

PROGRESSIVE DEFORMATION OF CRAVEN FAULT BELT IN THE PENNINES, ENGLAND

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Abstract

Hercynian compression has folded and fractured the carboniferous rocks in the pennines (England). The Hercynian deformation occurred during stephanian times in two pulses. The first pulse was in an approximately E-W direction, and the second pulse was produced by the activation of the North Craven Fault, with major dextral transcurrent movements. A dextral shear zone thus developed in the Craven lowlands, resulting in the rotation of the compression direction from E-W to NNW-SSE. The second pulse gave rise to NNW and ENE joint sets, which are "AC" and "BC". The change in strike orientation of the joints near the North Craven Fault results from a change in stress orientation. A higher density of stress trajectories is observed around the North Craven Fault which suggests a higher stress magnitude in this area. A weakened thus zone developed, which eventually gave rise to Craven fault belt.

Introduction

The exposed rocks in the research area are dominantly Carboniferous, which along with gross unconformity on a basement of strongly folded lower Palaeozoic rocks exposed in inliers adjacent to the North Craven Fault in the Ingleton district (Fig. 1). The basement of the Pennines has played an important role during the deformational history of the region. This basement with its intrusions influences the system of massifs such as Alston, and Askrigg Blocks, and the Derbyshire Dome, with their characteristic topography (Fig. 2). The research area was strongly influenced by movements associated with Craven Fault belt, as it marks the southern boundaries of Askrigg Block. During the Hercynian compressional phases the block area were only slightly affected, whereas the less competent basinal sediments display greater degree of deformation.

It has been difficult to interpret the origin of the joints from the data available from the aerial photographs (Kazi, 1994). A working classification of the various sets was required to relate them to the deformational history of the region. It was therefore decided to map the joints around

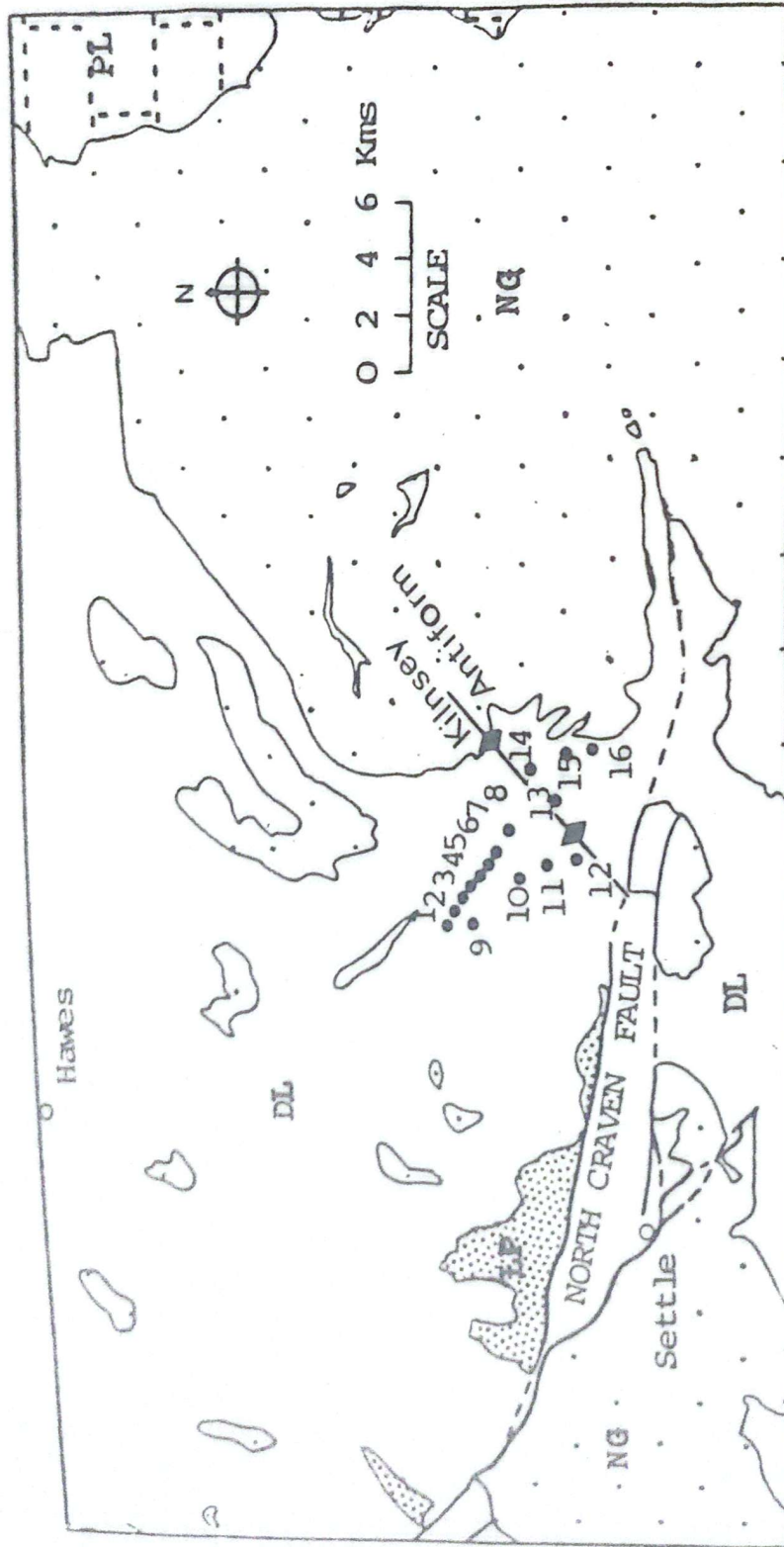


Fig.1 Localities of various sub-areas of joints sampling.
 PL is Peruvian Limestone, NG is Namurian Grit,
 DL is Dinantian Limestone, and LP is Lower Palaeozoic.

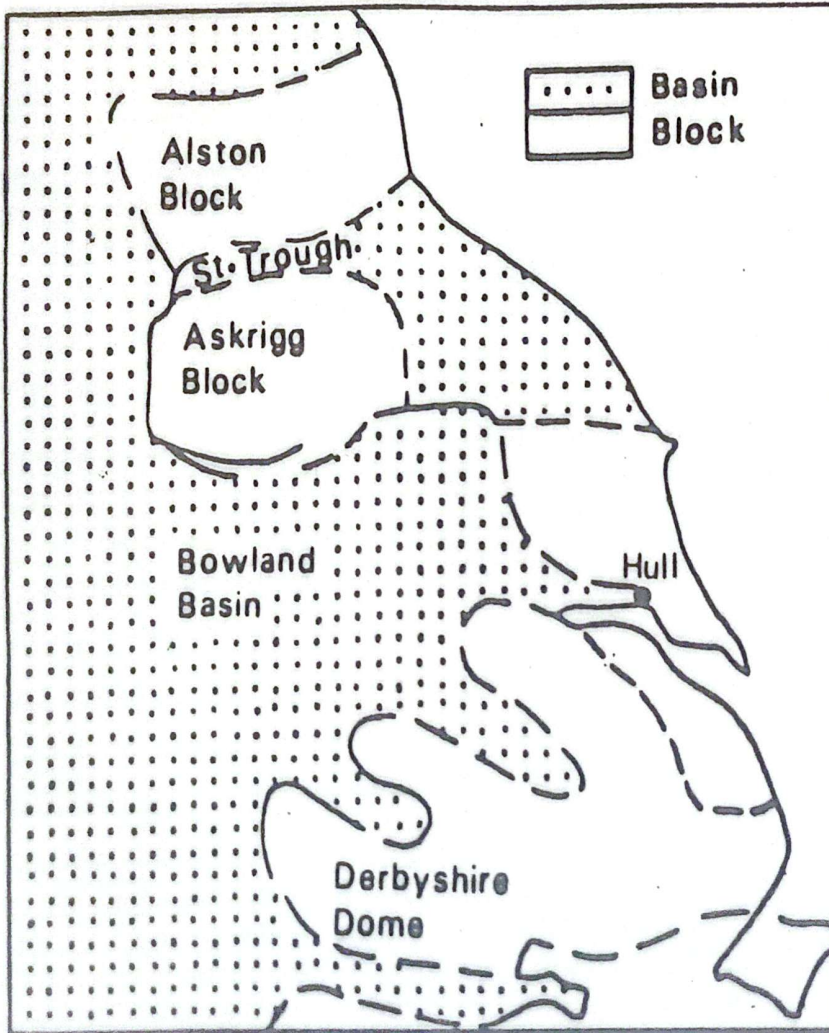


Fig. 2 Sketch showing distribution of the block and basin in the Dinantian time, of north-central Pennines (Modified after Kent, 1974) St. denotes Stainmore.

certain folds in the field in an attempt to determine more clearly the genetic relationship between the joints and the various other structures.

Background to Field Observations

The joints in the research area were grouped in three regular sets (Kazi 1994). Further work was conducted by the author to classify all of the available joint sets and to attempt to relate them to the different pulses of Hercynian folding (Kazi 1982). The so-called conjugate shear sets (nos. 1 & 2, Fig. 3) of joints (Wager, 1931; Doughty, 1968) in particular required re-consideration as recent authors such as Price (1966), Hobbs, Means and Williams (1976), and others have suggested that the angle of intersection between conjugate shear joints should be 60° not 90° , as shown by the Mohr stress envelope (Fig. 5).

The Mohr stress envelope is based on various triaxial compression experiments, in which ends of a cylinder under confining pressure are compressed. In these experiments σ_1 is parallel to the axis of the cylinders whereas σ_2 and σ_3 are equal. The horizontal line represents the normal stress values (σ_N) and vertical line represents the shearing stress value (σ_s) Fig. 5. The values of confining pressure σ_3 and compressive stress σ_1 are plotted on a horizontal line, and a circle passing through σ_1 and σ_3 is drawn separately on this line, for each experiment. Such experiments are repeated with different values of σ_1 and σ_3 . The stress circles drawn on a horizontal line for each experiment show that as the confining pressure is increased, the stress as well as the stress difference must be increased to produce fracture. Each stress circle cuts the horizontal line in two places. The left hand intersection is the confining pressure and the right hand intersection is the maximum compressive stress causing fracture in each experiment. A tangent line is drawn to these stress circles and this completes the Mohr envelope (Fig. 5). Hobbs et al. (1976) suggest that shear fracture is expected to occur where the tangent line touches the stress circles, on the planes P for each stress circle (Fig. 5). Fig. 5. shows that the 2θ angle (acute angle of intersection between conjugate shear fractures) is in generally 60° or even below. Price (1966) also suggests "It is usual for shear joints to intersect so that 2θ is considerable less than 90° and it is often 60° or less".

Since little has been described regarding the surface features of these joints, it was considered necessary to examine them in the field. Also it

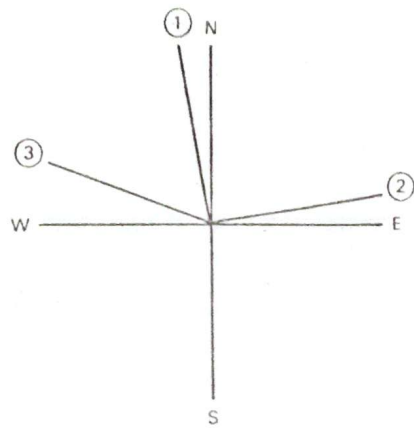


Fig. 3 Showing the average orientations of various joint sets.

Progressive Deformation of Craven Fault Belt

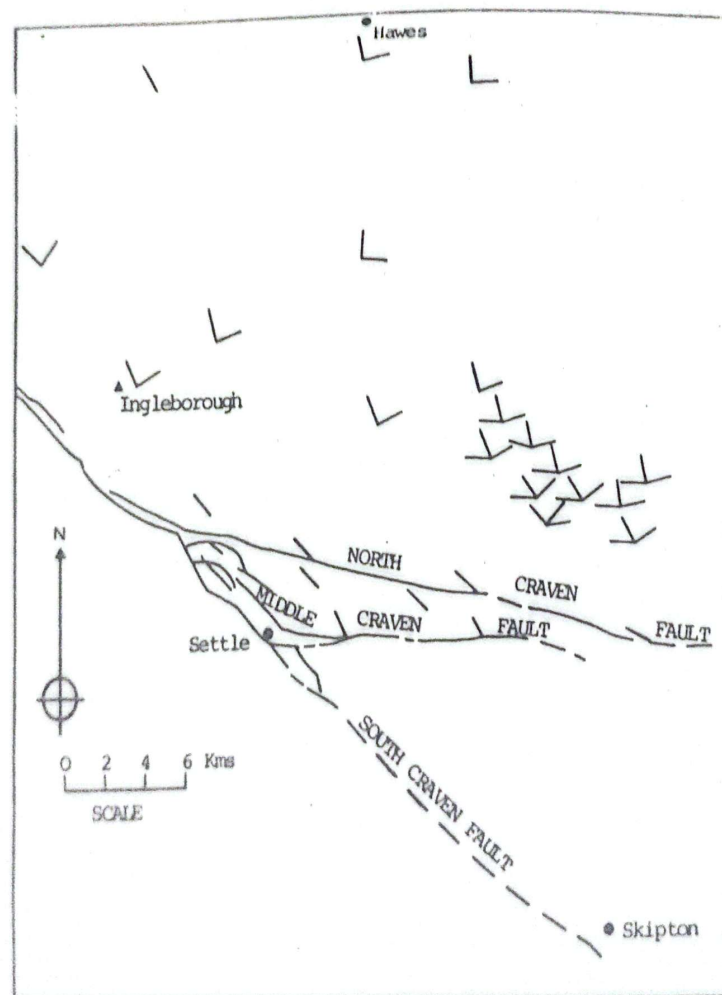


Fig. 4 Showing change in orientation of three main sets i.e. north-north-west, east-north-east and west-north-west around Craven Faults.

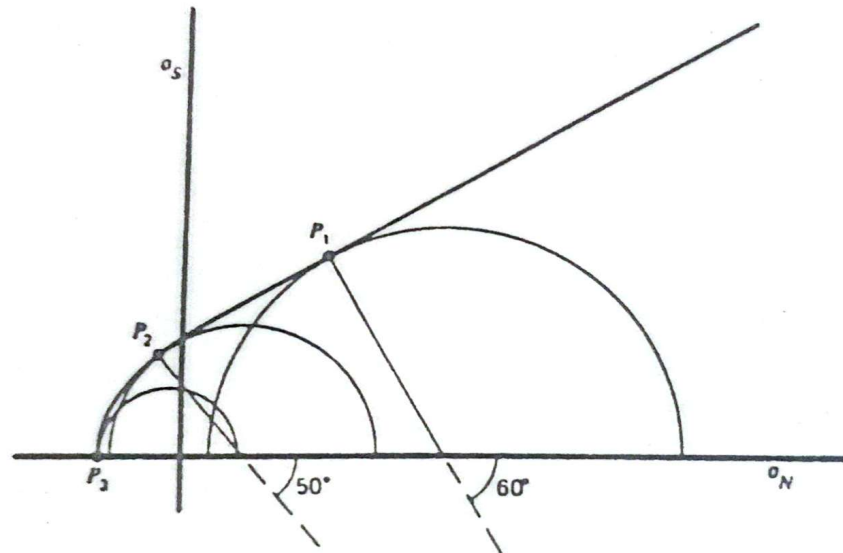


Fig. 5 Fracture orientation correlated with shape of the Mohr envelope. Fractures parallel to planes P_1 , P_2 and P_3 form, respectively, at 30° , 25° and 0° to the direction of σ_1 (After Hobbs et al., 1976)

is interesting to provide further evidence to date the jointing and re-examine Wager's (1931) observations and also to find the orientation relationship between barren joints and mineralised joints.

Kilnsey Antiform

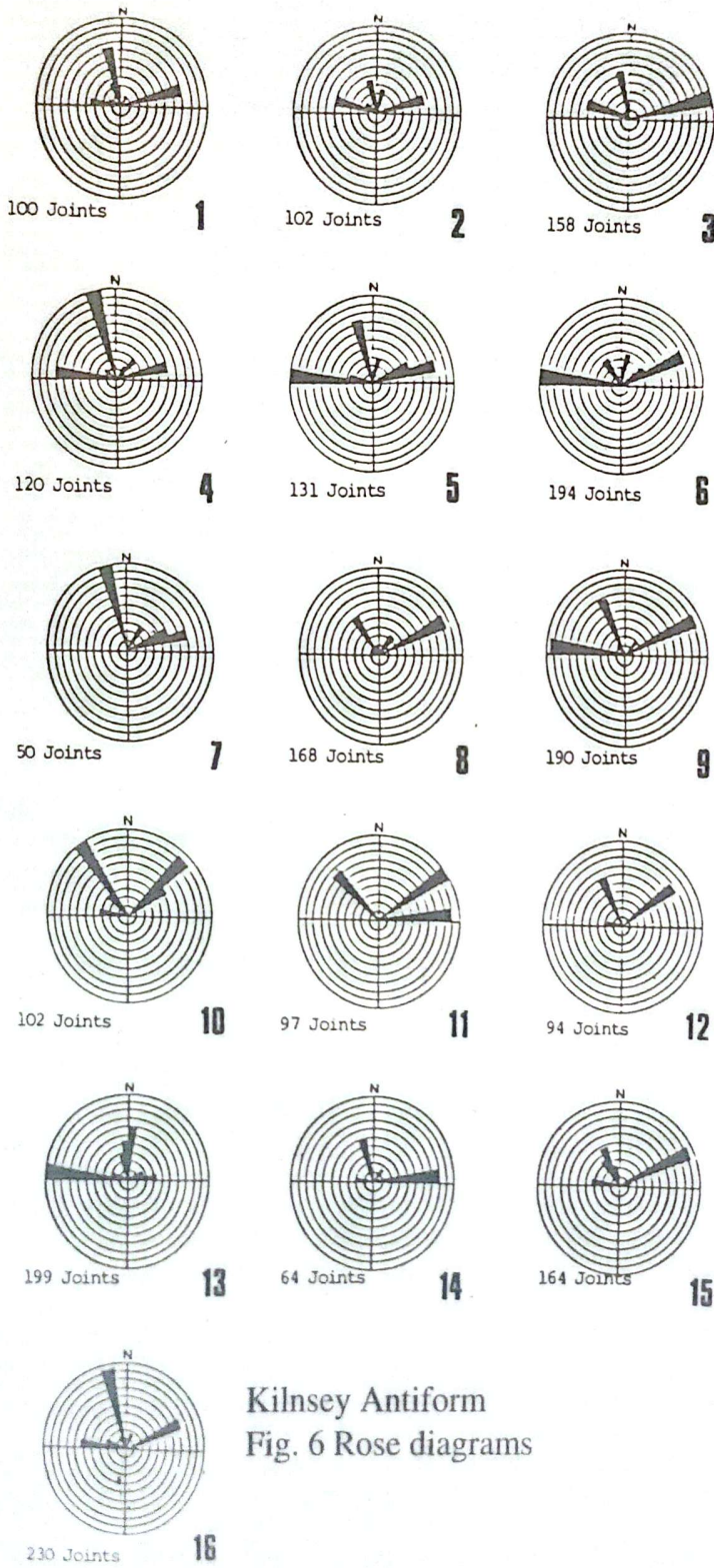
The kilnsey Antiform is a gentle asymmetrical fold which lies immediately north of the North Craven Fault (Fig. 1). Its hinge persists for approximately nine kilometers in an east-north-east direction.

The North-west limb has gentle dips not exceeding 10° whilst the South-east limb dips more steeply at upto 25° . This antiform is mainly displayed in Dinantian limestone which contains many mineral veins parallel to its hinge line. These mineral veins do not show displacement and therefore previous workers agreed with Wager (1931) in considering them to be mineralised joints. A set of barren joints is also found parallel to them.

Large areas of the Kilnsey Antiform around Arncliffe and Grassington were selected for sampling joints. This antiform has already been mapped by the author from aerial photographs (Kazi 1994). This mapping substantiated the swing in the direction of joint sets first described by Wager (1931). To illustrate this swing a single joint set, with north-north-west orientation may be considered. This joint set has an almost north-south orientation in upper Ribblesdale. While approaching the North Craven Fault, this joint set swings in an anticlockwise direction, its orientation changing to a west-north-west direction (see Fig. 4). After crossing the North Craven Fault towards the South this joint set again rotates but this time a clockwise direction. There is another set of joints at right angles to this set and these two sets rotate together. These observations were recorded from the Great Scar Limestone. The area was divided into sixteen sub-areas. Generally each continuous outcrop was taken as a sub-area without considering its size. The distance between various sub-areas also varied from a few meters to a few kilometers. For locations of various sub-areas (Fig. 1), and rose diagrams are identified by sub-area numbers, are shown in Fig. 6.

The strike orientation and the amount and direction of dip of bedding planes and of joint planes, were all measured in each sub-area. The data between the bedding and joint planes with the help of pole figures.

Joints are well exposed in a small vertical section between Arncliffe and Knipe Scar in the Great Scar Limestone. This area is also traversed by disused mineral veins with an ENE general trend. Between Arncliffe and Knipe Scar beds of Great Scar Limestone are exposed at various stratigraphic levels, their thickness varying from approximately half a metre to a few



metres. Elsewhere in the Kilnsey Antiform the Joints were examined in large pavements of thick, nearly horizontal Great Scar Limestone. On these pavements the joints are very large and almost all continue for more than a metre. They were also easily grouped into the various sets. Weathering has had a great effect upon these joints, since nearly every joint has been widened to more than 15 cms. They are generally not more than 10° from vertical. The spacing of the joints and the quality of jointing varies from one area to another.

Surface features of joints in the research area proved of little value. The classification of joints in folded rocks proposed by Price (1966) was therefore found to be very suitable for this research. Price's classification is based on their relative orientation with respect to other structures. The orientation of some joint sets on a fold, can be related to a-, b- and c-axes of tectonic cross, where "a" is the direction of compressive movement of the fold, "b" is parallel to the fold axis and "c" is perpendicular to the plane containing ab. Joints parallel to the fold axis are classified as "BC". Joints at right angle to fold axis are classified as "AC". Joints which make an acute angle with either the "AC" or "BC" joints are known as oblique joints.

The oblique joints have the same orientation as conjugate wrench faults, which might develop due to the same orientation of compression which gave rise to the folds. On dynamic grounds they are therefore classified as shear joints. "AC" and "BC" are classified as tension joints (Fig. 7).

The following observations were made in the joint survey around the Kilnsey antiform.

1. Results obtained from aerial photographs (Kazi, 1994) were found to be very accurate when compared with the strike orientations of joints observed in the field.

2. Joints are mainly found in three sets, with orientations of 340° , 075° and 275° (see rose diagrams). The two main sets 340° and 075° approximately at 90° are considered to be "AC" and "BC" tension joints.

3. The anticlockwise swing explained earlier is greater and more systematic with two sets at right angles (NNW and ENE). Change in the direction of the third set, with a WNW orientation is not systematic (Fig. 4).

4. The rotation of joints strike orientation is greater on the north-western limb of the Kilnsey Antiform than on the south-eastern limb.

5. In disused mineral veins there were barren joints with the same

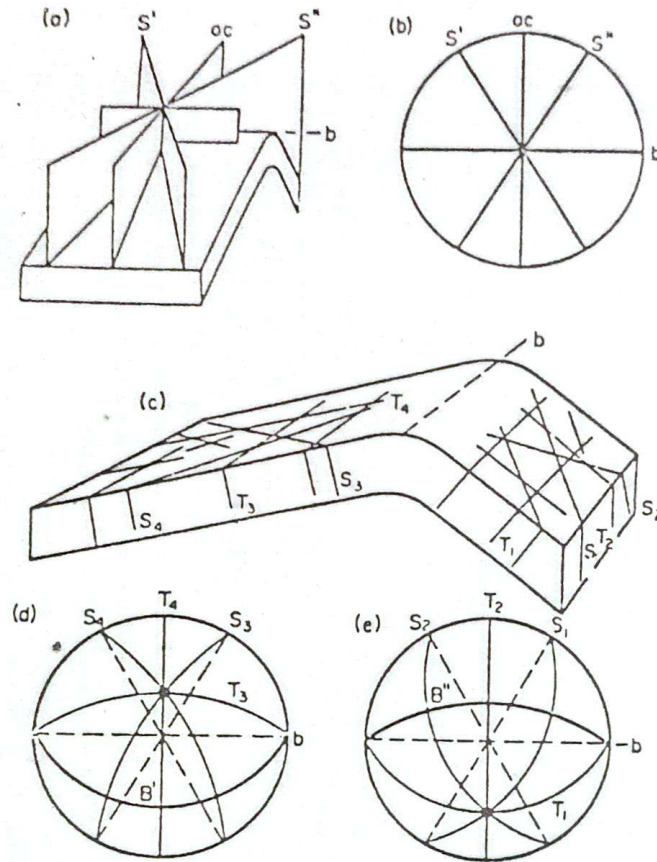


Fig.7 (a) Block diagram showing typical relationship of master joints to an antiformal. (b) Stereogram of master joints shown in (a). (c) Block diagram showing typical relationship of joints in the limbs of an asymmetrical antiformal. (d) Stereogram of joints in the gently dipping limb. (e) Stereogram of joints in the steeply dipping limb. (After Price, 1966).

orientation as joints in adjacent outcrops, suggesting that the same joints were produced after the period of mineralisation.

Stress Trajectories Map

Stress trajectories are orthogonal lines drawn to represent the directions of the principal stresses. By this method the maximum and minimum stresses can be represented in two dimensions. If the density of stress trajectories increases at certain places a stress concentration at this position is indicated.

The present study of stress trajectories was based on the complex pattern of joints around the Craven Fault System although data were also used from other parts of the research area. The joints study was based on field observations and aerial photographs. The data were collected from the Dinantian limestone. A geological map scale quarter inch: one mile, was compiled and the map was divided into numerous sub-divisions (Fig. 9). Separate rose diagrams were prepared for each sub-area. In general two peaks, at right angles to each other around the north-east and north-west directions, were discernible in each sub-area. The exact orientation can not be given because of the considerable swing of the joints (Fig. 4). These two peaks in the rose diagrams were taken as the principal directions of joints in the sub-areas. These two sets of joints are "AC" and "BC" tension joints. The north-westerly joint set has been classified as "AC", and it was considered as best representative of the greatest principal stress direction (σ_1) and hence the σ_1 stress trajectories were drawn in their orientation. The stress trajectories representing the least principal stress direction were produced at right angles to the greatest principal stress direction trajectories. By this method the stress trajectories map (Fig. 8) was prepared and was found to be very useful in interpreting various results and ideas regarding the two pulses of Hercynian deformation (Kazi, 1982).

The stress trajectories map (Fig. 8) represents the second pulse of Hercynian deformation to affect the research area since the stress system inferred from the stress trajectories map corresponds with the east-north-easterly folding. The inferred stress trajectories show a change in orientation near the North Craven Fault. This may be a true change in stress orientation near the fault or it may be the result of fault drag re-orienting the joint planes by simple shear. The latter possibility may however be ruled out because simple shear would cause the joints to be no longer at right angles to one another, and no such change in angle between joint sets is apparent.

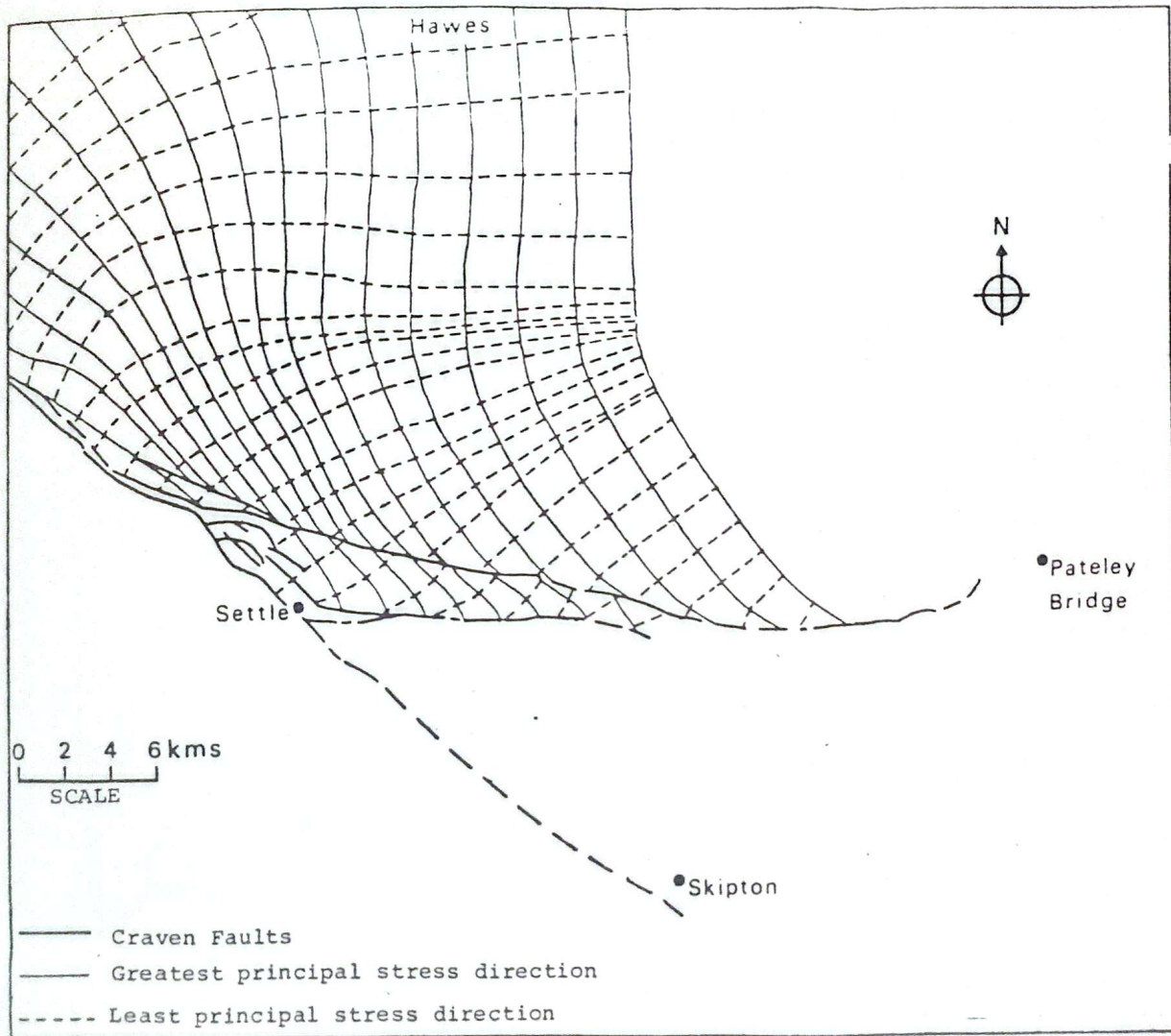


Fig.8 Showing stress trajectories around Craven Fault

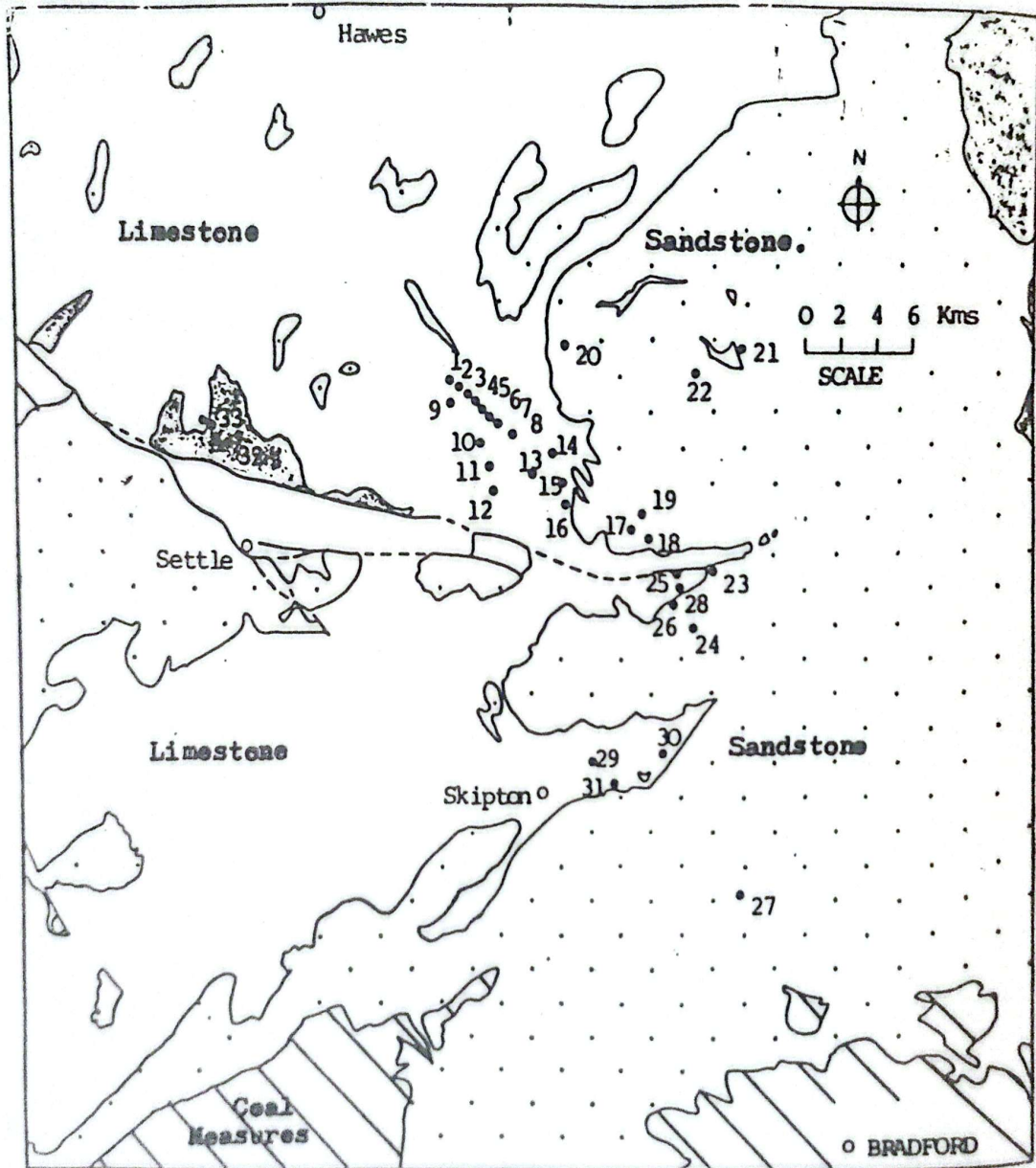


Fig. 9 Localities of various sub-areas of joints sampling from different stratigraphic units.

1 to 7 are between Arncliffe to Knipe Scar

- | | | |
|---------------------|--------------------------|-------------------------|
| 8. Knipe Scar | 17. Bolton Haw End | 26. Cracked Castle |
| 9. Blue Scar | 18. Back-Stone Edge | 27. Ilkley Crag |
| 10. High Sleets | 19. Thompsons Hole Ridge | 28. Trollers Ghyll |
| 11. High Ox Pasture | 20. Great Whemside | 29. Skibeden Quarry |
| 12. Cool Scar | 21. Lofthouse | 30. Hambleton Quarry |
| 13. Castle Scar | 22. Stott Crag | 31. Wheelam Rock Quarry |
| 14. Kelber | 23. High Crag | 32. Helwith Bridge |
| 15. Dib Scar | 24. Simon's Seat | 33. Sunny Bank Quarry |
| 16. Lea Green | 25. Fancarl Crag | |

In Fig. 8 a higher density of stress trajectories is observed around the North Craven Fault which suggests a higher stress magnitude in this area. It is proposed that a weakened zone developed, which eventually gave rise to the North Craven Fault and that the swing in joint orientations was caused by the further weakening of this zone. The stress trajectories map suggests dextral movement on the North Craven Fault not sinistral as suggested by Wager (1931).

The stress trajectories may be based on joint observations around the North Craven Fault suggests that the folds of the Craven Lowlands are in a dextral shear zone, since joints meet the northern side of the North Craven Fault at an angle of 30° whilst on the southern side the equivalent angle is 45° . Also the joints are "AC" which show the character of a shear zone.

Conclusions

The precise age of all the described three joint sets is Stephanian as they were produced by the Hercynian deformation. The first pulse of Hercynian deformation compression was approximately in an east-west direction. During this first pulse the North Craven Fault zone have acted as a weak ductile shear zone, which was devoid of any brittle failure. It is quite possible in brittle-ductile shear zones, that the ductile part of the deformation history formed at a different time from that of the brittle discontinuity (Ramsay, 1980).

The first pulse of Hercynian deformation was followed by the brittle failure of North Craven Fault. The presence of an oblique horizontal Hercynian compression and heterogeneity in basement (the Alston Block and the Craven Basin) initiated dextral transcurrent movement on the North Craven Fault and production of a dextral shear zone in the Craven Lowlands. The country to the south of the North Craven Fault moved westwards relative to the country to the north. The appearance of a dextral shear zone rotated the direction of compression from east-west to north-north-west, south-south-east, thus producing Craven Fault Belt. Wager (1931) suggested that sinistral movements had occurred on the North Craven Fault but if this had been the case the area around the western end of North Craven Fault, would have been highly distorted region. This is not even highly folded, which suggests that it was actually dextral movements which took place on the North Craven Fault. Namurian grit and Dinantain limestone were subjected to same stress fields, during Hercynian deformation.

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