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PAPER 64-24

STRUCTURAL ANALYSIS OF PART OF A-NORTH COAL MINE, MICHEL, BRITISH COLUMBIA

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D. K. Norris

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ABSTRACT

The layered, Jurassic and Cretaceous(?) Kootenay succession at the stratigraphic level of A-North coal mine has been deformed by shear consequent upon flexural slip and small-scale faults. Slickenside striae at bedding interfaces and shear surfaces within the coal provide a kinematic pattern consistent with the structural position of the mine in the Fernie synclinorium of the Lewis thrust plate. Joint surfaces are statistically in hkO; faults are in hkl and appear to be dynamically unrelated to the joints. The effect of layered anisotropy on the mechanics of shear failure in the succession is shown by slickensides associated with flexural slip and by faults cutting the coal-rock interface. There is a lack of preferred direction of dip of extension faults on the one hand and a preferred direction of dip of contraction faults on the other.

STRUCTURAL ANALYSIS OF PART OF A-NORTH COAL MINE, MICHEL, BRITISH COLUMBIA

INTRODUCTION

In cooperation with the Mining Research Section of the Mines Branch, Department of Mines and Technical Surveys, the writer made a detailed study of the geology in and around the test entry* driven in November 1963 in A-North mine, Michel, British Columbia. The object of the study was to assess the relationship between the rock fabric and the type of roof support that might be used safely and economically within the mine. Observations pertaining to this problem have been reported (Norris, 1963, unpublished manuscript). In addition a number of structural features were noted which may contribute to a better understanding of the kinematics and dynamics of emplacement and deformation of the Lewis thrust plate, and these features are analyzed here.

Acknowledgments

The writer is grateful to personnel of the Crow's Nest Pass Coal Company for helpful discussion and assistance underground, to F. Agterberg of the Geological Survey for discussion of the mathematical statistics and to D.F. Coates, head of the Mining Research Section, Mines Branch, for critically reading the manuscript.

GEOLOGICAL SETTING

A-North mine is in A seam, approximately 400 feet below the top of the Jurassic and Cretaceous(?) Kootenay Formation. The seam is of medium volatile bituminous rank; it may be as much as 22 feet thick (Newmarch, 1953, p. 92)**, although it is known to be as thin as 6 inches in some parts of the mine.

A thin, highly sheared coal seam lies less than 20 feet stratigraphically above A seam. It would appear to be an important detachment zone, allowing the roof to sag and ultimately to collapse in places where more than 60 per cent of the coal support has been removed.

The workings occur in Natal syncline (see Fig. 1) toward the north end of the Fernie synclinorium, a major structural feature of the Lewis thrust plate. The synclinorium is characterized by doubly plunging en échelon folds with curved axial surfaces. Natal

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* Hereafter referred to as "the entry".

** Names and/or dates in parentheses refer to publications listed in the References.

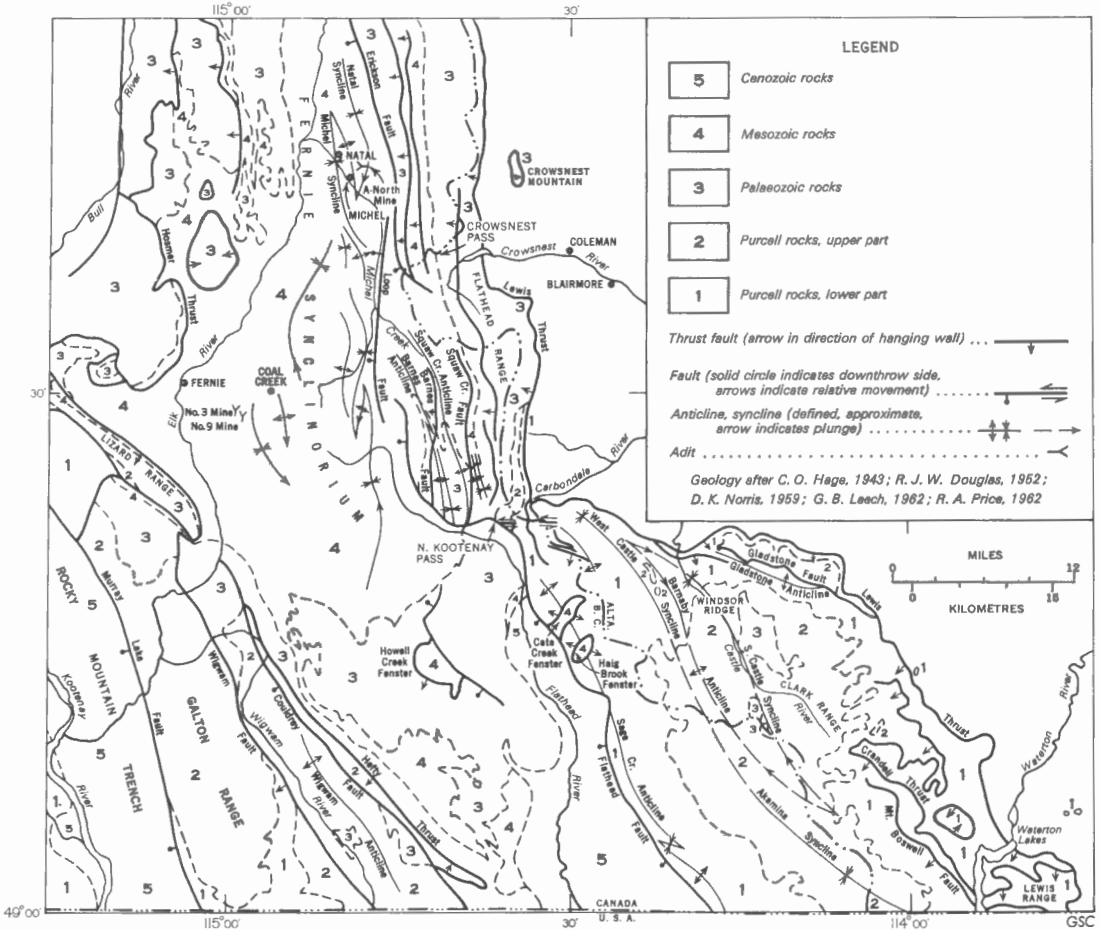


Figure 1. Generalized geological map of part of the southeastern Cordillera of Canada

syncline is linked with Michel syncline by a faulted anticline (see MacKay, 1934, p. 10B). It plunges southward beneath Natal Ridge and its axial surface joins that of the anticline on the hill slopes south of Michel Creek. A west-dipping thrust fault ("MacKay fault" of Crabb, 1962, Fig. 2) cuts the east flank of the anticline and has a dip separation of several hundred feet (MacKay, 1934). Detailed structural control of the merging northward of the anticline with Michel syncline is lacking but it is reasonably certain that they meet about 2 miles north of the town of Natal. The syncline is well developed on the slopes southwest of the town and becomes progressively less pronounced northward.

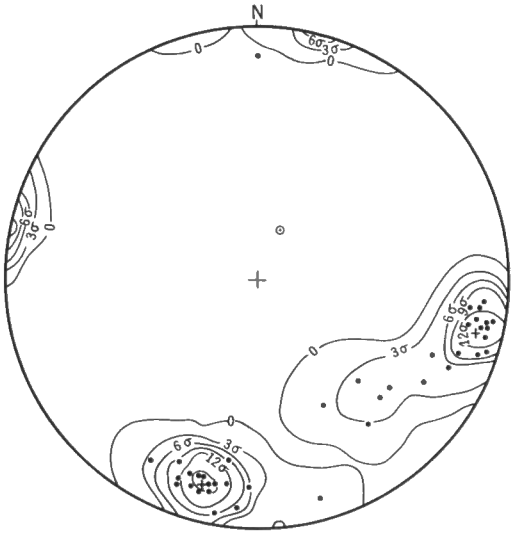
A-North mine is in the axial region of south-plunging Natal syncline. There the strata strike about 280° and dip 10 to 25°S. The strike of the beds is therefore nearly perpendicular to the axis of the syncline and their dip is approximately the plunge of the fold.

The most prominent structural feature of the stratigraphic succession containing A seam is the lithologic layering. The layering forms a penetrative family of discrete, planar and curviplanar deformation discontinuities which were kinematically active during the Laramide deformation. With the exception of the coal and other highly incompetent beds, they separate domains of no strain. The coal seams and carbonaceous shale interbeds on the other hand are shear domains in which depositional fabric elements have been largely destroyed through flexural slip. Slickenside striae are evident at both coal-rock interfaces of A seam as well as on bedding surfaces in the immediate roof and floor. In the coal, shear surfaces are abundant and intra-stratal folds are common.

The kinematic axes of the movement picture at the coal and roof rock interface in the area of the mine are defined by conventional notation as follows: "ab" is the glide surface of the interface, "a" is the relative glide direction of roof rock (east) and "b" is the glide axis. The b kinematic axis is therefore in near coincidence with the fold axis B of Natal syncline and its plunge is approximately that of the fold axis.

Faulting at the stratigraphic level of A seam is for the most part limited to deformation discontinuities at the top and bottom of the coal seam, to extension and contraction faults (Norris, 1958, p. 14) with stratigraphic separations of a few inches and to differential movement of a few inches on joint surfaces in directions ranging from parallel to perpendicular to the stratigraphic layering. Extension faults predominate.

Pinching and swelling of A seam appears to be a tectonic rather than a depositional phenomenon (J. Crabb, personal communication, 1963). Areas where the seam is thin are unpredictable in occurrence; in some instances they were observed to be in association with local shortening of the roof or floor along contraction faults (see Plate 1). With reference to the local kinematic axes, a few such faults examined in the mine are $\underline{hkl}$ surfaces. Depending on the intensity of deformation of the coal these faults may be traced from

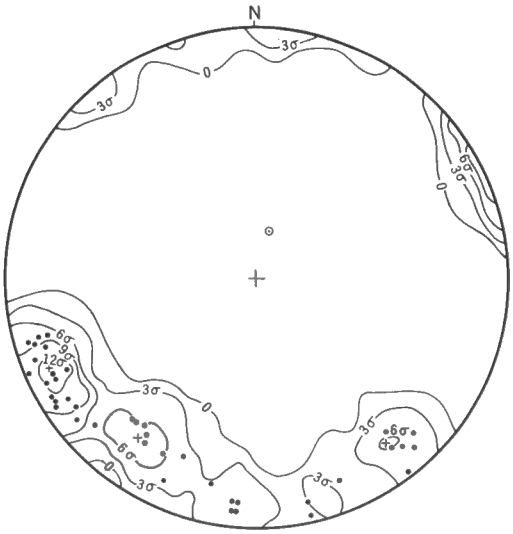


2a. Joint subfabric, A-North Mine, Location I

Joints, 40 poles . . . . . • Bedding . . . . . ⊙

Joint maxima greater than 6σ (E). . . . . +

Contours for joint poles at 0, 3σ,6σ,9σ,12σ,15σ; N=40; σ(E)/E=1; A=0.024



2b. Joint subfabric, A-North Mine, Location II

Joints, 40 poles . . . . . • Bedding . . . . . ⊙

Joint maxima greater than 6σ (E). . . . . +

Contours for joint poles at 0, 3σ, 6σ, 9σ, 12σ; N=40; σ(E)/E=1; A=0.024

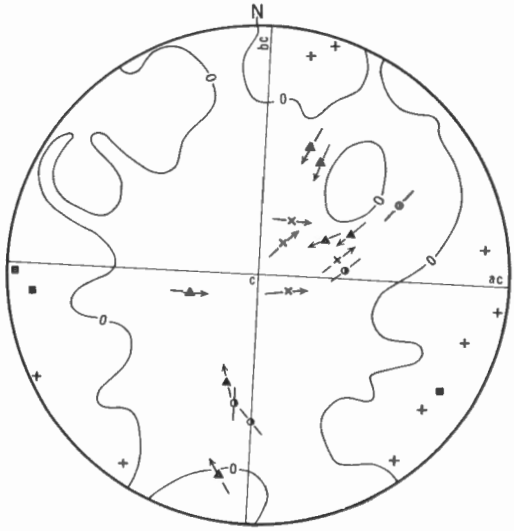
GSC

Figure 2. Fabric and synoptic diagrams, A-North Mine (equal-area projections from the lower hemisphere)

2c. Fracture fabric, A-North Mine, test entry

Joints, 62 poles . . . . . ●
Joints with differential slip, 3 poles . . . . . ■
Extension faults, 7 poles . . . . . ▲
Shear surfaces with no stratigraphic separation, 4 poles . . . . . ⊙
Joint maxima greater than 6 σ (E) . . . . . +
Bedding . . . . . ●
Slip linears (arrow indicates direction of relative motion) . . . . . —— , ⟶

Contours for joint poles at 0, 3σ, 6σ, 9σ; N = 62; σ(E)/E = 1; A = 0.016



2d. Synoptic diagram for fractures studied in A-North Mine

Joints with differential slip, 3 poles . . . . . ■
Extension faults, 7 poles . . . . . ▲
Shear surfaces with no stratigraphic separation, 4 poles . . . . . ⊙
Contraction faults, 4 poles . . . . . ×
Joint maxima greater than 6 σ (E) . . . . . +
Slip linears (arrow indicates direction of relative motion) . . . . . —— , ⟶
Limiting contour (0 σ (E)) for test entry fracture fabric 0

GSC

the floor or roof through the coal into their counterparts on the opposite side of the seam. The fact that extension faults on the other hand are rarely traceable across this seam would suggest that within the area of observation extension faults may in general be older and be offset at the coal-rock interfaces as a consequence of flexural slip.

Natural jointing in the roof and floor rocks is abundant throughout the area of the mine. In order to assess the possibility of a joint subfabric common to the entry and to other areas of the mine, two locations were selected along No. 1 level: Location I is approximately 2,500 feet outbye of the entry and Location II is approximately 1,500 feet outbye. In both instances joint measurements were made in the first 2 to 3 feet of floor rock in areas where A seam apparently had been thinned tectonically and the floor had been brushed. The joints commonly ranged from perpendicular to subperpendicular to the layering, a feature that may be characteristic of pre-tectonic, systematic joints. They would therefore have undergone external rotation as a consequence of the Laramide deformation. A few dip as little as 60 degrees to the layering and may have been formed in response to Laramide stresses.

The joint subfabric diagrams (Fig. 2) have been contoured according to the method proposed by Kamb (1959, pp. 1908-1909) in order that orientations of joint surfaces of statistical significance may be ascertained. The area A of the counter used in the conventional (Schmidt) contouring method is so chosen that if the sample of N poles lacks preferred orientation, the number of poles E expected to fall within the area A is one times the standard deviation σ (E) of the number of poles n that will actually fall within the area for random sampling, i.e. $\sigma(E)/E=1$. The expected density E of joint poles for no preferred orientation is therefore $1 \times \sigma(E)$ and areas within the $3 \times \sigma(E)$ contour, say, are likely to be significant.

Two joint sets predominate at Location I (Fig. 2a); one with a mean attitude of 285°, 75°NE, the other 013°, 80°NW for beds with an attitude of 297°, 17°SW. Both sets consist predominantly of planar surfaces with spacings ranging from 3 to 12 inches.

Joints at Location II on the other hand are not readily divisible into two principal sets although from Figure 2b it is apparent that there is a preferred orientation of surfaces with an attitude of 335°, 80°NE for beds with an attitude of 285°, 15°SW. Scattered poles in the lower part of the diagram have approximately the same orientation as the set at Location I which strikes 285°. There is however no positive correlation of joint sets between these two stations.

GEOLOGY OF THE ENTRY

A geological sketch map of the roof of the entry on a scale of 1 inch to 10 feet was prepared (Fig. 3) from observations taken November 5 and 6, 1963, four and five days respectively after the entry was completed. Ten-foot intervals were marked on the timber supports of the low side of the entry, with the zero point arbitrarily

set at the first wooden support next to the face. From there observations were made over a distance of 524 feet, with the location of joints, faults and other features being estimated to the nearest foot. A Brunton pocket transit was used to measure azimuth and dip readings and a protractor to measure pitch of lineations on shear surfaces. Azimuth readings are believed accurate to within 5 degrees, and dips of surfaces and pitches of lineations to within less than 5 degrees.

The attitude of the roof rock in the entry averages 280°, 18°SW, with measured strikes ranging between about 270 and 290°, and dips between 11 and 24°SW. The entry trends approximately parallel to the strike.

The principal pre-mining features observed in the entry were joints, bedding detachment surfaces, faults in the roof, and shear surfaces and intrastratal folds in the coal. The coal in the area of the test entry averages about 12 feet thick although it was observed to be as thin as about 7 feet between 500 and 520 feet from the face where the floor rock was exposed. The floor was highly polished, indicating differential translation at the coal-rock interface but it lacked slickenside striae there from which to establish the latest direction of relative motion.

Attitudes of joints or sets of joints were measured at many locations because of local caving and opening of cracks in the roof. Although the scatter is large, there would appear to be three orientations of joints of statistical significance (see Fig. 2c). They are:

Plate 1.

West-dipping contraction fault in hkl, No. 1 Level, A-North Mine. Dip-slip component approx. 6 feet.

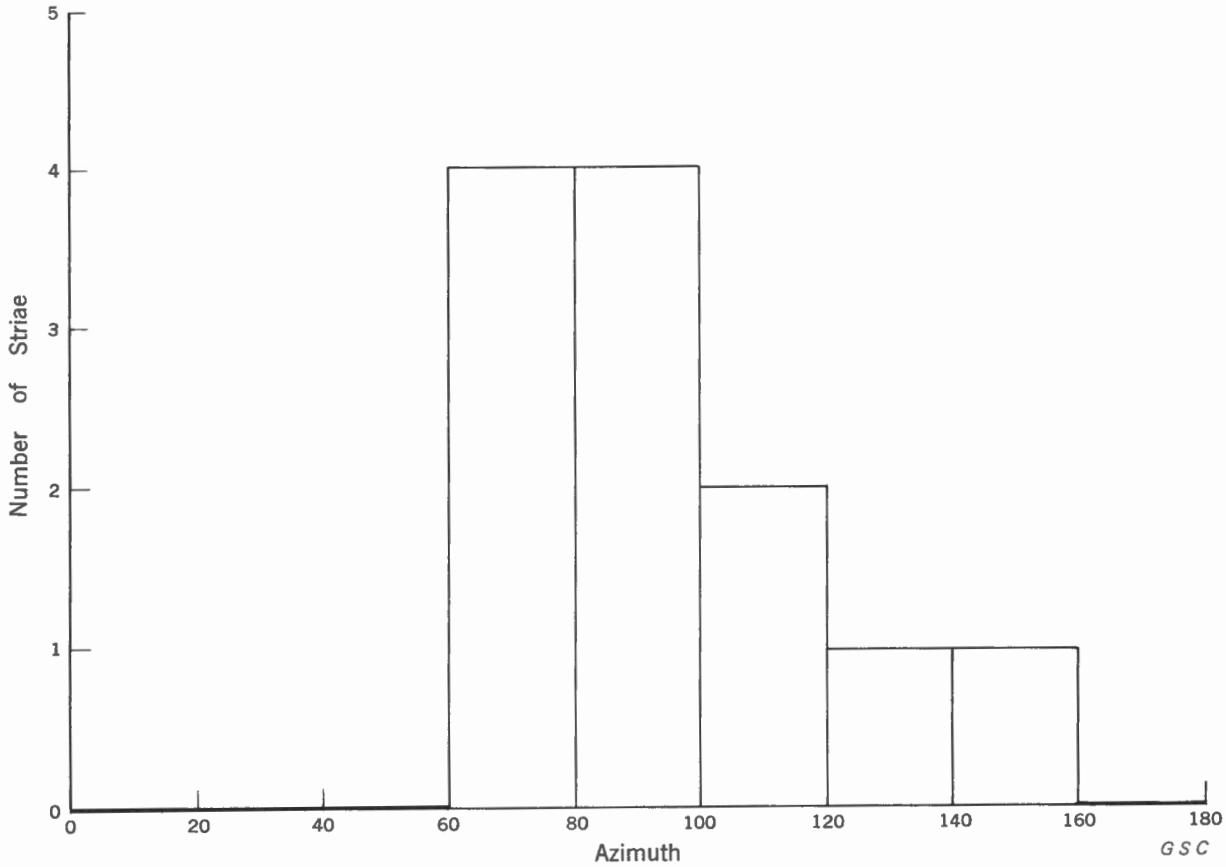


Figure 4. Histogram of azimuths of slickenside striae on roof of test entry, for horizontal bedding, A-North Mine

350°, 90°; 010°, 90°; and 285°, 85°NE. The last two are nearly identical with the principal sets at Location I, approximately 2,500 feet outbye of the entry.

The joints are for the most part planar surfaces, perpendicular and subperpendicular to the layering. They commonly continue through one or more beds. A few are slickensided because of microscopic differential movement in the plane of the joints. Because of their attitude with respect to the ab glide surface, their poles necessarily occur near the primitive circle of the Schmidt projection.

In many instances it was possible to examine polished and striated bedding interfaces where roof rock had been scaled prior to the placing of supports, as well as where the immediate roof had subsequently failed. There, shale beds commonly ranged from 1 to 6 inches thick and they have been tectonically detached from one another through flexural slip. Twelve measurements of the azimuths of slickenside striae on roof strata in the entry (see Fig. 4) indicate a mean preferred direction of differential slip of 093°, subparallel to the direction of relative transport of the Lewis thrust plate.

The fact that many of the joints cross these bedding interfaces (see Plate 2) indicates that either the amount of differential movement at such interfaces is small or that many of the joints were formed after the cessation of interbed slip. Slickenside striae have been produced in triaxial destructive tests on geological materials as a consequence of differential movement of less than 1/10 inch parallel to the failure surface (D.F. Coates, personal communication, December 1963). These tests suggest that the amount of flexural slip at successive deformation discontinuities could be very small so that

Plate 2.

Joint-controlled cavity in roof, 180 feet from face of test entry; timber in lower right is approx. 10 inches in diameter

pre-Laramide joints could cross slickensided discontinuities with only microscopic offset. Flexural slip at deformation discontinuities separating shear domains from domains of no strain (e.g. coal-rock interfaces) on the other hand is doubtless of considerably greater magnitude.

Faults cutting the roof of the entry consisted of joints with differential slip along them and of extension and contraction surfaces. Extension faults predominate and stratigraphic separations greater than 7 inches were not observed. Joints with displacement along them (see Plate 3) commonly occur in swarms of subparallel surfaces, along each of which the stratigraphic separation is less than 1 inch but for the swarm as a whole could amount to several inches. At 25 to 30 feet from the face of the entry for example, a series of them was observed to lie essentially perpendicular to the layering, to have an average spacing of 8 inches in the plane of the layering and to have the down-dropped side consistently inbye. They have an average stratigraphic separation of about 1 inch, with none exceeding 1 1/2 inches. About the middle of the entry they are intersected by a second series of parallel faults with spacing ranging from 4 to 6 inches, stratigraphic separation averaging 1/2 inch and with none exceeding 3/4 inch. The latter faults also have the downthrown side inbye. They are represented symbolically by one fault of each type in Figure 3.

Extension faults examined in the entry were rarely traceable into the coal and were never traceable into foot-wall beds by virtue of the fact that the foot-wall was exposed only in one small area. The extension fault at 500 feet was not seen to cut foot-wall strata. It was not traceable through the highly sheared coal and either died out downwards in the coal or was offset from its counterpart in the floor through interbed slip after the fault was formed. Of secondary importance are curviplanar and striated surfaces with no measurable stratigraphic separation. Four such surfaces were examined in the entry.

Poles to these various slip surfaces are plotted in Figure 2d where the reference plane is the local ab glide plane. Poles to the four contraction faults examined along No. 1 level are included, with the geometrical relation between these faults and the layering retained after the layering was rotated into coincidence with the glide plane on the roof of the entry.

The directions of slickenside striae are represented by segments of great circles through the tangent point of the slip surfaces with the lower hemisphere of the Schmidt net and the intersection of their respective lineations with this hemisphere (Hoeppener, 1955, pp. 37, 38). The arrowheads indicate the direction of relative motion of hanging-wall beds. Those faults resulting in a shortening of the strata in a direction perpendicular to the trace of the fault on the layering (contraction faults) must therefore be indicated by arrows pointing radially outward; faults permitting simple elongation of the strata (extension faults) on the other hand will be indicated by arrows pointing radially inward. The greater the strike-slip component of hanging-wall beds the more will the arrow deviate from a purely radial

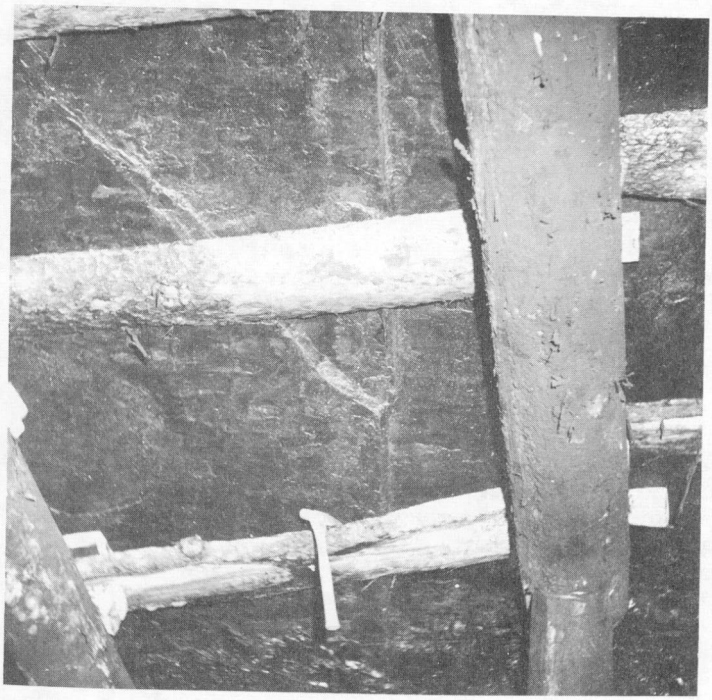


Plate 3.
Joints with differential slip in roof of A seam, 25 feet from face of test entry.

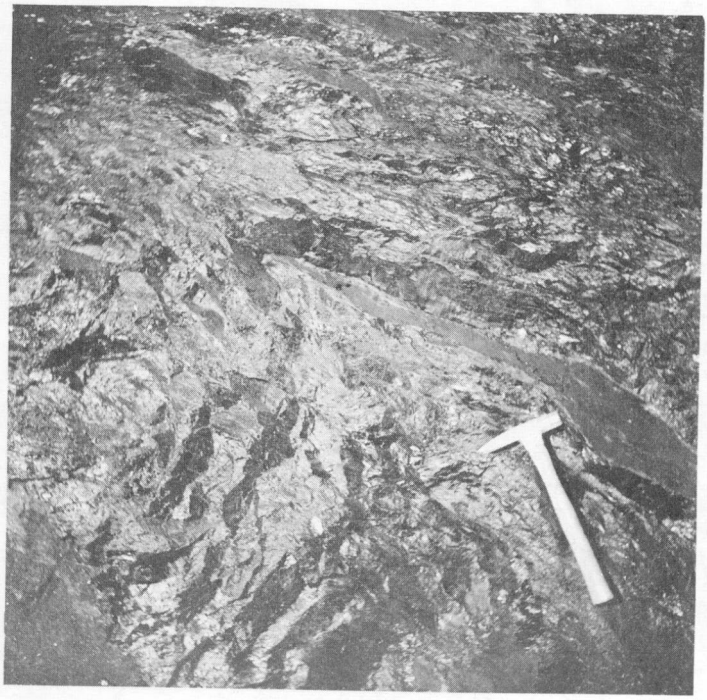


Plate 4.
West-dipping shear surfaces in coal at face of test entry, November 5, 1963.

direction. Striated, curviplanar shear surfaces with no measurable stratigraphic separation are represented by segments of great circles without arrowheads.

These extension faults and the few contraction faults noted along No. 1 level commonly trend northwest. Although in limited sample, the former dip in either direction whereas the latter dip exclusively to the southwest. The extension faults are therefore both synthetic and antithetic to local flexural slip and the contraction faults are exclusively synthetic. The suggested symmetry in dip for extension faults on the one hand and the asymmetry for contraction faults on the other is a natural consequence of the disposition at failure of the local stress system with respect to the layering (Norris, 1961, pp. 183-184).

It is evident from the synoptic diagram (Fig. 2d) that the striated shear surfaces studied in the mine have attitudes significantly different from the joints. They lie mainly in hkl whereas the joints are statistically in hkO. Displacement along them is generally not purely dip slip as indicated by the departure of their respective slip linears from a radial direction. In so far as the intermediate principal stress is assumed to lie in the plane of a fracture at the time of its initiation, it would appear that the dispositions of the local stress system which gave rise to the striated shear surfaces were essentially different from that which produced the joints. It is apparent moreover that the extension and contraction faults are the product of temporally distinct dynamic events.

CONCLUSIONS

Slickenside striae on bedding-surface deformation discontinuities and shear surfaces within A seam provide a kinematic pattern consistent with that of the transport and deformation of the Lewis thrust plate. It is therefore concluded that these discontinuities were kinematically active surfaces during the Laramide deformation.

The data would suggest moreover that the disposition and symmetry of extension and contraction faults are independent of the joint subfabric. Whereas the joints are statistically in hkO, both extension and contraction faults are in hkl. Consistent with theory and practice on the effect of layering on shear failure in anisotropic media, contraction faults have a preferred direction of dip (southwest) whereas extension faults may dip in either direction.

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