SYSTEMATIC JOINTING IN SOUTH DERBYSHIRE

by

John David Weaver

Summary

A study has been made of the systematic jointing of south Derbyshire, parts of eastern Staffordshire and western Nottinghamshire. A picture of the major structural features of the area has been obtained from a compilation of previous research. Four main joint sets have been established by the author's research within the area: N-S, E-W, NE-SW and NW-SE. It was noted that the NE-SW and NW-SE joint sets are the most strongly developed except in the Manifold Valley and Dovedale area where the dominant sets trend N-S and E-W.
A comparison of mineral veining and jointing in the Ashover, Crich and Matlock-Wirksworth areas suggests that mineralisation has mainly exploited the NE-SW and NW-SE joint sets.

From the results of the regional joint analysis it is suggested that south Derbyshire was subjected to an E-W maximum principal compressive stress during both the Variscan orogeny (post-Westphalian and pre-Permian) and in post-Triassic, probably Tertiary times. It is further suggested that the N-S and NNW-SSE trending structures together with the N-S and E-W joints of the Manifold-Dovedale area were produced, during Variscan times, by the influence of a Charnoid trending basement structure, possibly an extension of the Pre-Cambrian of Charnwood Forest.

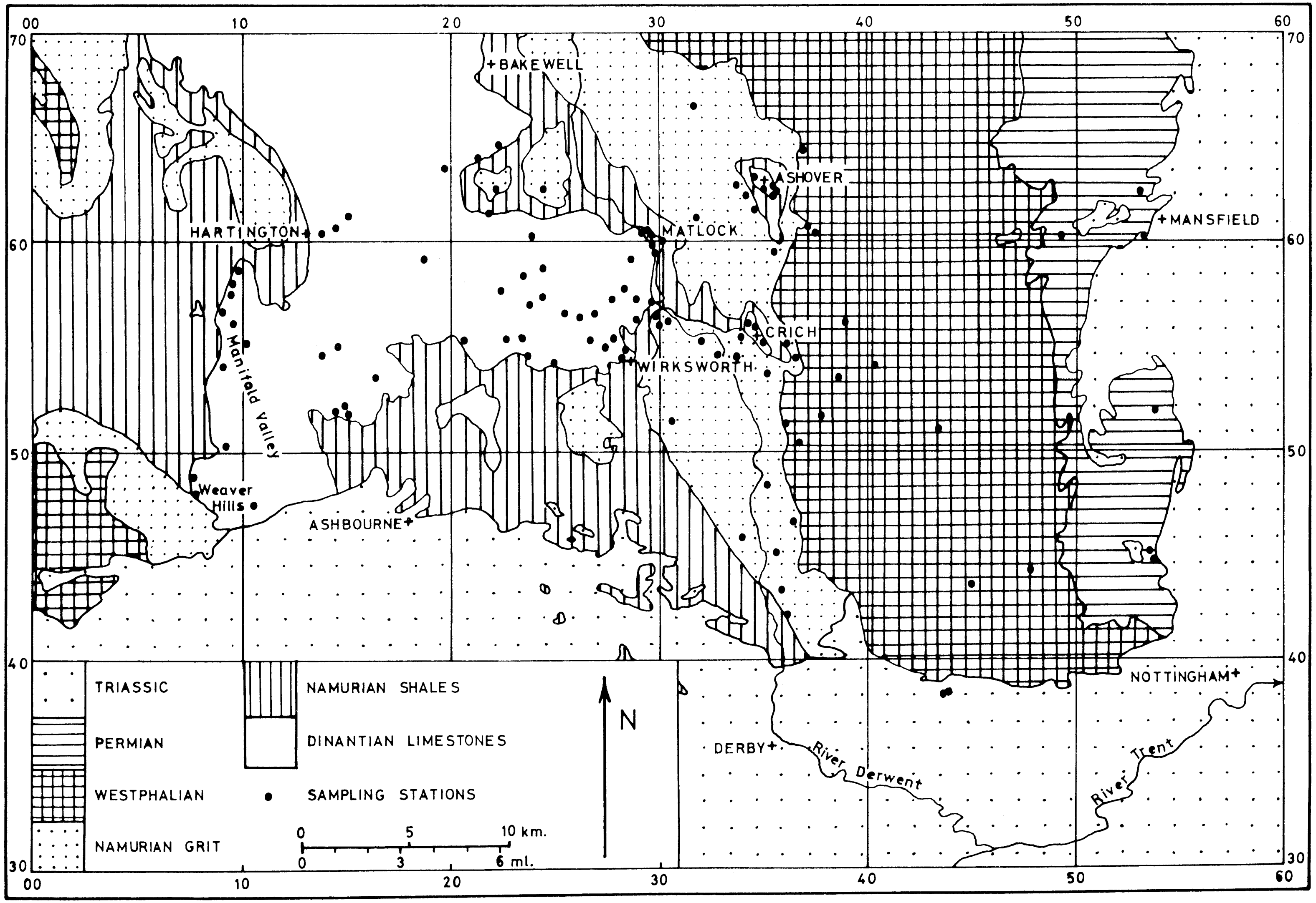
Introduction

The area of study lies between Rowsley in the north, Derby in the south, Nottingham and Mansfield in the east and the Weaver Hills and Hartington in the west. Most of the area is composed of the southern part of the Derbyshire Dome with extensions into eastern Staffordshire and western Nottinghamshire.

The whole area was covered by the Geological Survey Old Series sheets 1 inch to 1 mile 71 NE, 71 NW, 72 NE, 81 SE, 82 SW, and 82 SE between 1852 and 1858 with revisions between 1866 and 1879. At the present time there are detailed geological maps of parts of the area, such as the Geological Survey New Series 1 inch to 1 mile sheets 112 Chesterfield, 125 Derby, and new surveys of the Ashbourne (124) and Buxton (111) sheets which are at present being carried out. Various authors including, Parkinson and Ludford (1964) and Shirley (1958) have mapped parts of the area and a general picture of the structure and stratigraphy has been produced by Ford and Ineson (1971).

This paper is a study of the systematic jointing of the area based on a field survey. It is hoped to demonstrate the relationship between jointing, faulting and folding and from their orientations to gain some knowledge of the forces that produced the structures. A study of the coincidence of jointing and mineral veins in the Ashover, Crich and Matlock-Worksworth areas completes the paper.

Mercian Geol. Vol. 5, No. 2, 1974. pp.115-132, 6 text-figs.



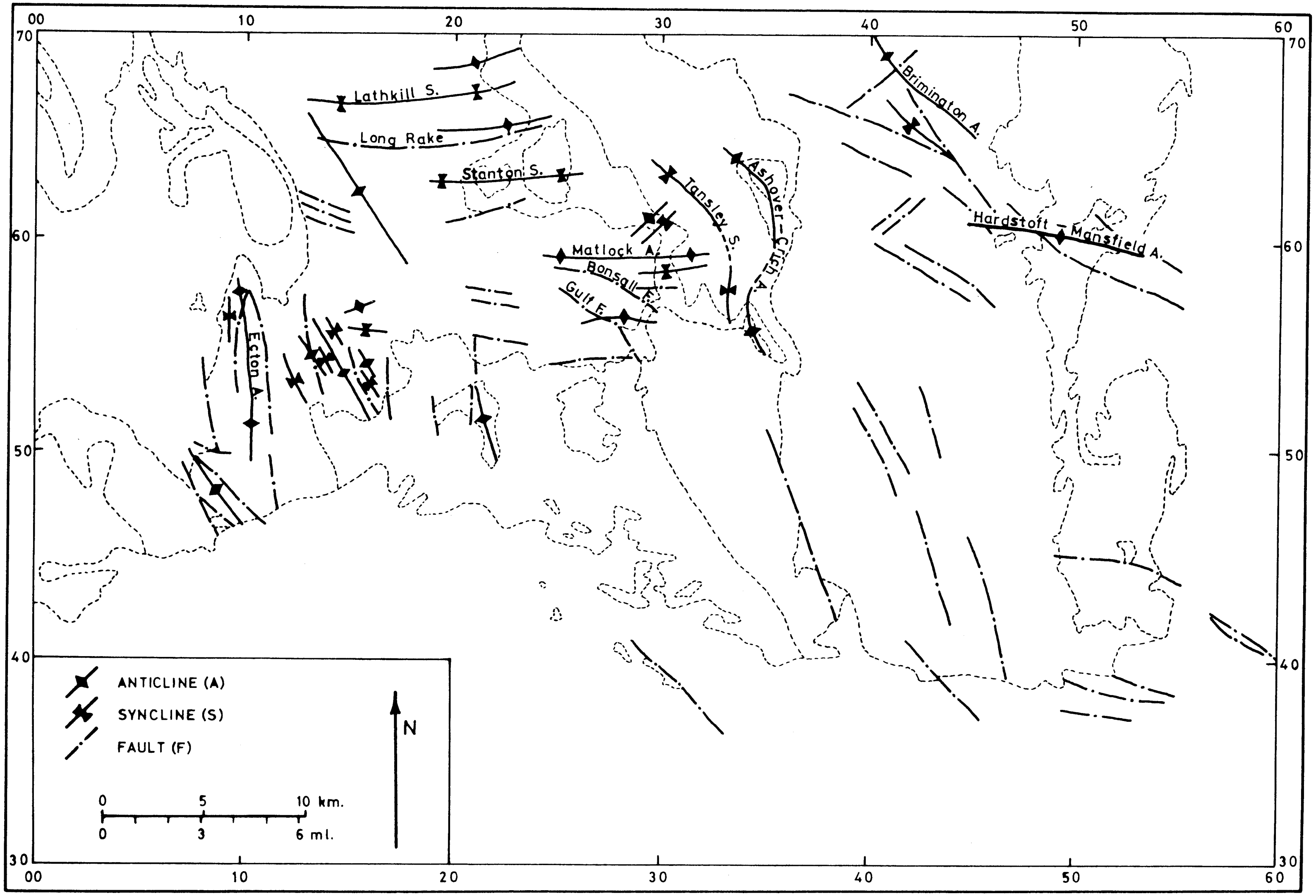
Text-fig. 1. General geology of South Derbyshire and adjacent regions.

The general succession of the rocks of the area is shown in table 1 and their distribution in text-fig. 1.

TABLE 1

		m.
PERMO-TRIASSIC	Keuper Marl	180
	Waterstones	15-30
	Keuper Basement Beds	0-7
	- - - - - non-sequence - - - - -	
	Pebble Beds	30-60
	Mottled Sandstone	0-30
	Red Marls	0-35
	Magnesian Limestone	5-45
	Dolomitic Siltstones	0-25
	Basal Breccia	0-6
————	- - - - - unconformity - - - - -	
WESTPHALIAN	Upper Coal Measures	up to 215
	- - - - - - - Top Marine Band - - - - - - -	
	Middle Coal Measures	533
	- - - - - Clay Cross Marine Band - - - - -	
	Lower Coal Measures	548
————	- - - - - Pot Clay Marine Band - - - - - -	
	Rough Rock Group	30-36
NAMURIAN	Middle Grit Group - Chatsworth and Ashover Grits	290
	Kinderscout Grit Group shales	40
	Edale Shales	up to 210
————	- - - - - - - unconformity - - - - - - -	

	Zone	Manifold - Dovedale	Wirksworth	Matlock	
DINANTIAN	P2	Hollington End Beds	Cawdor Lst.	Cawdor Lst.	
	D2/P1	Bull Gap Shales	Lathkill Lst.	Matlock Lst.	
	D1/B2	Apestor, Alsop Moor, Narrow-dale Lsts.	Via Gellia Lst.	Hoptonwood Lst.	450 - 800 +
	S2/B1	Manifold, Milldale, Alstonfield Lsts.		Griffe-Grange Lst.	
	C2 & ? C1	Manifold, Milldale, Dovedale, Cauldon Low Lsts.			



Text-fig. 2. Major structural features of South Derbyshire.

The succession is based on the work of Black (1948), Edwards (1948), Shirley (1948, 1958), Parkinson and Ludford (1964), Taylor (1965, 1966), Smith *et al* (1967), Sylvester-Bradley and Ford (1968) and Ford and Ineson (1971). The rocks range in age from Lower Carboniferous, C zone Dinantian Limestones to Triassic, Keuper Marl. Joint measurements were only taken in the more competent horizons: the Dinantian limestones, the various sandstone horizons in the Namurian and Westphalian, the Magnesian Limestone and the Mottled Sandstone.

Major Structures

Over much of the limestone massif the dip of the rocks seldom exceeds 10°, along the eastern flank the Namurian and Westphalian sequences dip generally eastwards at about 10° to 15° and the Permo-Triassic sequences eastwards at 2° to 4°. This relatively simple structure is disrupted in the eastern part of the area by a series of N-S and NW-SE trending folds and along the western margin of the limestone massif by N-S and NNW-SSE faulting and folding, where steeper dips are found. The major structural features of the area are shown in text-fig. 2, which represents a compilation of the work of Fearnsides (1933), Parkinson and Ludford (1964), Smith *et al* (1967), Edmunds (1971) and Ford and Ineson (1971) together with information from sheets 72 NE and 81 SE Old Series Geological Survey.

Folding The limestone massif has often been referred to as a "dome" but this is a misnomer. It is a complex of fairly gentle folds with a general E-W trend rising to a N-S line culmination (Ford and Ineson 1971 p. 186). The major folds of the area trend N-S, NW-SE and E-W. As shown in text-fig. 2, the N-S and NW-SE folds are found mainly along the western margin of the massif and in the Namurian and Westphalian sequences of the eastern flank, whereas the E-W folds are confined mainly to the central and eastern parts of the limestone massif.

The main folds of the western margin of the limestone massif are the Ecton and Dovedale anticlines, which trend approximately N-S and the Weaver Anticline, which trends NNW-SSE. In the Manifold Valley (SK 090575) the structure is complicated by a series of NNW-SSE and N-S folds characterised by dips between 50° and 80° in a belt about 500 to 1000 m wide. These folds are best exposed at Apes Tor (SK 100587) where the fold axial traces trend 340° - 160°* and the axes plunge 15°/340°. At Kirksteads (SK 090568), a similar series of folds are seen, with axial traces trending 358°-178° and plunging 5°/358°. All the folds in this area appear to plunge northwards.

The main E-W folds of the central and eastern parts of the limestone massif are the Matlock and Middleton anticlines and the Stanton Syncline. These folds tend to plunge eastwards.

To the east of the limestone massif the E-W folds of the limestone massif swing into a more NNW-SSE or N-S trend and extend into the Westphalian rocks, where the sinuous axial traces show crestal culminations and depressions (Sylvester-Bradley and Ford 1968 p. 93). The main folds of this area are the Ashover-Crich and Hardstoft-Mansfield anticlines and the Tansley Syncline. The Ashover-Crich Anticline is postulated (Edmunds 1971 Fig. 1) as a fairly tight fold which brings up inliers of limestone at Ashover and Crich, at the crestal culminations.

Faulting Along the western margin of the limestone massif there are a series of strongly developed N-S and NNW-SSE trending faults. These are mainly normal faults, those to the west of the Ecton Anticline having westerly downthrows and those to the east having mainly easterly throws. Along some of these faults the throws may be very large; for example, the Manifold Valley Fault on the southeast side of Ecton Hill (SK 097580) has an easterly throw approaching 610 m (Parkinson and Ludford 1964 p. 174.). The fault on the western side of the Manifold Valley must have a similar throw to the west.

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* All trend directions and orientations in the text and in Tables 1-6 are measured easterly from O.S. Grid North. e.g. Ng 340°E-Ng 160°E.

In the central and eastern parts of the limestone massif the main faults trend E-W, NW-SE, ENE-WSW and ESE-WNW. The major faults in this area are the Bonsall and Gulf Faults, which are NW-SE trending normal faults, the Bonsall Fault downthrowing southwards and the Gulf Fault northwards to produce a graben structure. There are also in this area a number of E-W mineral veins (rakes) which for the most part occur along faults. Ford and Ineson (1971 pp. 188, 189) have suggested that some of these faults may have wrench movements along them.

The E-W fault trends continue into the Namurian and Westphalian rocks of the Mansfield area, but south-east of the Matlock area the dominant fault trend is N-S or NNW-SSE. Most of these faults are normal faults with mainly easterly throws.

Earth Movements The south Derbyshire area appears to have been one of crustal instability from pre-S2 times to the end of the Carboniferous Period. This instability was most pronounced along the western margin of the limestone massif during Dinantian times. Parkinson and Ludford (1964 pp. 174, 175) demonstrated unconformities in the Manifold Valley prior to the S2 zone in the middle D1 and at the base of the Namurian rocks. In the eastern part of the limestone massif, unconformities of pre-D2 and sub-Namurian ages are found (Shirley 1948). Sylvester-Bradley and Ford (1968 p. 79) state that, from an analysis of published maps it appears that there were numerous minor folding movements within the Dinantian, though not necessarily affecting the whole area and not always synchronous in the different fold areas. The same authors (p. 79) suggest that unconformities in the area are of post-C2, post-S2, late D1 and D2 and P zone ages. In the Westphalian rocks of the eastern part of the area, Edwards (1948 p. 49) said that gentle movements took place at various times. It is stated by most authors (Shirley 1948, Smith *et al* 1967, Sylvester-Bradley and Ford 1968 and Anderson 1951 pp.80, 81) that the main movements were of late Variscan age in post-Westphalian, pre-Permian times.

Post-Triassic movements have given the Permo-Triassic rocks an easterly tilt and caused posthumous movements along pre-existing faults (Shirley 1948, Smith *et al* 1967 p. 221). Some movements along the Bonsall and Gulf Faults, for example, post-date the mineralisation, which has a Permian radiometric age (Ineson *et al* 1972 p. 145). The dome structure of Derbyshire, produced by the N-S culmination of the E-W fold axes, is thought to be a late formed structure, probably of Tertiary age (Sylvester-Bradley and Ford 1968 p. 78, Edmunds 1971 p. 2).

One problem that arises from the trends of the major structural features of south Derbyshire is the orientation of the stress system that produced them. The N-S trending folds would indicate that the maximum principal compressive stress (σ_1) was orientated in an E-W direction, while the E-W trending folds would indicate that σ_1 was aligned N-S. If, as is suggested, all these structures are basically Variscan in age, there must have been a number of local influences to modify the predominant maximum principal compressive stress. Many authors, including Fearnsides (1933 p. 68), Anderson (1951 p. 80) and Smith *et al* (1967 p. 215), thought that the Charnoid NNW-SSE trend of the structures in the Westphalian rocks to the east and south-east of the limestone massif and in the western margin limestones are basement controlled. Fearnsides (1933 p. 69) further suggested that the divergent fold structures were controlled by basement movements.

Anderson (1951 pp.108, 109) considered that the trend of σ_1 in the Derbyshire area in Variscan times was N-S. However, Moseley and Ahmed (1967 p. 78) argued that the structures in the Pennines north of Derbyshire were produced by an E-W maximum stress. In post-Triassic, possibly Tertiary times, it has been suggested that the N-S doming of the Pennines was produced in response to σ_1, directed E-W (Moseley and Ahmed 1967 p. 80, Sylvester-Bradley and Ford 1968 p. 78).

Jointing

"Joints are cracks and fractures in rock along which there has been extremely little or no movement" (Price 1966 p. 110). Parallel or sub-parallel groups of joints are termed joint sets and joints that form sets are said to be systematic (*ibid* p.111).

Sampling Method As joints are generally the most common structures developed at any locality, it is apparent that a rigid sampling method must be used throughout the area under study. Any sample taken will represent only a very small proportion of the total population of joints and therefore in any analysis care must be taken to ensure as far as possible that the selected measurements are representative of the total population.

At any exposure of competent rocks it can be seen that some joints are far more strongly developed than others. These joints will tend to be the easiest to measure, but one has first to find out if they are representative of the joints developed. For this reason four test localities were visited, one in each of the main lithologies studied within the area: Shaws Quarry, Wirksworth (SK 288552) in the Dinantian limestone; Milford Quarry (SK 352452) in one of the Namurian sandstones; Ridgeway Quarry, Ambergate (SK 358515) in one of the Westphalian sandstones; and Stanton Hill Quarry (SK 490603) in the Magnesian Limestone. At each of these localities all the joint orientations (dip and strike) along about 150 m of exposure were measured and plotted as rose diagrams. They were compared with diagrams illustrating the most dominant joints, which had been taken randomly, in the respective quarries. The dominant joint directions were calculated graphically from each of the eight rose diagrams produced. The results (table 2) show a high degree of correlation and suggest that it is valid to use measurements of the dominant joints in an analysis.

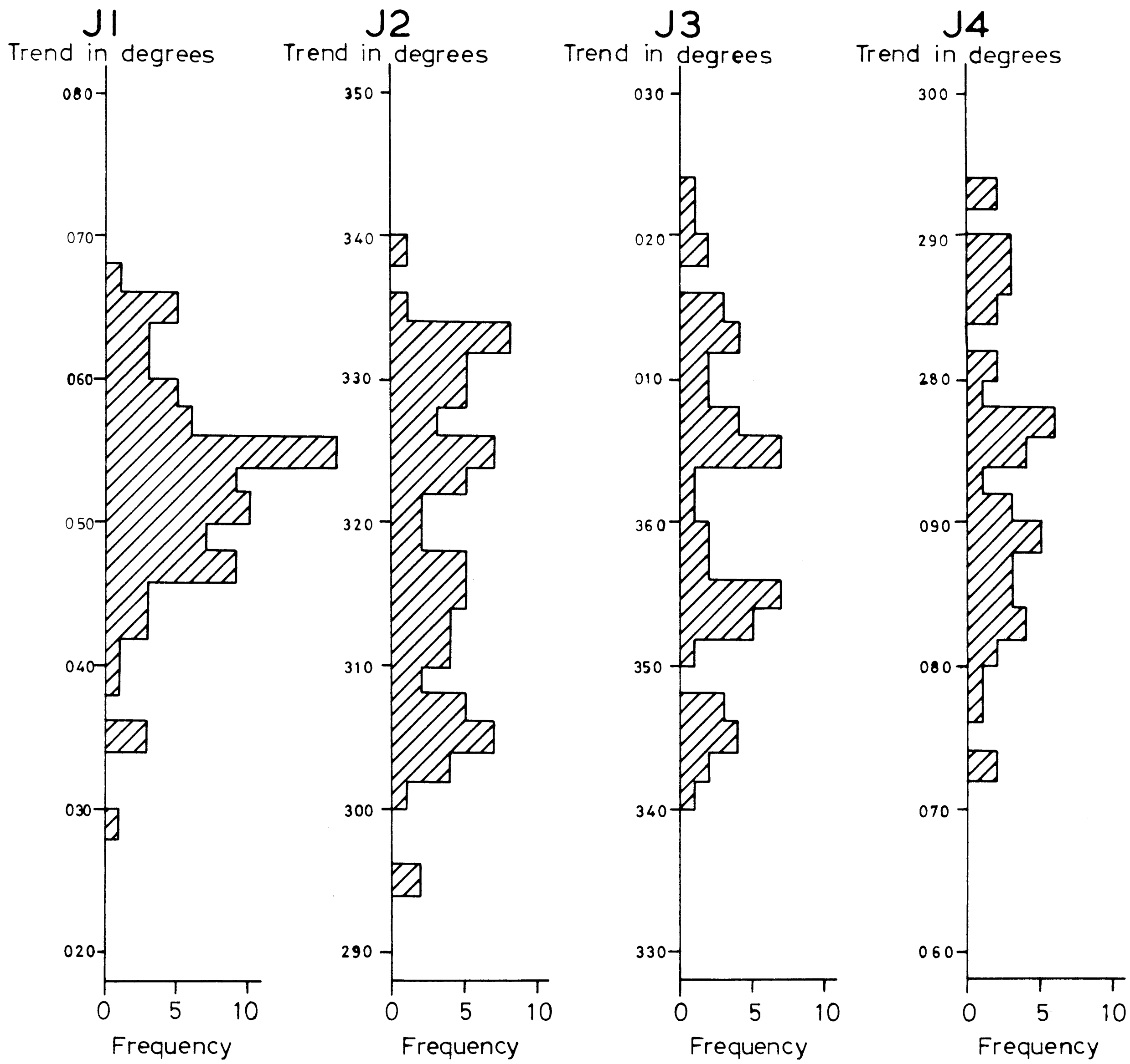
TABLE 2

Locality	Orientation of all joints	Orientation of main faces
Shaw's Quarry	072° . 342°	074° . 345°
Milford Quarry	062° . 332°	063° . 335°
Ridgeway Quarry	272° . 005°	088° . 011°
Stanton Hill Quarry	058° . 324°	060° . 322°

(All orientations are measured easterly from O.S. Grid North).

A sample of between 25 and 40 readings was taken at each of 108 localities (text-fig. 1 and appendix 1), and a total of about 3000 joint plane orientations (dip and strike) were measured. Almost all the joint planes were within 5° of vertical and could therefore be plotted as rose diagrams. The percentages of the joints for each locality were plotted as rose diagrams, from which the dominant joint sets were calculated graphically. The results from all the sampling stations showed that throughout the area four dominant joint sets were developed: NE-SW(J1), NW-SE(J2), N-S(J3) and E-W(J4). However some variation was seen within each of these sets.

Establishment of the Joint Sets To justify the designation of the four main sets, it is important to consider whether the degree of variation which occurs in each is acceptable. An idea of this variation can be obtained from a simple histogram (text-fig. 3) of the distribution of the dominant joint sets from each locality. From these graphs the mean of each set can be calculated and also the variation from the mean at different levels of significance.



Text-fig. 3. Histograms showing the variation within each of the joint sets.

From table 3, it can be seen that 90% of the readings for each set lie within approximately ± 15° variation from the mean, which other authors, for example Hancock (1969), find acceptable for defining one joint set.

TABLE 3

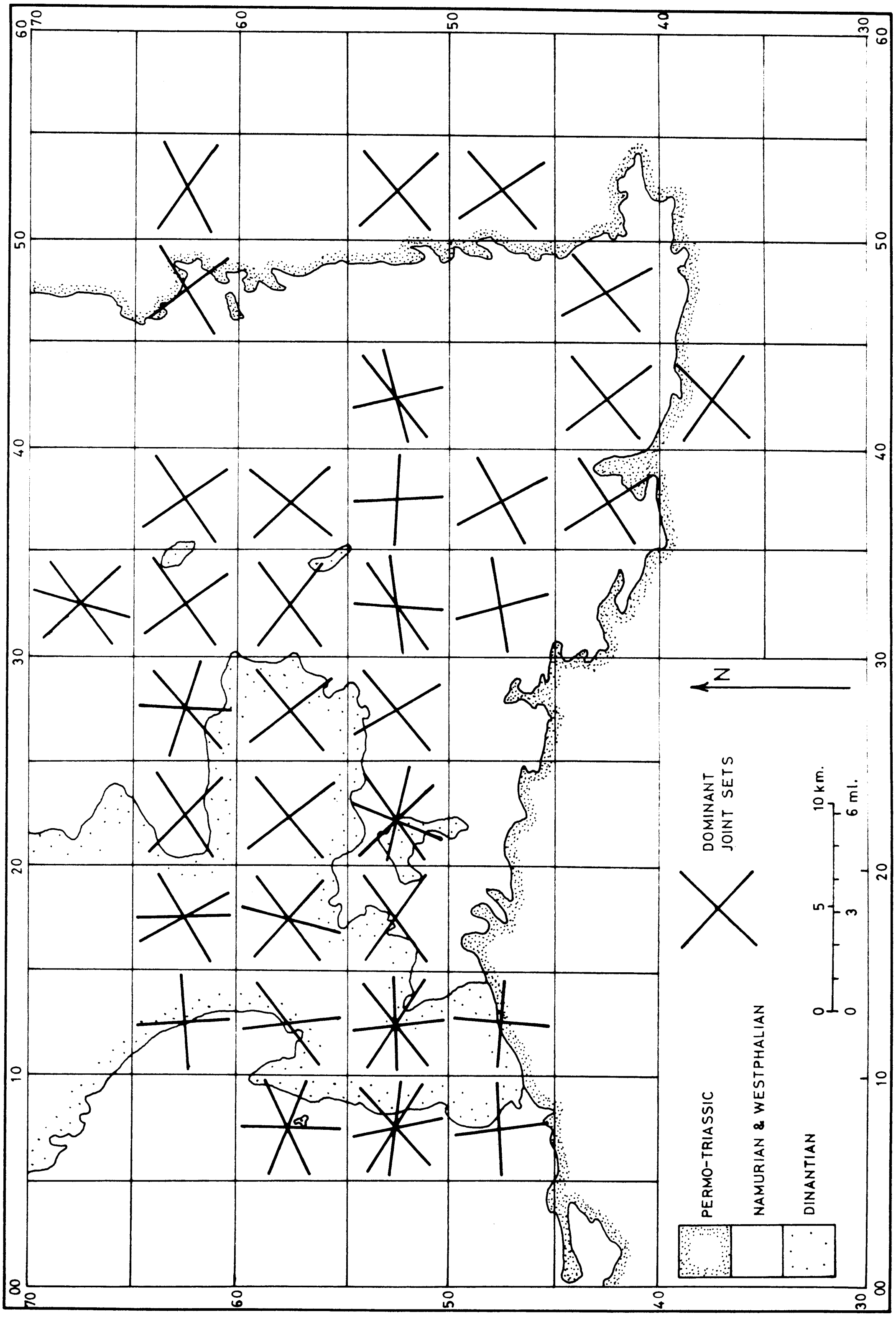
Joint Set	No. of stations at which set is developed Total 108	Modal Strike	Mean Strike	Deviation from the mean. Level of Significance (%)				
				50%	60%	80%	90%	100%
J1	86	055°	052°	047°-055° -5 +3	046°-057° -6 +5	043°-061° -9 +9	037°-064° -15 +12	029°-067° -23 +15
J2	78	333°	318°	307°-327° -11 +9	306°-329° -12 +11	303°-331° -15 +13	301°-333° -17 +15	295°-339° -23 +21
J3	55	355° 005°	359°	350°-007° -9 +8	349°-009° -10 +10	344°-012° -15 +13	343°-014° -16 +15	341°-023° -18 +24
J4	48	277°	273°	084°-279° -9 +6	083°-281° -10 +8	080°-285° -13 +12	076°-287° -17 +14	073°-293° -20 +20

(All measurements, in degrees, easterly from O.S. Grid North).

Results (i) Joint Sets Table 3 shows that four joint sets can be established, whose mean trends are 055°(J1), 318°(J2), 359°(J3) and 273°(J4). Of these the J1 set is the most strongly developed and also the most consistent in orientation. The J1 and J2 sets are the most commonly developed pair, as shown in table 4. Where only two sets are developed at a locality, it is seen that J1 with J2 are the most common. The next most commonly developed pair of joint sets is J3 with J4. One other feature of the joint sets is that at only six out of the 108 localities visited are all four joint sets developed together.

TABLE 4

Joint Sets	No. of stations at which pair is developed. Total 108.	No. of stations at which pair is exclusively developed. Total 108.	Mean dihedral angle
J1 with J2	71	42	86° ± 19°
J3 with J4	37	16	86° ± 22°
J1 with J3	33	2	
J1 with J4	26	1	
J2 with J3	27	1	
J2 with J4	20	1	



Text-fig. 4. Dominant joint sets for each 5 × 5 km grid square studied.

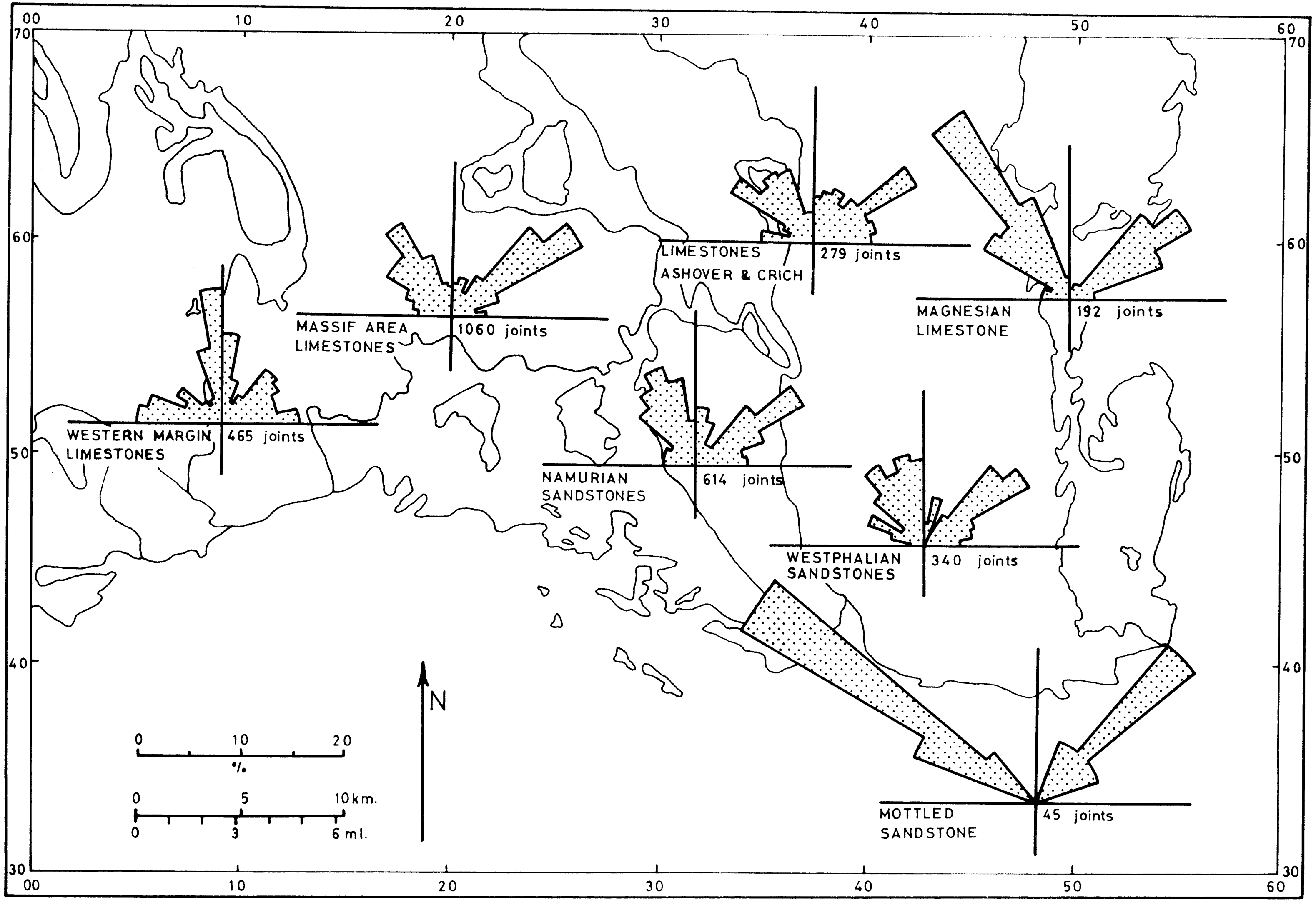
The dihedral angles (appendix 2) between the J1 and J2 sets at the various localities are very variable, all are over 60° and some are over 90°. This feature was also noted by Hancock (1969) in the Cotswold Hills. Although members of the J1 and J2 sets show horizontal striations none of the joint surfaces show any evidence to suggest the direction of shear. As a result, it is difficult to establish whether σ_1 was E-W or N-S in direction. Most of the stations at which the J1 and J2 sets are developed show an acute angle about the E-W bisectrix (Appendix 2). This is confirmed by the mean orientations of the J1 and J2 sets, 052° and 318°, giving a mean dihedral angle of 86°. This would suggest that σ_1 was orientated 095° - 275°, the minimum principal compressive stress (σ_3) 005° - 185° and the intermediate principal compressive stress (σ_2) vertical. The dihedral angles between J3 and J4 show similar variations and again are all over 60° and some over 90°. The mean dihedral angle is 86° and the acute bisectrix is 136° - 316°.

(ii) Joint Pattern An analysis of the systematic jointing was made for each 5×5 km grid square covered in the study and the dominant joint sets for each square calculated (text-fig. 4). It is again apparent that the J1 and J2 sets are most strongly developed and that these two are more consistent in direction than J3 and J4. J3 appears to be most consistently developed along the western margin of the limestone massif, a feature which is emphasized in text-fig. 5, which illustrates rose diagrams of the jointing for each of the main lithologies of the area. The dominant joint directions calculated from these rose diagrams are shown in table 5.

TABLE 5

Rock type and area	Orientation of joint sets
Mottled Sandstone	045° . 304°
Magnesian Limestone	054° . 323°
Westphalian sandstones	052° . 336°
Namurian sandstones	058° . 332°
Limestones - Ashover and Crich	055° . 318°
Massif area limestones	052° . 320°
Western margin limestones	274° . 356°

It appears that over almost the whole area the pattern remains constant, with the main joint sets being NE-SW(J1) and NW-SE(J2) in trend. The one exception to this pattern is the strong development of N-S(J3) and E-W(J4) sets along the western margin of the massif. There is little deviation in trend of the J1 and J2 sets with lithology or age of the beds and, regionally, it appears that these two sets indicate σ_1 orientated approximately E-W. The J3 and J4 sets of the western margin of the limestone massif, which also appear to have a shear origin, must have developed in response to a different or modified stress pattern. The development of the J3 and J4 sets of this area may have been to some extent controlled by a basement structure, which has been the suggested control of the N-S and NNW-SSE trending folds and faults.



Text-fig. 5. Rose diagrams (northern half, 10° class intervals) of the jointing for each of the main lithologies.

The Relationship between Jointing and Faulting

The relationship between joint direction and the major fault trends is close in some areas but appears to be unrelated in others, as is shown by a comparison of text-figs. 2 and 4. Along the western margin of the limestone massif the N-S faulting is paralleled by the strong development of the J3 joint set, which may suggest that their origins are similar. On the eastern side of the area, the NW-SE Bonsall and Gulf Faults run parallel with the J2 set and the NW-SE and NE-SW faults in the Matlock to Mansfield area have trends which approximate to those of the J1 and J2 sets. The vertical displacements shown by many of these faults would have been produced during a period of tension, whereas it has been suggested that the J1 and J2 joint sets have a shear origin. However, it should be noticed that parallelism of strike does not mean parallel surfaces, as most of the faults are inclined and nearly all the joints are vertical.

Over the rest of the area this strong correlation between joint and fault trends does not appear to exist. For although the dominant E-W faulting of the limestone massif and the N-S and NNW-SSE faults of the Westphalian rocks south-east of Matlock are paralleled by the J3 and J4 joint sets, these sets are not the most strongly developed in these areas.

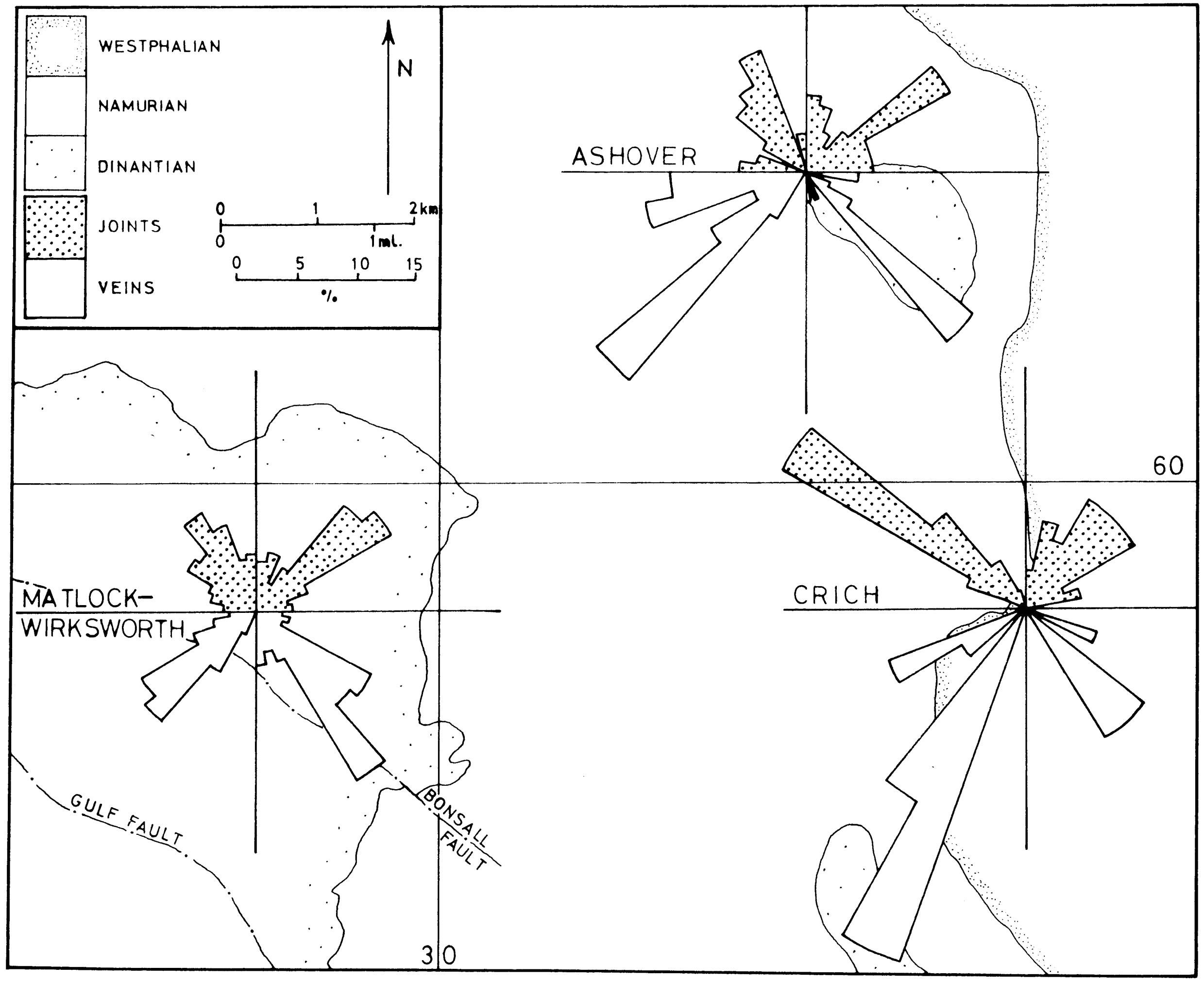
The Relationship between Jointing and Mineralisation

The relationship between jointing, mineralised joint planes and mineral veins was studied in the Ashover, Crich and the Matlock-Wirksworth areas. In each area a fair degree of correlation is seen, as listed in table 6 and shown in text-fig.6. The generalised trends of the mineral veins were taken from the Geological Survey 1:25000 Matlock Sheet (parts of SK25, 26, 35 and 36).

TABLE 6

Area	Orientation of:		
	Joints	Mineralised Joints	Veins
Ashover	056° 327° 009°	066° 323°	046° 314°
Crich	044° 307°	042° 307°	028° 320° 063°
Matlock-Wirksworth	051° 323°	050° 331° 305°	049° 321°
Matlock-Wirksworth north of Bonsall Fault	051° 294° 002°	045° 305° 001°	043° 306° 352°
Matlock-Wirksworth, between Bonsall and Gulf Faults	053° 326°	060° 326°	053° 323°
Matlock-Wirksworth, south of Gulf Fault	051° 327° 308°	046° 334° 306°	046° 322° 074°

(All orientations measured easterly from O.S. Grid North)



Text-fig. 6. Rose diagrams comparing the jointing and mineral veining of the Ashover, Crich and Matlock-Wirksworth areas.

The Matlock-Wirksworth area is divided into three blocks by the Bonsall and Gulf Faults and in each block there is a strong relationship between joint sets, mineralised joint planes and mineral veins. This relationship is also seen when the area is studied as a whole. In the Ashover area there is also a fairly strong correlation between joint sets, mineralised joint planes and mineral veins, but in the Crich area, although there is almost an identical relationship between joint sets and mineralised joints, the correlation is not as good for the joint sets and the veins. In all three areas, on the basis of published information, there is less evidence of mineralisation along N-S or E-W directions.

From the general correlation, it seems probable that mineralisation has mainly exploited the dominant joint directions, namely the J1 and J2 sets. As mineralisation is suggested to be Permian in age (Ineson *et al* 1972 p.145), the joints are probably pre-Permian in age. However, some veins and mineralised joint planes show renewed movements post-dating the mineralisation. In some areas, the mineralised joint planes show vertical slickensides, which suggests that movement took place during a period of tension.

Synthesis and Conclusions

The major structures of the area do not give a clear indication of the stress pattern that produced them and the divergent nature of the faulting and folding has been attributed to the influence of a basement with Charnoid-trending structures.

Almost all the joints seen in the area of study are vertical, smooth fractures, which do not change orientation with the different competent lithologies. The joints in each set appear to maintain their vertical attitude irrespective of the inclination of the beds, which indicates that they post-date the folding. In the Manifold Valley area some of the N-S joints appear to be contemporaneous with the folding. They are restricted to the outer margins of competent beds, orientated at right angles to the bedding surface, and are best developed in the axial regions of the minor folds. These joints were probably produced by tensional forces existing in these regions during folding. These joints tend to be less strongly developed than other near vertical N-S and E-W sets in Manifold Valley area. The jointing in south Derbyshire does not appear to have developed in early Variscan times, as has been suggested for the jointing in the area north of Derbyshire (Moseley and Ahmed 1967 pp.79, 80). Members of the J1 and J2 joint sets show, where suitably exposed, a horizontal extent greater than 50 m and a vertical extent in excess of 20 m, and the J3 and J4 sets a horizontal extent greater than 15 m and a vertical extent of more than 6 m.

As noted earlier in this work the J1 and J2 sets may be conjugate shear joints produced by an E-W orientated σ_1 with σ_3 N-S and σ_2 vertical. In addition the J3 and J4 sets found along the western margin of the limestone massif also show signs that they have suffered shear movement and it was argued that their trend is in some way related to the trend of the basement structures or to the trend of the Carboniferous structures produced under the influence of such basement structures. The change in the joint pattern in this area text-fig. 5 may help to delimit a possible basement fault zone in a similar way to the change in joint pattern along the Swansea Valley Disturbance in South Wales (Weaver 1973, 1974).

The J3 and J4 sets found over the rest of the area studied are more weakly developed and are probably late tensional joints formed by the release of residual strain energy in the way suggested by Price (1966 p. 130) and Hancock (1968 pp. 147, 148) and demonstrated by Hancock (1969) in the Cotswold Hills and Weaver (1974) in South Wales. This release of residual strain energy would have occurred in late or post-Variscan times. If the J3 and J4 sets have originated in this way, then their weaker development will be the result of some of this energy having been released along the pre-existing J1 and J2 sets. In the western margin area this release may have been completely taken up along pre-existing J3 and J4 sets. The J3 and J4 sets over most of the area would have formed during a period when σ_1 was vertical.

A tentative outline of the tectonic history of the area may be tabulated as follows:

(i) Early disruptions during Dinantian times, pre-S_2, various D zone movements and at the base of the Namurian probably caused by movements in Pre Cambrian and/or Lower Palaeozoic basement rocks with Charnoid trend, possibly an extension of Charnwood Forest Pre Cambrian rocks as suggested by Fearnsides (1933). The Manifold Valley area may have included early faulting along N-S lines.

(ii) Minor instability continued throughout Westphalian times.

(iii) Main Variscan movements in late-Carboniferous, pre-Permian times. The main compression was probably aligned E-W and gave rise to the development of the J1 and J2 joint sets as conjugate shears. The main folds and faults of the area were also produced at this time, their divergent trends probably resulting from basement influences. In the Manifold Valley area a basement zone, possibly of faulting, produced a complex series of N-S faults and folds and the development of J3 and J4 joint sets.

(iv) Post-Variscan tensional movements produced normal faulting and the J3 and J4 joint sets, which may have been produced by the release of residual strain energy at this time.

(v) Mineralisation along the stronger J1 and J2 sets probably took place in Permo-Triassic times during a period of tension.

(vi) Post-Triassic, probably Tertiary, period of E-W compression caused the doming of the Derbyshire area and the development of J1 and J2 joint sets in the Permo-Triassic rocks. These joints may be controlled by the trends of joints in the Carboniferous rocks below, as suggested by Moseley and Ahmed (1967 p.80) or they may be conjugate shears resulting from the E-W compression. Renewed movements along faults in the Carboniferous rocks extended these faults into the Permo-Triassic sequences.

Acknowledgements

The author wishes to thank Mr. M.F. Stanley of Derby Museum for his encouragement in the field and the provision of maps, also Dr. P.G. Baker and Dr. P.L. Hancock for their helpful criticims of the manuscript.

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John David Weaver, B.Sc., Ph.D., F.G.S.,
Dept. of Biological and Earth Sciences,
Derby College of Art and Technology,
Kedleston Road,
Derby, DE3 1GB.

APPENDIX 1

Grid References of the Sampling Stations

Each reference is prefixed by SK.

298594.	290605.	342556.	352452.	288552.	358515.	535520.
534600.	528627.	490603.	346551.	296570.	276573.	269567.
261565.	231556.	233547.	295558.	304516.	319554.	285592.
337460.	271551.	275553.	349539.	362547.	354552.	334544.
349484.	361469.	248536.	205556.	139549.	145551.	162538.
226556.	241589.	238601.	281579.	296598.	197637.	214639.
218615.	222621.	222645.	243627.	315666.	301598.	145519.
152513.	148509.	354434.	357421.	329546.	222578.	186592.
253567.	301562.	298561.	098587.	095580.	092578.	091568.
096561.	098549.	101553.	101542.	093542.	288573.	289563.
283545.	264554.	242574.	237570.	150613.	144608.	139605.
233584.	447439.	475445.	532456.	535452.	438388.	431512.
401543.	383538.	366506.	342617.	333629.	341631.	351628.
352621.	339622.	346625.	355625.	374519.	388562.	371605.
368607.	361644.	352597.	352542.	317612.	292606.	105476.
071480.	091502.	075487.				

APPENDIX 2