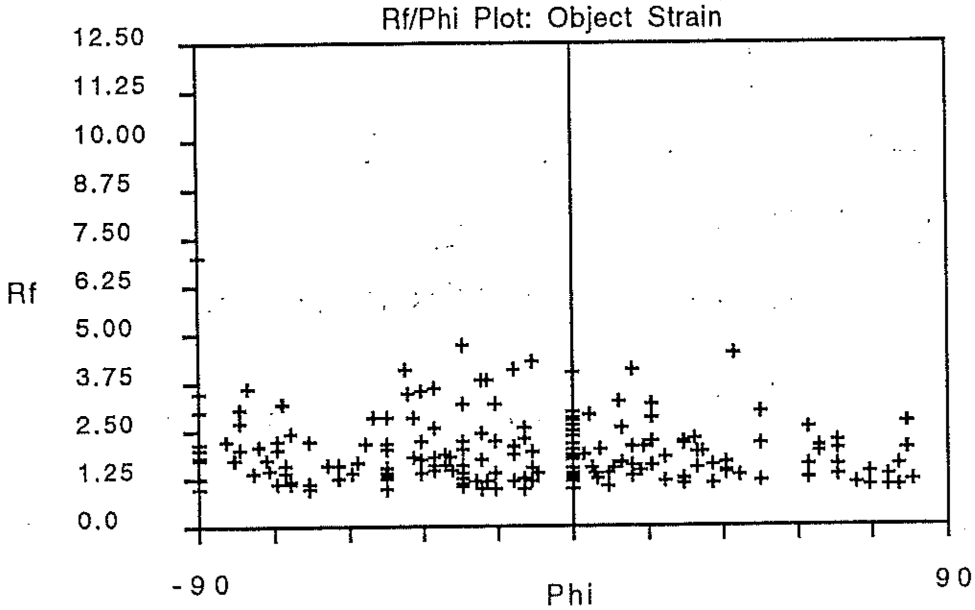
Mean Object Ellipse: X/Y = 1.958 Phi = 5.53
Average error: 16.36 %

INSTRAIN 2.5: INTEGRATED STRAIN ANALYSIS

Project: Rf-phi sample 2
Data File: data 2
Number of Objects: 254 defined by 4 points each.

Sample ID: sample 2
Surface Orientation: XZ

Rf/Phi Plot: Object Strain



Ellipticity Range: 1.000 to 7.000

MEANS (+/- 1 STD)

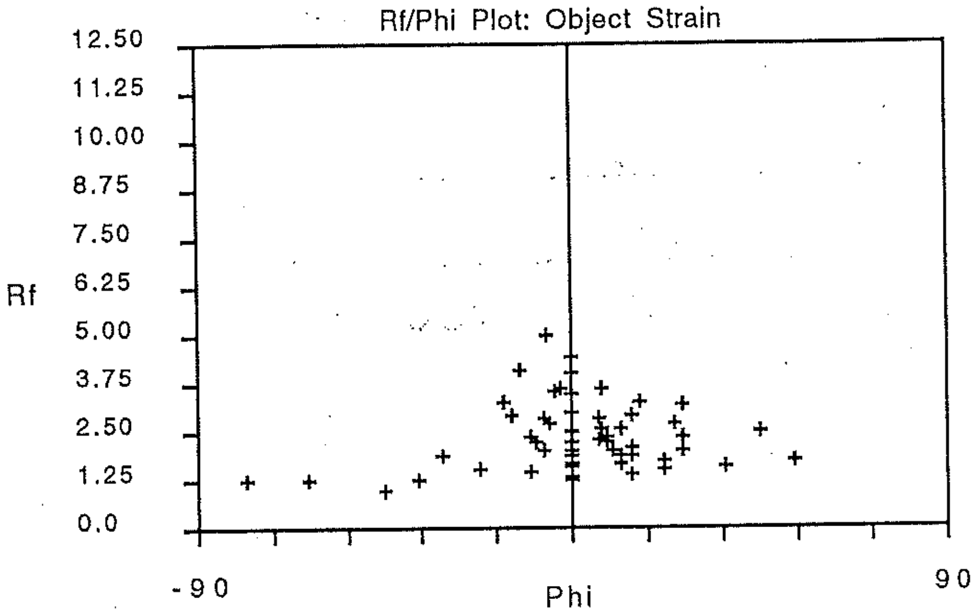
Phi (degrees) :	-11.010	+/-	40.637
X/Y (n = 254)			
Arithmetic	1.977	+/-	0.824
Harmonic	1.726		

Mean Object Ellipse: X/Y = 1.282 Phi = -30.00
Average error: 25.96 %

INSTRAIN 2.5: INTEGRATED STRAIN ANALYSIS

Project: Rf-phi sample 3
Data File: data 3
Number of Objects: 58 defined by 4 points each.

Sample ID: sample 3
Surface Orientation: XZ



Ellipticity Range: 1.000 to 5.025

MEANS (+/- 1 STD)

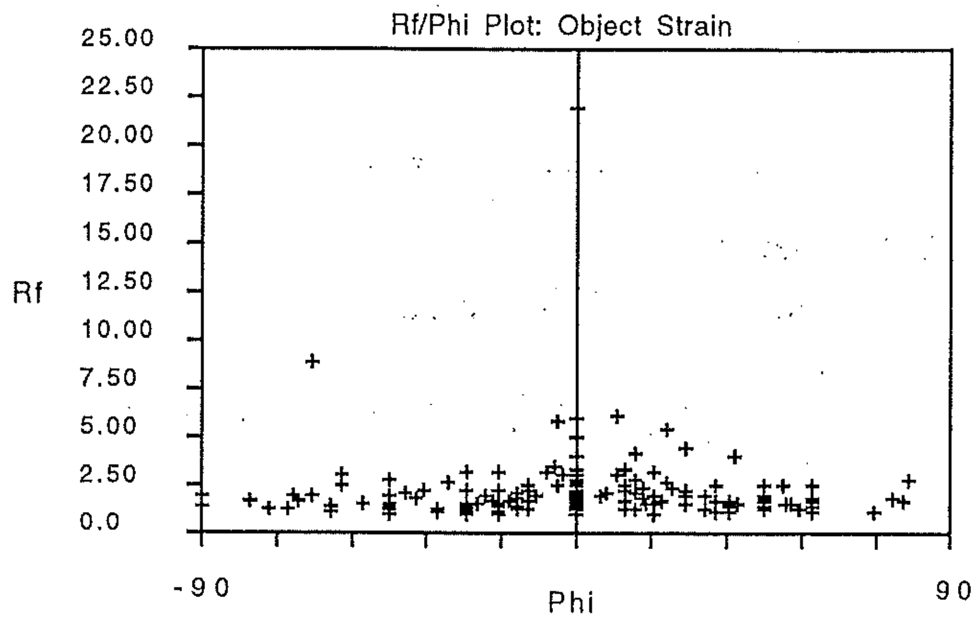
Phi (degrees) : 1.940 +/- 22.310
X/Y (n = 58)
Arithmetic 2.334 +/- 0.882
Harmonic 2.051

Mean Object Ellipse: X/Y = 2.138 Phi = 0.44
Average error: 17.01 %

INSTRAIN 2.5: INTEGRATED STRAIN ANALYSIS

Project: Rf-phi sample 4
Data File: data 4
Number of Objects: 227 defined by 4 points each.

Sample ID: sample 4
Surface Orientation: XZ



Ellipticity Range: 1.000 to 22.000

MEANS (+/- 1 STD)

Phi (degrees) : 0.597 +/- 31.781
X/Y (n = 227)
Arithmetic 2.199 +/- 1.659
Harmonic 1.820

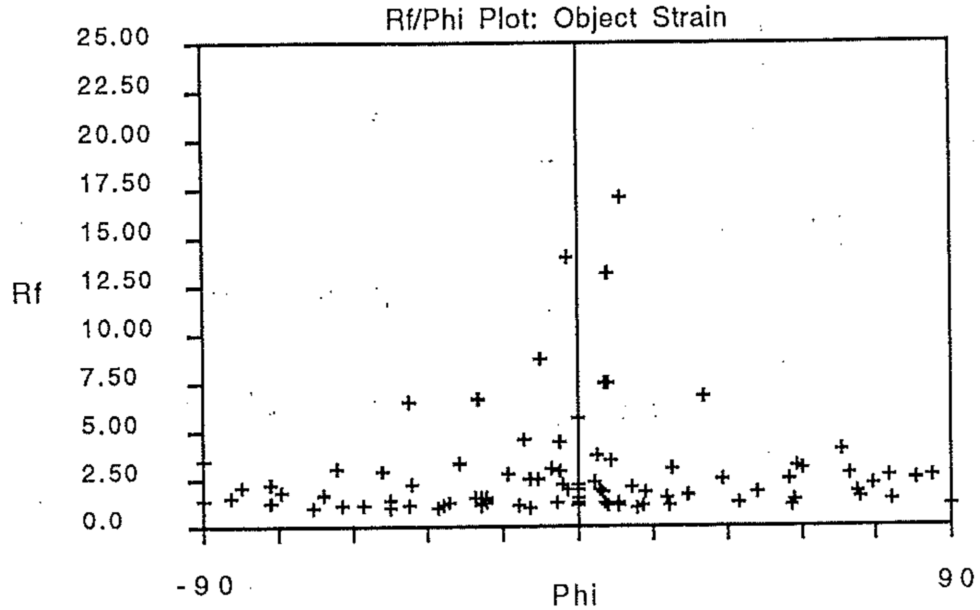
Mean Object Ellipse: X/Y = 2.069 Phi = -10.98
Average error: 26.90 %

INSTRAIN 2.5: INTEGRATED STRAIN ANALYSIS

Project: Rf-phi sample 5
Data File: data 5
Number of Objects: 97 defined by 4 points each.

Sample ID: sample 5
Surface Orientation: XZ

Rf/Phi Plot: Object Strain



Ellipticity Range: 1.000 to 17.057

MEANS (+/- 1 STD)

Phi (degrees) : -2.089 +/- 41.405
X/Y (n = 97)
Arithmetic 2.686 +/- 2.702
Harmonic 1.763

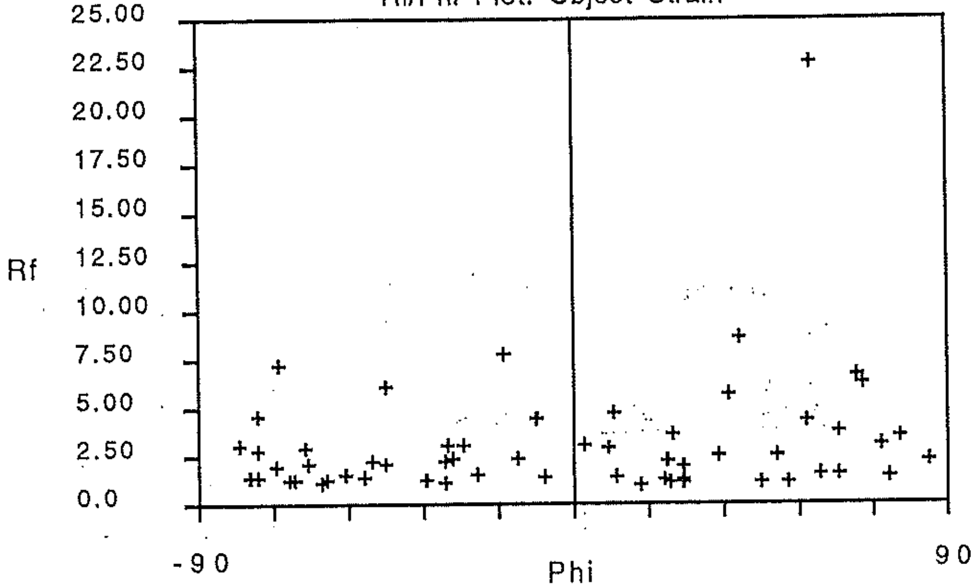
Mean Object Ellipse: X/Y = 2.186 Phi = 0.41
Average error: 37.84 %

INSTRAIN 2.5: INTEGRATED STRAIN ANALYSIS

Project: Rf-phi sample 6
Data File: data 6
Number of Objects: 58 defined by 4 points each.

Sample ID: sample 6
Surface Orientation: XZ

Rf/Phi Plot: Object Strain



Ellipticity Range: 1.010 to 22.832

MEANS (+/- 1 STD)

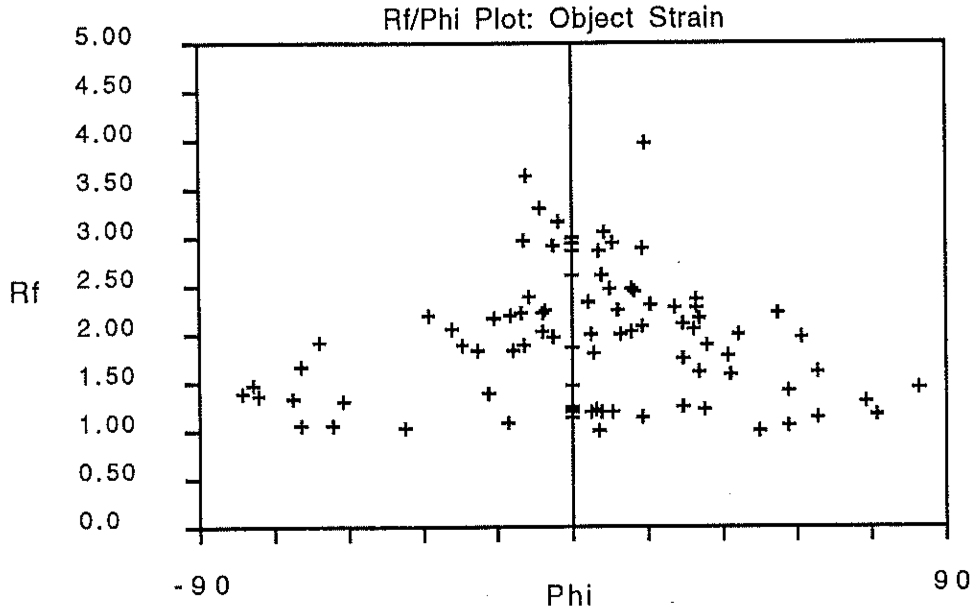
Phi (degrees) : -3.104 +/- 51.395
X/Y (n = 58)
Arithmetic 3.108 +/- 3.225
Harmonic 1.989

Mean Object Ellipse: X/Y = 1.795 Phi = 56.41
Average error: 45.93 %

INSTRAIN 2.5: INTEGRATED STRAIN ANALYSIS

Project: Rf-phi sample 7
Data File: data 7
Number of Objects: 90 defined by 4 points each.

Sample ID: sample 7
Surface Orientation: XZ



Ellipticity Range: 1.005 to 3.985

MEANS (+/- 1 STD)

Phi (degrees) : 3.833 +/- 33.704
X/Y (n = 90)
Arithmetic 1.942 +/- 0.680
Harmonic 1.719

Mean Object Ellipse: X/Y = 1.678 Phi = 0.35
Average error: 18.55 %

Appendix 3: Thin section descriptions.

Sample 6627 RS 816

Sturt Formation diamictite. Fine grained shaly matrix. Clasts abundant. Cleavage dominant. Bedding absent, cleavage refracted around clasts. Pressure shadows and fringes. Clasts of varied size. some clasts are diamictite reworked.

Clast types: 95% qtz 5% anorthoclase, biotite, calcite.

Sample 6627 RS 817

Sturt Formation diamictite. Fine grained shaly matrix. Clasts abundant. Cleavage dominant, bedding absent, cleavage refracted around clasts. Pressure shadows and fringes. Clasts of varied size, rounded. Qtz 98%, biotite and calcite 2%.

Sample 6627 RS 818

Sturt formation diamictite. Fine grained shaly matrix. Cleavage dominant, bedding planes absent, clasts pulled apart. Clasts 95% qtz, 5% heavy minerals, anorthoclase, plagioclase, calcite.

Sample 6627 RS 819

Similar description as RS 818

Sample 6627 RS 820

Belair Subgroup Quartzite/sandstone. Rounded and subrounded grains. Grain supported, no matrix. Qtz 95%, 5% anorthoclase, plagioclase, feldspar, heavy minerals. Well sorted.

Sample 6627 RS 822

Sandstone Belair Subgroup, similar to RS 820.

Sample 6627 RS 823

Medium grained quartz-arenite. Grain supported, well sorted. Grain boundaries 90-120 degrees.

Sample 6627 RS 824a

Medium grained quartz arenite. Moderate sorting. Grains subrounded. Clast supported. Some calcite matrix (10%). 95% qtz 5% anorthclase, plagioclase.

Sample 6627 RS 824b

As above

Sample 6627 RS 825

Shale and fine sandstone. Qtz 99% (microcrystalline and very fine grains), heavy minerals ans anorthoclase 1%. Cleavage dominant, low angle cleavage duplexes. isolated interbeds of medium-finr grains.

Sample 6627 RS 826

Fine grained sandstone and shale. very low angle-bedding planar cleavage. Fine sandstone beds clast supported. 5% matrix of shale and very fine sandstone.

Sample 6627 RS 827

Shale, high strain. Cleavage dominant, clast shapes changed dramatically. Some fine grains. 70% very fine grained qtz (microcrystalline).

Sample 6627 RS 828

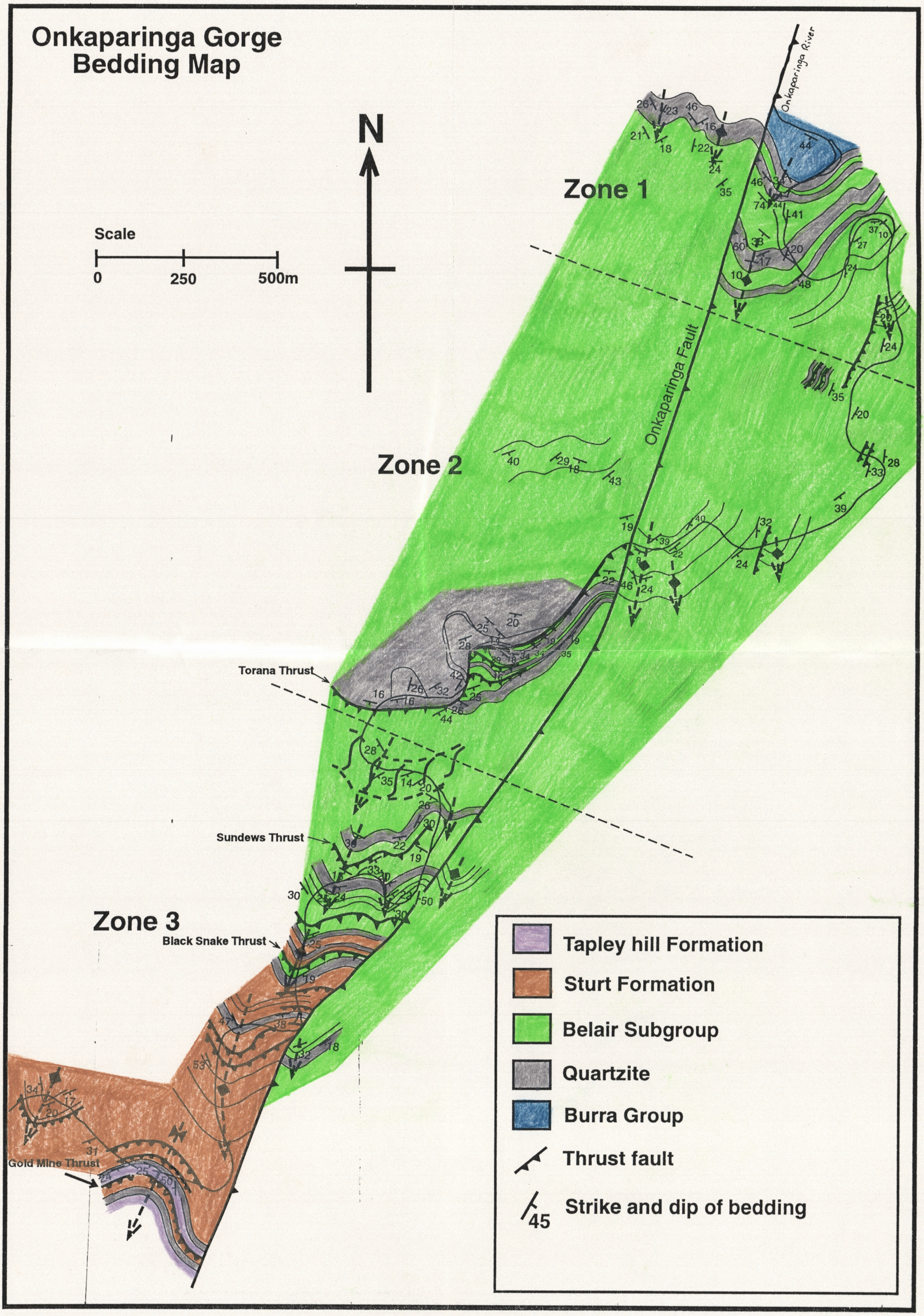
Shale and very fine grained sandstone. Qtz 99% 1% heavy minerals and anorthoclase. Cleavage dominant. Grain shapes distorted by strain. Matrix of microcrystalline silicate. Bedding not observed.

Sample 6627 RS 829

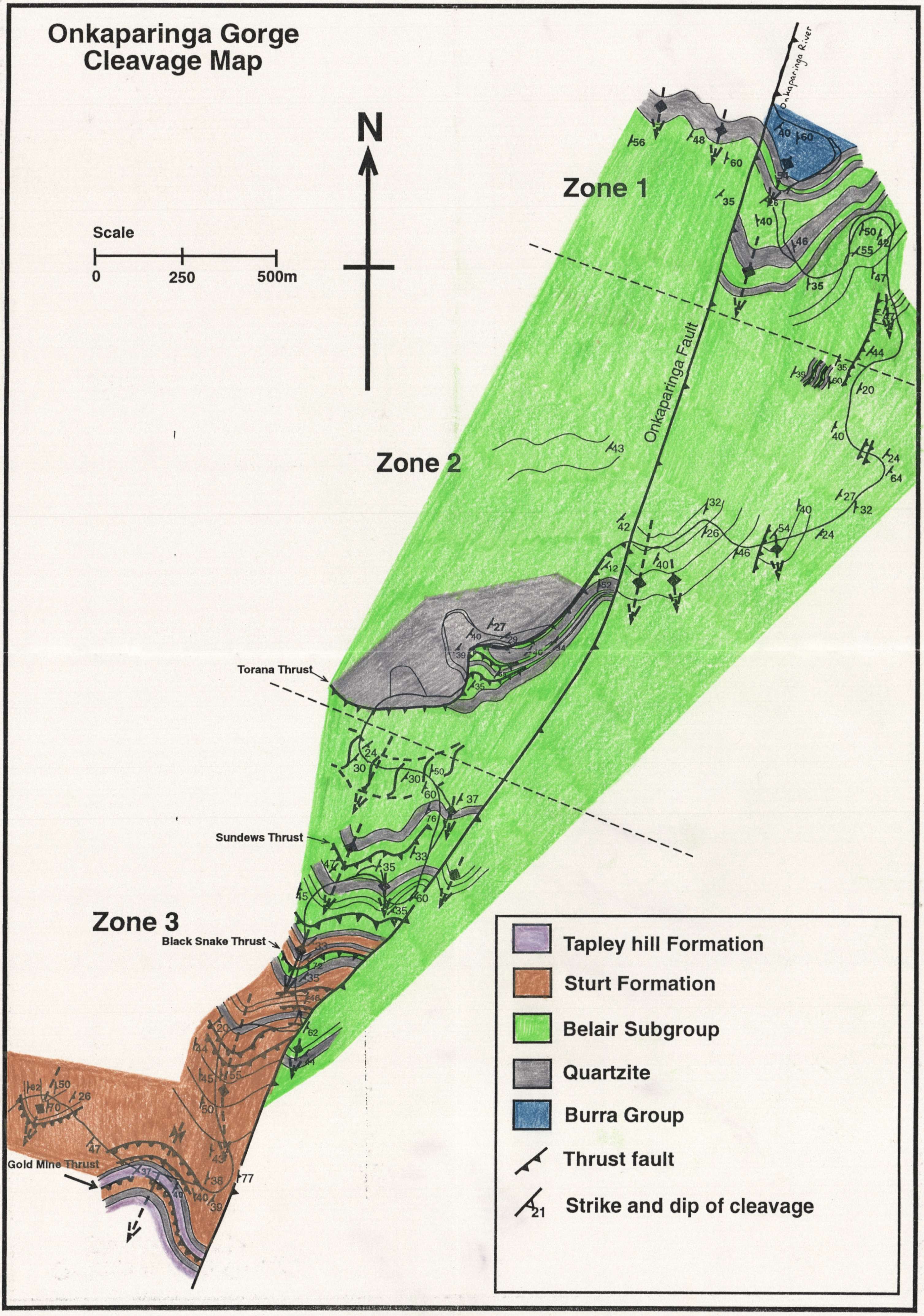
Slate. Reduction spots of heavy mineral opaques (5%). Microcrystalline Qtz. Recrystallised quartz silicates. Prominent cleavage, high strain.

Sample 6627 RS 830

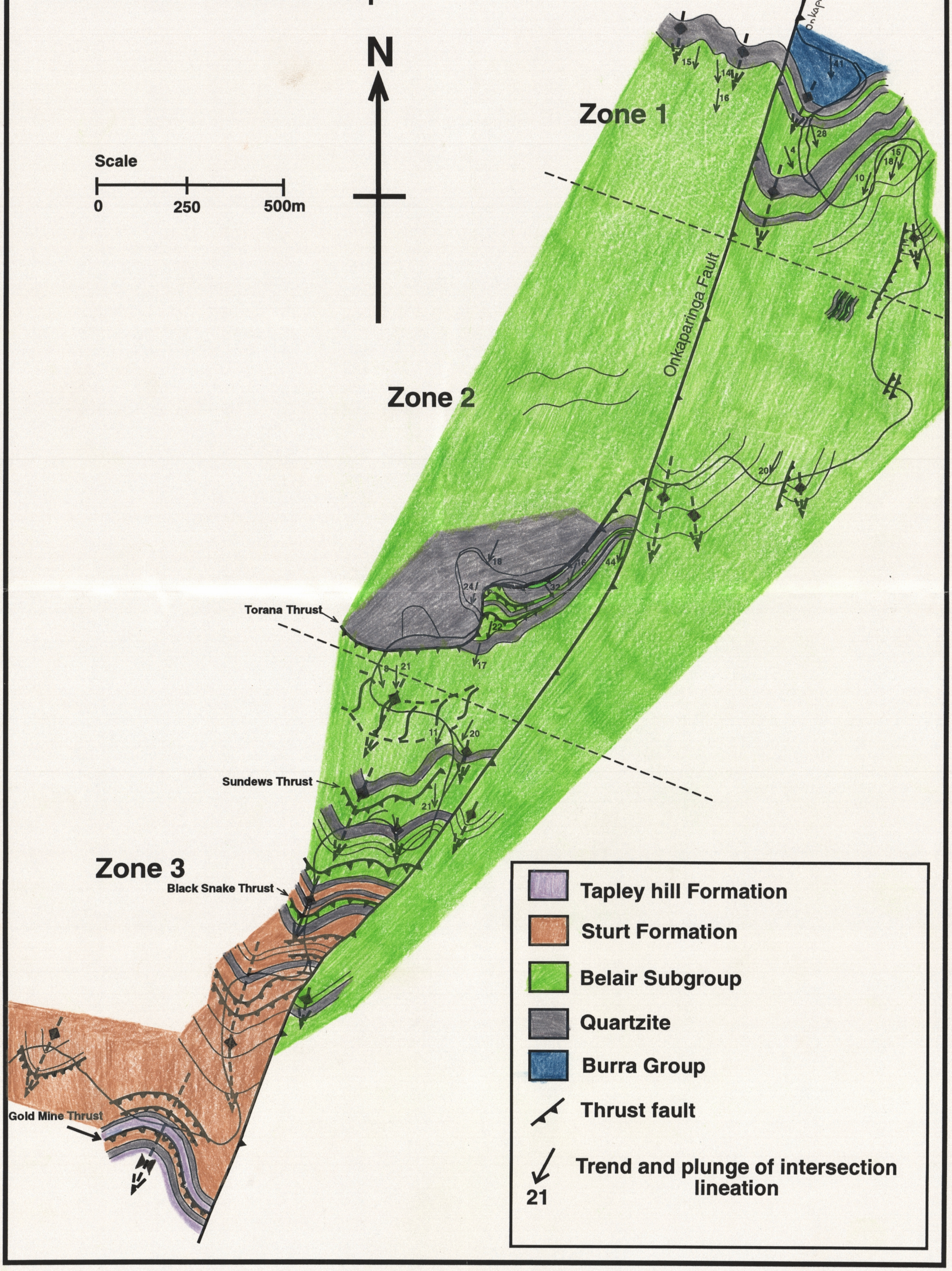
Fine grained sandstone and shale. Qtz 95%. Clasts 60% matrix 40% (very fine qtz/silicate).

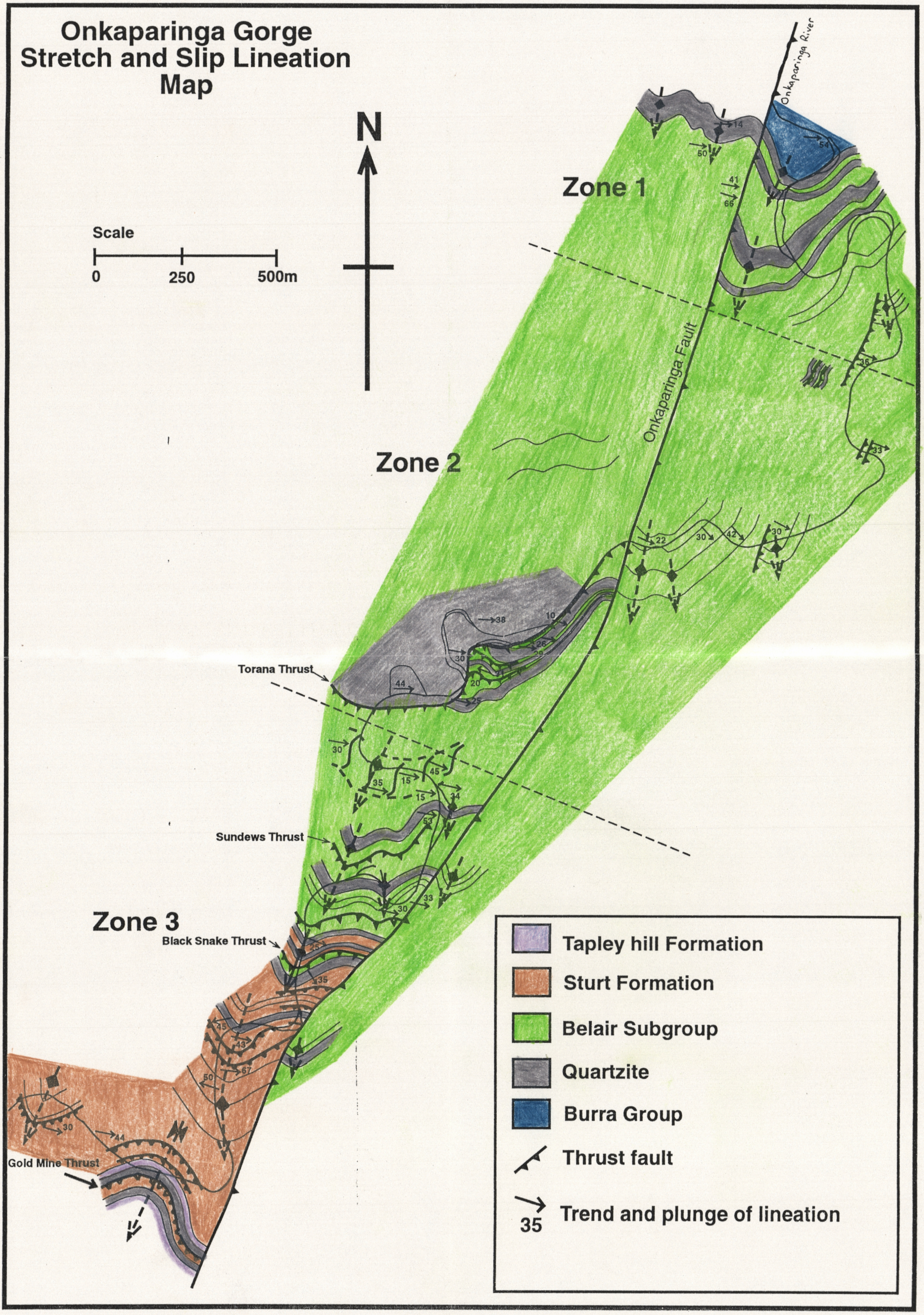

Onkaparinga Gorge
Bedding Map
N
Scale
0
250
500m
Zone 1
Zone 2
Zone 3
Onkaparinga River
Onkaparinga Fault
Torana Thrust
Sundews Thrust
Black Snake Thrust
Gold Mine Thrust
Tapley hill Formation
Sturt Formation
Belair Subgroup
Quartzite
Burra Group
Thrust fault
45
Strike and dip of bedding

Onkaparinga Gorge Cleavage Map



Onkaparinga Gorge Intersection Lineation Map




Onkaparinga Gorge
Stretch and Slip Lineation
Map
N
Scale
0
250
500m
Zone 1
Zone 2
Zone 3
Onkaparinga River
Onkaparinga Fault
Torana Thrust
Sundews Thrust
Black Snake Thrust
Gold Mine Thrust
Tapley hill Formation
Sturt Formation
Belair Subgroup
Quartzite
Burra Group
Thrust fault
Trend and plunge of lineation
35