A STRUCTURAL ANALYSIS OF THE SOUTHERN HORNSBY PLATEAU, SYDNEY BASIN, NEW SOUTH WALES

by

Anthony Richard Norman, B.Sc. (Hons)

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ABSTRACT

The Hornsby Plateau rises north of Sydney. Aerial photo interpretation of an area north of Hornsby and south of the Hawkesbury River revealed two well defined extensive traces. These are the ESE trending Berowra Waters Fracture Lineament and the NNE trending West Head Fracture Lineament. A broad series of parallel NNE trending traces also formed the less well defined Coastal Fracture Lineament Zone. Outcrop fracture analyses revealed that these lineaments consist of master joints and conjugate fractures subparallel to the traces and that multiple deformation has taken place along the lineaments.

Throughout the Hornsby Plateau outcrop examination revealed that NNE planar joints form the most widespread and dominant joint set. Some of these joints may have formed early in the history of the Sydney Basin along with N-NNE trending depositional hinge-lines. The orientation and location of these hinge lines was probably determined by structures in the basement. However, most NNE joints and joint zones appear to have formed as a result of unloading through erosion together with a residual NNE-N horizontal compression. This compression was subsequent to the intrusion of the Barrenjoey dyke about 171Ma and many NW trending dykes in the Sydney region. This NNE-N compression may be related to the present northward migration of Australia and may have commenced when separation of the Antarctic and Australian continents began about 50-60Ma.

On the Blue Mountains Plateau NNW planar joints form the dominant and most widespread joint set. These joints appear to be similar in style to the NNE joints on the Hornsby Plateau and are probably related to the same residual tectonic stress and the removal of the overburden. The change in orientation of these joints across the central Sydney Basin may be related to the change in dip direction of the Permo-Triassic rocks.

WNW to NW trending joints are also common on the Hornsby Plateau and are generally associated with subparallel dykes. The NW trending dykes appear to have formed an anisotropy prior to the regional NNE-N compression. The initial development of NW planar joints and joint zones may have resulted from a NE-SW extension which existed in the adjoining continental crust when the Tasman Sea rifting began to wane or ceased about 60Ma. Down-dragging of the Hornsby Plateau and Cumberland Basin from the Blue Mountains Plateau may have occurred during this period of extension and increased the rate of erosion.

Prior to the NE-SW extension, rifting in the Tasman Sea may have imposed a NE compression on the south-eastern coastline. This resulted in thrusting from the NE and epeirogenic uplift and tilting. NNE trending hinge-lines were probably reactivated during this compression and deformation may have occurred within pre-existing ESE trending structures.

Deformation within ESE trending structures, such as the Berowra Waters Fracture Lineament, probably initially occurred prior to the NE compression, NE-SW extension and NNE compression. This Lineament has had a complex history of deformation but may have developed initially during an E-W compression which existed after Late Permian time and is probably related to movements in the basement.

ACKNOWLEDGMENTS

Three years of research on the Hornsby Plateau and many years wandering through the Northern Blue Mountains would not have been possible without the help and interest of many people. I am extremely grateful to Assoc. Prof. D. F. Branagan whose constant help and encouragement went well beyond the normal expectations of a supervisor. Many of the conceptual problems and the resulting enlightenment in structural geology came about after long discussions with Assoc. Prof. D. F. Branagan and John Creasey (C.S.I.R.O.). Much of the field work and interpretations in the Kuring-gai/Berowra were undertaken with John Creasey whose knowledge and experience were invaluable. I would like to thank the University of Sydney and C.S.I.R.O for their financial assistance with a research grant and Prof. G. M. Philip for his backing of the collaborative research fund. I am also indebted to Prof. G .M. Philip for the use of Departmental facilities and to the staff of the Department of Geology and Geophysics.

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CHAPTER 1

INTRODUCTION

1.1 PURPOSE

There are three main aims to this study. The first is to provide an integrated structural analysis of the southern Hornsby Plateau in the Kuring-gai/Berowra area and adjacent Sydney Region, the second is to compare this analysis with the structural geology of the Blue Mountains Plateau and the third is to derive a history of deformation from a synthesis of the above information. Airphoto interpretation and detailed fracture mapping have been used to extend the previous lineament study by C.S.I.R.O. (Mauger et al., 1984) and to provide a structural synthesis in the study areas, in order to understand the arrangement and timing of fracturing in the central Sydney Basin.

1.2 OUTLINE

This thesis is divided into 5 study areas shown on fig.1. They are as follows;

(1) The Kuring-gai/Berowra area

(2) The Sydney region

(3) The Western Coalfield (southern portion)

(4) The western margin of the Sydney Basin

(5) The Lapstone Structural Complex

The first two study areas are situated on the southern Hornsby Plateau and were examined in detail. Chapters two and three contain the observations and analyses of these two areas.

The other three study areas are situated on the Blue Mountains Plateau and were examined in less detail because of the previous structural geology mapping by C.S.I.R.O. (Shepherd et al., 1978, 1981a, 1981b; Shepherd and Huntington, 1981; Mauger et al., 1984), Pedram (1983) and others. A review of the previous work on the Blue Mountains Plateau and observations during this study are contained in chapter four and were used as a comparison with the detailed structural analysis on the Hornsby Plateau. The comparison of the Hornsby Plateau with the Blue Mountains Plateau and a interpreted history of deformation are contained in chapter five.

1.3 METHODOLOGY

1.31 THE KURING-GAI/BEROWRA AREA:

The study of the Kuring-gai/Berowra area was conducted in 3 stages. The first was interpretation of linear features on 1:40,000 black and white aerial photos and 1:16,000 colour aerial photos; the second was detailed outcrop fracture analysis and the final stage was a synthesis of all available data in order to determine the history of deformation in the area.

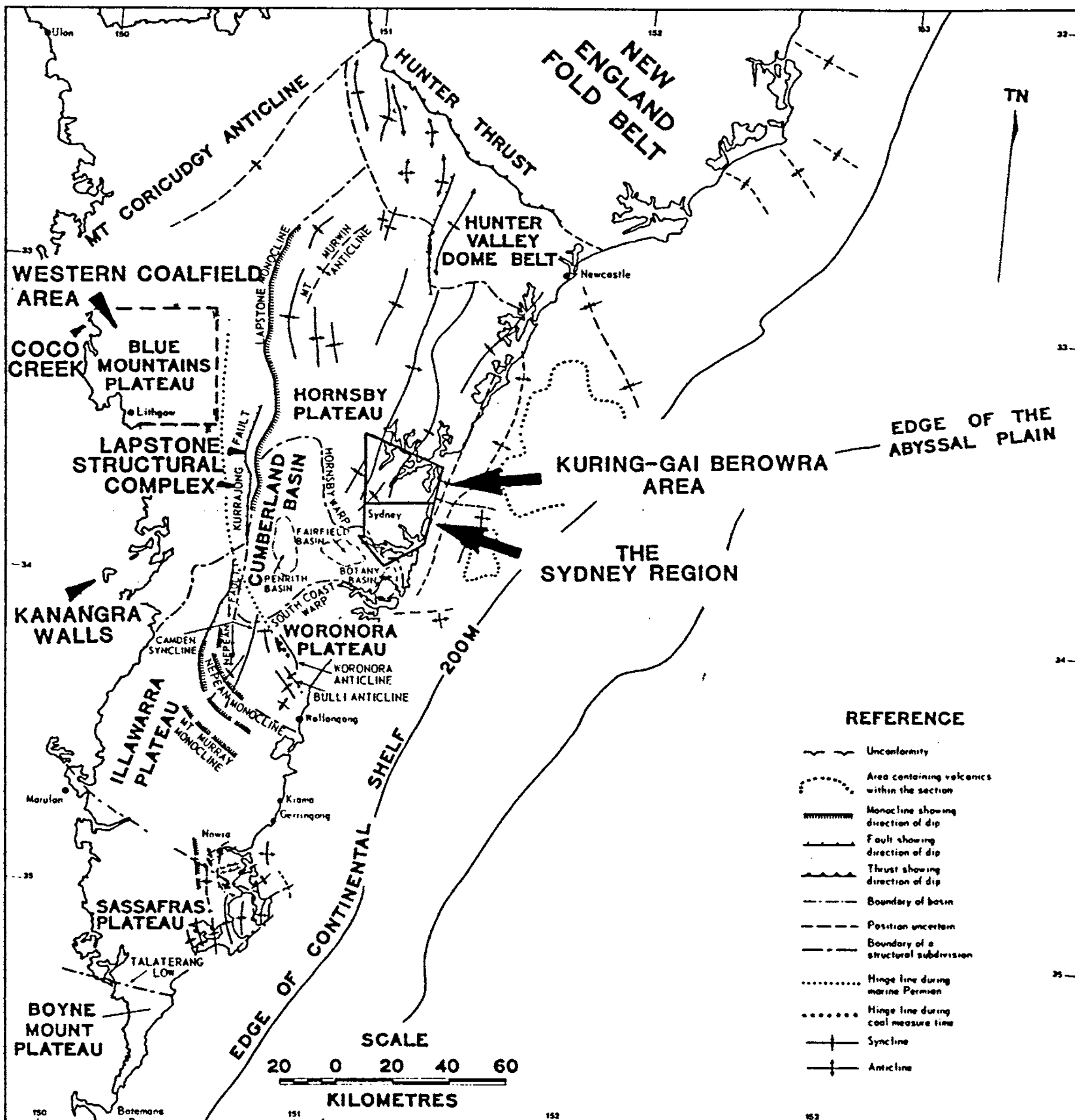


Figure 1. Location of the study areas and the structural subdivisons of the Sydney Basin (Bembrick et al., 1973).

Air photo interpretation was compiled onto the Cowan, Hornsby, Mona Vale and Berowra Waters 1:25,000 topographic sheets. Through a process of digital-data-interpretation a 1:50,000 lineament map (fig.8, in back pocket) was produced and analysed. This interpretation was added to the previous Landsat imagery and small-scale (1:100,000) airphoto interpretation compiled by C.S.I.R.O. (Mauger et al., 1984). The present lineament study provided a basis for selecting outcrop fracture analysis sites. These sites were visited in order to define the linear features identified by air photo interpretation and to provide a regional fracture analysis. The outcrop fracture analysis at each site was summarised onto data sheets (appendix A) and onto 1:25,000 base maps which were reduced to a 1:50,000 map of the area (fig.12, in back pocket).

1.32 THE SYDNEY REGION:

Like the Kuring-gai/Berowra area the study of the Sydney Region was conducted in 3 stages although aerial photo interpretation was hindered by the lack of visible outcrop. Outcrop fracture analyses were conducted where-ever there was good outcrop, such as along coastal platforms, excavation sites, road cuttings and quarries. Along the coast and along a warp between Waverton and and Turramurra 1:65,000 black and white aerial photos aided the outcrop fracture analysis, however no separate lineament map was produced. The fracture analysis at each site was summarised onto data sheets (appendix B) and onto 1:4,000 and 1:10,000 orthophoto maps and 1:25,000 topographic maps. These maps were reduced to a 1:50,000 map of the area (fig.44, in back pocket). These sites were visited to define a regional fracture pattern and delineate any anomalies such as fracture zones.

1.33 THE WESTERN COALFIELD (southern portion):

The study of the southern portion of the Western Coalfield consisted of geological mapping of an area between Bell and the Capertee River in the 'Northern Blue Mountains', an examination of 1:45,000 black and white aerial photos in this area in order to define the main structural trends, a review of the detailed structural analyses by C.S.I.R.O. in the coal mining areas, a perusal of mine record tracings held by the Department of Mineral Resources and some outcrop fracture mapping. The geological mapping of the Northern Blue Mountains was compiled onto 1:25,000 maps which were reduced to a 1:50,000 map (fig.94, in back pocket). Because of the detailed work by C.S.I.R.O. defining areas of bad roof conditions in underground mines from a structural analysis of the overlying massive sandstones of the Narrabeen Group (Shepherd et al., 1978; 1981a; Shepherd and Huntington, 1981), only a few detailed fracture analyses were conducted in this area and are summarised in appendix C. Observations on the extent of major structures and the regional structural trends were made using aerial photos and compared with C.S.I.R.O.'s observations. Regional fault and cleat directions were also noted from mine records. The above information was used to construct a structural synthesis of the Blue Mountains Plateau which was compared with a structural synthesis of the Hornsby Plateau.

1.34 THE WESTERN MARGIN OF THE SYDNEY BASIN:

The study of the western margin of the Sydney Basin consisted of an examination of two areas; the Kanangra Walls region and the Coco Creek unconformity, Capertee Valley (fig.1). Discontinuities in the basement rocks and Basin rocks were examined in order to determine whether there is any continuity between these structures and whether basement structures have influenced the structure of the overlying Sydney Basin sediments. A summary of fracture analyses in these areas is contained in appendix C. In the Kanangra Walls area, fracture analysis sites were chosen after the interpretation of linear features on 1:45,000 black and white aerial photos. Previous lineament studies by C.S.I.R.O and joint studies by Johnstone et al. (1983) and Rudd (1972) of basement and basin discontinuities were reviewed and compared with observations in this thesis. This information was used to construct a structural synthesis of the Blue Mountains Plateau which was compared with the structural synthesis for the Hornsby Plateau.

1.35 THE LAPSTONE STRUCTURAL COMPLEX:

The study of the Lapstone Monocline consisted of an examination of fracturing at a road cutting at Bell Bird Hill on the monoclinal part of the complex near Kurrajong. A summary of this fracture analysis is contained in appendix C. These observations were compared with those of Pedram (1983) and then also used in the structural synthesis of the Blue Mountains Plateau.

1.4 OUTCROP FRACTURE ANALYSIS TECHNIQUES AND TERMINOLOGY

Because the Sydney Basin is only weakly deformed, the study of joint and fault patterns at both outcrop and regional scales has been used to identify the stress/strain relationships which have existed in each study area. While it may not be wise to attribute the formation of different joint sets to particular events, as joint formation is probably a continuing process, the relative ages of the initiation of joints and faults have been determined using the terminations and intersections of discontinuities.

At each outcrop site the field analysis consisted of an examination of all fractures (<1m long), joints (1m-10m long), master joints (>10m long), joint zones (in which joints are spaced <0.5m), breccia zones, faults, slickensides and dykes. In addition to fracture orientation, data were collected on the number and dominance of fracture sets, the style (planar, curved, stepping, etc.), extent (both vertical and horizontal where possible), fill and country rock. The pattern, including terminations and intersections, of joint sets, faults and dykes was also noted. This information was compiled onto data sheets and summarised onto the 1:50,000 fracture analysis maps.

In the field, all orientation data were recorded as magnetic bearings, however, all readings in this thesis are given to True North. In this thesis, the word 'fracturing' refers to all discontinuities including fractures, joints, master joints, faults, etc. Genetic terms such as 'shear' joints were not used in field descriptions.

The age relationships of fractures were determined predominantly by using fracture architecture (Hancock, 1983, 1985), that is, younger fractures and joints generally abut older fractures and joints. Joint/fault intersections were also useful in determining the relative ages of fracturing although in these instances the older discontinuity usually abuts the younger discontinuity. Dykes and breccia vents associated with fracturing were also used in determining age relationships and where they have been dated were the only means of determining geological time constraints. From a synthesis of the above information a history of deformation for each study area was attempted. However, the interpretations reached in this thesis were only for the study areas and in order to understand fully the structural history of the Sydney Basin other fracture analyses will need to be carried out.

Conjugate fractures and joints were observed at a number of localities and are important because they probably indicate the direction of maximum compressional stress, σ_1, at their formation (Price, 1966). In this thesis vertical conjugate joints are joints whose acute bisectrix is vertical, that is, σ_1 was vertical during their formation. These joints have a horizontal intersection and dip at high angles. Price (1966) suggests that vertical conjugate joints form during uplift as a result of residual tectonic stresses. The formation of vertical conjugate joints will be discussed in later sections. Horizontal conjugate joints are also referred to in this thesis. These joints can have a vertical or sub-horizontal intersection depending on whether the joints dip at high or low angles, however their acute bisectrix is always horizontal. Horizontal conjugate joints indicate that σ_1 was horizontal during their formation. In the areas studied, because of the lack of vertical markers and the small displacements within deformation zones, horizontal conjugate joints may be the only evidence of lateral compression.

Conjugate joints may not necessarily be cross-cutting. They may also have a Y intersection (Hancock, 1985).

1.5 PREVIOUS WORK

Many workers have contributed to our knowledge of the structural subdivisions of the Sydney Basin. However, there have been few detailed studies of in-situ structural geology. The structural subdivisions are summarised by Bembrick et al. (1973), and are shown in fig.1. There is however some doubt as to the validity of these subdivisions and structures in outcrop. For instance, the Coricudgy Anticline appears to have no surface expression yet is used as a major structural boundary.

1.51 THE HORNSBY PLATEAU (fig.2):

The Hornsby Plateau was probably first defined (geologically) by Taylor (1923). Taylor regarded the area as having been uplifted 800 feet with the southern margin being well marked by warping. T.L.Willan (1925) using structure contours on the base of the Wianamatta Group superimposed a number of minor anticlines and

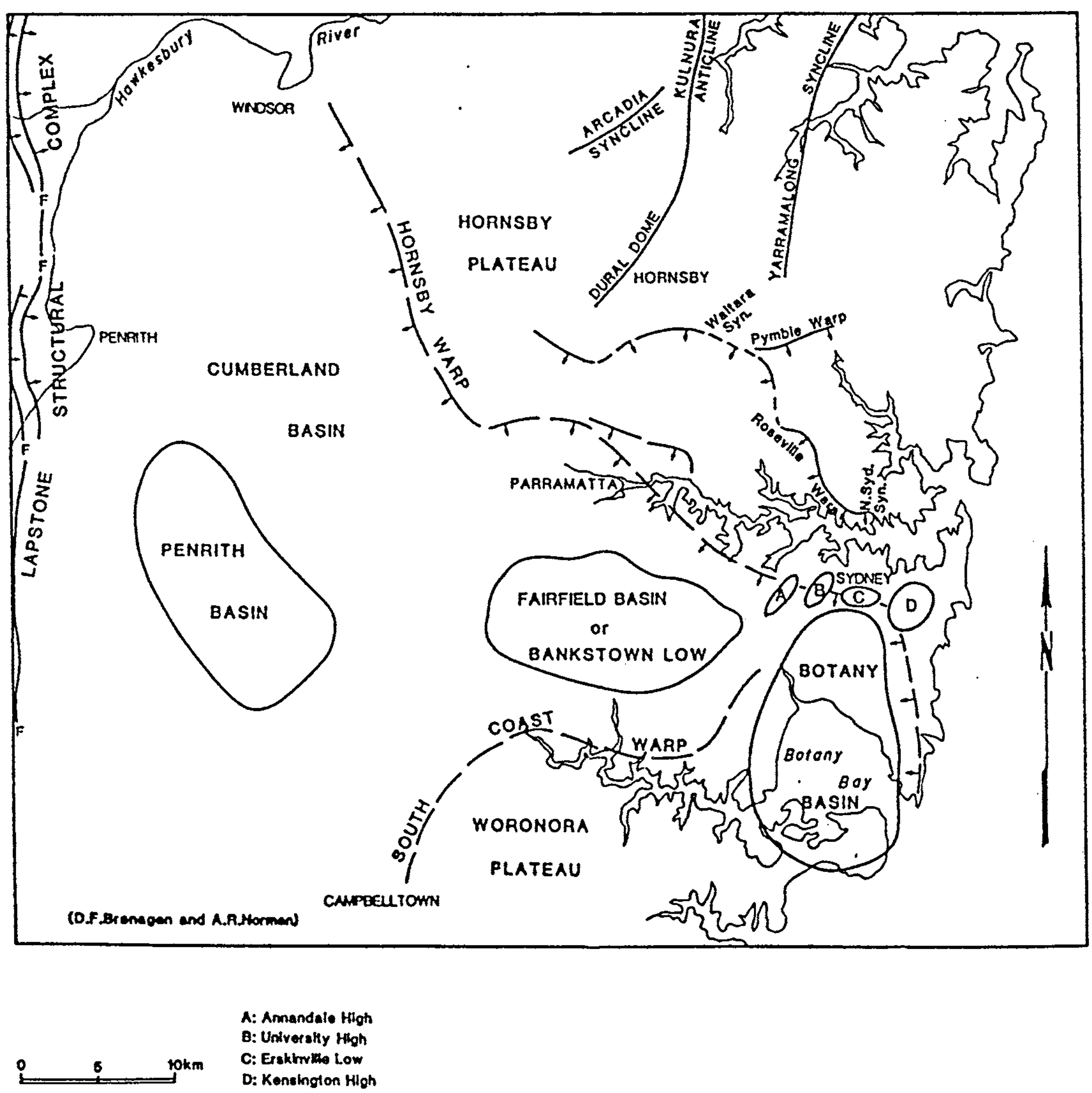


Figure 2. The main structural features of the southern Hornsby Plateau, Cumberland Basin, and Woronora Plateau (Branagan, 1985).

synclines such as the Waitara and North Sydney Synclines on the Hornsby Plateau. Using similar methods Raggatt (1938) defined the Yarramalong Syncline, Kulnura Anticline and Dural Dome, the last being a southern extension of the Kulnura Anticline. While Raggatt's (op. cit.) structures are shown on the Sydney 1:100,000 geology map (Wilson et al., 1983) they were not recognised during the present study due to the small dip of their limbs. Similar small undulations were also recognised by Lovering (1953) north of Willan's (1925) Botany Basin. These features do not appear on the Sydney 1:100,000 geology map and were not recognised during the present study. Figure 2 shows all of the above features and the marginal warps identified during this present study and by Taylor (1923).

Regional jointing and faulting for the Sydney region were first summarised by Osborne (1948). He believed that, 'at least two periods of joint and/fault formation characterised much of the Sydney Basin and that probably rotational stresses have not been responsible for the major systems'. These interpretations do not agree with those of the present study, however they represent the first attempt to analyse fracturing in the Sydney Basin.

Within the Sydney region joint and fault orientation data are often contained in geotechnical reports. Reports by the Snowy Mountains Hydro-electric Authority (1968, 1969a, 1969b) on tunnelling for the eastern suburbs railway were very useful in identifying faults, joint zones and the main joint sets in the Sydney city area. A rose diagram of dykes, faults and lineaments shown on a map in these reports is shown in fig.3. Most dykes in the Sydney city area trend WNW-NW and most lineaments also trend WNW-NW. The tunnelling also revealed that the dominant joint set trends 020-035. These joints dip mostly at high angles (75-80 degrees) to the west although in the Woolloomooloo viaduct easterly dipping joints were also recorded. In this viaduct joints trending 005-020 were also recorded. Other joint sets recorded during tunnelling trend 090-130 (dip 75-80/Nth) and 145-165 with a variable dip. A contoured polar plot of joints in these tunnels is shown in fig.4. At Martin Place zones of close-spaced jointing trend 025 and dip 75-80/W. One of these zones passes under Sydney Hospital. On the corner of Pitt and Hunter Streets there is a normal fault which strikes 016. This fault is also shown in Branagan (1985). South of Woolloomooloo Bay close-spaced jointing, trending 030-035 and dipping mostly to the SE, forms a zone 16 metres wide.

Reports by the Electricity Commission (1982) and Coffey and Partners (1983) were also useful. Coffey and Partners report (1983) on the outfall tunnels at North Head, Bondi, and Malabar contains a summary of joint directions at Long Reef, North Head and Bondi. At North Head they found that the dominant joint set trends 020-030 and dips at high angles to the east and west. At Bondi there are two orthogonal sets trending (010 and 105) and (050 and 335). At Long Reef the jointing is more variable.

South of the Hornsby Plateau on the Woronora Plateau, Wilson et al. (1958) and Bunny (1972) gave a description of faulting and jointing in the southern coalfield which was useful for its comparison with the

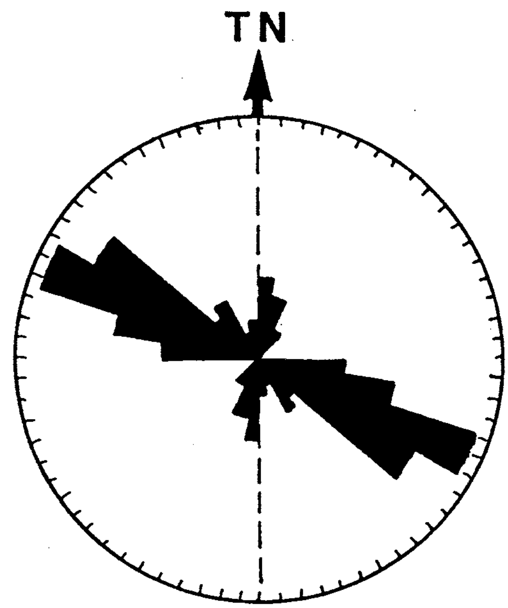


Figure 3. Rose diagram of dyke, lineament and fault orientations in the Sydney city area from reports by the Snowy Mountains Hydro-electric Authority (1968, 1969a, 1969b).

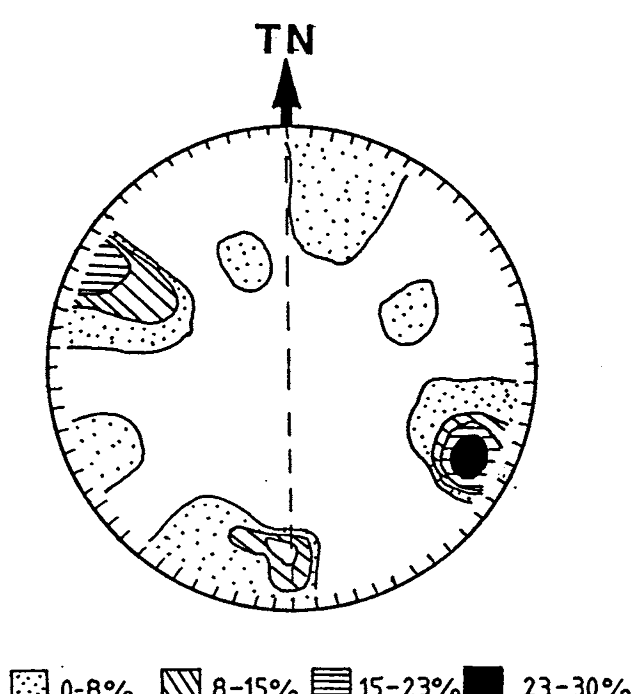


Figure 4. Contoured equal area polar plot of joints and joint zones intersected during tunnelling for the eastern suburbs railway.

Hornsby Plateau. They found that the major faults strike NW-SE and parallel the fold axes in the area. Other faults trend NNE and NE and their bisector is normal to the fold axes. Bunny (op. cit.) also found a good correlation between fault directions and lineament trends and implied that the NE and NNE trends form a conjugate set as a result of folding. There is however no statement on the timing of this compression although Bunny (op. cit.) says that there is a profound relationship between folding and sedimentation. Conjugate faults and lineaments in the coal seams and overlying Narrabeen Group as a result of brittle failure are however incompatible with folding contemporaneous with sedimentation. It seems likely that the structure of the coal basin was affected by undulations in the basement and that folding was superimposed on the undulations as a result of later compression, probably orientated NNE-SSW. Moelle (1977) also carried out joint measurements in the Illawarra area and found two major joint sets orientated 020 and 090.

The zonal nature of faults around Sydney has been discussed by Branagan (1977) and the style and dominant orientations of joint sets are discussed by Herbert (1983) in the notes to the Sydney 1:100,000 geology map. Herbert (op. cit.) points out the significant gaps in joint directions (035-055, 135-145 and 165-180). Norman and Branagan (1984) gave a sequence of tectonic events based predominantly on fracturing in the Ashfield Shale of Sydney. They recognised a regional NNE trending joint set which they suggest resulted from extension over the Basin. The NNE joints were subsequently reactivated to form joint and fault zones. Norman and Creasey (1985) examined the regional fracture systems and fracturing within major deformation zones in the Kuring-gai/Berowra area. The investigations and results of this study in the Kuring-gai/Berowra area are given in chapter two.

Recently, there has been considerable attention given to geological fracture mapping in the western and southern coalfields of Sydney in order to predict bad mining conditions (Shepherd et al., 1978; 1981a; Shepherd and Huntington, 1981). This work led to a lineament interpretation of the Sydney Basin which is published on 1:100,000 structural synthesis maps (Mauger et al., 1984). On the Hornsby Plateau, Mauger et al. (1984) recognised 3 major lineaments, shown on fig.5. They are the ESE trending Berowra Waters Lineament, the Coastal Lineament trending NNE and the Mt. Kuring-gai Lineament trending in a NNW direction. The Coastal Lineament was previously recognised by Scheibner (1976) using landsat imagery. Scheibner (op. cit.) also recognised the Lachlan River Lineament which passes through Sydney and is subparallel to the Berowra Waters Lineament. According to Herbert (1983), the Lachlan River Lineament appears as several parallel lineaments within a 20km zone which is related to an east-west graben-like structure that confines the extent of the Wianamatta Group. Presumably, these lineaments represent faults which were active during or prior to deposition of the Wianamatta Group. Mauger et al. (1984) also undertook minor joint orientation measurements. Balloon density diagrams of these fracture analyses are shown on their Sydney 1:100,000 geology and bedrock fracture trend map.

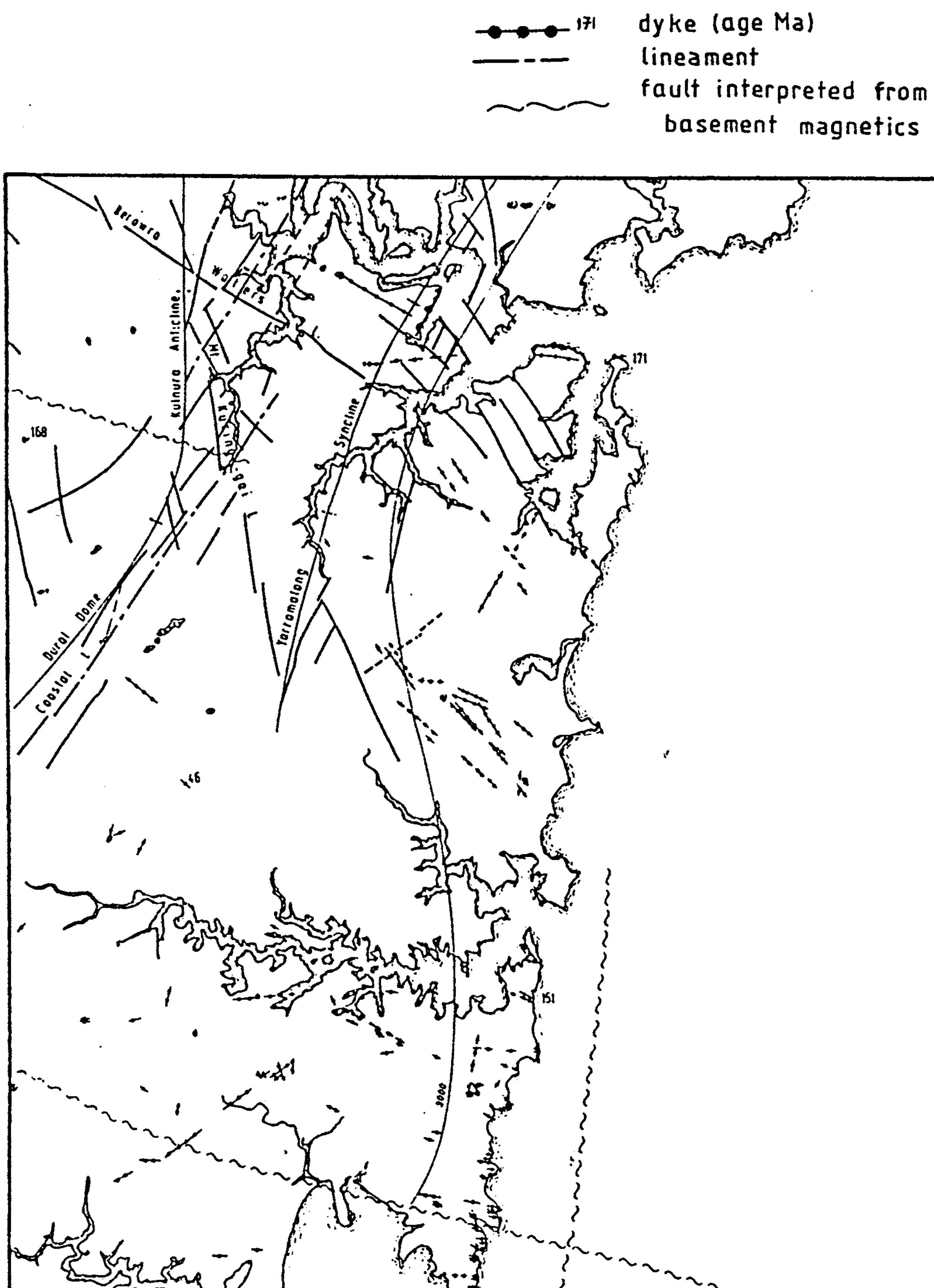


Figure 5. Structural synthesis of the Sydney 1:100,000 sheet (Mauger et al., 1984).

Apart from the regional structural analysis and lineament interpretation by Mauger et al. (1984) there has been no detailed fracture analysis on the Hornsby Plateau prior to Norman and Creasey (1985) and this study. Part of the aim of the present study has been to examine the surface expression of the above lineaments and to determine their origin and the age of their formation. While some joint orientation data are scattered in various reports there has been no previous synthesis of this data nor detailed systematic study of the in-situ structural geology of the Hornsby Plateau.

The Hornsby Plateau forms part of a warped margin around Sydney which includes the Blue Mountains Plateau and the Woronora Plateau. According to Browne (1969) and most early workers, these plateaux were uplifted during the Kosciusko Epoch in Late Pliocene or Early Pleistocene time. However, the timing of this uplift has been questioned by recent workers such as Young (1978), Wellman (1979), Bishop et al. (1982) and Branagan (1985) who believe that uplift was initiated much earlier possibly towards the end of the Cretaceous or Late Palaeocene. It has also been suggested by Stephenson and Lambeck (1985) that there has been continuous uplift since the Palaeozoic. While uplift may have been initiated in the Cretaceous or earlier and continued steadily or periodically until the Pleistocene it is clear that the overall effect was to rejuvenate streams such as the Hawkesbury River and dissect the Hornsby Plateau.

Numerous dykes and breccia vents occur throughout the area and are shown on the Sydney 1:100,000 geological map. Crawford et al. (1980)

have suggested that the breccia vents (diatremes) are associated with Jurassic volcanism. The dating of dykes (Wellman and McDougall, 1974; Embleton et al., 1985) shows that they have a wide range of ages. The Barrenjoey dyke (171 million years, Embleton et al., 1985) is an example of Jurassic volcanism while at Gladesville, a dyke may be only 47 million years old (op. cit.). This indicates that igneous activity probably occurred over a long period of time. Branagan (1985) has suggested possibly 3 significant periods of igneous activity between 207 million years and 14 million years. It is not known to what extent this volcanism has affected the structure of the Hornsby Plateau nor to what extent any pre-existing structures affected volcanism.

Adjacent to the Australian continent in the Tasman Sea, sea-floor spreading is postulated to have occurred between 80 and 60 million years B.P. (Hayes and Ringis, 1973). It is not known to what extent this has affected the structure of the rocks in the Sydney Basin.

Recent studies of earthquakes along the east coast suggest that the Sydney Basin is presently being affected by compressive stress (Gray, 1982; Denham et al., 1985). The precise orientation of this stress is arguable, however it appears to be in a general N-S direction direction. The effect of this stress upon the structure of the rocks in the Sydney Basin is also unknown.

1.52 THE BLUE MOUNTAINS PLATEAU:

Like the Hornsby Plateau, the Blue Mountains Plateau was probably first defined by Taylor (1923) although the first detailed description of the structure and origin of the Blue Mountains was by David (1897). Darwin who travelled across the Blue Mountains in 1836 recognised the easterly dip of the plateau although he thought that the valleys and escarpments resulted from erosion by the sea at the time of deposition of the sandstones (Darwin, 1839). Prior to David (1897), the early explorers and C.S.Wilkinson (1886) thought that the Blue Mountains formed through "violent convulsions within the earth's crust". Wilkinson recognised the displacement between the Blue Mountains and the coast and suggested that this is the result of down-faulting of the coast. David also agreed with this coastal down-faulting and gave a description of the Kurrajong Fault and monocline (David, 1902). David suggested that faulting occurred at the close of the Tertiary epoch. Wilkinson also believed that a fault existed about twenty miles east of the coast which had thrown down the basin beneath the waters of the ocean. A coastal fault has not yet been disproved.

The main structural feature on the Blue Mountains Plateau is the N-S trending Lapstone Structural Complex (Pedram, 1983) consisting of a monocline/fault and a series of parallel faults to the west. Pedram (op. cit.) recognised a number of minor anticlines and synclines to the east of the monocline. To the north in the Macdonald River area, Galloway (1968) also recognised a number of minor flexures to the east of the monocline, although in this area the dip of beds associated with the monocline is only about 10 degrees. Pedram (1983) also observed faults and joints on the monocline. Pedram believed that westerly dipping joints on the monocline are radial tensional joints related to folding. While observations during the present study suggest that not all westerly dipping joints on the monocline are tension joints Pedram's (op. cit.) observations are important for an overall structural synthesis.

To the west of the Lapstone Structural Complex the only significant flexure is the subparallel Tomah Monocline (David, 1902; Goldbery, 1969 east of which rapid thickening of the Permian Illawarra Coal Measures occurs (Bembrick et al., 1973). This monocline extends from the Colo River south to the Camden-Picton area and probably developed contemporaneously with sedimentation. Likewise, the monoclinal part of the Lapstone Complex may have originated as one of Bembrick's "hinge lines". Qureshi (1984) and Harrington and Korsch (1985) have also suggested that the Lapstone Monocline is related to a large basement structure. This structure may have been active during sedimentation and been subsequently reactivated. Subparallel structures such as the Tomah Monocline probably have a similar origin.

Jointing on the Blue Mountains Plateau was first documented by Branagan (1960) who also commented on the effects of basement structures on the sedimentation and structure of the coal basin. Recent fracture mapping in the coal mining districts of the western coalfield in order to predict bad roof conditions by Shepherd et al. (1978, 1981a) and Shepherd and Huntington (1981) found that there was a correlation between bad mining conditions in the Lithgow and Katoomba Seams and surface joint zones and lineaments in the overlying Triassic sandstones. This work led to 1:100,000 lineament interpretation maps and notes being produced (Mauger et al., 1984). A lineament summary of the Katoomba, Wallerawang, Mount Pomany sheets is shown in fig.6. Mauger et al. (1984) recognised that the dominant lineament and joint trend was NNW, while the most extensive traces, often forming major lineaments, trend N-S to NNE. Major basement anomalies and linear trends interpreted from a BMR-CSIRO aeromagnetic survey and basement/basin fracturing mapping by Mauger et al. (1984) show that there is a good correlation with NNE and N-S lineaments. The NNE trending Blackheath Lineament was mapped by Mauger et al. (1984) to extend into the basement and parallel basement fold axes. ESE and ENE lineament trends also parallel basement structures within the Lachlan Fold Belt. The Gospers Mountain Lineament is coincident with an ENE trending structural zone in the Devonian basement (Mauger et al. 1984). ESE lineaments parallel the Lachlan River Lineament (Scheibner, 1976) along which the Carboniferous Bathurst Granite has intruded and the Silurian Capertee High (Packham, 1969) may have been dextrally offset. To the south, at Yerranderie, ESE trending lineaments form dominant traces (Mauger et al., 1984) and one of which, the Yerranderie Lineament, appears to have influenced mineralisation (Jones et al., 1977).

At Ulan, about 20 kilometres north of Mudgee, Johnstone et al. (1983) also found a correlation between joint systems in the Permian coal measures and Triassic sediments and the underlying Carboniferous granite. The dominant joint trends at Ulan are ENE and NNE (op. cit). In the southern Sydney Basin joint and lineament orientations in the cover rocks were found by Cudahy et al. (1985) to be similar to

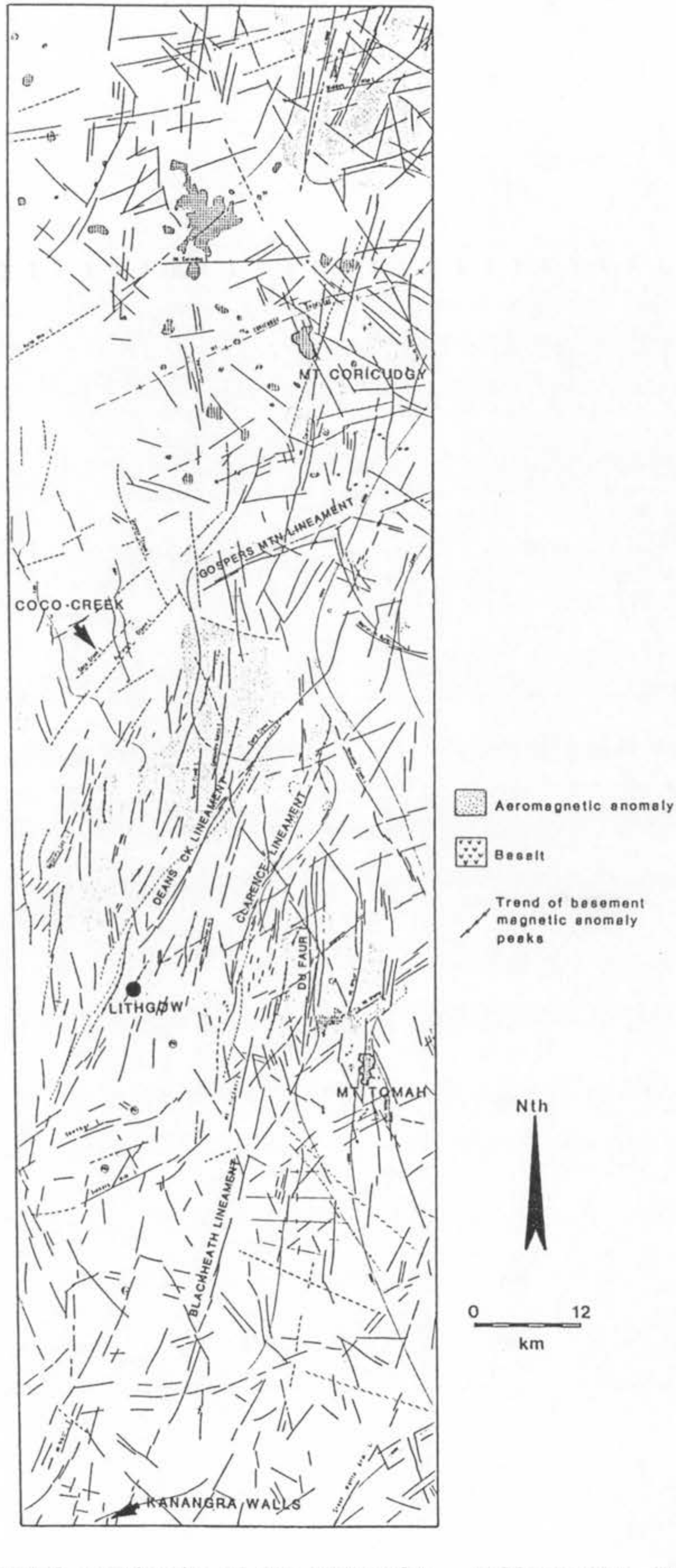


Figure 6. Structural synthesis of the Katoomba, Wallerawang, and Mt. Pomany 1:100,000 sheets (Mauger et al., 1984).

mesoscopic kink and megakink orientation in the basement.

Ironstone and goethite veins within NNW trending joints in the Western Coalfield have been studied by Creasey (1984). The ironstone has been highly stressed during a NW directed compression. Creasey and Huntington (1985) suggest that this deformation and the lineament pattern in the Sydney Basin can be related to a regional sinistral shear couple that was probably active during the upper Cretaceous. Evans and Roberts (1979) proposed a NNW dextral shear couple for central eastern Australia up to the mid Triassic and a reversal of this shear couple since the Late Triassic.

Within the study areas there are few post Triassic intrusive rocks. Basalt capping of hills is common on the Blue Mountains, however it is not known whether the distribution of basalt is structurally controlled. Between Mount Coricudgy and Putty breccia necks and basalt caps are very common and may be related to deep seated structure. It is generally considered that the breccia vents are Jurassic in age and the basalts are Tertiary in age (Crawford et al., 1980). However, at Cherry Tree Hill a breccia intrudes a basalt indicating that some breccia vents may be Tertiary (Bradley et al., 1984). The Mount Tomah basalt has been dated at 14.6 Ma (Wellman and McDougall, 1974) and lies close to the deep gorge of the Grose River which may suggest that erosion of the gorge has occurred primarily after extrusion of the basalt. However, Bishop et al., (1982) and Young and McDougall (1986) have pointed out that the Blue Mountain basalts could have been extruded at high level, upstream from the gorge heads. The lack of stream gravels preserved under most of the Blue Mountains basalts tends to support this hypothesis.

CHAPTER 2

THE KURING-GAI/BEROWRA AREA

2.1 LOCATION AND ACCESS (fig.7)

The study area covers 420 square kilometres from Berowra Waters in the north to Hornsby in the south and from Maroota in the west to the eastern coastline. The western portion of the area lies within Kuring-gai National Park and Mougamarra Nature Reserve. Access to the National Park and Nature Reserve was along ridgetop firetrails. Permission to use four wheel drive vehicles along these firetrails was granted by the National Parks and Wildlife Service.

Along the eastern coastline, access to the rock platforms was by foot.

2.2 GEOLOGICAL SETTING

The Kuring-gai/Berowra area is situated on the central Hornsby Plateau within the Sydney Basin (Taylor, 1923). The Hornsby Plateau (fig.2), which rises north of Sydney, dips between 1 and 2 degrees to the south. This dip approximates the dip-slope of the Hawkesbury Sandstone in the area. In the Kuring-gai/Berowra area the Hawkesbury River and its tributaries have dissected the plateau to form a rugged landscape.

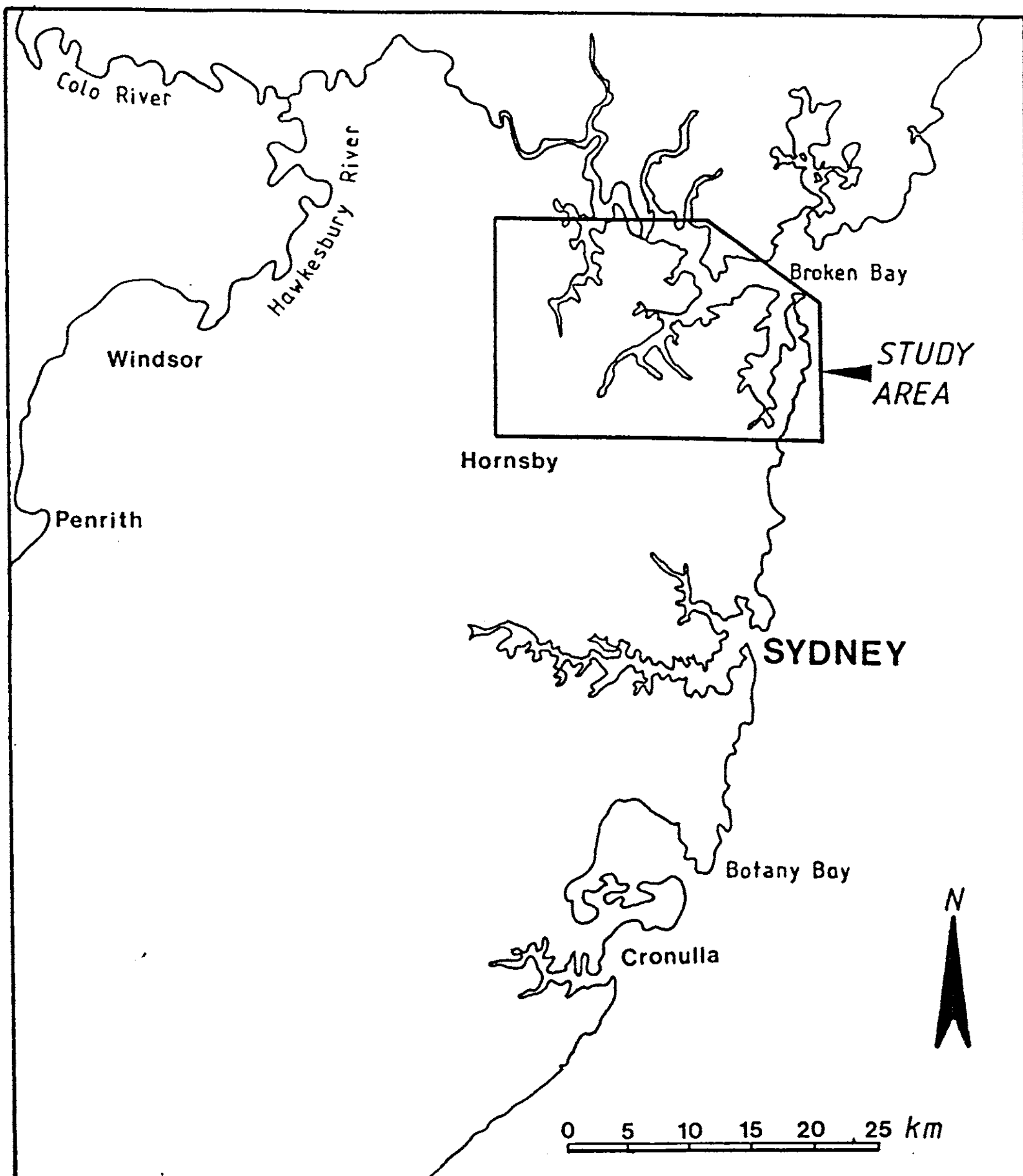


Figure 7. Location of the Kuring-gai/Berowra study area.

The Triassic Hawkesbury Sandstone outcrops throughout much of the area and consists of medium to coarse-grained quartz sandstone with minor siltstone lenses. Within the Hawkesbury Sandstone there are two contrasting sandstone facies. These facies are well exposed in the study area and are designated the 'sheet-like' facies (crossbedded) and the 'massive' facies (Conaghan and Jones, 1975). The Hawkesbury Sandstone is overlain by thin beds of siltstone and sandstone which belong to the Mittagong Formation. This formation is not well exposed in the study area. The Triassic Mittagong Formation is conformably overlain by the Ashfield Shale which is the lowermost formation of the Wianamatta Group and consists predominantly of grey siltstone with sandstone laminae. The Mittagong Formation and Ashfield Shale outcrop on the ridgetops. Triassic Narrabeen Group sandstones and siltstones belonging to the Newport Formation underlie the Hawkesbury Sandstone and are well exposed around the coastline and the Hawkesbury River valley. The Bald Hill Claystone which underlies the Newport Formation and consists predominantly of red and green siltstone outcrops along the coast between Mona Vale and Bigola.

The north-south trending Yarramalong Syncline and Kulnura Anticline, the Dural Dome (Raggatt, 1938), the Arcadia Syncline (Willan, 1925) occur on the Hornsby Plateau. These features were defined using structure contours on the base of the Wianamatta Group. They represent minor undulations and probably owe their formation to movements contemporaneous with sedimentation.

The Hawkesbury River and its' tributaries deeply dissect the Hornsby

Plateau in the study area. The dissection of the Plateau is due in part to rejuvenation of the streams as a result of uplift; however, as mentioned in section 1.51 the timing of this uplift is uncertain. It is also not known to what extent fluctuations in sea level have played in retarding or assisting down-cutting by these streams.

Apart from the possible southward tilting of the Hornsby Plateau the only indications of post-depositional deformation in the study area are mesoscale joints, minor faulting, dykes and breccia vents. A study of these features is an important part of a structural analysis in a relatively undeformed area and will be discussed in detail in the next section.

Numerous dykes and vents occur throughout the area and many are shown on the Sydney 1:100,000 geological map (Wilson et al., 1983). Additional intrusions have been mapped during this study.

2.3 AERIAL-PHOTO INTERPRETATION

The first stage of the study in the Kuring-gai Berowra area was the interpretation of photo-linear features on 1:40,000 black and white airphotos and 1:16,000 colour airphotos. These linear traces were divided into 3 orders of decreasing importance. They are ;

(1) fracture traces

(2) vegetation traces

(3) drainage traces.

Fracture traces include visible joints and faults, and are the most reliable of the linear features.

Vegetation traces are usually regarded as poor indicators of fracture pattern; however, in the Kuring-gai/Berowra area vegetation is often well developed along open joints. Angophora trees grow along cracks in search of water, so that in the field and on airphotos these trees often follow a joint trace. Dykes are well defined by vegetation changes. Ceratopetalum gummiferum (Christmas Bush) preferentially grows on the more fertile soil of weathered dykes and forms a distinctive trace in the field and on airphotos.

Gullies, creeks and river bends also may reflect the regional fracture pattern; however, in the study area it was common for large and small structures, such as the Berowra Waters Lineament and a NNE trending fracture zone at Bobbin Head to have little, if any, topographical expression. Therefore, drainage traces were less reliable indicators of fracture pattern than fracture or vegetation traces and are considered 3rd. order, that is, of least importance.

The airphoto traces were compiled onto 1:25,000 maps and reduced to produce a 1:50,000 regional lineament map (fig.8, in back pocket). An analysis of photo linear azimuths (fig.9) shows that the dominant trace direction is NNE-NE. A subdominant trace set trends E-W and there is a minor ESE trace set. While NNE-NE traces are more common and widespread than other traces, ESE traces are the longest.

The major lineaments of airphoto traces recognised during the present study are summarised in fig.10. ESE vegetation traces form a continuous lineament between Maroota and Kuring-gai which is called the Berowra Waters Lineament. Fracture traces also occur along and adjacent to this lineament, although they are only minor.

The NNE-NE traces occur throughout the study area. NNE trending drainage traces are particularly common in the vicinity of the Coastal Lineament which was identified by Mauger et al. (1984). However, these traces do not form an extensive trace or lineament in the area. In addition to further delineating the Berowra Waters Lineament, the present investigation recognised a NNE trending lineament of fracture and vegetation traces between Terrey Hills and West Head, this lineament is called the West Head Lineament (Norman and Creasey, 1985) and is shown in fig.10.

The NNW trending Mt. Kuring-gai Lineament which was recognised by Mauger et al. (1984) using Landsat imagery and small scale airphotos was not recognised during the present airphoto study. This shows that at different scales of study there will be different lineament interpretations.

The Sydney 1:100,000 geology map shows dykes trending in an ENE to E-W direction between Cowan and West Head. These dykes were easily recognised by vegetation changes which form an almost continuous onshore trace between these localities. An examination of fracturing associated with these dykes is contained in section 2.43.

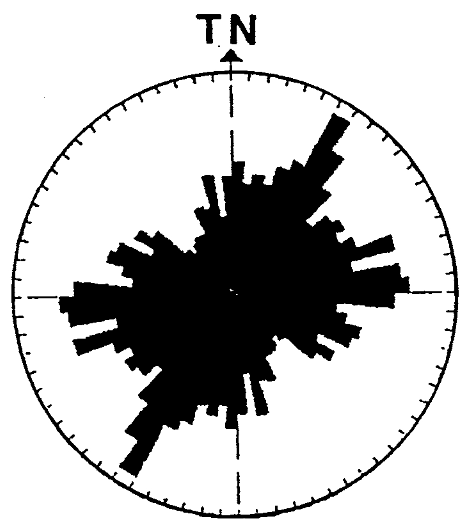


Figure 9. Rose diagram of photo linear azimuths.

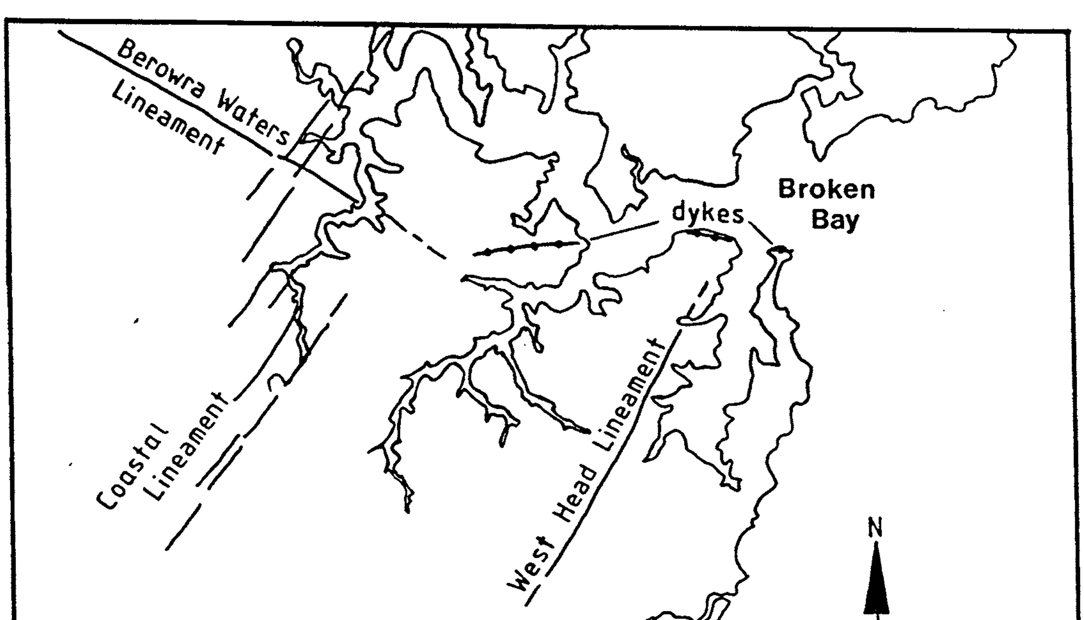


Figure 10. Lineament summary of Kuring-gai/Berowra area.

Following airphoto interpretation, a field analysis was undertaken in order to define the regional fracture pattern and to determine the nature of the above lineaments. Fifty nine sites were examined in the Kuring-gai/Berowra area. The location of these sites is shown in fig. 11.

2.4 SITE INVESTIGATIONS

The following outcrop descriptions are given in detail to describe the fracture characteristics of major structural trends in the Kuring-gai/Berowra area. Four main trends have been recognised and are ; WNW-ESE, NNE-SSW, ENE-WSW and NW-SE. A coastal domain is also recognised and is discussed separately. While not all localities are discussed in detail in this section, a list and summary of all localities can be found in appendix A and a summary of the fracture pattern is shown on the map in the back pocket (fig. 12).

The use of fracture architecture to determine age relationships is discussed in section 1.4 and this procedure has been used to interpret the structural history in section 2.5. The use of conjugate fractures and joints to interpret the direction of maximum compressional stress, σ_1 , at their formation (Price, 1966) is also important and has been discussed in section 1.4.

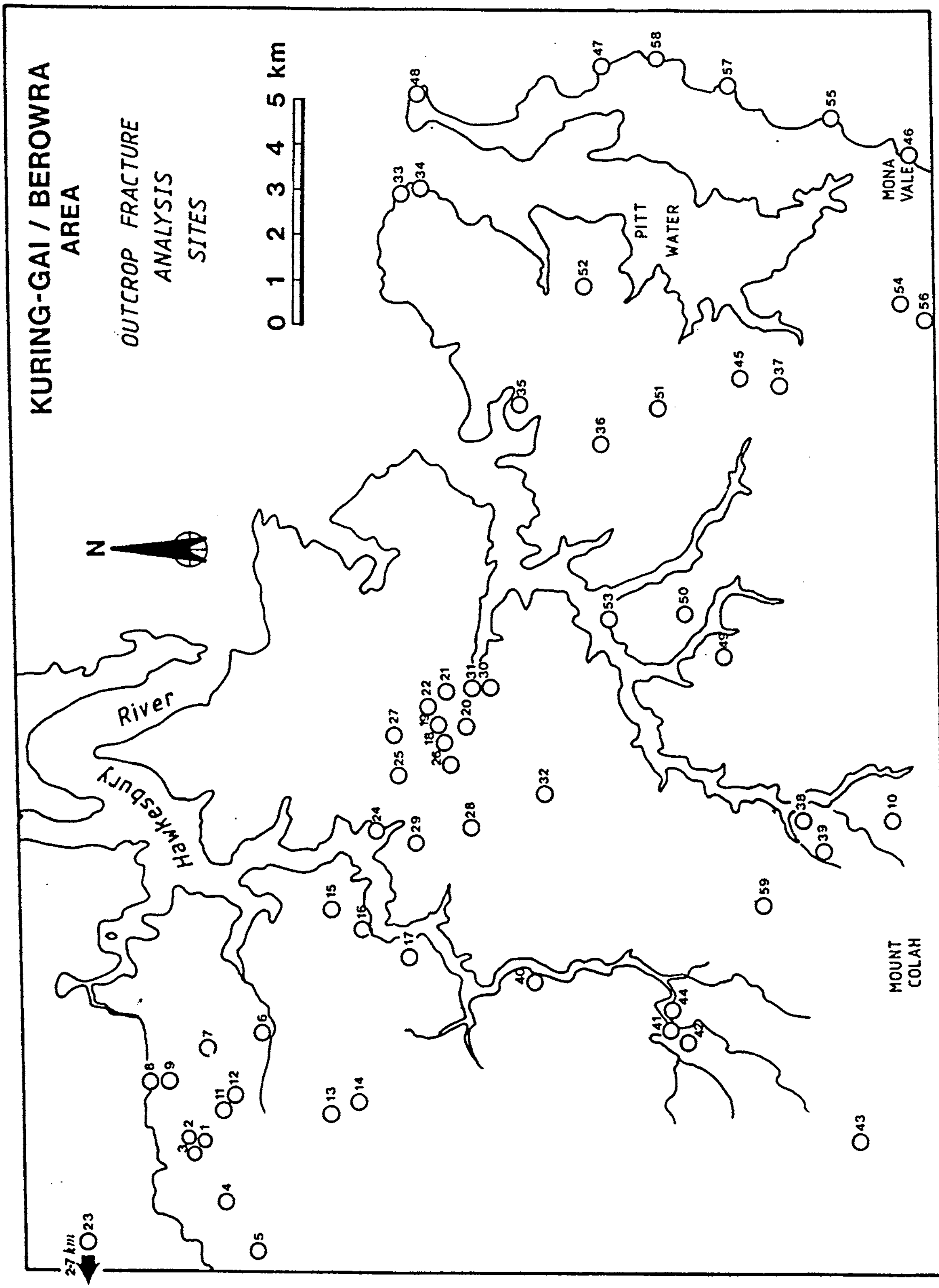


Figure 11. Outcrop fracture analysis sites.

2.41 WNW TRENDING STRUCTURES:

A. The Berowra Waters Lineament:

This Lineament trends 300 degrees and was first recognised by Mauger et al. (1984) using 1:100,000 airphoto interpretation. The Lineament extends for 42 Kilometres from the lower Colo River to the Mougamarra Ridge and is 0.5 to 2.5 kilometres wide.

The Berowra Waters Lineament was recognised during the present study by vegetation traces on airphoto and was examined at 8 localities. These localities are 1, 2, 3, 6, 11, 12, 16 and 29 (figs 11 and 12). In the study area the Berowra Waters Lineament trends in an ESE direction for 38 kilometres from Maroota to the Newcastle expressway and is shown in fig. 10. Similar trending joint/fault zones examined on the coast and linear features on the lower Colo River may also be an expression of this lineament.

An analysis of fracturing at the above localities, along the Berowra Waters Lineament, showed that the Lineament is defined by a prominent master joint set trending ESE which is coincident with the lineament interpreted from airphoto. Fig.13 shows a polar plot and rose diagram of fracturing at these localities.

The ESE trending joint set is generally close spaced (1m), planar, zonal and is restricted to a 40 metres wide zone about the lineament. Away from the lineament ESE trending joints or faults are rare although ESE trending joint zones do occur at West Head and on the coast and may be related temporally to this Lineament.

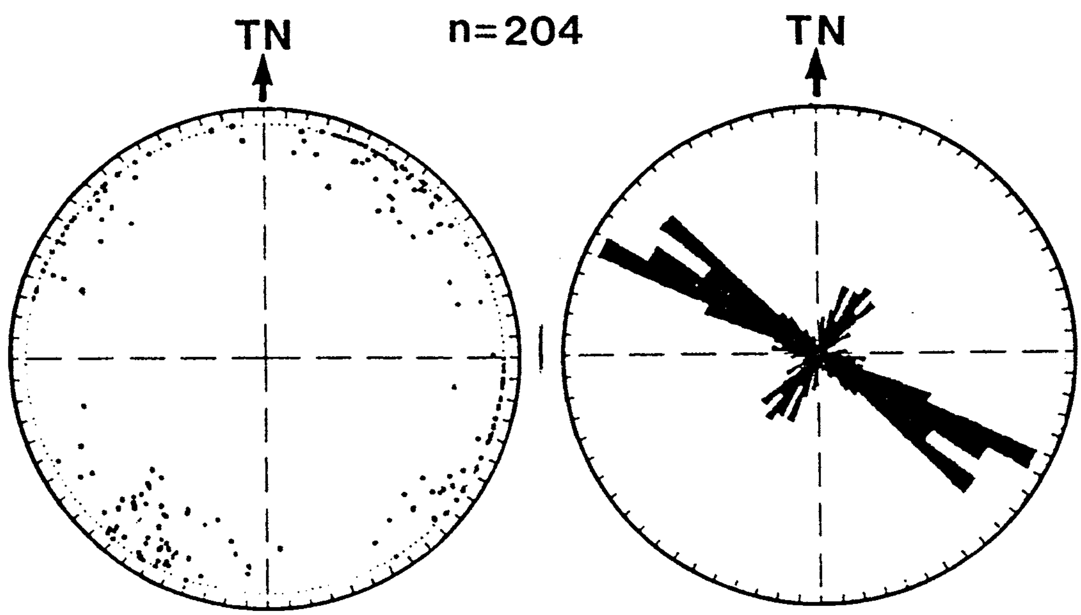


Figure 13. Equal area polar plot and rose diagram of fracturing along the Berowra Waters Lineament.

The internal structure of part of the Lineament is revealed in a small road cutting at locality 6 and is shown in fig. 14. The section shows a 5 metre wide zone of intense, steeply dipping conjugate fractures and joints and the abrupt boundary between the relatively undeformed Hawkesbury Sandstone adjacent to the lineament. In addition to the conjugate joints dipping to the north and south.the fracture zone contains horizontal slickensides on ESE trending vertical joints.

A thin, highly weathered dyke occurs on the northern side of the section with an adjacent silicified and ferruginised zone up to 1 metre wide (fig. 14). Sub-horizontal and vertical slickensides occur on the dyke wall and on adjacent conjugate fractures. This section shows that the intense fracturing is asymmetric to the dyke and that multiple deformation has occurred within a narrow zone, subsequent to dyke emplacement.

A polar plot of joints (fig. 13) shows that a number of ESE joints dip at high angles to the north and south.These dipping joints were observed to be conjugate with a sub-horizontal intersection. Some ESE vertical joints varied in strike around a mean trend. This may suggest that conjugate joints with a sub-vertical intersection exist within the lineament, although they were not observed in the field. That is, both vertical and horizontal conjugate joints exist within the Lineament.

NNE to NE trending joints occur within and adjacent to the lineament and are generally planar and vertical. NNE joints are wider spaced

Figure 14. A zone of intense fracturing within the Berowra Waters Lineament (Locality 6).

and less extensive (horizontally) than the ESE joints and generally cut through or terminate against the ESE joints. However, in a few cases, ESE joints do terminate against NNE-NE joints. While ESE joints and faults are usually restricted to this Lineament and not developed regionally, NNE to NE trending joints occur throughout the study area not just within the Berowra Waters Lineament.

Dykes exist along most of the length of the Lineament making it easily recognisable by the change in vegetation. At locality 4, a dyke contained slickensided surfaces. These slickensides dipped at low angles and revealed 2 directions of sub-horizontal movement. One was directed from the east (076-105) to the west and the second from the SSW (207-209). No overprinting of slickensides was observed and the age of the dyke is unknown.

B. St. Michaels Cave:

ESE trending joints, joint zones and faults are generally restricted to the Berowra Waters lineament. However, along the coast there are some similar trending features. At St. Michaels Cave (Loc.No.58), north of Avalon Beach, large (20m) planar master joints trend in an ESE direction (115-121). St. Michaels Cave is probably the result of weathering of a breccia dyke (Crawford et al., 1980). This breccia contains large subrounded fragments of siltstone and sandstone up to 20cm in diameter which Crawford et al. (op. cit.) suggested collapsed into a fissure that could have been a feeder dyke to a diatreme; however, Hamilton (pers comm.) has pointed out that the breccia contains coked coal and is probably part of a plastic dyke. The dominant ESE joint set is parallel to this dyke. These joints are closely spaced adjacent to the dyke; however, the intensity of jointing decreases to be almost non-existent only 20 metres away from the dyke. Zones of intense fracturing up to 1.5m wide which parallel the dyke are contained between the master joints. These fracture zones contain cross-cutting conjugate fractures whose intersections are both horizontal and vertical (fig.15). This fracturing is best developed in a silicified lithic sandstone and is almost absent within the breccia. This may indicate that the breccia emplacement occurred subsequent to shearing, however, the lack of fracturing within the dyke may also have resulted from a difference in the brittle behaviour of the two rocks.

Apart from joints parallel to the dyke, the other dominant joint sets at St Michael's Cave trend NE (046-056) and NW-NNW (167-183). NE joints are planar and cross-cut the ESE joints. The NNW joints, however, terminate against the NE joints.

At St. Michaels Cave NNE trending joints which are common elsewhere are almost absent, except for small (<1m long) fractures. These fractures have a sigmoidal shape in horizontal plan and resemble tension gashes in more deformed regions.

2.42 NNE TRENDING STRUCTURES:

A. The Coastal Lineament:

The Coastal Lineament was first recognised by Scheibner (1976) using Landsat imagery. Mauger et al. (1984) further defined the Lineament

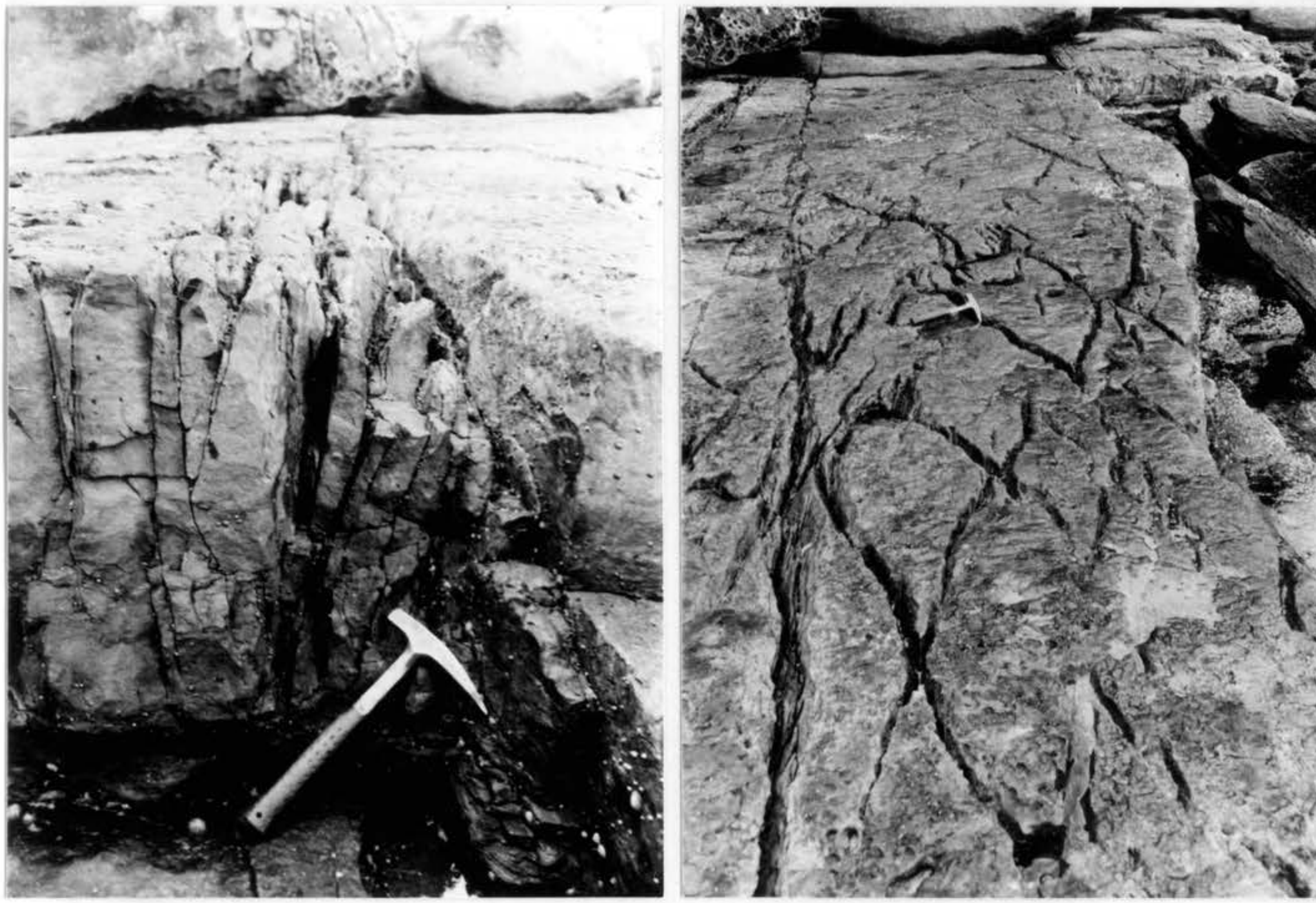


Figure 15. Conjugate joints and fractures adjacent to St. Michaels cave (Locality 58).

using small scale airphoto interpretation. They found that the Lineament parallels the well developed NE trending airphoto fracture traces in the area and has a left lateral step which coincides with the deflection of the Kulnura Anticline (fig.5). However, prior to this present study there has been no correlation of these small scale observations with outcrop fracture mapping.

In the Kuring-gai/Berowra area the Coastal Lineament is recognised by a number of NE-NNE trending drainage features. These features do not form a continuous linear pattern, but a rather poorly defined zone about 1 kilometre wide. The left lateral step of the Lineament, previously recognised by Mauger et al. (1984) using small scale airphotos was not evident during the present study using a larger scale of observation.

An analysis of fracturing within the Coastal Lineament at localities 40, 41, 42, 43, and 44 reveals that the Lineament consists of closely spaced (0.5-1.0m) planar NNE trending master joints. Orthogonal WNW trending joints form a subdominant set and terminate against the NNE joints. NNE trending joint zones, some of which contain breccia and conjugate fractures, are common. At Loc. 41 the Coastal Lineament contained NNE trending sigmoidal fractures in vertical section. These fractures are shown in fig.16. Fig.17 shows a polar plot and rose diagram of fracturing within the Lineament at the above localities.

At Bay Road, Berowra Waters (Loc.40), a section through the Lineament was mapped. This section (fig.18) revealed that joint zones less than

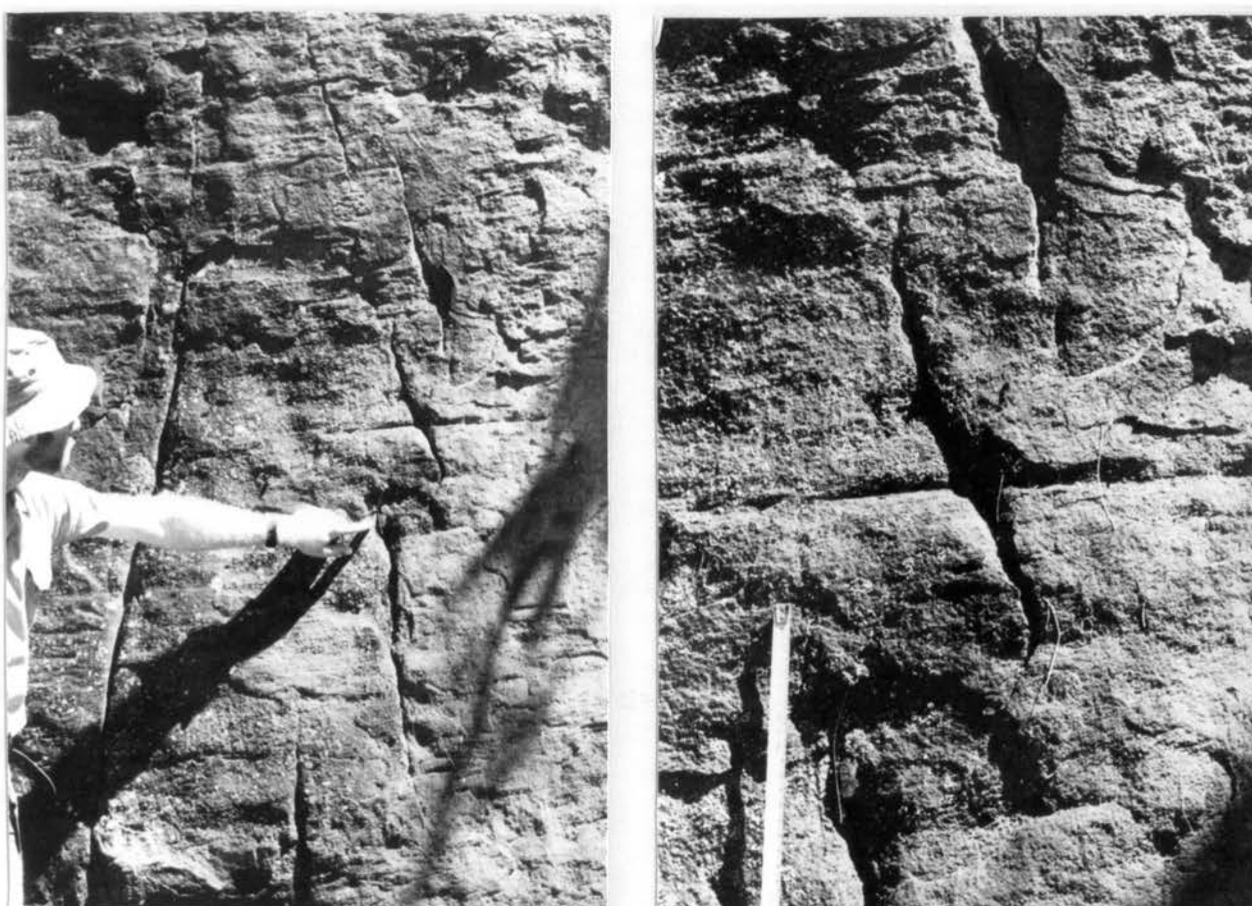


Figure 16. Sigmoidal fractures within the Coastal Lineament (Locality 41, Crosslands Convention Centre).

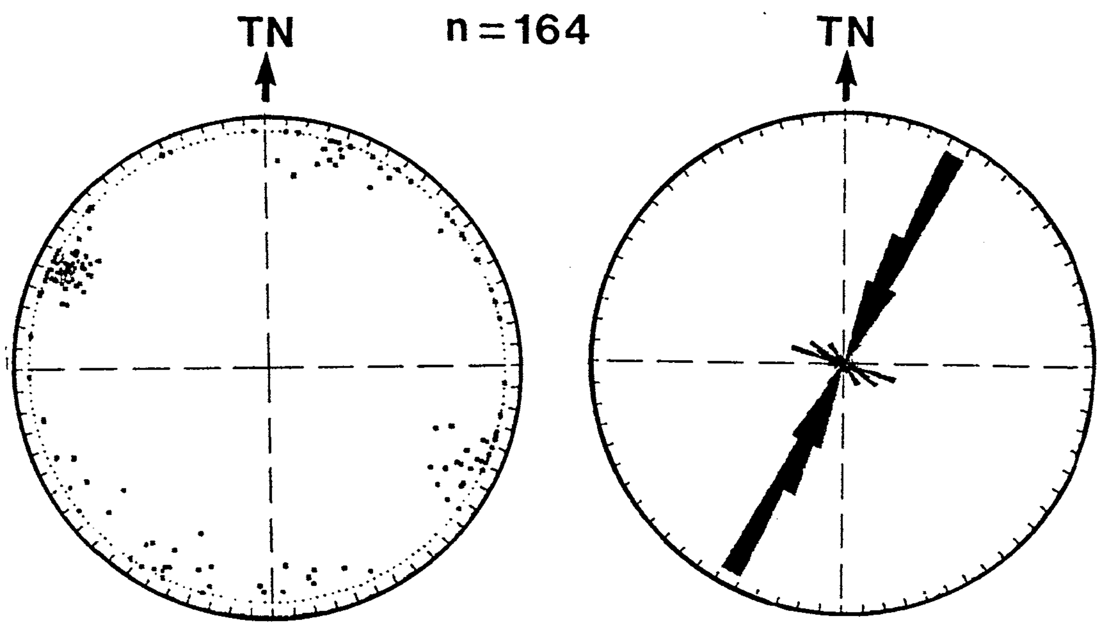


Figure 17. Equal area polar plot and rose diagram of fracturing within the Coastal Lineament.

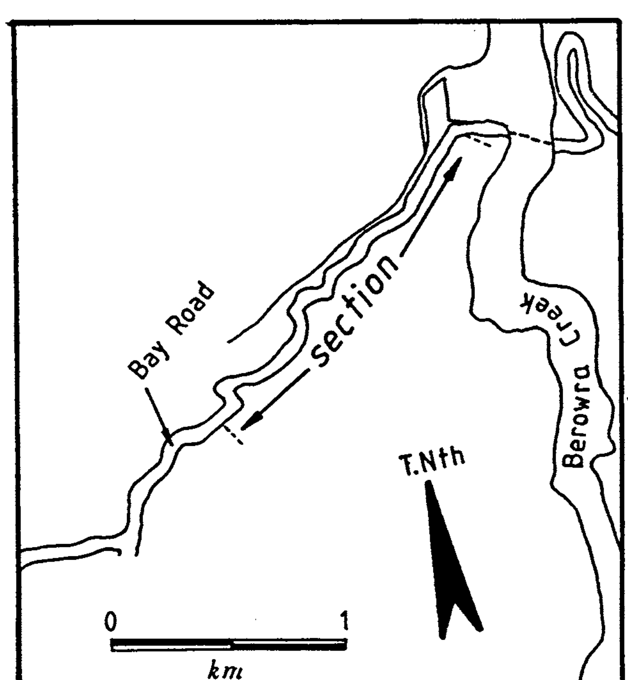


Figure 18. Location of the Bay Road section (Locality 40).

1 metre wide, containing intense fracturing and minor normal faulting, are subparallel to the Lineament. Fig.19 shows a cross-section of the section mapped along Bay Road. The dominant joint set trends NNE (018-033) and has spacing less than 1 metre. These joints are planar and horizontally more extensive than other joints at the locality. Most NNE joints are subvertical, however some do dip at high angles to the SE.

Within some NNE joint zones low-angle conjugate fractures were observed (fig.21). These fractures indicate that a perpendicular (ESE-WNW) lateral compression has taken place within these NNE zones. Since these conjugate fractures are confined within the NNE joint zones, this ESE compression probably occurred subsequent to the formation of NNE joints and zones. Normal faulting with displacement up to 10cm is also associated with the NNE zones. This indicates that tension has also taken place within these zones.

WNW trending joints, orthogonal to the NNE joints, form a subdominant set at Bay Road and generally terminate against the NNE joints. NW trending joints are only minor along Bay Road and no terminations of NW joints against NNE trending joints were observed.

B. Bobbin Head Road Structure:

A NNE structure was mapped along Bobbin Head Road (Loc.10, figs 11 and 22). Although not within the broad Coastal Lineament, this subparallel structure is probably congruent with the Lineament. The Bobbin Head structure extends for over 2 kilometres from Cowan Creek

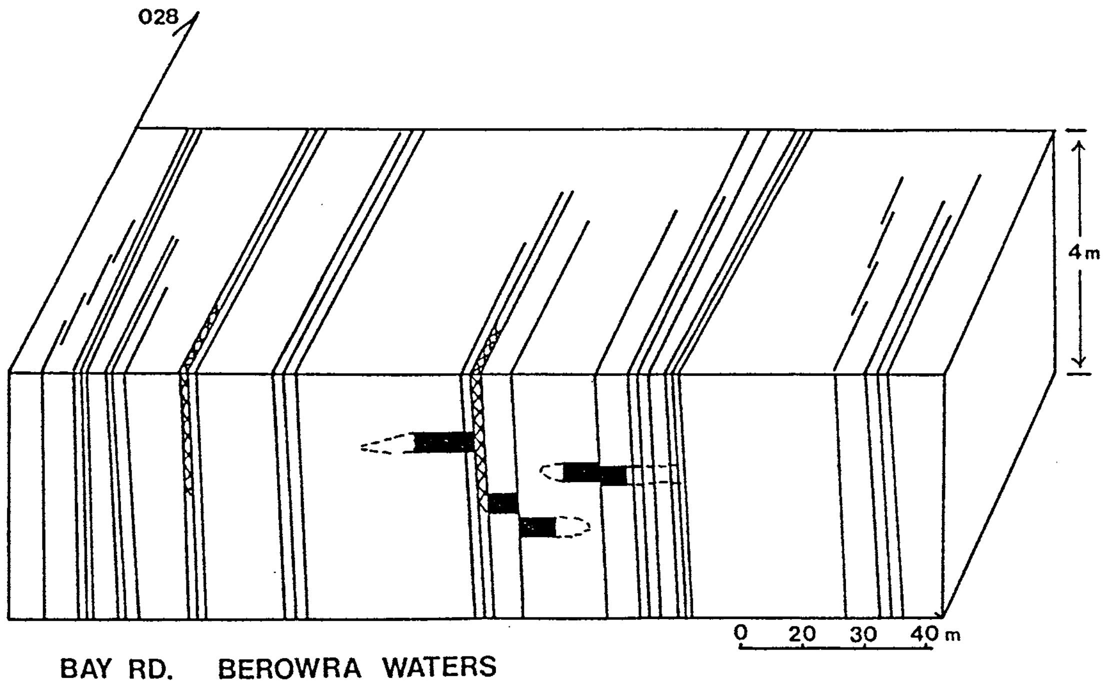


Figure 19. Cross-section along Bay Road (Locality 40) within the Coastal Lineament.

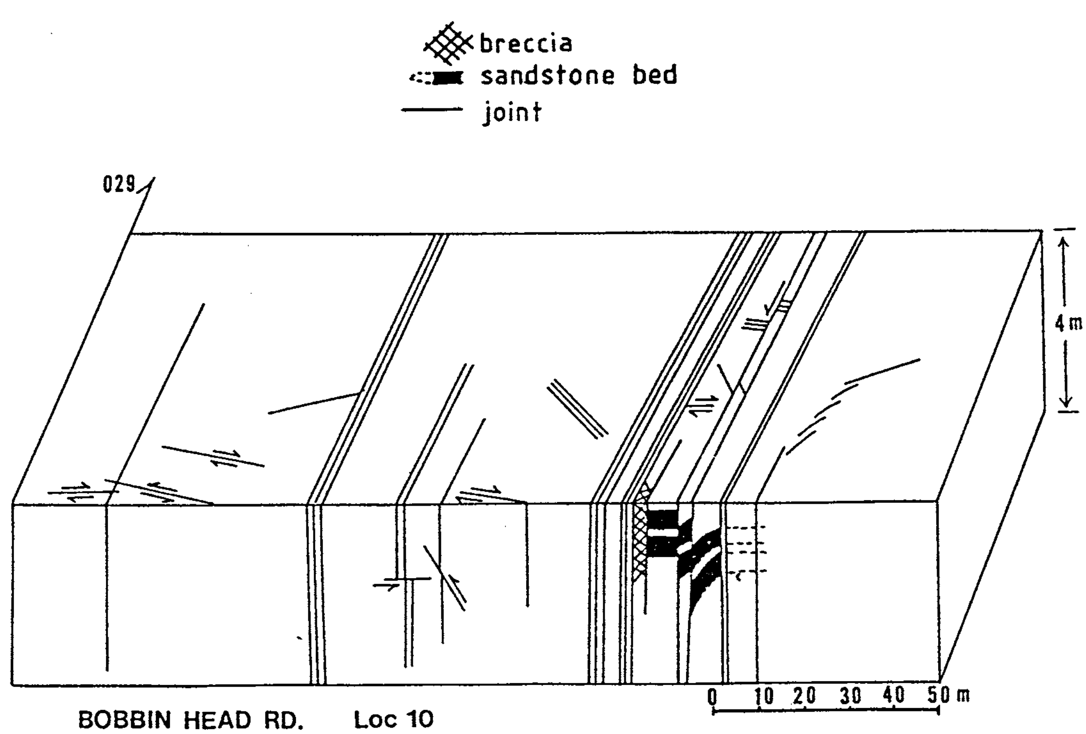


Figure 20. Cross-section along Bobbin Head Road (Locality 10).

Figure 21. Low angle conjugate NNE trending frctures within NNE joint zone at Bay Road (Locality 40).

to North Turramurra. At Cowan Creek, the structure is marked by a metre-wide weathered dyke trending 024. There is little fracturing associated with this dyke. North of Turramurra, along Bobbin Head Road, the NNE trending structure consists of a 40 metre wide zone in which there are close-spaced NNE master joints, intense fracturing, faulting, minor horizontal slickensides and brecciation. A cross-section of the Bobbin Head road section (fig.20) shows the intensity of jointing in this structure.

The dominant joint set trends NNE and there is a subdominant set of orthogonal ESE trending joints which either cut through or terminate against the NNE joints. One ESE joint near a fault towards the centre of the structure was observed to curve and step as it approached a NNE joint until its strike was almost NNE. Hancock (1985) would classify this as an extension joint. Horizontal slickensides were also observed on a number of vertical joint faces trending 090 to 100. This would suggest that shearing has taken place along these ESE joints. The relationship of this lateral movement to other joints was not determined.

Fig.23a shows folded beds adjacent to a fault towards the centre of the structure. This fault strikes 028 and dips steeply (75 degrees) to the west. Joints and master joints parallel the fault and decrease in intensity away from the fault. For a distance of 2 metres on either side of the fault intense fracturing is confined between vertical planar NNE joints. This fracturing consists of fractures up to 0.5 metres long and perpendicular to bedding. The fractures

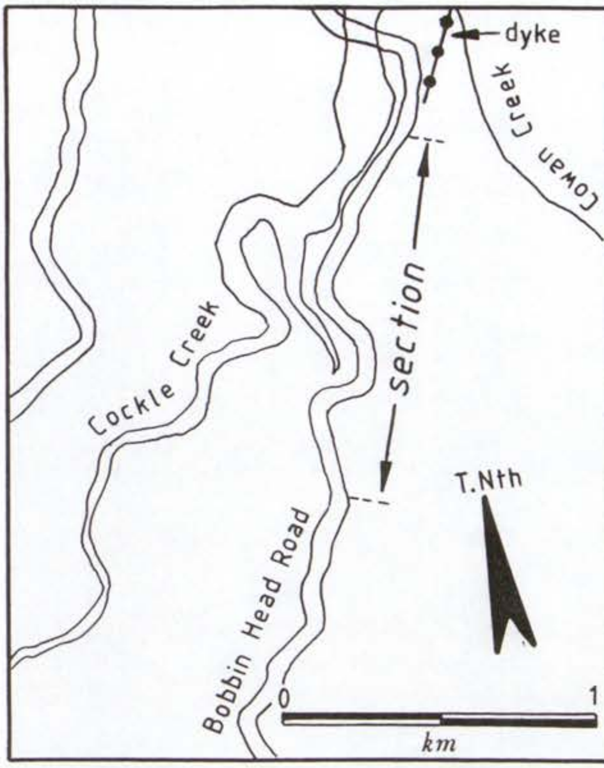


Figure 22. Location of the Bobbin Head Road section.

ESE——WNW

Figure 23a. Folded beds adjacent to a fault within a NNE fracture zone at Bobbin Head (Locality 10).

increase in dip towards the fault as the dip of the beds increases (fig.23b) and may be regarded as radial a-b tension fractures which resulted from folding of the beds during faulting. The fracturing may also have existed prior to faulting and has been subsequently rotated. If this is the case, the fracturing may have formed in a shear zone in which normal faulting later took place.

Some NNE joints contain ironstone fill up to 2cm wide. In places, this fill is in the form of pisolites. This suggests that the joints were dilated prior to infilling which allowed for the development of pisolites. The pisolites are undeformed and may have developed subsequent to deformation in the area. The iron fill thickness appears to decrease rapidly away from the present land surface. This suggests that the age of the pisolites is related to the formation of the present landscape.

NW trending joints and joint zones (0.51.0m wide) exist within and adjacent to the NNE Bobbin Head Structure. NW joints are planar, vertical and less common than NNE or ESE joints.

Brecciation is common along the road section within the NNE structure and is usually confined between bedding planes. This suggests that bedding plane thrusting has taken place within the above NNE zone. One NW trending joint zone shown in fig.24 appears to be displaced horizontally along a bedding plane containing breccia. However, this is based upon the assumption that the NW joints did not step horizontally across the breccia during the joint zone formation. The

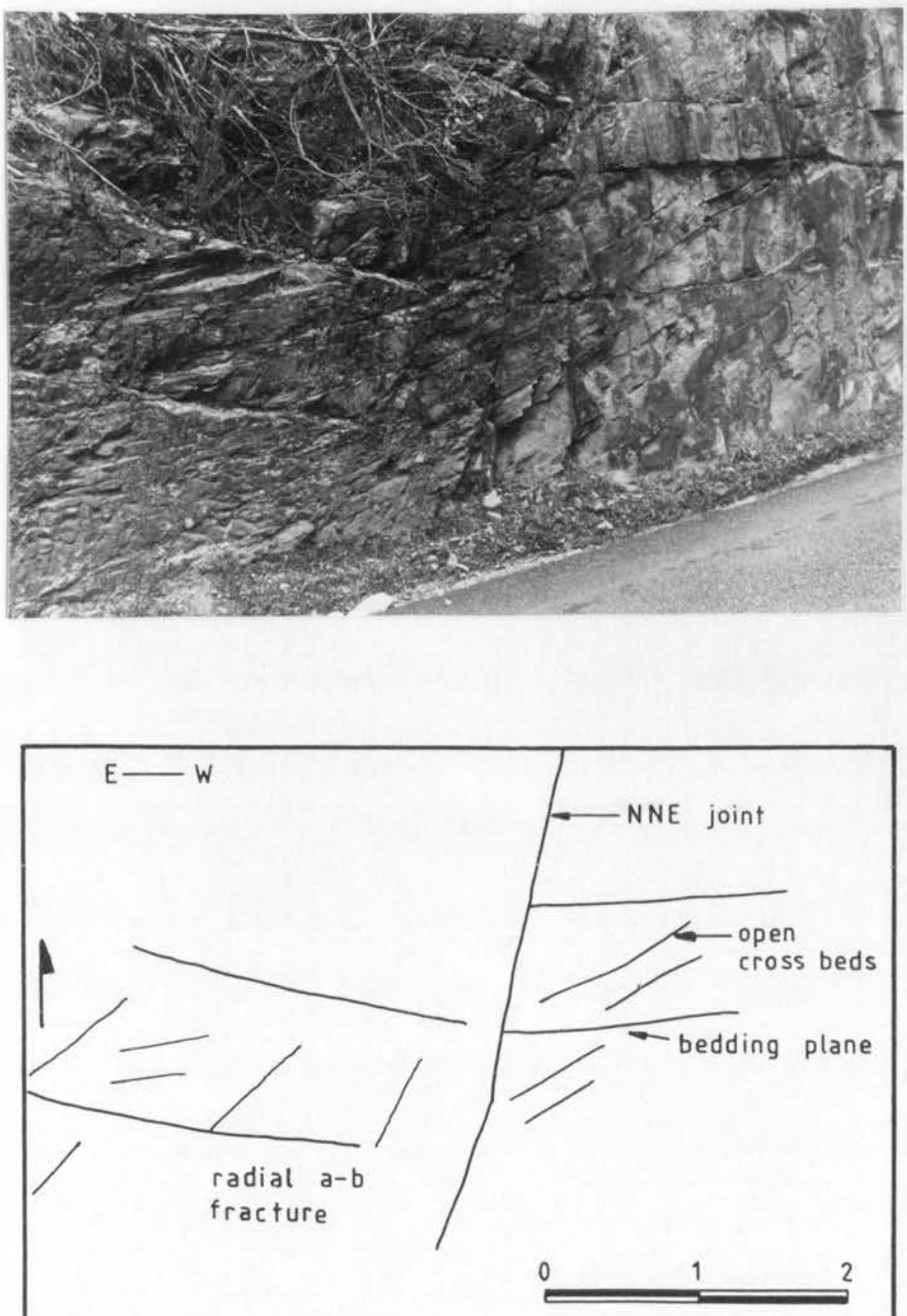


Figure 23b. Fracturing adjacent to the fault in figure 23a.

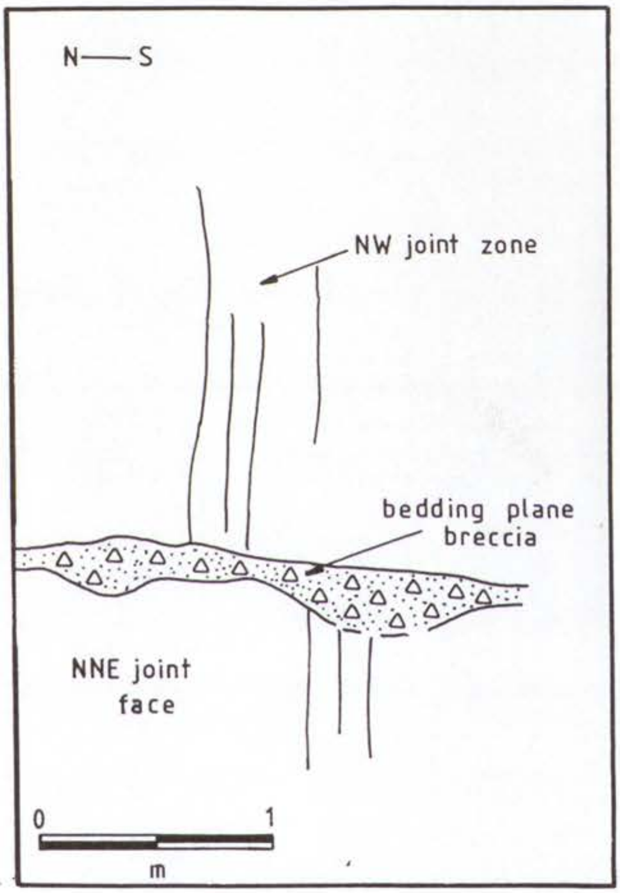


Figure 24. NW joint zone displaced horizontally along bedding plane breccia (Locality 10).

horizontal movement is in a NE-SW direction. This suggests that horizontal NE-SW compression, probably resulting in bedding plane breccia, displaced a pre-existing NW joint zone.

At Bobbin Head there has been tension such as normal faulting and the development of curved ESE joints, horizontal compression in both a NE-SW and ESE-WNW direction and dyke emplacement. The timing of the dyke emplacement relative to the other tectonic events is unknown. What this locality reveals is the discontinuity of mesoscopic features such as joint zones, fracturing, faulting and brecciation along a macroscopic structure. It is possible that stresses resulting in a deformation zone at one locality may have only resulted or caused deformation along a single pre-existing joint at another locality. The deformation along a single joint would not be easily recognisable, especially if this fracture was later dilated and infilled with a dyke. This pattern of deformation may have occurred along the NNE trending structure at Bobbin Head.

C. West Head Lineament:

The West Head Lineament has not been recognised in any previous studies. This Lineament was recognised by the linear arrangement of vegetation and fracture traces on 1:40,000 airphotos. It was observed to extend in a NNE direction from Terrey Hills towards West Head for about 10 kilometres (fig.10). With field mapping the extent of this Lineament was further increased from Belrose to West Head in the Kuring-gai/Berowra area. South of Belrose the Lineament becomes lost amongst the northern Sydney suburbs. However, planar close-spaced NNE trending master joints at East Lindfield (Loc.54, Sydney Region) may be part of this Lineament.

The Lineament is well exposed on a Hawkesbury Sandstone platform along the West Head Road (Loc.45), at the Terrey Hills tip (Loc.34, Sydney Region) and at Belrose (Loc.36, Sydney Region). An analysis of fracturing at the above localities reveals that the Lineament consists of a dominant subparallel NNE joint set (fig.25). These master joints are usually greater than 15 metres in horizontal extent, planar, vertical, closely spaced (0.5-3.0m) and right stepping.

At West Head NNE master joints are well developed. Orthogonal joints terminate against the NNE joints and are usually curved. These ESE joints are probably extension joints. The NNE joints are usually right stepping, and associated with the end points of the joints are well-developed NE-trending 'en echelon' fractures (figs 26a and 26b). Some of these en echelon fractures have a sigmoidal shape which suggests that a shear component (fig.27; Beach, 1975) existed during their formation. The NNE joints may have been initiated as extension joints and with subsequent lateral shear further extended as extension shear joints.

At Terrey Hills, large (30m) planar NNE joints are well developed and form a zone about 40-50 metres wide. At Belrose, the NNE trending lineament consists of 2 dominant joint sets trending NNE and NE. Fracturing at these two localities and at East Lindfield will be discussed in more detail in the next chapter on the Sydney Region.

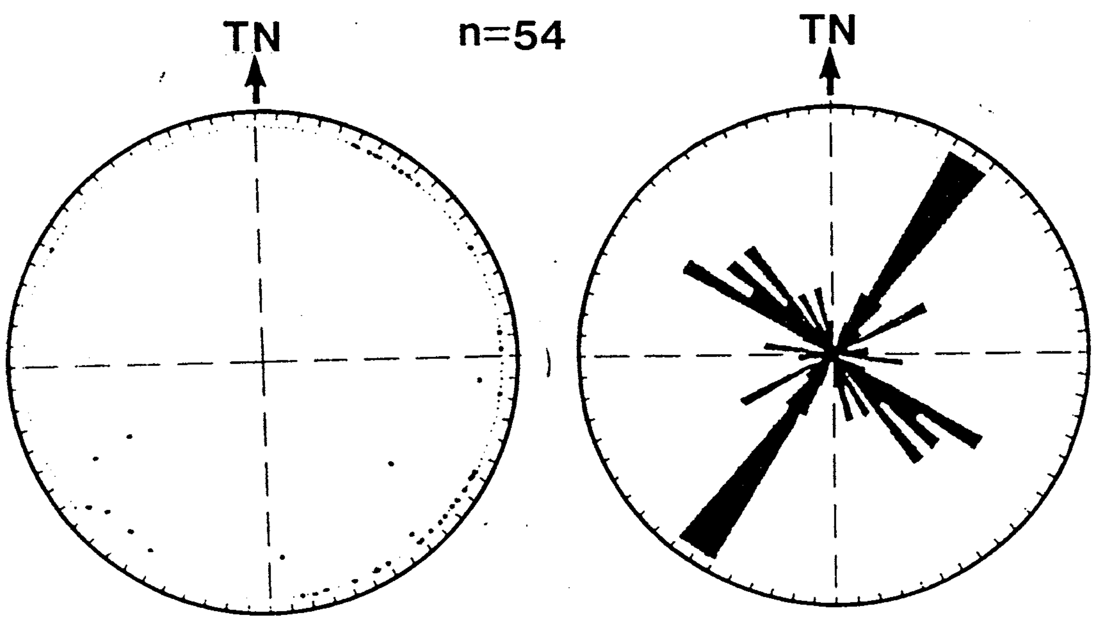


Figure 25. Equal area polar plot and rose diagram of fracturing along the West Head Lineament.

igure 26a. Right-stepping NNE joints within the West Head Lineament (Locality 45, West Head).

Fi;ure 26b. NE trending en echelon fractures at the end points of NNE joints at Locality 45.

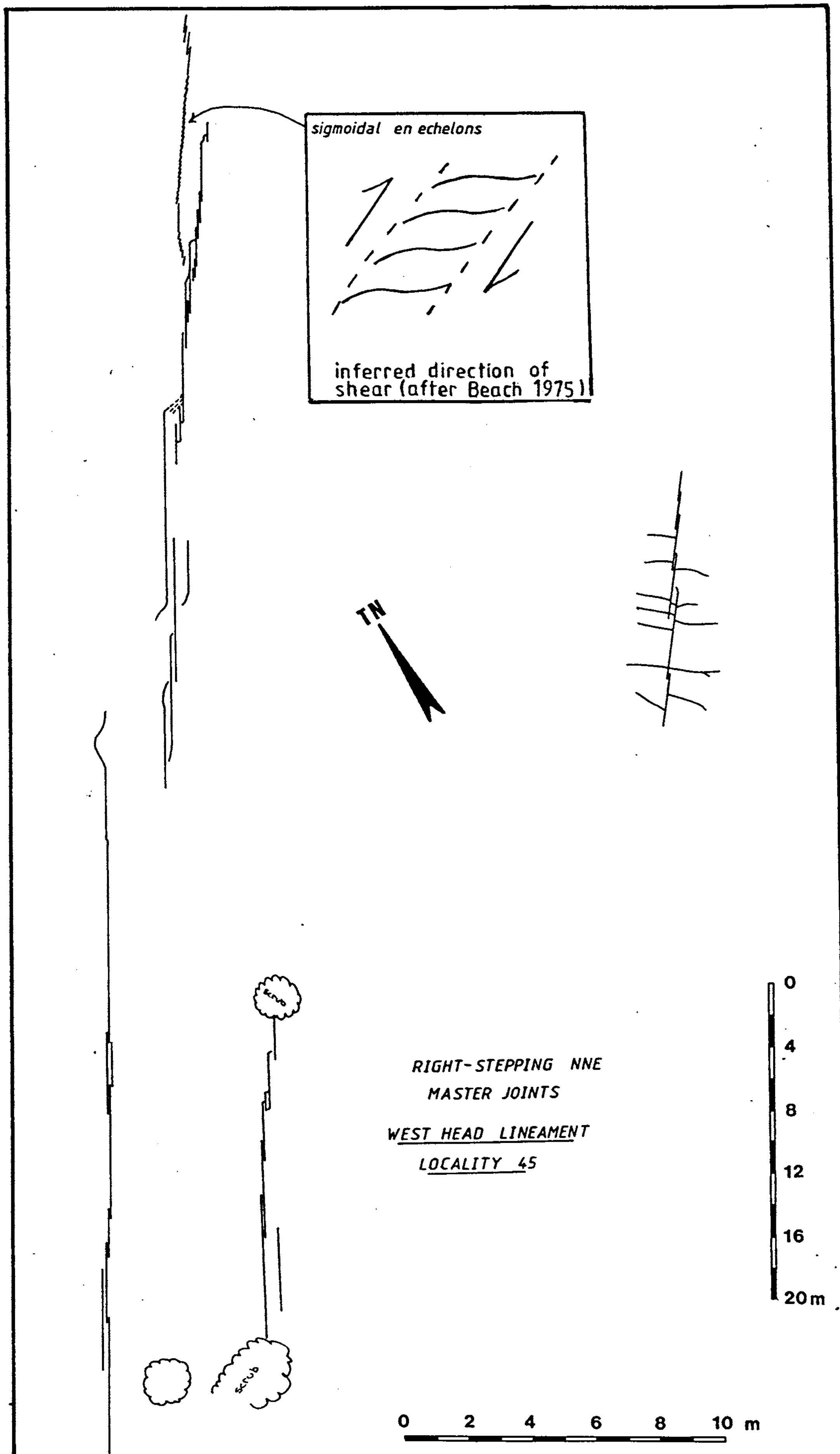


Figure 27. Sketch of NNE master joints at Locality 45, West Head, showing en echelon fractures and inferred direction of shear (interpretation after Beach, 1975).

The similar trend and style of fracturing of the West Head Lineament to those of a fracture zone at Bobbin Head and zones within the Coastal Lineament suggest that these fracture traces are genetically related.

2.43 ENE AND E-W TRENDING STRUCTURES:

ENE trending joints and faults are not common in the Kuring-gai/Berowra area and are generally restricted to a 100 metre wide structure extending ENE of Cowan (fig.28). E-W trending joints and faults are also rare. E-W trending dykes and joints exist at Barrenjoey and West Head and appear to change in strike to ENE-WSW as they are traced to the West. At Cowan the dykes are associated with an ENE trending fracture zone and are close to the intersection with the Berowra Waters Lineament. Although the Berowra Waters Lineament is not well defined at Cowan the change in strike of the West Head dykes/Cowan fracture zone may be related to the presence of the Berowra Waters Lineament. It is likely that the Berowra Waters Lineament was a pre-existing structure which deflected the Cowan Fracture zone during its formation.

A. The Cowan Fracture Zone:

This narrow fracture zone (100m wide) extends ENE from a breccia neck at Cowan to Campbell's Crater which may also be a breccia neck (fig.28). ENE trending master joints form a well-defined zone in which there are brecciation, minor dykes, horizontal slickensides and conjugate fractures.

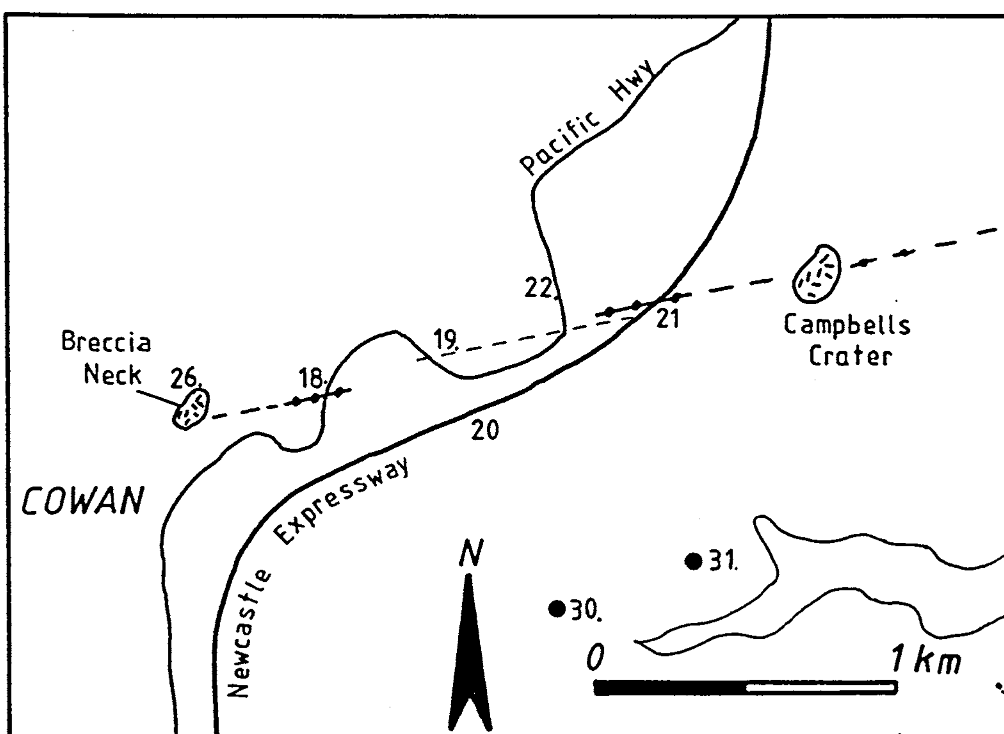


Figure 28. Location of ENE dyke/fracture zone between Cowan and Campbell's Crater.

An analysis of fracturing at localities 18, 19, 20, 21, 22, and 26 indicates that there are two sets of joints within this ENE fracture zone. ENE joints are the dominant set and there is a subdominant NW trending set. The NW joints are planar, vertical and terminate against the ENE joints. The NW joints may be an orthogonal joint set to the ENE joints, however, they may also be related to a more regionally developed joint set. The termination of NW joints against ENE joints suggests that they formed subsequent to the ENE joints.

Adjacent to the Cowan neck, fractures, up to 1 metre long within a siltstone bed, are filled with sand derived from the overlying sandstone (fig.29). This probably indicates that jointing and/or fracturing was developing when the sediment was still mobile, although it is possible that the sediments adjacent to the volcanic vent may have been remobilised during intrusion.

A polar plot of fracturing at the localities within the fracture zone (fig.30) shows that the ENE joints dip at high angles to the north and south. Near Millicent Trig (Loc.18) high angle conjugate joints were observed (fig.31a). These joints are usually cross-cutting: however, they may also have an inverted Y termination in vertical section (fig.31b). Horizontal slickensides were also observed on ENE vertical joint faces which indicates that lateral shearing has taken place along these joints.

Brecciation occurs within the ENE structure between ENE joint zones and also between cross-beds. At locality 20 brecciation is confined

Figure 29. Fractures containing sandstone fill, Cowan Quarry, Locality 26.

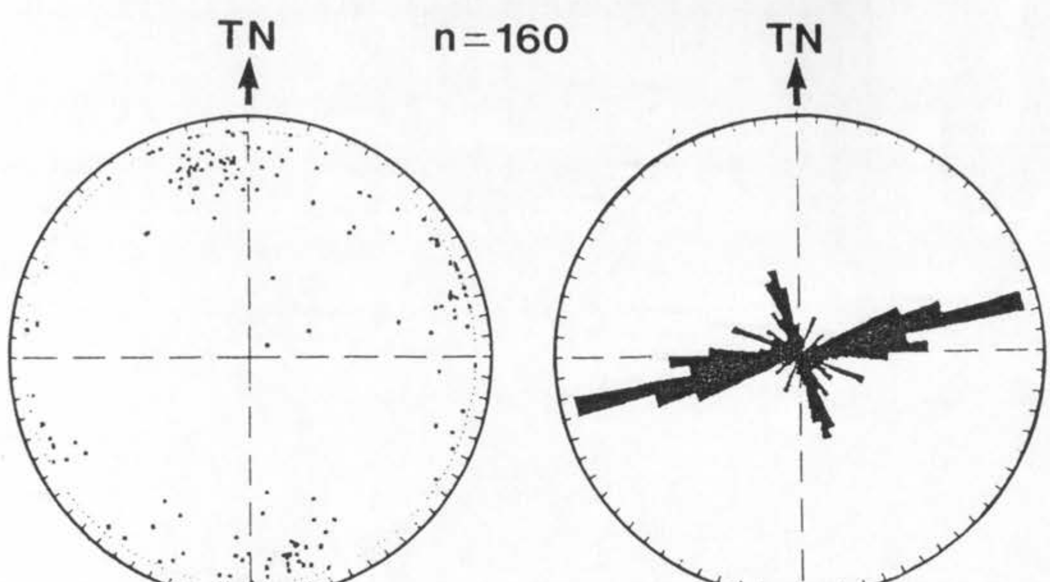


Figure 30. Equal area polar plot and rose diagram of fracturing within ENE trending zone between Cowan and Campbell's Crater.

Figure 31a. ESE trending conjugate joints near Cowan (Locality 19).

Figure 31b. Inverted Y termination of ESE conjugate joints in figure 31a.

between NE dipping cross-bed foresets (fig.32). This suggests that bedding-plane thrusting from the NE may have taken place. An ENE dyke, ENE joints and NW joints, exposed on the Newcastle expressway at locality 21, are also displaced along horizontal bedding planes. The sense of displacement is again NE-SW. However, breccia obscures the intersection of the dyke with the bedding plane (fig.33) and it is unknown whether this dyke was horizontally displaced subsequent to intrusion or whether it intruded along a pre-existing displaced joint. Nevertheless, the sense of displacement is consistent. Minor normal faulting within the ENE fracture zone and along the dyke wall further suggests that this zone has also been the site of later tension.

Like the Berowra Waters Lineament and the NNE fracture zones, it appears that multiple deformation, including shearing, has taken place in this ENE fracture zone. A horizontal NE-SW compression occurred subsequent to the development of the ENE and NW trending joints. The rarity of ENE trending joints or zones elsewhere in the Kuring-gai/Berowra area suggests that this zone is a local phenomenon probably related to the breccia necks between which it extends. The fracture zone may have begun as an extensional dyke/fissure which provided a weakness for subsequent NE-SW compressional deformation. Crawford et al. (1980) suggested that breccia vents or diatremes elsewhere in the Sydney Basin are Jurassic in age. If the vents in the study area are of a similar age then the NE-SW compression must be post Jurassic. However, it is possible that the intrusion of breccia vents occurred during several volcanic phases from the Jurassic to the Tertiary.

Figure 32. Breccia confined between NE dipping cross-beds of Hawkesbury Sandstone (Locality 20).

Figure 33. Dyke and breccia exposed on Newcastle Expressway (Locality 21).

The conjugate fractures within the fracture zone indicate that σ_1 was vertical during their formation. However, slickensides, brecciation and displacement of fractures indicate that there was also lateral compression (σ_1, horizontal). It may be possible that these features are related to the same period of compression. Where there was a pre-existing fracture, joint or crossbed, lateral shearing may take place due to a horizontal compression, however if there was sufficient overburden and the rock was competent σ_1, may become vertical. Price (1966) suggests that tectonic stresses which develop during a compressional phrase can remain as residual stresses. During uplift the vertical load due to gravity may assume the role of greatest principal stress. At Cowan, the conjugate joints with a horizontal intersection may also have developed during uplift of the Hornsby Plateau as a result of a residual compressional stress.

B. West Head Dykes:

At West Head (Locs 33 and 34) E-W trending dykes probably represent an easterly extent of the ENE trending fracture zone at Kuring-gai. Four main joint sets were recognised in the Narrabeen Group siltstones and sandstones at West Head. The two dominant joint sets trend NNE/NE and NW. Joints parallel to the dykes are only minor and there is a minor N-S set. NW joints terminate against NE joints and NE joint zones and are also confined between the E-W trending dykes. The NE joints are generally planar and subvertical while the NW joints have a more variable dip and strike. This suggests that the NW joints are not related to the NE joints, that is, they are not an orthogonal set.

Similar joint sets were observed in the Hawkesbury Sandstone at West Head except that the N-S joint set and E-W set were more frequent. Again, NW trending joints terminated against NE joints and one E-W trending joint terminated against a NE joint. The E-W joints which parallel the dykes at West Head are not regionally developed. The initial development of E-W joints is probably related to dyke emplacement. N-S joints terminate against the E-W joints and may represent an orthogonal extensional joint set.

At West Head joints which strike in the north-east quadrant trend in a more easterly direction than joints further to the west in the study area. This will be discussed in the section 2.45 on the coastal domain.

In addition to dykes intruding the Narrabeen Group at West Head there is a breccia, similar to breccia at St. Michael's Cave and Bondi (figs 34a and 34b). This breccia contains large blocks of Hawkesbury Sandstone (up to 3m diameter) in a matrix of clay and subrounded fragments (up to 10cm) of siltstone and sandstone derived from the adjacent Narrabeen Group. The plane of contact between this breccia and the Narrabeen Group is discordant and strikes perpendicularly to the dykes. This breccia probably represents the rim of a collapsed vent with the dykes trending radially away from the vent.

C. Barrenjoey Head:

At Barrenjoey Head (Loc.48) an E-W dyke is an extension of the dykes at West Head. This dyke has been dated at 171 Ma (Embleton et al.,

Figure 34a

Figure 34b

Figures 34a,b. Breccia containing blocks of Hawkesbury Sandstone at West Head (Locality 33).

Figure 35. Conjugate fractures within an E-W dyke at Barrenjoey (Locality 33).

1985). The dominant joint set at Barrenjoey trends in a NNE to NE direction (035). These joints are planar, extend between 1 and 30 metres both horizontally and vertically,and have an average spacing of 5 metres. These NE joints are well developed in both the Narrabeen Group and Hawkesbury Sandstone; however, they form a more dominant set in the Hawkesbury Sandstone. E-W joints and NW trending joints form subdominant joint sets. The NW joints terminate against the NE set and are not as extensive as the NE joints. E-W joints also terminate against a minor N-S joint set. These terminations are the same as those at West Head and the same age relationships can be inferred. Small (0.25m) conjugate fractures are contained within the E-W trending dyke (fig.35) at Barrenjoey. The acute bisectrix of these fractures strikes 013 and suggests that the dyke has been subjected to compression in this direction. These fractures are only locally developed and may not have any regional significance.

On the south side of Palm Beach there is a NNE-NE trending dyke which appears to have influenced the physiography of Pittwater. This dyke is shown on the Sydney 1:100,000 geological sheet (Wilson et al., 1983) and continues to the Bahai Temple on Mona Vale Road (Loc.55, Sydney Region). NNE and NE trending joints form a well defined regional joint set and would have also provided an anisotropy for the intrusion of dykes. This suggests that some NNE/NE joints formed prior to and/or contemporaneously with dyke emplacement.

2.44 NW TRENDING JOINTS, FAULTS AND DYKES:

NW trending joints exist throughout the study area, however, they are more frequent in an area 10km wide extending from the Kuring-gai expressway to Dee Why. These NW trending joints occasionally form zones and are often associated with normal faults and dykes. NW trending joints exist within the ENE trending Cowan fracture zone and a NNE trending fracture zone along Bobbin Head Road (Loc.10). Along West Head Road (Loc.51) there is a NW trending fault (fig.36) This fault is subparallel to a dyke at McCarrs Trig (Loc.37) to the south. At Ingleside (Loc.56) a normal fault containing breccia in a 3 metre wide zone is also parallel to thin (0.25m) dykes (fig.37).

Where both NNE/NE trending joints and NW joints exist, such as at Bobbin Head (Loc.10), Ingleside (Loc.56) and West Head (Locs 33 and 34), the NW joints terminate against the NNE joints. This suggests that the formation of the NW trending joints was probably initiated subsequent to the NNE joints. The displacement of NW joints along bedding plane breccia within the NNE fracture zone at Bobbin Head and within the ENE fracture zone at Kuring-gai indicate that a NE-SW horizontal compression took place subsequent to the initial formation of NW joints.

At South Avalon headland (Loc.57) both NE planar master joints and NW joints exist. The NW joints are not as extensive as the NE joints and are curved. The strike of the NE joints is well defined and constant. This suggests that the NW joints formed in a different and variable stress regime to the NE planar joints. That is, the NW joints at this locality are not an orthogonal joint set to the NE joints.

Figure 36. NW trending fault, along West Head Road (Locality 51).
note: artifical fill obscures part of fault zone.

Dykes throughout the study area, such as at Ingleside and McCarrs Trig and to the south near Sydney, parallel the NW trending joints. This suggests that the formation of NW joints predated or was simultaneous with the intrusion of the dykes. K/AR dating of some of these dykes suggests that they may be as young as 47 Ma (Gladesville dyke, Embleton et al., 1985). This indicates that the NW joints and faults are at least Tertiary in age. Some NW joints may also have formed as an orthogonal extensional set to the NNE/NE joints. However, there is no way of delineating between NW joints associated with the dykes and the NW orthogonal joint set at the localities examined during this study.

2.45 NE TRENDING JOINTS:

NE trending joints are common along the coast although they are not common in the western part of the study area. NNE trending joints form the dominant set to the west while along the coast NNE joints are rare. For this reason the coastal region is considered as a separate domain where NE joints form the dominant set and NNE joints are rare.

A. The Coastal Domain:

An analysis of fracturing at localities 33, 34, 46, 47, 48, 55, 57, 58 along the coast,indicates that there are two dominant joint sets. They are a NE trending joint set and an NW trending joint set (fig.38). The NE trending joints are planar, extensive (often being master joints) and similar to the NNE trending joints to the west. NNE joints are almost absent along the coast.

NW trending joints are often associated with dykes, as mentioned in section 3.6. They are also frequently curved such as the joints at South Avalon (Loc.57, fig.39). At South Avalon the curved NW joints are less continuous and cut across and terminate against the planar NE trending joints. These two joint sets probably formed under different stress conditions with the NW joints forming in a more variable stress regime. Since most NW joints terminate against the NE joints they probably formed subsequent to the NE joints. The abutting relationship of NW joints against NE and NNE joints appears to be common throughout the Kuring-gai/Berowra area.

The similarity in style and architecture between the NE joints, along the coast, and NNE joints to the west suggest that they are related. It may be postulated that the rotation of these joints reflects a lithological change from the Hawkesbury Sandstone which outcrops to the west, and the Narrabeen Group sediments which outcrop along the coast. However, a rose diagram (fig.40) of joint azimuths, in both the Hawkesbury Sandstone and the Narrabeen Group in the coastal region, shows that there is no appreciable change in azimuth due to lithological change. It appears that the initial formation of the NE joints was probably simultaneous with the NNE joints, representing a slight rotation of the stress field towards the coast. It is these planar NE master joints which characterise the coastal domain.

Figure 37. NW trending fault/breccia zone at Ingleside Locality 56).

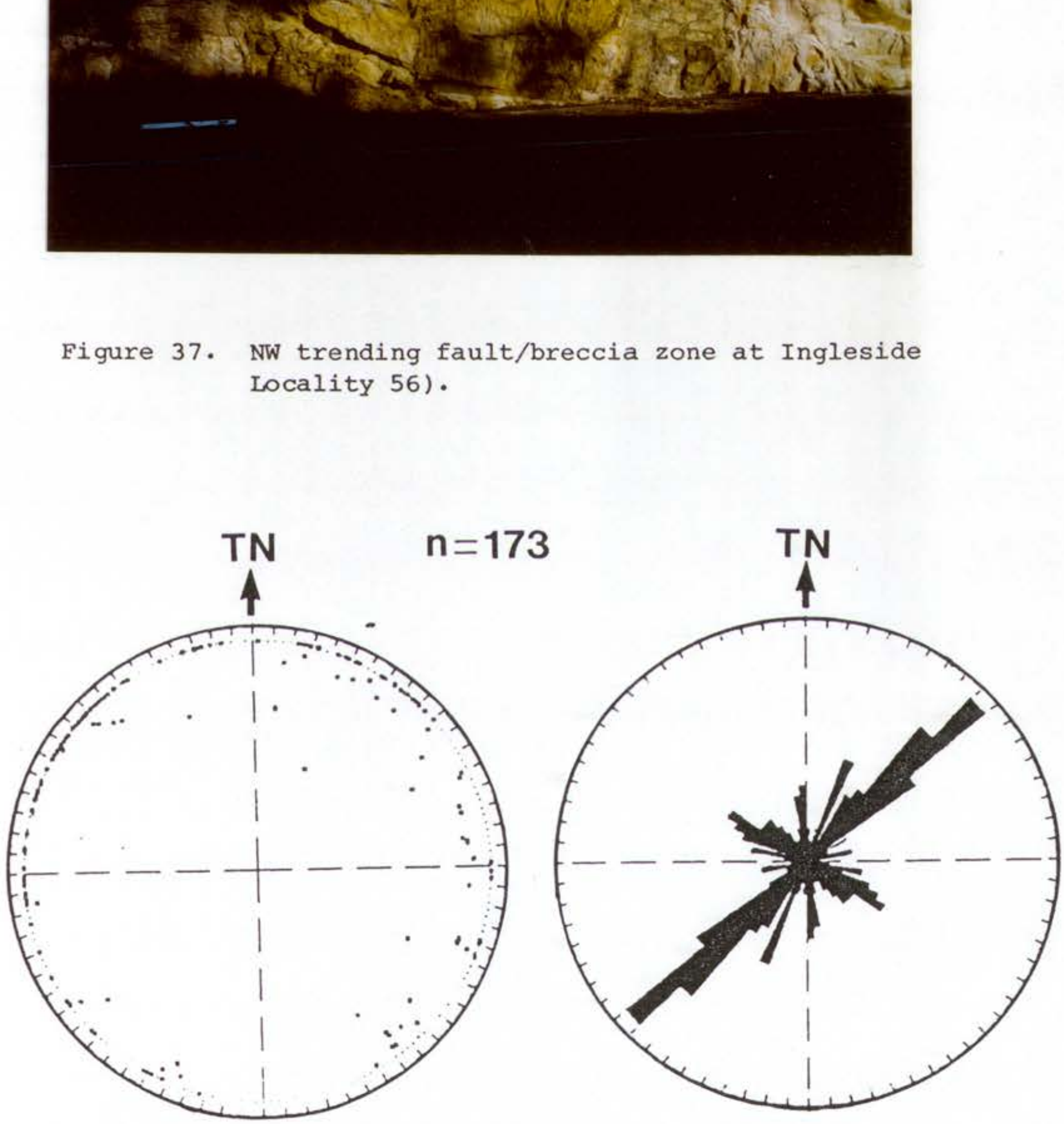


Figure 38. Equal area polar plot and rose diagram of fracturing along the coast.

Figure 39. Planar NE joints and curved NW joints at South Avalon (Locality 57).

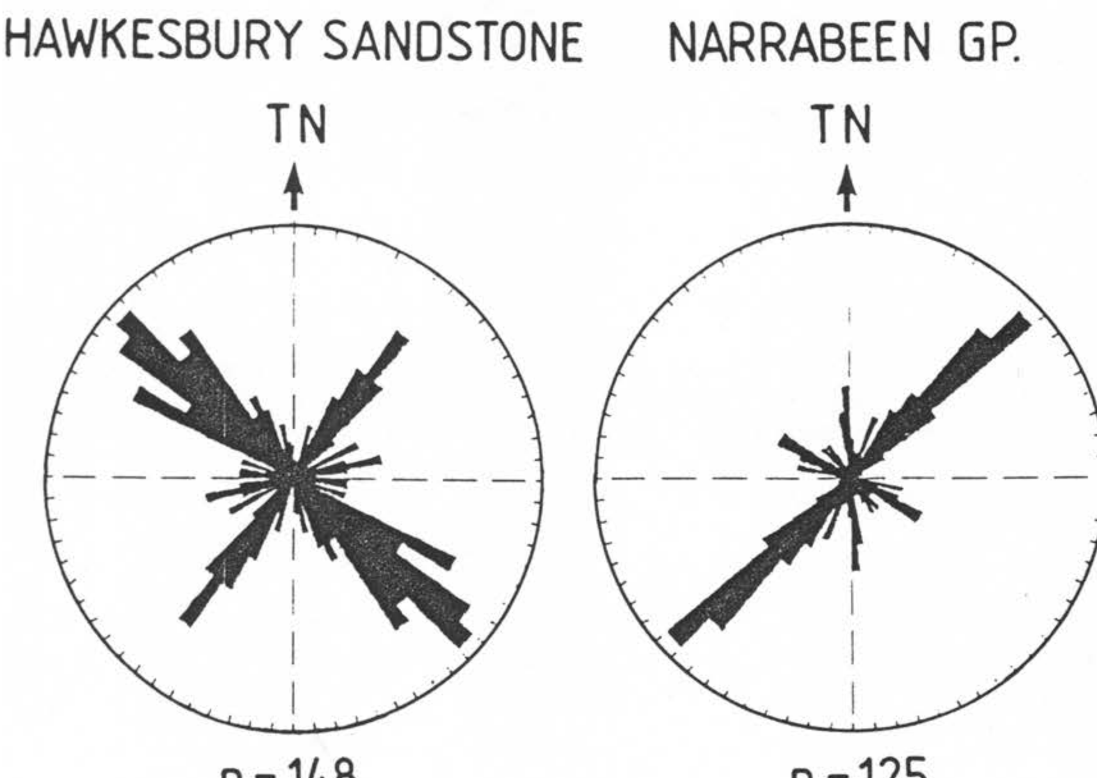


Figure 40. Rose diagrams of joint azimuths within the Hawkesbury Sandstone and Narrabeen Group in the coastal domain.

2.5 INTERPRETATIONS

The results of airphoto and outcrop fracture analyses are summarised in fig.41. The most common and widespread joints in the area are planar NNE trending joints. They are also commonly zonal, and swing to the NE along the coast. These joints were probably initiated during an early extension within the basin; however, the reason for the easterly rotation of the stress field is not apparent. Joint terminations also suggest that the formation of NNE joints was a continuing process in this area and may have formed an anisotropy along which subsequent lateral shearing took place. This anisotropy has in places influenced the shape of the topography such as drainage in the broad Coastal Lineament but in most cases NNE joints and structures have had little, if any, physiographical affect. Both the Bobbin Head Road Structure and the West Head Lineament are more easily recognised by vegetation traces than by drainage. Likewise, other structures such as the ESE Berowra Waters Lineament and ENE Cowan Fracture Zone have had little influence upon physiography. This suggests that either the major structures developed after the present shape of the topography or the structures were tightly closed during development of the topography and thus did not provide a good line of weakness. The trend of Pittwater appears to be controlled by a dyke, however in most instances dykes do not appear to have had a marked effect upon physiography.

An examination of fracturing, associated with the lineaments identified by airphoto, allowed further definition of these

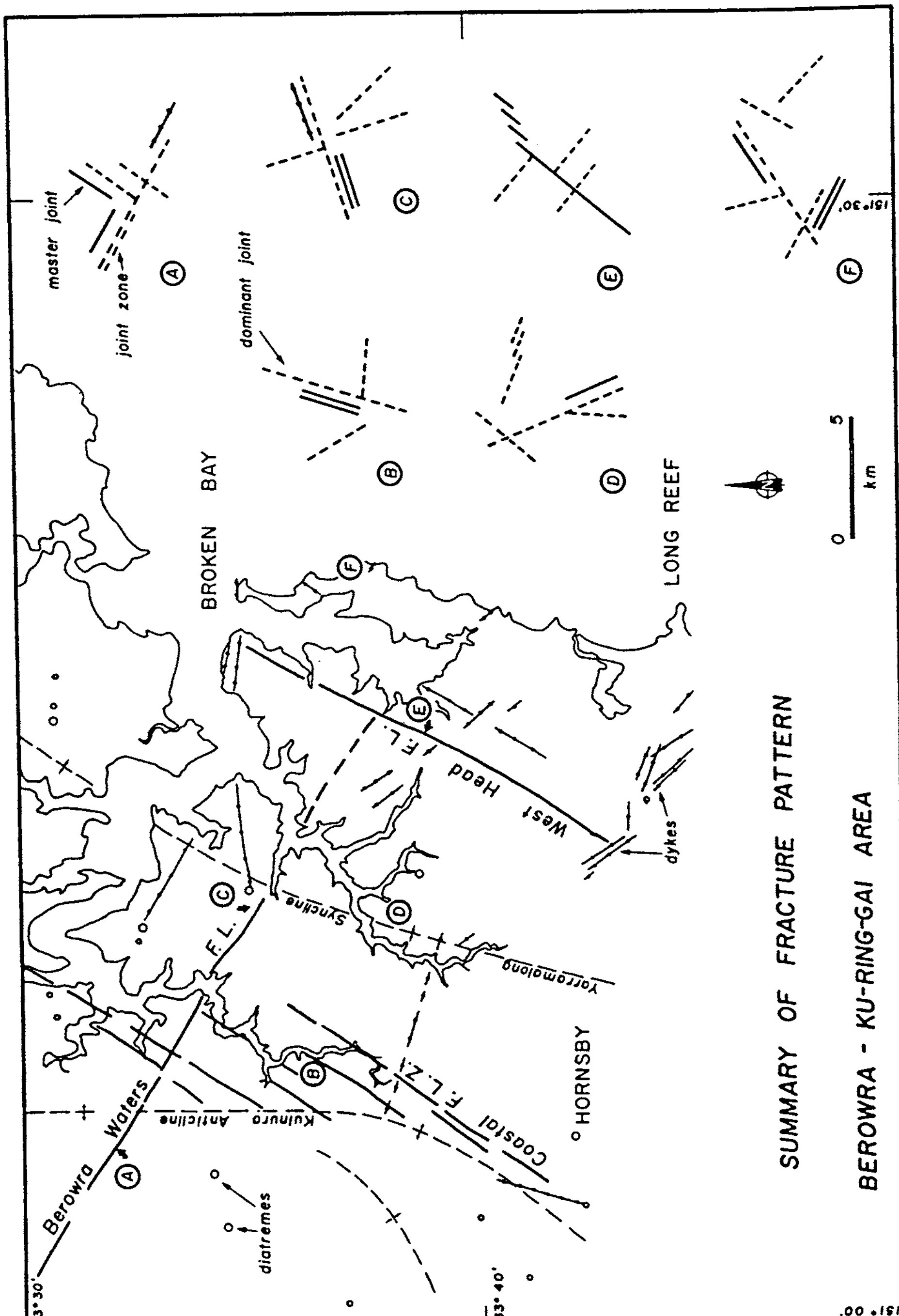


Figure 41. Summary of the fracture pattern in the Kuring-gai /Berowra area.

structures. The ESE trending Berowra Waters Lineament consists of close-spaced conjugate fractures and horizontal slickensides which suggests that lateral shearing has taken place along it. Therefore, the Berowra Waters Lineament should be more precisely termed the Berowra Waters Fracture Lineament. An examination of joint terminations within the lineament indicated that NNE trending joints formed prior to and subsequent to the formation of ESE trending joints which are sub-parallel to the lineament. That is, the Berowra Waters Fracture Lineament was probably initiated after the initial WNW-ESE extension which resulted in NNE joints. This lineament parallels a major basement structural trend (Mauger et al., 1984) and also the Lachlan River Lineament to the south. The Berowra Waters Fracture Lineament may be related to the reactivation of a deep-seated structure. Dykes, of an unknown age, exist within the lineament and at one locality slickensides within a dyke suggest that subhorizontal E-W and SSW-NNE compression occurred subsequent to dyke emplacement. However, most of the lateral shearing probably took place prior to intrusion of the dykes as they are generally undeformed. Evans and Roberts (1980) have proposed that deformation during the Late Triassic to the Late Cretaceous was a responses to a 'prolonged application of a dextral rotational force couple' in a NNW-SSE direction. This shear couple may have initiated deformation along the WNW-ESE Berowra Waters Fracture Lineament and may have influenced and/or initiated other major structures such as the Lapstone Structural Complex.

ENE joints and joint zones are not common; however, they do occur adjacent to Campbell's Crater at Cowan. Associated with ESE trending dykes and breccia vents are conjugate fractures, horizontal slickensides, brecciation and horizontally displaced fractures. These features indicate that the ESE dyke/fracture zone has also been the site of NE-SW compression and that this compression was subsequent to dyke emplacement, formation of ESE joints and NW trending joints. Horizontal conjugate fractures within a probable Jurassic (171 Ma) dyke at Barrenjoey Head, which is probably an easterly extension of the dykes at Cowan, suggests that the lateral NE-SW compression was post Jurassic. The relationship of this ENE dyke/fracture structure Berowra Waters Fracture Lineament near their intersection is obscure; however, the dyke/fracture structure appears to change its strike from an E-W to ENE-WSW direction. This may indicate that the Berowra Waters Fracture Lineament existed prior to the formation of ENE joints, Jurassic volcanism and the NE-SW compression. This E to ENE dyke/fracture structure may be a westerly continuation of the Tasman Fracture Zone 4 (Ringis, 1975) which was probably a transform fault during rifting of the Tasman Sea. If this is correct and if the age for the Barrenjoey dyke is correct, then this Fracture Zone must have been active during the Jurassic about 100 m.y. before the Tasman Sea rifting.

NW trending joints are common throughout the study area, however they are more common in a 10km wide area extending south-east of Kuring-gai particularly between Terrey Hills and Dee Why. These joints are associated with dykes in this area and probably resulted from an NE-SW extension prior to dyke emplacement. This extension parallels the NE-SW sea floor spreading in the Tasman Sea 60-80 m.y.B.P. (Hayes and

Ringis, 1973). Dilation of these NW-trending joints and intrusion of dykes may have been simultaneous or postdated sea floor spreading in the Tasman Sea. However, the ages of dykes is usually older than or younger than 60-80 Ma (Rickwood, 1985; Embleton et al., 1985). This suggests that either the age of sea floor spreading is inaccurate or that extension in the continental margin post-dated rifting.

The Coastal Lineament was recognised on airphotos by the NNE trending drainage pattern within an area 1km wide. Within this area the lineament consisted of planar master joints and minor normal faulting subparallel to the lineament. Minor conjugate fractures confined between joint zones suggest that an E-W compression existed subsequent to formation of the NNE joint zones. The Coastal Lineament however, could not be delineated as clearly as the Berowra Waters Fracture Lineament. Because NNE fracturing is common within the Coastal Lineament, the lineament should be more precisely termed the Coastal Fracture Lineament Zone.

A NNE trending structure at Bobbin Head and the NNE trending West Head Lineament contain features such as bedding plane breccia, bedding plane faults, sigmoidal en echelon fractures and conjugate joint sets which suggest that these NNE structures may have resulted initially from a NE-SW compression. NNE extension joints may have existed prior to this compression and provided an anisotropy for subsequent deformation. Because of the fracturing within the West Head Lineament, this Lineament should be more precisely termed the West Head Fracture Lineament.

At Bobbin Head a NW trending joint zone is displaced along bedding plane breccia which indicates that the NE-SW compression existed subsequent to the formation of NW joint zones and hence subsequent to rifting in the Tasman Sea. Jones and Veevers (1983) suggested that prior to rifting, from 200-90Ma, a plate boundary was located parallel (NNE-SSW) to the east coast of Australia. This boundary experienced 'prolonged oblique slip' as a result of a sinistral shear couple. Creasey and Huntington (1985) have suggested that the NNE lineaments in the Sydney Basin may have developed as a continuation of this shear couple and motion of the Australia Plate. However, the limited information in the study area suggests that a NE-SW compression [dextral shear couple] has acted upon the NNE lineaments. The origin of this stress is unknown but may indeed be related to the northward motion of the plate.

From the above observations a sequence of tectonic events which initiated the joint patterns in the Kuring-gai/Berowra area can be summarised. These are as follows;

1. Formation of NNE and NE joints related to a regional extension within the Basin.
2. Development of ESE joints along the Berowra Waters Fracture Lineament, possibly through lateral shearing.
3. Development of ENE joints associated with the intrusion of dykes and formation of breccia vents in the Jurassic.
4. Development of NW trending joints and intrusion of NW trending dykes probably related to an NE-SW extension associated with Tasman Sea rifting.

5. Re-activation of NNE extension joints associated with a NE-SW compression to form evenly spaced NNE trending fracture zones and lineaments.
6. Minor E-W compression.

This summary is based solely upon observations in the Kuring-gai Berowra area. While this area is only weakly deformed, the study of joint and fault patterns has been used to identify the stress/strain relationships which have existed in the study area and to determine a history of deformation.

The Kuring-gai/Berowra area covers only 1% of the onshore Sydney Basin and any basinwide structural analysis should incorporate studies from different domains such as the Lapstone Monocline and margins of the basin. In the next chapters the Sydney Region and Blue Mountains Plateau will be examined. It is not expected that every joint or fracture pattern will fit into the above model nor is it suggested that all joint formations can be placed neatly into time slots. Once a joint set is developed the development of further joints parallel and perpendicular to these joints is probably a continuing process. The terminations of NNE trending joints and other joints tend to support this. While there did not appear to be any great changes in the strike of joints due to lithological variations, it was, however, observed that the dominance of jointing at each locality does depend upon the character of the rock. It was observed that joints in the Hawkesbury Sandstone are best developed and more frequent in the 'cross bedded facies' than the 'massive facies'. Where both facies existed at one locality, it is common for joints in the cross bedded sandstone to terminate against the massive sandstone. It appears that joints were more easily propagated in rocks containing a pre-existing sedimentary fabric, such as cross bedding. Joints are also more frequent and more closely spaced in siltstones of the Narrabeen Group than joints in sandstone. It appears that a microscopic anisotropy is also important in the propagation of joints.

The important features that this study revealed are:

1. The variability of joint directions.
2. The zonal nature of joints, and that between these zones there are frequently areas with little, if any, jointing.
3. Multiple deformation including shearing appears to have taken place within these zones.
4. A pre-existing fabric is important in any subsequent deformation whether this fabric is of a sedimentary or structural origin.

CHAPTER 3

THE SYDNEY REGION

3.1 LOCATION AND ACCESS (fig.42)

The Sydney Region in this study covers about 445 square kilometres from Hornsby in the north to St. Peters in the south. The northern boundary of the Sydney Region is adjacent to the southern boundary of the Kuring-gai/Berowra area. The southern boundary is a line drawn from St. Peters to North Head and a line from St. Peters to Parramatta. Outcrop was examined in many excavation sites and rail and road cuttings. Permission to enter these sites was granted by site managers, and State Rail Authority and Main Roads personnel.

Along the eastern coastline access to the rock platforms was by foot.

3.2 GEOLOGICAL SETTING

The Sydney Region rises from the Botany Basin in the south to the central Hornsby Plateau in the north (Willan, 1925) as shown on fig.2. The Hornsby Plateau generally dips between 1 and 2 degrees to the south: however, around its southern margins there are steep escarpments which are probable warps (fig.2). The dip along these warps is up to 20 degrees. The most prominent escarpment lies to the

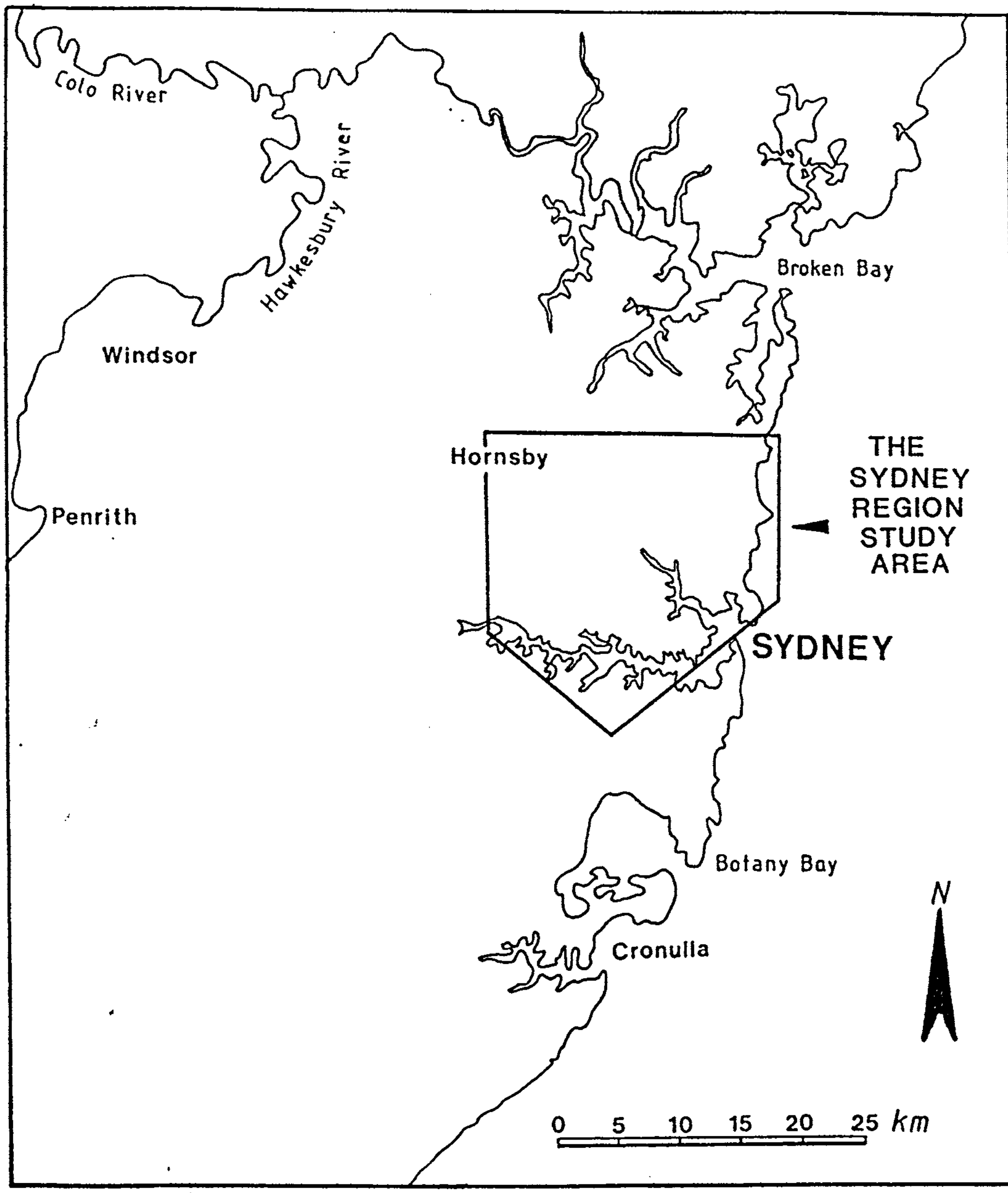


Figure 42. Location of the Sydney Region study area.

west and subparallel to the Pacific Highway between Waverton and Turramurra. This NW trending escarpment is called the Roseville Warp in the present study and is discussed in further detail in section 3.34. Easterly trending escarps also occur adjacent to Pennant Hills Road and Castle Hill Road and may be a continuation of the Roseville Warp. Just north of Pymble Station a similar escarp crosses the Pacific Highway and may form a split of the Roseville Warp. This escarp is called the Pymble Warp (fig.2) in this study.

Another prominent escarpment occurs between Ryde and Telopea (fig.2). This escarpment trends ESE for about 8 kilometres but has a north-south orientation where it crosses Victoria Road at Ryde. This escarp has not been named as it is probably part of the Hornsby Warp, although it lies one to two kilometres to the north of the Hornsby Warp (Willan, 1923) as shown by Bembrick et al. (1973). Throughout most of the Sydney Region the Hornsby Warp (op. cit.) forms a gentle rise from the Cumberland Basin (Willan, 1923; Taylor, 1923) to the Hornsby Plateau and is not as prominent as the above warps.

Throughout much of the Sydney Region the Lane Cove River and Middle Harbour Creeks and their tributaries have dissected the Hornsby Plateau. The Triassic Hawkesbury Sandstone outcrops throughout most of this dissected area and along the coast and harbour fore-shores. The "Sheet-like" facies (Conaghan and Jones, 1975) of the Hawkesbury Sandstone is more common than the "massive" facies, and bed thickness is usually between 1 and 2 metres. The top of the Hawkesbury Sandstone is interbedded with siltstone. These siltstone beds increase in thickness into the overlying Ashfield Shale which is the lowermost formation of the Wianamatta Group. In most places this passage from the Hawkesbury Sandstone into the Triassic Ashfield Shale is called the Mittagong Formation. The Mittagong Formation is between 3 and 10 metres thick. In some places the Ashfield Shale overlies the Hawkesbury Sandstone indicating that this boundary is , in part, disconformable. The Mittagong Formation and Ashfield Shale outcrop on the ridge-tops north of Port Jackson. South of Port Jackson, the Ashfield Shale outcrops throughout the Botany and Cumberland Basins. The regional geology is shown on the Sydney 1:100,000 map (Wilson et al., 1983).

The Narrabeen Group which conformably underlies the Hawkesbury Sandstone outcrops along the eastern coastline. The uppermost Newport Formation consisting of sandstones and siltstones outcrops on all the headlands between North Head and Barrenjoey Head. Red and green claystones and siltstones of the Bald Hill Claystone which conformably underlie the Newport Formation outcrop between Long Reef and the Bigola Beach.

The Yarramalong Syncline (Raggatt,1938) which extends throughout the Kurring-gai/Berowra area may extend into the Sydney Region towards Pymble. Structure contours on the base of the Wianamatta Group by Willan (1925) show that small synclines occur at Waitara and North Sydney (fig.2). The Waitara Syncline occurs to the west of the Yarramalong Syncline. These features are only minor and were probably formed contemporaneously with sedimentation.

Lovering (1953) also using structure contours on the base of the Wianamatta Group recognised a number of highs and lows to the north of the Botany Basin (fig.2). These features may also have formed contemporaneously with deposition. Lovering's (1953) Annandale High and University High trend NNE-NE and are separated by a narrow low which trends towards Pyrmont and Lavender Bay. This low is parallel and coincident with joint and fault zones in the area. This similarity will be discussed in later sections.

The Hornsby Plateau is an uplifted area, however, the timing of this uplift is unknown. The most prominent post depositional features are the warps around the southern margin of the Plateau. Fracturing along these warps and elsewhere in the Sydney Region is examined to determine a post depositional structural history of the Hornsby Plateau. Numerous dykes and vents occur throughout the area and may also be related to regional deformation. In the present study, the cross-cutting and abutting relationships of warps, joints, faults, dykes and vents and the known radiometric ages of some dykes are used to provide a structural synthesis of the Sydney Region.

3.3 SITE INVESTIGATIONS

The following outcrop descriptions are given in detail to describe the fracture characteristics of the Sydney Region. Because of the city development no major structural trends have been recognised by previous lineament studies (Mauger et al., 1984) nor by examination of aerial photos during this study. Fracture analysis sites were chosen by the availability of good outcrop rather than by a lineament study as in the Kuring-gai/Berowra area. 65 localities were examined in the Sydney Region and are shown in fig.43. To supplement this study, geotechnical reports, where available, were used to identify major structures and regional patterns. Some of these reports are discussed in section 1.51. The main structural trends that have been recognised in this study are : NNE, NW-NNW, and ENE-ESE. While not all localities are discussed in detail in this section, a list and summary of all localities can be found in appendix B and a summary of the fracture pattern is shown on the map in the back pocket (fig.44).

The use of fracture architecture and the interpretation of conjugate fractures and joints is the same as for the Kuring-gai/ Berowra area.

3.31 REGIONAL PATTERN:

A. St. Peters Brickpit (Austral brick-shale quarry):

General Geology: The Austral brick-shale quarry was the last of the St. Peters brickpits and is located 7 kilometres south of Sydney G.P.O. on the SE side of the Princess Highway (Loc.32, fig.43). The brickworks are bounded by an industrial area to the south, a residential area to the north and a stockpile of sandstone to the north-east which has slumped into the quarry (fig.45). The quarry trends in a north easterly direction and is about 500 metres long and 200 metres wide. The trend of the quarry is partly controlled by the dominant fractures in the shale. The surrounding surface elevation varies from +14m ASL an the north east margin to +1m ASL on the south

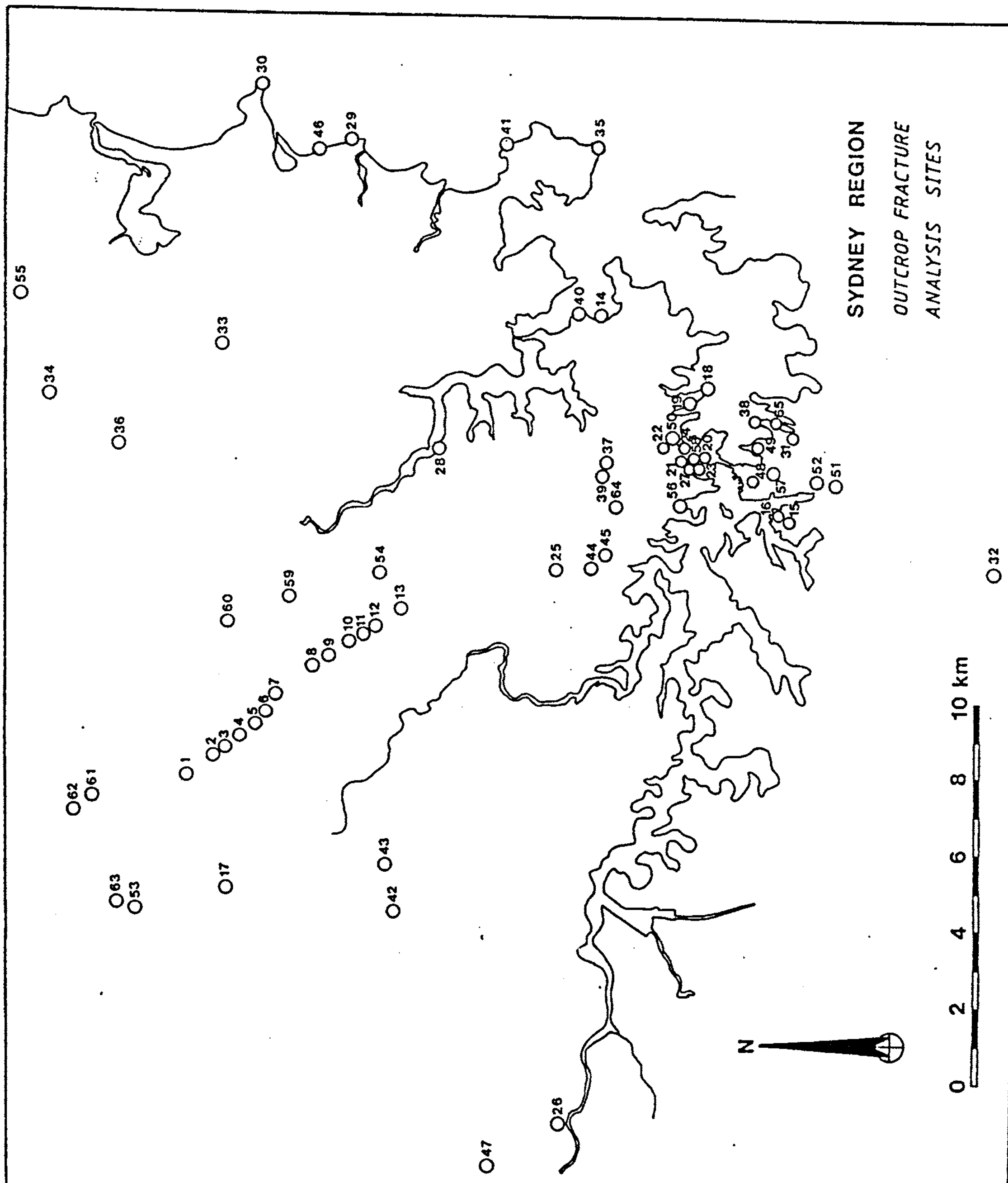


Figure 43. Outcrop fracture analysis sites in the Sydney Region.

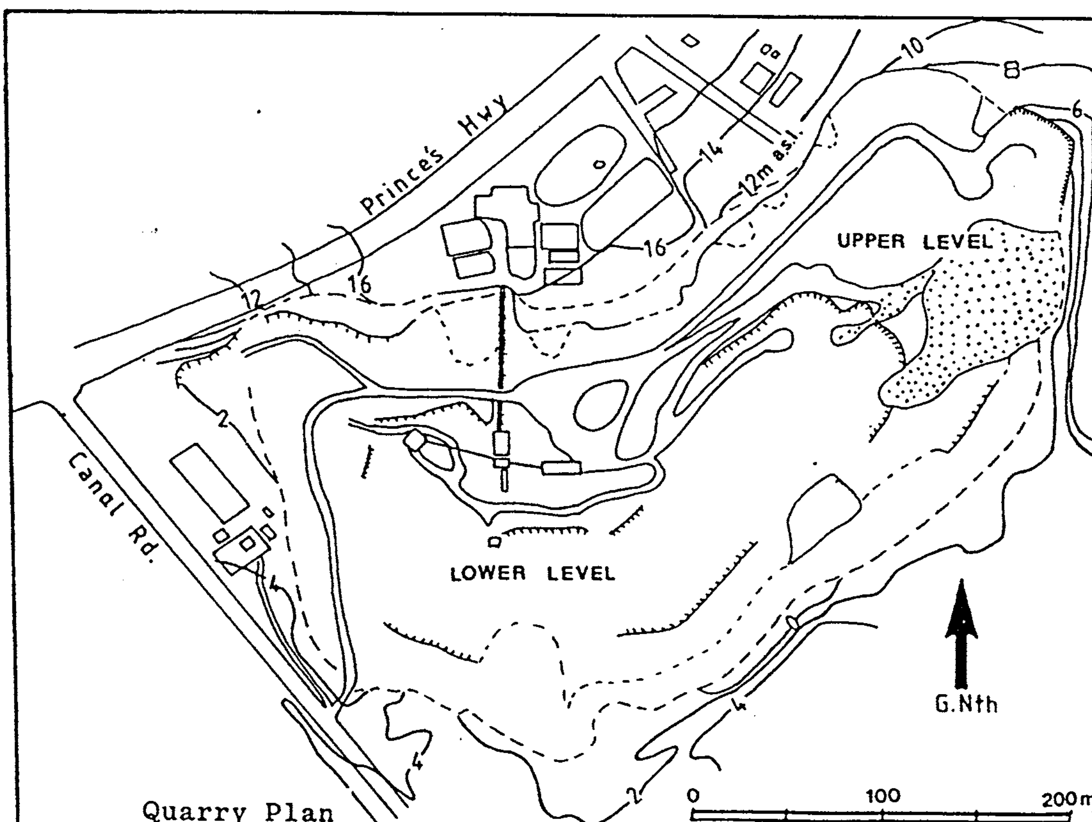


Figure 45. St. Peters brick-shale quarry (Locality 32)

east margin. The brickpit has been quarried on two levels, the upper level to a depth of -20 metres ASL and the lower level to a depth of -32 metres. Leichhardt 1:2,000 orthophoto maps and a 1:1000 topographic map supplied by the Sydney City Council were used during mapping of the brickpit.

St Peters brickpit has been quarried for Ashfield Shale which forms the lowermost formation of the Wianamatta Group. Neither the top nor the bottom of this formation is exposed in this quarry although the bottom of the quarry probably lies very close to the base of the Ashfield Shale. Contouring of the base of the Wianamatta Group indicates that the quarry lies within a depression called the Botany Basin (Willan, 1925) and there is a 1 to 2 degree dip of the sediments into Botany Bay. This regional dip was not evident in the quarry. The strata exposed in the quarry are generally flat-lying except where it is affected by faulting and where depositional slumping is preserved. In the lower level of the quarry the dip can be variable with dips upto 10 degrees being recorded (fig.46a, in back pocket).

The Ashfield Shale exposed in the quarry belongs to the basal Rouse Hill Siltstone Member (Herbert, 1979) which is interpreted as a delta-front deposit at the beginning of a regression during deposition of the Wianamatta Group. The bottom part of the quarry consists of dark grey to black siltstone with laminae of quartzose sandstone containing ripples and with occasional trace fossils. Cross-lamination in the siltstone, exposed in the quarry, indicates that the sediments were probably derived from the south east. The laminite grades up into a fine grey siltstone which at times, especially on the western margin of the upper part of the quarry, tends to become carbonaceous containing some plant fragments, hard concretionary nodules and radially slickensided compaction structures called "guilielmites" (Byrnes et al., 1978). Siderite bands up to 10 cm thick are also common. Byrnes et al. (op. cit.) believe that the guilielmites probably formed from phosphatised carbonate concretions (nodules) by solution during compaction. At St. Peters the nodules and slickensided guilielmites were observed in the same horizon adjacent to each other (Byrnes' unit 3) and the nodules were not deformed. A preliminary analysis of guilielmites, country rock and a siderite band (fig.47) indicates that the guilielmites are not as phosphate-rich as found by Byrnes et al. (op. cit.) and that there is little difference in their phosphate concentration to the country rock. Although the nodules were not analysed it seems that the origins of the guilielmites and nodules are different. The guilielmites may be traces of soft-bodied marine organisms. No vertebrate or invertebrate fossils were found during this study, however such fauna have been recorded from the St. Peters brickpits. These include pelecypods, isopods, insects, and fish fauna (references in Herbert, 1979).

A weathered profile up to 4 metres thick is well developed on the top of the Ashfield Shale around the margins of the quarry. The profile is thicker on the NW margin than the SE margin and usually has a sharp boundary with the underlying shale. In places this profile has been displaced by normal faults. On the SE margin a pisolitic laterite which has developed towards the top of the weathered profile is partly derived from circulating groundwater from the overlying 'Botany Sands'. The extent of the laterite, weathered profile, Ashfield Shale and Botany Sands is shown on fig.46b, in the back pocket.

Overlying the Ashfield Shale in the Botany area is a succession of Quaternary sands, peats and muds called the Botany Sands (Griffin, 1969) which were deposited during the last rise in sea-level between 18,000 and 6,500 years ago. These Sands are up to 70 metres thick at Botany Bay. Blue/grey clay, yellow sand and shell horizons of the Botany Sands directly overlie the laterite on the southern and eastern margin of the quarry. There are no Quaternary sediments on the topographically higher western margin of the quarry.

The sequence of Botany Sands adjacent to the brickpit is up to 4 metres thick although it is generally obscured by man-made fill. The basal part of the Sands consists of a blue/grey clay about 1.5 metres thick which may have an estuarine origin. This clay becomes sandy up the sequence. At locality A (fig.46b) a 0.5 metre section is exposed above the clay and is shown in fig.48. This section contains a 10 centimetres thick layer with abundant small (1 cm diameter) shell fragments in a well sorted sand. Above this fragmented layer is a layer containing disarticulate shells of the bivalve <u>Anadara trapezia</u> (fig.49) with intermittent charcoal fragments. Other shells found in the area include Ostrea. All the shells occur in a well sorted, quartz-rich matrix and were probably deposited at a high water mark when the sea level dropped.

	Guilielmites		Typical Guilielmites (Byrnes et al., 1978)	Matrix		Siderite Band
SiO_2	54.62	54.80	45.8	58.95	61.24	12.91
TiO_2	0.86	0.92	0.69	0.92	0.82	0.20
Al_2O_3	21.10	23.00	16.92	22.57	18.60	5.28
Fe_2O_3(T)	5.13	3.49	9.70	2.49	4.25	43.36
MnO	0.10	0.09	0.15	0.05	0.12	2.59
MgO	1.15	0.91	1.28	0.63	0.82	2.25
CaO	1.23	0.80	4.59	0.21	0.63	2.57
Na_2O	<0.01	<0.01	0.20	<0.01	<0.01	<0.01
K_2O	2.90	3.08	2.39	3.09	2.44	0.68
P_2O_5	0.80	0.58	3.22	0.10	0.21	1.52
SO_3	<0.01	0.04	--	<0.01	<0.01	0.02
L.O.I.	11.35	11.42	--	9.95	10.06	27.14
TOTAL	99.24	99.13	--	98.96	99.19	98.52

Figure 47. Provisional Analyses of guilielmites, country rock and a hard siderite band from St. Peters brick-shale quarry and a typical guilielmite analysis from Byrnes et al., (1978).

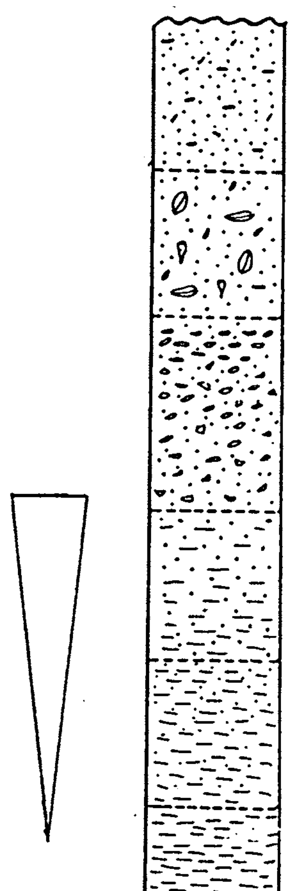


Figure 48. A section through the Botany Sands above the basal clay exposed on the SE margin (position A) of the St. Peters quarry (Locality 32).

Although obscured by man-made fill, the shell occurrences appear to be patchy within a lenticular horizon that extends about 300 metres along the south-eastern edge of the quarry. This horizon thins out to the north-east although it may extend south of the quarry beyond Canal Road where the sand sequence thickens. Although the character of the shells at locality A (fig.46b) points to deposition on a beach front , the possibility of them being aboriginal kitchen middens cannot be entirely dismissed. Aboriginal artifacts were found to the east in similar sediments during excavation for the Alexandria Canal at Sheas Creek (Etheridge et al., 1897).

Overlying this shell and charcoal horizon on the eastern side of the quarry is a sequence of well-sorted yellow sands. The sands consist of sub-rounded grains of quartz, usually coated with an iron oxide giving the sand a yellow appearance. Minor fragments of charcoal and shells are randomly dispersed within the sand. Cross-stratification sets up to 5cm thick occur towards the base of the sands horizon. These sands were probably part of the dune system behind a beach front which may mark the beginning of a regression. In one section 3 thin horizons containing pisolites (small iron-rich nodules) occur within the sand. These may represent periods when the sand dunes were quite stable allowing lateritisation to occur.

These yellow sands thicken from the southwestern corner of the quarry to the northeast. The thickening of the sands may represent the transition from beach in the southwest to dunes in the northeast. The north-western margin of the quarry, which is 15 metres above the southeast margin, formed the ancient shoreline (fig.50). This ancient shoreline of Botany Bay trended in a NE direction from the present quarry to Redfern and may have been structurally controlled.

Structural Geology (fig.46a): The quarry was mapped in three parts; the NE wall, the west wall, and the lower quarry. The most common structure in the quarry is jointing and an analysis of joints is shown in fig.51. Throughout the quarry there two distinct sets. NNE (025-040) trending vertical planar joints are the most common and ENE to ESE (080-120) curved joints of variable (90-40) dip to the north and south form a subdominant set.

NNE trending joints are more continuous than the easterly joints and are up to 10 metres long. Spacing varies from 40cms to only a few centimetres, with the close-spaced jointing occurring close to fault and breccia zones. Although the joint openings are generally narrow, seepage of water and quarrying in places has caused these joints to open up to 20cms.

In the lowest part of the quarry the NNE jointing deviates from the average trend of 030, for the whole quarry, to 020. This sinistral rotation is greater in the southern part of the quarry. The origin of this change in trend is not clear.

Curved easterly trending joints are more complex than the planar vertical NNE joints. They have a wide range of strike and vary in dip from vertical to 10 degrees to the north and south. Joint spacing

Figure 49. Disarticulate and articulate shells of Anadara trapezia in a sand matrix on the SE margin (position A) of St. Peters quarry (Locality 32).

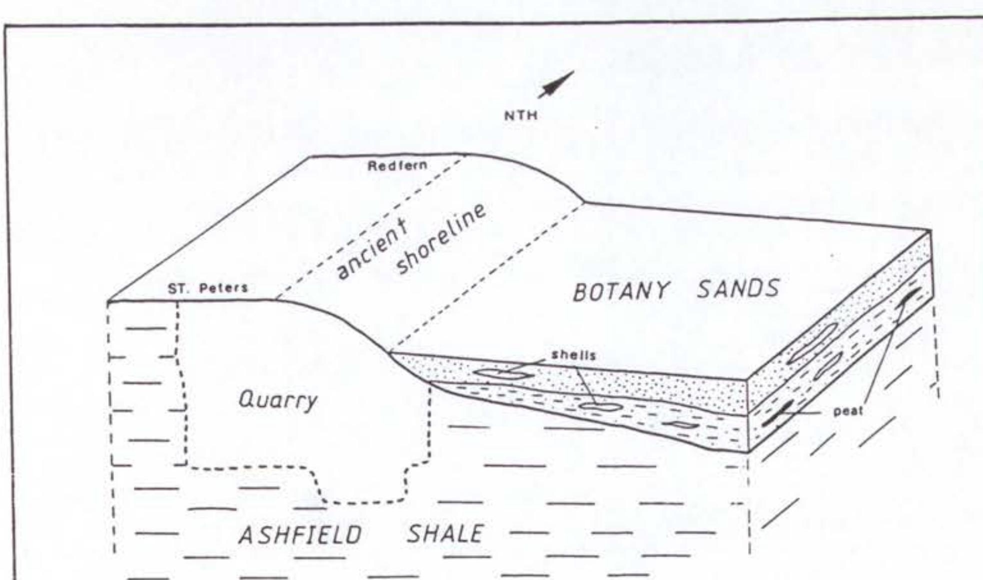


Figure 50. The ancient Botany Bay shoreline at St. Peters.

varies from 0.5 to 2 metres and the joints are less continuous than the NNE joints. NNE planar joints generally terminate against the very curved low angle easterly joints, however the high angle easterly joints terminate against the NNE joints. Some easterly trending joints were observed to curve into the planar NNE joints which may indicate that they are extension joints (Hancock, 1985). Other curved easterly joints were also observed to be associated with small scale slumping indicating that some easterly joints were forming soon after deposition.

Normal and reverse faults with vertical displacements ranging from 2 centimetres to 1.5 metres are common in the quarry. A contoured polar plot of fault planes is shown in fig.52. Fault planes are generally curved and discontinuous. Zones of intense vertical jointing, some showing vertical displacement and brecciation, are also present. There appearto be six distinct fault sets:

1. Normal faults dipping NW: These consist of a series of curved normal faults dipping at low angles (about 20 degrees) to the northwest (fig.53). These are continuous for only short distances, usually less than two metres. Vertical displacement of bedding is usually less than 2cm and NNE joints usually cut through or terminate against the fault plane.

Curved joints orientated in a similar direction are often slickensided and were probably formed contemporaneously with these faults although movement due to unloading cannot be dismissed.

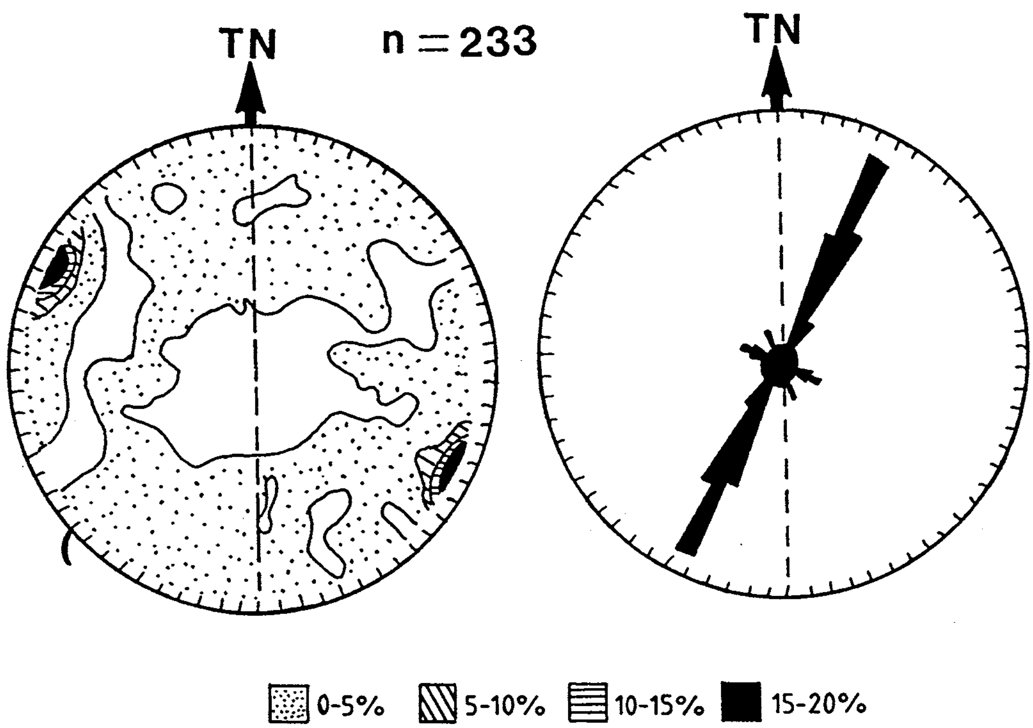


Figure 51. Contoured equal area polar plot and rose diagram of joints at St. Peters quarry (Locality 32).

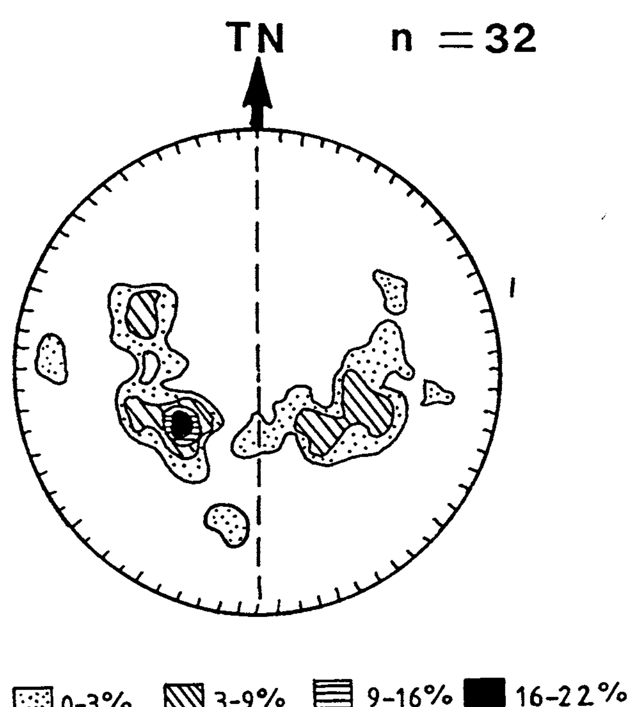


Figure 52. Contoured equal area polar plot of faults at St. Peters quarry (Locality 32).

2. Reverse Faults Dipping NE to E: These consist of reverse faults dipping at moderate angles (25 -50) to the NE and are located in the basal part of the quarry. They displace the NW dipping normal faults and NNE joints, (fig.54). Vertical displacements is between 2cm and 4cm. They are more planar and generally dip more steeply than the normal faults referred to above. They are also more continuous extending for more than 4 metres. Brecciation is sometimes associated with these faults.

3. Easterly Dipping Normal (and Minor Reverse) Faults: These are planar faults dipping at angles of 40 to 60 in directions varying from NE through to SE. These faults have the largest displacements measured (up to 1.5m). Some of the higher angle normal faults have a wedge of brecciated material adjacent to the fault plane. These easterly dipping normal and reverse faults do not appear to have been displaced by any other faults within the quarry.

4. Westerly Dipping Reverse Faults: These faults are less common. They are generally planar and dip at angles of 50 to 60 to the NW. Vertical displacement is small, up to 4cm. However, these faults are probably the most continuous of any of the faults, extending up to and through the weathered zone in the uppermost part of the quarry. Fault planes often splay causing a heavily fractured zone. In the NE corner of the quarry a westerly dipping reverse fault which displaces a siderite band is subparallel to a series of normal faults. However, dragging of beds adjacent to the fault including the siderite band, indicates that normal movement has taken place. In this case normal

Figure 53. Curved, NW dipping normal faults displaced by a NE dipping reverse fault at St. Peters quarry (Locality 32).

Figure 54. NE dipping reverse fault displacing NNE joints at St. Peters quarry (Locality 32).

movement may have taken place first and then rebounding occurred resulting in reverse movement. Rebounding may have occurred because of the close proximity of the Ashfield Shale/Hawkesbury Sandstone boundary, with the sandstone being stiffer than the Ashfield Shale.

5. Westerly Dipping Normal Faults: A number of westerly dipping normal faults have the same orientation as the previously mentioned reverse faults. These faults often splay resulting in a wedge of brecciated material. Small drag folds adjacent to some of these faults (fig.55a and fig.55b) indicate that reverse movement may have taken place prior to dip slipping.

6. Vertical NNE Trending Shear Zones: Zones of intense vertical NNE trending jointing are quite common (fig.56a). These zones intersect all other fault planes. Brecciation (fig.56b)is often associated with such zones. No displacement is usually apparent, but at one locality a NW dipping reverse fault is displaced vertically 0.75m, and elsewhere easterly joints curve into the NNE joint zones. Horizontal displacement may have occurred parallel to the shear zone in addition to vertical movements.

Except for intense jointing associated with NNE shear zones, jointing at St. Peters brickpit appears to have originated prior to faulting. There appear to have been 2 primary directions of stress resulting in faults dipping in almost opposite directions. These faults display both normal and reverse movements. Where cross-cutting relationships exist, faulting along planes dipping westerly occurred prior to

Figure 55a. Westerly dipping listric fault at St. Peters quarry (Locality 32).

Figure 55b. Reverse drag folds adjacent to the fault in fig.55a.

Figure 56a.

Vertical close-spaced NNE joints and normal fault displacing a NW dipping fault at St. Peters quarry (Locality 32).

Figure 56b.

Breccia in joint zone shown in fig.56a.

faulting along easterly dipping planes. In both cases compressional deformation gave rise to thrusting prior to slipping along pre-existing fault planes. Remobilisation along NNE jointing causing lateral shearing and vertical displacement occurred subsequent to both periods of thrusting and slipping. There appear to have been 2 phases of compressional deformation, each in turn followed by stress relief.

B. The Northern Suburbs Railway:

The fracture characteristics of railway cuttings between Warrawee and Lindfield were examined because of the good exposures of Ashfield Shale and because the NNW trend (approximate) of the cuttings should provide a good statistical analysis of east-west fracturing. 13 localities (1-13, fig.43) were examined and a rose diagram and polar plot of joints is shown in fig.57.

Except for warping around the margin of the Hornsby Plateau, the regional dip of the Ashfield Shale is 1 to 2 degrees to the south. However, because the dip of beds in the cuttings is variable (up to 12 degrees) adjacent to faults, this regional dip was not evident. The variable dip in the railway cuttings may be due to the close proximity of the Roseville Warp which is generally 1 kilometre to the west and subparallel to the railway.

The most dominant joint set exposed in the railway cuttings trends NNE (010-020). These joints are planar, generally vertical and more extensive, horizontally and vertically than other joints. However, at locality 7 NNE planar joints dip at high angles to the east and the beds dip 12 degrees to the NW. At this locality the NNE joints have either been rotated due to local folding or they developed as a-b tensional joints. At localities 9, 10 and 12 faults and small anticlines and synclines with amplitudes up to 2 metres occur and NNE joints are vertical. In these cases, NNE joints probably formed subsequent to minor folding and faulting. Because NNE vertical joints are regionally developed it seems likely that the easterly dip of NNE joints at locality 7 were rotated as a result of local folding.

NNE joints also form zones up to 2 metres wide in which joint spacing is 4-10cm and there is minor brecciation. Regionallly, NNE joints are spaced about 1.5 metres. No displacement was observed in these zones although faulting has probably taken place.

N-S planar, vertical joints are also common. However it was not clear whether N-S joints form a separate set to NNE joints. Fig.57 shows that there is a statistical gap between the N-S and NNE joints and that these joint sets have accompanying orthogonal sets trending E-W (090-095) and ESE (100-105). This suggests that the two northerly sets are separate.

The easterly-trending joints are both planar and curved. They are not as extensive as NNE joints and generally abut against NNE joints. Easterly joints have a variable dip from 55 degrees to the north and south and can have slickensided faces. Some of these joints may be related to faulting.

NE and NW trending joints were also observed. However, they are not common. At locality 4 a NE joint terminated against a NW joint although no other terminations were observed. The relationship of these joints to other joint sets is unknown.

Faults are common in the cuttings and usually result in tilting of the surrounding beds. Fig.58 shows a polar plot of faults. Small reverse drag folds are common adjacent to the fault planes even where there is apparent normal displacement. This suggests multiple deformation has taken place. At locality 12 and at other localities low angle (20-40 degrees) planes, some of which are associated with breccia, dip to the west and NW. Some planes have reverse movement but displacement is not usually evident. The low angle of the planes suggests that they are mostly thrusts. The relationship of these faults to NNE and other joints was not recognised. These westerly-dipping reverse faults are the most common fault set although other faults also exist. Unlike St. Peters , where it could be suggested that thrusts resulted from unloading, it seems unlikely that the small thrusts at locality 12 developed after excavation of the cutting. The thrusting from the west could be related to regional tectonics such as flexuring on the adjacent Roseville Warp.

C. The Coastal Region:

Fracturing at 5 localities (29, 30, 35, 41 and 45, fig.43) was examined along the coast between North Head and Long Reef. These sites were chosen because of the good three-dimensional outcrop which should aid the regional analysis of the Sydney region. Where possible

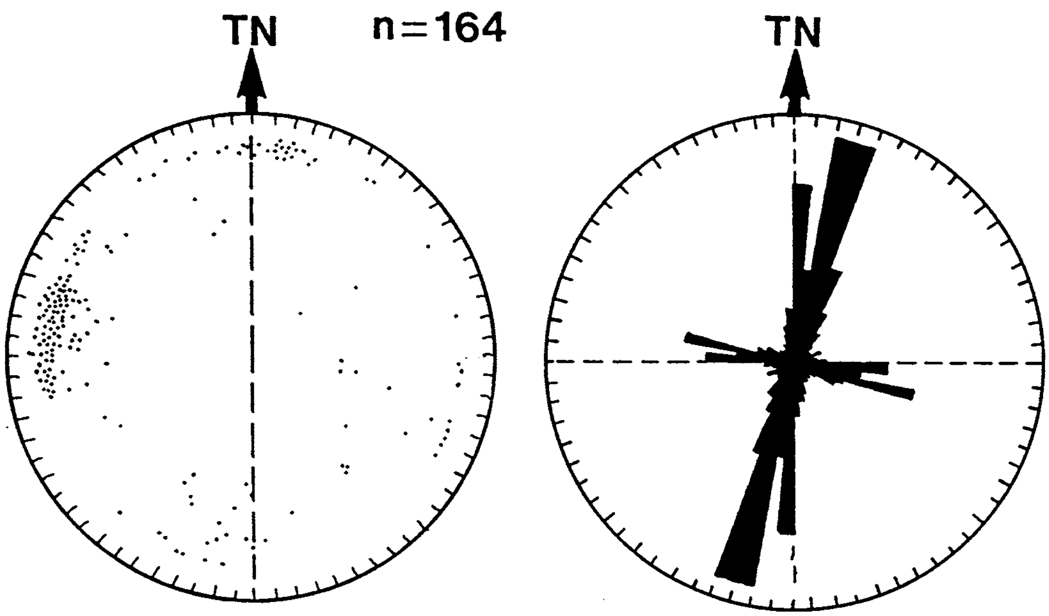


Figure 57. Equal area polar plot and rose diagram of joints along the northern suburbs railway.

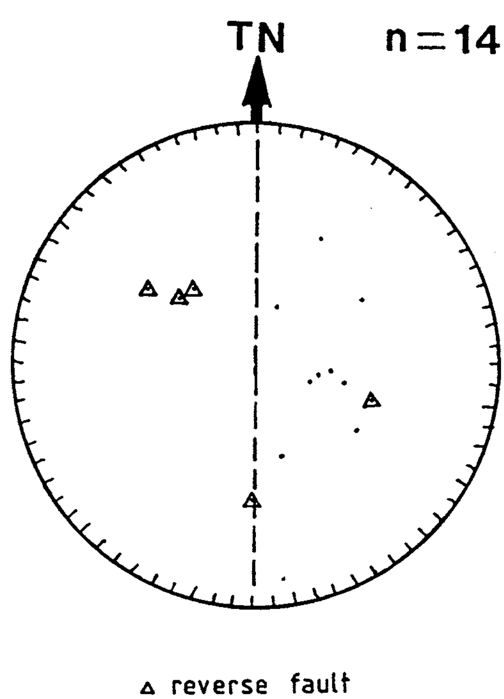


Figure 58. Equal area polar plot of faults along the northern suburbs railway.

a fracture analysis was conducted in the cliffline as well as the rock platform so that the dip of joints could be examined. The rock platforms, such as at Long Reef (Loc.30), provide good information on joint orientation and intersection but give little indication of the dip of the joints.

An analysis of fracturing examined during the present study at the above localities is shown in fig.59. The most common joint sets along the coast trend NNE and NW. However, fig.59 shows that there are other minor sets trending NE, ESE to SE and ENE.

The NNE joints are generally planar and vertical and at North Head (Loc. 35) form large master joints which are spaced about 2-5 metres and are clearly visible on aerial photo. Coffey and Partners (1983) also recognised these joints and an orthogonal set trending 105. A contour polar plots of joints at North Head from Coffey and Partners (op. cit.) is shown at fig.60. Mauger et al. (1984) also recognised these joints and another set trending 150. These orientations are similar to those found during the present study.

On the North Head peninsula, east of Cabbage Tree Bay (Loc.41), two orthogonal joint sets are developed. NNE and ESE joints form the dominant orthogonal set and NE and NW joints form the less dominant orthogonal set.. ESE joints generally terminate against the NNE joints and are both planar and curved. NNE joints are planar, vertical and more extensive than the ESE joints.

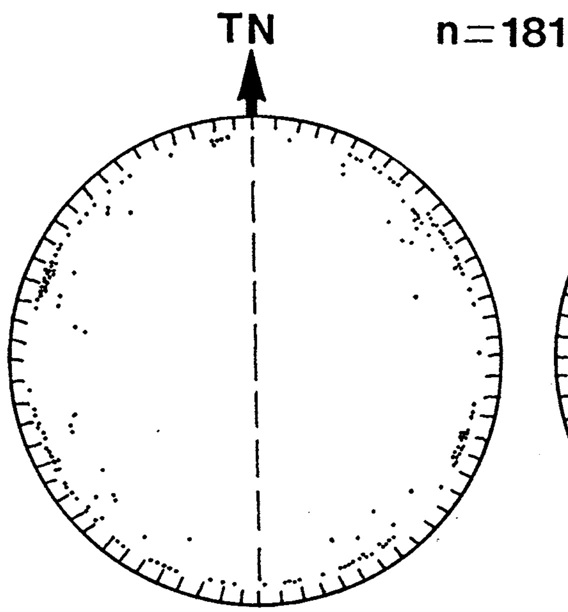


Figure 59. Equal area polar plot and rose diagram of fracturing in the coastal region.

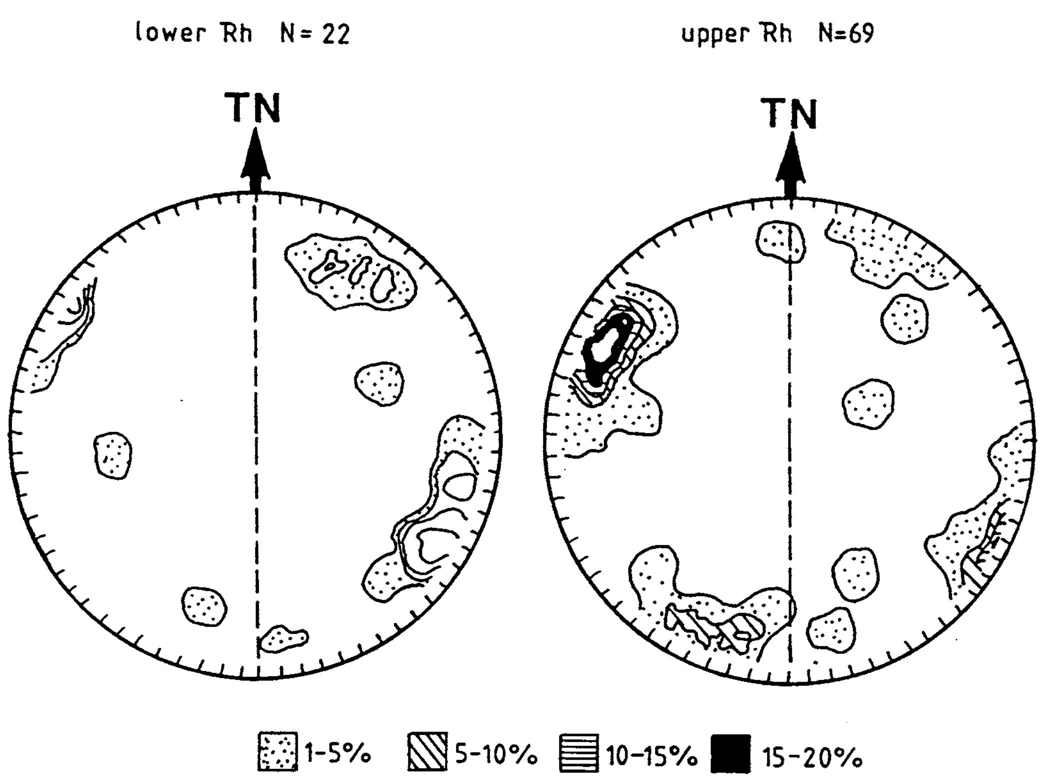


Figure 60. Contoured polar plots of joints at North Head (Coffey and Partners, 1983).

A dyke at Loc.41 strikes 122 and there are many subparallel NW trending joints with an orthogonal set trending NE. NNE and NE joints were not observed together and it is not clear whether they form two separate sets or whether the NNE joints changed orientation from NNE to NE to become orthogonal to the dyke and its associated joints. A rose diagram of fracturing at Loc.41 (fig.61) shows that the two orthogonal joint sets are well-developed and statistically separate. If NNE and NE joints form separate sets then their formation must relate to different stress conditions and the NE joints probably formed as an orthogonal set to the dyke.

At Dee Why Head (Loc.29) the most dominant joint set trends NW and has an orthogonal NE trending set. NW master joints and joints are more common and generally more extensive and more closely spaced than NE joints. However, NW joints terminate against NE joints and a minor set of NNE joints. The NW joints can be seen on airphotos and form a southerly continuation of a broad area containing NW trending dykes shown on the Sydney 1:100,000 geology sheet. However, no dykes were observed at Dee Why Head.

Both NE and NW joints at Dee Why form zones in which spacing is as close as 10cm. Like Loc.41, both NNE and NE joint sets and their orthogonal joints are developed at Dee Why Head. Again NNE and NE joints were not observed together and it is not clear whether they form one or two separate sets or whether they are conjugate.

At North Curl Curl (Loc.45) to the north of Dee Why Head the dominant

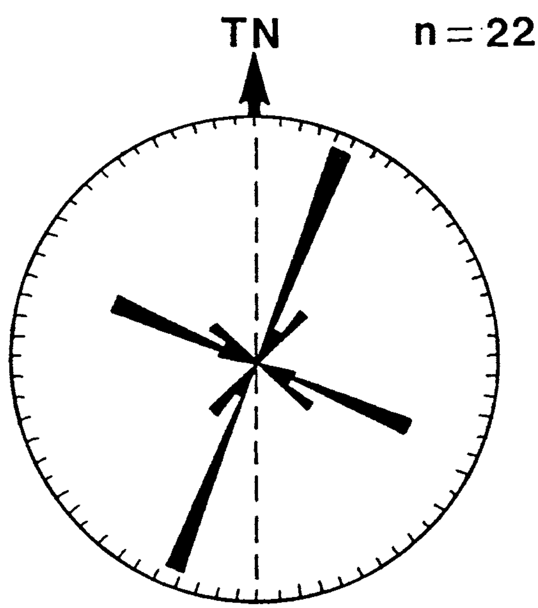


Figure 61. Rose diagram of joints east of Cabbage Tree Bay (Locality 41).

joints are NNE planar vertical joints. NE and NW planar and vertical joints form subdominant sets. In contrast to Dee Why where NW joints terminate against NE joints, NNE and NE joints at North Curl Curl generally terminate against the NW joints. Subvertical NNE joint zones are also common. One NNE zone which is about 2 metres wide contained numerous small scale (up to 10cm) horst-graben faults and brecciation. Within this zone the orientation of joints varied from 015 to 036 possibly reflecting a horizontal conjugate set. Similar subparallel joint/fault zones occur to the south such as at Lavender Bay, Cremorne and Balmoral (section 3.32). The NNE zones at North Curl Curl may be a northerly extension of a zone between Mrs Macquarie's Chair and Balmoral although the lack of outcrop hindered this investigation. ESE joints form an orthogonal set to the NNE joints at North Curl Curl although they are not as continuous as NNE joints. Like Loc 41 and 29 there appear to be two orthogonal sets with the dominant set containing joints trending NNE and NW.

At Long Reef Point (Loc.30) joint orientation was more variable and joints were less extensive than at other localities along the coast. This may be a result of the lithological variation. Bald Hill Claystone outcrops at Long Reef while elsewhere fractures were analysed in overlying sandstones and siltstones of the Newport Formation and in the Hawkesbury Sandstone. Never-the-less at Long Reef NNE joints and NW joints are quite common and NNE joints generally terminate against NW joints. A dyke trending 147 crops out on the rock platform. This dyke terminates against and steps across NE -ENE joints. This suggests that the NE-ENE joints formed prior to dyke emplacement which was probably between Late Cretaceous and Jurassic (Herbert, 1983). There is no evidence that the dyke has been laterally displaced along these NE-ENE joints. Herbert (op. cit.) also recognised the stepping of this dyke. ENE joints are quite common and generally cut across the dyke, however, the relationship to other joints was not observed.

NW trending joints which parallel the dyke at Long Reef have an orthogonal NE (050-055) set. This NE set strikes more easterly than NE joints at the other localities along the coast probably as a result of the more northerly strike of the dyke at Long Reef than dykes elsewhere along the coast and in the Sydney area. NE joints with a similar strike to the joints at other localities along the coast were not observed at Long Reef. Coffey and Partners (1983) recognised two joint sets at Long Reef, one trending 020-030 and the other 105. Mauger et al. (1984) recognised an additional set trending 150 which is subparallel to the dyke. It is not clear why Coffey an Partners (op. cit.) did not recognise these NW joints.

NE joints along the coast in the Sydney Region appear to form an orthogonal set to NW joints which subparallel dykes in the area. The variation in strikes of the NE joints probably reflects changes in strike of the dykes. NNE joints exist at all localities and appear to form a separate set to the NE joints. NNE joints terminate against NW joints and in some cases NW joints terminate against NNE joints. This suggests that NNE joints formed both prior to and subsequent to dyke emplacement. At Dee Why Head NNE joint zones contain normal faults and possible horizontal conjugates suggesting that they have been the sites of multiple deformation, including lateral compression. ENE and ESE joints are minor and not very continuous. Their relationship to other joint sets was not observed, although some ENE joints probably formed subsequent to dyke emplacement as evidenced at Long Reef.

In chapter 2 it was suggested that the NNE planar joints which formed a well developed regional set were rotated to the NE along the coast and consequently formed the 'coastal domain'. Evidence along the coast in the Sydney region suggests that both the NNE and NE joints are present and that the dominance and strike of the NE joints is related to the dominance and strike of NW joints which are subparallel to dykes in the area. Therefore in the 'coastal domain' of the Kuring-gai/Berowra area NE joints may be more dominant than NNE joints because of nearby NW trending igneous intrusions. Although few NW dykes crop out on the headlands in the Kuring-gai/Berowra area many of these dykes which impose a NE orthogonal joint set on the headlands may be obscured by beach sand.

3.32 NNE TRENDING STRUCTURES:

A. The West Head Lineament:

In the Kuring-gai/Berowra area (chapter 2), the West Head Lineament was observed to extend in a NNE direction from Terrey Hills towards West Head for about 10 kilometres. With field mapping to the south, in the Sydney Region, the extent of this Lineament was further increased from Belrose (Loc.36) to West Head and possibly as far south as Lindfield (Loc.54) where there are planar close-spaced NNE trending master joints subparallel to the Lineament. The extent of the lineament in the Sydney Region is shown in fig.62.

In the Kuring-gai/Berowra area the West Head Lineament consists of a dominant subparallel NNE master joint set which are usually greater than 15 metres in horizontal extent, planar, vertical, closely spaced (0.5-3.0m) and right stepping. In the Sydney Region similar master joints also exist.

At Terrey Hills (Loc.34), large (30m) planar NNE joints are well developed and form a zone about 40-50 metres wide in which joint spacing is 1-3m. NNE joints terminate against ESE joints which are parallel to a dyke trending 117 and one NW joint terminates against a NNE joint. Left-stepping NNE master joints are also common which contrasts with the right-stepping joints at West Head. At this locality NNE joint development appears to have been subsequent to dyke emplacement.

At Belrose (Loc.36), the NNE trending lineament consists of 2 dominant joint sets; a NNE trending set and a NE trending set, both of which consist of closely spaced, planar, vertical joints (fig.63). However, the NE set contains more joint zones than the NNE set. NNE joints are often right-stepping and display end point en echelon fractures like the NNE joints at West Head. The relationship of the NNE set to the NE set could not be determined except that they both occur within the West Head Lineament and that NNE joints tend to step into NE joints.

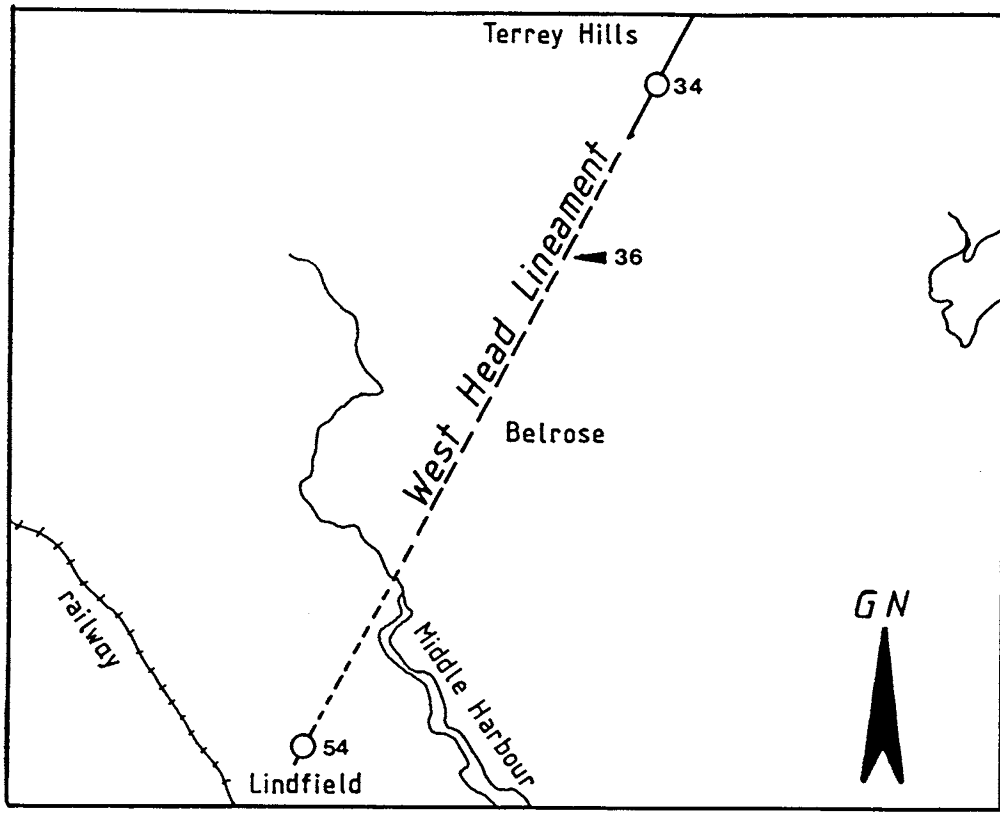


Figure 62. Extent of the West Head Lineament in the Sydney Region study area.

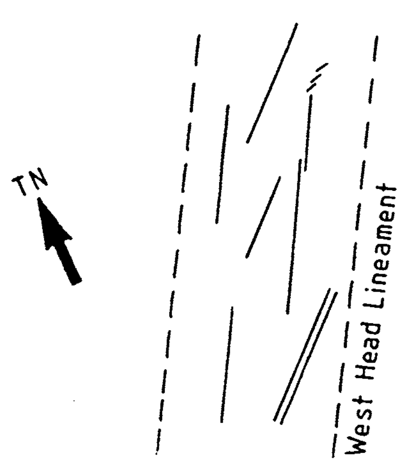


Figure 63. Jointing at Belrose (Locality 36) within the West Head Lineament.

The NE and NNE joints at Belrose may form a conjugate set, which implies that they formed as a result of a NE/SW (037) maximum horizontal compression. Alternatively, the NNE joints may represent a pre-existing set of extension joints and the NE joints may be shear joints which developed subparallel to later compression. Instead of the NNE joints being extended by a NE-SW shear couple, which was suggested for the joints at West Head, a separate NE-trending shear joint set developed. The reason for a difference in joint development at West Head and Belrose is unknown. However, along the coast NE joints are more common where there is a NW trending dyke or where NW joints form the dominant set (section 3.31C). While no NW joints or dykes were exposed at the Belrose locality, dykes do exist in the vicinity as shown on the Sydney 1:100,000 geology sheet and it seems more likely that the NE joints at Belrose form an orthogonal set to the NW dykes than separate shear joints. In addition, NNE joints tend to step into NE joints suggesting that the NE joints formed a pre-existing set.

At Lindfield (Loc.54) planar, close-spaced (1-3m) joints are well developed and may be a southerly extension of the West Head Lineament. ESE joints with rough faces terminate against NNE joints and have a greater spacing (5m) and less horizontal extent. The mapping of the Lineament further to the south is limited however by urban development.

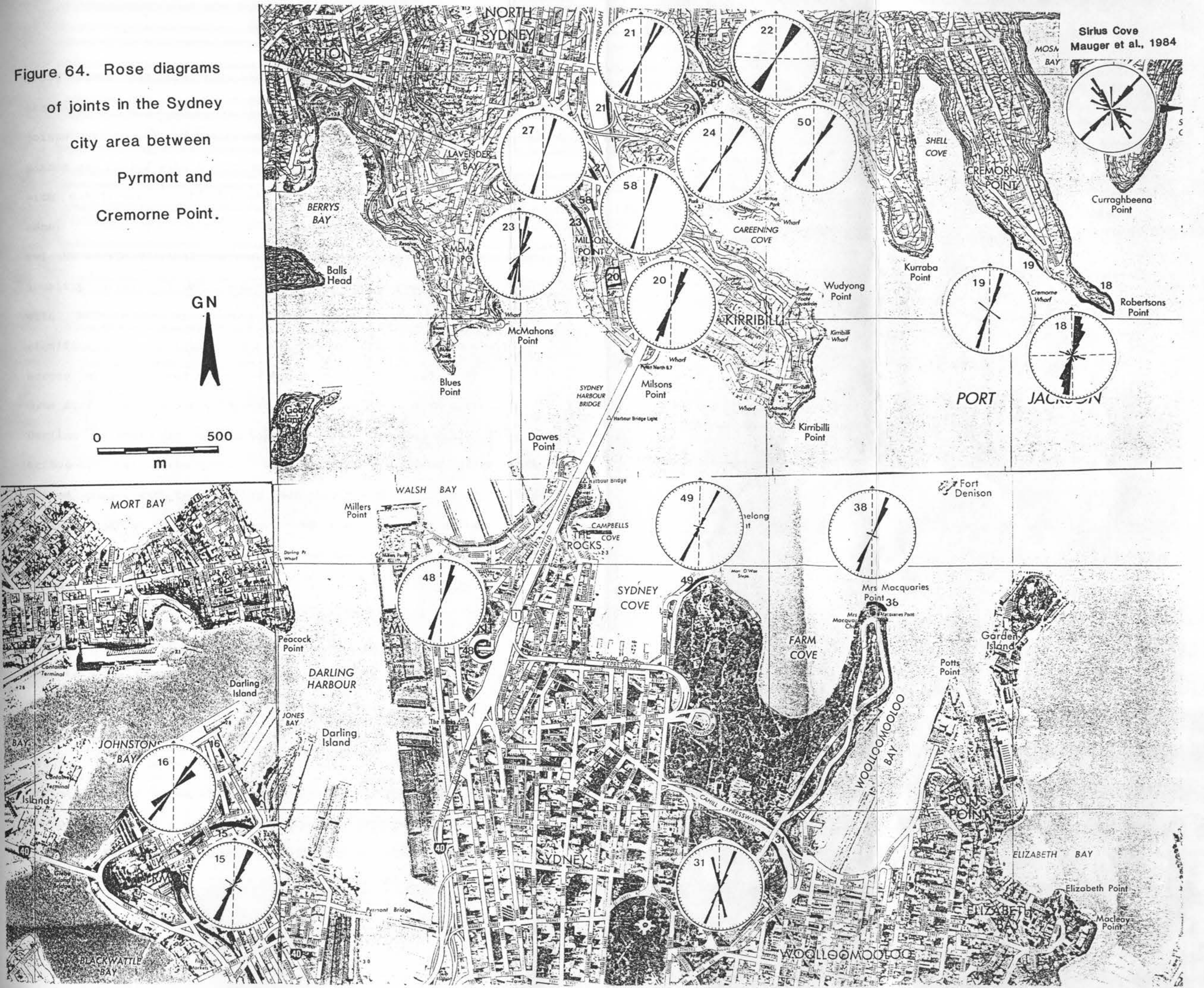
B. Pyrmont-Lavender Bay-North Sydney-Anderson Park Fracture Zones:

A number of NNE to NE trending zones containing close-spaced (10-

50cm), vertical to westerly dipping joints, brecciation and normal faults were observed between Pyrmont and Neutral Bay. These fracture zones were examined at localities 15, 16,, 20, 21, 23, 24, 27, 48, 50 and 58. Fracturing at the above localities is summarised on rose diagrams in fig.64. While the horizontal continuity of these zones could not be established due to lack of outcrop, a number of them appear to be continuous for up to 1 kilometre. All of the zones are subparallel.

At Pyrmont two localities (15 and 16) were examined. Within the Pyrmont railway cutting (Loc.15) a vertical dyke 0.5m wide strikes 172, whilst the dominant joint set and joint zones trend 018-035. These joints are planar, vertical, with an average spacing of 4 metres and a vertical extent of up to 6 metres and the joint zones are up to 1 metre wide. There are no joints subparallel to the dyke and N-S joints are rare in the Sydney City and Sydney Region areas. The strike of this dyke is also unusual because most dykes in the Sydney Region, such as at Grosvenor Place (Loc.57) and Haymarket (Loc.51) trend WNW to NW. Although, it should be noted that Rickwood (1985) believes that there is no consistency of dyke direction over large areas. The development of NNE-NE joints and joint zones in the Pyrmont railway was probably subsequent to dyke emplacement since the dyke strikes N-S rather than NNE-NE. The dyke wall also contained slickensides dipping 5 degrees to the north which indicates that either dyke emplacement was subhorizontal or that lateral movement has occurred along the dyke wall after intrusion.

Figure 64. Rose diagrams of joints in the Sydney city area between Pyrmont and Cremorne Point.



Along Jones Bay Road (Loc.16) two joint sets exist within a zone trending 052 and 1 metre wide. One set trends 032-037 similar to joints at Loc.15 and the other trends 045-059. These joints are planar and filled with ironstone or clay. Subparallel normal faults with displacement up to 10cm and brecciation are also confined to the zone. These two joint sets may be conjugate, but this was not evident in the vertical section. NE joints do not exist at any other locality between Pyrmont and Neutral Bay and if they are conjugate with NNE joints at Pyrmont they probably are not regionally significant. The dyke at Grosvenor Place strikes 122 and should cut across Darling Harbour about 300 metres north of Loc.15. While this dyke strikes WNW in George Street, it may swing to a NW direction in Darling Harbour and the NE joints in Jones Bay Road would form an orthogonal set to the dyke. Also, if NNE joints and joint zones formed subsequent to NW dykes then they may tend to become NE in strike adjacent to the NW dykes. NE joints adjacent to both dykes and NW dominant joints were also observed along the coast in the Sydney region.

At Lavender Bay (Loc.23) close-spaced (40cm) westerly dipping (53-66) NNE trending joints form a zone 4 metres wide (fig.65). Away from this zone NNE joints are spaced about 5 metres. At Greenwich Point, 1.5 kilometres west of Lavender Bay, no planar joints with extent greater than 1 metre were observed. The Lavender Bay zone may have influenced the shape of the bay and probably continues into Cliff Avenue (Loc.58). A master joint zone, 1.5 metres wide, crosses the Warringah Expressway (fig.66, Loc.21) and may also be a continuation

Figure 65. Close-spaced westerly dipping NNE joints at Lavender Bay (Locality 23).

Figure 66. NNE joint zones on the Warringah Expressway (Locality 21).

of the fracture zone in Cliff Avenue and Lavender Bay. This master joint zone contains breccia and both east and westerly dipping joints spaced as close as 5cm. There are other subparallel close-spaced (30cm) joint zones on the Warringah Expressway to the north of the master joint zone and similar zones in Middlemiss Street (Loc.27). Along the Warringah Expressway from Cammeray (Loc.37), where there is a possible subparallel westerly dipping fault, to North Sydney, zones of intense jointing are separated by blocks of essentially intact sandstone with widely spaced (30-40) NNE joints. These blocks of intact material appear to increase in size away from the North Sydney fracture zones.

At Glen Street, Milson's Point (Loc.20) to the east of the Lavender Bay-Cliff Avenue-Warringah Expressway fracture zone, four subparallel westerly-dipping master joint zones were observed (fig.67). The largest zone is 15 metres wide and the joint spacing is 30-10cm. Normal faults with displacement up to 20cm are common (Fig.68) and the general throw is with the east-side down. The spacing between the zones is between 5 and 15 metres which is closer than the spacing of zones along the Warringah Expressway which is about 30 metres. All the joints at Glen Street dip to the west (70-86) as do most joints and joint zones in the Milson's Point-North Sydney-Neutral Bay area.

At Anderson Park, Neutral Bay, a zone of close-spaced (30cm) westerly dipping NNE joints continues from Kurraba Road (Loc.50) to a similar fault/joint zone at Clarke Road (Loc.24). This zone is subparallel to the fracture zone on the Warringah Expressway and may be an

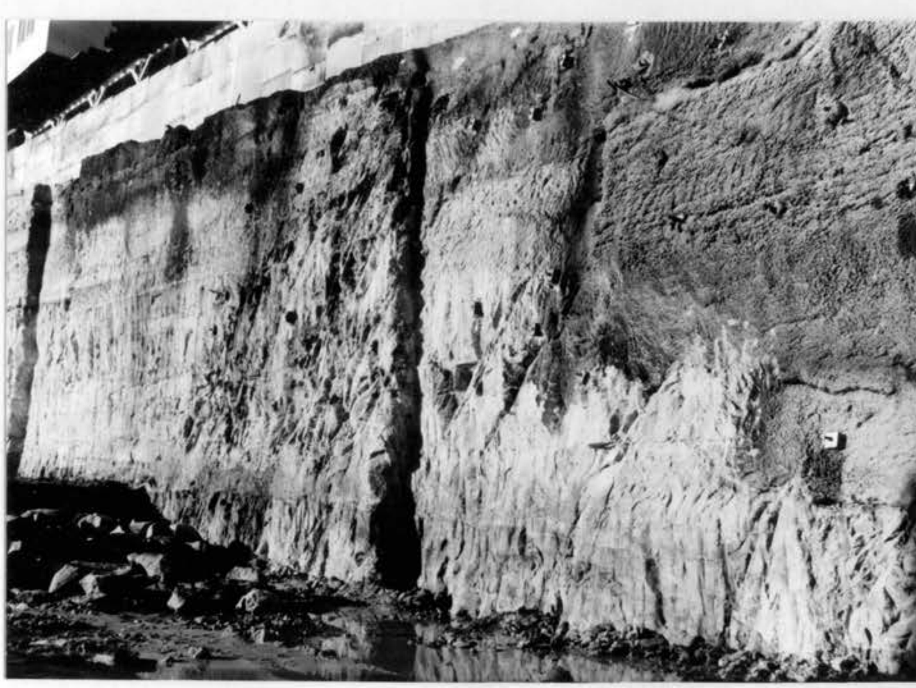


Figure 67. Westerly dipping NNE joint zones at Glen Street, Milsons Point (Locality 20).

extension of the fault/joint zones at Glen Street, Milson's Point.

At Clarke Road, the joint spacing is about 0.5 metres adjacent to a high angle fault. The fault plane along which a siltstone bed has been displaced (fig.69) dips about 70 degrees to the east while a sandstone breccia abutting and adjacent to the fault dips 49 degrees to the west. The siltstone bed has been displaced 1.5 metres along the easterly dipping fault plane and there has been normal movement. Reverse faulting may have occurred adjacent to the westerly-dipping breccia. This indicates that the fault zone at Clarke Road has been the site of multiple deformation with normal faulting occurring subsequent to reverse faulting.

C. Art Gallery-Mrs Macquaries Chair-Cremorne-Balmoral Fracture Zone:
Close-spaced (10-50cm) NNE trending joints, breccia zones and faults appear to form a continuous zone from the N.S.W Art Gallery to Edwards beach, Balmoral and may continue to Dee Why. Fracture analyses were undertaken adjacent to the Art Gallery (Loc.31), Mrs. Macquarie's Road and Chair (Locs 65 and 49), Cremorne Point and Reserve (Locs 18 and 19) and at Balmoral (Locs 14 and 40). Rose diagrams of fracturing around Port Jackson are shown on fig.64.

In the Cahill Expressway cutting, adjacent to the Art Gallery (Loc.31), there are two dominant planar joint sets which trend NNW and NNE. NNW joints dip between 69-88 degrees to the WSW and occur on the northerly side of a easterly striking low angle dipping bed of breccia. The breccia plane and breccia are shown in figs 70a and 70b.

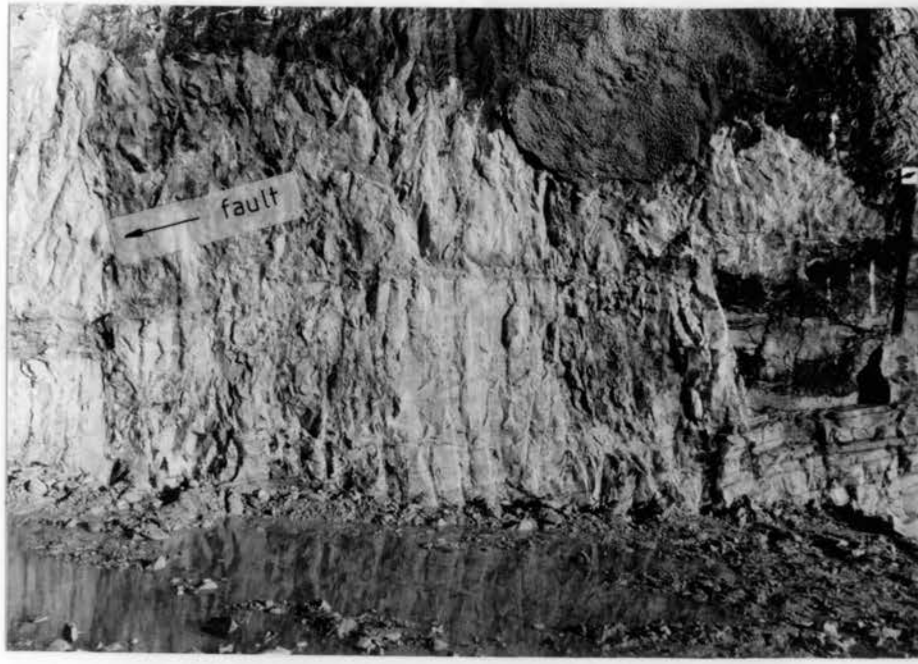


Figure 68. Normal faults (east-side down) within a joint zone at Glen Street, Milsons Point (Locality 31).

Figure 69. High angle NNE fault in Clarke Road (Locality 24).

NNE joints dip between 69-78 degrees to the East and occur on the southerly side of the breccia plane. A diagrammatic cross-section of the Cahill Expressway cutting is shown in fig.71. Minor normal faulting with displacement up to 2 centimetres was observed on NNE trending discontinuities.

The NNW and NNE joints may form a conjugate set although they were not observed to cut across or abut each other. If these joints are conjugate then σ_1 would plunge 37 degrees to 005 at the time of their formation.

The lack of continuity of bedding planes across the breccia, which dips about 25 degrees to 350, suggests that faulting has also occurred at this locality. The breccia is variable in thickness, with a maximum thickness of 1.5 metres, and consists of angular fragments of sandstone (fig.70b) up to 30cm in diameter cemented by iron-rich material. If the above joints are conjugate then this breccia may be part of a low angle reverse fault with thrusting from the NNW to north. At Pyrmont railway (Loc.15) slickensides on a dyke wall also plunge to the north. A northerly plunging σ_1 is difficult to explain especially as the present topography and bedding dips to the south. The important point is that σ_1 strikes in an approximate north-south direction.

Along the western side of Woolloomooloo Bay (Loc.65) easterly dipping planar joints are dominant and are spaced between 1 metres and 10 centimetres. These joints are similar to those on the southern or

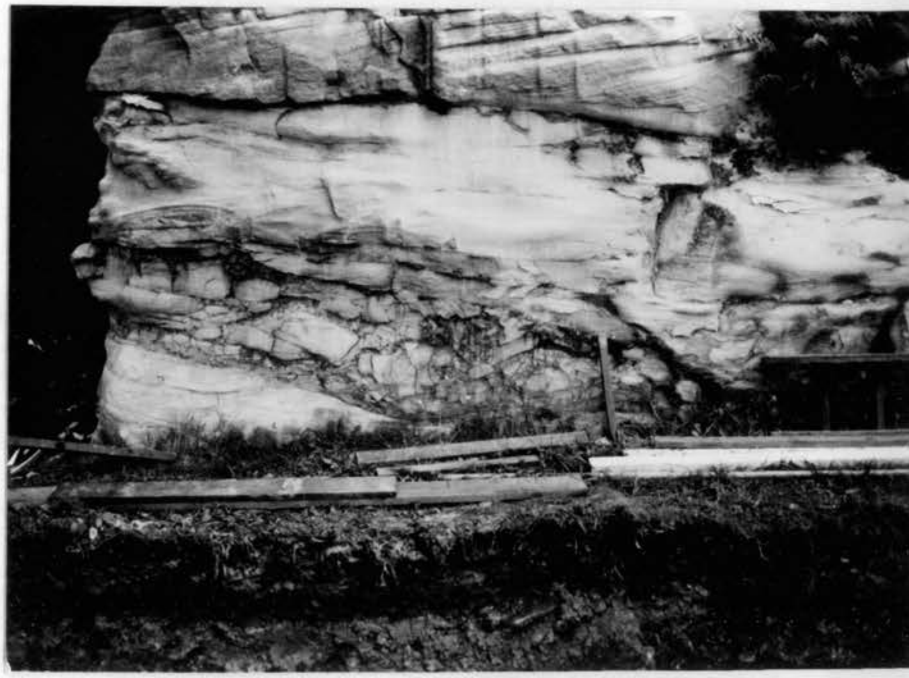


Figure 70a. Northerly-dipping low angle breccia plane in the Cahill Expressway, near the Art Gallery (Locality 31).

Figure 70b. Breccia adjacent to plane shown in fig.70a.

underside of the fault breccia at the Art Gallery (fig.71). High angle N-S to NNE westerly dipping joints also exist and were also observed to be vertically conjugate with the easterly dipping joints (fig.72). At Mrs. Macquarie's Chair (Loc.38) the westerly dipping NNE joints are more common than the easterly dipping NNE joints. To the west of Mrs. Macquarie's Chair easterly dipping NNE joints are almost non existent. Between the Art Gallery and Mrs. Macquarie's Chair this zone of close-spaced NNE joints is about 150 metres wide, with the westerly-dipping joints on the west-side of the zone and the easterly-dipping joints on the east side of the zone. Vertical and horizontal conjugate joints occur towards the centre of the zone along with a possible easterly striking reverse fault. Away from this zone joint spacing increases such as at the Opera House (Loc.49) where it is 3.5 metres.

At Cremorne Point both easterly and westerly-dipping NNE dominant planar joints exist. The easterly dipping joints occur on the Point (Loc.18) while the westerly dipping joints occur about 400 metres to north-west at Cremorne Reserve (Loc.19). At Loc.18 there is also a minor N-NNE (002-017) joint set which is confined between the NNE joints. These joints may form a conjugate set. NW trending joints are both planar and curved and generally cut across or abut against the NNE joints. NNE trending joint zones upto 2 metres wide containing close-spaced (5.20cm) joints and breccia also exist (fig.73). Small horst-graben faults are often associated with these zones, similar to faults in a subparallel zone at Glen Street, Milson's Point. The Sydney 1:100,000 geology sheet shows NNE and NW

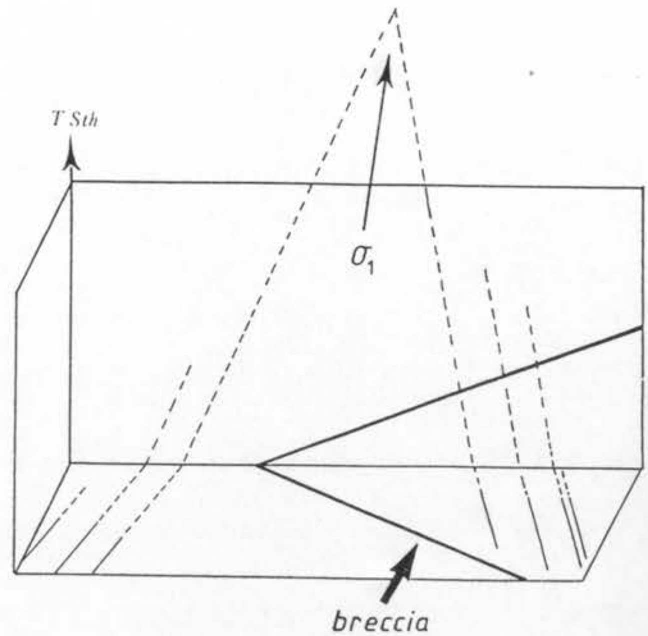


Figure 71. Diagrammatic cross-section of the Cahill Expressway cutting (Locality 31) showing inferred direction of compression.

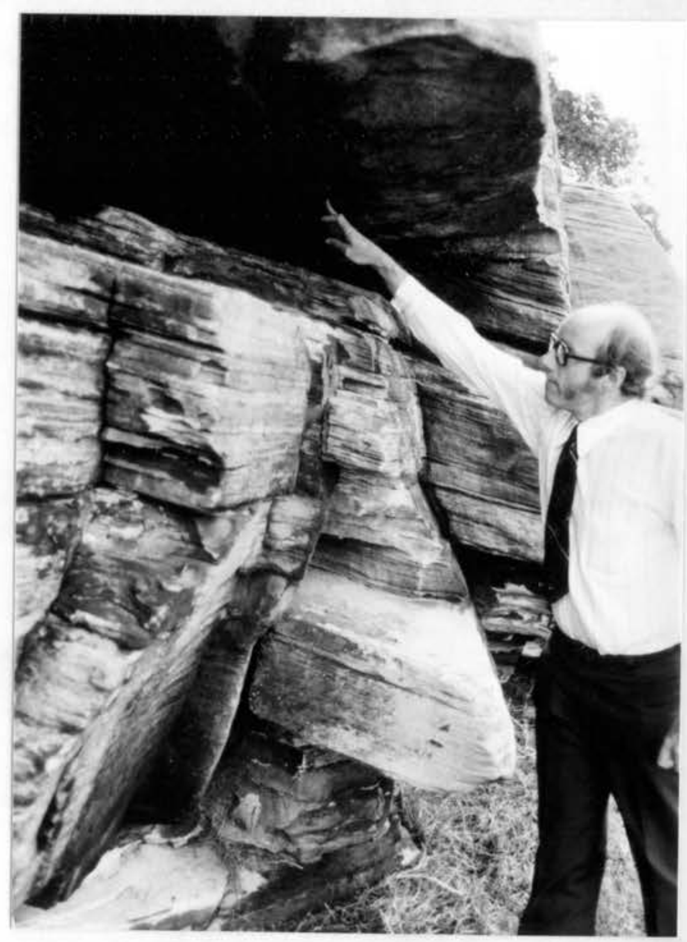


Figure 72. Vertical conjugate NNE joints at Woolloomooloo Bay (Locality 65).

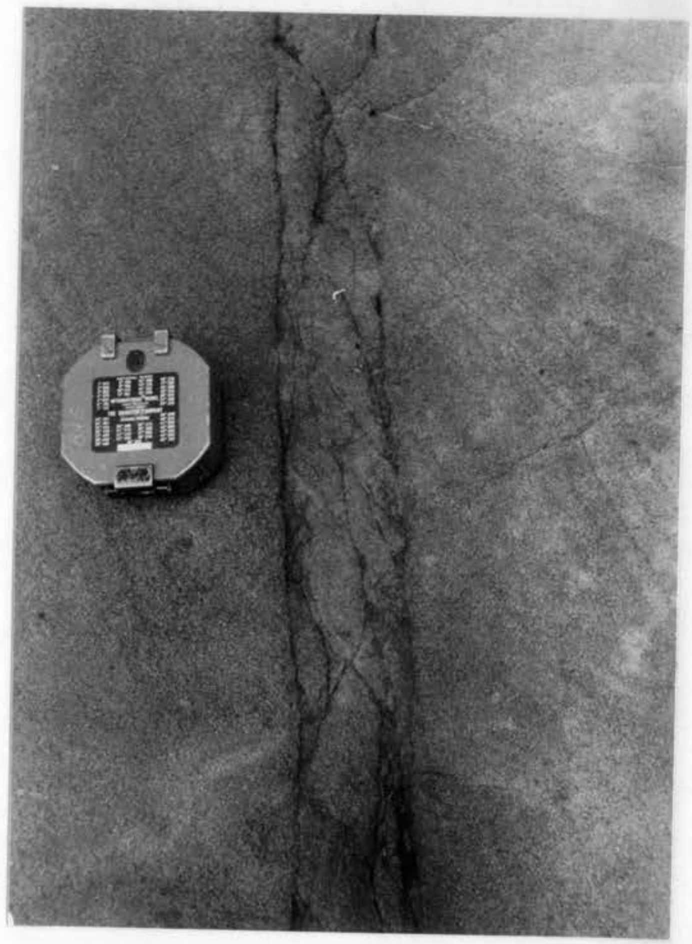


Figure 73. Breccia and conjugate fractures confined between NNE joints at Cremorne Point (Locality 19).

trending dykes at Cremorne Point, however, they were not observed during this analysis and may be intrusions encountered in the Cremorne Bore. Mauger et al. (1984) undertook a fracture analysis at Sirius Cove and found four joint sets trending N-S, NE, NW and WNW. Away from Cremorne Point the density of NNE joints decreases. At Athol Bay a fracture analysis was not undertaken because of the lack of well-developed joints. The extent of easterly-dipping NNE joints east of Cremorne Point is unknown although Coffey and Partners (1983) found easterly-dipping NNE joints in the upper Hawkesbury Sandstone at North Head.

On the western Headland at Edwards Beach (Loc.40) zones of close-spaced NNE master joint zones, in which there is breccia and ironstone filled joints, may form a continuation of the Art Gallery-Cremorne Point fracture zone. At Edwards Beach, there are six main zones up to 12 metres wide and which are separated by 20-30 metres. Within these zones there is intense fracturing with spacing of only a few centimetres. Fractures trending 015 to 020 are confined between joints trending about 030, within the zones, and in some instances form a horizontal conjugate set as shown in fig.74. ESE and E-W joints generally terminate against the NNE joints and a similar termination was observed on the headland in Balmoral (Loc.14) and is shown in fig.75. At Loc.14 the NNE master joints dip at high angles to the west and are spaced 2-4 metres. The outcrop at localities 14 and 40 was however not good enough to observe whether there are easterly and westerly dipping joints as at Mrs. Macquarie's Chair and Cremorne Point.

Figure 74. NNE trending horizontal conjugate joints on the western headland at Balmoral (Locality 40).

Figure 75. ESE joints terminating against NNE joints on the middle headland at Balmoral (Locality 14).

The close-spaced NNE joints continue across to Clontarf and appear to be mostly westerly dipping. Elsewhere in Middle Harbour NNE trending joint zones are not common and the rock is generally poorly jointed. Curved and planar ESE joints are common opposite Killarney Point at Loc.28; however, NNE joints are almost non-existent. These ESE joints may have controlled the orientation of Middle Harbour at this point although the curved nature of these joints suggests that they may be tension joints related to the present steepness and shape of the Harbour. Above Bantry Bay adjacent to the Wakehurst Parkway a fracture analysis was not undertaken in the massive Hawkesbury Sandstone because of the lack of joints greater than 0.5 metres extent.

To the north of Clontarf the fracture zone could not be traced due to the lack of outcrop, although NNE master joints and minor joint zones at North Curl Curl (Loc.46) may be part of this structure.

Overall, normal faulting is east-side down in the Art Gallery-Cremorne-Balmoral structure. If this structure does continue to Dee Why then this may explain the lack of Bald Hill Claystone on the North Curl Curl/Dee Why Headland which lies to the south of Long Reef where a thick sequence of the Newport formation and Bald Hill Claystone is exposed.

3.33 ENE TO ESE TRENDING JOINTS AND FAULTS:

Although the ESE trending Lachlan River lineament (Scheibner, 1976) may have controlled the orientation of part of Port Jackson, easterly trending planar master joints and faults are rare in the Sydney Region. Notable exceptions occur at Norman Street, Thornleigh (Loc.53), Hornsby (Loc.63) and at the Art Gallery (Loc.31). As mentioned in section 3.32C the Art Gallery fault is probably part of a NNE trending fracture zone.

Curved easterly trending joints however, often form an orthogonal set to planar NNE joints. In the Hawkesbury Sandstone these joints are usually curved and more widely spaced than the NNE joints and usually have rough faces. Curved joints and faults are common in the Ashfield Shale along the Roseville Warp and low angle thrusts also occur on the Hornsby Warp (Section 3.34A and 3.34B). Some of these joints and faults may have formed as a result of a N-S compression.

At Long Reef (Loc.30) a dyke steps across ENE trending joints which suggests that ENE joints pre-existed dyke emplacement at this locality. ESE trending master joints occur in Middle Harbour (Loc.28) although they are generally curved in strike and filled with ironstone. Most of these joints in Middle Harbour also dip away from the shoreline. Although the east-west orientation of Middle Harbour at this locality may have been controlled by these joints, the curved and the once open nature of these joints suggests they developed as tension joints joints parallel to cliff-line retreat during erosion of Middle Harbour.

Easterly trending joint and fault zones occur at localities 53 and 63 and may be related to the nearby Hornsby Diatreme. At Loc.53

horizontal slickensides occur on a E-W vertical joint (fig.76) and there is a breccia plane dipping 21 degrees to the NW. This suggests that westerly thrusting and lateral movement has occurred. High angle normal faults also occur at Loc.53 and appear to cut across the breccia. This indicates that a tensional regime existed subsequent to thrusting. Similar ESE trending normal faults were observed at Loc.63 and also at King Road, Hornsby (Loc.61).

At the junction of the Lane Cove River and Comenarra Parkway (Loc.17) low angle thrusting has occurred from the east and like the Hornsby localities may be related to the close proximity of a diatreme (JV 19, Wilson et al., 1983). This will be discussed in greater detail in section 3.35.

3.34 NNW TRENDING STRUCTURES:

NNW trending joints and faults are not common in the Sydney Region. However, the most extensive traces in the area are NNW trending scarps along the western margin of the Hornsby Plateau. The two main escarpments are the Roseville Warp (Branagan, 1985) and the Hornsby Warp (Taylor, 1923; Willan, 1923; Bembrick et al, 1973) which are shown on fig.2. Fracturing was examined along these escarpments and is summarised below.

A. The Roseville Warp:

The Roseville Warp is predominantly a physiographical feature extending from Waverton in the south to Turramurra (fig.2). It generally forms a steep westerly facing escarpment trending in an approximate NNW direction, although it swings to an East-West direction south of Waverton. The close relationship between the geology and physiography at the western edge of the Cumberland Basin suggests that a similar parallel between a geological structure and an escarp may exist along the Roseville Warp. While no continuous structures greater than 50 metres extent were observed along the escarpment, dipping beds, faults and low angle joints were observed at a number of localities along or adjacent to the scarp. This suggests that the escarpment has been the site of tectonic movements and is a structural warp.

At Ronald Avenue, Gore Hill (Loc.44), the Ashfield Shale and sandstone beds at the top of the Hawkesbury Sandstone dip between 9 and 22 degrees to the south-west (fig.77). There is also a low angle reverse fault dipping 20 degrees to the NE along which NNW to N-S joints are offset. A cross-section through the escarp along Mona Vale Road, Pymble, by the Dept. of Main Roads using borehole correlation shows that at this locality there is westerly dip of about 10 degrees (Branagan, pers comm.). An easterly trending escarpment adjacent to Pennant Hills Road and Old Northern Road is shown on fig.2. This escarpment may be a continuation of the Roseville Warp although no dipping beds were observed. Fell (1985) considers that landslides along the Pennant Hills Road-Old Northern Road scarp are due to the beds beginning to dip into the Cumberland Basin.

Localities 45 and 65 are within 100 metres of the Rosevile Warp

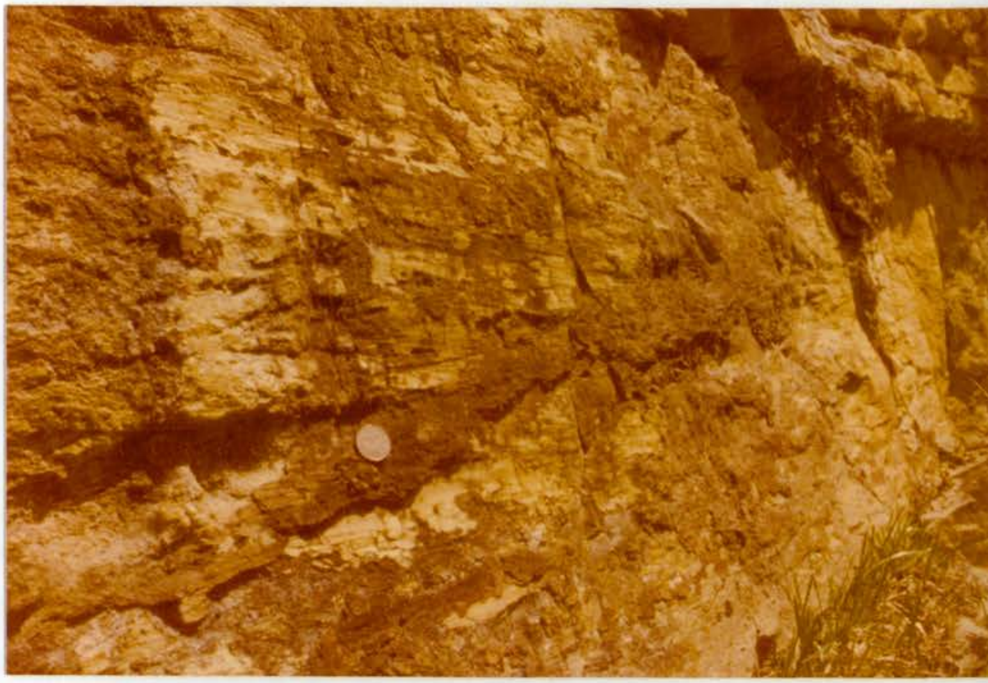


Figure 76. Horizontal slickensides on an E-W joint at Norman Street, Thornleigh (Locality 53).

Figure 77. Dipping beds at Ronald Ave., Gore Hill (Locality 44) on the Roseville Warp.

escarpment and at both localities low angle faults and goethite-filled joints are common. At Locality 64, Crow's Nest, there are many joints dipping 15 to 67 degrees to the west and north-west. These joints are parallel to small reverse faults and may form a conjugate set with a plunging σ_1. It is unlikely that the joints have been rotated on the Warp or are radial joints along a westerly-dipping warp because such joints would be expected to be easterly-dipping. At Crow's Nest, there are also SW dipping reverse faults and normal and reverse faults dipping to the NNW. The spatial relationship of all these features to each other could not be determined.

At Locality 45, Gore Hill, NNE to NE joints and normal faults dip to the east. These joints and faults may be radial tension joints on the warp. There are also reverse and normal faults which dip between the SW and south and there are minor reverse faults dipping to the NE and SE.

Fracturing was also examined at Artarmon (Loc.25) and along the northern suburbs railway (section 3.31B) both of which are close to the Warp. Fig.78 shows an equal area polar plot of faults at all of the above localities including the railway section. There appear to be five and possibly six fault sets, all of which include some reverse faults. Most of the faults are low angle and generally dip less than 60 degrees. An average of the fault sets is as follows;

1. strike 103 dip 50/Sth.
2. strike 090 dip 54/Nth.
3. strike 015 dip 42/NW

4. strike 029 dip 53/SE

5. strike 157 dip 41/NE

6. strike 134 dip 35/SW

The low angle of these faults suggests that they may form subhorizontal conjugate sets. That is, sets 1 and 2 are conjugate, 3 and 4 are conjugate, and 5 and 6 are conjugate. If this is the case, there have been three different stress conditions acting upon the warp. However, these sets may not form subhorizontal conjugates, but may be conjugates with a plunging maximum principal stress. If this is the case the relationship of each set would be difficult to determine without field evidence.

Fig.79 is a polar plot of joints dipping at angles less than 70 degrees at all of the above localities. These joints have a similar orientation to the faults although there is a wider spread.

The Pymble Warp (fig.2) is an easterly trending scarp which splays off the Roseville warp about 500 metres north of Pymble station. However, no structural features were observed on this scarp and it is not clear whether the scarp is a tectonic warp.

B. The Hornsby Warp:

This warp was recognised by Willan (1923) and defined as a compound warp and low arch which borders the Hornsby Plateau. The general shape of this warp can be seen on Willan's map (1925). Bembrick et al. (1973) showed the Hornsby Warp as a line trending NNW on the

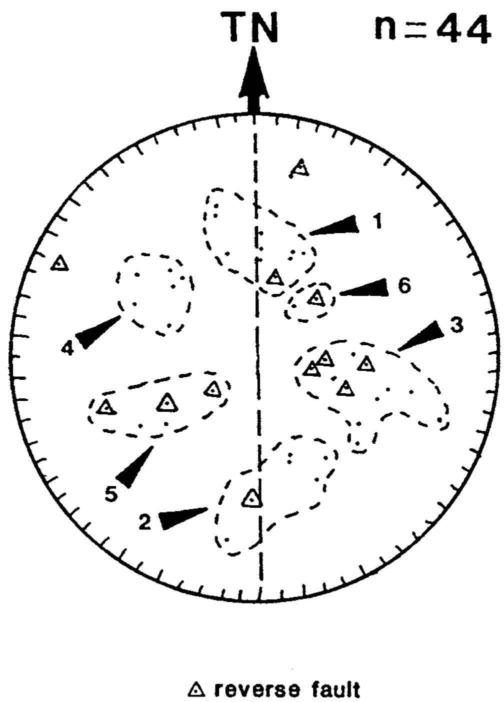


Figure 78. Equal area polar plot of faults along and adjacent to the Roseville Warp showing 6 possible sets.

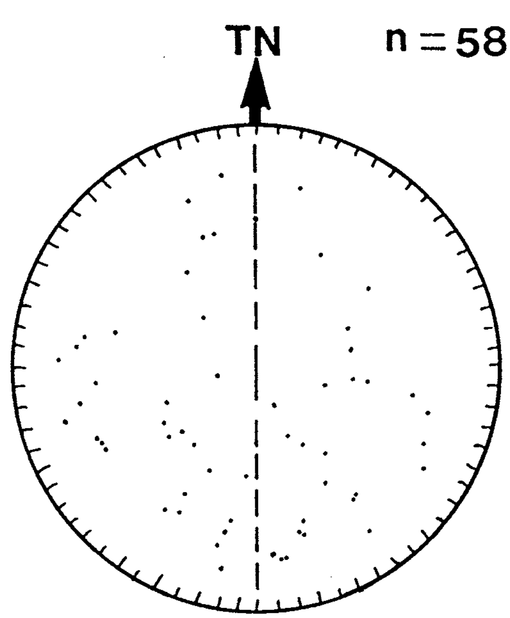


Figure 79. Equal area polar plot of joints dipping less than 70 degrees along and adjacent to the Roseville Warp.

western margin of the Hornsby Plateau between the junction of Wianamatta Creek and Parramatta, then swinging to the east along the Parramatta River and parallel to Scheibner's (1976) Lachlan River Lineament. The warp crosses the Parramatta River at Rydalmere and then swings to the SE towards Botany Bay.

The Hornsby Warp forms a more gentle escarp than the Roseville Warp although. This subdued relief may be due to less deformation on the Hornsby Warp than the Roseville Warp, and to erosion taking place largely in the Ashfield Shale. No major zones of deformation were observed on the Hornsby Warp, although at Rydalmere and Parramatta reverse faults were observed on the warp.

At Rydalmere (Loc.26) a series of low angle (20-30degrees) reverse faults (fig.80) trend ENE to E. These faults dip to the north. At North Parramatta (Loc.47) a reverse fault with displacement of 30cm (fig.81) strikes 136 and dips to the SW. The fault at Parramatta lies close to the top of the warp while the Rydalmere faults lie close to the base of the warp (fig.82). Reverse faults of similar orientation also occur on the Roseville Warp. Like the Roseville Warp, the Hornsby Warp appears to have been the site of multiple deformation.

3.35 NW AND NNW JOINTS, FAULTS AND DYKES:

NW trending master joints and faults are usually associated with NW trending dykes in the Sydney Region. At Long Reef and Loc.41, NNE-NE joints terminate against NW joints which are subparallel to dykes. At these localities NNE joints form a subdominant set. At Grosvenor

Figure 80. Low angle reverse faults dipping to the north at Rydalmere (Locality 26).

Figure 81. Reverse fault dipping to the SW at North Parramatta (Locality 47).

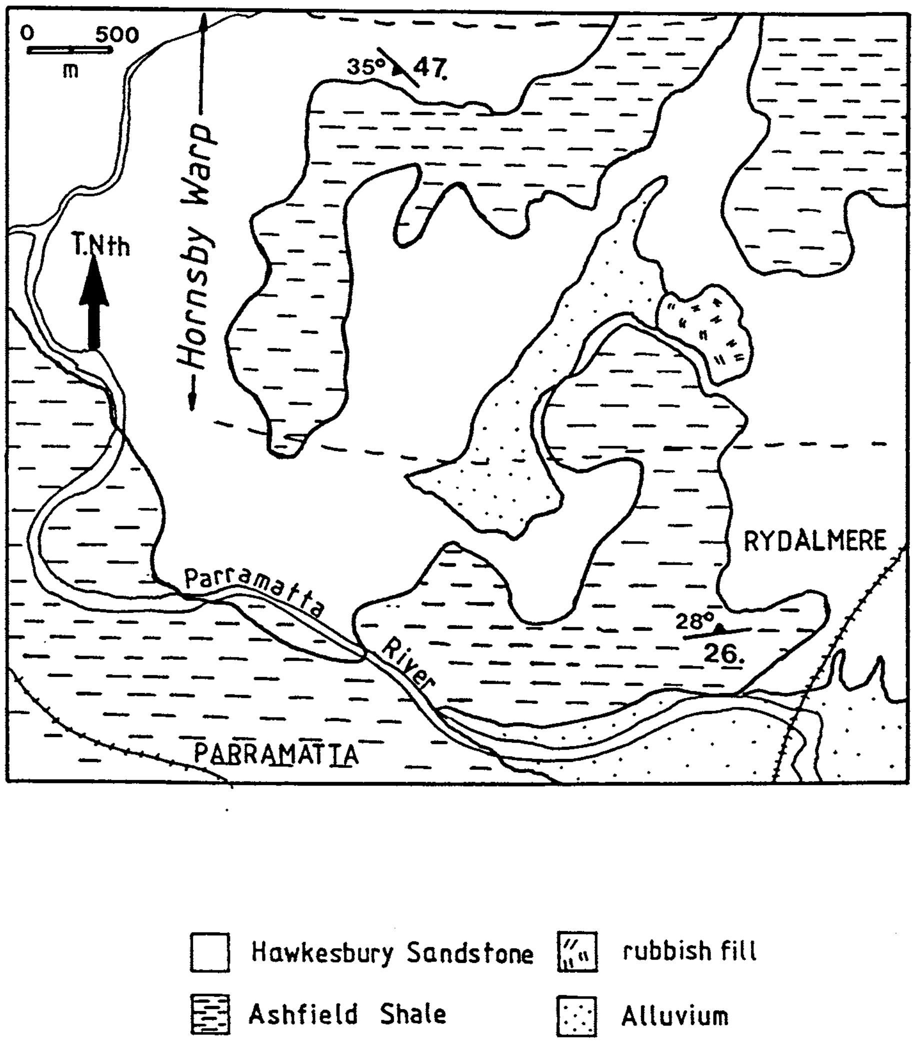


Figure 82. Location of the Hornsby Warp and faults shown in figs 80 and 81 (geology after Chesnut, 1983).

Place (Loc.57) and in the Haymarket (Loc.51), similar NNW-NW trending dykes occur. The Haymarket dyke is 1.5 metres wide and varies in strike between 108 and 134 degrees. Normal faulting has also taken place along the dyke wall (fig.83). NNE to NE planar joints are common at the Haymarket site and dip between 65/W to vertical. Within this excavation there is a 0.5 metre wide zone with close-spaced (5cm) NNE westerly dipping joints. NNE joints terminate against the dyke and cut through the dyke. NNE joints are also confined within the dyke suggesting that NNE-NE joints formed subsequent to dyke emplacement.

NW master joints and joint/fault zones also occur at North Curl Curl (Loc.46), however, there are no dykes. At this locality NW joints terminate and cut through NE joints. This suggests that some NW joints also formed subsequent to NE joints.

Not all dykes trend NW. The dyke at the Bahai Temple (Loc.55) trends NNE-NE and a dyke at Pyrmont trends N-S. Both of these dykes have been discussed previously.

NNW trending joints are less common than NW joints. At Cammeray (Loc.39) NNW joints dip to the west and east and form a conjugate set. Joint spacing is between 1 metre and 10 centimetres and there is bedding plane breccia 1 - 2 metres thick confined between sandstone and siltstone at the top of the Hawkesbury Sandstone (fig.84). The NNW joints terminate against this breccia which dips about 10 degrees to the SW (fig.85). The NNW joints are not displaced across the breccia

Figure 83. NW trending dyke at the Haymarket with the beds on the NE side dragged down (Locality 51).

Figure 84. Bedding plane breccia dipping to the SW at the Brook Street turnoff, Cammeray (Locality 39).

Figure 85. NNW joints terminating against breccia in fig.84.

which suggests that these joints formed subsequent to the breccia, that is bedding plane thrusting occurred prior to the formation of NNW vertical conjugate joints.

NNW planar master joints also occur at the junction of the Comenarra Parkway and the Lane Cove River (Loc.17). At this locality an easterly-dipping reverse fault (fig.86) displaces NNW joints 1 metre indicating that thrusting from the east occurred subsequent to the formation of NNW at this locality. A cross-section of the road section at this locality is shown in fig.87. Subvertical NE joints and a joint/fault zone also exist at this locality and may form a horizontal conjugate set with E-W joints. The acute bisectrix of this set is approximately perpendicular to the strike of the thrusts. A normal fault displaces a low-angle discontinuity subparallel to the reverse faults, indicating that normal faulting probably took place subsequent to thrusting.

Low angle NW trending reverse faults dipping to the east also occur at Leighton Place, Hornsby and at King Road, Hornsby. In section 3.33, E-W joints and faults along which there has been horizontal and vertical movement appear to be associated with diatremes. At the above localities thrusting appears to have been from the east and may also be associated with the breccia vents in the area.

Figure 86. Easterly dipping reverse fault on the Comenarra Parkway (Locality 17).

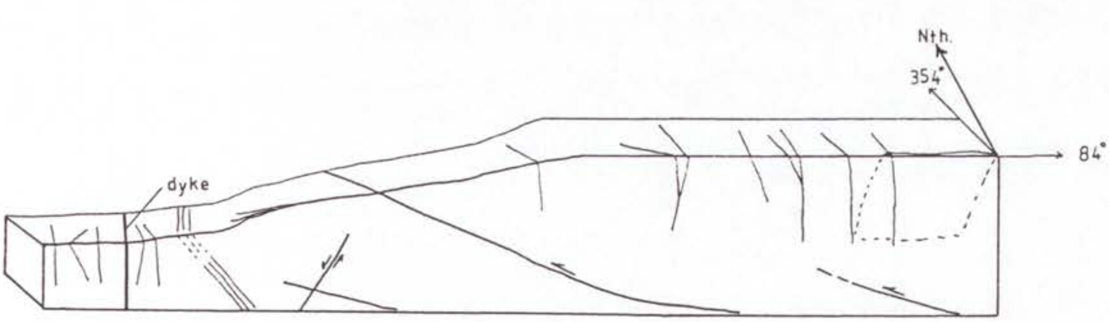


Figure 87. Cross-section of the Comenarra Parkway cutting (Locality 17).

3.4 INTERPRETATIONS

Like the Kuring-gai/Berowra area the most dominant and widespread joints in the Sydney Region are planar NNE master joints. These joints are frequently zonal and are more extensive horizontally and vertically than other joints in the Sydney Region. NNE joints in the Ashfield Shale are more closely spaced than NNE joints in the Hawkesbury Sandstone. The Ashfield Shale usually contains a greater intensity of joints and greater variability in orientation than the Hawkesbury Sandstone. The greater intensity of jointing in the Ashfield Shale is probably due to its low strength and the laminae of siltstone and sandstone. Bed thickness in the Hawkesbury Sandstone is between 1.5 and 2.0 metres.

Between Pyrmont and North Head NNE joints dip mostly to the west at high angles (75-85 degrees). NNE joint/fault zones up to 15 metres wide are common between Pyrmont and Neutral Bay. These zones also dip to the west. A NNE fracture zone occurs to the east of the Pyrmont-Neutral Bay zones between the Art Gallery and Balmoral and contains both vertical and horizontal conjugate NNE joints. Along the western side of Woolloomooloo Bay there are easterly and westerly dipping high-angle NNE joints which were observed to be conjugate. These joints whose dihedral angle is about 30 degrees indicate that σ_1 was vertical during their formation. These joints are extensional (or oblique) shear joints. Price (1966) has suggested that conjugate joints with a vertical σ_1 can form as a result of a residual strain energy during unloading. At North Head and South Head and throughout most of the Sydney city area westerly dipping NNE joints predominate and easterly dipping NNE joints are minor. However, it is likely that individual westerly dipping NNE joints are also extensional shear joints. Paterson (1978), using experiments on marble showed that there is a transition from an extension fracture to shear fracture with increasing confining pressure. Single dipping shears occur at low confining pressures and conjugate shears occur at higher confining pressures in the upper part of the brittle range. In the brittle-ductile transition zone the shear failure tends to become a zone of intense deformation. Pells (1977) found that under uniaxial compression, specimens of Hawkesbury Sandstone deformed into fracture zones separated by discrete volumes of essentially intact material. This anisotrophy caused considerable variation in the load displacement curves once the load on the post-peak curve had reduced to about 80% of the peak value. Thus Pells (op. cit.) concludes that "the load-deformation behaviour is an expression of the energy interaction between the intact blocks and the narrow fracture zones". The brittle failure of small specimens of Hawkesbury Sandstone is probably similar to deformation that has occurred within the NNE joint/fault zones and the larger NNE lineament/fracture zones in the Sydney Region. The joint/fault zones between Pyrmont and the Art Gallery may have developed in the brittle-ductile transition zone with a high confining pressure. The confining pressure was probably mostly due to overburden and as the overburden was removed by erosion the confining pressure was reduced and conjugate shears developed followed by single westerly dipping shears and finally subvertical extension joints. This change in jointing with confining pressure is illustrated in fig.88.

At Balmoral and at the Art Gallery there is also evidence that lateral compression has taken place within the NNE fracture zone between these localities. At Balmoral there are horizontal conjugate joints confined between NNE master joints. The dihedral angle between these conjugate joints is about 15 degrees and σ_1 would have been oriented about 010-190. Breccia is also confined within this zone. At the Art Gallery breccia and possible horizontal conjugate joints indicate that thrusting from the north has occurred. Horizontal and vertical conjugate joints were not observed together, however, it is probable that a N-S horizontal compression took place prior to σ_1 becoming vertical and it was the residual strain energy from this lateral compression which resulted in vertical conjugates and westerly dipping shears as the overburden was removed by erosion. The upper part of the NNE joints at Balmoral is iron-filled, however, these joints become closed downwards away from the rock platform. This indicates that iron-filling is related to dilationof the joints, due to the present shape of the topography, and post-dates the vertical and horizontal compression within the zone. The dissection of the Hornsby Plateau has resulted from the rejuvenation of streams through uplift and changes in sea-level. It is probable that the N-S lateral compression existed prior to uplift and as uplift and erosion occurred the confining pressure was reduced and σ_1 became vertical.

At North Head the beds dip about 10 degrees to the west (fig.89) and NNE joints at the quarantine station dip consistently about 75-80

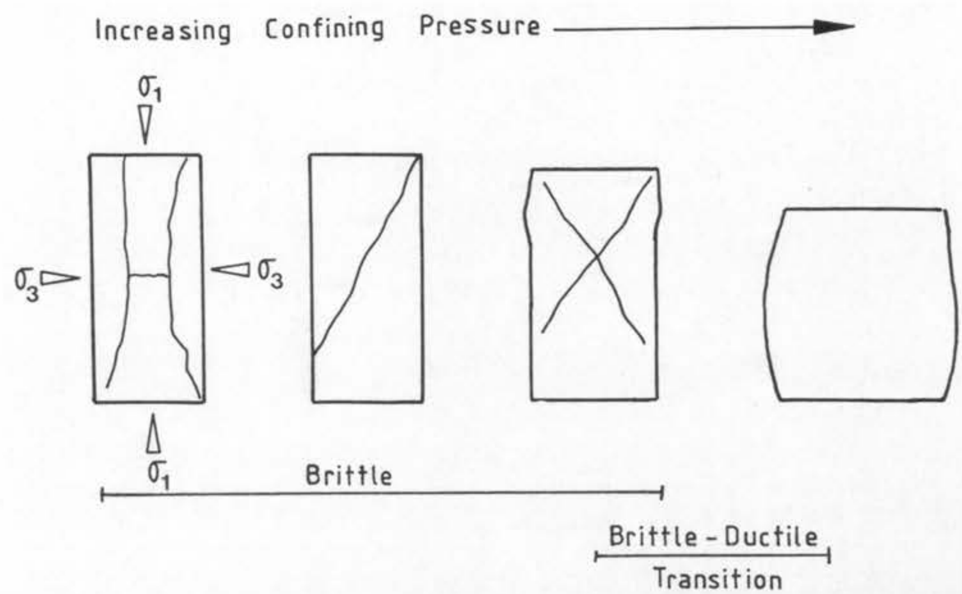


Figure 88. Types of fractures resulting from increasing confining pressures (after Paterson, 1978).

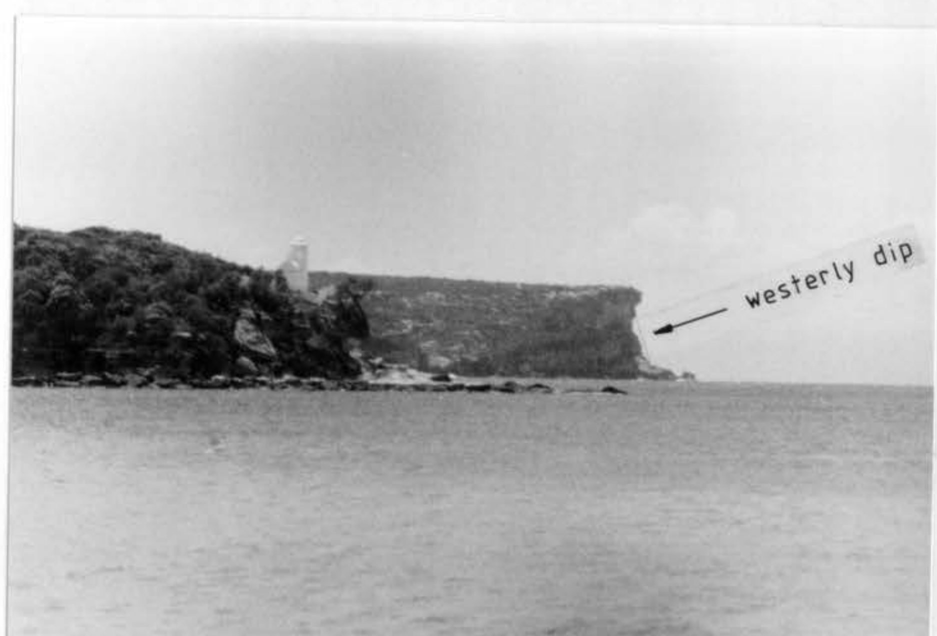


Figure 89. Westerly dip at North Head. Vegetated bench is approximate to the base of the Hawkesbury Sandstone.

degrees to the west. Westerly dipping NNE joints can also be seen on South Head from North Head. If the NNE joints are extension joints then they would be expected to be perpendicular to bedding, that is, they should dip to the east. Therefore, the westerly dipping NNE joints at North Head and South Head are probably part of the extensional shear joint set between Pyrmont and the Art Gallery. These joints have not been rotated at North Head and therefore formed subsequent to the dip at North Head. The westerly dip of bedding is greater than would be expected during depositional and may be related to folding or faulting prior to the N-S compression and thus prior to uplift.

These NNE fracture zones appear to have had little influence on the physiography although the elongation of Lavender Bay and Woolloomooloo may be controlled by NNE structures. Port Jackson and the Parramatta River are generally orientated ESE coincident with the Lachlan River Lineament (Scheibner, 1976). The upper part of Port Jackson lies close to the Hornsby Warp: however, down stream, near Balmain, Port Jackson cuts through the Hornsby Plateau. The Parramatta River has been entrenched into the Hornsby Plateau in a similar manner to the Nepean River which passes through the Blue Mountains Plateau. Port Jackson changes from a ESE orientation to a NNE direction adjacent to the Heads. This NNE direction is subparallel to the fracture zones to the west and it is possible that a NNE fracture zone controls the orientation of Port Jackson adjacent to the Heads, south of the Manly Spit. The westerly dip at North Head probably impeded down-cutting of the easterly flowing steam and a NNE structure may have provided a greater line of weakness for erosion. Initially the outlet from Port Jackson was probably through the Manly Spit but back-cutting of a NW trending dyke may have opened up the Heads to provide the present outlet.

Except for jointing associated with NNE shear zones, an examination of of the Ashfield Shale suggests that jointing was initiated prior to faulting. Some easterly trending curved joints in the Ashfield Shale are associated with small depositional slumps, indicating that some curved joints were developing when the sediments were still mobile. In the Hawkesbury Sandstone low angle planes are also associated with depositional, slumps and dip in the opposite direction to the direction of slumping. However discontinuities associated with depositional structures are rare and most joints have been the result of brittle failure. In the Ashfield Shale NE and NW dipping faults displace NNE subvertical joints. The NE dipping faults usually show reverse movement and displace NW dipping faults. This suggests that thrusting from the NE was subsequent to the initial development of NNE joints and NW dipping faults. The NW dipping faults usually display normal movement: however reverse drag folds adjacent to the faults suggest that these faults have been the site of multiple deformation. NNE zones of close-spaced NNE joints and breccia cut across all of the above faults suggesting that remobilisation of NNE joints has occurred subsequent to faulting. It is not possible to distinguish NNE joints which existed prior to the development of NNE joints in these NNE shear zones. It is probable that once NNE joints were developed further joint development was governed by this pre-existing anisotropy. The NNE zones in the Ashfield Shale are similar to NNE shear zones in the Hawkesbury Sandstone and they are probably temporally related. While it is difficult, in the Ashfield Shale, to distinguish between NNE joints which were initiated prior to NNE joints in the shear zones, most NNE joints in the Hawkesbury Sandstone appear to have formed in association with and subsequent to the NNE shear zones.

On the Roseville Warp and Hornsby Warp there appear to have been three separate compressional events oriented N-S, NW-SE and SW-NE, although the relative timing of these events could not be determined. It is possible that N-S compression is related to the development of NNE shear zones such as at Balmoral. SW-NE compression may be related to stress associated with the development of the NNW-NW trending warp. However, it should not be assumed that the warp resulted from lateral compression as lateral compression may have occurred subsequent to warping, because of the relative downward movement of the Cumberland Basin. The stress that might be associated with this downward movement is shown in fig.90. The downward sagging or faulting is a result of tension: however lateral compression may develop at the margins of this downwarped block. NW-SE compression on the Roseville Warp may be associated with WNW-ESE shearing that has occurred at Norman Street, Thornleigh and on the Comenarra Parkway at the Lane Cove River. Both of these localities occur close to breccia vents which Crawford et al.(1980) regard as probably Jurassic in age. It is not known in the Sydney Region whether the breccia vents have occurred along major ESE structures or whether the WNW-ESE compression

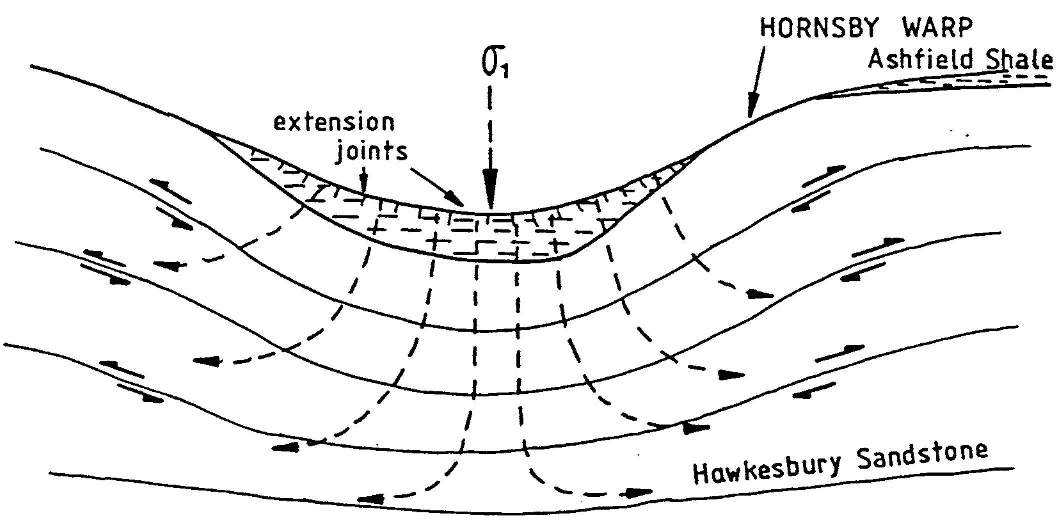


Figure 90. The stress that might occur with downward sagging of the Cumberland Basin.

resulted from the volcanic activity.

In the Sydney Region, particularly in the Hawkesbury Sandstone, NW trending planar joints form a subdominant set. NW trending joints and zones appear to be related to dykes in the area which strike mostly between WNW and NNW. NNE joints generally terminate against NW joints and in the Haymarket, NNE joints cut across a NW trending dyke. NNE joints also swing to the NE adjacent to dykes. This suggests that the development of NNE joints was subsequent to dyke emplacement. However, there are minor exceptions where NW joints terminate against NNE joints suggesting that some NNE joints developed prior to dyking. In addition, some dykes strike between N and NE suggesting that there was a N-NE anisotropy at this time although this anisotropy may have only been minor.

On the Comenarra Parkway an easterly dipping reverse fault displaces NNW-NW joints indicating that NNW joints formed prior to thrusting. The origin of these NNW joints on the Comenarra Parkway is unknown, however, they may be related to the subdominant regional NW-NNW joints which appear to be associated with dyke formation. If the NNW joints on the Comenarra Parkway are associated with dykes then thrusting and intrusion of some breccia vents has occurred subsequent to dyke formation. It is not known when this thrusting occurred in relation to the development of NNE shear zones.

From the above observations a sequence of tectonic events has been proposed for the Sydney Region. These interpretations do not include observations in the Kuring-gai/Berowra area. A synthesis of the southern Hornsby Plateau and comparison with the Blue Mountains Plateau will be undertaken in chapter five. The suggested sequence of tectonic events for the Sydney Region is as follows;

1. Formation of curved easterly joints (deposition)
2. Formation of NNE vertical extension joints
3. Thrusting from the WNW
4. Slipping of westerly block along westerly dipping fault planes
5. Formation of vertical NW joints and zones through NE-SW extension (dyking)
6. Thrusting from the east
7. Slipping of easterly blocks along easterly dipping faults
8. Formation of NNE shear zones through a N-S lateral compression
9. Initiation of uplift - further deformation along NNE and formation of vertical conjugate joints
10. Formation of westerly dipping NNE shears
11. Formation of NNE subvertical extension joints
12. Iron-filling of NNE joints from surface extension

It is not intended that all joint and fault development should be placed into neat time slots. The formation of NNE joints has probably continued since an early regional extension and NNE shear zones, including the West Head Lineament, have had a history of multiple deformation. A history of deformation and tectonic events will be discussed in further detail in chapter 5. Regional events such as

Tasman sea-floor spreading and movement of the Australia-India plate will be compared to the proposed tectonic events for the Sydney Region, Kuring-gai/Berowra area and Blue Mountains Plateau.

CHAPTER 4

THE BLUE MOUNTAINS PLATEAU

The Blue Mountains Plateau (Bembrick et al., 1973) rises steeply west of the Cumberland Basin and more gently from the Hornsby Plateau. The boundary between the Blue Mountains Plateau and the other structural subdivisions to the east is taken as the Lapstone Structural Complex-Nepean Fault System (fig.1). The Lapstone Structural Complex is a term introduced by Branagan (1975) to replace the Lapstone Monocline.

The Blue Mountains Plateau dips gently about 1-3 degrees to the east which is similar to the dip of the Permo-Triassic sediments exposed on the Plateau and at its margin. The Plateau has been deeply dissected by the Grose River, the Wollondilly-Coxs River system and the Colo River system. These river valleys are generally accessible only by foot. The dissection of the Plateau has resulted largely from rejuvenation of the streams through uplift and possibly through down warping to the east and changes in sea-level. The timing of this uplift or uplifts is arguable and it is the aim of this chapter and chapter 5 to relate the history of fracturing on the Blue Mountains Plateau to more regional deformation such as uplift.

On the Blue Mountains Plateau fracture analyses were undertaken at 11 localities (fig.91). These localities occur on the Lapstone Structural Complex, in the southern part of the Western Coalfield, which is situated on the western margin of the Plateau, and at Permian outliers below which folded metasediments crop out. These outliers occur in the Kanangra Walls region and in the Capertee Valley (Coco Creek). A 1:50,000 geology map of an area north of Bell was also compiled. The location of these fracture analysis sites and 1:50,000 geology map is shown on fig.91. A summary of each fracture analysis site on the Blue Mountains Plateau is contained in appendix C.

4.1 THE LAPSTONE STRUCTURAL COMPLEX

The Lapstone Structural Complex (Branagan 1975; Branagan and Pedram 1982; Pedram 1983) consists of a N-S trending monocline or fault previously known as the Lapstone Monocline and a series of subparallel faults to the west. This complex forms the eastern boundary of the Blue Mountains Plateau and the western boundary of the Hornsby Plateau and Cumberland Basin. Fracturing was examined in a road cutting on Bell Bird Hill (Loc.1, fig.91) to determine whether any regional joint sets identified on the Hornsby Plateau (NNE and NW joints) exist within this complex and whether these joints formed prior, during or subsequent to monoclinal folding at this locality. An equal angle polar plot and rose diagram of fracturing at Bell Bird Hill is shown in fig.92.

At Bell Bird Hill the top of the Hawkesbury Sandstone is exposed and it dips between 11 and 19 degrees to the SE. This locality lies towards the top of an easterly facing monocline. The most extensive

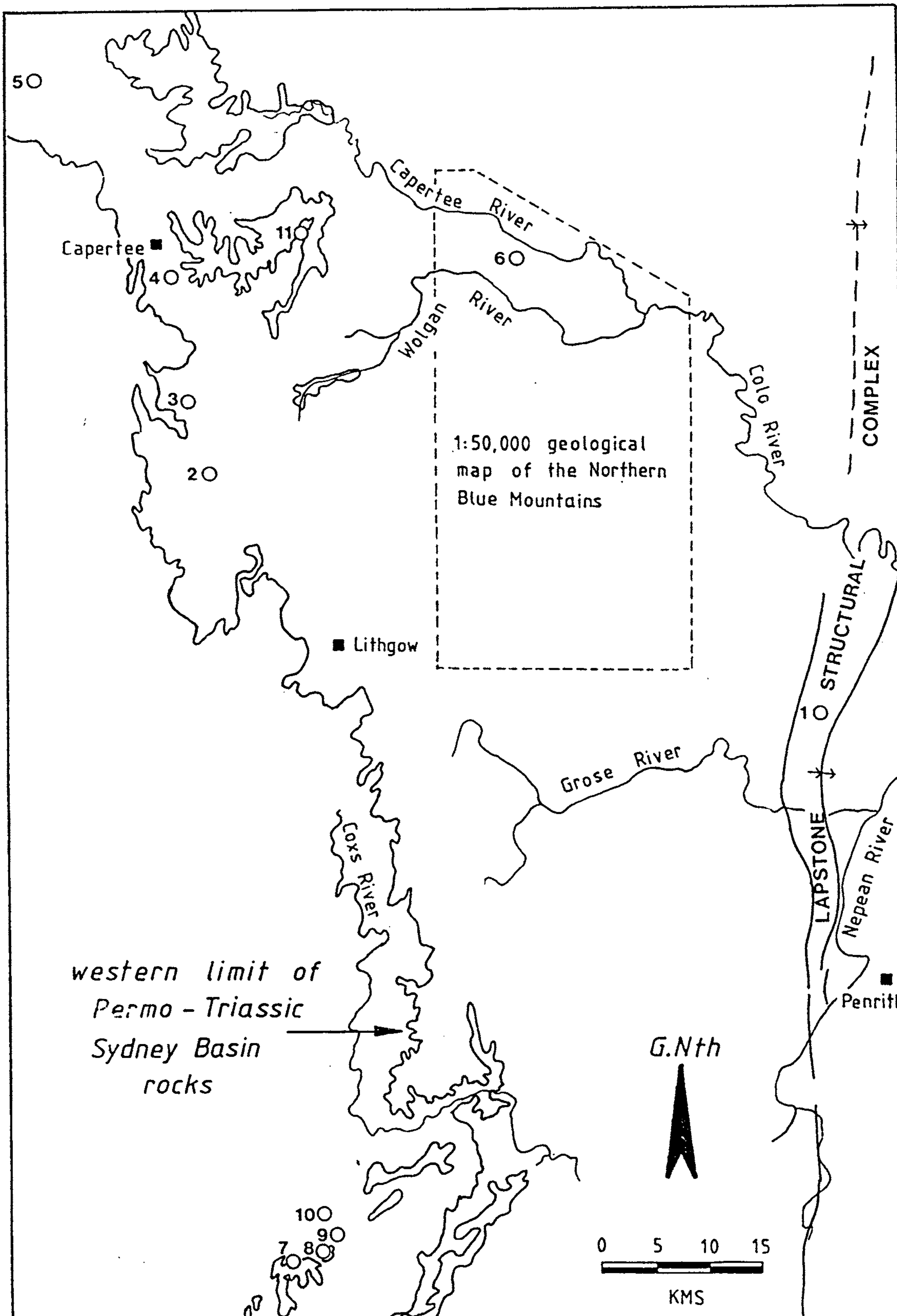


Figure 91. Location of the study areas and fracture analysis sites on the Blue Mountains Plateau.

joints at Bell Bird Hill are NE (059-070) trending, planar, iron-filled master joints. These joints dip between 59 and 76 degrees to the west. The dip of these joints is generally orthogonal to bedding plane dip. The strike of the NE master joints is subparallel to the bedding plane strike. These features suggest that the NE joints are radial tension joints resulting from monoclinal folding.

NE planar joints terminate against and are confined between NW trending (130-156) joints at Bell Bird Hill. NW joints occur predominantly adjacent to a NW (130) trending dyke. This suggests that the NE joints and master joints (and hence folding) occurred subsequent to the formation of the NW joints and probably subsequent to intrusion of the dyke. The NW joints are planar and ironfilled and are asymmetric to the dyke. Within the dyke there is subhorizontal E-W slickensides which may be related to an E-W extension associated with folding or post-intrusion E-W compression.

Planar NNE to NE trending conjugate joints, 1-2.5 metres long were observed between and adjacent to the NE planar ironfilled master joints. These conjugate joints cut across the master joints and are closed containing no in-fill material. On the southern part of the road cutting the conjugate joint sets trend 003-012 and 23-037 with the acute bisectrix trending about 015 and the dihedral angle averaging 20 and 25 degrees. However, there is an easterly rotation in the strike of the conjugate joints towards the centre of the cutting where the NE master joints are more closely spaced. Towards the centre of the cutting the acute bisectrix of the conjugate joints strikes about 045.

The dip of the conjugate joints is between 70 and 85 degrees to the west although the average is closer to 83 degrees. The dip of the conjugate joints is consistently greater than the dip of the NE master joints. The conjugate joints do not appear to be fringe joints to the NE master joints as they generally cut across the NE master joints. These features suggest that the conjugate joints formed subsequent to the NE master joints and thus subsequent to the main folding event or events. If the conjugate joints formed prior to folding then the conjugate joints would be expected to dip at the same or greater angle than the radial NE master joints.

Towards the northern part of the road cutting, about 7 metres north of the NW trending dyke, easterly trending conjugate closed joints 1-2 metres long were observed. The NNE to NE conjugate joints are absent at this point which indicates that either the stress conditions were different compared to where NNE-NE conjugate joints formed or that an E-W compression has also occurred at this site. Except for their strike these easterly trending conjugate joints are identical to the NNE-NE conjugates. NNE and easterly trending conjugates were not observed together at any point in the road cutting. It is possible that the E-W conjugates which exist north of the dyke are temporally related to the NNE-NE conjugates and that the pre-existing anisotropy of NE master joints, a NW dyke, NW joints and SE dipping beds influenced the compression at this site by changing the lines of stress as illustrated in fig.93. If the initial compression was

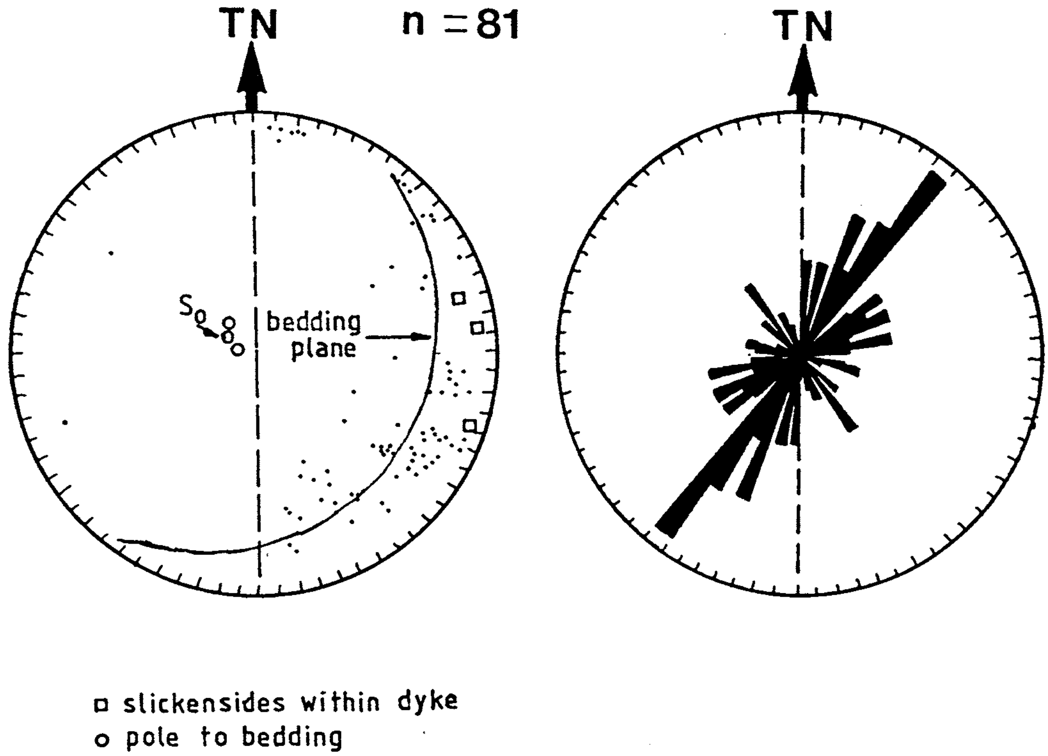


Figure 92. Equal angle polar plot and rose diagram of fracturing at Bell Bird Hill (Locality 1).

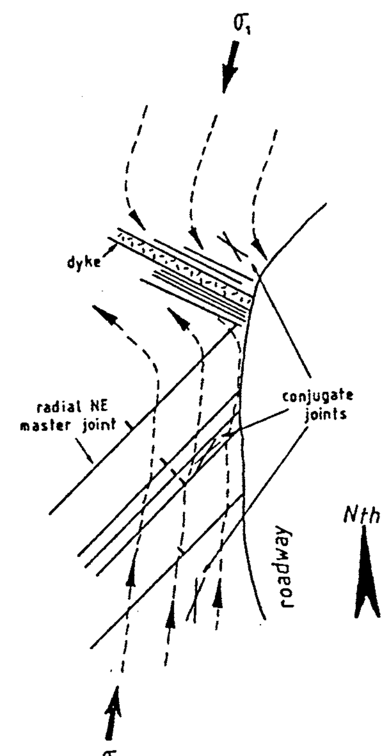


Figure 93. Inferred lines of stress at Bell Bird Hill from a NNE compression (plan).

orientated NNE then the lines of stress may swing to the NE adjacent to the NE joints forming NE conjugate joints, and rotate to a E-W direction adjacent to the dyke. The E-W orientation of the lines of stress adjacent to the dyke may result in E-W conjugate joints and also E-W slickensides within the dyke.

The high angle westerly dip of the conjugate joints at Bell Bird Hill suggests that either the beds have been slightly rotated subsequent to this NNE compression or that the pre-existing SE dipping beds resulted in σ_1 dipping in a similar direction to bedding during compression thus resulting in westerly dipping conjugate joints.

The Bell Bird Hill locality reveals that the Lapstone Structural complex has been multiply deformed and that a pre-existing structural fabric is very important in the orientation of subsequent deformation. A possible sequence of tectonic events at this site is as follows:

1. NE-SW extension resulting in NW joints.
2. Intrusion of NW dyke.
3. Monoclinal folding of the beds, resulting in NE planar westerly dipping master joints.
3. NNE subhorizontal compression resulting in 1-2.5 metre long closed conjugate joints and localised E-W compression about a NW dyke and joints.
4. Further easterly rotation of the beds. (??)

Pedram (1983) mapped easterly trending reverse faults and folds to the south of Bell Bird Hill which he suggested resulted from an E-W compression prior to relaxation and the main tensional tectonic event responsible for the major folding and faulting in the Lapstone Structural Complex. Evidence for an early E-W compression prior to folding was not observed at Bell Bird Hill. However, conjugate joints and slickensides indicating an E-W compression were observed. With further examination it appears that the easterly conjugates and slickensides resulted from a NNE compression which changed orientation about pre-existing NW trending anisotropy. Evidence of a similar NNE compression was also found on the Hornsby Plateau which suggests that this compression was regionally developed. Pedram (1983) identified the dominant joint set within the Lapstone Structural complex as trending E-W which is surprising if most of the structures resulted from a tensional event with extension orthogonal to the main N-S trend Complex. This E-W joint set does not exist at Bell Bird Hill.

4.2 THE WESTERN COALFIELD (southern portion)

The Western Coalfield covers an area from Kanangra Walls in the south to the Liverpool Range in the north on the western margin of the Sydney Basin. However, this study is concerned with the southern part of the Western Coalfield between Lithgow and Cherry Tree Hill.

The structural geology of the coal mining districts is well known because of the work by Branagan (1960) and C.S.I.R.O. (Shepherd et al., 1978, 1981a, b; Shepherd and Huntington, 1981). However, this information has not been compared with the structural geology elsewhere in the Sydney Basin. It is the aim of this section to review some of this previous work to provide some additional information so that a comparison with the Hornsby Plateau and a structural synthesis of the central Sydney Basin can be undertaken in chapter 5.

The geology of the southern Western Coalfield is also well known mainly through the work of Carne (1908) and the 1:50,000 geology maps by Bembrick and Goldbery (1967) and Goldbery (1968, 1969b). The Permo-Triassic rocks in the southern Western Coalfield have been subdivided into formations and members by Crook (1957), Goldbery (1969) and Bembrick (1983). The stratigraphy of the southern portion of the Western Coalfield is shown in fig.95. However, there is no 1:50,000 geology map north of the Katoomba 1:50,000 sheet and south of the Glen Davis 1:50,000 sheet, probably due to the difficult terrain and lack of access. This section contains a review of the geology of this unmapped area which in this thesis is called the Northern Blue Mountains and a 1:50,000 geology map of the area (fig.94, in back pocket) compiled using aerial photos and field mapping.

A. Regional geology of the Northern Blue Mountains:

The geology of the Northern Blue Mountains is quite simple and is shown on fig.94 (in back pocket). The oldest rocks exposed in this area belong to the Permian Illawarra Coal Measures which crop out in the Capertee and Wolgan Valleys. The Illawarra Coal Measures consists of interbedded marine (pro-delta and interdistributary bay) sediments and non marine sediments (Bembrick, 1983). However, outcrop of the

PERIOD	GROUP	SUB-GROUP	FORMATION	MEMBER
TRIASSIC	WIANA - MATTA GROUP		Ashfield Shale	
			Mittagong Formation ??	
			Hawkesbury Sandstone	
	NARRABEEN GROUP		Burralow Formation ??	
		Grose Sub-group	Banks Wall Sandstone	
			Mount York Claystone	
			Burra-Moko Head Sandstone	
			Caley Formation	Hartley Vale Claystone Govetts Leap Sandstone Victoria Pass Claystone Clwydd Sandstone Beauchamp Falls Shale
PERMIAN	ILLAWARRA COAL MEASURES	Wallerawang Subgroup	Farmers Creek Formation	Katoomba Coal Woodford Coal Burragorang Claystone Middle River Coal
			Gap Sandstone	
		Charbon Subgroup	State Mine Creek Formation	Moolarben Coal
			Angus Place Sanstone	
			Baal Bone Formation	
			Glen Davis Formation	
			Newnes Formation	Ivanhoe Sandstone
			Irondale Coal	
			Long Swamp Formation	Bunnyong Sandstone
		Cullen Bullen Subgroup	Lidsdale Coal	
			Blackmans Flat Congl.	
			Lithgow Coal	
			Marrangaroo Conglomerate	
		Nile Sub-group	Gundangaroo Formation	
			Coorongooba Ck. Sandstone	
			Mt Marsden Claystone	
			Berry Siltstone	
			Snapper Point Formation	

Figure 95. Permo-Triassic stratigraphy of the Western Coalfield (southern portion) after Goldbery (1969) and Bembrick (1980, 1983).

Illawarra Coal Measures is generally poor in the Northern Blue Mountains and is usually covered by large talus slopes which result from the retreat of the overlying Narrabeen Group cliffline. The top of the Illawarra Coal Measures is usually defined as the uppermost coal-bearing horizon although the base of the Narrabeen Group (the Caley Formation), in places, tends to be carbonaceous. During this study the top of the Coal Measures was taken as the uppermost coal/carbonaceous horizon. In Freshwater Creek (Loc.6, fig.91), a tributary of the Capertee River the top of the Coal Measures was well defined because lowermost interbedded siltstones and sandstones of the Narrabeen Group are missing (fig.96).

The most prominent rocks in the Northern Blue Mountains belong to the Narrabeen Group which form the clifflines throughout the area. The Narrabeen Group has been divided into five formations in the Western Blue Mountains (Bembrick, 1980). Four of these formations can be recognised in the Northern Blue Mountains. The basal formation is the Permo-Triassic Caley Formation (Crook, 1957) which consists of carbonaceous claystone, siltstone and lithic sandstone. In the field, the boundary between the Caley Formation and the Illawarra Coal Measures is not always well defined. In some places, this boundary appears to be gradational and in other places, such as Freshwater Creek, the boundary is erosional. The Caley Formation is overlain by the Burra-Moko Head Sandstone (Goldbery, 1969) which consists of cross-bedded quartz-lithic sandstone with pebbles of chert, jasper and volcanics and distinctive bluish quartz grains. Narrow slot canyons (Holland, 1977) are well developed in this sandstone throughout the area. In hand specimen the Burra-Moko Head Sandstone is harder than other Narrabeen Group Sandstones, probably due to cementing of the quartz grains. The Burra-Moko Head Sandstone is overlain by a red-brown claystone called the Mount York Claystone (Goldbery, 1969). This claystone forms a characteristic bench which separates the Burra-Moko Head Sandstone from the overlying Banks Wall Sandstone. The Mount York Claystone is up to 5 metres thick: however, in many places it is split by soft sandstone channels which are lithologically similar to the overlying Banks Wall Sandstone. The Banks Wall Sandstone (Goldbery, 1969) overlies the Mount York Claystone and consists of a friable crossbedded quartz-sandstone. The Banks Wall Sandstone contains more siltstone lenses than the Burra-Moko Head Sandstone and is more easily eroded probably due to a greater percentage of clay matrix. This has resulted in an irregular landscape of beehive-shaped pagodas. The Banks Wall Sandstone also contains abundant ironstone bands which protrude from the easily eroded sandstone. Slot Canyons are rarely developed in the Banks Wall Sandstone. However, where the canyons have formed in the Banks Wall Sandstone they appear primarily to be joint controlled. The overlying Burralow Formation (Crook, 1957), appears to be absent in the Northern Blue Mountains. The Banks Wall Sandstone is overlain directly by the Hawkesbury Sandstone which forms outliers such as at Rock Hill. The Hawkesbury Sandstone is harder than the underlying Banks Wall Sandstone and is characterised by its rounded, granite-like, outcrop. Goldbery (1968) has over-estimated the extent of Hawkesbury Sandstone outcrop on the Glen Davis 1:50,000 sheet and this is corrected on fig.94, in the back pocket. Tertiary basalt covers the Hawkesbury

Sandstone in some places (fig.94) and remains as resistant caps on the top of hills. In most cases stream gravel is not present below the basalt which suggests that the basalts are either intrusions or close to the source of eruption or have not flowed into major streams or rivers. Radiometric dating of basalt near Mt. Wilson, to the south, by Wellman and McDougall (1974) has yielded an age between 15.9 and 18.4 m.y. Breccia vents are not common in the mapped area. Wollangambe Crater (figs 94 and 99) is masked with sand eroded from the Banks Wall Sandstone which obscures it volcanic origin. However on aerial photo, Wollangambe Crater has a circular shape and appears to be surrounded by a ring fault. The age of this volcanic neck is not known.

B. Regional structure of the Western Coalfield (southern portion):
The regional dip of the Narrabeen Group and Illawarra Coal Measures in the southern Western Coalfield is to the ENE-NE. This dip is generally between 1 and 2 degrees. An exception occurs in Freshwater Creek (fig.96) where the dip is about 12 degrees to the NNW which is probably related to a local structure.

Fracturing was examined at five localities (localities 2-6, fig.91) in the Southern Western Coalfield. A rose diagram of fracturing at the above localities (fig.97) shows that the main joint sets trend NNW, NW, NE and E-W. The most dominant joint set trends NNW. NNW joints are generally planar and subvertical and are frequently greater than 100 metres long. A planar NNW master joint is shown in fig.98. NNW joints are regionally developed, occurring at Cherry Tree Hill and at

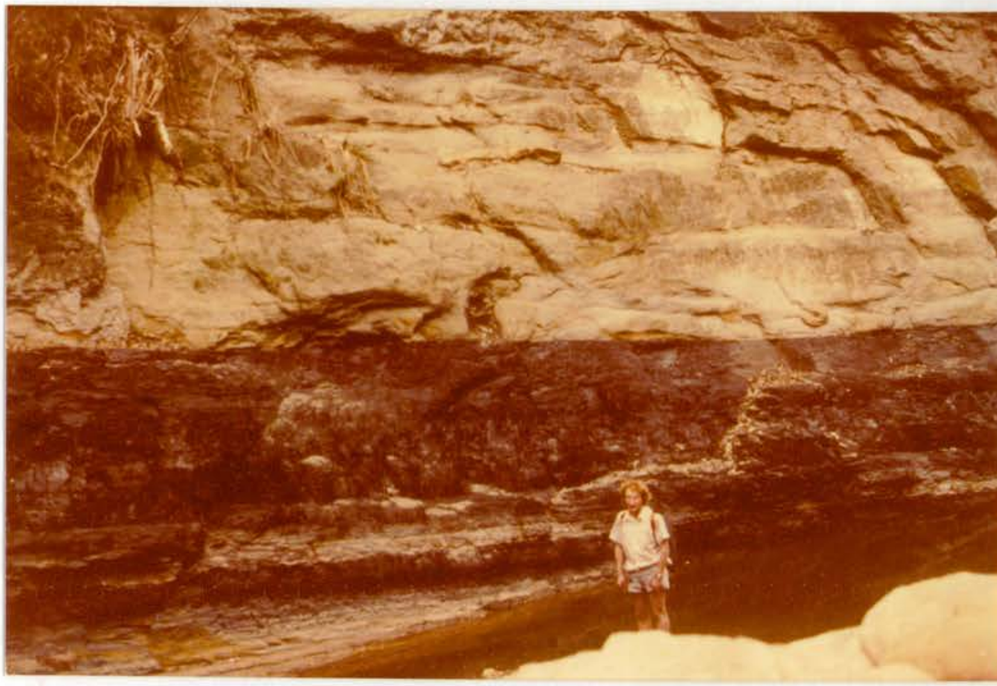


Figure 96. The boundary between the Illawarra Coal Measures and the Narrabeen Group, Freshwater Creek (Locality 6).

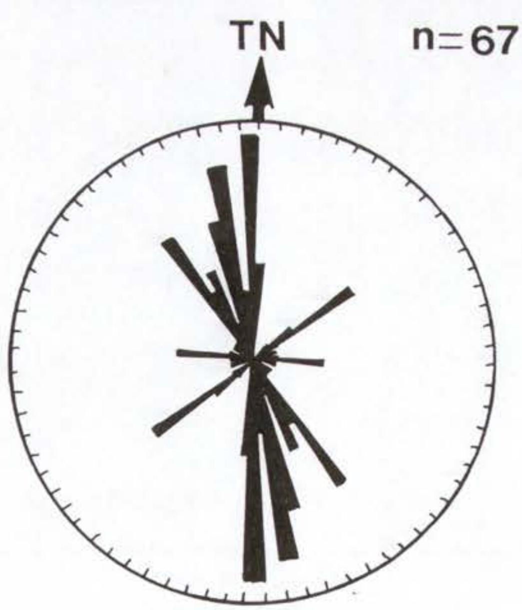


Figure 97. Rose diagram of fracturing in the southern portion of the Western Coalfield.

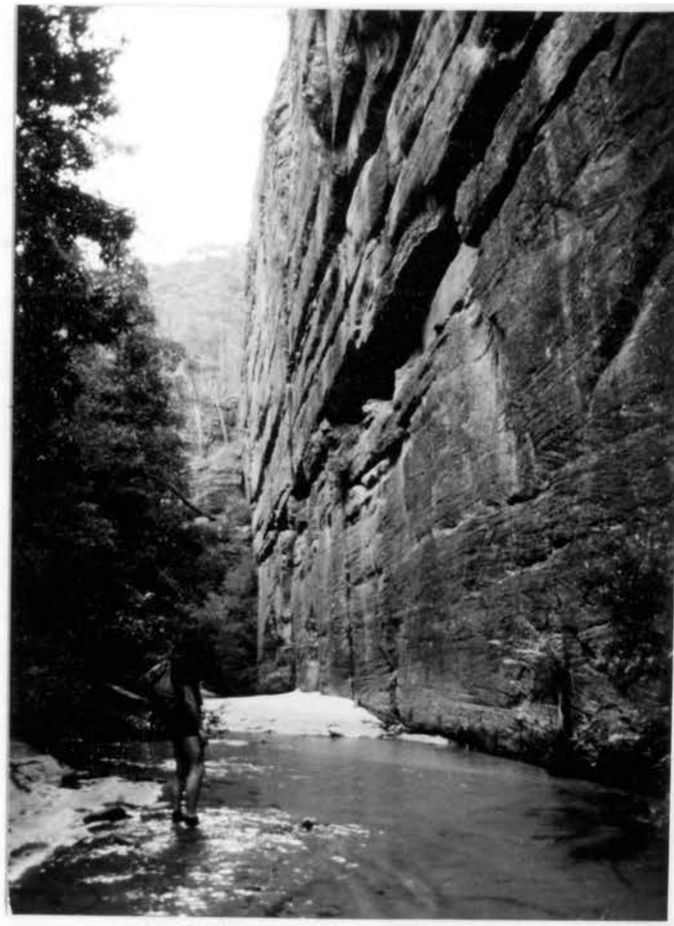


Figure 98. A planar NNW master joint in Bunglboori Creek.

Kanangra Walls. The regional NNW joint set can be seen on an airphoto to the north of Bell on the Newnes Plateau (fig.99). This airphoto also shows a NNE lineament which Mauger et al. (1984) called the Du Faur Lineament. This lineament extends from Wollangambe Creek to Bungleboori Creek in the north. Upstream and down-stream of this Lineament the west to east flowing creeks are cut through the resistant Burra-Moko Head Sandstone to form narrow gorges, in places as narrow as 3-4 metres. However, where these creeks cut through the Lineament the gorge widens to around 100 metres. Although there are no good marker beds in the Burra-Moko Head Sandstone, it is possible that this Lineament is a small monocline. At the point where the creeks cut through the monocline the dip of the Burra-Moko Head Sandstone becomes greater than the gradient of the creek. The widening of the creeks may be due to a persistent siltstone causing undercutting of the overlying sandstone, although no siltstone was observed. The change in dip results in the gorge-forming sandstone outcropping both above and below the monocline.

Du Faur Monocline is subparallel to the Tomah Monocline (David, 1902) which occurs to the east and to the Lapstone Structural Complex. While NNW master joints are the most common structural element in the southern Western Coalfield, N-NNE lineaments are the most extensive. Mauger et al. (1984) have mapped the NNE trending Blackheath Lineament into basement rocks and it appears that these lineaments owe their origin to basement structures. The basement structures may be inherited as structural discontinuities containing close-spaced jointing in the Sydney Basin Rocks or they may have been influential

Figure 99. Aerial photo of an area north of Bell.

in determining the position of hinge lines, east of which rapid subsidence occurred which resulted in thickening of the sediments. Like the Tomah Monocline, the Du Faur Monocline may be also be a depositional hinge line.

The NNE trending Tomah Monocline is shown on the Katoomba 1:50,000 geology map (Goldbery, 1969b) and is believed by Goldbery (1969) to have been active as a depositional hinge line. The map of the Northern Blue Mountains (fig.94) shows the northern extension of the Tomah Monocline. The Monocline was mapped by using aerial photos, by observing the change in the regional drainage pattern and by mapping the Mount York Claystone. North of Mount Irvine, the Tomah Monocline does not appear to be a simple structure. Changes in the dip of the Mount York Claystone indicate that the Tomah Monocline consists of several subparallel monoclines (fig.94). However, further mapping is needed to delineate the structures associated with the northern extent of the Monocline. First-order streams in the Northern Blue Mountains, such as Wollangambe River generally flow from the west to east down the dip-slope. However, Wollangambe River changes its flow to a NNE direction for 12 kilometres where it meets the Tomah Monocline. The widespread NNW joint pattern influences the meander direction of these first-order streams: however, it has a greater influence on the direction of second and third order streams which are tributaries of the first order streams. To the west of the Tomah Monocline and NNE flowing Wollangambe River, the NNW joints swing to a NW orientation to be almost orthogonal to the larger scale NNE trending structure. This is evidenced by the bending of second-order drainage into an arcuate shape adjacent to the Monocline. The change in orientation of NNW joints adjacent to the Monocline indicates that the NNW joints developed after the initial development of the Monocline. The Monocline may have been the site of subsequent deformation although this was not observed. To the south, the Grose River continues to flow roughly west-east across the Monocline. This is probably due to the gradient of the Grose River from its headwaters to the Cumberland Basin which is greater than the gradient of the Wollangambe River, which flows into the Colo River and through the Hornsby Plateau.

While N-NNE lineaments form the most extensive traces in the southern Western Coalfield, NNE joints outside these lineaments are not common. In some collieries such as at Wallerawang and to the west of the old Newcom Colliery, NNE linear zones of bad roof conditions are the result of close-spaced N-NNE jointing and Shepherd et al. (1978, 1981a) have shown that surface fracture patterns are remarkably similar to those at the level of the coal seams. Shepherd and Huntington (1981) show that the NNE lineaments are spaced about 4-5 kilometres at least as far east as the Kurrajong Fault.

Fig.97 also shows that minor E-W and ENE joint sets also exist in the southern Western Coalfield. The relationship between these joints and the regional NNW joint set or the NNE lineament/fracture zones was not observed.

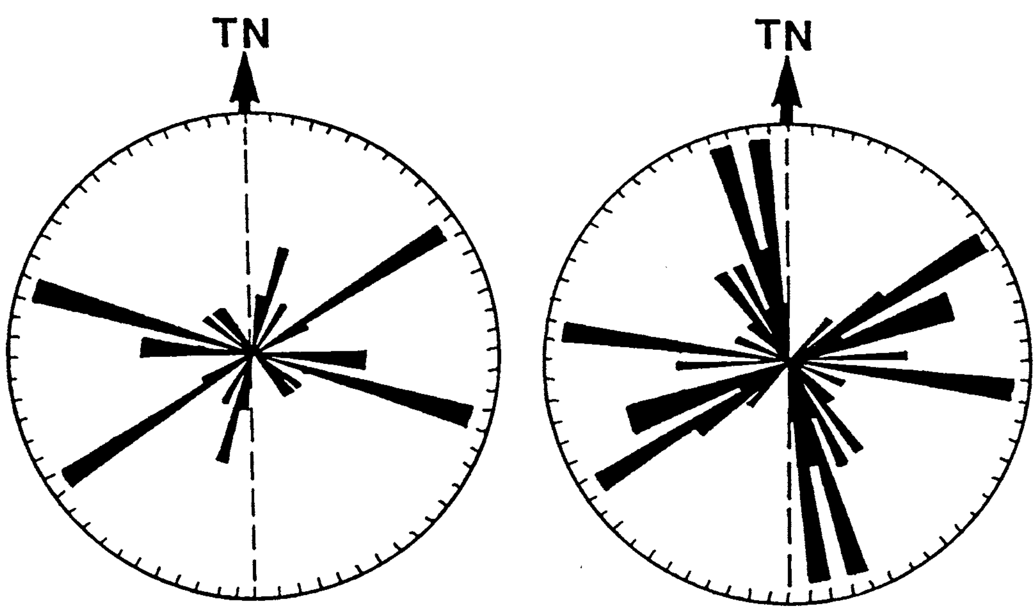
4.3 BASEMENT STRUCTURES

A. Kanangra Walls region:

A SE trending lineament in the Late Devonian Lambie Group metasediments, extending from the Thurat Range to the Kowmung River, can be seen on aerial photo (fig.100). Fracturing was examined along this lineament in the Lambie Group metasediments as well as in the flatlying Permian sediments which unconformably overlie the Lambie Group at Kanangra Walls (Loc.7), Crafts Walls (Loc.8) and Mt. Berry (Loc.9). Rose diagrams of fracturing in the basement rocks and overlying Permian sediments are shown in fig.101. This region was examined to determine the relationship between basement structures and structures in the western Sydney Basin.

At Kanangra Walls ENE planar master joints are common with NW-NNW master joints forming a less dominant set. At Crafts Walls NNW master joints are dominant and ENE joints less dominant. At Mount Berry there is a wide spread of joint orientation, with ESE joints being the most common. Fig.101 shows that ENE and ESE joints are common to both the basement rocks and overlying Permian sediments, while NNW joints occur, almost exclusively, in the Permian sediments. At Mount Berry planar ESE joints were observed to extend from the basement rocks into the overlying Permian boulder-conglomerate cutting through Permian boulders. ESE and ENE joints may form a conjugate set although this was observed in outcrop. The ENE and ESE fractures in the basement rocks may also form conjugate sets which suggests that an E-W compression was common to both the basement of Late Devonian rocks and

Figure 100. Aerial photo of the Kanangra Walls region.



Basement

n = 21

Permian Rocks

n = 39

Figure 101. Rose diagrams of fracturing in the basement rocks and overlying Permian rocks in the Kanangra Walls region.

overlying Permian rocks.

The structural synthesis map for Burragorang (Mauger et al., 1984) shows many ENE and ESE lineaments in the Mid Devonian Bindook complex south of the Kanangra Walls region, some of which appear to have controlled sulphide mineralisation at Yerranderie (Jones et al., 1977). It is possible that some of these lineaments have been reactivated under an east-west compression since deposition in the Sydney Basin commenced, and that this resulted in ENE and ESE conjugate joints in the Permian sediments of the Kanangra Walls region.

NNW joints are common throughout the southern part of the Western Coalfield and it is probable that the NNW joints in the Permian sediments in the Kanangra Walls region are related to this regional joint set. In the Kanangra Walls region there are no subparallel NNW joints in the basement, suggesting that the development of the NNW joints was not related to post-Permian deformation in the basement.

Little fracturing was observed in the Permian sediments subparallel to the NW-SE trending lineament identified in fig.100. This suggests that the lineament is a pre-Permian structure which has not been reactivated during deposition of the Sydney Basin sediments. At Gabes Gap (fig.100) and to the south in Gingra Creek, quartz-porphyry (Carboniferous) dykes have intruded along part of this lineament. This indicates that the lineament had developed prior to intrusion of these dykes. While deformation may not have taken place within this lineament since the Carboniferous, the NW-SE structure may have been inherited into the overlying Permian rocks. Gabes Gap is the lowest saddle between Kanangra Walls and Mt. Cloudmaker which suggests that the lineament has provided a good line of weakness for erosion. This would only have been a good point of weakness if the lineament had been inherited into the Permian sediments which have now been eroded.

The Kanangra Walls region shows that there is a correlation between basement structures and structures in the Sydney Basin. The fabric of the basement, such as the NW lineament, can be inherited into the Basin sediments without further deformation, while other structures such as ENE and ESE joints may be related to reactivation of basement structures through compression, subsequent to the commencement of Permian sedimentation.

B. Coco Creek unconformity:

Fracturing at the Coco Creek unconformity (Loc.11, fig.91) was examined because of the continuation of basement mesoscopic structures into the overlying horizontal Sydney Basin sediments. An equal angle polar plot of fracturing is shown in fig.102.

The unconformity separates westerly dipping Silurian (or Mid Devonian?) metasediments from the flat-lying Permian Megalong Conglomerate. Westerly to north-westerly dipping, low angle, (22-43 degrees) reverse faults displace the unconformity up to 0.75 metres (fig.103). These reverse faults and low angle subparallel planes with no displacement appear to be subparallel to kink planes in the

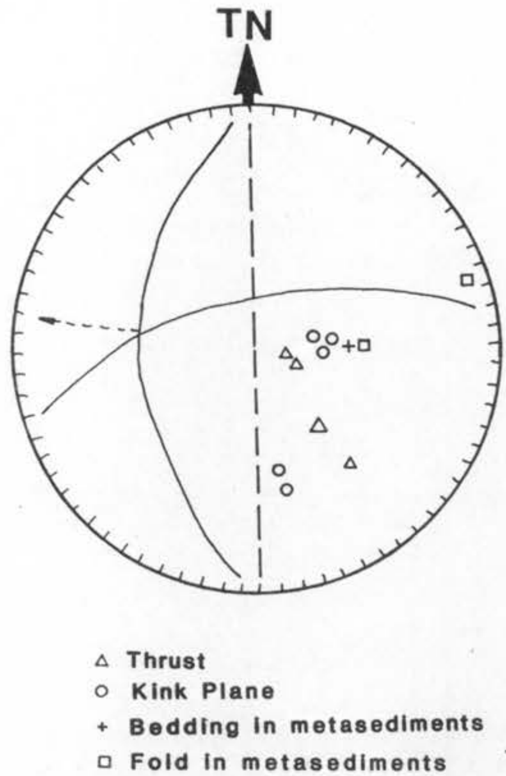


Figure 102. Equal angle polar plot of structures at the Coco Creek unconformity (Locality 11).

Figure 103. Reverse fault displacing the Permian unconformity at Coco Creek (Locality 11).

metasediments. Fig.102 shows that there is probably a conjugate set of kink planes in the basement rocks and if the kink planes are rotated so that the bedding (S_0) is horizontal, the intersection of the kink planes is subvertical and the acute bisectrix is orientated NE-SW. Deformation causing kink planes appears to have occurred prior to folding of the metasediments and prior to deposition of the Megalong Conglomerate. The orientation of the reverse faults through the unconformity is, in part, related to the orientation of the kink planes which provided an anisotropy for the post-Permian compressional deformation.

Vertical planar ENE joints cut through the metasediments (fig.104), the unconformity and through cobbles in the Megalong Conglomerate. These joints are parallel to the Gospers Mountain Lineament identified in the Triassic Narrabeen Group by Mauger et al. (1984) to the NE of Coco Creek (fig.6). Mauger et al. (op. cit.) found this lineament to be coincident with an ENE structural zone in the basement containing complex deformation which has an overall dextral offset. The Coco Creek site indicates that folding in the basement was controlled by NE-SW compression. Large deformation zones in the basement may have been inherited into the basin sediments and these zones may have been acted upon by a later W-NW compression as evidenced by the reverse faults. Rudd (1972) examined jointing in Permian sediments near Rylstone and identified six joint sets. Rudd (op. cit.) believes that four of these joint sets resulted from a N70 deg.W compression which was active in the late Cretaceous and early Triassic Period and which initiated uplift. This compression probably resulted in the reverse

Figure 104. ENE planar joint cutting through the Permian unconformity and cobbles at Locality 11.

faults in the Coco Creek unconformity. However, the timing of this compression is not known at this site, and it is not known whether this compression resulted in uplift. The two other joint sets that Rudd (1972) observed are an orthogonal set about N05 deg.W. This set is regionally developed throughout the southern Western Coalfield. Rudd (op. cit.) believes that NNW joints in the Sydney Basin are related to joints in the underlying basement rocks.

The important features that the Coco Creek site illustrates are that basement structures can influence the orientation of structures in the overlying basin sediments and that compressive deformation has taken place in the basement subsequent to the commencement of deposition in the Sydney Basin.

4.4 SUMMARY

The most common and widespread joints on the western margin of the Blue Mountains Plateau in the Triassic Narrabeen Group sandstones trend NNW. These joints are planar, spaced between 1 and 30 metres and can be greater than 100 metres long. NNW joints were also observed in the Permian rocks around Kanangra Walls: however, they are absent in the Hawkesbury Sandstone on the Lapstone Structural Complex. Swarms of close-spaced NNW-NW joints have also been recorded in the coal seams of the southern Western Coalfield (Shepherd et al., 1981b). In the vicinity of major, depositional, low amplitude NNE trending monoclines, such as the Tomah Monocline, NNW joints swing to a NW direction. This indicates that the NNW joints are a post-depositional feature. NNW joints are often filled with ironstone or goethite. Creasey (1984) examined a fracture foliation which occurs within the ironstone margins of NNW joints in the southern Western Coalfield. He found that the fractures are extensional and that fracturing, dilation and infilling are repetitive. Deformation of the ironstone has also taken place and Creasey (op. cit.) believes this to be related to a post easterly extensional NW directed compression.

The NNE trending Tomah Monocline and Du Fair Monocline are subparallel to a major structural trend in the southern Western Coalfield. NNE lineaments form the most extensive traces in the Narrabeen Group sandstones and have been traced into basement structures (Mauger et al., 1984). This suggests that these NNE lineaments and probably NNE monoclines are related to basement structures such as faults, fold trends or granite boundaries. An examination of faults within some of NNE joint/faults in the coal seams of the Western Coalfield by Shepherd et al. (1981b) suggests that an E-W compression occurred subsequent to an extensional phase. Evidence for this E-W compression was found in Invincible Colliery while a NW-SE compression was inferred from observations at Grose Valley Colliery (Shepherd et al., op. cit.) However, they could not determine the overall chronological order of faulting and jointing. The NW compression inferred from ironstone-fill deformation along NNW joints by Creasey (1984) is probably related to this E-W to NW-SE within the NNE joint/fault zones. Creasey (op. cit.) suggests that this compression was related to a regional sinistral shear couple that was probably active during the Early Cretaceous (Jones and Veevers, 1983).

On the Lapstone Structural Complex small conjugate joints cut across NE trending, westerly dipping, radial, master joints indicating that a NNE-SSW subhorizontal compression has occurred subsequent to folding and SE-NW extension. In addition, a NW trending dyke and associated subparallel joints cutting across the Complex resulted in a change in orientation of σ_1 to approximately E-W during this compression, forming easterly trending conjugate joints adjacent to the dyke. However, no evidence was observed to indicate a separate E-W compressional event on the Complex. This suggests that either the E-W to NW-SE compression in the southern Western Coalfield did not affect the Complex or that the NNE compression on the Complex and E-W compression to the west were related to the same regional and temporal stress conditions and the change in stress orientation was related to pre-existing basinal or basement structures.

Reverse faults through the Permian unconformity at Coco Creek indicate that thrusting from the west has affected both basement and basin rocks. ENE and ESE joints and fractures in basement and Permian Sydney Basin sediments around Kanangra Walls also indicate that a W-E compression was common to both the basement and overlying Sydney Basin Rocks. In contrast NNW joints do not appear to penetrate into the basement, suggesting that they developed in a separate stress environment to ENE and ESE joints. It is not known whether this W-E compression in the Kanangra Walls region and Coco Creek unconformity is related to the westerly compression evidenced in the southern

Western Coalfield by Shepherd et al. (1981b) and Creasey (1984). It is possible that there were two separate compressional events, one oriented W-E and the other more to the north. Rudd (1972) suggested that a W-E compression occurred in the later Cretaceous and initiated uplift, and that the NNW joint trends are related to the trend of axial fold structures in the basement rocks. The NNW joints do not appear to be related to basement structures at the areas examined in this study, and it is possible that the NNW joints resulted from a regional extension during uplift. Furthermore, the orientation of NNW joints may be related to the NNW strike of the Permo-Triassic sediments on the western margin of the Plateau.

NNE trending structures appear to be the earliest developed structures on the western margin of the Blue Mountains Plateau, although these structures were probably reactivated a number of times through extension and compression. Subparallel structures may have also formed during this later deformation. W-E to NW-SE compression occurred after the initial development of these NNE structures. The NNE trending Lapstone Structural Complex may have initially developed as a hinge-line during sedimentation. This Complex has undergone folding subsequent to dyke emplacement. The age of this dyke is unfortunately not known. A NNE compression acted upon the Complex after folding and possible faulting. This compression may be temporally related to a NW-SE compression which existed in the southern portion of the Western Coalfield. A tentative sequence of tectonic events on the Blue Mountains Plateau is as follows;

(1) Formation of NNE joint/Fault zones and NNE depositional monoclines.

(2) Thrusting from the west (post-Lithgow Coal time).

(3) Intrusion of dyke across Lapstone Structural Complex, which at this time may have only been a low-amplitude monocline.

(4) NW-SE extension resulting in folding on monocline and deformation along NNE structures.

(5) NNE compression on Lapstone Structural Complex and NW compression on the western margin of the Plateau.

(6) Uplift and formation of NNW joints on the western margin of the Plateau.

(7) Minor folding on the Lapstone Structural Complex (??).

CHAPTER 5

STRUCTURAL SYNTHESIS

AND

COMPARISON BETWEEN THE HORNSBY PLATEAU AND BLUE MOUNTAINS PLATEAU

Except for faulting and folding along the Lapstone Structural Complex, the central Sydney Basin is composed of weakly deformed flat-lying sedimentary rocks within which the only indicators of the stress history are fractures, joints and minor faults. On the Appalachian Plateau regional joint sets together with slightly deformed fossils have been used to indicate trajectories of palaeostress fields (Engelder and Geiser, 1980; Engelder, 1982). Unfortunately, the lack of fossils in the present study areas precluded their use as strain indicators. Hancock (1985) also uses an analysis of mesofractures for the solution of tectonic problems. The general rule of younger joints abutting older joints has been used for quite a while, but it was Hancock (1985) who highlighted this field technique. Hancock's (op. cit.) use of the architectural style of joint systems to determine the relative age and mode of formation of joints has been used during this study. However, it should be mentioned there are problems and ambiguities with using abutting relations. Engelder (1985) has pointed out that extension joints will propagate up to but not cut across older joints if the older joints had no tensile strength at the time of propagation of the younger joints. At Leichhardt Colliery, Queensland, Hanes and Shepherd (1981) believe that 'butt' cleats in the coal formed prior to the dominant 'face' cleats, with the 'face' cleats propagating from the end points of the 'butt' cleats. In the Sydney Basin the study of joint arrangements has largely been inferred from small-scale lineament studies (e.g. Bunny, 1972, Mauger et al., 1984). Shepherd et al. (1981b) and Mauger et al. (1984) undertook some bedrock fracture analyses, but their results were mainly confined to delineating the main joint and fracture orientations. Never-the-less the orientation of the joints and abutting relationships, relative to other structures, including joints, is probably the most useful tool for determining the relative ages.

There are two problems associated with a regional study of mesoscopic fractures. The first is a matter of scale and the second is statistical. Fracture zones, joints and faults can often be traced across an outcrop or through a quarry. However, at smaller scales such as 1:25,000 and 1:50,000, these features can lose their significance. It is also a problem to determine the number of joints and sample sites that should be recorded. During this study sample sites were mainly determined by the availability of good outcrop, and were generally situated around anomalous zones. At each analysis site the dominant joint set was identified and only enough joint orientations were measured to determine the mean direction of the joint set. Other joint orientations were recorded to determine subdominant joint set directions and to observe the abutting relationship between these sets. Therefore, a rose diagram can be misleading because it does not indicate the dominant joint set present, but just the spread of orientation. If possible, sample sites in any future regional studies should be based not only on anomalous zones but also on a grid system with a spacing of about 1 kilometre.

Figs 105a and 105b show a rose diagram of all fracture, joint and master joint orientations measured on the Hornsby Plateau and a rose diagram of only master joints. A rose diagram of all fractures, joints and master joints excluding those in major zones of deformation on the Hornsby Plateau is shown in fig.106. The regional joint set consists of planar NNE joints with minor orthogonal (curved) ESE cross joints. Figures 105 and 106 show the dominance of NNE joints on the Hornsby Plateau. These joints frequently dip to the west and can form zones of close-spaced joints, faults and brecciation. Some zones are very extensive and contain evidence of multiple deformation. The Art Gallery-Cremorne Point-Balmoral fracture zone is an example. These zones are also subparallel to major lineaments such as the West Head Lineament and Coastal Lineament both of which contain multiply deformed NNE joint/fault zones. On the Blue Mountains Plateau some NNE structures appear to have developed during sedimentation as sites of differential subsidence, and were probably inherited from basement structures. Likewise, on the southern margin of the Sydney Basin, NNE-NE trending lineaments and fracture zones are believed to be the oldest structures and to have been inherited from the basement (Cudahy et al., 1985). Initially, deformation along these extensive NNE structures was probably through extension forming normal faults. Subsequent E-W and NNE compressional deformation further deformed

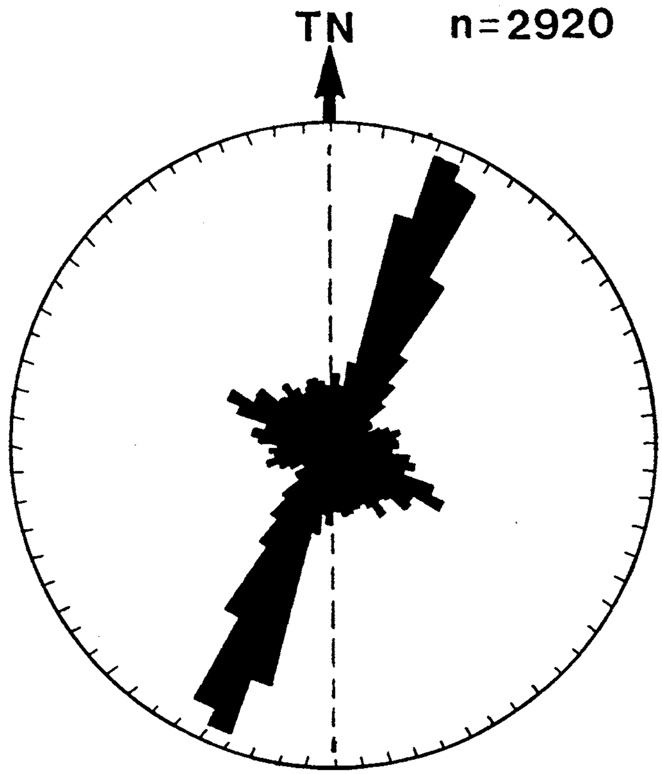


Figure 105a. Rose diagram of all fracture, joint and master joint orientations measured on the Hornsby Plateau.

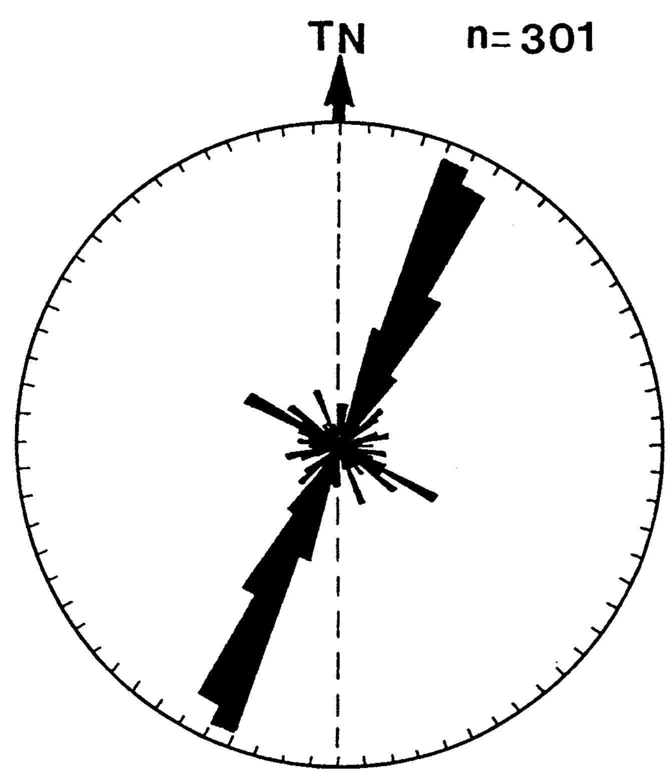


Figure 105b. Rose diagram of all master joint orientations measured on the Hornsby Plateau.

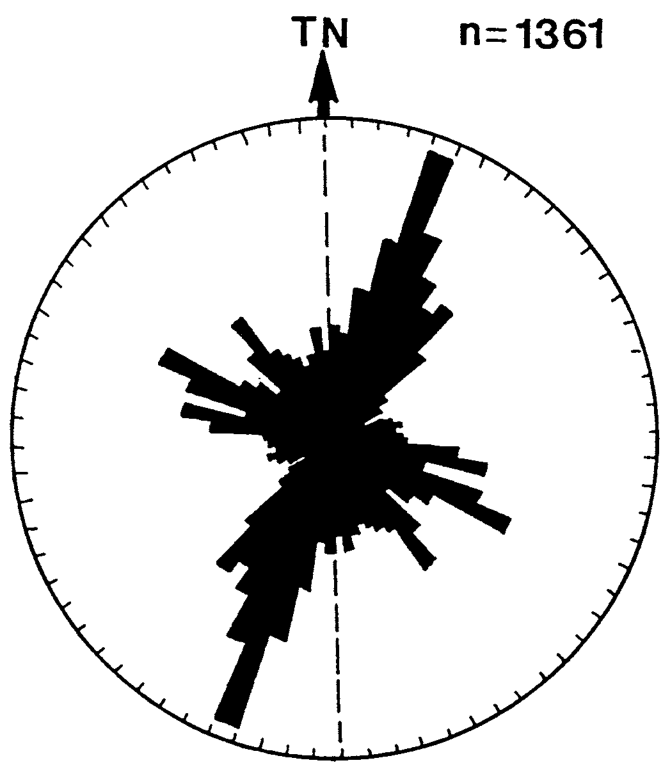


Figure 106. Rose diagram of all fracture, joint and master joint orientations measured on the Hornsby Plateau except those in major zones of deformation.

these structures and probably formed subparallel structures to the initial NNE structure. The Lapstone Structural Complex may have formed as a N-S depositional hinge-line which has subsequently suffered multiple deformation.

Some NNE zones contain vertical and horizontal conjugate joints indicating that the maximum compressive stress (σ_1) has been both vertical and horizontal during deformation is these zones. From the observations in chapter 3 it was inferred that the initial deformation within these zones occurred through lateral compression and that with unloading, σ_1 became vertical, and vertical conjugate joints formed. With further unloading there was a transition from vertical conjugate joint zones to zones with westerly joints to single westerly dipping joints to vertical extension joints. This mode of development of NNE joints is based on the model of Price (1966) when there is a residual tectonic stress, and on experimental data given by Paterson (1978). The dihedral (2θ) angle of the vertical and horizontal conjugate joints is small (15-30 degrees). The westerly dipping joints and vertical conjugates developed through extensional shear failure. The small dihedral angle of the horizontal conjugate joints also indicates that these joints formed through extensional shear failure according to Hancock (1985). However, the important point is that σ_1, was initially horizontal which resulted from a lateral NNE compression. Surface morphology, such as plumose markings which usually indicate development through extension were not observed on NNE joints, except for a possible occurrence near the Sydney Opera House. This also suggests that most NNE joints developed with some shear component.

The lack of plumose markings also indicates that these joints did not develop as hydraulic tectonic joints under high pore pressures which can exist at significant depths in the crust (Engelder, 1985). The transition towards true extension joints results from the removal of overburden through erosion. The erosion on the Hornsby Plateau has mainly occurred because of the rejuvenation of streams. This rejuvenation has traditionally been attributed to uplift. However, downwarping and faulting to the east and fluctuations in sea-level may have been more significant in increasing the gradient of streams flowing to the east and erosion. When the overburden has been reduced so that shear failure occurs, the release of stress may result in the overburden pressure being greater than the lateral stresses. σ_1 then becomes vertical and vertical conjugates and westerly dipping extensional shears can develop. It is suggested that a lateral NNE (010-015) compression existed at or prior to an increased rate of erosion. However, NE trending en echelon fractures at the end points of NNE joints in chapter 2 indicate that this compression was oriented more to the NE. The use of these en echelon fractures as kinematic indicators is probably not as reliable as conjugate joints. This transition from horizontal conjugate joints to extension joints should result in 4 and possibly 5 sets of joints. In outcrop these joints are accompanied by subparallel minor normal faults. Two sets should strike in similar directions, but dip at high angles in different directions, another two sets should be subvertical, but vary up to 30 degrees in strike and the fifth set should be vertical extension joints whose strike should bisect the dihedral angle of the horizontal conjugates. Orthogonal cross joints may also be developed.

This would produce a complicated (rhombohedral) pattern in outcrop plan. However, the development of this pattern was progressive with one or two sets developing at one time, as predicted by the Navier-Coulomb theory of brittle failure. Aydin and Reches (1982) have recorded rhombohedral arrays of faults with very minor displacement in Entrada and Navayo Sandstones which they believe develop more or less simultaneously. However, on the Hornsby Plateau a similar array could be explained by changing stress conditions through erosion.

The most common master joints on the Blue Mountains Plateau trend NNW and are similar in fracture style and morphology to the NNE joints on the Hornsby Plateau. NNW and NW trending conjugate faults have been found in the Grose Valley Colliery (Shepherd et al., 1981b) similar to the horizontal conjugates found on the Hornsby Plateau. The similarity between NNE joints on the Hornsby Plateau and NNW joints on the Blue Mountains Plateau suggests that they have a similar tectonic origin. The NNE joints on the Hornsby Plateau developed through progressive extensional shear failure during unloading. Likewise the NNW joints probably developed through a removal of overburden after an initial NNW lateral compression. During joint development through unloading, σ_1 became vertical because of this residual tectonic stress (Price, 1966). The major difference between these two regional joint sets is the initial stress conditions. Why was the lateral compression orientated NNE on the Hornsby Plateau and apparently NNW on the Blue Mountains Plateau? The small dihedral angle of the horizontal conjugate joints suggests that during failure through lateral compression the differential stress was small and that the intermediate principal stress (σ_2) was probably vertical. At this time both σ_1 and σ_3 are horizontal and σ_3 tends to become parallel to the bedding plane dip. When erosion occurs σ_1 becomes vertical, σ_2 becomes horizontal and σ_3 remains horizontal and parallel to the bedding plane dip. On the Blue Mountains Plateau the Permo-Triassic strata dip ENE and this should result in NNW extensional shear joints during erosion. However, on the Hornsby Plateau the dip is variable and not well defined. Mayne et al. (1974) show the base of the Narrabeen Group dipping ESE to SE, but the Sydney 1:100,000 geology map shows the base of the Narrabeen Group dipping more to the SW. NNE joints are well developed throughout the Hornsby Plateau and only deviate from this direction adjacent to igneous dykes. On the Hornsby Plateau it is possible that the initial lateral maximum principal stress direction was the main, or only, determining feature on subsequent joint direction during unloading and that the gentle dip of the Plateau did not influence joint direction. During this NNE to NNW lateral compression across the central Sydney Basin pre-existing NNE structures were probably further deformed and extended.

As previously mentioned NNE joints frequently deviate to a NE direction adjacent to NW dykes and NW joint zones. This occurs near the Grosvenor Place Dyke, the Cabbage Tree Bay Dyke and the Barrenjoey Dyke and indicates that the intrusion of these dykes occurred prior to a NNE compression. A similar deviation in NNE joints can also be explained at Belrose and along the coast in the Kuring-gai/Berowra area by pre-existing NW trending dykes. NNE to NE joints also cut across the Haymarket dyke. The Barrenjoey Dyke has been radiometrically dated at 171∓3Ma which indicates that the NNE compression and an increased rate of erosion occurred subsequent to this time. Horizontal NNE conjugate fractures were also observed in this dyke indicating a post intrusion NNE compression.

A histogram of K-Ar ages for volcanic rock units in the Sydney Basin by Embleton et al. (1985) is shown in fig.107. This histogram shows 3 prominent peaks. These peaks occur at 45Ma, 185Ma and 245Ma. The 45Ma peak is associated with a wide spread of ages between 10Ma and 120Ma and Embleton et al. (op. cit.) suggest that the major thermal event occurred around 90Ma. According to Hayes and Ringis (1973), seafloor spreading occurred in the Tasman Sea between 60-80Ma. The ages given by Embleton et al. (1985) for volcanic rocks suggest that the main thermal peak occurred prior to rifting and that substantial volcanism occurred subsequent to rifting. The Tasman Sea spreading ridges trend NNW to NW and the cross-cutting transform faults trend ENE. The predominant NW trend of dykes in the central Sydney Basin is probably a result of extension perpendicular to this spreading ridge. However, the results of Embleton et al. (op. cit.) suggest that this NE-SW extension would have occurred before and after rifting. Because rifting occurred in the continental crust, extension perpendicular to the spreading ridge may only have occurred after rifting during a period of relaxation. During rifting a lateral compression parallel to the spreading direction (NE-SW) may have occurred in the adjacent continental crust. NE thrusts along the Comenarra Parkway, easterly strike-slip faults at Thornleigh and a suggested NE-SW compression along the Roseville Warp may have developed at this time. It is

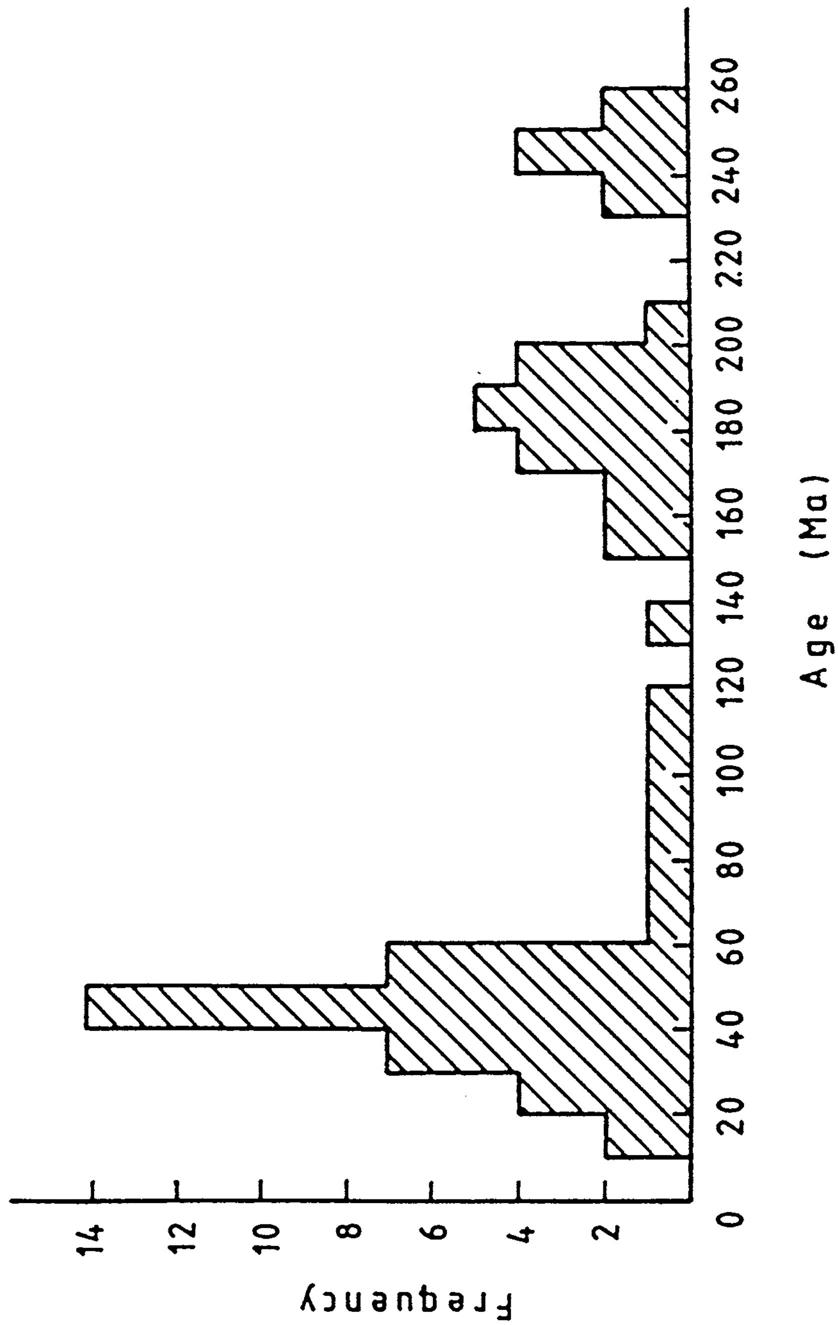


Figure 107. Histogram of K-Ar ages for volcanic rock units in the Sydney Basin (Embleton et al., 1985)

interesting that breccia necks are associated with some of these easterly structures which implies that they could be Tertiary in age and have formed during a regional compression. A NE-SW compression may also have reactivated any pre-existing easterly trending structures such as the Barrenjoey Head-Cowan dyke/fracture zone and the Berowra Waters Fracture Lineament Zone. Prior to rifting, volcanism and the stress conditions in the continental crust were probably unrelated to the subsequent seafloor spreading. Intrusion of dykes prior to rifting occurred along existing anisotropies. Jones and Veevers (1983) suggested that prior to rifting, from 200-90Ma, a plate boundary was located parallel to the east coast of Australia. This boundary experienced 'prolonged oblique slip' as a result of a sinistral shear couple. This shear couple may have reactivated the NNE structures and caused some thrusting, but there is no evidence of this pre-rift shear couple.

The NNE lateral compression appears to have occurred after the intrusion of NW trending dykes. This lateral compression occurred at or prior to renewed erosion. Therefore, the upper limit for an increased rate of erosion through downwarping of the Hornsby Plateau must be the end of rifting about 60Ma. If renewed erosion was the result of uplift of the Hornsby Plateau and if a NE-SW extension occurred after rifting the upper limit for uplift would be about 45Ma.

The Barrenjoey dyke is coincident with a transform fault extending WSW from the spreading ridge (Fracture Zone 4; Ringis, 1975). If the age of the Barrenjoey dyke is correct then this fracture zone must have existed 171Ma, well before rifting.

Measurements of the present-day in situ stress in underground coal mines in the central Sydney Basin indicate that a N-S compressive stress predominates (Shepherd and Huntington, 1981). However, the use of underground stress measurements should be used with caution during a regional analysis, because of local variations which can result from the shape and direction of roadways, the orientation of pre-existing structures and the variable thickness of overburden. Using in situ stress measurements, seismic studies and geological studies, Gray (1982) concludes that the major structures of the Sydney Basin probably formed as a result an E-W horizontal compression during cratonisation of the Permo-Triassic sediments and that this horizontal stress subsequently changed to a N-S direction. Worotnicki and Denham (1976) inferred that the direction of maximum horizontal stress is broadly E-W throughout most of the Australian continent. Denham (1980) re-studied the Robertson earthquake records and suggested that the direction of horizontal stress in the Sydney Basin is broadly NE-SW. In this thesis it is suggested that the process leading to a regional NNE joint set on the Hornsby Plateau involved an initial NNE lateral compression subsequent to rifting and a NE-SW extension. It seems likely that this compression and the NNE joints are subparallel to the contemporary N-S stress field which exists in the eastern part of the Sydney Basin. It is also possible that this N-S compression has existed since the downwarping and/or uplift of the Hornsby Plateau and has been approximately of the same magnitude. In the United States, the contemporary stress field has been attributed to movement of the continental lithosphere across the asthenosphere, with the drag of the lithosphere setting up a horizontal compression in the direction of the motion of the lithosphere relative to the asthenosphere (Engelder, 1982). The present northward migration of Australia away from the Antarctic Continent, commencing about 50-60Ma (Weissel and Hayes, 1971), may have generated this N-S compressive stress in Eastern Australia. This stress varied and may continue to vary in direction across the basin because of pre-existing structures such as dykes and bedding plane dip. The local variations in stress direction resulted in different regional joint directions as evidenced by the NNE regional joint set on the Hornsby Plateau and the NNW regional joint set on the Blue Mountains Plateau. From the previous discussions it can be further inferred that the uplift of the Hornsby Plateau was initiated at or after the separation of the Australia and Antarctic Continents about 50-60Ma when the N-S compression commenced.

The Lapstone Structural Complex appears to have been affected by a NNE horizontal compression subsequent to the main folding episode. This folding also occurred subsequent to the intrusion of a NW trending dyke. This suggests that the folding episode occurred prior to the splitting of the Australian and Antarctic Continents between 50-60Ma and presumably after the NE-SW extensions associated with the intrusion of the dyke. Pedram (1983) has suggested that an E-W compression occurred on the Complex prior to the main tectonic event. This stress could have resulted from an easterly compression during seafloor spreading or may have originated early in the history of the basin. However, I believe that the E-W compression acted upon the

Complex after folding, and could be attributed to local lateral compressive stress conditions resulting from the subsidence of the adjoining Cumberland Basin. However, more structural information is required from the Complex to determine clearly its structural history.

Because a NNE compression acted upon the Lapstone Structural Complex after folding it could be inferred that uplift of the Blue Mountains Plateau occurred prior to the Hornsby Plateau if folding was associated with uplift and if the removal of overburden on the Hornsby Plateau resulted from uplift. However, it is possible that both Plateaux were uplifted at the same time and that subsequent downward faulting and folding of the eastern blocks produce the present structural subdivisions and rejuvenated stream erosion. Therefore, epeirogenic uplift and the main folding episode are separate with uplift occurring prior to folding. The reason for epeirogenic uplift is an enigma but a possibility is that uplift and easterly tilting of the Blue Mountains-Hornsby Plateaux occurred during rifting when there was an NE-SW compression on the adjoining continental crust. Branagan (1975) regards downdragging of the Cumberland Plain as the logical outcome of tensional forces acting during seafloor spreading. While tensional forces may have resulted in downdragging, a NE-SW extension associated with rifting probably only occurred in the adjoining continental crust when rifting began to wane or ceased. This tensional regime may have existed until splitting of the Antarctica and Australian continents which resulted in a regional N-S compression.

An E-W compression existed at the western margin of the Sydney Basin

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An E-W compression existed at the western margin of the Sydney Basin at least until deposition of Late Permian rocks. On the Hornsby Plateau the abutting relationship of joints indicates that deformation along major ESE trending structures such as the Berowra Waters Lineament occurred prior to the NNE compression and prior to the intrusion of NW trending dykes. Regionally, ESE master joints are not common except within major zones of deformation. The Berowra Waters Lineament has been the site of multiple deformation, including lateral compression, and is parallel to a major structural trend in the Sydney Basin (Mauger et al., 1984). ENE trending structures, such as the Barrenjoey Head-Cowan Fracture Zone, appear to change orientation adjacent to the ESE trending structures, suggesting that the ESE structures pre-existed ENE structures. Overall , these easterly trending structures appear to have initially developed prior to a regional N-S compression and NE-SW extension and after the initial development of NNE depositional structures.

The easterly trending structures did not influence deposition of the Triassic sediments in the central Sydney Basin unlike some NNE structures, but may have been inherited from basement structures during a regional easterly compression. The origin of an E-W compression is not known, but was suggested by Gray (1982) to have developed during cratonisation of the Sydney Basin Sediments to the older Palaeozoic rocks. On the western margin of the Blue Mountains Plateau this stress appears to have originated in the basement rocks. This deformation may be part of Harrington and Korsch's (1985) tectonic period 7 which has been linked with the Rangitata Orogeny in New Zealand.

Mesoscale structures, such as slump planes and small scale normal faults, which originated during deposition occur on the Hornsby Plateau although they are not as common as other discontinuities. Most of the major and minor discontinuities in the central Sydney Basin result from post-depositional tectonics. A possible sequence of geological events affecting the central Sydney Basin incorporating data from Shepherd and Huntington, (1981) and this thesis is shown in fig.108.

Creasey and Huntington (1985) have attributed the basin lineament pattern (fig.109) and mesoscale fracture patterns to the reactivation of basement structures because of a pre-Tasman Sea rifting rotational shear couple. While this couple may have caused deformation, the general structural pattern of the basin has accumulated through geological time under varying stress conditions. In addition the well developed regional master joint patterns probably developed after rifting.

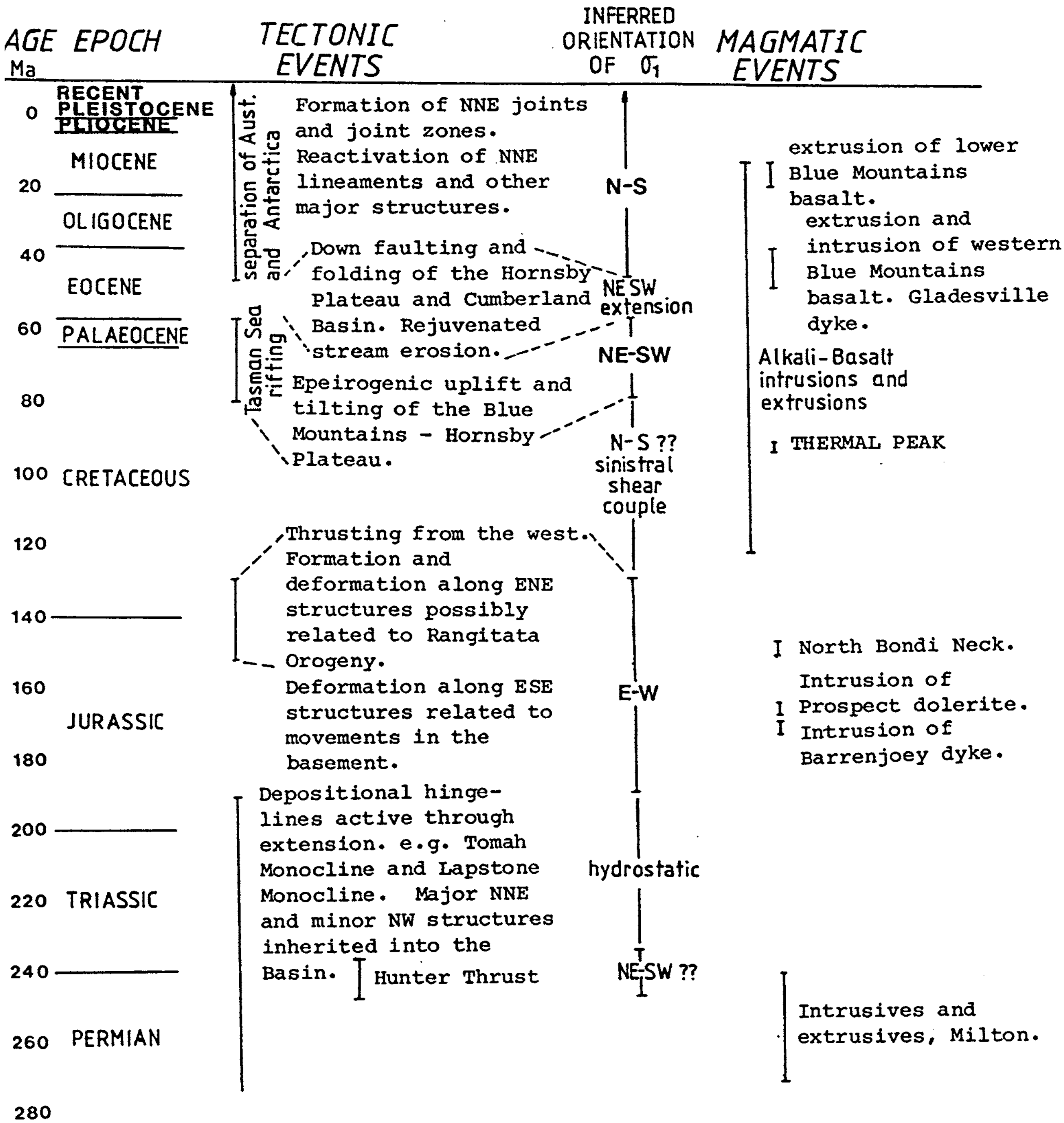

Figure 108. A possible sequence of tectonic events affecting the central Sydney Basin.

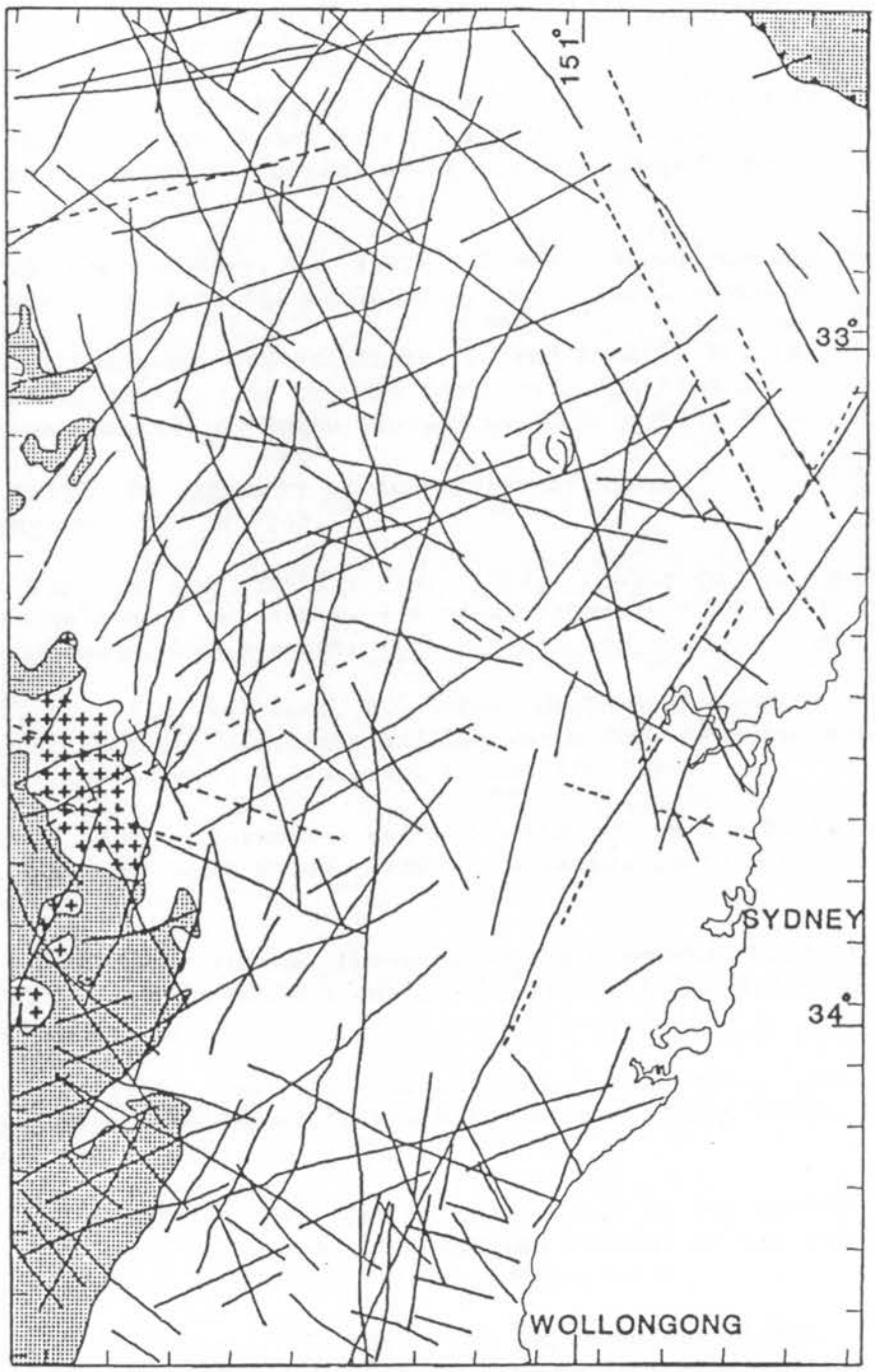

Figure 109. Lineament summary of the Sydney Basin (Mauger et al., 1984).

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APPENDIX A

Appendix A contains a list and summary of all fracture analysis sites in the Kuring-gai/Berowra area shown on figures 11 and 12. Grid references are based on the Australian Map Grid (U.T.M.) and all bearings are given to true north. The fracture summary of each locality includes three plots of fracturing ; a plot of the strike, a rosette diagram using 5 degree class intervals, and an equal area polar plot. A summary of the joint and master joint sets and their characteristics is also given. The arrangement of fracturing (terminations) and any other structures are also noted.

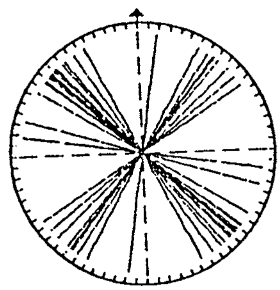
Locality number	Grid Reference	Locality Description
1.	3217.2,62877.2	Smugglers Ridge Road.
2.	3216.6,62878.9	50m NW of loc.1, Smugglers Ridge Road.
3.	3214.6,62878.5	100m Sth of loc.2, Smugglers Ridge Road.
4.	3204.7,62873.1	NW ridge off Smugglers Ridge Road, 1.5km SW of loc.3.
5.	3194.6,62864.6	Smugglers Ridge, West of Nat. Park gate.
6.	3242.3,62863.6	Coba Ck. near Mangrove Swamp.
7.	3239.5,62875.5	Marramarra Ridge.
8.	3231.2,62885.5	Marramarra Ck., Nth. end of road (Rn).
9.	3232.4,62884.7	Marramarra Ridge Road, adjacent to loc.8.
10.	3223.5,62874.4	Bobbin Head Road.
11.	3223.8,62872.4	Marramarra Ridge Road (BWL).
12.	3226.7,62869.6	200m SW of loc.12, Marramarra Ridge Road.
13.	3223.8,62847.4	Marramarra Ridge 2.3km Sth. of loc.12.
14.	3224.8,62843.2	Nth. of Coba Ridge Road.
15.	3269.1,62849.5	Coba Ridge Road. (BWL).
16.	3264.8,62843.1	Easterly ridge from hairpin on Coba Ridge Road.
17.	3259.0,62831.5	East of Coba Ridge near Neverfail Bay.
18.	3308.0,62822.7	Millicent trig.

Locality number	Grid Reference	Locality Description
19.	3311.7,62822.3	Pacific Hwy. NW of Millicent trig.
20.	3310.8,62820.5	Berowra Expressway, 1km NE of Cowan.
21.	3317.3,62823.9	Berowra Expressway, 1.5km NE of Cowan.
22.	3315.1,62825.1	Pacific Hwy, 0.75km Nth of tollgate.
23.	3168.0,62902.4	Canoelands Road (BWL).
24.	3288.3,62839.1	East side of Berowra Ck., Bujwa Fire trail.
25.	3299.7,62833.5	Bujwa Ridge.
26.	3302.6,62833.5	Cowan Quarry.
27.	3308.9,62834.4	Muogamarra Nature Reserve.
28.	3283.4,62828.0	Djarra Ridge.
29.	3283.4,62828.0	Djarra Crossing and Nth of Mt.Dewrang.
30.	3315.2,62814.6	Jerusalem Bay track.
31.	3320.4,62816.2	Jerusalem Bay track.
32.	3295.6,62800.4	Pacific Hwy.
33.	3431.4,62830.0	West Head (Rn).
34.	3430.1,62829.0	West Head (Rn).
35.	3381.1,62807.6	Refuge Bay track.
36.	3372.3,62790.0	Salvation track.
37.	3385.7,62748.5	McCarrs trig.
38.	3290.9,62744.1	Bobbin Head Road (down from Ranger's H.Q.).
39.	3281.8,62735.6	Top of Bobbin Head Road (West side).
40.	3252.6,62800.7	Berowra Waters Road (Section).
41.	3243.5,62773.2	Crosslands convention centre, Berowra Waters Ck.
42.	3242.0,62772.3	1km along road from loc.41.
43.	3218.7,62731.0	Galston Gorge.
44.	3246.9,62773.8	Somerville Rd., Crosslands.

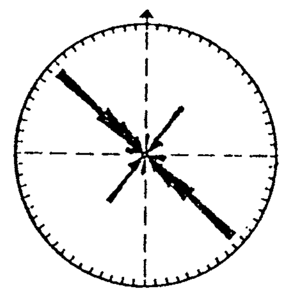
Locality number	Grid Reference	Locality Description
45.	3388.6,62755.0	West Head tesselates.
46.	3440.0,62724.1	Nth. Head of Mona Vale Beach.
47.	3458.0,62788.8	The Ovens, South Whale Beach.
48.	3446.0,62831.4	Barrenjoey Head.
49.	3327.0,62761.5	Duffy's Forest.
50.	3336.2,62769.2	Cottage Point Road (near trig).
51.	3384.6,62777.9	West Head Road (near Salvation track)
52.	3409.0,62791.6	Bairne track, adjacent to trig.
53.	3334.2,62787.3	Cottage Point.
54.	3403.6,62721.5	Ingleside, cnr. Lane Cove Road and Mona Vale Road.
55.	3445.2,62741.4	South Newport Head.
56.	3402.1,62716.8	Ingleside, up from Lane Cove Road.
57.	3452.1,62765.0	South Avalon Head.
58.	3458.7,62773.8	St. Michael's Cave.
59.	3270.3,62752.6	Sth. of Beaumont Rd. Kuring-gai Expressway.

LOC NO. 1 SMUGGLERS RIDGE ROAD   E 3217.2   N 62877.2

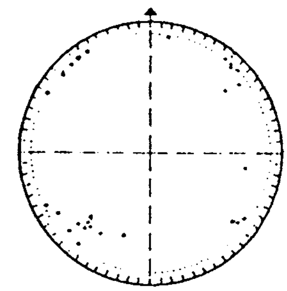
N=28   Lithology - Hawks. Sst./crossbedded



Raw angle data

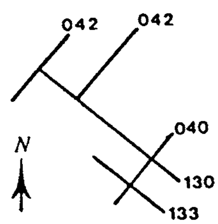


Rose diagram
5° class interval



Equal area polar plot

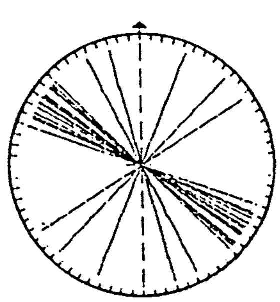
JOINTS SETS	MASTER JOINT SETS
1. 125-135, planar, dominant	1. 125-135
2. 035-055	2. 041
3. 100-107	



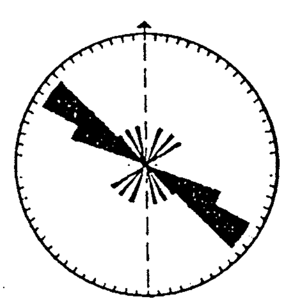
TERMINATION SUMMARY

LOC NO. 2 50 METRES NW OF LOC 1   E 3216.6   N 62878.9

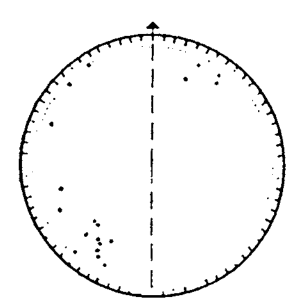
N=19   Lithology - Hawks Sst/crossbedded



Raw angle data

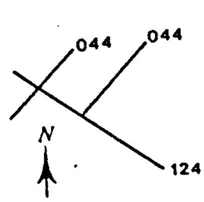


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 110-135, dip 90 to 57 to E, planar dominant	1. 110-135 zonal
2. 044 057, planar	

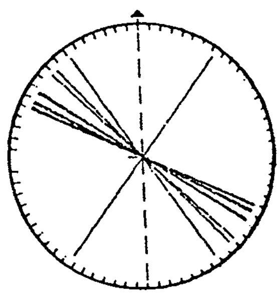


OTHER STRUCTURES: joint zone ; 129 strike, vertical
master joint zone ; 143 strike, vertical

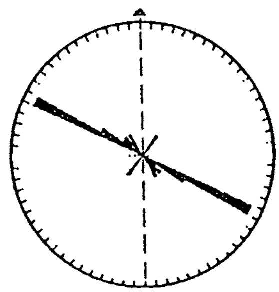
TERMINATION SUMMARY

LOC NO. 3 100 METRES SOUTH OF LOC 2 E 3214.6 N 62878.5

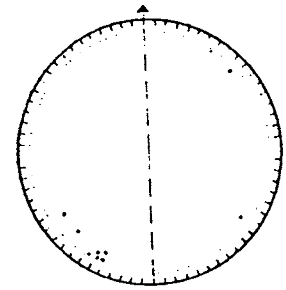
N=11 Lithology - Hawks Sst/crossbedded



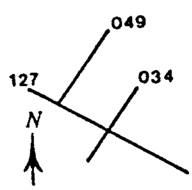
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



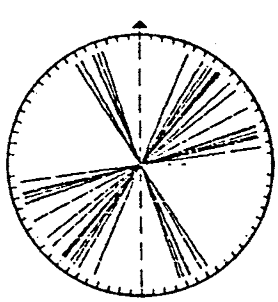
TERMINATION SUMMARY

JOINTS SETS	MASTER JOINT SETS
1. 115-122, planar dominant, iron-filled, subvertical	
2. 134-146	
3. 034-049	

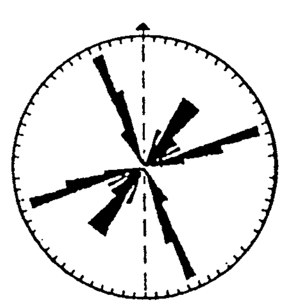
OTHER STRUCTURES: Dyke; strike 127°, width 15cm parallel to joint set 1.

LOC NO. 4 NW TRENDING RIDGE OFF SMUGGLERS RIDGE E 3204.7 N 62873.1

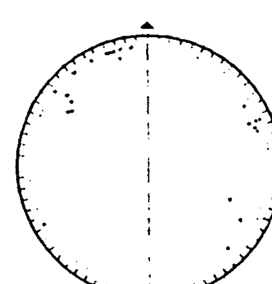
N=23 Lithology - Hawks Sst/crossbedded



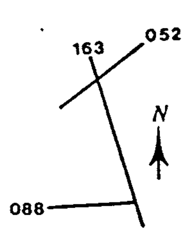
Raw angle data



Rose diagram
5° class interval



Equal area polar plot

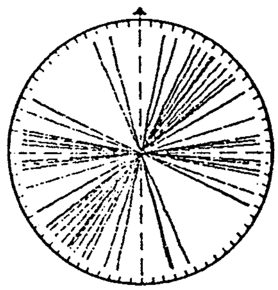


TERMINATION SUMMARY

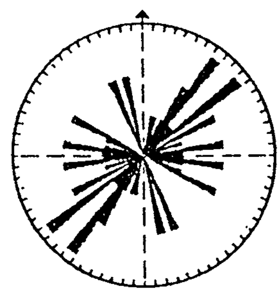
JOINT SETS	MASTER JOINT SETS
1. 030-060, dip 90-60 to SE, planar	1. 071
2. 070-083	2. 157
3. 147-163	

LOC NO. 5 RIDGE STH OF LOC 4 E 3194.6 N 62864.6

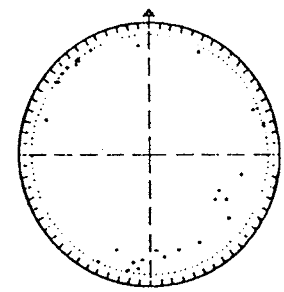
N=30 Lithology - Hawks Sst/crossbedded, silicified



Raw angle data

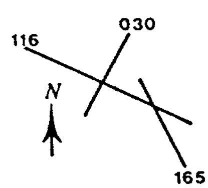


Rose diagram
5° class interval



Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 022-055, planar, vertical	1. 086-116
2. 075-110, dip 75 to 90 to NTH	2. 157
3. 155-165, discontinuous fractures	

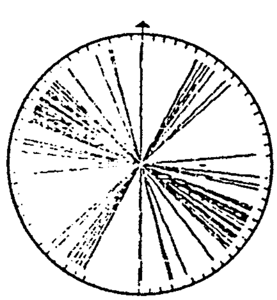


TERMINATION SUMMARY

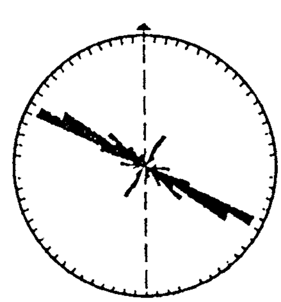
OTHER STRUCTURES: Normal Faults; displacement up to 5cm, strike 027-052, dip 45-55 to NW

LOC NO. 6 MARRA MARRA RIDGE E 3242.3 N 62863.6

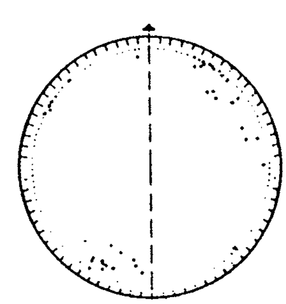
N=47 Lithology Hawks Sst/massive



Raw angle data

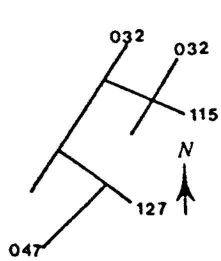


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 110-135, dip 65 to NE to 70 to SW	1. 117-128
2. 027-047	2. 027-037
3. 084-101	
4. 157-165	

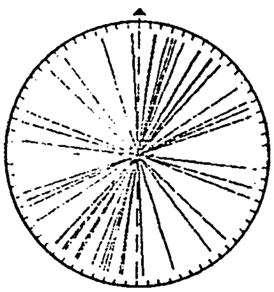


TERMINATION SUMMARY

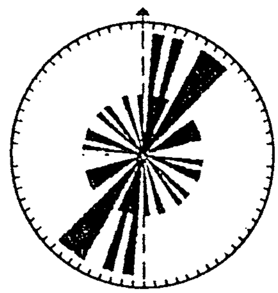
OTHER STRUCTURES: Vertical conjugate fractures; strike 110 to 135, slickensides - both vertical and horizontal in fracture zone
4 dykes-strike 118, 122, 117, 144 subvertical
Normal Fault - strike 113 dip 78 to NE

LOC 7 **MARRA MARRA RIDGE** E 3239.5 N 62875.5

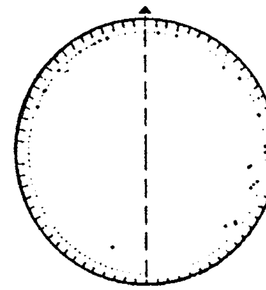
N=23 Lithology - Hawks Sst/crossbedded



Raw angle data

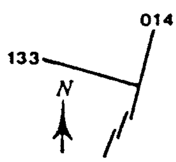


Rose diagram
5° class interval



Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 007-042, planar, vertical, dominant	1. 022
2. 095- 110	2. 067-071
3. 057-072	
4. 135-160	

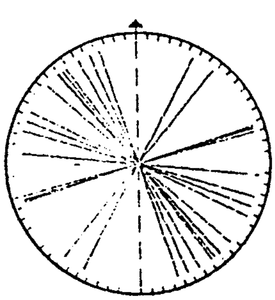


OTHER STRUCTURES: 'en echelons' strike 017 on joint with strike 007

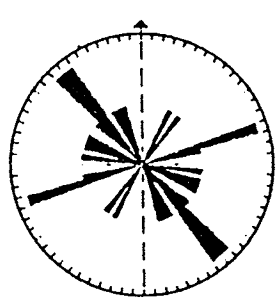
TERMINATION SUMMARY

LOC 8 **NORTH END OF MARRA MARRA RIDGE ROAD** E 3231.2 N 62885.5

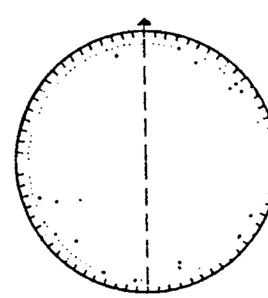
N=17 Lithology - Narrabeen Group sandstone



Raw angle data



Rose diagram
5° class interval



Equal area polar plot

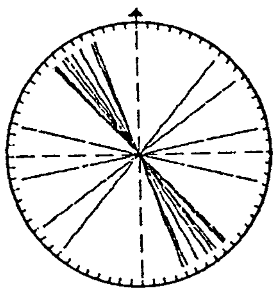
JOINT SETS	MASTER JOINT SETS
1. 145-160, dominant	1. 162
2. 027-038	
3. 105-117	
4. 070-075	

OTHER STRUCTURES: joint zones; width up to 2m

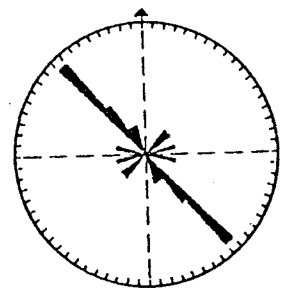
1. 132-144, subvertical
2. 117, dip 83 to SW
3. 072, dip 78 to NW

LOC NO. 9 END OF MARRA MARRA RIDGE ROAD E 3232.4 N 62884.7

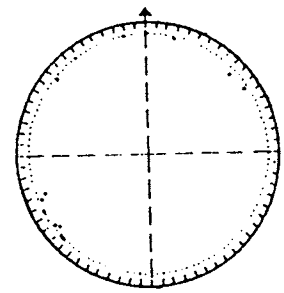
N=14 Lithology - Hawks Sst/crossbedded and massive



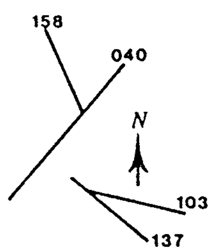
Raw angle data



Rose diagram
5° class interval



Equal area polar plot

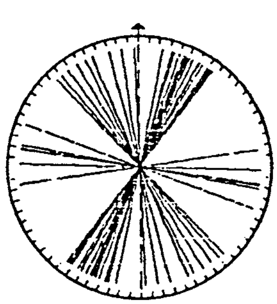


TERMINATION SUMMARY

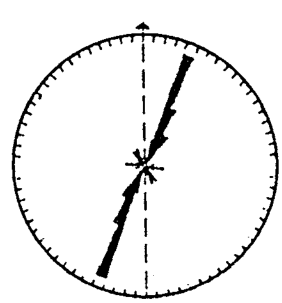
JOINTS SETS	MASTER JOINT SETS
1. 135-160, planar, vertical, dominant	
2. 040-055	

LOC NO. 10 BOBBIN HEAD ROAD - SECTION E 3223.5 N 62874.4

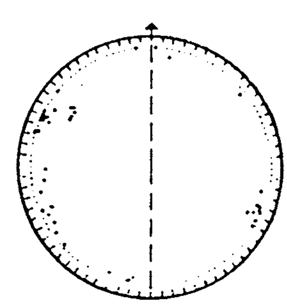
N=48 Lithology - Hawks Sst/crossbedded



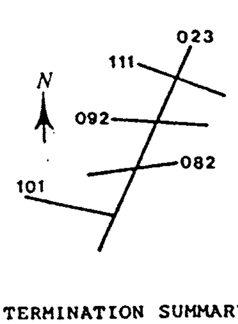
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



TERMINATION SUMMARY

JOINT SETS	MASTER JOINT SETS
1. 020-040, planar, sub-vertical, dominant iron fill	1. 025-035
2. 135-155	2. 119
3. 085-100, iron fill	

OTHER STRUCTURES: joint zones, 1-2m wide

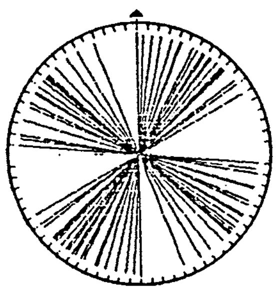
1. 020-030 vertical 2. 150-160 vertical

Normal Fault/Fracture Zone; trend 028 dip 75 to W

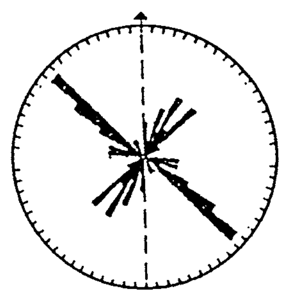
slickensides - horizontal strike 099
- dip 8 to NTH on joint with strike 137

LOC No. 11 MARRAMARRA RIDGE ROAD E 3223.8 N 62872.4

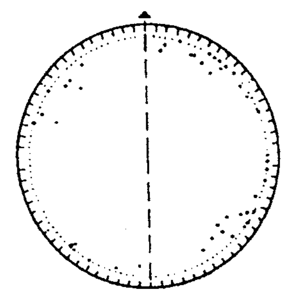
N=50 Lithology - Hawks Sst/crossbedded



Raw angle data

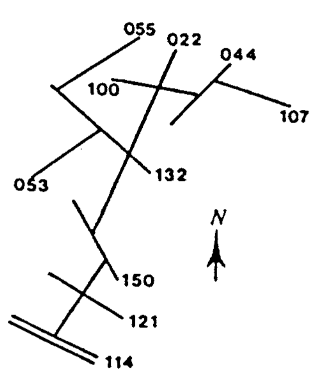


Rose diagram
5° class interval



Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 020-050, planar dip 70° to E and W	1. 030-035
2. 120-135, vertical planar, dominant	2. 115-130
3. 095-105, subdominant	
4. 003-015 subdominant	
5. 137-160 subdominant	



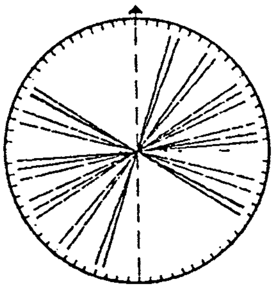
TERMINATION SUMMARY

OTHER STRUCTURES: 2 dykes; strike 120, sinistral step, slickensides in dyke; dip 15-33 to Sth on 016/57/286, dip 33 to E on 110/65/020, dip 66 to E on 122/68/032, dip 430° to E on 131/60/041
joint zones; (1) 114-116 (master joint zones)
(2) 132

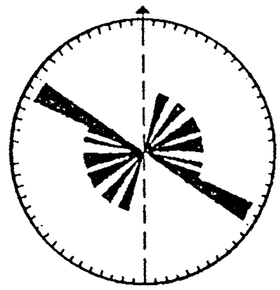
LOC NO. 12 MARRAMARRA RIDGE ROAD E 3226.7 N 62869.6

N=16

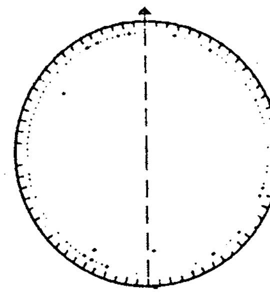
Lithology - Hawks Sst/crossbedded



Raw angle data



Rose diagram
5° class interval



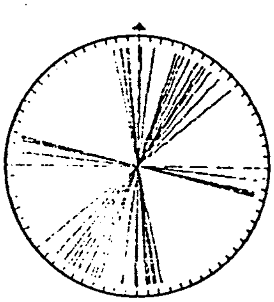
Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 110-125, planar dominant, vertical	1. 067
2. 075-085	2. 084
3. 055-065	
4. 015-025	

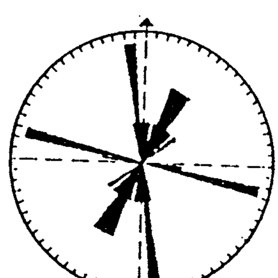
OTHER STRUCTURES: Pisolites along 110-125 joint set

LOC NO. 13 EAST OF MARRAMARRA RIDGE E 3223.8 N 62847.4

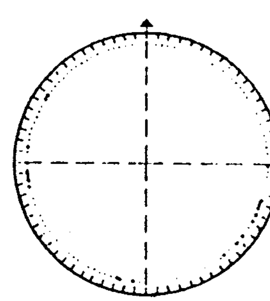
Lithology - Hawks Sst/crossbedded



Raw angle data

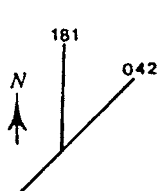


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 020-040, dominant planar, vertical	1. 025-035
2. 095-105	
3. 165-180, fine fractures	



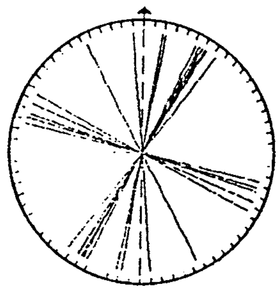
TERMINATION SUMMARY

OTHER STRUCTURES:

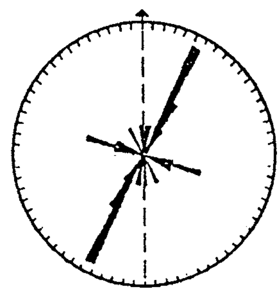
Slump plane; dip 36° to 270

LOC NO. 14. NTH OF COBA RIDGE ROAD E 3224.8 N 62843.2

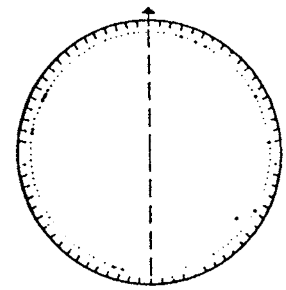
N=16 Lithology - Hawks Sst/crossbedded



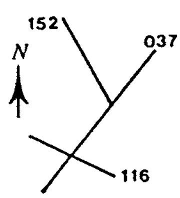
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



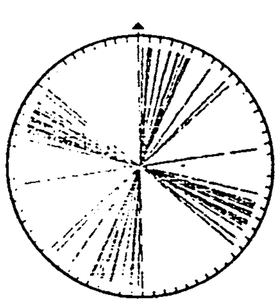
TERMINATION SUMMARY

JOINTS SETS	MASTER JOINT SETS
1. 025-035, planar dominant, vertical	1. 025-035, dominant spacing 5-10m
2. 100-120, vertical	2. 155
3. 005-010	3. 116

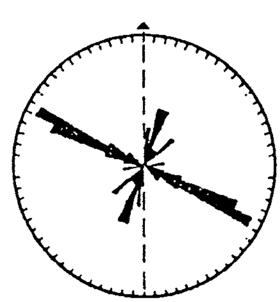
OTHER STRUCTURES: Master joint zones
(1) 025-035
(2) 005-010

LOC NO. 15 COBAH RIDGE E 3269.1 N 62849.5

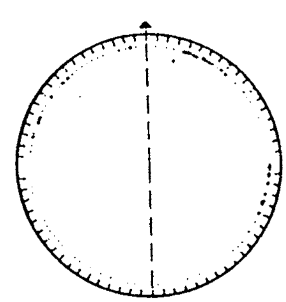
N=33 Lithology - Hawks Sst/crossbedded



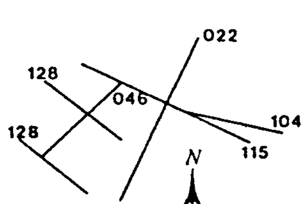
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



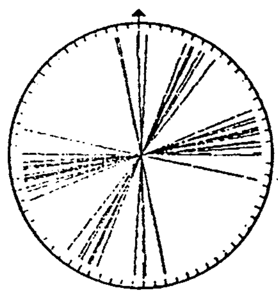
TERMINATION SUMMARY

JOINT SETS	MASTER JOINT SETS
1. 105-130, dominant, planar, vertical	1. 097-107
2. 005—25, planar, common	2. 116-120
3. 035-050	3. 012

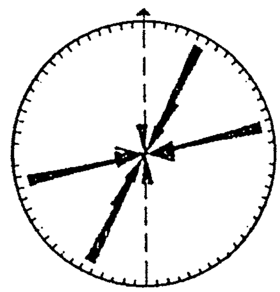
OTHER STRUCTURES: Vertical conjugate joints within 105-130 joint set

LOC NO. 16. HAIRPIN BEND ON COBA RIDGE RD. E 3264.8 N 62843.1

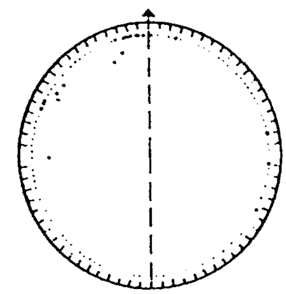
N=24 Lithology Hawks Sst/crossbedded



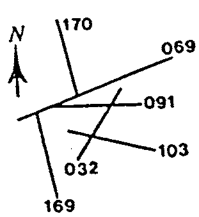
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



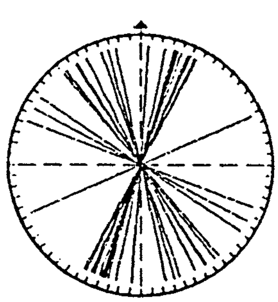
TERMINATION SUMMARY

JOINTS SETS	MASTER JOINT SETS
1. 070-090, dominant, subvertical	1. 063-069
2. 025-040, vertical	2. 010-020
3. 165-180, minor	3. 179

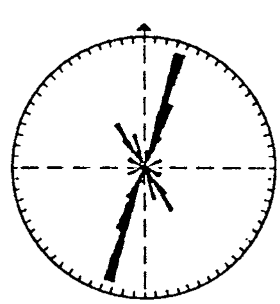
OTHER STRUCTURES: Slump plane; dips 32 to 214

LOC NO. 17 EAST OF COBA RIDGE ROAD, NEVERFAIL BAY E 3258.9 N 62831.5

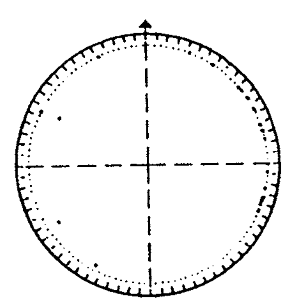
N=28 Lithology -Hawks Sst/crossbedded



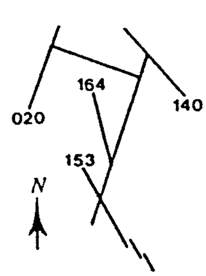
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



TERMINATION SUMMARY

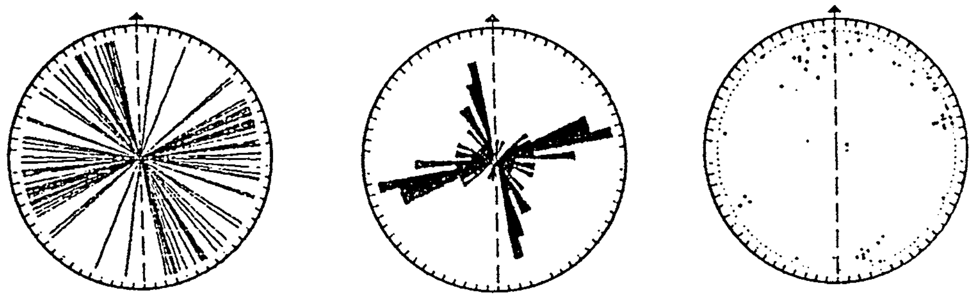
JOINT SETS	MASTER JOINT SETS
1. 015-030, planar vertical dominant	1. 015-030
2. 140-167	2. 145-160
3. 110-125, minor	3. 066.

OTHER STRUCTURES: Master joint zone; strike 018, vertical

'en echelon' joints - dip 90 to 258, sinistral step

LOC NO. 18. MILLICENT TRIG E 3308.0 N 62822.7

N=56 Lithology Hawks Sst/crossbedded

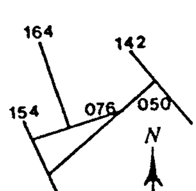


Raw angle data

Rose diagram
5° class interval

Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 065-100, dominant, planar, dip from 75 Sth to 60 to Nth	
2. 165-170 planar, subvertical	
3. 125-150, iron fill planar, vertical	
4. 145-150 planar	



TERMINATION SUMMARY

OTHER STRUCTURES: Joint Zones; strike 070, dip 70 to 160, strike 085 vertical, en echelon joint; dip 83 to 252, on joint 78/217

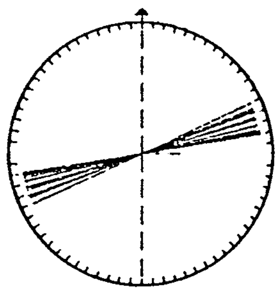
Dyke; strike 082 dip 40-82/172

Slickensides; dip 7 /w on joint dipping 70/189
dip 7 /w " " " 75/175
dip 3 /w " " " 80/186

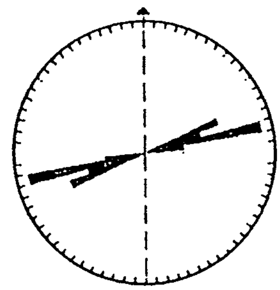
Conjugate joints; strike 090 dip 70 to E and W

LOC NO. 19. PACIFIC HWY. NTH OF MILLICENT TRIG E 3311.7 N 62822.3

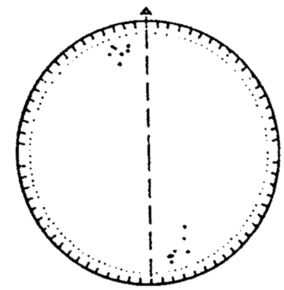
N=15 Lithology Hawks Sst/crossbedded



Raw angle data

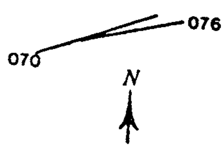


Rose diagram
5° class interval



Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 065-080, dip 70 to Nth and 70 to Sth, planar, iron filled	

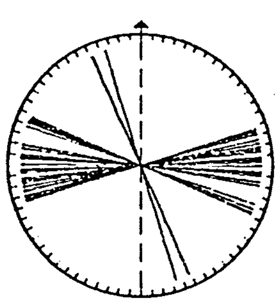


TERMINATION SUMMARY

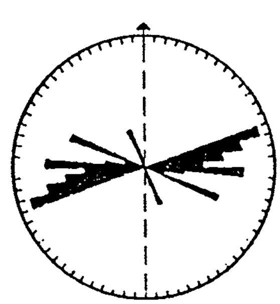
OTHER STRUCTURES: conjugate joints in 065-080 joint set

LOC NO. 20 BEROWRA EXPRESSWAY E 3310.8 N 62820.5

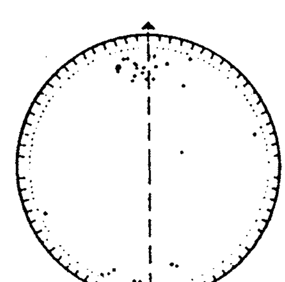
N=35 Lithology - Hawks Sst/crossbedded and massive



Raw angle data



Rose diagram
5° class interval



Equal area polar plot

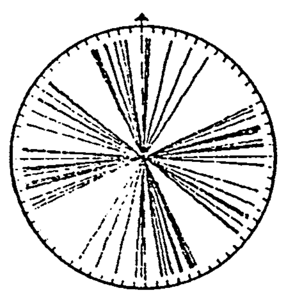
JOINT SETS	MASTER JOINT SETS
1. 073-095 dip from 75 to SE to vertical, planar, dominant	1. 072-080
2. 110-115, vertical	
3. 155-165, minor	

OTHER STRUCTURES:

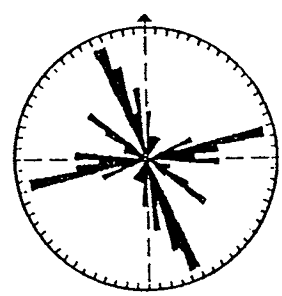
Joint/breccia zone; strike 070 dip 75 to SE, 6m wide, normal fault; strike 079 dip 65 to 169, dyke in breccia zone.

LOC NO. 21 BEROWRA EXPRESSWAY E 3317.3 N 62823.9

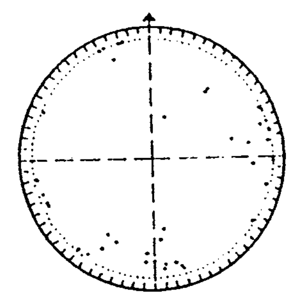
N=43 Lithology Hawks Sst/crossbedded



Raw angle data

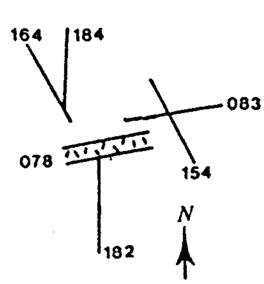


Rose diagram
5° class interval



Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 155-170, planar, dip from vertical to 70 to SW	1. 155-165
2. 065-090, dip from 76 to NW to vertical	2. 075-080
3. 115-130, dip 65 to NE to vertical	
4. 002-030	

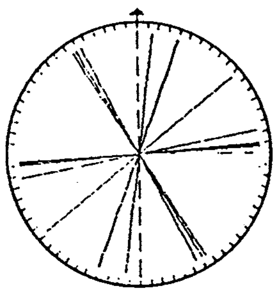


TERMINATION SUMMARY

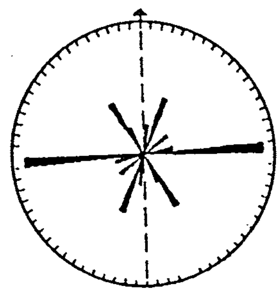
OTHER STRUCTURES: Dyke; strike 078, vertical width 30 cm. 115-130 joint set displaced along bedding
Normal Fault and Brecciation associated with dyke
Conjugate joints; strike 102 and 117.

LOC NO. 22   PACIFIC HWY   E 3315.1   N 62825.1

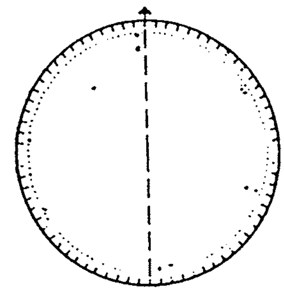
N=12   Lithology - Hawks Sst/crossbedded



Raw angle data

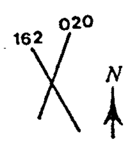


Rose diagram
5° class interval



Equal area polar plot

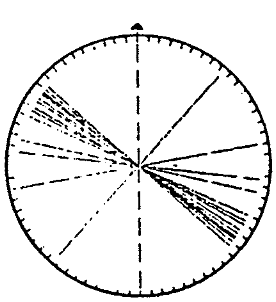
JOINTS SETS	MASTER JOINT SETS
1. 010-020, planar, vertical	
2. 080-085	
3. 145-155	



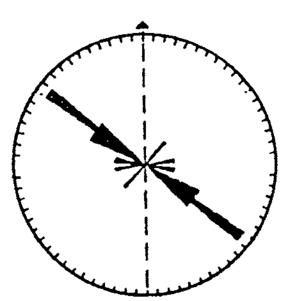
TERMINATION SUMMARY

LOC NO. 23   CANOELANDS RD.   E 3168.0   N 62902.4

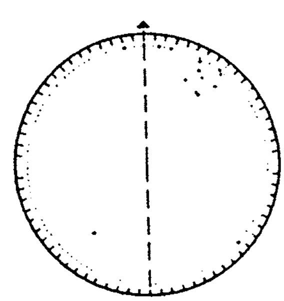
N=14   Lithology-Hawks Sst/crossbedded



Raw angle data

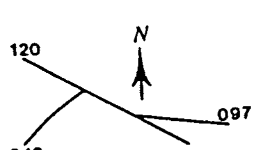


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 115-130, planar, dominant, dip from 65 to SW to vertical	1. 115- 120
2. 080-100	
3. 042, curved	



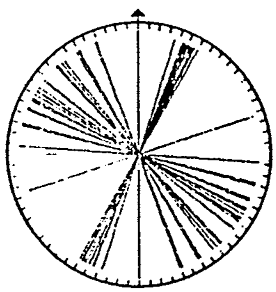
TERMINATION SUMMARY

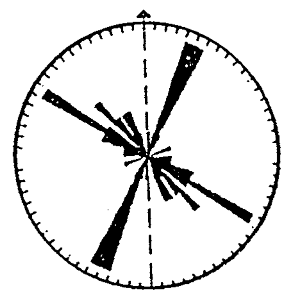
OTHER STRUCTURES: joint zone; strikes 120, dips 87 to 210, width 30 cm.
Normal Fault; strike 132, dip 76 to 222, displacement 4cm.

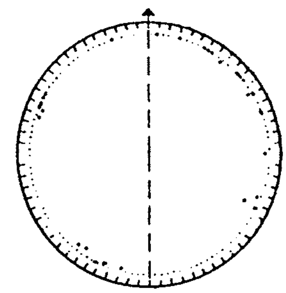
LOC NO. 24 EAST SIDE OF BEROWRA CK., BUJWA FIRETRAIL E 3288.3 N 62839.1

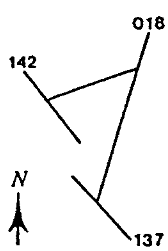
N=39

Lithology - Narrabeen Gp. sandstones and Hawks Sst


Raw angle data


Rose diagram
5° class interval


Equal area polar plot



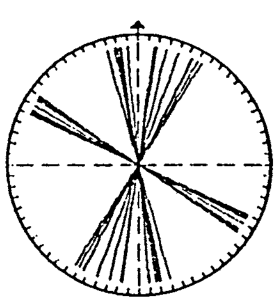
TERMINATION SUMMARY

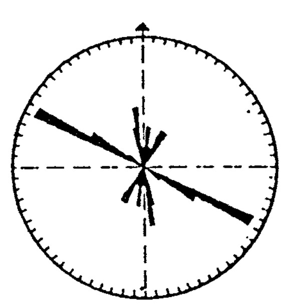
JOINTS SETS	MASTER JOINT SETS
1. 020-030, planar vertical, iron fill	1. 020-025, spacing 4-5m
2. 105-130, iron fill	
3. 140-160	

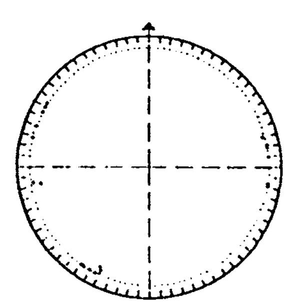
LOC NO. 25 BUJWA FIRE TRAIL E 3299.7 N 62833.5

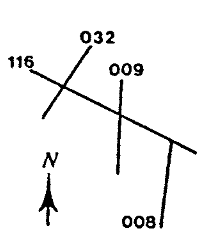
N=24

Lithology - Hawks Sst/crossbedded


Raw angle data


Rose diagram
5° class interval


Equal area polar plot



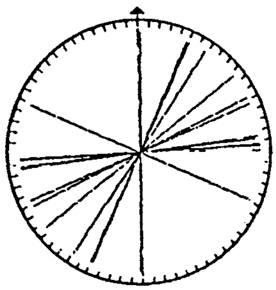
TERMINATION SUMMARY

JOINT SETS	MASTER JOINT SETS
1. 115-125, planar vertical, zonal	1. 165-169
2. 008-032 planar vertical	2. 116
3. 165-175	

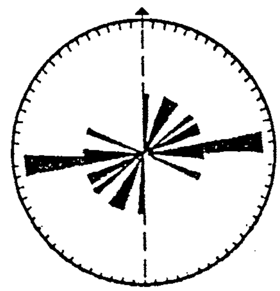
OTHER STRUCTURES: Master joint zone; strike 169 vertical, width 4m, joint zone; strike 120, vertical

LOC NO. 26 COWAN QUARRY E 3302.6 N 62833.5

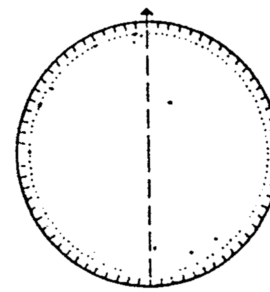
N=13 Lithology - siltstone and sandstone, Rh



Raw angle data



Rose diagram
5° class interval



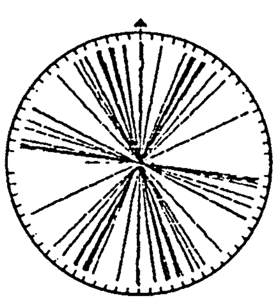
Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 025-035, planar, vertical	
2. 083-090	
3. 074-078, sandstone fill	

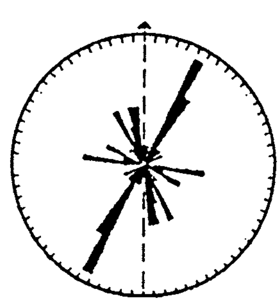
OTHER STRUCTURES: Dyke; (plume) strikes 077, vertical, width 0.5m-10m, slickensides; dip 27 to NE on plane dipping 79 to 337, vertical slickensides on dyke wall overprinted by slicks. dipping 47 to NE on wall dipping 80 to 322.

LOC NO. 27 MUOGAMARRA NATURE RESERVE E 3308.9 N 62834.4

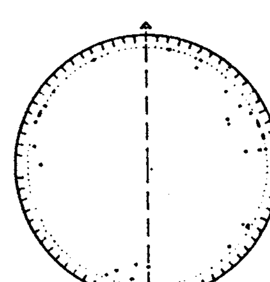
N=39 Lithology - Hawks Sst/crossbedded



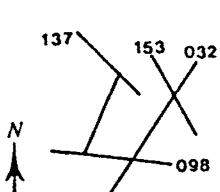
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



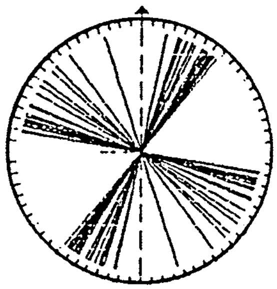
TERMINATION SUMMARY

JOINT SETS	MASTER JOINT SETS
1. 022-035, planar, dominant	1. 027
2. 097-117	2. 137-150
3. 147-173	

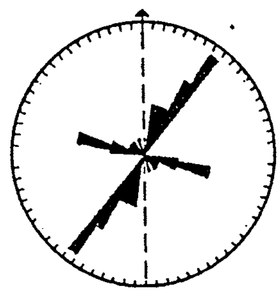
OTHER STRUCTURES: Master joint zone; strike 027, vertical, joint zone; strike 031 dip 88 to 121 en echelon joints; strike 101, vertical, dextral step

LOC NO. 28 DJARRA RIDGE E 3283.4 N 62828.0

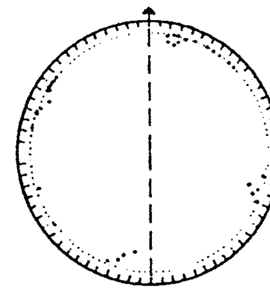
N=43 Lithology - Hawks Sst/crossbedded and massive



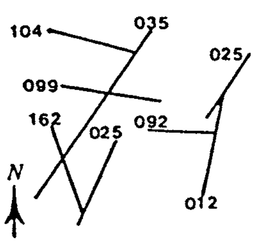
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



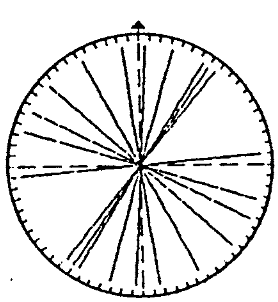
TERMINATION SUMMARY

JOINTS SETS	MASTER JOINT SETS
1. 012-039, planar, vertical, dominant	1. 032-035
2. 088-112, planar, sub-dominant	2. 099
3. 117-135, small fractures.	

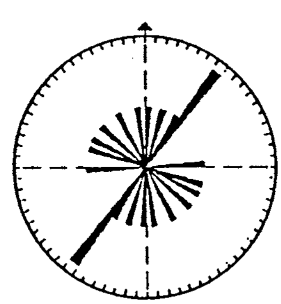
OTHER STRUCTURES: 'enechelon' joints; trend 032, dextral step, on joint trending 015.

LOC NO. 29 NTH OF MT DEWRANG E 3283.4 N 62828.0

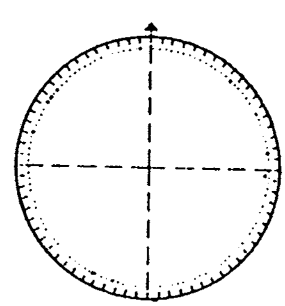
N=11 Lithology - Hawks Sst/crossbedded



Raw angle data



Rose diagram
5° class interval



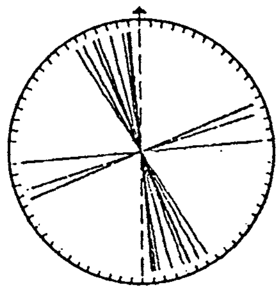
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 030-040, planar	
2. 106-132	

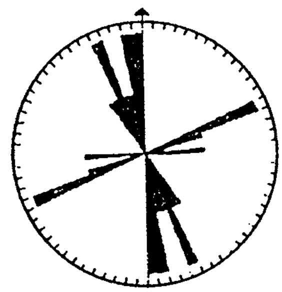
LOC NO. 30 JERUSALEM BAY TRACK E 3315.2 N62814.6

N=14

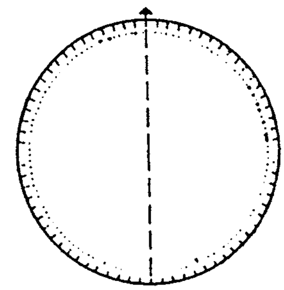
Lithology - Hawks Sst/crossbedded



Raw angle data



Rose diagram
5° class interval



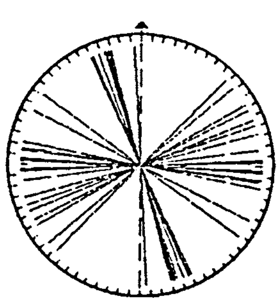
Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 148-160, planar, dominant, vertical	1. 157
2. 067-083	
3. 160-176, small fractures	

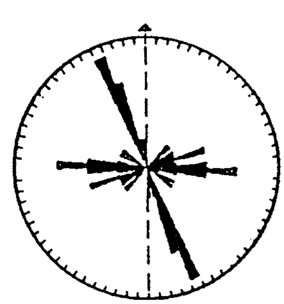
LOC NO. 31 JERUSALEM BAY TRACK E 3320.4 N 62816.2

N=27

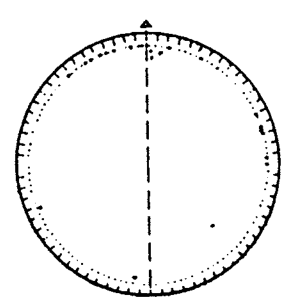
Lithology - Hawk Sst/crossbedded



Raw angle data



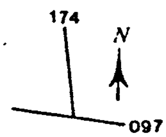
Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 154-165, planar, vertical	1. 082-097
2. 082-102	
3. 044-070	
4. 117-126	

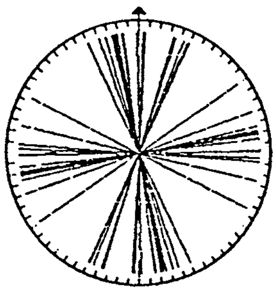
OTHER STRUCTURES: joint zones; strike 082 to 088, vertical 3m wide.



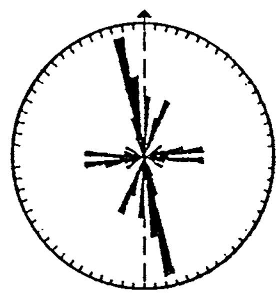
TERMINATION SUMMARY

LOC NO. 32 PACIFIC HWY E 3295.6 N 62800.4

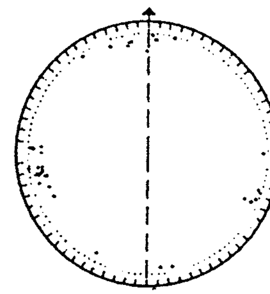
N=35 Lithology - Hawks Sst/crossbedded.



Raw angle data

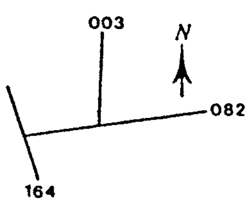


Rose diagram
5° class interval



Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 017-024, planar, vertical	1. 022-024
2. 155-172, dipping 75/E to vertical	
3. 077-103	
4. 179-183	

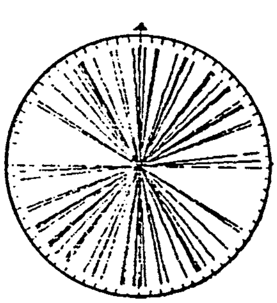


OTHER STRUCTURES: Joint Zones; strike 180-182, subvertical

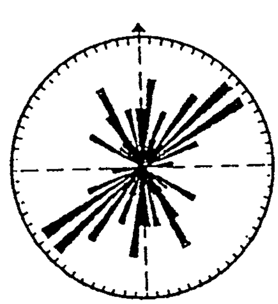
TERMINATION SUMMARY

LOC NO. 33 WEST HEAD E 3431.4 N 62830.0

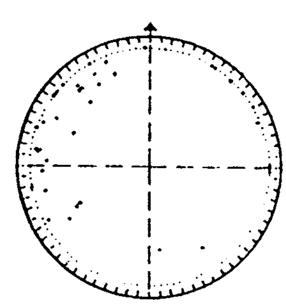
N=39 Lithology - Narrabeen Group - Sandstone and siltstone



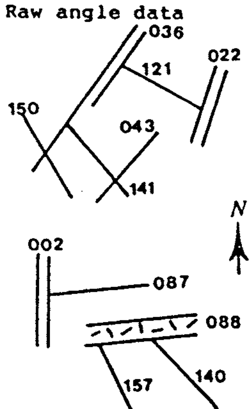
Raw angle data



Rose diagram
5° class interval



Equal area polar plot

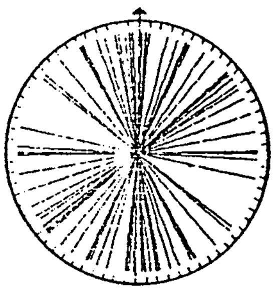


JOINT SETS	MASTER JOINT SETS
1. 166-188, dominant, sub-vertical, iron filled	1. 002-036
2. 035-060, dip 60 to SE to vertical	2. 166-169
3. 017-027	
4. 121-152	

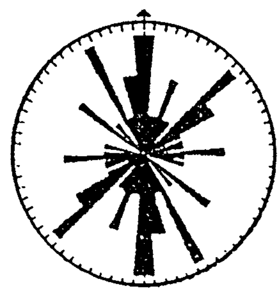
OTHER STRUCTURES: Joint Zones; strike 149, vertical 20 cm wide; strike 133, vertical; strike 037, vertical Dykes; strike 085, dip 73/355; strike 093, vertical; strike 091, vertical. Breccia Plane; strike 151, dip 45/061. Normal Fault; strikes 083, dips 60/353

LOC NO. 34 WEST HEAD E 3430.1 N62828.9

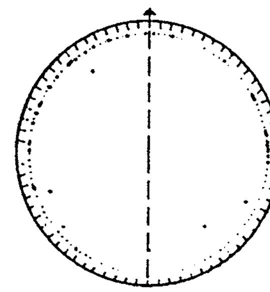
N=40 Lithology - Hawks Sst/crossbedded



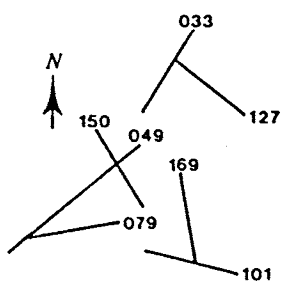
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



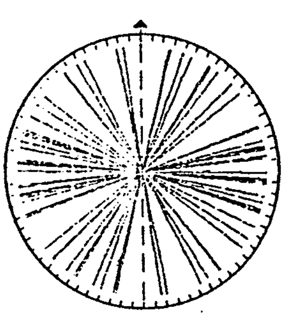
TERMINATION SUMMARY

JOINTS SETS	MASTER JOINT SETS
1. 167-185, planar, vertical	1. 175-183
2. 023-026, vertical	2. 023-031 (possibly 2 sets)
3. 047-060	3. 150-159
4. 087-093	

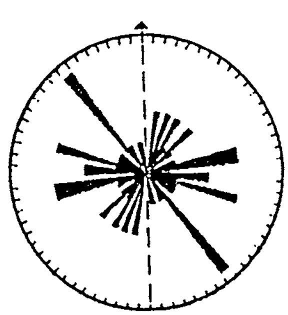
OTHER STRUCTURES: Joint Zones; strike 129, vertical 40 cm wide; strike 152, vertical, 20 cm wide.

LOC NO. 35 REFUGE BAY TRACK E 3381.1 N 62807.6

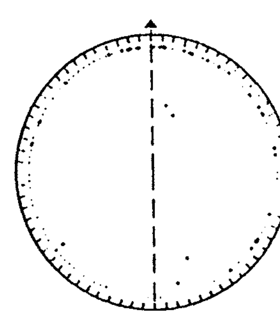
N-38 Lithology - Hawks Sst/crossbedded



Raw angle data



Rose diagram
5° class interval



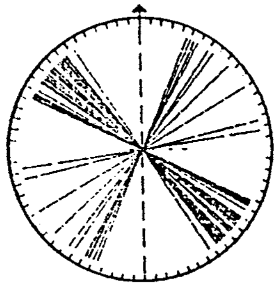
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 020-046, planar, vertical	1. 020-046
2. 068-110	2. 080-095
3. 142-153	3. 142-153
	4. 123

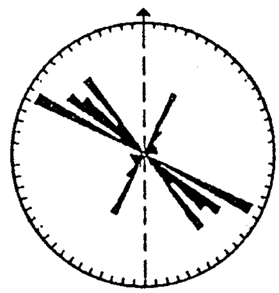
OTHER STRUCTURES: Joint Zones; strike 172, vertical 4m wide; strike 064, vertical, 1m wide
Master joint zone; strike 123, vertical, 1m wide
Silicified Breccia Zone; strike 046 vertical 10m wide, fractures in zone trend 142 and 52-69
Slump plane: strike 055 dips 45/SE

LOC NO. 36 SALVATION TRACK E 3372.2 N 62789.7

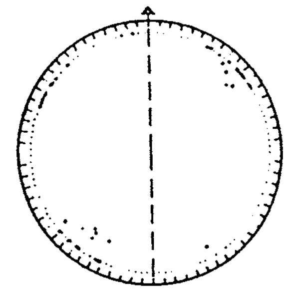
N=46 Lithology - Hawks Sst/crossbedded



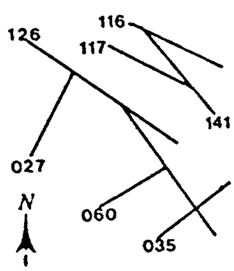
Raw angle data



Rose diagram
5° class interval



Equal area polar plot

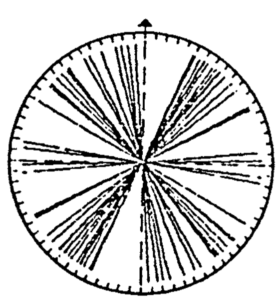


TERMINATION SUMMARY

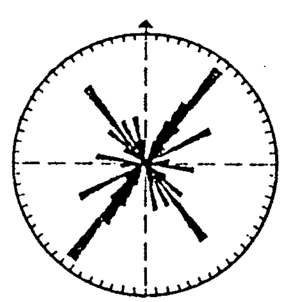
JOINTS SETS	MASTER JOINT SETS
1.106-143, dominant, dip from 75/NE to 80 SW, planar	1. 116-125 2. 023-027
2.023-046	3. 140-142
3. 077-082	4. 060

OTHER STRUCTURES: Joint Zones; strike 125, dip 70/035, 4m wide; strike 142, dip 80 to 052 1.5m wide
'enechelon' joints 116 to 128 set, sinistral and dextral

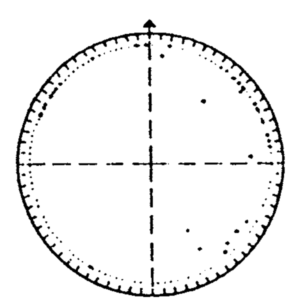
LOC NO. 37 McCARRS TRIG E 3385.7 N 62748.5
N=38 Lithology - Hawks Sst/crossbedded



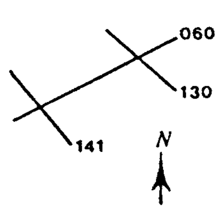
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



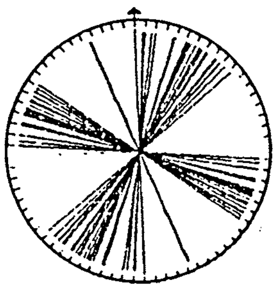
TERMINATION SUMMARY

JOINT SETS	MASTER JOINT SETS
1. 024-052 planar, dominant	1. 024-030
2. 129-170 planar, dominant, zonal	2. 129
3. 060-063	
4. 084-100, zonal	

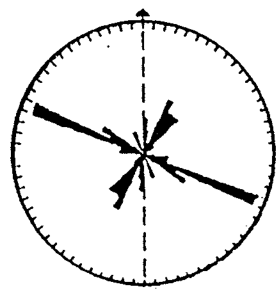
OTHER STRUCTURES: Joint Zones; strike 166, vertical ; strike 084, vertical
Dyke; strike 132 vertical, 075m wide.

LOC NO. 38   BOBBIN HEAD RD., 100ms down from N.P.W.S. HQ   E 3290.9   N62744.1

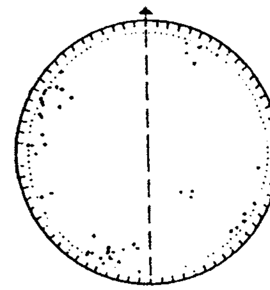
N=52   Lithology - Hawks Sst/crossbedded



Raw angle data

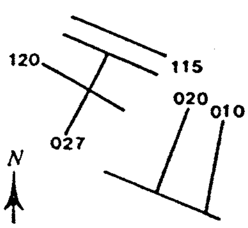


Rose diagram
5° class interval



Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 025-045 planar, dipping 75/SE to vertical	1. 034
2. 110-127 dip 70/NE to vertical	2. 117-122
3. 003-010	

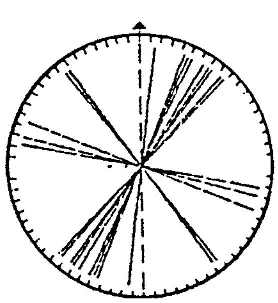


TERMINATION SUMMARY

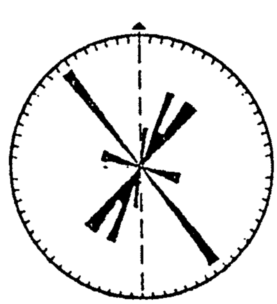
OTHER STRUCTURES: Dykes; (1) strike 099-124
(2) strike 011-022

LOC NO. 39   TOP OF BOBBIN HEAD RD.   E 3281.7   N 62735.6

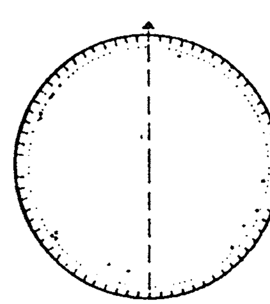
N=15   Lithology - Hawks Sst/crossbedded



Raw angle data



Rose diagram
5° class interval



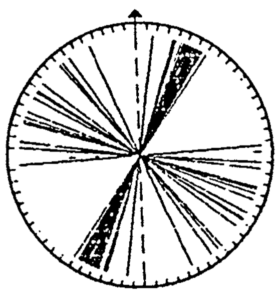
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 022-044, planar, vertical	1.007-024
2. 140-145	
3. 101-112	

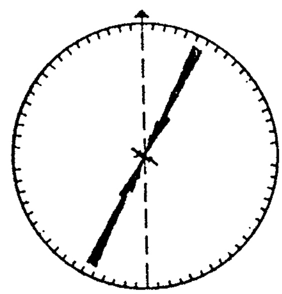
OTHER STRUCTURES: Iron fill joints; strike 022 and 144
Sand/clay filled dyke; strike 024-044, 101-112, 007

LOC NO. 40 BEOWRA WATERS RD. SECTION E 3252.6 N 62800.7

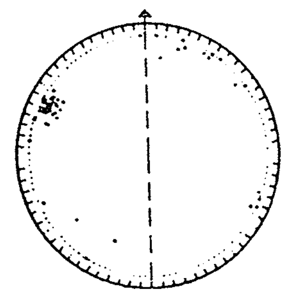
N=78 Lithology - Hawks Sst/crossbedded



Raw angle data

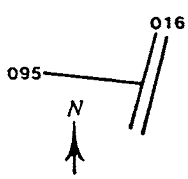


Rose diagram
5° class interval



Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 027-033 planar, dominant, dip 70/SE to vertical	1. 018-033
2. 086-097	
3. 107-127	
4. 140-155	

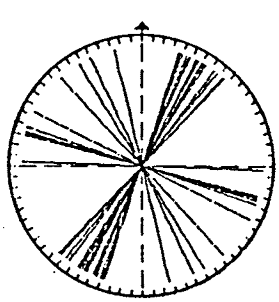


TERMINATION SUMMARY

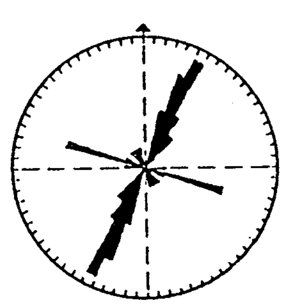
OTHER STRUCTURES: Joint zones; strike 018-033 vertical
Normal Faults; strike 026, dip 82/116, strike 024 dip 83/144 (breccia)
'enechelon' joints; strike 031 dip 83/121 sinistral strike 022 dip 76/112.

LOC NO. 41 CROSSLANDS CONVENTION CENTRE E 3243.5 N62773.2

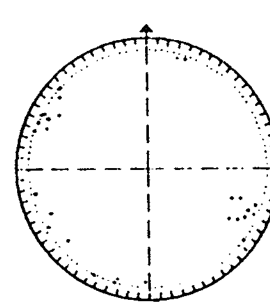
N=31 Lithology-Hawks Sst/crossbedded



Raw angle data

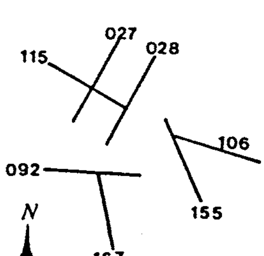


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 017-031, planar dipping from 70/NW to 75 SE, dominant	1. 107
	2. 138
2. 105-115	
3. 140-165	
4. 037-043	

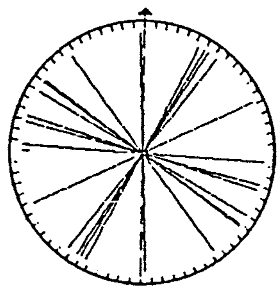


TERMINATION SUMMARY

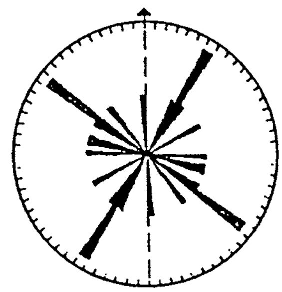
OTHER STRUCTURES: 017-031 joint set possibly conjugate

LOC NO. 42   CROSSLANDS RD. 1 KM SW OF LOC 41   E 3241.5   N62772.3

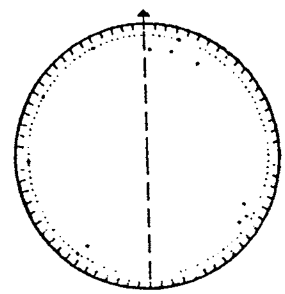
N=13   Lithology-Hawks Sst/crossbedded



Raw angle data



Rose diagram
5° class interval



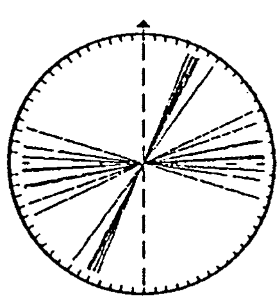
Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 027-037 dipping 70-80/W, planar	1. 027-037
2. 105-127 dip 70/NE to 70/SW	2. 126
3. 093	
4. 142	

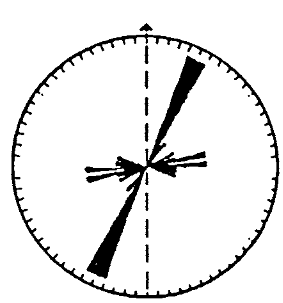
OTHER STRUCTURES: master joint zone;strikes 126,vertical, sandst. fill.

LOC NO. 43   GALSTON GORGE   E 3218.7   N62731.0

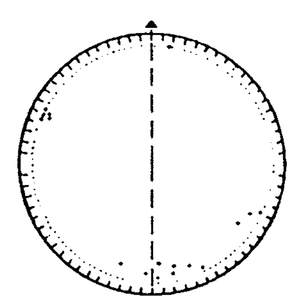
N=18   Lithology-Hawks Sst/crossbedded and massive



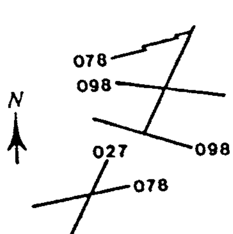
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



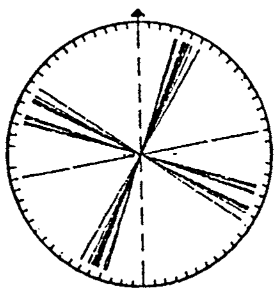
TERMINATION SUMMARY

JOINT SETS	MASTER JOINT SETS
1. 022-027 planar subvertical	1. 022-024
2. 065-100 dip 70/Nth to vertical	2. 098,zonal

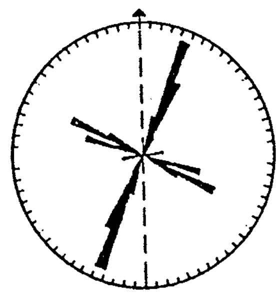
OTHER STRUCTURES: master joint zone; strike 098,vertical
'enechelon' joints; strike 078, dextral step.

LOC NO. 44 SOMERVILLE RD. CROSSLANDS E 3246.9 N 62773.8

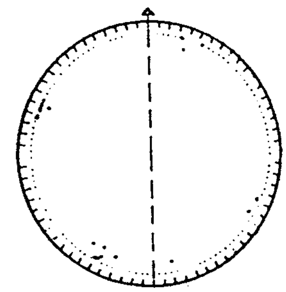
N=24 Lithology-Hawks Sst/crossbedded



Raw angle data

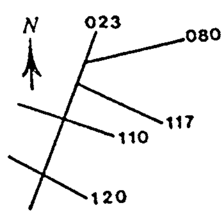


Rose diagram
5° class interval



Equal area polar plot

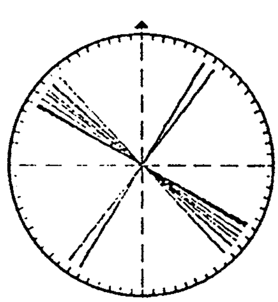
JOINTS SETS	MASTER JOINT SETS
1. 017-027 planar, dominant, subvertical	1. 027
2. 107-123 dip/NE to vertical	2. 110



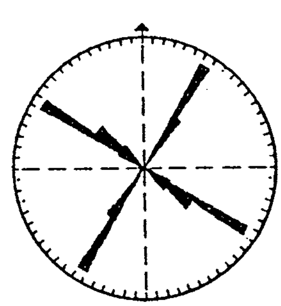
TERMINATION SUMMARY

LOC NO. 45 WEST HEAD TESSELATES E 3388.6 N62755.0

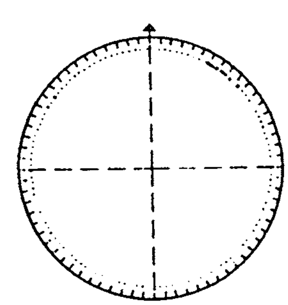
N=16 Lithology-Hawks Sst/massive



Raw angle data

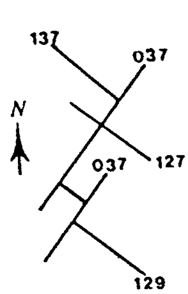


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 030-037, right stepping, enechelons, dominant	1. 030-037
2. 117-135 curved	



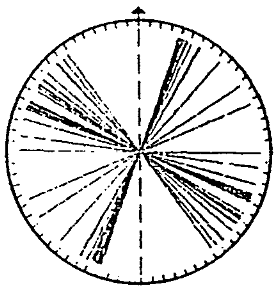
TERMINATION SUMMARY

OTHER STRUCTURES: dextral stepping joints;030-037
enechelons;043

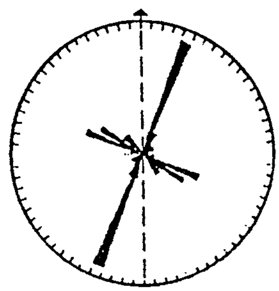
LOC NO 46 NTH HEAD OF MONAVALE BEACH E 3440.0 N 62724.1

N=38

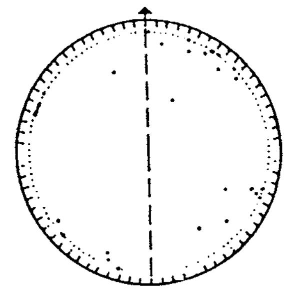
Lithology-Narrabeen Group-siltstones and sandstone



Raw angle data

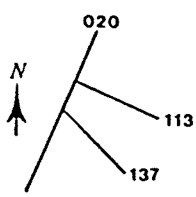


Rose diagram
5° class interval



Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 017-030, planar, dip from 65/NW to vertical 2. 097-115, subvertical, curved 3. 123-140, curved	1. 020-024



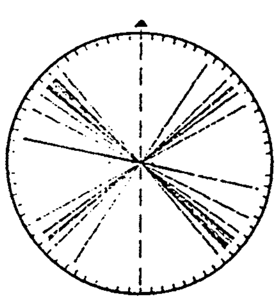
TERMINATION SUMMARY

OTHER STRUCTURES: joint zone; strike 023, vertical
Normal Faults; strike 206, dip 60/W; strike 222, dip 75/NW; strike 237, dip 65/NW, right step joint; strike 020, dip 80/W
'enechelons'; strike 019-030, vertical

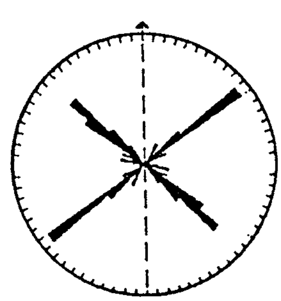
LOC NO. 47 THE OVENS, STH WHALE BEACH E 3458.0 N 62788.8

N=21

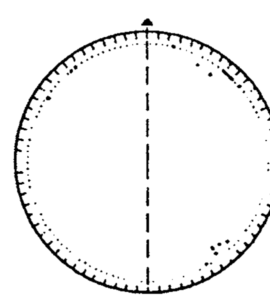
Lithology-Narrabeen Group-Sandstone



Raw angle data

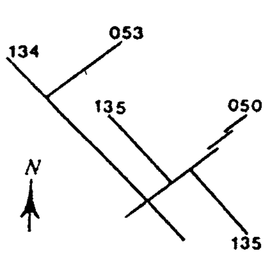


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 125-140 planar, dominant, vertical, zonal 2. 035-060, left stepping	1. 125-140 2. 053

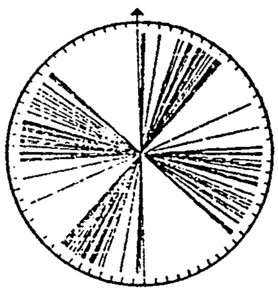


TERMINATION SUMMARY

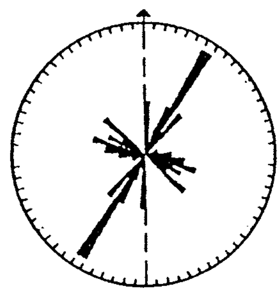
OTHER STRUCTURES: joint zones; strike 052-053
134 and 129 (brecciated)
Sigmoidal enechelons; strike 008-010

LOC NO. 48 BARRENJOEY HEAD N 3446.0 E 62831.4

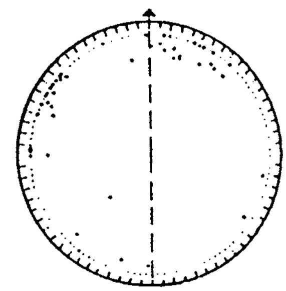
N=54 Lithology-Hawks Sst and Narr. Gp sandst and siltst.



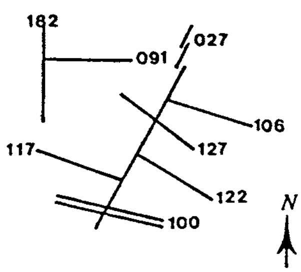
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



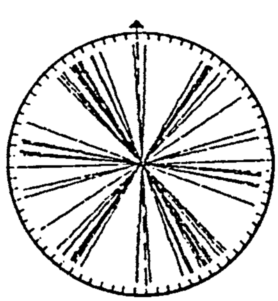
TERMINATION SUMMARY

JOINTS SETS	MASTER JOINT SETS
1. 024-043, planar, dominant, subvertical, left stepping	1.022-030 2.100-103
2. 087-107 dip from 72/SW to vertical, curved	3.003-011
3. 115-135, iron fill	

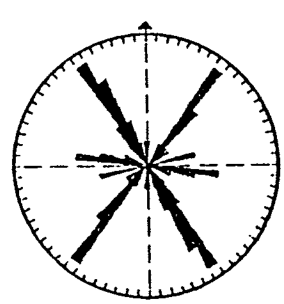
OTHER STRUCTURES: joint zone; strike 100, vertical
Dyke; strike 087, layered, contains conjugate fractures striking 167, dip 82/SW and 023 vertical
Normal Fault; strike 134 dip 22/NE

LOC NO. 49 DUFFY'S FOREST E 3327.0 N 62761.5

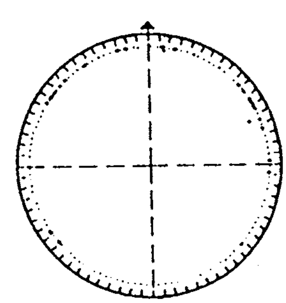
N=37 Lithology-Hawks Sst/crossbedded and massive



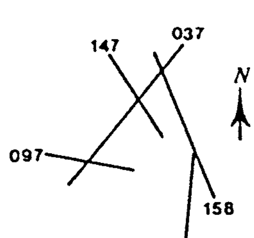
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



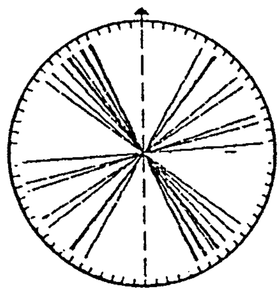
TERMINATION SUMMARY

JOINT SETS	MASTER JOINT SETS
1. 137-157, planar, dominant, vertical	1. 158
2. 032-047, subvertical	
3. 002-010, minor	
4. 095-102, minor	

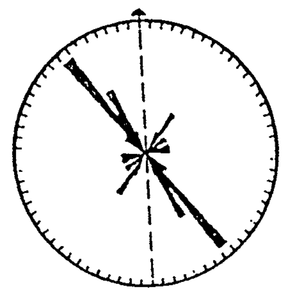
OTHER STRUCTURES: joint zone; strike 150, 5m wide
Left stepping joint; strikes 112, vertical
iron filled joints; strike 178 and 138 vertical

LOC NO. 50   COTTAGE PT. ROAD   E 3336.2   N 62769.2

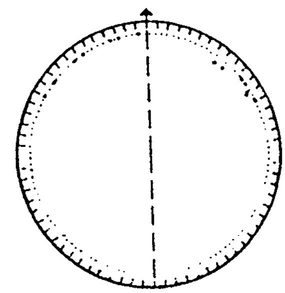
N=22   Lithology-Hawks Sst/crossbedded



Raw angle data

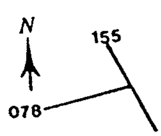


Rose diagram
5° class interval



Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 126-155 , dominant, vertical, planar 2. 030-057 3. 077-090 minor	1. 142-143, spacing 5 metres.



TERMINATION SUMMARY

OTHER STRUCTURES: joint zone; strikes 138, dip 89/NE

LOC NO. 51   WEST HEAD, SALVATION TRACK   E 3384.6   N 62777.9

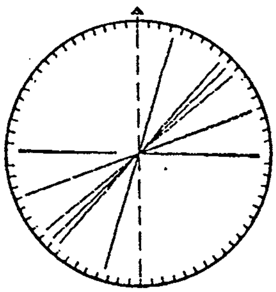
Lithology-Hawks Sst/crossbedded

JOINT SETS	MASTER JOINT SETS
1. 140-144,dip SW	

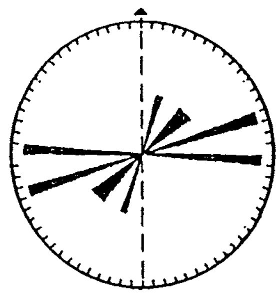
OTHER STRUCTURES: Fault; (reverse?) strike 162

LOC NO. 52 BAIRNE TRACK E 3409.0 N 62791.6

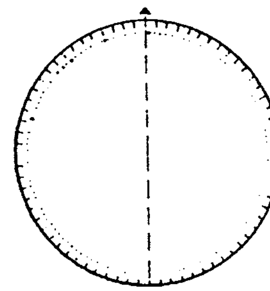
N=8 Lithology Hawks Sst/massive



Raw angle data



Rose diagram
5° class interval

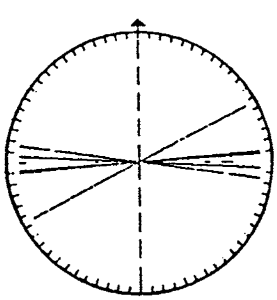


Equal area polar plot

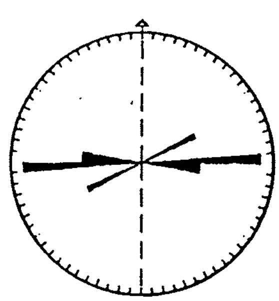
JOINTS SETS	MASTER JOINT SETS
1. 042-051	
2. 070	
3. 091	
4. 017	

LOC NO. 53 COTTAGE POINT E 3334.2 N62787.3

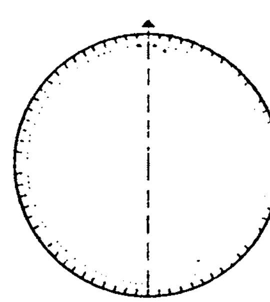
N=5 Lithology - Hawks Sst/crossbedded



Raw angle data



Rose diagram
5° class interval

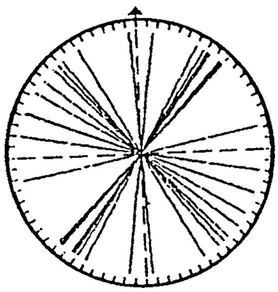


Equal area polar plot

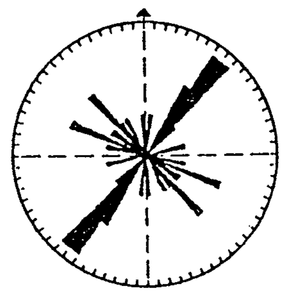
JOINT SETS	MASTER JOINT SETS
1. 085-098	
2. 062	

LOC NO. 54 MONAVALE RD. CNR OF LANE COVE RD E 3403.6 N 62721.5

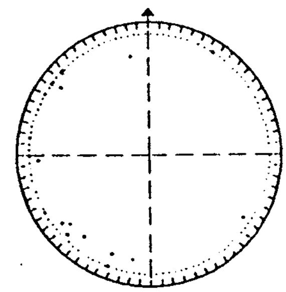
N=21 Lithology - Hawks Sst/crossbedded



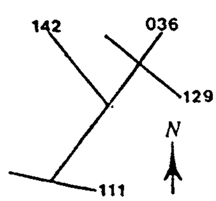
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



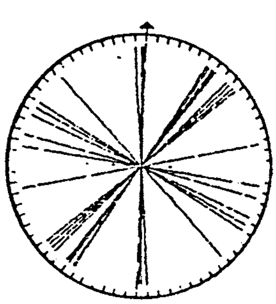
TERMINATION SUMMARY

JOINTS SETS	MASTER JOINT SETS
1. 030-045, planar vertical, dominant	
2. 129-142, planar	
3. 079-111	
4. 357-008	

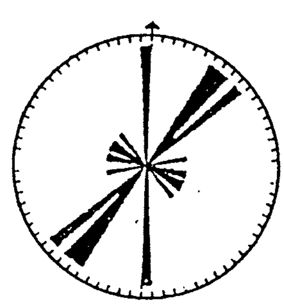
OTHER STRUCTURES: Dykes; (1) strike 148, vertical 2.5m wide (2) strike 136, vertical, 15cm wide
sinistral step joint; strike 100 dip 78/Nth
Iron filled joint; strikes 122, vertical

LOC NO. 55 SOUTH NEWPORT HEAD. E 3445.2 N 62741.4

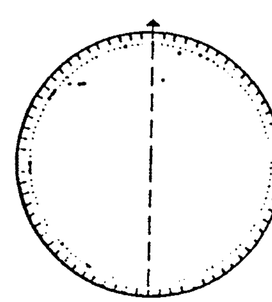
N=20 Lithology - Narrabeen Gp. - sandst.



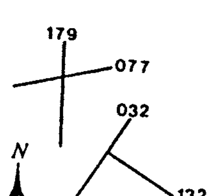
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



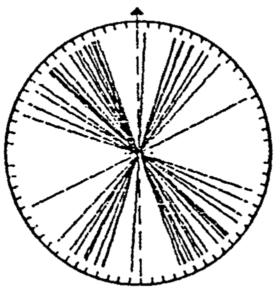
TERMINATION SUMMARY

JOINT SETS	MASTER JOINT SETS
1. 031-049 planar dominant	1. 031
2. 175-179	
3. 097-120, curved	

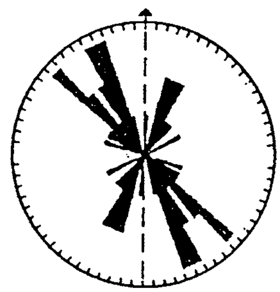
OTHER STRUCTURES: Normal Fault; strikes 097, dips 65/Sth.

LOC NO. 56 INGLESIDE 300m STH OF LOC 54 E 3402.1 N 62716.8

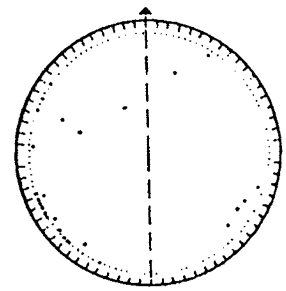
N=30 Lithology-Hawks Sst/crossbedded



Raw angle data



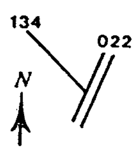
Rose diagram. 5° class interval



Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 018-043 planar, vertical	
2. 133-161 planar, iron fill, vertical, dominant	possible conjugate sets
3. 109-126	
4. 181	

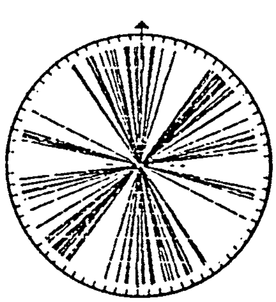
OTHER STRUCTURES: Dyke; strikes 117, vertical, 30cm wide Breccia/Fault Zone; strikes 154, vertical Iron filled joints; strike 233 to 161



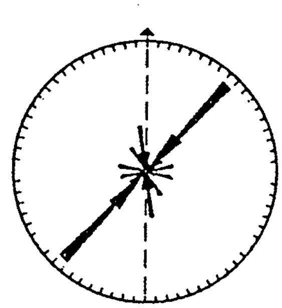
TERMINATION SUMMARY

NOC NO. 57 STH AVALON HEAD. E 3452.1 N 62765.0

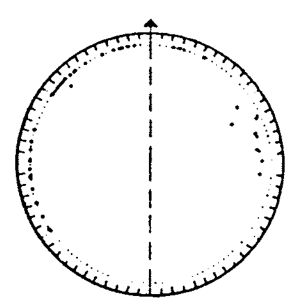
N=61 Lithology - Narrabeen Gp - Sandst and siltst.



Raw angle data



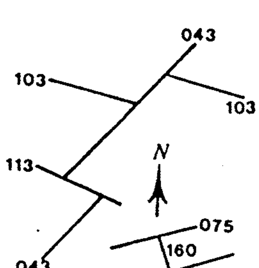
Rose diagram 5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 035-057, planar, vertical, dominant, enechelon	1. 072-075
	2. 045-051
2. 145-167, curved	
3. 172-196, curved	
4. 076-106	

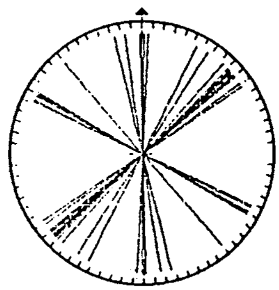
OTHER STRUCTURES: Iron filled joints; (1) strike 044-050 (2) strike 155 and (3) strike 156 Dextral step joint; strike 156, dip 85/Sth Sinistral step joint; strike 035, vertical.



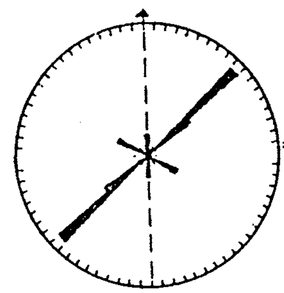
TERMINATION SUMMARY

LOC NO. 58 ST. MICHAELS CAVE E 3458.7 N 62773.8

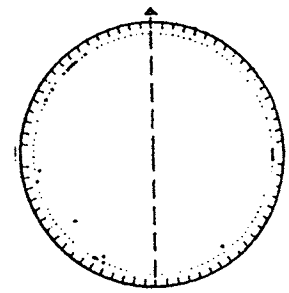
N=33 Lithology-Narrabeen Gp-Sandst and Siltst.



Raw angle data

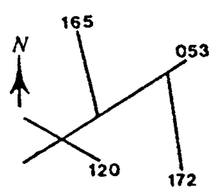


Rose diagram
5° class interval



Equal area polar plot

JOINTS SETS	MASTER JOINT SETS
1. 042-056 planar, vertical, dominant, iron filled	1. 046-055
2. 116-121, planar, vertical, dominant	2. 120
3. 167-183	
4. 027-033	

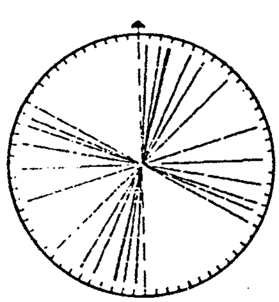


TERMINATION SUMMARY

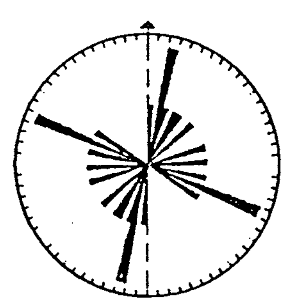
OTHER STRUCTURES: Joint Zone; strikes 120 vertical conjugate joints in zone
Dyke/breccia: strikes 120

LOC NO. 59 STH OF BEAUMONT RD. KURING-GAI EXP E 3270.3 N 62752.6

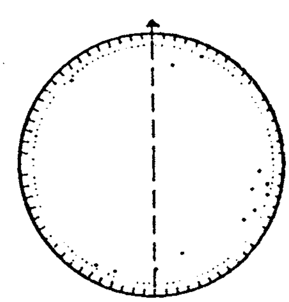
N=13 Lithology-Hawks Sst/crossbedded



Raw angle data



Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 003-045 vertical, planar	
2. 100-120 vertical, planar, iron fill	
3. 075-090	

OTHER STRUCTURES: Dyke: strikes 110-120, vertical.

APPENDIX B

Appendix B contains a list and summary of all fracture analysis sites in the Sydney Region shown on figures 43 and 44. Grid references are based on the Australian Map Grid (U.T.M.) and all bearings are given to true north. The fracture summary of each locality includes three plots of fracturing; a plot of the strike, a rosette diagram using 5 degree class intervals, and an equal area polar plot. A summary of the joint and master joint sets and their characteristics is also given. The arrangement of fracturing (terminations) and any other structures are also noted.

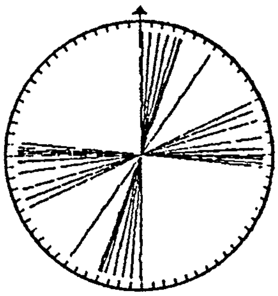
Locality number	Grid Reference	Locality Description
1.	3258.7,62666.4	Warrawee railway station.
2.	3264.2,62658.9	Turramurra railway station.
3.	3266.0,62656.7	Railway cutting 100m Sth of Locality 2.
4.	3269.8,62651.8	Cutting between Turramurra and Pymble stations.
5.	3272.4,62648.4	400m Sth of Locality 4.
6.	3275.8,62645.4	225m Nth of Pymble railway station.
7.	3280.7,62642.9	Bridge 270m Sth of Pymble railway station.
8.	3287.8,62634.8	Cutting 300m long between Mona Vale Rd. and Pymble Station, Park Ave.
9.	3290.0,62631.2	60m Sth of Gordon railway station.
10.	3294.6,62624.5	Cutting 150m long, 720m Sth of Gordon railway station.
11.	3296.5,62621.5	Killara railway station.
12.	3298.7,62618.0	Cutting 300m long, 350m Sth of Killara railway station, Stanhope Road.
13.	3303.6,62610.5	Lindfield railway station.
14.	3382.2,62558.8	Middle head of Balmoral Beach.
15.	3328.3,62501.7	250m long cutting in Pyrmont railway, opp. Scott St.
16.	3328.4,62511.6	Jones Bay Road.
17.	3230.4,62656.2	Lane Cove River, cutting 150m long on Comenarra Parkway.

Locality number	Grid Reference	Locality Description
18.	3364.0,62531.0	Cremorne Point.
19.	3361.3,62532.1	Cremorne Reserve.
20.	3343.4,62532.5	Glen St., Milsons Point.
21.	3343.5,62538.8	Warringah Expressway, North Sydney.
22.	3347.9,62540.2	Holdsworth St., Neutral Bay.
23.	3342.4,62534.0	Lavender Bay Shunting Station.
24.	3347.3,62538.4	Clarke Road, Neutral Bay.
25.	3313.0,62567.9	Artarmon Refuse Transfer Station.
26.	3168.7,62566.3	Rydalmere.
27.	3343.9,62536.4	Middlemiss St., North Sydney.
28.	3346.7,62601.4	Middle Harbour.
29.	3426.5,62623.0	Dee Why Head, cliff 500m long.
30.	3443.3,62648.8	Long Reef Point.
31.	3350.7,62508.4	Art Gallery.
32.	3315.0,62454.4	St. Peters Brickpit.
33.	3372.9,62658.0	Oxford Falls.
34.	3360.5,62703.5	Terrey Hills rubbish tip.
35.	3427.0,62559.0	North head.
36.	3345.0,62688.0	Belrose.
37.	3343.0,62557.2	Warringah Expressway, Cammeray.
38.	3354.6,62518.5	Mrs. Macquarie's Chair.
39.	3339.3,62558.4	Brook St. turnoff, Cammeray.
40.	3382.2,62563.1	Western headland of Edwards Beach, Balmoral.
41.	3423.6,62586.1	Cliffline east of Cabbage Tree Bay, 300m long.
42.	3222.8,62612.1	Epping railway station.
43.	3236.1,62614.1	Epping faults.

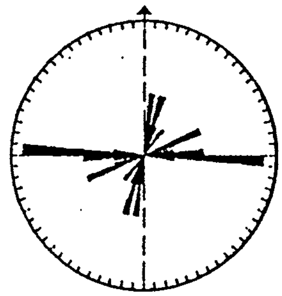
Locality number	Grid Reference	Locality Description
44.	3316.5,62562.1	Ronald Avenue, Gore Hill.
45.	3321.4,62556.9	Gore Hill, cnr. of Pacific Highway and Bellevue Ave.
46.	3425.0,62631.4	Cliffline 580m long at North Curl Curl.
47.	3167.7,62586.9	North Parramatta.
48.	3338.2,62516.2	Cahill Expressway Roundabout.
49.	3347.3,62519.3	Sydney Opera House.
50.	3348.1,62539.7	Kurraba Road, Neutral Bay.
51.	3337.7,62494.0	Haymarket, cnr. of Thomas and Quay Streets.
52.	3340.4,62504.0	Queen Victoria Building.
53.	3221.5,62682.7	Norman St., Thornleigh.
54.	3312.3,62616.7	Lindfield, cnr of Tryon Rd. and Arterial Rd.
55.	3385.5,62710.5	Bahai Temple.
56.	3332.8,62537.8	Waverton Park.
57.	3340.4,62514.4	Grosvenor Place dyke.
58.	3343.0,62534.8	Cliff Street, North Sydney.
59.	3307.1,62640.6	Nicholson Avenue, Barra Brui.
60.	3300.2,62655.1	Arterial Road, St. Ives.
61.	3253.6,62690.4	King Road, Hornsby.
62.	3247.2,62696.3	Leighton Place and Brennan Close, off Salisbury Road, Hornsby.
63.	3225.5,62683.8	Brushwood Place, Hornsby.
64.	3332.7,62553.5	Nicholson and Hume Streets, Crows Nest.
65.	3355.0,62515.0	West side of Woolloomooloo Bay.

LOC NO. 1 WARRAWEE RAILWAY STATION   E 3258.7 N 62666.4

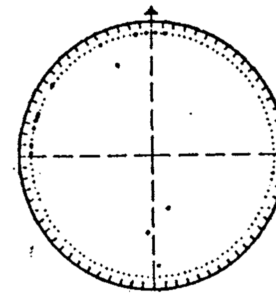
N=19   Lithology - sand/silt laminite, Ashfield Shale



Raw angle data



Rose diagram
5° class interval



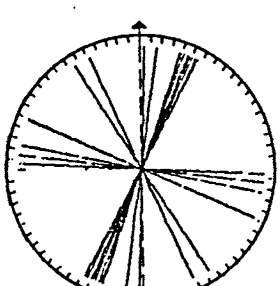
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 000-019, planar, vertical and dominant 2. 066-091, planar and curved, mostly vertical 3. 034, only one	

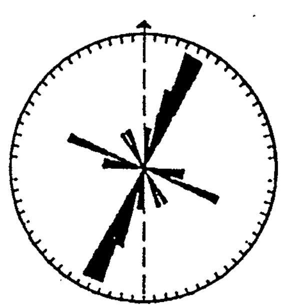
OTHER STRUCTURES: faults; 093/53/Nth, splayed with reverse drag ; 073/38/Nth, normal

LOC NO. 2 120m NTH OF TURRAMURRA RAILWAY STATION   E 3264.2 N 62658.9

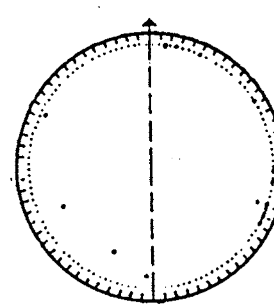
N=17   Lithology - sand/silt laminite, Ashfield Shale



Raw angle data



Rose diagram
5° class interval

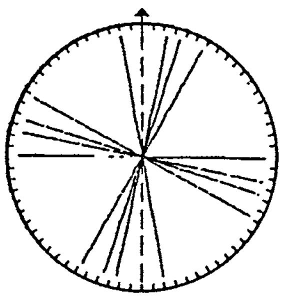


Equal area polar plot

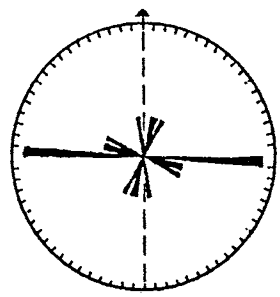
JOINT SETS	MASTER JOINT SETS
1. 018-027, planar, mostly vertical, some dip (80-V)/Nth and Sth, dominant 2. 096-113, vertical to 80/Nth, subdominant 3. 147-155, vertical and 67/East, minor 4. 002-007, minor	

LOC NO. 3 100m STH OF TURRAMURRA RAILWAY STATION E 3266.0 N 62656.7

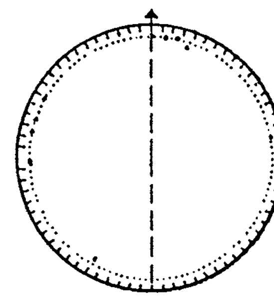
N=10 Lithology - sand/silt laminite Ashfield Shale



Raw angle data



Rose diagram
5° class interval

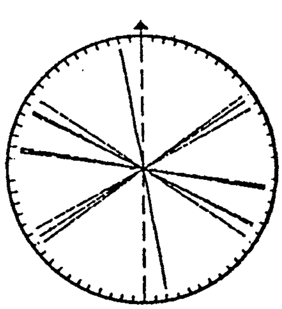


Equal area polar plot

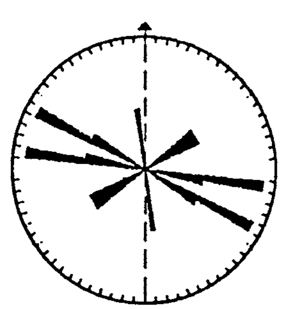
JOINT SETS	MASTER JOINT SETS
1. 011-028, vertical 2. 089-101, vertical, zonal, spaced 1m 3. 107-118, dip from 85 to V/Nth and Sth 4. 169, only one	

LOC NO. 4 BETWEEN TURRAMURRA AND PYMBLE STATIONS E 3269.8 N 62651.8

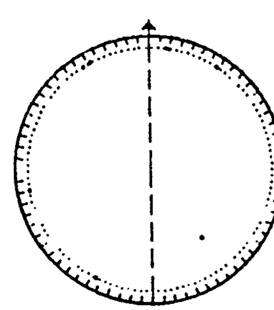
N=10 Lithology - weathered Ashfield Shale



Raw angle data

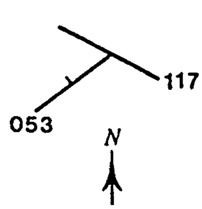


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 053-060, dip of 60/NW to vertical, planar 2. 098-099, planar, vertical 3. 117-123, vertical part of set 2.?? 4. 169, only one	

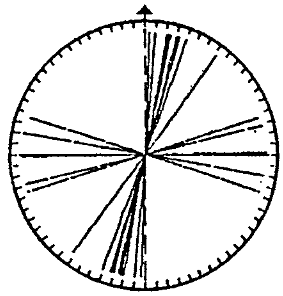


OTHER STRUCTURES: bedding dips 6/SE.

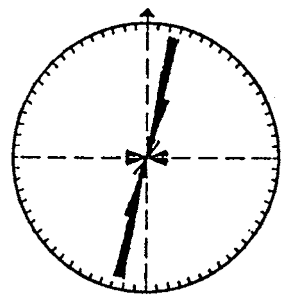
TERMINATION SUMMARY

LOC NO. 5 400m STH OF LOCALITY 4 E 3272.4 N 62648.4

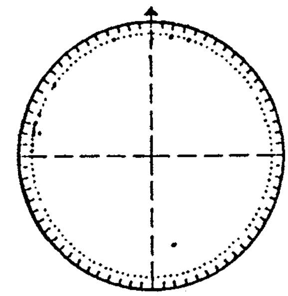
N=19 Lithology - sand/silt laminite, Ashfield Shale



Raw angle data



Rose diagram
5° class interval

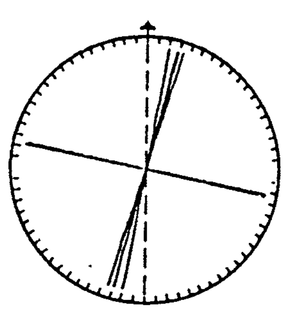


Equal area polar plot

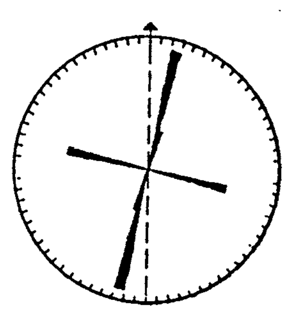
JOINT SETS	MASTER JOINT SETS
1. 001-026, dominant planar, mostly vertical 2. 071-089, some curved, dip from 70/Sth to 65/Nth 3. 099-108, minor 4. 035, only one	

LOC NO. 6 225m NTH OF PYMBLE RAILWAY STATION E 3275.8 N 62645.4

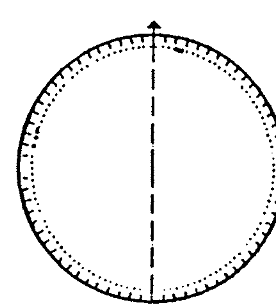
N=6 Lithology - sand/silt laminite, Ashfield Shale



Raw angle data



Rose diagram
5° class interval

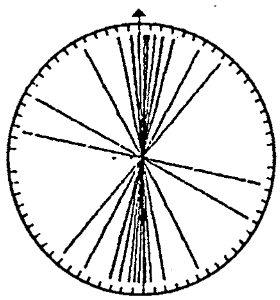


Equal area polar plot

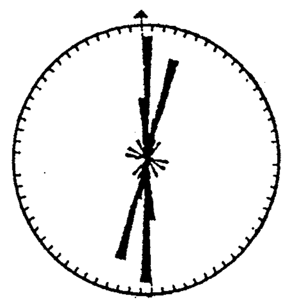
JOINT SETS	MASTER JOINT SETS
1. 009-016, dominant planar, vertical 2. 100-101	

LOC NO. 7 BRIDGE 270m STH OF PYMBLE STATION E 3280.7 N 62642.9

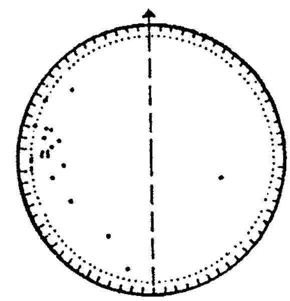
N=23 Lithology - sand/silt laminite, Ashfield Shale



Raw angle data



Rose diagram
5° class interval



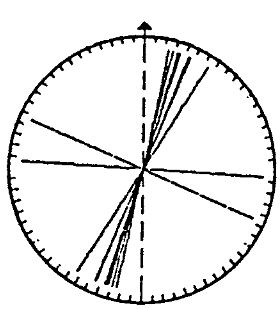
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 349-019, dominant planar, dip from 62/E to vertical 2. 029-041, minor 3. 102-120, minor 4. 152, only one	

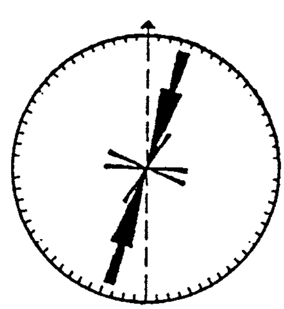
OTHER STRUCTURES: fault; 015/50/W, normal, 4cm throw. *** dip of bedding is 057/12/NW (approx.) ***

LOC NO. 8 CUTTING BETWEEN MONAVALE RD. AND PYMBLE STATION E 3287.8 N 62634.8

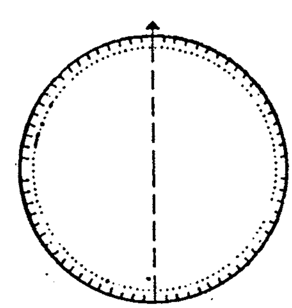
N=10 Lithology - weathered Ashfield Shale



Raw angle data



Rose diagram
5° class interval

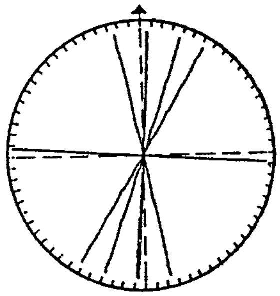


Equal area polar plot

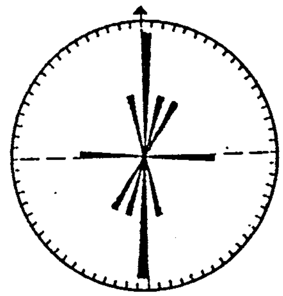
JOINT SETS	MASTER JOINT SETS
1. 013-021, dominant, planar, vertical 2. 092-112, minor, dips 80/Nth and vertical 3. 031, only one	

LOC NO. 9 60m STH OF GORDON STATION E 3290.0 N 62631.2

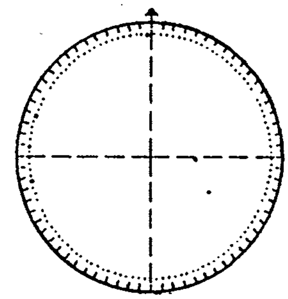
N=5 Lithology - sand/silt laminite, Ashfield Shale



Raw angle data



Rose diagram
5° class interval



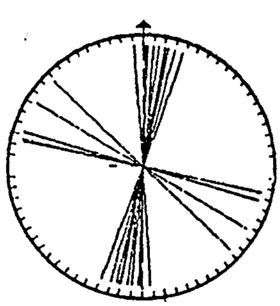
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 001-018, planar, vertical 2. 093, only one 3. 167, only one	

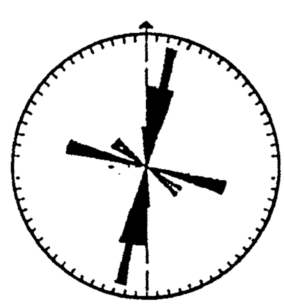
OTHER STRUCTURES: faults; 182/30/W and 210/47/W. little displacement: Small anticline and syncline, limbs dip 12 degrees and axial plane strikes 210.

LOC NO. 10 CUTTING 720m STH OF GORDON STATION E 3294.6 N 62624.5

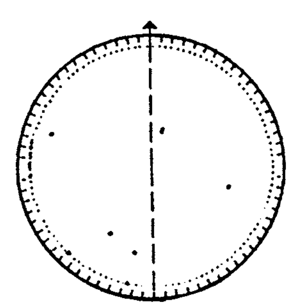
N=16 Lithology - sand/silt laminite, Ashfield Shale



Raw angle data



Rose diagram
5 class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 355-018, dominant, planar, mostly vertical 2. 101-133, dips from 55/ Nth to vertical, planar	

OTHER STRUCTURES: 2 faults; 285/35-20/Sth, reverse drag. There are 2 anticlines and 1 syncline, dips 202/10-15/W, 223/10/SE. Dip of beds changes strike of N-NNE joints but not dip.

LOC NO. 11 **KILLARA RAILWAY STATION** E 3296.5 N 62621.5

Lithology - weathered Ashfield Shale

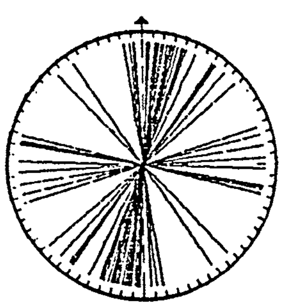
JOINT SETS	MASTER JOINT SETS
NIL	

OTHER STRUCTURES: bedding dips 7 degrees to the SE.

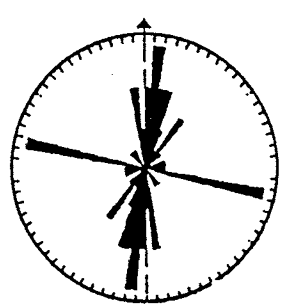
LOC NO. 12 **CUTTING 350m STH OF KILLARA STATION** E 3298.7 N 62618.0

N=45

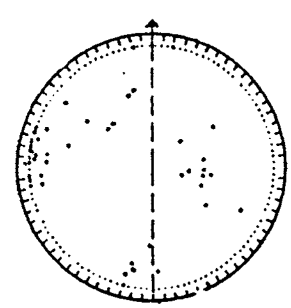
Lithology - sand/silt laminite, Ashfield Shale



Raw angle data

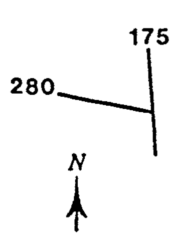


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 350-023, dominant, planar, zonal, mostly vertical but some dip from 75/E 2. 035-050, minor, dip 75/SE 3. 071-092, curved 4. 099-105, dip 70/Nth to vertical 5. 136-145, dip 50/SW	

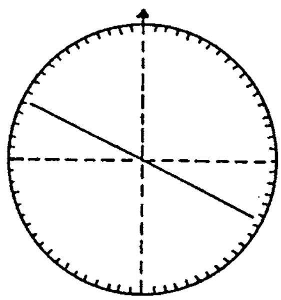


TERMINATION SUMMARY

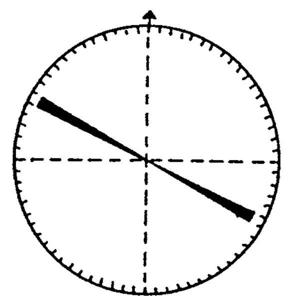
OTHER STRUCTURES: Reverse faults;
(1) 001-020/20-40/W
(2) 136/30-20/SW
Normal faults; (1) 014/60/SE
(2) 035-048/40-55/SE, throws up to 1.5m
(3) 034/45/NW
(4) 075/55/Sth
(5) 101/70/Nth
Joint zones; 016-018, vertical, 1-2m wide, 4-10cm spacing; 335-005, dip 80-85/E, 5m wide, 4cm spacing.

LOC NO. 13 LINDFIELD RAILWAY STATION E 3303.6 N 62610.5

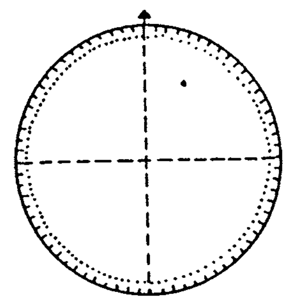
N=1 Lithology - weathered Ashfield Shale



Raw angle data



Rose diagram
5° class interval



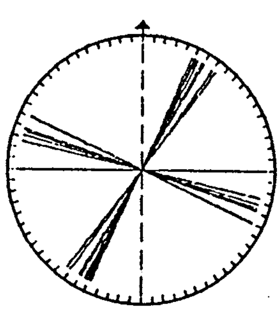
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
NIL	

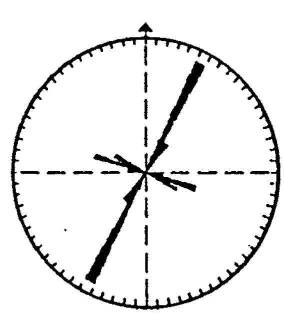
OTHER STRUCTURES: fault; 296/70/SW, reverse?
bedding dips 10/NW at Sth end of station

LOC NO. 14 MIDDLE HEAD OF BALMORAL BEACH E 3382.2 N 62558.8

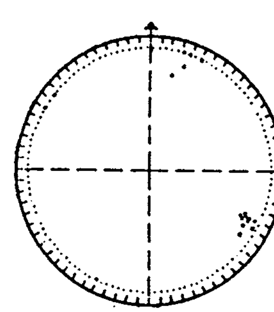
N=19 Lithology - Hawks Sst., crossbedded



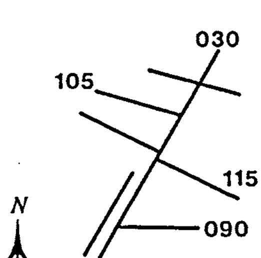
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



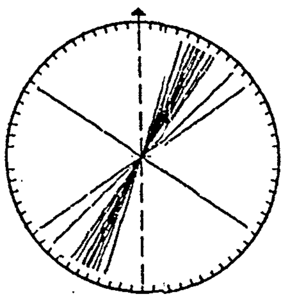
TERMINATION SUMMARY

JOINT SETS	MASTER JOINT SETS
1. 024-035, dominant, planar, dip from 72/W to vertical 2. 103-115, planar, mostly vertical some dip 68/SW 3. 090, only one	1. 024-029, planar, vertical

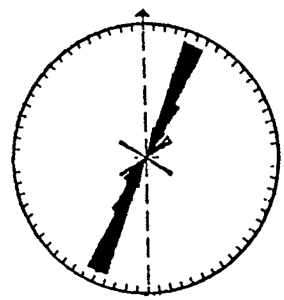
OTHER STRUCTURES: joint zone; 025/77/W, 15cm wide, spacing 3cm: en echelons 036 on joint 024: left lateral step of 030 joint

LOC NO. 15 CUTTING IN PYRMONT RAILWAY, OPP SCOTT ST E 3328.3 N 62501.7

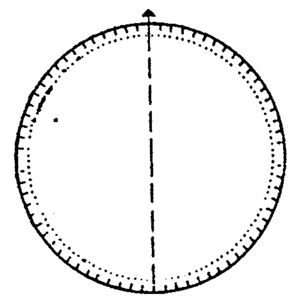
N=15 Lithology - Hawks Sst., massive and crossbedded



Raw angle data



Rose diagram
5° class interval



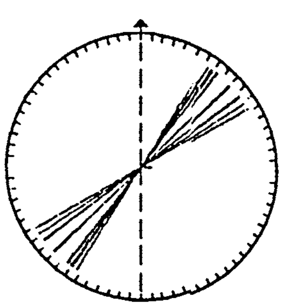
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 018-035, dominant, planar, subvertical 2. 046-055, minor, planar and curved 3. 124, planar, vertical	

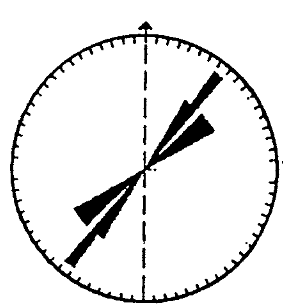
OTHER STRUCTURES: joint zones: 032, vertical, 5cm wide; 027, vertical, 1m wide, contains brecciation. dyke: 172, vertical, slickensides on wall dip 5/Nth.
** bedding dips 3/SE (approx.).

LOC NO. 16 JONES BAY ROAD E 3328.4 N 62511.6

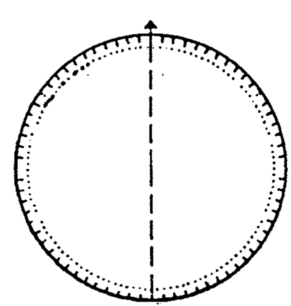
N=11 Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



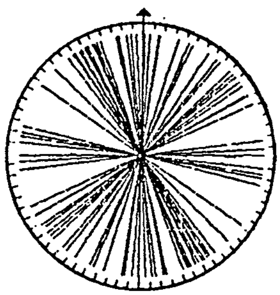
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 032-037, planar, vertical 2. 045-059, planar, vertical, iron-fill	1. 032, planar, vertical 2. 052, as above

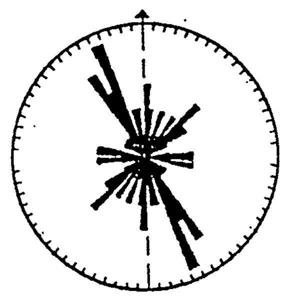
OTHER STRUCTURES: joint zone: 052, vertical, 1m wide, contains brecciation and clay (dyke?) pugh.
normal faults: 052-059, subvertical, upto 10cm throw.

LOC NO. 17 LANE COVE RIVER, COMENARRA PARKWAY E 3230.4 N 62656.2

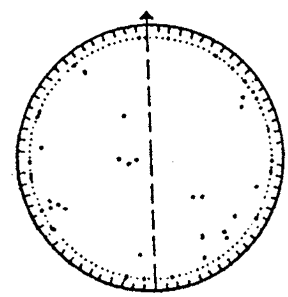
N=46 Lithology - Hawks Sst., crossbedded



Raw angle data

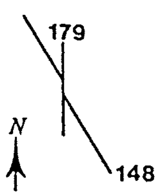


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 141-159, mostly planar and subvertical, mean at 155, some curved and dip 72/NE to 80/SW 2. 167-188, planar, sub vertical 3. 032-064, planar, dip 60/NW to vertical 4. 082-103, planar and curved, vertical 5. 017-024, minor	

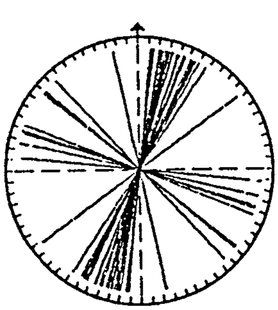


TERMINATION SUMMARY

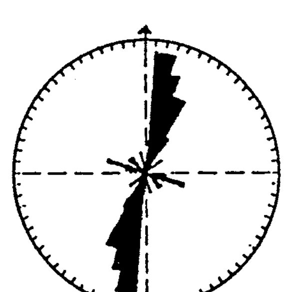
OTHER STRUCTURES: 2 reverse faults: 179/22/E, 167/15/NE, 1m throws. normal fault: 047/75/NW, 25cm throw. fault/breccia zone: 049/44/W. dyke?: strikes 043, 30cm wide.

LOC NO. 18 CREMORNE POINT E 3364.0 N 62531.0

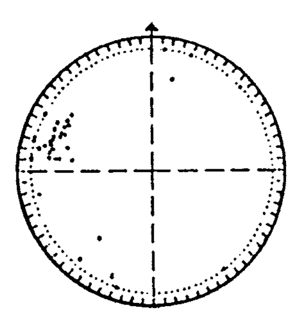
N=37 Lithology - Hawks Sst., crossbedded



Raw angle data

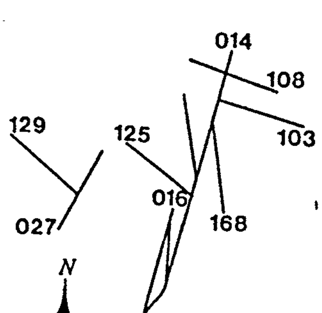


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 002-017, planar, dip 57/E to vertical, iron-fill 2. 019-034, planar, dip 68/E to vertical 3. 129-137, planar and curved, dip 60/Nth to vertical 4. 103-112, planar and curved dip to Nth and Sth	1. 007-010, planar, dip 70/E

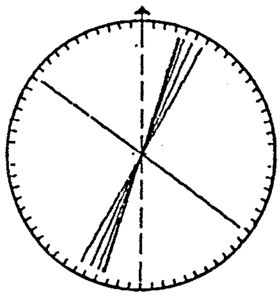


TERMINATION SUMMARY

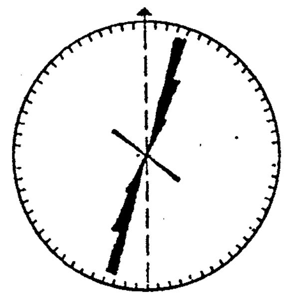
OTHER STRUCTURES: 6 joint zones: 013-030/70-80/E, 0.5-2.0 wide, contain breccia and N-S to NNE joints. right-stepping joint: 034/70/E

LOC NO. 19 CREMORNE RESERVE E 3361.3 N 62532.1

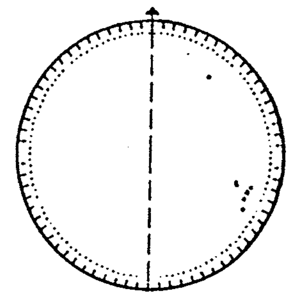
N=7 Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



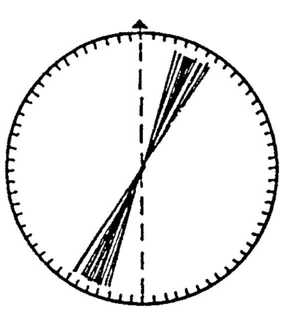
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 017-029, dominant, planar, dip 64-78/W 2. 126, dip 69/Sth, iron-fill	

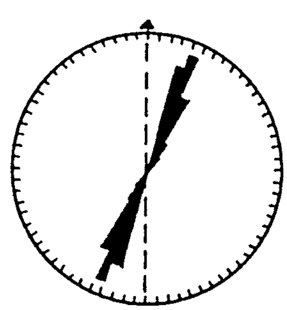
OTHER STRUCTURES: joint zone: 017/64/W, 0.5m wide.

LOC NO. 20 GLEN ST, MILSONS POINT E 3343.4 N 62532.5

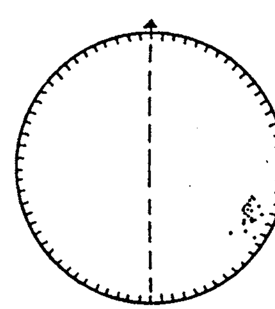
N=21 Lithology - Hawks Sst., massive and crossbedded.



Raw angle data



Rose diagram
5° class interval



Equal area polar plot

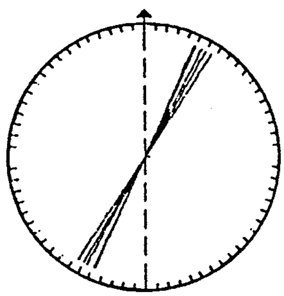
JOINT SETS	MASTER JOINT SETS
1. 016-030, planar, dip 70-86/W	1. 022, planar, dips to W

OTHER STRUCTURES: joint zones: 020/74/W, 2m wide, joints spaced 25 cm, contains horst/graben faults with 1cm throws; 028/71/W, 15m wide, contains small normal faults and brecciation; 023/73/W, 3.5m wide contains subparallel normal faults with 25cm throw; 025/74/W, 5m wide, joints spaced 10cm.

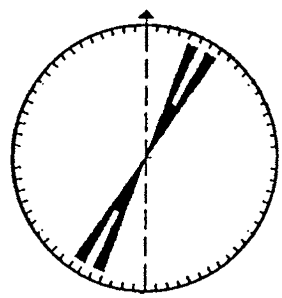
LOC NO. 21 WARRINGAH EXPRESSWAY, NORTH SYDNEY E 3343.5 N 62538.8

N=6

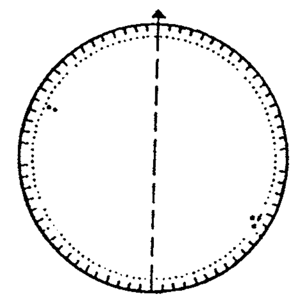
Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



Equal area polar plot

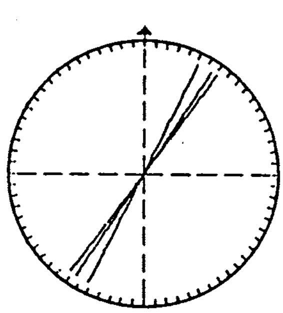
JOINT SETS	MASTER JOINT SETS
1. 024-033, planar, dip 80/E to 85/W, spaced 10-12m	

OTHER STRUCTURES: joint zone: 033, vertical, 1.5m wide, contains brecciation.

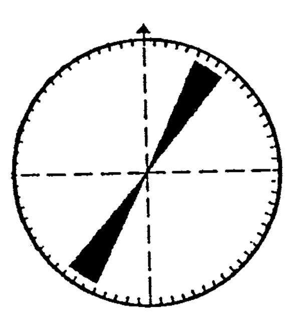
LOC NO. 22 HOLDSWORTH ST, NEUTRAL BAY E 3347.9 N 62540.2

N=3

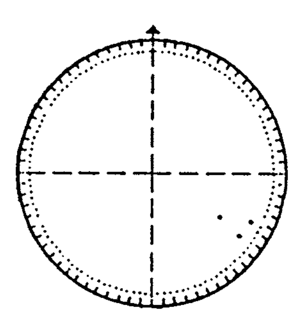
Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval

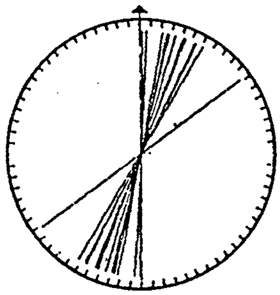


Equal area polar plot

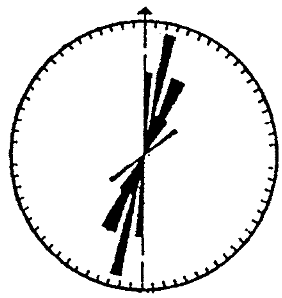
JOINT SETS	MASTER JOINT SETS
1. 026-036, planar and curved, dip 56-80/W, iron fill	

LOC NO. 23 LAVENDER BAY SHUNTING STATION E 3342.4 N 62534.0

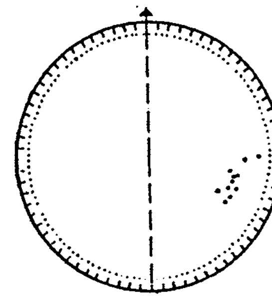
N=12 Lithology - Hawks Sst., massive and crossbedded



Raw angle data



Rose diagram
5° class interval



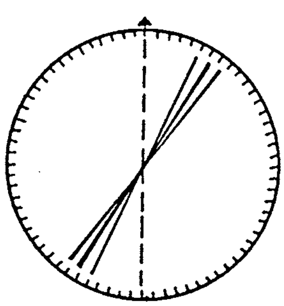
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 010-031, dominant, planar, dip 53-66/W	

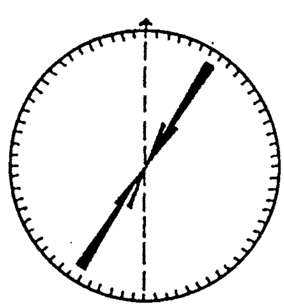
OTHER STRUCTURES: joint zone: 027/63/W, 2m wide, joints spaced 45cm

LOC NO. 24 CLARKE ROAD, NEUTRAL BAY E 3347.3 N 62534.0

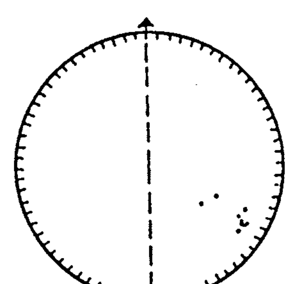
N=9 Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



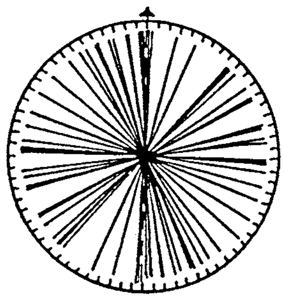
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 025-038, planar, dip 70-80/W, spaced 1.5m	

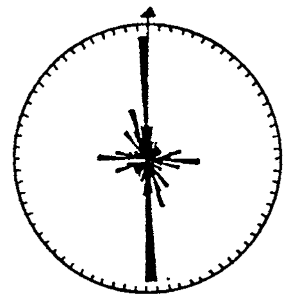
OTHER STRUCTURES: breccia/fault zone: 025/49/W, 1.5m throw, reverse movement.

LOC NO. 25 ARTARMON REFUSE TRANSFER STATION E 3313.0 N 62567.9

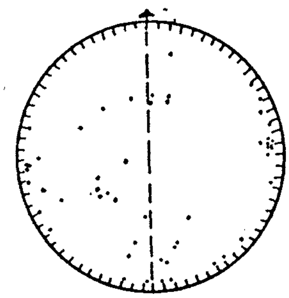
N=46 Lithology - sand/silt laminite, Ashfield Shale



Raw angle data

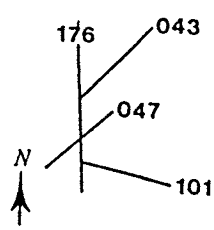


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 176-015, dominant, planar, dip 85/W to vertical 2. 055-104, planar and curved, dip 61/Nth to 70/Sth 3. 130-165, curved and planar, dip 37/NE to vertical	1. 176, planar, vertical



TERMINATION SUMMARY

OTHER STRUCTURES: faults (normal?): 047-110/35-44/S-SE, curved, slickensided; 171/16/W; 150/51/Nth; 024/50/SE.

LOC NO. 26 RYDALMERE E 3168.7 N 62566.3

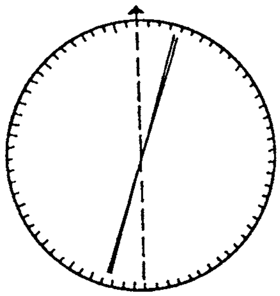
N=2 Lithology - weathered Ashfield Shale

JOINT SETS	MASTER JOINT SETS
Nil	

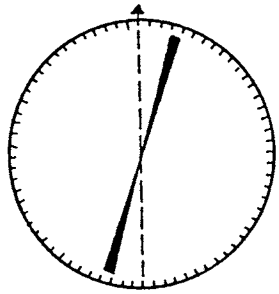
OTHER STRUCTURES: reverse faults: 084-090/28/Nth, displacement upto 30cm.

LOC NO. 27 **MIDDLEMISS ST, NORTH SYDNEY** E 3343.9 N 62536.4

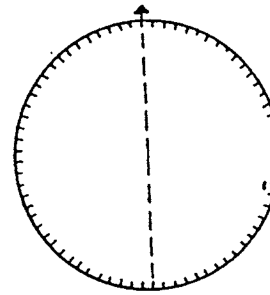
N=2 Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



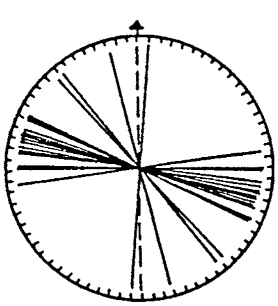
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 017-018, planar, dip 86/W to vertical	

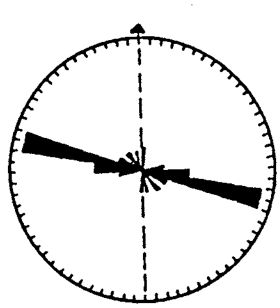
OTHER STRUCTURES: joint zone: 018/86/W, 1m wide, joints spaced 10-20cm.

LOC NO. 28 **MIDDLE HARBOUR** E 3346.7 N 62601.4

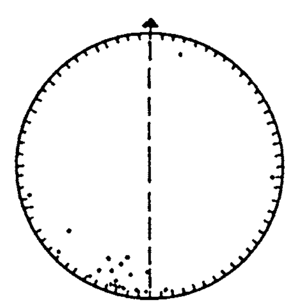
N=21 Lithology - Hawks Sst., crossbedded and massive



Raw angle data

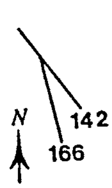


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 083-119, dominant, curved and planar, dip 66/Nth to vertical, iron-fill 2. 137-142, curved	1. 116, planar, dips 81/Nth



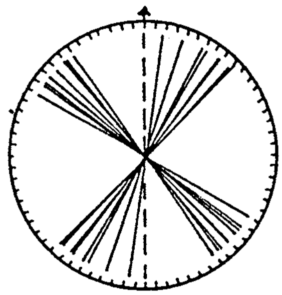
TERMINATION SUMMARY

OTHER STRUCTURES: joint zones: 097, vertical, 0.5m wide; 137, vertical, 1m wide; 109, vertical, 1.5m wide. left-step joint: 117, vertical

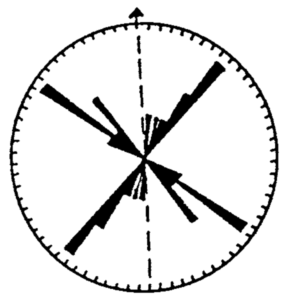
LOC NO. 29 DEE WHY HEAD, CLIFF 500m LONG E 3426.5 N 62623.0

N=18

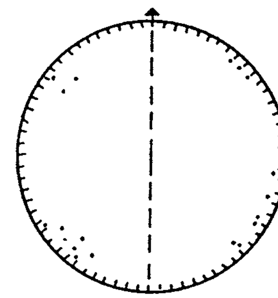
Lithology - sandstone + siltstone of Narrabeen Gp. and Hawks. Sst.



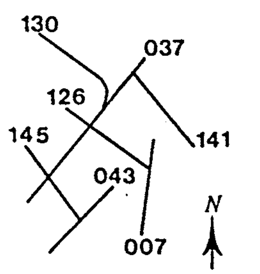
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



TERMINATION SUMMARY

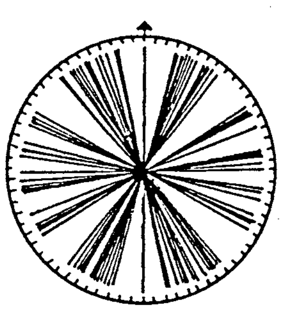
JOINT SETS	MASTER JOINT SETS
1. 120-145, common, planar, zonal, dip from 74-90/NE 2. 028-045, planar, zonal, vertical 3. 007-018, minor,	1. 126-135, planar, vertical

OTHER STRUCTURES: joint zones: 130/V, 2m wide; 032/V, 3m wide.

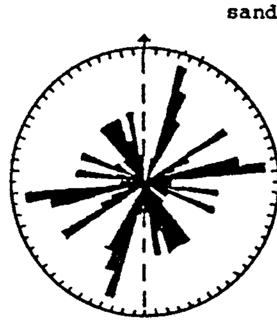
LOC NO. 30 LONG REEF POINT E 3443.3 N 62648.8

N=58

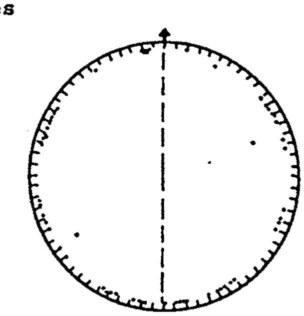
Lithology - Narrabeen Gp., siltstones + sandstones



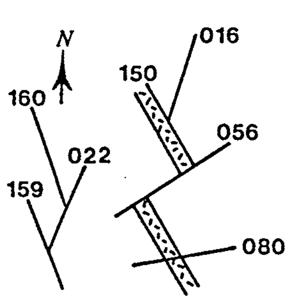
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



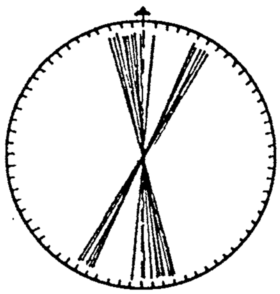
TERMINATION SUMMARY

JOINT SETS	MASTER JOINT SETS
1. 015-032, planar, spaced 2-0.5m 2. 140-167, planar and curved, spaced 1-0.5m 3. 056-068 4. 080-089, close-spaced 5. 097-117	1. 159, planar, only one

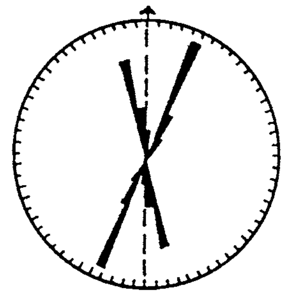
OTHER STRUCTURES: normal fault: 180/48/W, 1m throw. dyke: strikes 147, slightly curved.

LOC NO. 31 ART GALLERY E 3350.7 N 62508.4

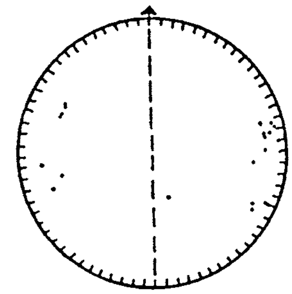
N=19 Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



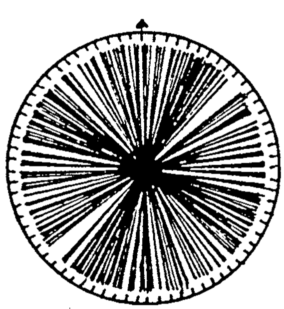
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 163-005, planar, dip mostly 69-88/W, iron-fill 2. 024-031, planar, dip 88/W west of fault, dip 69-78/E east of fault	

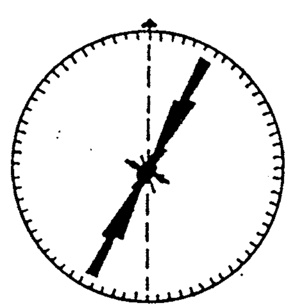
OTHER STRUCTURES: fault: strikes between 056 and 083, dips 21-28/NW, contains breccia upto 0.5m thick, movement unknown.

LOC NO. 32 ST PETERS BRICKPIT E 3315.0 N 62454.4

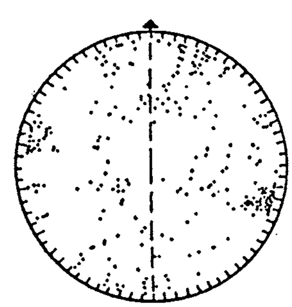
N=265 Lithology - sand/silt laminite, Ashfield Shale



Raw angle data

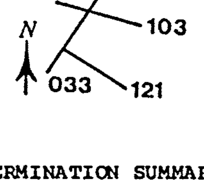


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 013-040, dominant, planar, dip 80/W to vertical 2. 103-135, subdominant, curved and planar, dip 65/Nth to 65/Sth 3. 053-099, curved, dip 45/Sth to 75/Nth 4. 340-010, planar and curved, subvertical	1. 013-040, planar, vertical



TERMINATION SUMMARY

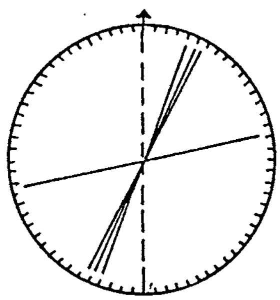
OTHER STRUCTURES: normal faults: (1) dip 20-35/NW, displaces bedding upto 2cm, curved (2) dip 40-60/NE-SE, throws of upto 1.5m (3) dip 50-60/W-NW, planar, throws of upto 5cm. reverse faults: (1) dip 25-50/NE-E, planar, displace NW dipping normal faults and NNE joints upto 4 cm (2) dip 50-60/NW, planar, throws of upto 5cm, subparallel to normal faults. joint/fault zone: trend NNE, subvertical contains breccia, and normal fault.

LOC NO. 33 OXFORD FALLS

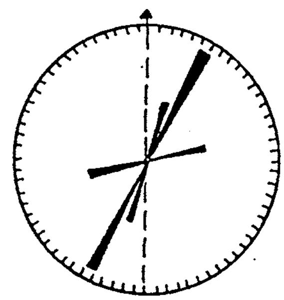
E 3372.9 N 62658.0

N=4

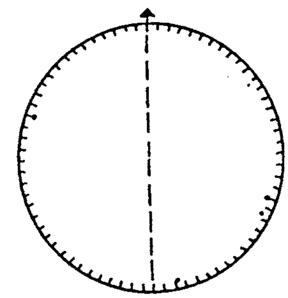
Lithology - Hawks Sst., massive



Raw angle data

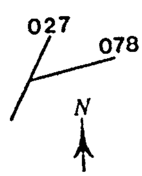


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 020-027, dominant, planar, vertical 2. 078, vertical, planar	1. 027, planar, vertical



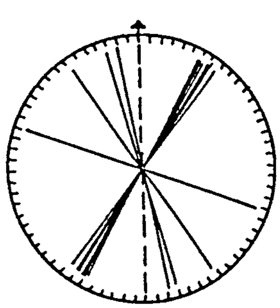
TERMINATION SUMMARY

LOC NO. 34 TERREY HILLS RUBBISH TIP

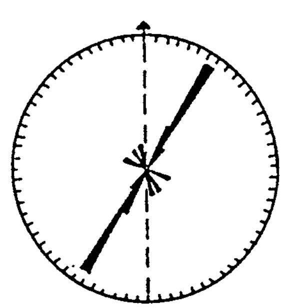
E 3360.5 N 62703.5

N=12

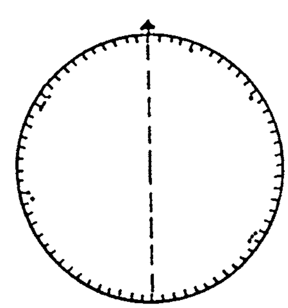
Lithology - Hawks Sst., masssive and crossbedded



Raw angle data

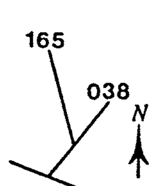


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 029-038, dominant, planar, vertical, left-stepping, iron-fill 2. 147-169, planar, subvertical 3. 111, only one	1. 031-038, planar, vertical

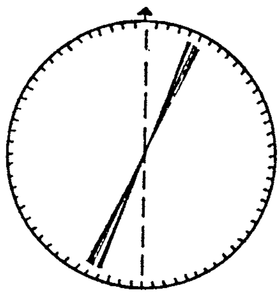


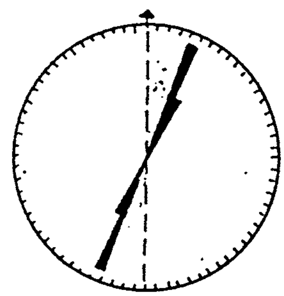
TERMINATION SUMMARY

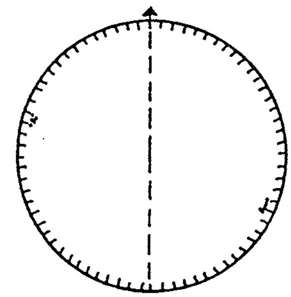
OTHER STRUCTURES: dyke: strikes 117, vertical, 2.5 m wide. joint zone: 032, vertical, 1.5m wide. left-step joints: 035-038, vertical

LOC NO. 35 NORTH HEAD | E 3427.0 N 62559.0

N=11 | Lithology - Hawks Sst.


Raw angle data

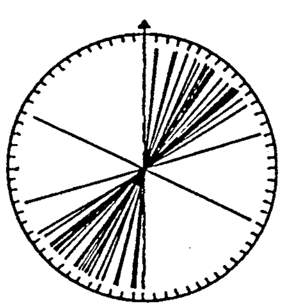

Rose diagram
5° class interval

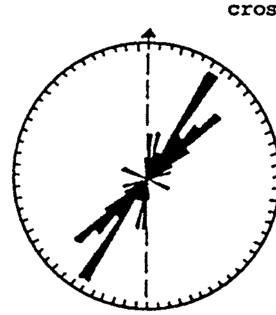

Equal area polar plot

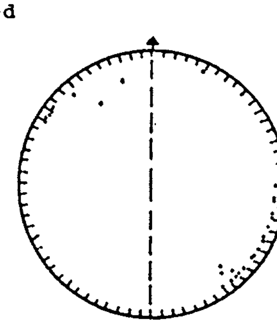
JOINT SETS	MASTER JOINT SETS
1. 021-027, dominant, planar, vertical, spaced mostly 2-5m although sometimes 30m	1. 023-025

LOC NO. 36 BELROSE | E 3345.0 N 62688.0

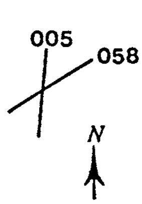
N=28 | Lithology - Hawks Sst., massive and crossbedded


Raw angle data


Rose diagram
5° class interval


Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 000-036, planar, vertical, right-stepping and right step en echelons 2. 042-055, planar, vertical 3. 115, only one 4. 074, dips 75/Sth	1. 047, planar, dips 75/W

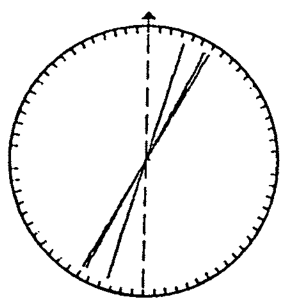


TERMINATION SUMMARY

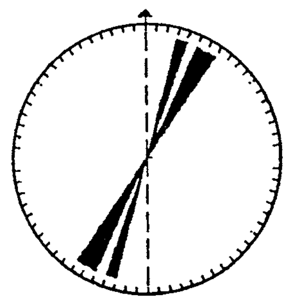
OTHER STRUCTURES: joint zone: strikes 049-055, vertical, 2.5m wide. right-stepping joints: strike 024-036, vertical

LOC NO. 37 **WARRINGAH EXPRESSWAY, CAMMERAY** E 3343.0 N 62557.2

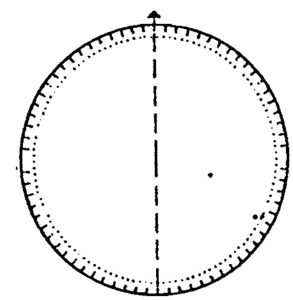
N=3 Lithology - Hawks Sst., siltstone and sandstone



Raw angle data



Rose diagram
5° class interval



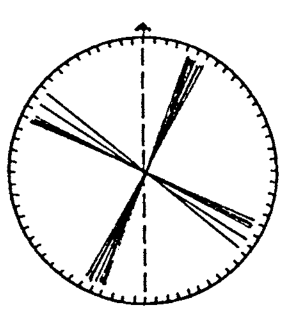
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 028-030, planar, dip 85/W to vertical, spaced 10m	

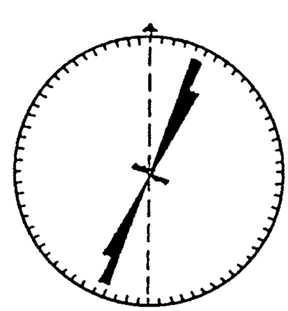
OTHER STRUCTURES: fault: 017/39/W, displacement unknown.

LOC NO. 38 **MRS MACQUARIES CHAIR** E 3354.6 N 62518.5

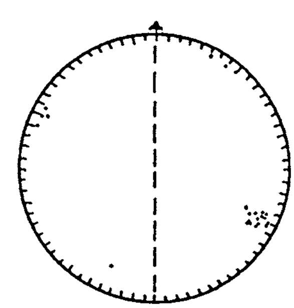
N=23 Lithology - Hawks Sst., crossbedded



Raw angle data

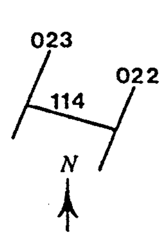


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 021-030, dominant, planar, dip 68/W to 85/E, spaced 1m 2. 114-129, curved and planar, subvertical, iron-fill	1. 025-027, planar, dip 72-80/W, left-step



TERMINATION SUMMARY

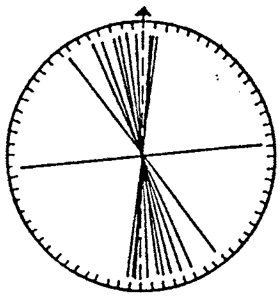
OTHER STRUCTURES: joint zones: 022/82/W, 0.5m wide, contains 7 joints; 030/82/W, 25cm wide; 027/85/E, 0.5m wide. left-step joint: 025/72/W.

LOC NO. 39 BROOK ST TURNOFF, CAMMERAY

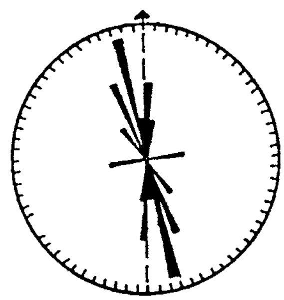
E 3339.3 N 62558.4

N=12

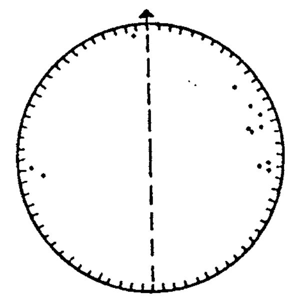
Lithology - Hawks Sst., crossbedded



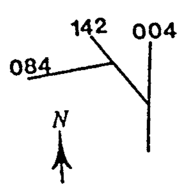
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



TERMINATION SUMMARY

JOINT SETS	MASTER JOINT SETS
1. 156-177, dominant, planar, dip 70/W to 73/E, iron-fill 2. 005-007, planar, dip 79-87/W 3. 084, only one	

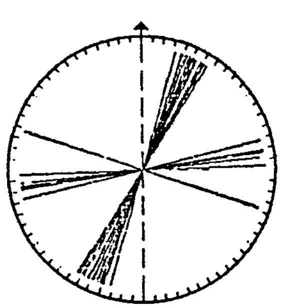
OTHER STRUCTURES: brecciation: dips 10/SW, 1-2m wide. joint zone: 168/73/W, 5m wide, contains E dipping joints.

LOC NO. 40 WESTERN HEADLAND OF EDWARDS BEACH, BALMORAL

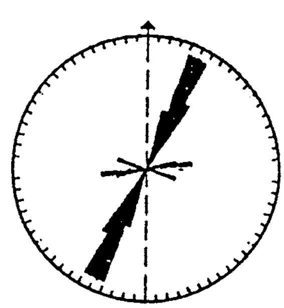
E 3382.2 N 62563.1

N=33

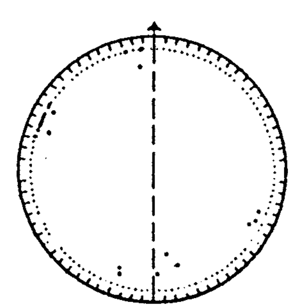
Lithology - Hawks Sst., crossbedded



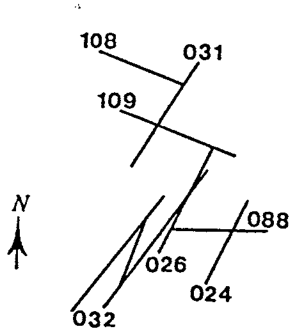
Raw angle data



Rose diagram
5° class interval



Equal area polar plot



TERMINATION SUMMARY

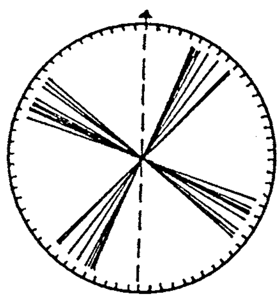
JOINT SETS	MASTER JOINT SETS
1. 016-032, dominant, planar, dip 80/W to 84/E, iron-fill 2. 076-088, planar, dip 75/Nth-75/Sth, iron-fill 3. 108-109, planar, dip 75-80/Nth	1. 023-031, planar, dip 84/E to vertical

OTHER STRUCTURES: joint zones: 023-026, vertical, 1.5-2.0m wide; 025, vertical, 2m wide, contains joints 019 and 027; 030/84/E, 4m wide; 024, vertical, 12m wide, contains fractures 019 and 032. right-step joints: 032, 026, vertical.

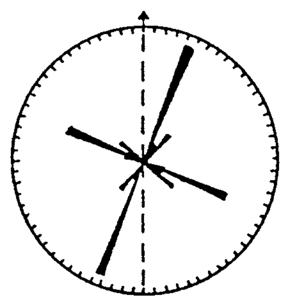
LOC NO. 41 CLIFFLINE EAST OF CABBAGE TREE BAY E 3423.6 N 62586.1

N=22

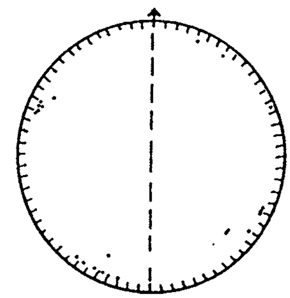
Lithology - Narrabeen Gp. sandstone + siltstone and Hawks Sst.



Raw angle data

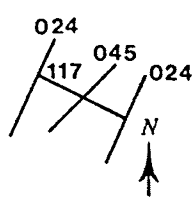


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 022-026, dominant, planar, vertical 2. 031-045, planar, vertical, probably part of set 1. 3. 107-117, planar and curved, vertical 4. 124-127	1. 024



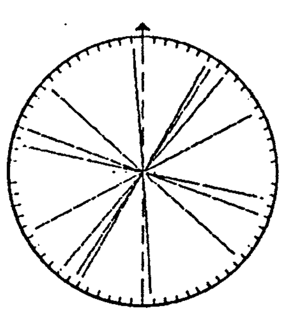
TERMINATION SUMMARY

OTHER STRUCTURES: dyke: strikes 122, vertical, 1.5m wide. slickensides: dip 15-20/NW on dyke wall. ** bedding dips to the west.

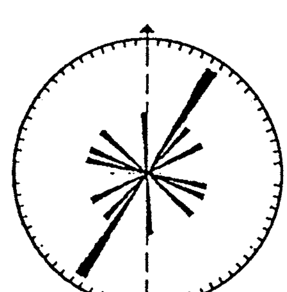
LOC NO. 42 EPPING RAILWAY STATION E 3222.8 N 62612.1

N=10

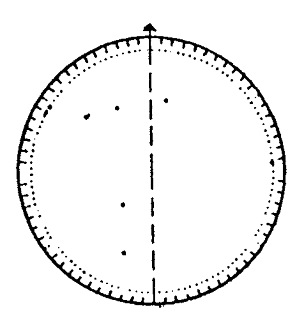
Lithology - weathered Ashfield Shale



Raw angle data



Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 029-033, vertical 2. 176, vertical	

OTHER STRUCTURES: normal faults: 035-040/70/SE, 102/50/S, 110/60/N, 132/30/NE. small monocline hinge strikes 065-080, limb dips 30/SE.

LOC NO. 43 EPPING FAULTS E 3236.1 N 62614.1

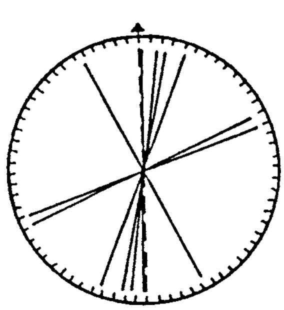
N=2 Lithology - siltstone and sandstone, Hawks Sst.

JOINT SETS	MASTER JOINT SETS
Nil	

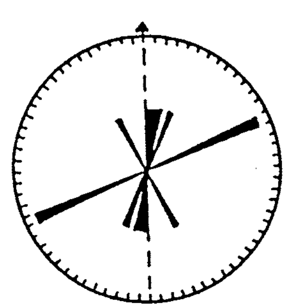
OTHER STRUCTURES: normal faults: 021 and 023, vertical, 1 metre displacement.

LOC NO. 44 RONALD AVENUE, GORE HILL E 3316.5 N 62562.1

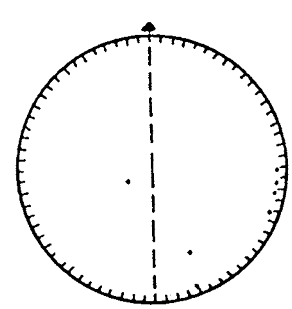
N=7 Lithology - weathered siltstone, Ashfield Shale



Raw angle data

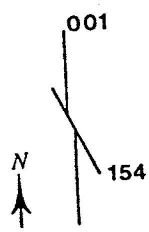


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 001-021, dominant, planar, vertical 2. 066-070, curved, dip 61/Nth to vertical	

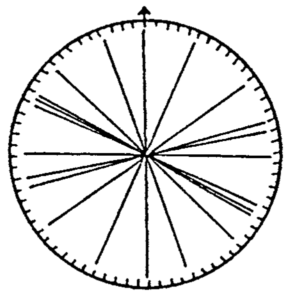


TERMINATION SUMMARY

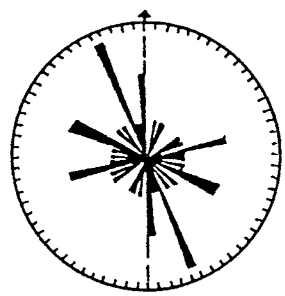
OTHER STRUCTURES: reverse fault: 154/20/NE, displaces 001 joint 5cms. slickensides on 070 plane dip 15/NE. *** bedding dips 22/198 ***

LOC NO. 45 GORE HILL, CNR OF PACIFIC HWY AND BELLEVUE AVE E 3321.4 N 62556.9

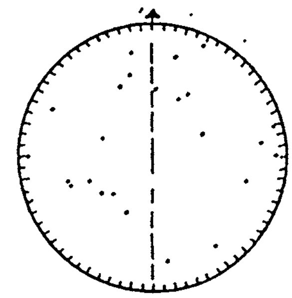
N=24 Lithology - sand/silt laminite, Ashfield Shale



Raw angle data

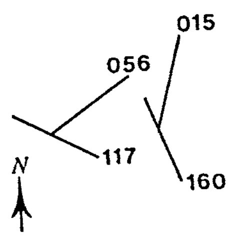


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 354-000, planar, sub vertical 2. 056-082, planar and curved, right-step, variable dip 4. 104-117, curved and planar, variable dip 6. 157-167, planar, dip 36/SW to 45/NE	

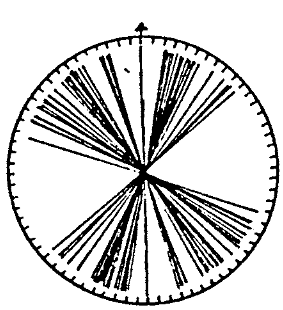


TERMINATION SUMMARY

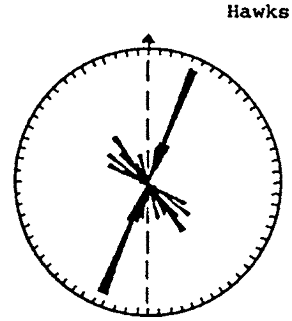
OTHER STRUCTURES: reverse faults: 134/37/NE, throw of 8 cm; 026/87/SE, about 30cm displacement; 162/60/NE. normal faults: 115-120/41-48/Sth; 092/45/Sth; 132/41/NE. faults (movement unknown): 076/58/SE; 160/58/NE. joint zone: 067/52/SE, 2m wide

LOC NO. 46 CLIFFLINE AT NORTH CURLCURL E 3425.0 N 62631.4

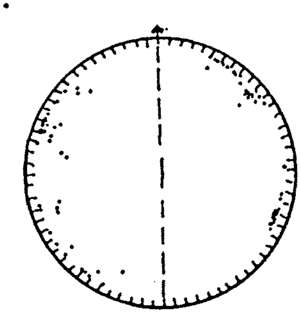
N=72 Lithology - Narrabeen Gp. sandstone and Hawks Sst.



Raw angle data

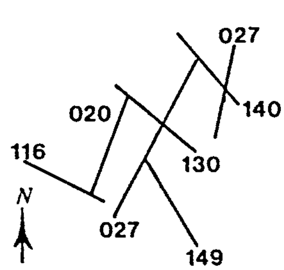


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 010-028, planar, dip 78/E to vertical 2. 036-051, planar, dip 75/E to vertical 3. 112-134, planar, zonal iron-fill, some curved spaced 1.5m 4. 139-165, planar, zonal , dip 72/SW to 83/NE	1. 020-025,planar, vertical 2. 047-051, planar, dips 75-83/E, left-step 3. 119, planar, vertical, part of a zone



TERMINATION SUMMARY

OTHER STRUCTURES: joint zones: strikes 119-127 vertical, 1-4m wide; 148/76/E, 0.5m wide; 024/88/E, 4m wide, contains 6 subparallel faults.

LOC NO. 47 NORTH PARRAMATTA E 3167.7 N 62586.9

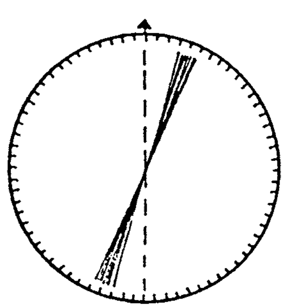
N=1 Lithology - Hawks Sst., sandstone and siltstone

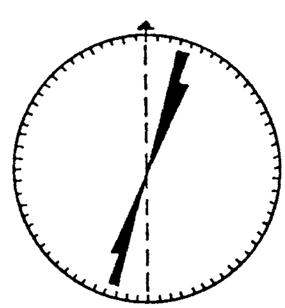
JOINT SETS	MASTER JOINT SETS
Nil	

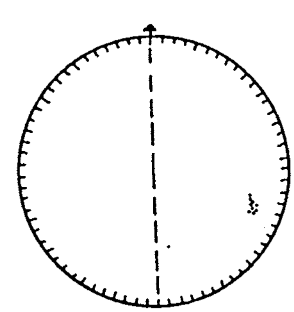
OTHER STRUCTURES: reverse fault: 136/35/SW, 0.75m throw.

LOC NO. 48 CAHILL EXPRESSWAY ROUNDABOUT E 3338.2 N 62516.2

N=9 Lithology - Hawks Sst., crossbedded


Raw angle data


Rose diagram
5° class interval

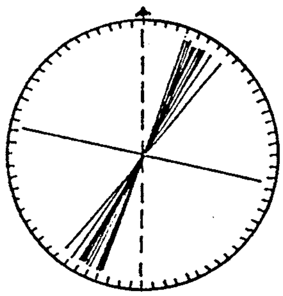

Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 016-024, planar, dip 68-76/W	1. 018-020, planar, dip 69-70/W

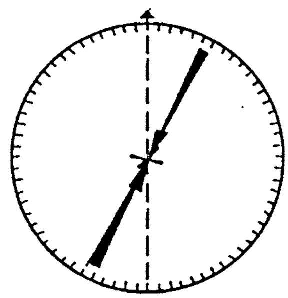
OTHER STRUCTURES: joint zone: 024/75/W, 2m wide, contains 5 joints.

LOC NO. 49 SYDNEY OPERA HOUSE E 3347.3 N 62519.3

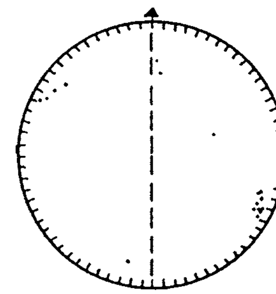
N=15 Lithology - Hawks Sst., crossbedded



Raw angle data

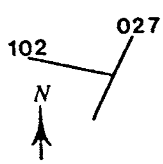


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 019-031, dominant, planar, dip mostly 78 -85/W, spaced 3m 2. 102, curved dip 77/N	1. 028-029, planar, dip to W

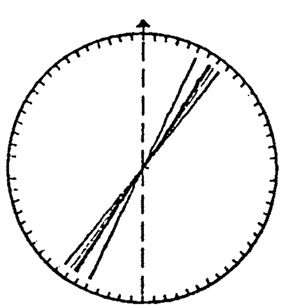


OTHER STRUCTURES: joint zone: 027, vertival, 15 cm wide. left-step joints: 029-034, dip 83/W.

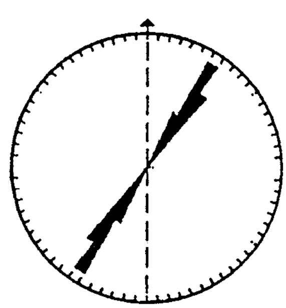
TERMINATION SUMMARY

LOC NO. 50 KURRABA ROAD, NEUTRAL BAY E 3348.1 N 62539.7

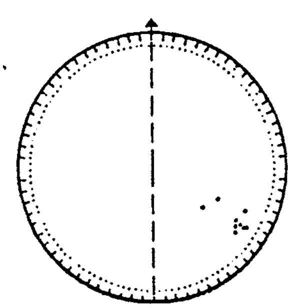
N=9 Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



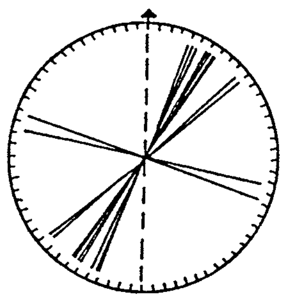
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 014-032, planar, dip 55-80/W	

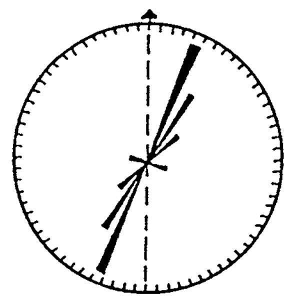
OTHER STRUCTURES: joint zone: 027/75/W, 2m wide, joints spaced 10-20cm.

LOC NO. 51 HAYMARKET, CNR OF QUAY AND THOMAS STREETS E 3337.7 N 62494.0

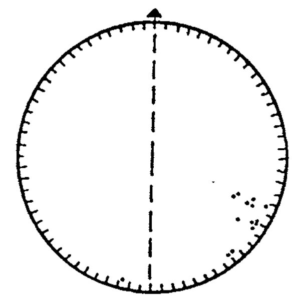
N=14 Lithology - sandstone and siltstone, Hawks Sst.



Raw angle data

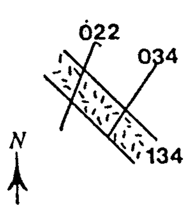


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 021-034, dominant, planar, dip 65/W to vertical 2. 048-050, planar, vertical 3. 102-108, minor	

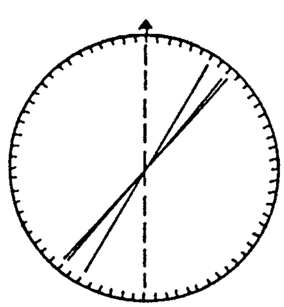


TERMINATION SUMMARY

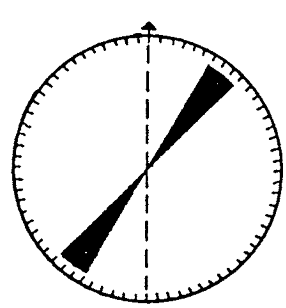
OTHER STRUCTURES: dyke: strike varies from 085-134, 1.5m wide, normal fault along dyke wall, Nth side down 0.5m. joint zone: 022/65/W, 0.5m wide. joint/fault zone: 012/63/W, 2m wide, curved dip.

LOC NO. 52 QUEEN VICTORIA BUILDING E 3340.4 N 62504.0

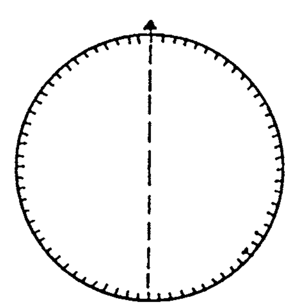
N=3 Lithology - Hawks Sst., massive and crossbedded



Raw angle data



Rose diagram
5° class interval



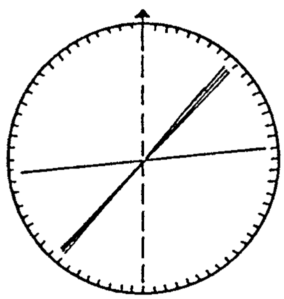
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 030-042, planar, sub vertical	1. 042, planar, vertical

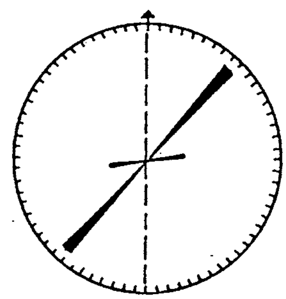
OTHER STRUCTURES: master joint zone: 040 (approx), 2m wide, vertical.

LOC NO. 53 NORMAN ST., THORNLEIGH   E 3221.5 N 62682.7

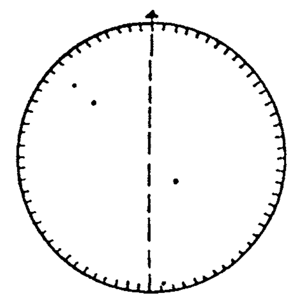
N=4   Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



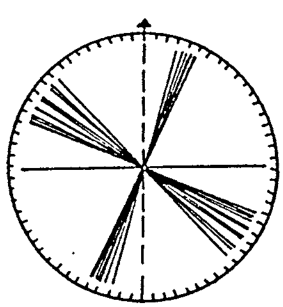
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 084, planar, vertical 2. 044, planar, dip 21/NW	

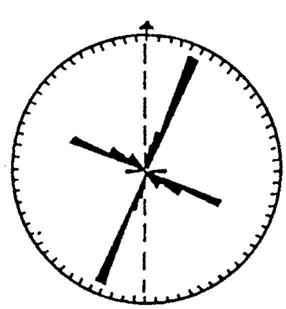
OTHER STRUCTURES: normal faults: 042/52/SE, 1.5m throw; 043/73/NW, 1.5m throw. joint zone: 044/21/NW, contains brecciation.

LOC NO. 54 LINDFIELD, CNR OF TRYON RD AND ARTERIAL RD   E 3312.3 N 62616.7

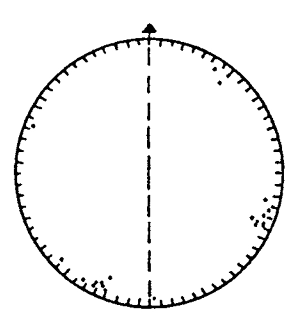
N=21   Lithology - Hawks Sst., crossbedded



Raw angle data

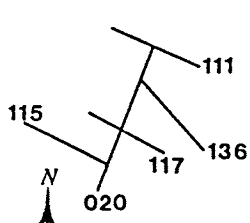


Rose diagram
5° class interval



Equal area polar plot

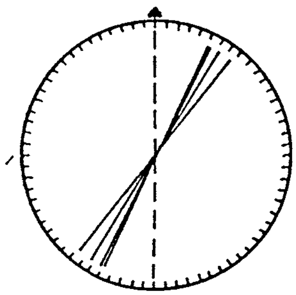
JOINT SETS	MASTER JOINT SETS
1. 015-025, dominant, planar, dip 79/W to vertical, spaced 1-3m right-step 2. 111-136, planar and curved, dip 76/Nth to 79/Sth, rough faces	1. 018-023, planar, vertical



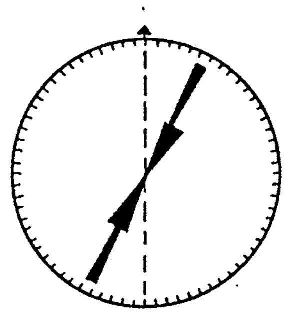
TERMINATION SUMMARY

LOC NO. 55 BAHAI TEMPLE E 3385.5 N 62710.5

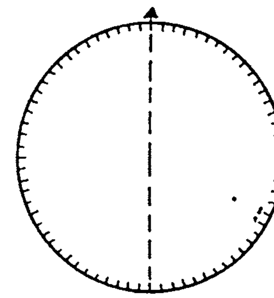
N=5 Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



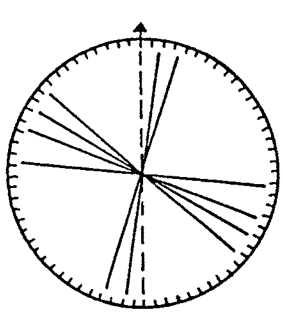
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 025-031, planar, dip 65/W to vertical	

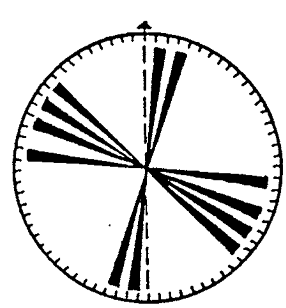
OTHER STRUCTURES: dyke: strikes 039, vertical.

LOC NO. 56 WAVERTON PARK E 3332.8 N 62537.8

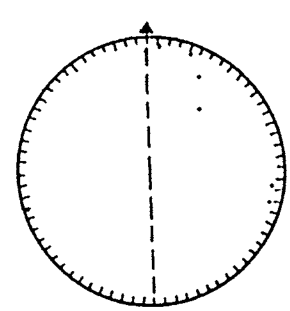
N=6 Lithology - Hawks Sst., crossbedded and massive



Raw angle data

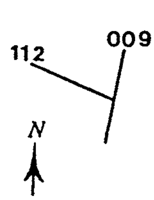


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 009-017, planar, vertical 2. 096-132, planar and curved, dip from 53/SW to 73/NE	

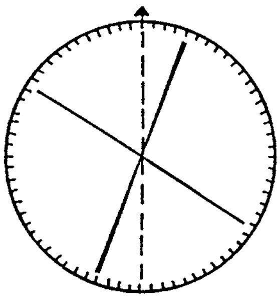


TERMINATION SUMMARY

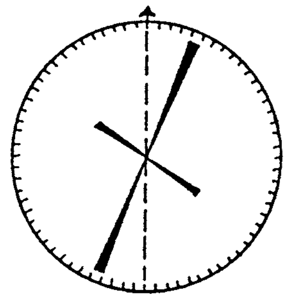
LOC NO. 57 **GROSVENOR PLACE DYKE** E 3340.4 N 62514.4

N=3

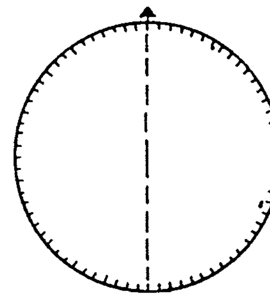
Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



Equal area polar plot

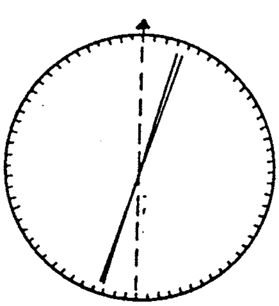
JOINT SETS	MASTER JOINT SETS
1. 020-022, planar, vertical, spaced 10m 2. 122, curved, subvertical	

OTHER STRUCTURES: dyke: strikes 107, vertical, 3.5-1m wide.

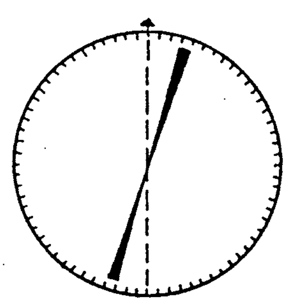
LOC NO. 58 **CLIFF ST, NORTH SYDNEY** E 3343.0 N 62534.8

N=3

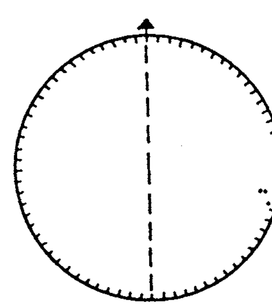
Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



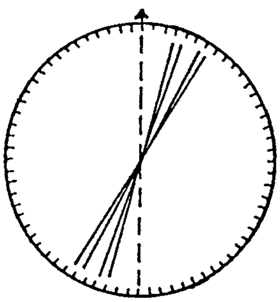
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 016-018, planar, dip 77/W to vertical	

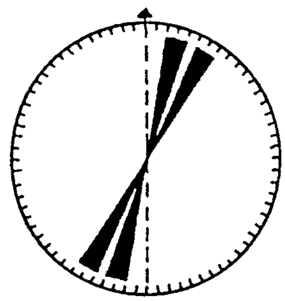
OTHER STRUCTURES: joint zone: 016/77/W, 1m wide.

LOC NO. 59 NICHOLSON STREET, BARRA BRUI   E 3307.1   N 62640.6

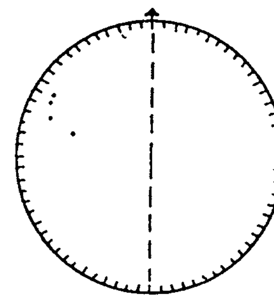
N=4   Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



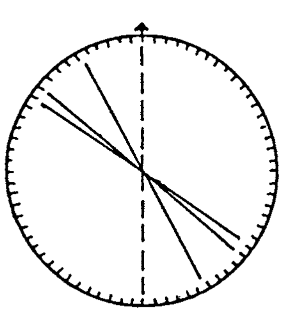
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 027-032, planar, dip 80/E	

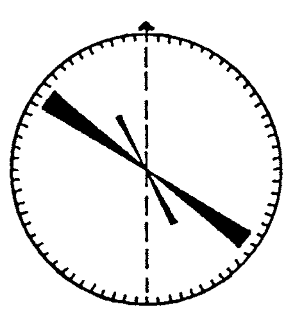
OTHER STRUCTURES: <u>normal faults</u>: 015-019/55-75/E, displacement 2-10cm.

LOC NO. 60 ARTERIAL ROAD, ST. IVES   E 3300.2   N 62655.1

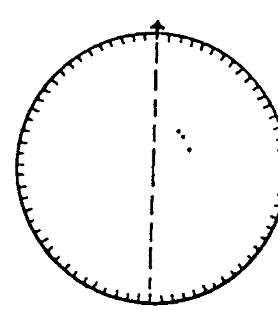
N=3   Lithology - weathered Ashfield Shale



Raw angle data



Rose diagram
5° class interval



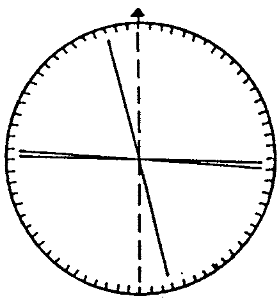
Equal area polar plot

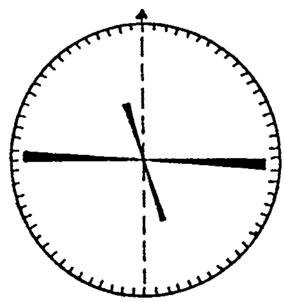
JOINT SETS	MASTER JOINT SETS
1. 124-130, curved, dip 29/Sth	

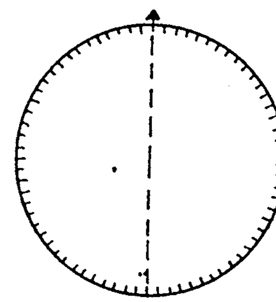
OTHER STRUCTURES: <u>reverse fault</u>: 152/27/SW, little displacement.

LOC NO. 61 KING ROAD, HORNSBY E 3253.6 N 62690.4

N=3 Lithology - Hawks Sst., crossbedded


Raw angle data


Rose diagram
5° class interval

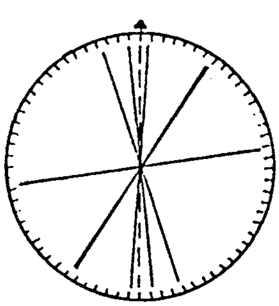

Equal area polar plot

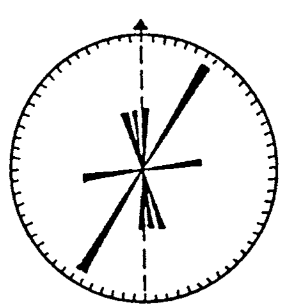
JOINT SETS	MASTER JOINT SETS
1. 092-094, planar, dip 80/Nth	

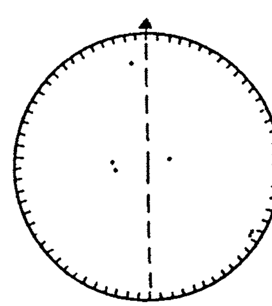
OTHER STRUCTURES: <u>reverse fault?</u> : 165/25/NE, 0.5m wide.

LOC NO. 62 LEIGHTON PLACE AND BRENNAN CLOSE, HORNSBY E 3247.2 N 62696.3

N=6 Lithology - sandstone and siltstone, Hawks Sst.


Raw angle data


Rose diagram
5° class interval

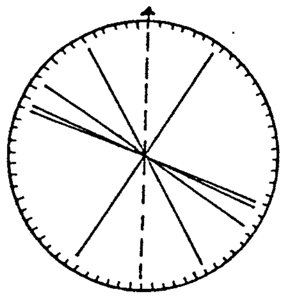

Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 033, planar, vertical	

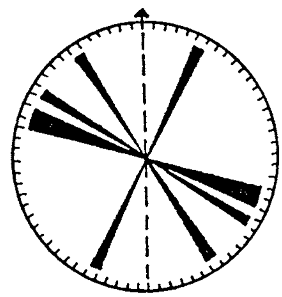
OTHER STRUCTURES: <u>reverse fault?</u> : 174/21/E, displacement unknown. <u>normal faults</u>: 033, vertical, 3cm displacement; 004/24/E, contains breccia. <u>joint fault zones</u>: 081/72/SE; 162/15/SW, contains breccia.

LOC NO. 63 BRUSHWOOD PLACE, HORNSBY E 3225.5 N 62683.8

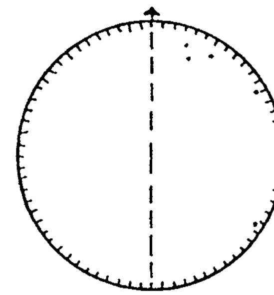
N=5 Lithology - Hawks Sst., crossbedded



Raw angle data



Rose diagram
5° class interval



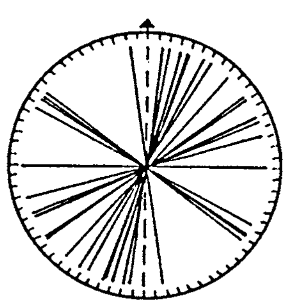
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 110-123, planar, dip 70-80/Sth 2. 030, planar, vertical 3. 150, curved, vertical	

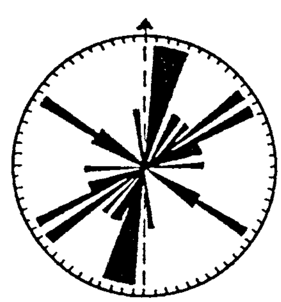
OTHER STRUCTURES: normal faults: 110-123/70-80/Sth, displacement 10cm-1.5m.

LOC NO. 64 NICHOLSON AND HUME STREETS, CROWS NEST E 3332.7 N 62553.5

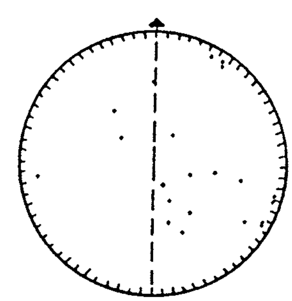
N=21 Lithology - sand/silt laminite, Ashfield Shale



Raw angle data



Rose diagram
5° class interval



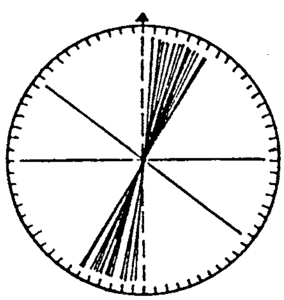
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 007-027, dominant, planar, dip 88/E to 60/W, goethite fill 2. 042-067, planar, dip 15/NW to 27/SE 3. 118-124, planar and curved, sudvertical	

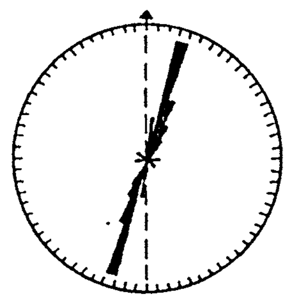
OTHER STRUCTURES: normal faults: 065/50/NW, throw of 80cm; 032/75/NW; 090/55/Sth, little displacement. reverse faults: 126/23/SW; 074/40/NW, little displacement.

LOC NO. 65 WEST SIDE OF WOOLLOOMOOLOO BAY E 3355.0 N 62515.0

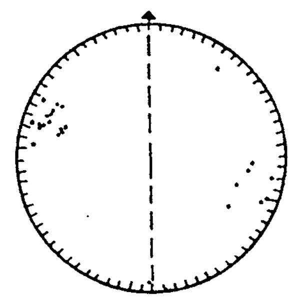
N=25 Lithology - Hawks Sst., massive and crossbedded



Raw angle data



Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 016-030, dominant, planar, dip 65/E to vertical, spaced 10-50cm 2. 004-032, planar, dip 62/W to vertical 3. 090-127, curved, spaced 5m	

OTHER STRUCTURES: left-step joint: 021/63/E. right step joint: 017, vertical. joint zone: 024/78/E, 0.5m wide, joints spaced 10 cm. sets 1 and 2 are vertical conjugates.

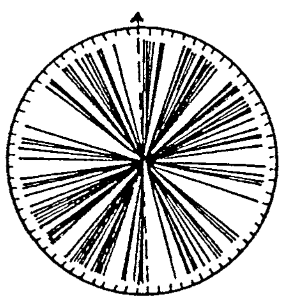
APPENDIX C

Appendix C contains a list and summary of the fracture analysis sites on the Blue Mountains plateau shown on fig.91. Grid references are based on the Australian Map Grid (U.T.M.) and all bearings are given to true north. The fracture summary of each locality includes three plots of fracturing; a plot of the strike, a rosette diagram using 5 degree class intervals, and an equal area polar plot. A summary of the joint and master joint sets and their characteristics is also given. The arrangement of fracturing (terminations) and any other structures are also noted.

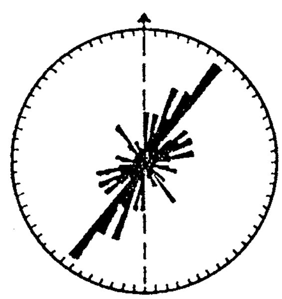
Locality number	Grid Reference	Locality Description
1.	2802.1,62860.0	Bell Bird Hill.
2.	2240.6,63075.0	Mudgee Road, Great Dividing Range.
3.	2219.4,63141.0	Railway cuttings, 2.75km Nth of Cullen Bullen.
4.	7794.0,63260.5	Pearsons lookout, Mudgee Road.
5.	7674.5,63436.5	Cherry Tree Hill, Mudgee road.
6.	2508.1,63292.0	Freshwater Creek.
7.	2340.8,62356.1	Kanangra Walls.
8.	2361.9,62364.4	Crafts Walls.
9.	2366.8,62374.2	Mount Berry.
10.	2352.8,62395.2	Kanangra Gorge.
11.	2318.4,63295.0	Coco Creek unconformity.

LOC NO. 1 BELL BIRD HILL E 2802.1 N 62860.0

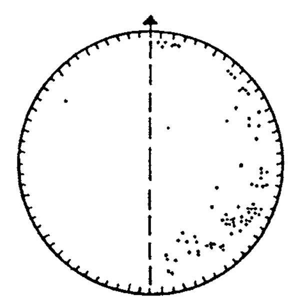
N=81 Lithology - Hawks Sst., crossbedded



Raw angle data

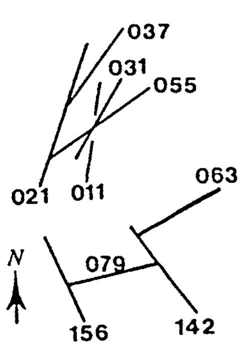


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 059-070, planar, 4-20m extent, dip 59-76/W, spaced 1-3m, iron-filled 2. 003-012, planar, dip 77-85/W, 0.2-4m extent 3. 035-038, planar, dip 70/W to vertical 0.4-2.5m extent 4. 023-037, planar, dip 73-83/W, 1-2m extent 5. 050-080, planar, dip 73-83/W, 0.5-2m extent 6. 130-156, dip 61/SW to vertical, iron-filled 7. 094-102, planar, dip 87/W to vertical	1. 059-065, planar, dip 62-66/W, iron-filled

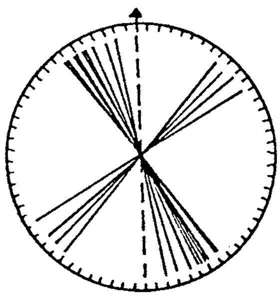


TERMINATION SUMMARY

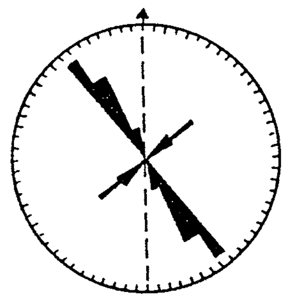
OTHER STRUCTURES: dyke: strikes 130, 0.2-0.4m wide. joint zones: strike 034-037, dip 53/W to vertical, 10-15cm wide. slickensides in dyke: dip 10/NE on 072/70/SE, horizontal on 097/75/Sth and 072/90. bedding planes: 051/19/SE, 033/16/SE, 014/11/SE

LOC NO. 2 MUDGEE ROAD, GREAT DIVIDING RANGE E 2240.6 N 63075.0

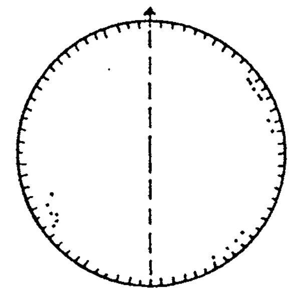
N=18 Lithology - Farmers Ck. Fm., siltstones, clay stones and coal



Raw angle data

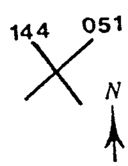


Rose diagram
5° class interval



Equal area polar plot

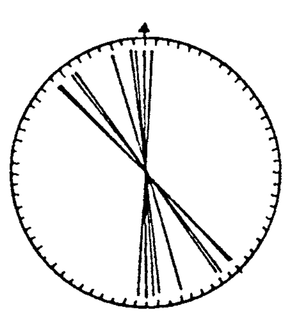
JOINT SETS	MASTER JOINT SETS
1. 143-170, dominant, planar, dip 82/NE to vertical 2. 041-059, planar, 10-30cm extent	1. 170, planar, vertical



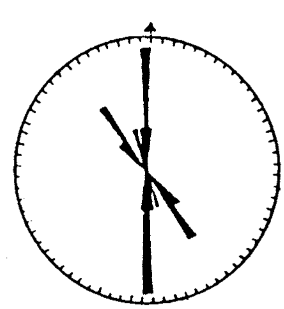
TERMINATION SUMMARY

LOC NO. 3 RAILWAY CUTTINGS, 2.75KM NTH OF CULLEN BULLEN E 2219.4 N 63141.0

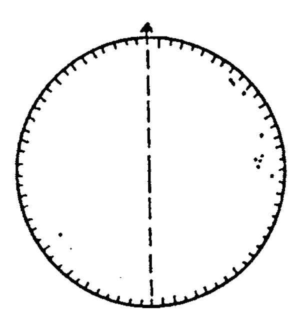
N=10 Lithology - Lithgow Coal, Marrangaroo Congl.



Raw angle data



Rose diagram
5° class interval



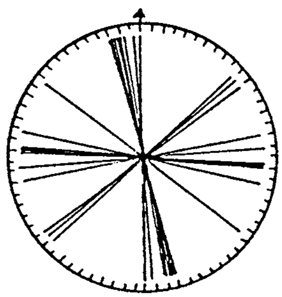
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 174-184, dominant, planar, dip 77/W to vertical 2. 135-164, planar, vertical	1. 174-180, planar dip 78-82/W

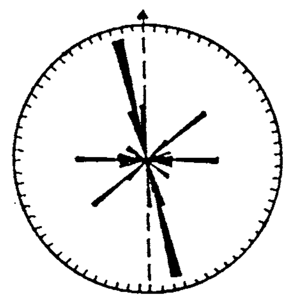
OTHER STRUCTURES: joint zone: 176/82/W, 0.5m wide.

LOC NO. 4 PEARSONS LOOKOUT, MUDGEE ROAD E 7794.0 N 63260.5

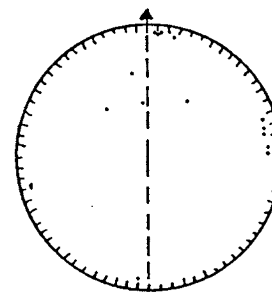
N=22 Lithology - Illawarra Coal Measures



Raw angle data

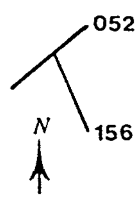


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 165-180, dominant, planar, vertical 2. 052-055, planar, vertical 3. 094-103, planar, 10-20cm extent	

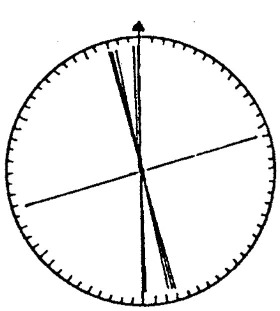


TERMINATION SUMMARY

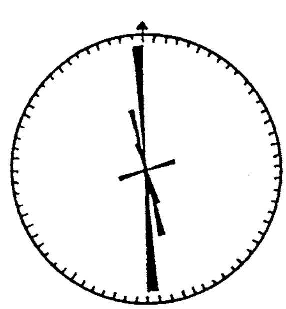
OTHER STRUCTURES: normal faults: 049/42/SE, 50cm throw; 080/58/Sth, 15cm throw; 086/36/Sth, 10cm throw; 127/45/Sth, 20 cm throw.

LOC NO. 5 CHERRY TREE HILL, MUDGEE ROAD E 7674.5 N 63436.5

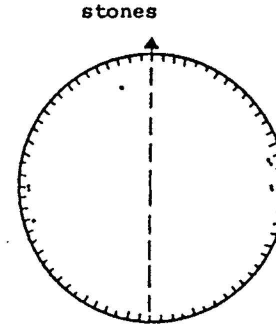
N=8 Lithology - Farmers Ck. Fm, siltstones, clay stones



Raw angle data



Rose diagram
5° class interval

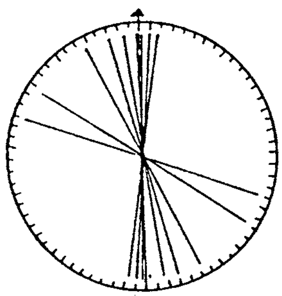


Equal area polar plot

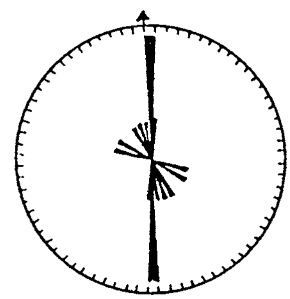
JOINT SETS	MASTER JOINT SETS
1. 165-180, dominant, planar, vertical 2. 074, only one	

LOC NO. 6 FRESHWATER CREEK E 2508.1 N 63292.0

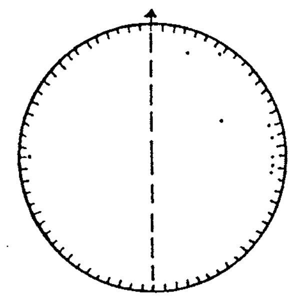
N=9 Lithology - carbonaceous claystone



Raw angle data



Rose diagram
5° class interval



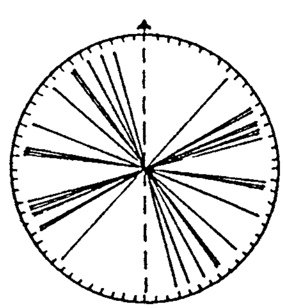
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 165-185, dominant, planar, vertical 2. 153-160, planar, vertical 3. 110-124, planar, vertical	

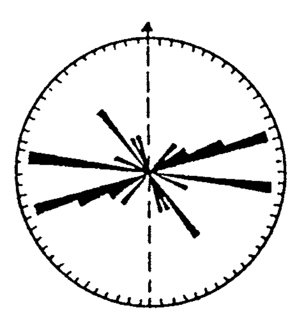
OTHER STRUCTURES: normal fault: 153/54/SW, throw 10cm

LOC NO. 7 KANANGRA WALLS E 2340.8 N 62356.1

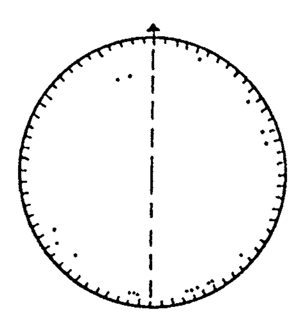
N=17 Lithology - sandstone and conglomerate



Raw angle data

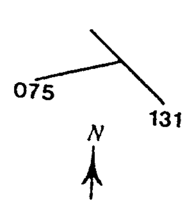


Rose diagram
5° class interval



Equal area polar plot

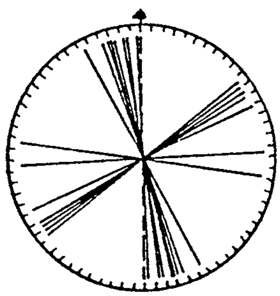
JOINT SETS	MASTER JOINT SETS
1. 060-075, planar, vertical 2. 097-100, planar, vertiical 3. 131-165, planar, subvertical, iron-fill 4. 112, only one 5. 041, only one	1. 060-071, planar, vertical 2. 131-143, planar, subvertical 3. 097, planar, vertical



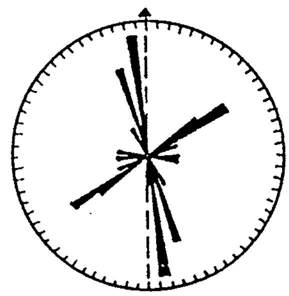
TERMINATION SUMMARY

LOC NO. 8 CRAFTS WALLS E 2361.9 N 62364.4

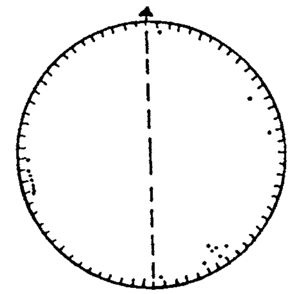
N=18 Lithology - sandstone and conglomerate



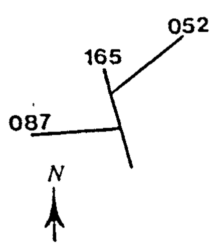
Raw angle data



Rose diagram
5° class interval



Equal area polar plot

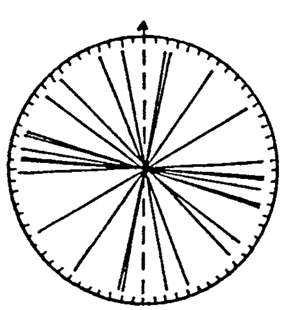


TERMINATION SUMMARY

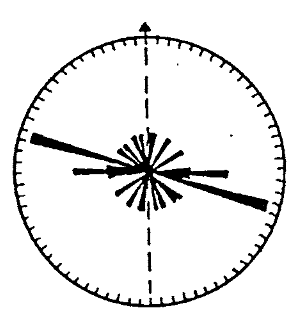
JOINT SETS	MASTER JOINT SETS
1. 152-179, planar, vertical 2. 052-066, planar, dip 75/NW to vertical vertical 3. 087-097, planar	1. 152-174, planar, vertical 2. 052-060, planar, dip 80-85/NW

LOC NO. 9 MOUNT BERRY E 2366.8 N 62374.2

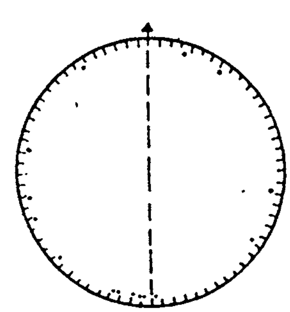
N=15 Lithology - conglomerate and quartzite



Raw angle data



Rose diagram
5° class interval



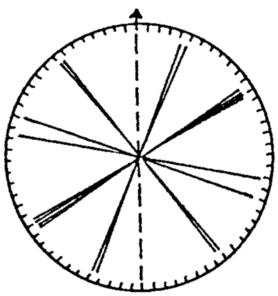
Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 089-108, planar, vertical, in basement and Permian sediments 2. 126-137, planar, vertical 3. 159-012 4. 035, only one 5. 060. only one	

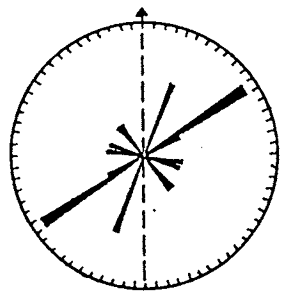
LOC NO. 10 KANANGRA GORGE E 2352.8 N 62395.2

N=10

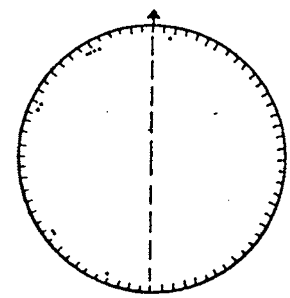
Lithology - Lambie Group quartize



Raw angle data

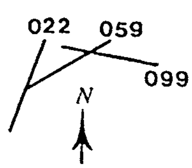


Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 058-062, planar, vertical 2. 022-024, fractures 3. 099-110, quartz fill 4. 140-142, most continuous	

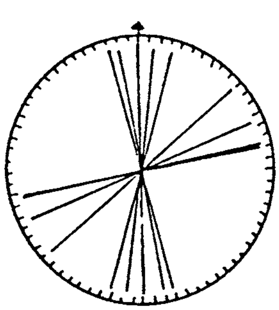


TERMINATION SUMMARY

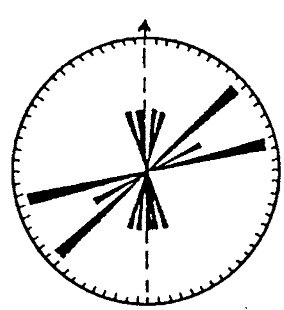
LOC NO. 11 COCO CREEK UNCONFORMITY E 2318.4 N 63295.0

N=10

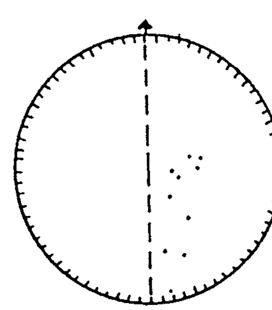
Lithology - quartzite and Permian conglomerate



Raw angle data



Rose diagram
5° class interval



Equal area polar plot

JOINT SETS	MASTER JOINT SETS
1. 079, planar, vertical, cuts through unconformity	

OTHER STRUCTURES: reverse faults through unconformity: 008-016/16-22/W, throw upto 0.75m; 038/23-43/NW, throw upto 0.30m. kink planes: 153-180/30-37/W, 2-10cm wide; 067-078/57-67/NW, 2-10cm wide. metasediment dip: 175/47/W. axial planes of folds in basement: 160-175/50-90/W