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Interpretation of Discontinuity Data at Selected Sites in the Adelaide Region

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Summary Rock discontinuities are defects of low tensile strength, including bedding, foliations and joints. Systematic discontinuity analysis is undertaken during rock excavation design, to quantitatively determine the defect pattern. Survey results are applicable at the exposed face. However, extrapolation is essential, although difficult without an understanding of the large scale. Generally for rocks that have been affected by the same deformation events, discontinuities have similar orientations, although other characteristics may vary. Examples are cited illustrating the controls exerted on discontinuities in the Adelaide region. In competent rocks discontinuities are penetrative surfaces or controlled by the last folding event. For incompetent rocks they are influenced by an earlier event. In recent sediments they exhibit similar orientations to the older metasediments. Structural geology assessment can be beneficial during discontinuity analysis, having the potential to improve efficiency and safety.

1. INTRODUCTION

In rock engineering, discontinuities are mechanical defects with low tensile strength, which influence rock stability (Priest 1993). The nature of discontinuities commonly depends on their origin. However difficulties exist in the application of rock mechanics theory due to material variability and stress conditions. To characterise rock properties, rock engineers often use a scanline sampling method (Priest 1993), where a tape is extended across a rock mass, such as depicted in Fig. 1. Ideally with close to 100% exposure, the properties of each discontinuity that intersects the tape are recorded, i.e. intersection distance, orientation, semitrace length and roughness. The data are input into programs, to undertake modelling and yield quantitative information enabling rock stability determination, such as SCANMASTER (Meyers et al. 1993). Variables are the cone angle i.e. the angle used to subtend a cone from the centre of a search area to assign sets (in this article a 15° angle is used), and the maximum weighting: a correction for surfaces at low angle to the tape. The program's output includes the mean set orientation, their variability denoted by the Fishers constant (for high clustering the constant is > 20-30, if random the constant is close to 1), the set spacing and distribution.

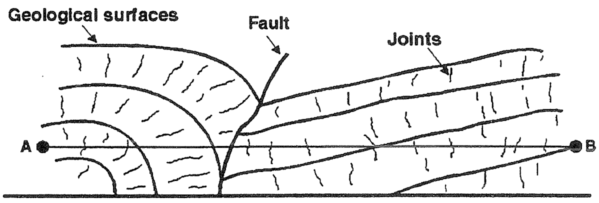

Figure 1. Rock face, showing scanline A to B.

Discontinuity determination ideally necessitates analysis along three orthogonal scanlines, but this places a restriction on the identification of suitable sites. Where ideal sites are not present the results may be biased, however the general advantages of this method are that it: 1) does not require highly trained staff, 2) produces quantitative data and 3) generally unbiased results. Disadvantages are that the method is : 1) unable to predict beyond the sample zone, 2) does not examine the macroscale, 3) is time consuming, and 4) ignores the possible bias contributed by individual major defects. Where large scale features influence local discontinuity characteristics, e.g. in areas of faulting or folding, there can be important discontinuity variations. In such cases it is necessary to subdivide the zone into homogeneous sections. Surveys in areas modified by folding, faulting and/or both, can have limited application unless the macrostructure is taken into account. Extrapolation in such areas requires an appreciation of the macrostructure, as Fig. 2 illustrates, where discontinuities at D are not the same as at C.

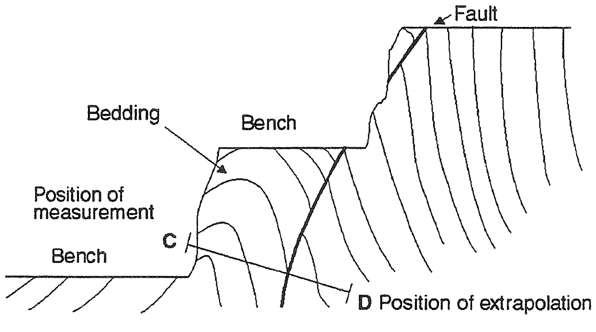

Figure 2. Section normal to scanline, illustrating extrapolation problem from C to D.

Structural geologists examine the intermediate to large scale, relative timing and modification conditions. Descriptive information and geometrical data concerning rock fabric, relative timing and the processes involved are collected. Local meso- and microscopic evidence is used to establish the structural history. Through such investigations the spatial and sequential relationships between structural elements are identified, discontinuities classified, their origin inferred and extrapolation postulated. An advantage of structural geology as an aid to discontinuity analysis is the possibility of prediction beyond an exposed rock face. A significant disadvantage is that results are not quantitative.

2. DISCONTINUITY CONTROLS

Discontinuities are commonly influenced by the rock type and modification phases. Rocks can be classified according to their formation processes. Sedimentary rocks are produced by weathering, transportation, sediment settling, burial and lithification. Igneous rocks are solidified magma that has been intruded into a pre-existing rock, or flowed out onto the Earth's surface and solidified. Metamorphic rocks have been modified due to changes in temperature and/or pressure. For the each rock group, discontinuities are either primary, forming at the time the rock was solidified or lithified; or secondary, forming at a later stage. In sedimentary rocks discontinuities include bedding surfaces, which may be planar, continuous or at variations to nonplanar, noncontinuous. They reflect the mineralogical alteration of the sediment during deposition. Bedding spacing depends on composition, grain size, homogeneity and stress conditions. For igneous rocks, primary flow or cooling surfaces can be present, related to the flow direction, or parallel to the magma margins. Cooling surfaces have a spacing often dependent on cooling rate and composition. In metamorphic rocks discontinuities are usually, controlled by the macrostructure, with spacing dependent on local and/or regional controls.

In geology the term rock fabric describes discontinuities that are repeated at the observation scale; they may be penetrative e.g. bedding or nonpenetrative e.g. joints. Although both types can be present, it is often the penetrative types that influences rock stability (Hobbs 1993).

3. FOLDED-DEFORMED TERRAINS

Any rock mass can be affected by Earth forces, which may be due to contractile strains where the rock mass is shortened, resulting in folds, thrusts, cleavages and fractures, or may be extensile, producing normal faults, veins and fractures. Knowledge of the structural history, orientation of regional forces, together with local geological formation can enable discontinuity geometry determination. Across a simply folded sequence, where folds are upright and gently to moderately plunging, ideal discontinuities can be predicted. Figure 3 shows the joints that could develop across a gently N plunging anticline. The potential of using regional data to determine fractures has been successfully applied by Winsor (1985). For multiple (poly) deformed areas, discontinuity characteristic prediction can be more problematic.

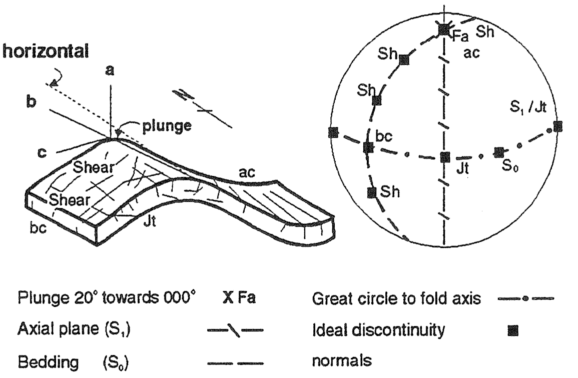

Figure 3. Ideal discontinuities across a plunging fold.

4. EXAMPLES: ADELAIDE REGION

To investigate discontinuities at structural positions, analysis has been undertaken in the Delamerian Fold Belt (Preiss 1987), close to Adelaide (Fig. 4). Sites A - I are in *deformed* rocks, J is in *undeformed*, recent sediments.

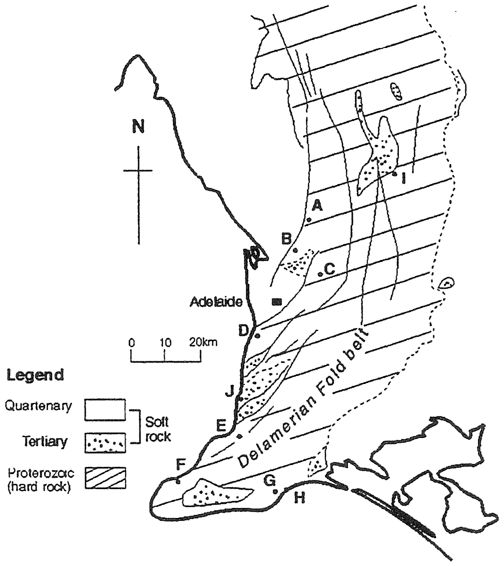

Figure 4. Scanline survey sites A-J Adelaide region.

4.1 Geological background

The older rocks under examination have been variably affected by three folding phases (Preiss 1995), of which initial phases resulted in localised tight folds, that generally follow the arcuate fold belt (Fig. 4). A penetrative cleavage is locally related to these events. Folds trend either NS (330-30°) to the NE of Adelaide, or to the NE (30-60^0) on Fleurieu Peninsular. The third event produced minor folds and veins which trend NW-SE (300-330^0).

4.2 Sites Visited

4.2.1 Site A

Site A is a disused quarry in folded quartzite. A site plan and structural data are shown in Fig. 5. Scanline results are displayed in Table 1. *Area 1:* Three sets are assigned using SCANMASTER. The line around the mean reflects the spread of set orientations. *Area 2:* Is an area of folding divided into three zones: E,W limb and hinge, Fig. 6a, b, c.

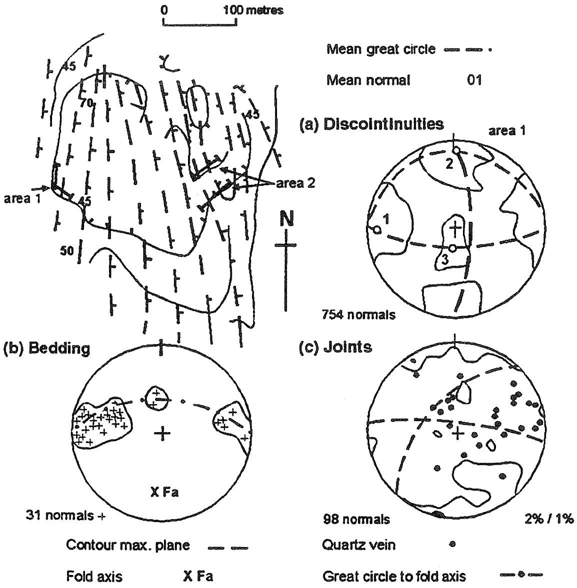

Figure 5. Geological plan of site A with data.

Regional data indicate that bedding is folded about a S plunging axis 180/32 (trend/plunge) (Fig. 5b), normal max 280/15. Two joints were identified with normals 134/10, 197/02 (Fig. 5c). Mesofolds plunge 45-48° towards 224-240. Across Area 1 bedding is subvertical to steeply E dipping (098/70). Joints dip steeply to the N and NW related to folds (278/85 & 226/61N). Comparison of Fig. 5a with Fig. 5b-c reveals that set 1 discontinuities are parallel to bedding, set 2 are joints trending E-W and set 3 are subhorizontal joints. Set 2 & 3 joints are believed to be related to the folds. The E-W trending (ac) joints and the subhorizontal joints are normal to the fold axis and bedding. Although apparently related to the fold, there is a geometrically discrepancy, believed to be due to the closeness of a fault, 300 metres W.

Discontinuity analysis was undertaken in area 2 across a syncline plunging 153/17, as displayed in Fig. 6. Although bedding (set 1) changes geometry across the fold, the main joint (set 2) maintains its orientation in the hinge and the east limb. In this area, subhorizontal joints (set 3) and a set parallel to the fold axial plane (set 4) are noted. Table 1 reveals discontinuity spacing, indicating that bedding (set 1) is more widely spaced in the hinge, ac joints (set 2) are abundant in the hinge, but exhibit greater geometrical variation. bc joints (set 4), are more prominent on the W limb. i.e. the more open limb. On the steeper (E) limb there is a of discontinuities, parallel to the axial plane (set 5). A variation in Fisher's constant across the fold is indicated, decreasing from the E to W limb.

Table 1. Discontinuity data site A, area 1.

	Set no. type	Fisher const.	No. dis.	Mean Spacing (metres)
Area 1				
Total			754	
Unass'd			118	
mean	1 bedding	21	212	0.08
normal	267/10			
" "	2 ac, D2	20	250	0.14
	267/10			
" "	3 subhor.	22	85	0.20
	179/69			
Area 2				
Total			212	
Unass'd			39	
east	1 bedding	98	39	0.25
	277/30			
	2 ac, D2-3	22	78	0.24
	337/15			
	3 subhor.	31	29	0.38
	177/87			
	5 ap,D2-3		37	0.61
	080/04	33		
Total			402	
Unass'd.			81	
hinge	1 bedding	49	33	0.33
	308/63			
	1 bedding	54	139	0.01
	037/63			
	2 ac	4	234	0.15
	315/05			
Total			441	
Unass'd			102	
west	1 bedding	14	116	0.15
	2 ac	-	-	-
	3 subhor.	-	-	-
	4 bc, D3	17	123	0.14

4.2.2 Site B (Boral Resources Para Hills)

Scanline surveys have been carried out on a W limb of a plunging assymmetrical anticline, depicted in Fig. 7. The rock type is metaphyllite- sandstone. Four sets were assigned using Scanmaster. Their characteristics are indicated in Table 2. Bedding is folded about an axis (178/12), with normal max 282/51, (Fig. 7b). Most joints trend NW transecting folds (023/85), a weaker developed set is orthogonal (Fig. 7c). A penetrative cleavage related to the folds is present with a trend parallel to fold axial planes 281/26 (Fig. 7b). Most folds have steep axial planes (normal 288/20) and variable S plunging axes 194/15-85 (Fig. 7c). Veins are parallel to cleavage or subhorizontal.

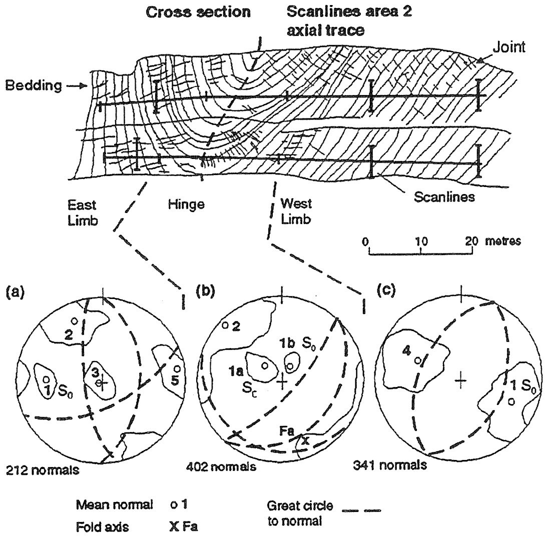

Figure 6. Section of syncline Site A, area 2 with structural data and scanline positions.

Table 2. Discontinuity data Site B.

	Set no. type	Fisher. const.	No. dis.	Mean Spacing metres
Total			703	
Unass'd.			106	
mean	1 bedding	20	57	1.41
normal	300/51			
	2 ac, D2	3	428	0.22
" "	013/06			
	3 bc, D2-3	40	46	1.64
" "	116/28			
	4 D2 ap	64	64	1.20
" "	274/35			

Although variable discontinuity orientations are indicated, four main sets (Fig. 7a) correspond to the fabric elements, i.e. set 1: bedding E dipping, but folded about a S plunging axis (Fig. 7b); set 2 and 3: WNW and NNE trending subvertical joints, normal and parallel to the fold axis (Fig. 7b), set 4: NS trending subvertical cleavage surfaces. Set 2, exhibits considerable orientation variation, other sets are well defined.

4.2.3 Site C

Surveys were carried out in two areas of this quarry. Results are depicted in Fig. 8 and Table 3. The rock type includes dolomitic siltstone and schist. In area 1, four sets were identified related to the early ductile deformations.

Bedding has a contour max. normal 080/53 being folded about a N plunging axis (349/05) in Fig. 8c. The orientation of the fold axis is indicated in Fig. 8c by the intersection of the maximum bedding (080/37) and cleavage (174/35). The main regional joint normals are perpendicular to the second deformation fold axis. Most mesofolds are consistent with the large scale.

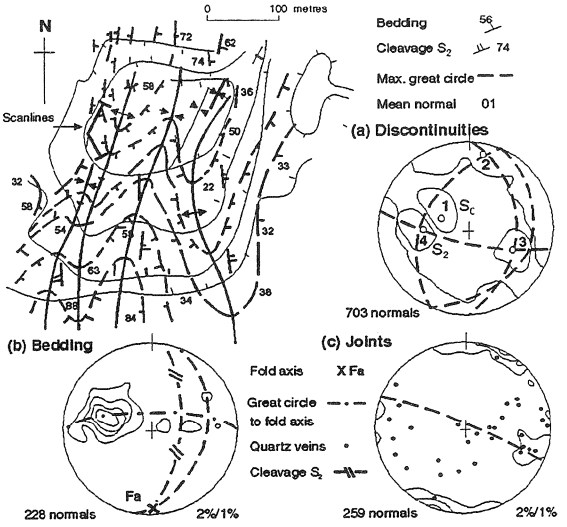

Figure 7. Site B, showing positions of scanlines and structural data.

Table 3. Discontinuity data Site C.

	Set no. type	Fisher const.	No. dis.	Mean Spacing metres
Area 1				
Total			401	
Unass'd.			72	
mean	1 bedding	16	24	0.23
normal	270/05		116	
" "	2 ac, D2	27	84	0.27
	347/04			
" "	3 subhor.	15 1	117	0.22
	177/87			
" "	4 sh, D2		12	1.93
	079/28	50	85	
		22		
Area 2				
Total			1715	
Unass'd.			313	
mean	1 bedding	358	292	0.04
normal	087/19			
" "	2 subhor.	123	1739	0.02
	257/19			
" "	3 S1-2 or	31	29	0.38
	shear.			
" "	055/64	14	37	0.01

The strongly deformed rock mass with three pervasive discontinuities presents problems in applying large scale knowledge to determine characteristics. Comparison of Fig. 8a with Fig. 8c & d reveals that most discontinuities are controlled by these fabrics. Set 1 in area 1 corresponds to either bedding moderately W dipping, but folded about a N plunging axis or S2 cleavage, Fig. 8c. Set 2 are joints normal to the regional fold axis and set 3 are subhorizontal about normal to the fold axis, compare Fig. 8a & d. Set 4 are shear fractures. Table 3 indicates the sets identified, discontinuity nos. and their respective mean spacings. In area 2 three sets are present corresponding to the penetrative fabrics, (compare Fig 8b with 8c-f). Set 1 represents bedding, set 2 joints and set 3 corresponds to cleavages or shear. In area 2 all discontinuities are closely spaced, reflecting rock type control and deformation intensity.

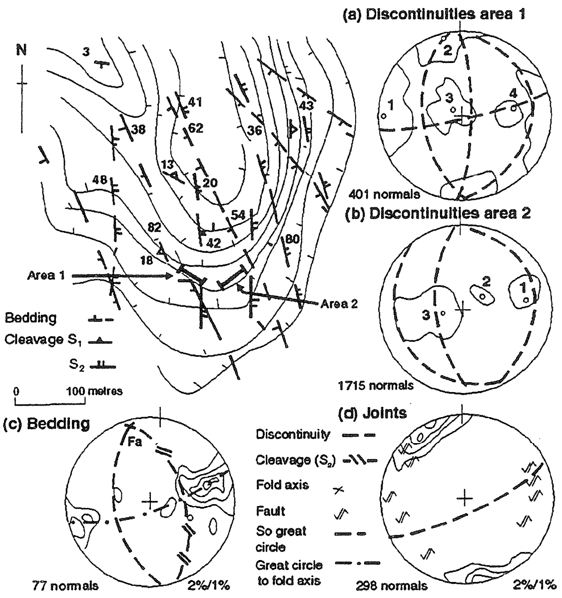

Figure 8. Location C, showing positions of scanlines and structural data.

4.2.4 Location D (Boral Resources Linwood quarry)

Location D is in metalimestone on an anticline (Fig. 9). Scanline results are shown in Fig. 9a and Table 4. Four discontinuity sets were assigned. Bedding maintains an orientation, normal 109/21 (set 1, Fig. 9b). Regionally three joint sets are present with normals 206/14 (set 2), & 214/84 (set 3), 309/24 (set 4). A penetrative cleavage has a normal 289/12 (Fig. 9). Joints and veins are related to this orientation (compare fig. 9b with c). Set 1 is parallel to bedding (see Fig. 9b), set 2 corresponds to ac joints, set 3 is subhorizontal and corresponds to joints normal to the cleavage and the tensile direction. Set 4 is parallel to the cleavage (see Fig. 9).

4.2.5 Location E, F, G, H, I & J

Scanline surveys results are shown in table 5 and Fig. 10.

Loc. E: metadolostone, 396 discontinuities, 2 sets, bedding (set 1), and joints normal to bedding and the regional fold axis (set 2 ac).

Loc. F: dolomitic metasiltstone 278 discon., 3 sets, bedding (1), joints normal to bedding, fold axis (2 ac) parallel to fold axis (3 bc).

Loc. G: greywacke, 310 discon., 2 sets, i.e. bedding (1) and joints (2 ac).

Loc. H: granite, 336 discon., 2 sets parallel and normal to folds in adjacent sediments

Loc. I: marble, 301 discon., 4 sets identified, i.e. bedding (1), ac, bc and subhoriz. joints.

Loc. J: limestone, 400 discon., 3 sets, bedding (1), ac & bc D2/3 joints.

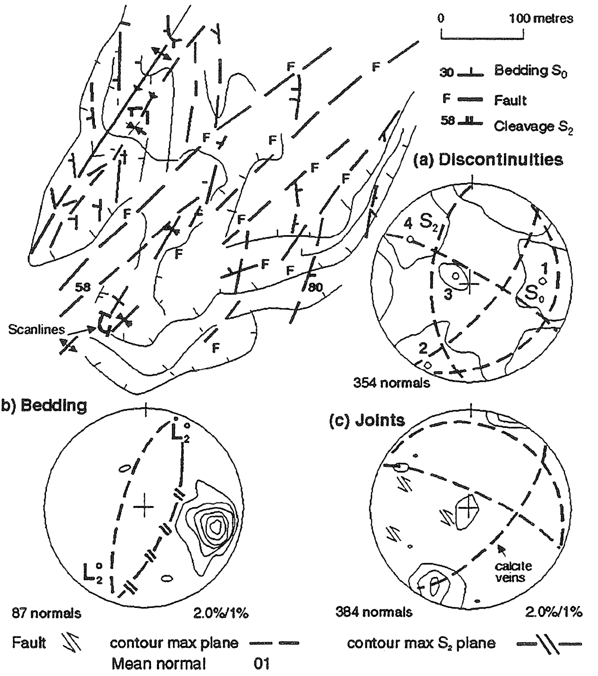

Figure 9. Location D, showing positions of scanlines.

Table 4.Discontinuity data location D.

	Set no. type	Fisher const.	No. dis.	Mean Spacing (metres)
Total			354	
Unass'd..			44	
mean normal	1 bedding 092/18	16	61	0.53
" "	2 ac, D2 207/05	19	115	0.18
" "	3 subhor. 207/05	55	23	0.21
" "	4 S2 D2 307/75	23	115	0.19

Discontinuities at sites E-I are related to the last folding phase resulting in NW trending folds. From Fig. 10 it is apparent that a NNW-NW trending joint set is present at all locations, parallel to the axial plane of the last deformation (bc), an additional set is normal to the fold axis, a horizontal set may also be present. Bedding spacing depends on rock type.

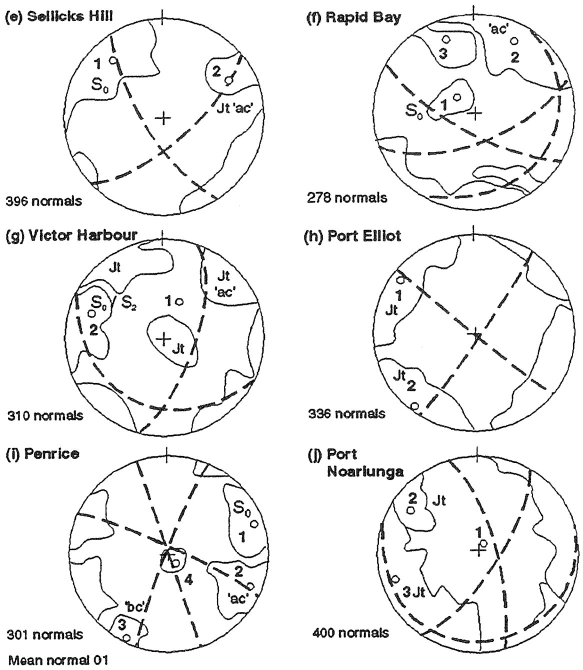

Figure 10. Results of scanline surveys, locations E-J.

Table 5. Discontinuity data locations E-J.

	Set no. type	Fisher const.	No. dis.	Mean Spacing (metres)
E	1 bedding	15	211	0.07
dolostone.	2 ac D3	211	24	0.34
F	1 bedding	38	19	0.91
dolostone	2 ac D3	8	119	0.36
	3 bc D3	13	46	0.68
G	1 bedding	2	112	0.17
greywacke	2 ac D3	23	152	0.14
H	1 ac D3	3	23	0.74
granite	2 bc D3	14	7	2.34
I	4 S2 D2	23	115	0.19
marble	307/75			
J	1 bedding	147	52	0.01
limestone	2 ac D3	40	27	0.08
	3 bc D2/D3	7	246	0.14

5. PREDICTION POTENTIAL

Regional geology can assist in discontinuity prediction, particularly for simple deformed areas. Where there has been multiple deformations and variable lithologies, discontinuity characteristics are influenced by a range of factors. Generally for incompetent rock types discontinuities are dependent on the geometry of early folding events, in competent lithologies they are controlled by the later brittle phases. A fold belt, represents just one type of geological terrain that exists, others are under investigation as part of on-going research.

6. CONCLUSIONS

Structural geology can be an aid to rock mechanics investigations, as discontinuity properties often reflects large deformation. Characteristics such as spacing and continuity are dependent on the degree of stress and rock type. Spacing is often greater in competent rocks exposed to tension. In polydeformed areas discontinuity patterns are commonly complex, reflecting the overprint history. In such areas an appreciation of the regional structure, is useful at an initial stage. Discontinuities in the ancient incompetent sediments near Adelaide are controlled by the penetrative fabrics and macrofolding. For competent rocks, discontinuities appear to be influenced by the orientation of the penetrative fabric and the last folding event. Recent sediments have similar discontinuity orientations.

7. ACKNOWLEDGMENTS

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