CHATHAM FAULT ZONE, OLD CHATHAM - EAST CHATHAM, NEW YORK

Mesostructures and Microstructures: Their Spatial and Age Relationships

A thesis presented to the Faculty
of the State University of New York
at Albany
in partial fulfillment of the requirements
for the degree of
Master of Science

College of Science and Mathematics
Department of Geological Sciences

Jorge Mora M.

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ABSTRACT

Detailed studies in rocks of Mettawee (Late Precambrian ? to Early Cambrian) and Walloomsac (Middle Ordovician) slates between Old Chatham and East Chatham, New York, have shown that these rocks were intensely deformed during the Taconic orogeny and a later deformation event (?). Two generations of structures are clearly recognized in the area. The first generation (G1) includes tight west-verging folds whose axial plane foliation is the regional foliation slaty cleavage (S1). These structures are considered synchronous with the regional metamorphism of the Taconic orogeny and correlative with those structures belonging to the D2 deformation event proposed by Ratcliffe (1979) and Rowley (1983).

The second generation of structures (G2) is represented by NE-trending kink bands, concentric folds and their associated crenulation cleavage (S2) which overprint the pre-existing regional foliation (S1). This kind of deformation seems to be localized in the metapelitic rocks and is, at least partially, synchronous with the development of the Chatham fault zone. These structures are considered here to be correlative with those belonging to the D3 deformation event of Rowley (1983) and the F5 generation of folds of Ratcliffe (1979). Their overprinting relationships relative to the faulting are consistent with the Rowley idea about the generation of the crenulation cleavage during thrusting (c.f. T3, Rowley 1983).

Evidence of an earlier deformation event (e.g. dismembered intrafolial folds in the metapsammites) in rocks of Mettawee slate has been sporadically observed, and is correlated with the D1 deformation event of Rowley (1983). Other structure present in the Chatham area and not included in the above generations is a NW-trending macrofold in the

regional foliation, which reflects the geometry of the Chatham fault zone. This fold has been correlated with the NW-trending folds belonging to the F4 generation of Ratcliffe (1979).

ACKNOWLEDGMENTS

The writer gratefully acknowledges Dr. W. Means for introducing him to the problem and for his advice, discussions and criticism during the course of this study. Dr. W.S.F. Kidd read various drafts of this work and made many helpful suggestions during its preparation. Mrs. Diana Paton is kindly thanked for her typing of the manuscript. The author also wishes to thank Thomas Ray and Steve Tanski for providing drafting materials. Expenses were provided by Consejo de Desarrollo Cientifico y Humanistico de la U.C.V. Caracas, Venezuela.

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CHAPTER 1

INTRODUCTION

The Chatham Fault Zone termed the Chatham fault by Ratcliffe *et al.* (1975) and Bell (1978) forms part of the Taconic thrust belt in Eastern New York. It is a very narrow zone (approximately 0.4 to 1.4 km width), which runs subparallel to the Hudson River for almost 100 km, with a trend about N30E. The study area includes several large outcrops of the fault zone located along Interstate Highway 90 and surrounding areas, between Old Chatham and East Chatham (34 km southeast of Albany, New York, Figure 1-1).

The area includes Late Precambrian (?) to Early Cambrian (Mettawee slate of Nassau formation, Bird 1962) and Middle Ordovician (Walloomsac slate, Berry 1962) rocks, both intensely deformed. The Mettawee slate in the Chatham area consists mainly of green metashales and graywackes. The Walloomsac slates are black-grey metashales with orange weathering color. The contact surface between these lithostratigraphic units are faults (see cross section BB' at 88 m and EE' at 85 m).

Previous workers have mainly concentrated their attention on mapping and stratigraphic problems (Talmadge 1956, Craddock 1957, Bird 1962, Zen 1967, and Fisher 1971), and on the determination of the relative ages and geometry of the different thrust sheets (Ratcliffe *et al.* 1975, Ratcliffe and Bahrami 1976).

The last detailed geological mapping of the Chatham fault zone was made by Bell (1978). His work was mainly concerned with the location and mapping of the traces of the main faults, determination of the structural-age relationships between the Chatham, Rensselaer and Giddings Brook slices, and the geometric relationship between Chatham fault zone

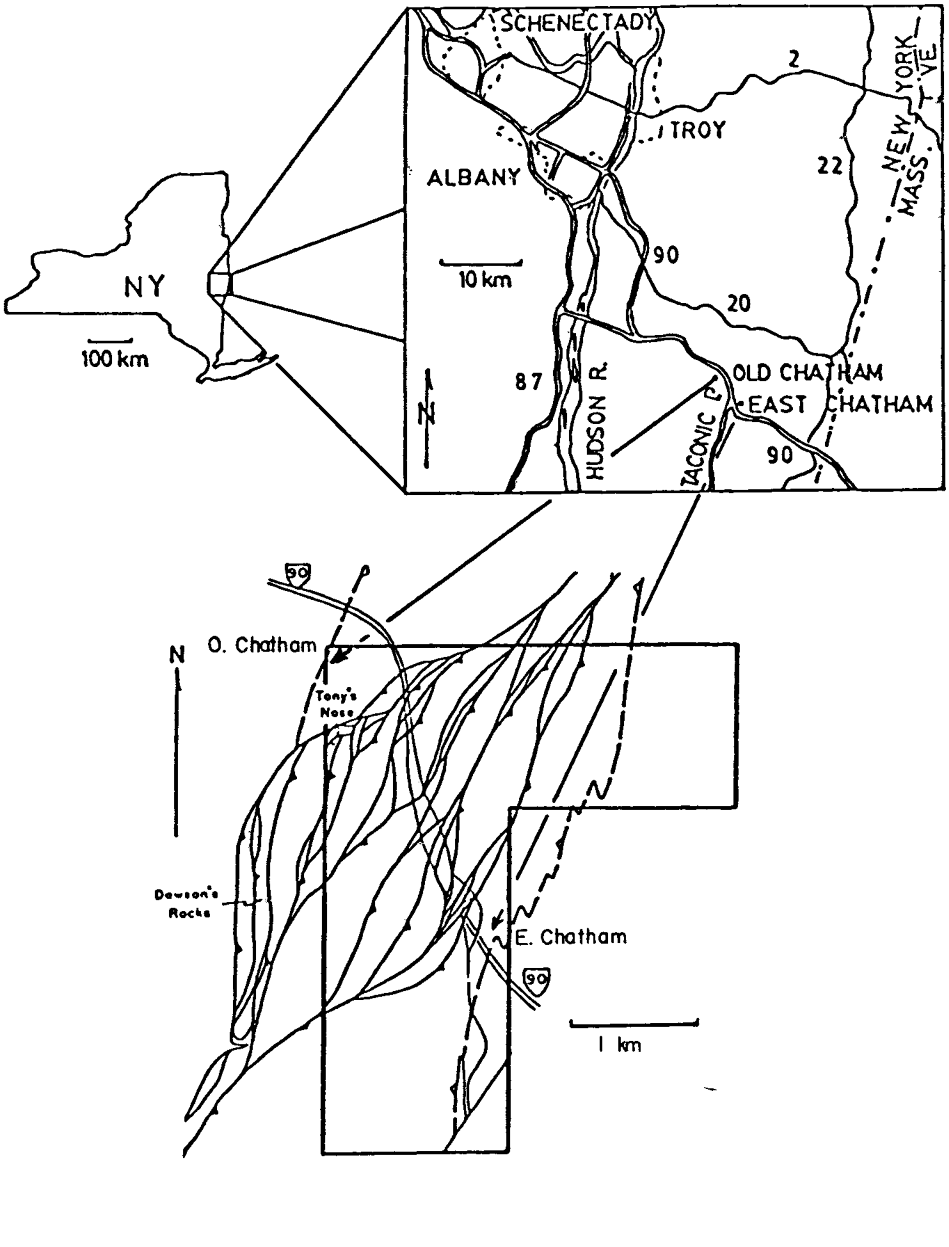


Figure 1-1. Locality maps of the study area, including a generalized structural map of the Chatham Fault Zone (after Bell 1978).

and Rensselaer fault. The main conclusions of this work are: (1) The location of the Chatham Fault Zone (see geological map in Bell 1978), (2) The Rensselaer fault truncates major structures in the Gidding Brook slice and the Chatham fault zone inbricate the Rensselaer slice; and (3) The folding of Gidding Brook rocks is probably Medial to Late Ordovician in age. A late Ordovician age is implied for the emplacement of the Rensselaer slice, and the Chatham fault zone is a post-Taconic structure, probably Acadian.

The Chatham fault zone is a multiply-deformed area and the geometrical-age relationships of the structures present is a problem that remains unsolved. It is the aim of this work to recognize the different generations of folds and faults in order to determine the geometrical-age relationships between the different folds and their associated cleavages and the relative age of the faulting and the cleavage development.

CHAPTER 2

DESCRIPTION OF STRUCTURES

The aim of this chapter is to describe a number of contrasted types of mesostructures and microstructures, including: morphology, occurrence and orientation data. We rarely know the mechanism that operated in forming a particular structure, so that a genetic classification is often impractical. Therefore, in order to avoid ambiguous terms in the description of structures, I will use mainly morphological classifications.

2.1 Fault Systems

The Chatham area is a relatively strongly deformed narrow zone within the Taconic thrust belt. It is characterized by closely-spaced faulting. This type of structure is termed a fault zone (Hobbs *et al.* 1976, p. 300) or a brittle shear zone (Ramsay 1980, p. 80). Markers at both sides of the fault surfaces suitable for interpretation of the relative movement of one block with respect to another are absent. Alternative diagnostic features to determine such movement are drag structures and striations with small steps facing perpendicular to them. Striations are the most common and they were used to determine the relative movement between the faulted blocks.

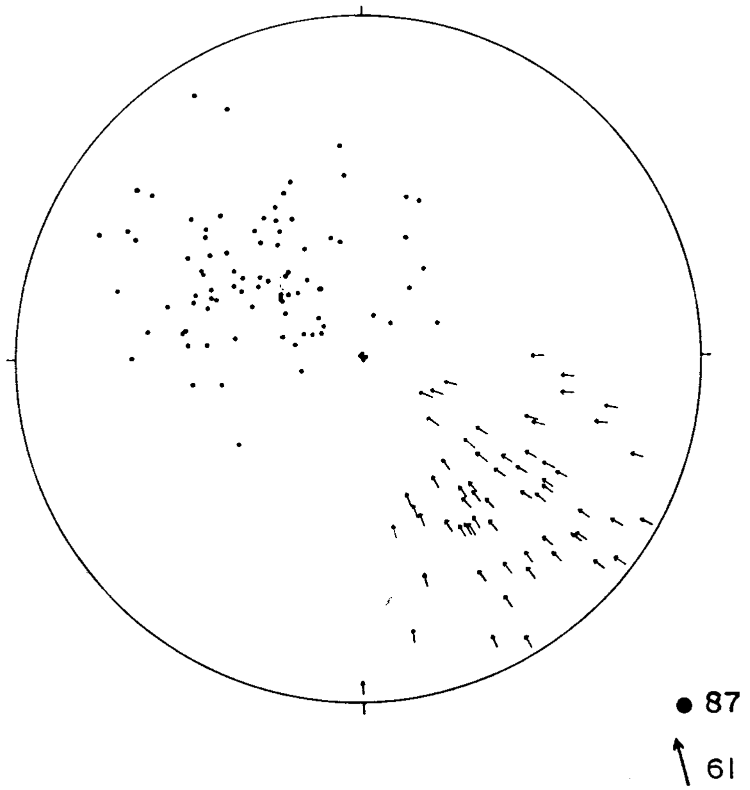
It has long been considered that the steps on one block face in the direction of movement of the opposite block. However, several researchers (Paterson 1958; Norris and Barron 1969) have shown experimentally that the steps can be formed facing in the opposite direction relative to the movement. Durney and Ramsay (1973) have pointed out that when the steps show needlelike crystal fibers perpendicular to the step traces and growing from the step walls, the steps on one block face in the direction of movement of the opposite block. In this work, I will use these features to determine the relative movement between the footwall and the hanging wall blocks of Chatham faults.

Using the above techniques and Anderson's classification (Anderson 1951), the Chatham faults were grouped in two types: thrust and normal. Thrust faults are the most abundant (70%). These are non-planar surfaces (see cross section AA' between 10 and 40 m) in some cases they follow a staircase trajectory (Rich 1934) made up of ramps and flats (Butler 1982). The ramps can be at the same time subdivided into frontal, oblique and lateral depending on their orientation with respect to the displacement direction (Butler 1982). In this work the ramp classification is based in the latest displacement given by the striations.

There is mainly a conjugate thrust fault system in the Chatham fault zone. The f1 thrust fault set striking NE and dipping SE is the most common. The steeply dipping faults of this set are often parallel or subparallel to regional foliation and the direction of displacement determined from its striations is NW (Figure 2-1A). The f2 set strikes EW and NE and dips N-NW; this set shows a direction of displacement to the S (Figure 2-1B). The normal faults have NE strike and dip at generally high angles to the SE or NW (Figure 2-1C).

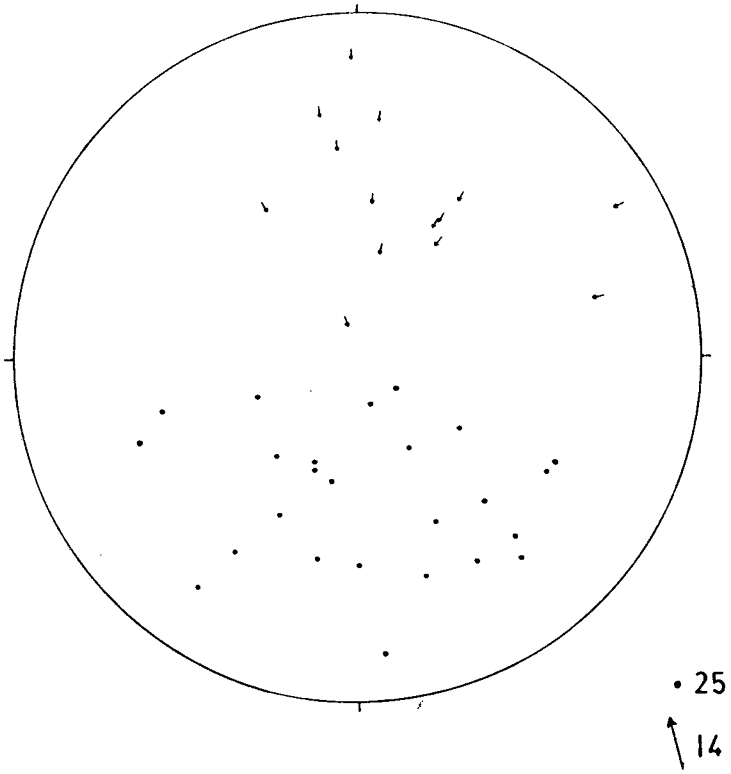
Morphology

In cross sections the thrust fault-bounded blocks show different shapes. Some thrust sheets (Elliott and Johnson 1980, p. 70) show wedge shapes (see cross section AA' between 110 and 125 m), forming sometimes imbricate stacks with their thrust surfaces diverging in the direction of displacement (Dahlstrom 1970, p. 353), see cross section DD' between 105 and 110 m.

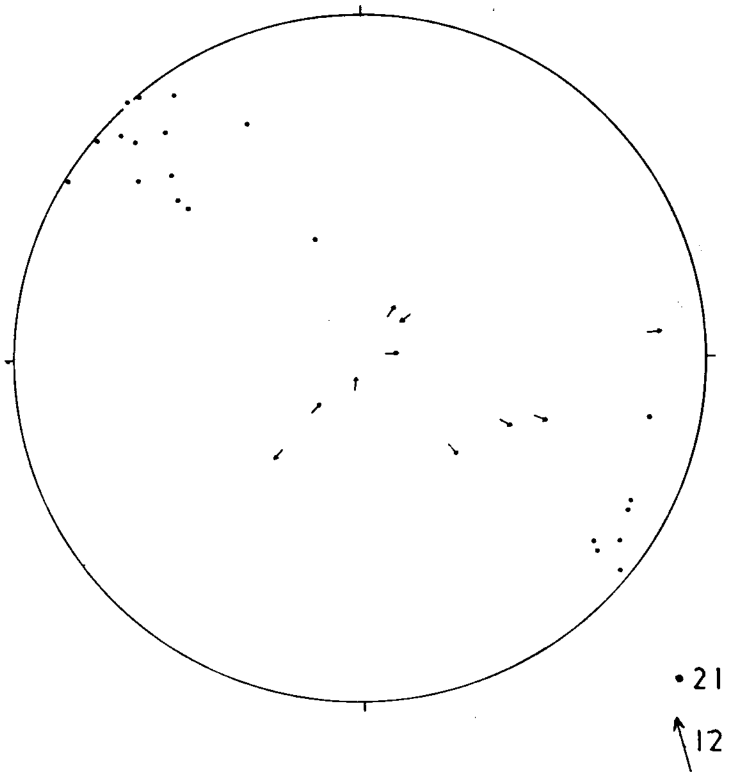


A. f1 thrust fault set

Figure 2-1. Orientation data for fault sets, plotted on the lower hemisphere of an equal area projection. Black dots represent poles of the fault planes. Arrows indicate the displacement of the hangingwall block with respect to the footwall block and they represent the striations lineations. Numbers to right of these diagrams are numbers of points plotted.



B. f2 thrust fault set



C. Normal faults

In exposures where the thrust fault-bounded blocks are preserved, three distinct configurations are shown: lenticular blocks produced by anastomosing fault patterns are common at different scales (see cross section DD' between 100 and 105 m); and triangular or rhomboidal blocks resulting from intersecting fault patterns (see cross section CC' between 145 and 150 m, and between 150 and 160 m, respectively). The triangular blocks are similar to those described by Butler (1982) as triangular zones where a pop-up back thrust and forward directed imbricate thrust fault converge (c.f. Butler 1982, Figure 16-18).

The configuration described in the above paragraphs are shown in cross sections subparallel to the direction of displacement. They are combinations of oblique ramps and flats. Cross sections perpendicular to the direction of displacement may show profiles of flats changing gradually to lateral ramps (see cross section EE' between 50 and 70 m).

Normal faults are rare and they occur with thrust faults bounding rhomboidal blocks. They often show a steeply dipping attitude (see cross section DD' between 55 and 65 m).

Associated Structures

Slickensides: These structures are common features on the fault surfaces. In the Chatham area, they display prominent parallel striations, which generally terminate at small steps oriented more or less perpendicular to them, and at which fibrous crystals have grown parallel to the striations (Figure 2-2).

Drag folds: This type of structure is uncommon, but when present it shows the same sense of displacement deduced from the striations-step combination. These structures are termed normal drag (Hobbs et al. 1976, p. 305) and they fold the regional foliation at the thrust fault

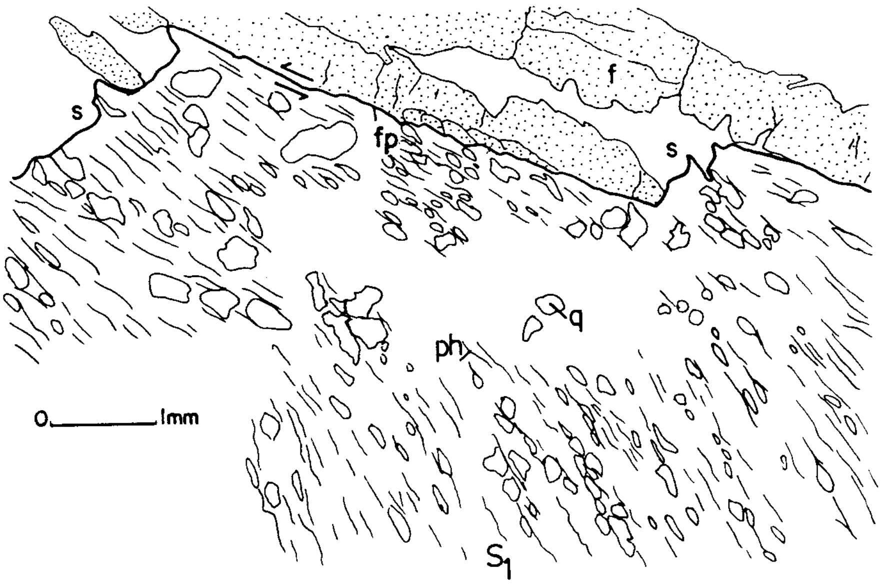


Figure 2-2. Thin section cut parallel to the quartz fiber lineation and perpendicular to the step-fault plane intersection line. The arrows indicate the relative movement of the faulted blocks. Fibers (f), step (s), fault plane (fp), slaty cleavage (S_1), quartz grains (q) and phyllosilicate grains

(see cross section BB' between 80 and 85 m).

Kink bands: Fault terminations are rare features in the Chatham fault zone. Only one case has been observed and it shows the accommodation of the deformation at the thrust fault termination by splay faults branching from the main fault plane (Figure 2-3A). Associated with the splay faults are kink bands in the fine-grained rocks and concentric folds in the coarse-grained rocks (Figure 2-3B).

2.2 Kink Bands

Kink bands are narrow transverse zones in laminated materials, bounded by surfaces called kink band boundaries (KBB's) at which the laminations are deflected with a small radius of curvature. The width of kink bands may be constant or variable, and at their extremities the KBB's commonly converge instead of diverging. In an individual kink band the angle between the lamination in the band and the KBB's becomes generally smaller while the KBB's approach one another.

Classification

Anderson (1964, p. 273) suggested a kink band classification based on the sense of displacement of one long limb domain (LL) with respect to a geographic reference frame fixed in the other LL domain in terms more usually applied to faults, as normal, reverse, dextral, sinistral or oblique.

The normal and reverse terms have also been used by Dewey (1965, p. 460). His terminology in effect rotates kink bands until the LL domains are horizontal and after that classified them using fault terminology. Later, Dewey (1969, p. 194) pointed out that the writer must specify what classification is applied, in order to avoid mis-

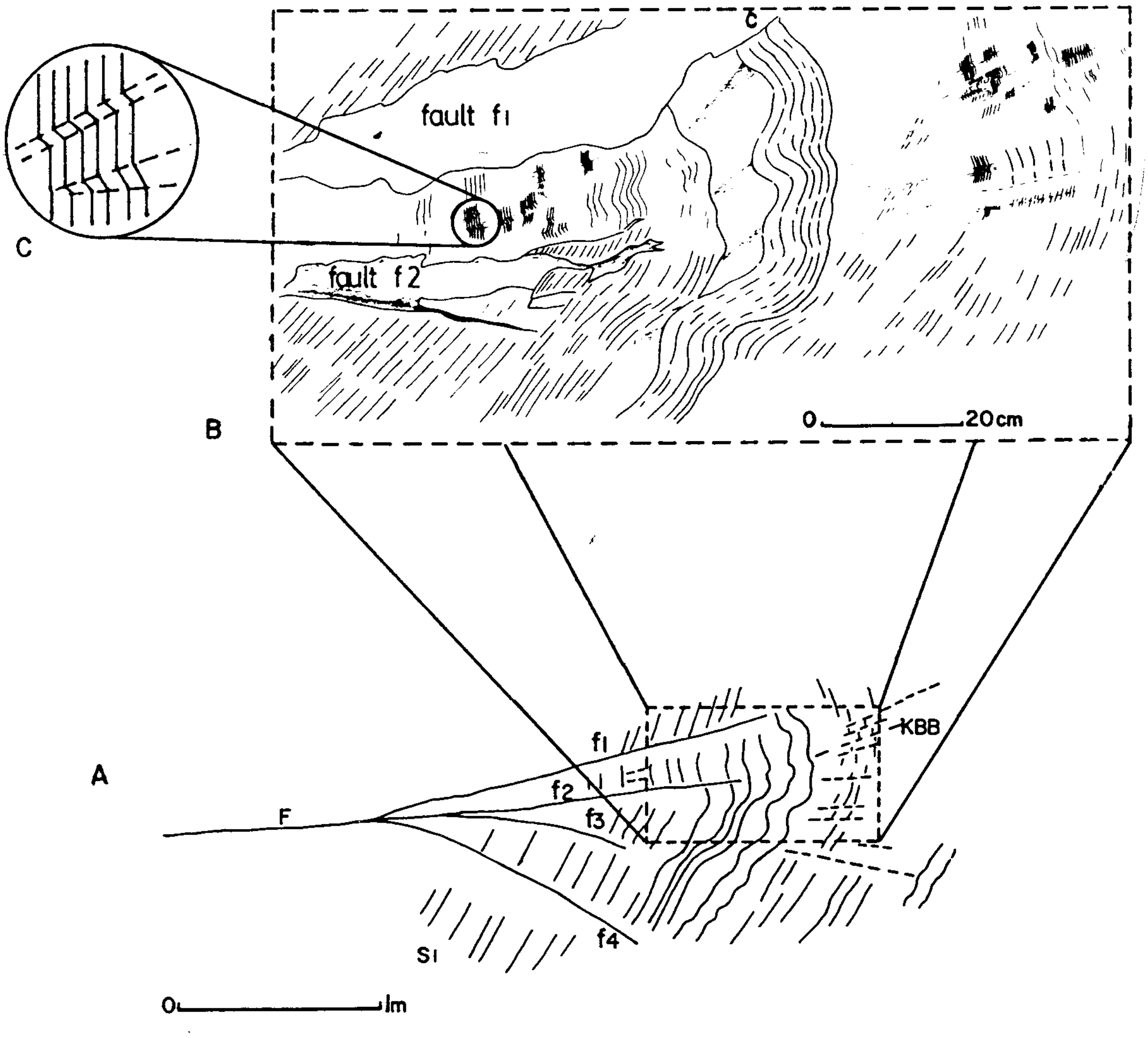


Figure 2-3. Fault termination located between 70 and 75 m of the DD' cross section. A) The displacement on the main fault plane F is accommodated by splay faults branching (f1-f4) and by folding of the regional foliation S1. Kink bands show their KBB's with the same branching pattern as the faults (f1-f4). B) From the concentric fold c is deduced that the block between f1 and f2 has undergone a sinistral shear which was registered by the NE negative kink bands. C) Detail of kink bands.

understanding; for example, a kink band classified as a dextral oblique kink band using Anderson's classification can be called a reverse kink band applying Dewey's classification.

Since reverse kink bands result in a shortening parallel to the foliation and normal kink bands result in an extension, Dewey (1969, p. 194) proposed to term them negative and positive, respectively. The use of these terms is unambiguous and no external reference frame is necessary for their application; therefore, I prefer to group the Chatham kink bands using this terminology.

The classes negative and positive can be divided in sinistral or dextral depending on the sense of rotation of the SL domain with respect to the LL domains. A way to group kink bands is therefore to use Dewey's classes accompanied with a term that specifies the sense of rotation. However, sinistral and dextral terms have the same problem of "direction of observation" pointed out by Hobbs et al. (1976, p. 168) in the application of vergence concept to fold limbs. To specify the sense of rotation of the short limb domain (SL) with respect to LL domains, I prefer to apply the right-hand rule (using the hinge line of the kink band as rotation axis) and register the rotation by the geographic direction of the thumb. The application of this technique is illustrated in the Figure 2-4. In the particular case of kink bands with vertical KBB's the terms sinistral and dextral can be used without any difficulty. In areas where a group of kink bands, with the same sense of rotation, show two subgroups dipping in opposite directions, for example: NE negative kink band with their KBB's dipping SE, and NE negative kink bands with their KBB's dipping NW, a new term can be added to specify the KBB's dipping direction. In the above example the first group becomes NE-SE negative kink bands and the second NE-NW negative kink

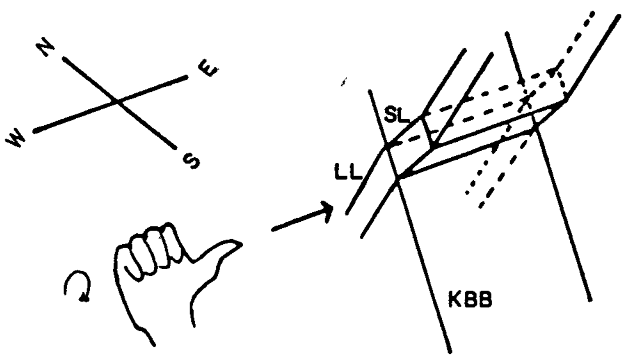


Figure 2-4. The figure illustrated a negative kink band with an horizontal EW hinge line and S dipping KBB's. Its SL domain has rotated in the clockwise sense with respect to the LL domains. Using the hinge line of the kink band as rotational axis and the direction of the thumb from the right-hand rule, this kink band is classified as an E negative kink band.

bands. In the Chatham area it was unnecessary to specify the KBB's dipping direction, because all the kink bands are dipping NW.

Morphology

Some idea of the morphology and scale of the Chatham kink bands may be obtained from the accompanying illustrations. They occur mainly in rocks, such as phyllites, that possess a closely spaced foliation, in most cases slaty cleavage. The width of the kink bands varies between 0.5 and 5 cm. Predating structures such as slaty cleavage, bedding, porphyroblasts, etc. are deflected at the KBB's (Figure 2-5). In an individual kink band, the KBB's are sub-parallel giving to it an apparent tabular morphology in areas where their extremities are not exposed, but many kink bands may be seen to terminate in either direction though the convergence of the KBB's, which define a very flat lens (Figure 2-6A). However, in a few cases the KBB's have been seen to diverge (Figure 2-6B).

The predating structures are commonly continuous across the KBB's, although in many cases the KBB's are marked by joints or faults (Figures 2-7 and 2-8, respectively).

The kink bands can be divided into three groups depending on the structures associated with them: (1) kink bands with flat foliae, (2) kink bands with crenulation cleavage and (3) kink bands with vein arrays.

In those kink bands with flat foliae and continuous predating structures across the KBB's the maximum curvature of the foliation is concentrated at the KBB's and varies from sharp to the slightly rounded. The first type approach the form of ideal kink bands (Weiss 1980, p. 4), and they are better developed in fine-grained rocks with

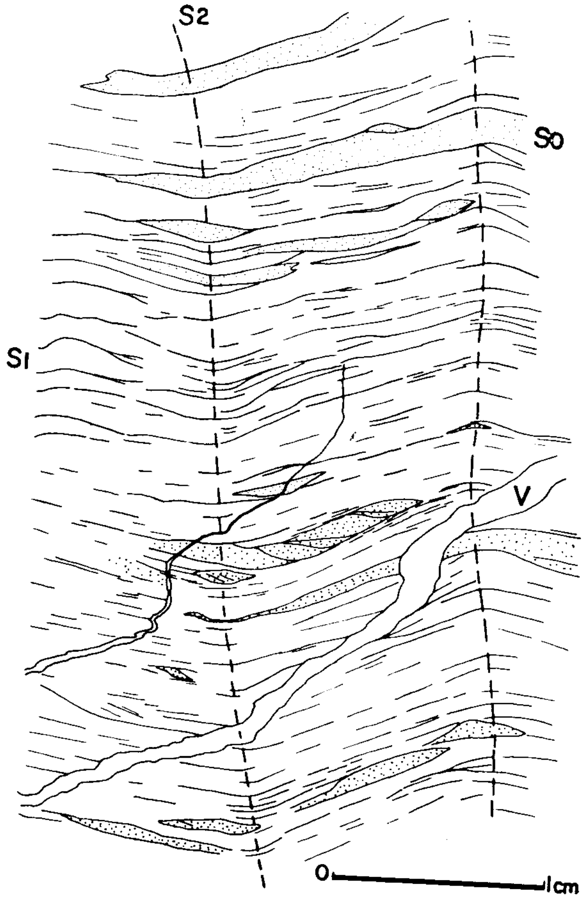


Figure 2-5. Thin section cut perpendicular to the hinge line of the kink band shows the deflection of predating structures such as foliation (S1), Veins (V) and bedding (So) at the KBB's (S2).

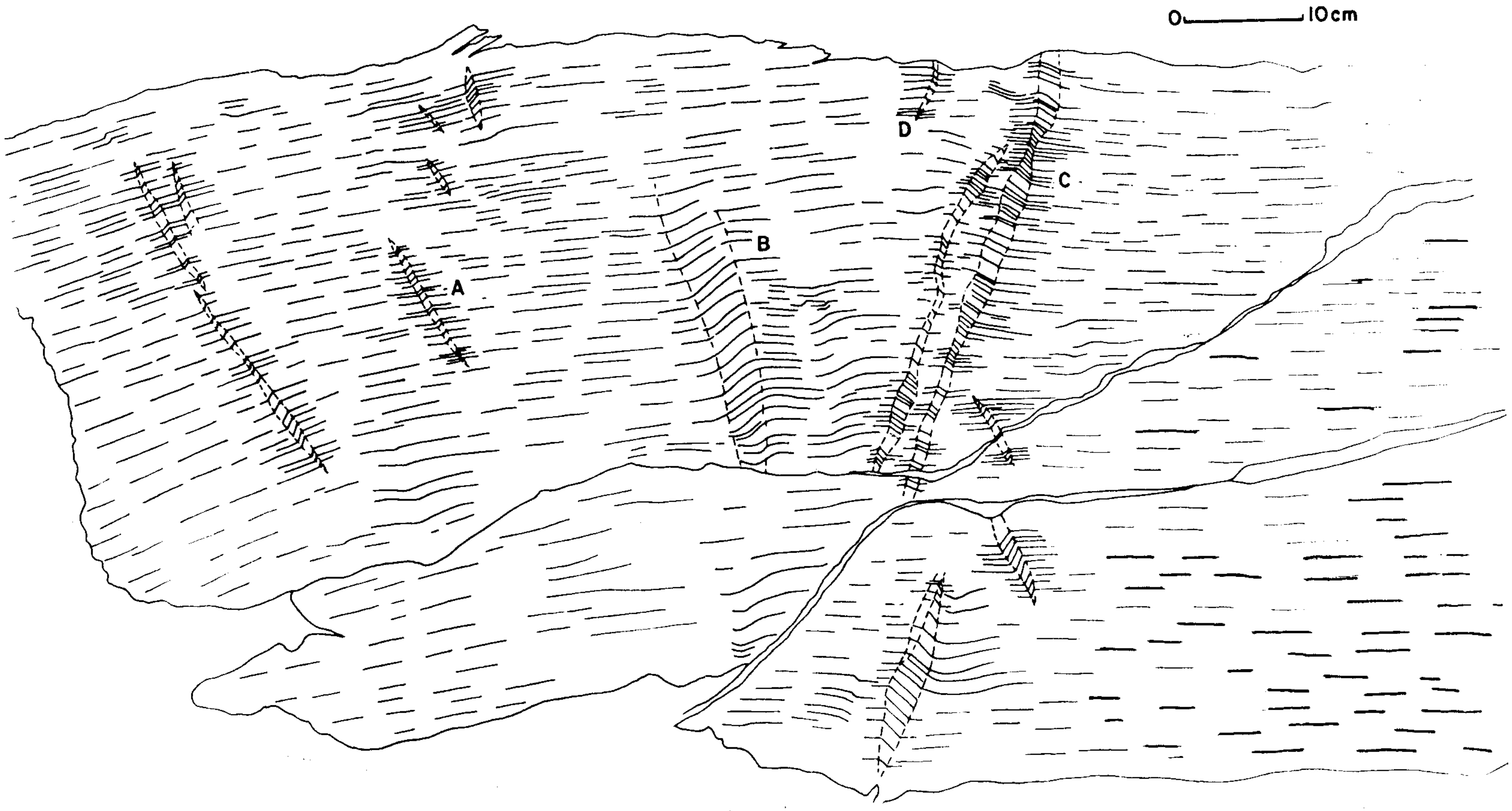


Figure 2-6. Outcrop of conjugate kink bands located at 4 meters on the BB' cross section. A) Convergent KBB's. B) Divergent KBB's. The amount of rotation of the SL domains with respect to the LL domains (β) increases with the thinning of the kink band (for example see A and C). The acute angle between SL foliae and KBB's (α) decreases when a kink band slightly changed in orientation with respect to the LL domains (see D).

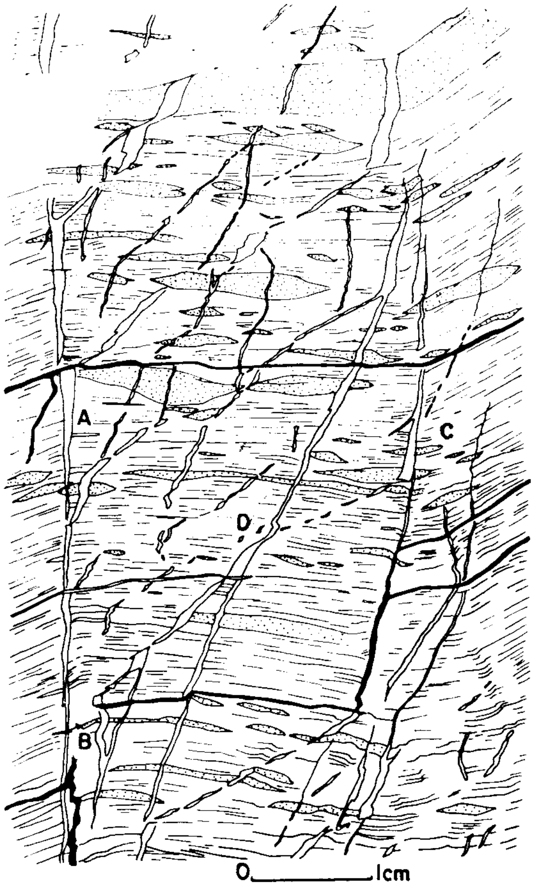


Figure 2-7. Negative kink band and associated arrays of veins composed of types 1 and 3. Dilatational triangular veins (see A, B and C). Notice at C that the lens is not sheared. The older discordant veins (D) form a bigger acute angle with the KBB's than the younger ones and they are sheared parallel to the SL foliae and fragmented into sigmoidal segments indicating a sense of shear (sinistral) opposite to the sense of rotation of the SL domain with respect to the LL domains.

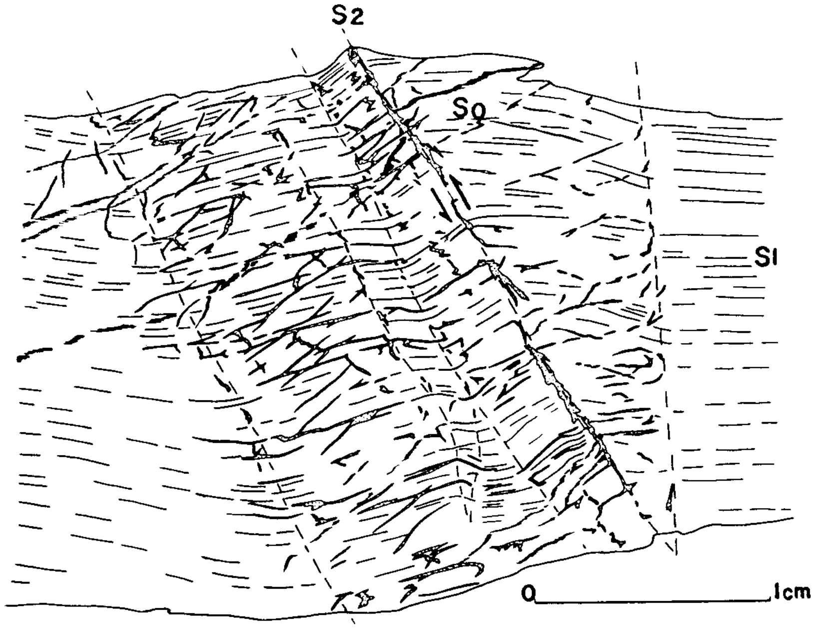


Figure 2-8. Kink band showing microfault parallel to the KBB's (S2). The anticlockwise rotation sense of this kink band is in agreement with the sense of offset of the predating structures such as bedding (So)

closely-spaced foliation (Figure 2-6). The second type occur generally in rocks with widely-spaced foliation planes (Figure 2-5). However, this last type is common in rocks with closely-spaced folation when the width of the kink band becomes narrower (Figure 2-9).

The fold limbs which constitute a kink band are rarely bisected by the KBB's. In 75% of the examples where exact measurements were taken, the acute angle between the KBB's and the foliae outside the band (α) is less than the acute angle between the KBB's and the re-oriented foliae (β) (Figure 2-10). In the kink bands with flat foliae (1) these angles (α and β) are bigger than in kink bands with associated crenulation cleavage (2) but the difference between α and β approximately maintained. The kink bands with associated crenulation cleavage also show continuous predating structures across the KBB's (Figure 2-12 and 2-13).

Many kink bands show associated sigmoidal en echelon vein arrays and/or faults, which offset the predating structures. They also have α angles smaller than the angles but with the peculiarity that β = 90° (Figure 2-7).

Few individual kink bands extend for more than a few meters. While a very few pass into faults along their length (Figure 2-9), the majority die out in all directions. At the wedged extremities of the band there is commonly a gradual but marked increase in the amount of rotation of the SL domain with respect to the LL domains and the angle β decreases (Figure 2-6A). A similar relationship may be observed in those kink bands which show changes in thickness, thinning being invariably associated with increased rotation (Figure 2-6C). Close to the extremities there is also commonly a slight change in the orientation of the band so that it makes a smaller angle α with

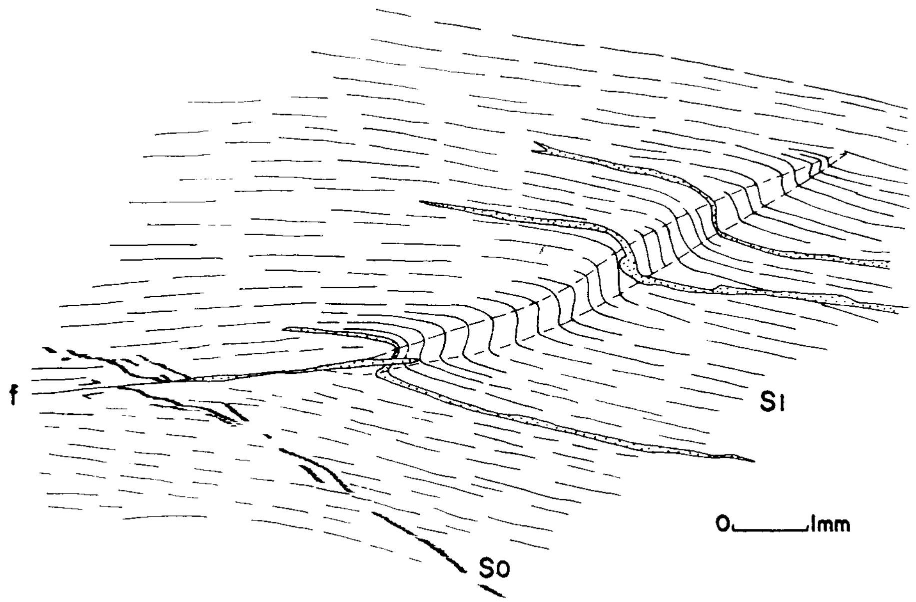


Figure 2-9. Kink band changing laterally into a micro-fault. The sense of shear on the fault plane deduced from the offset bedding (So) is in agreement with the kink band rotation. Microfault (f), foliation (S1) and veins (V).

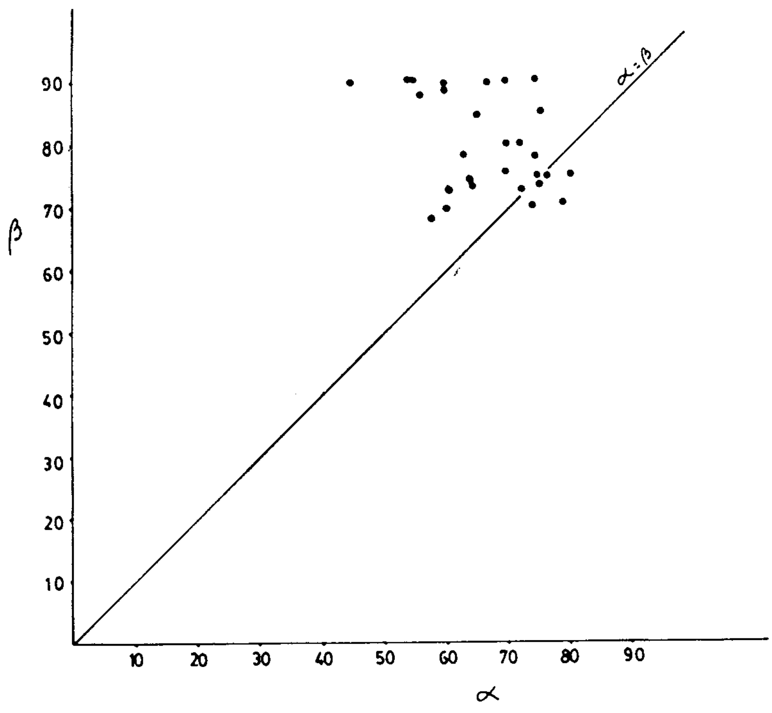


Figure 2-10. In the Chatham Fault Zone 75% of the kink bands show β (acute angle between SL foliae and KBB's) bigger than α (acute angle between LL foliae and KBB's).

the regional foliation (Figure 2-6D).

Associated Structures

Veins: Veins of quartz and/or calcite occur commonly in association with the kink bands. A complete array of these veins is composed of three types of elements: (1) Triangular or irregular nodes formed approximately at the intersection of the KBB's with the foliation; (2) Concordant veins formed between the foliae, mainly in the SL domain (which often pass across the KBB's boundaries into the LL domains); and (3) Discordant veins corsscutting the foliae and lying within or outside of the SL domains.

Triangular veins (type 1) are present at the KBB's and at both sides of them. They are dilatational veins whose walls converge, intersecting in a line parallel to the hinge line of the kink bands. The rotation of one wall vein with respect to the other thas the same sense shown by the SL domain with respect to the LL domains (Figures 2-7A, C). Vein wall traces are approximately straight lines at the KBB's and in the LL domains (Figure 2-7A), but curved in the SL domain (Figure 2-7B).

Concordant veins (type 2) occur mainly in the SL domain. They show variable thickness and are commonly connected with the triangular veins. Matching opposite walls from the triangular-concordant veins combination, the shear component on the concordant veins is determined and it shows a sense of shear parallel to the SL domain foliae contrary to the sense of shear across the kink band as a whole. The intersection of concordant and discordant veins produce a rhomboidal pattern in which the resulting blocks rotate in the same sense that SL domain does with respect to the LL domains (Figure 2-11).

Discordant veins are also connected with the type 1 veins. They

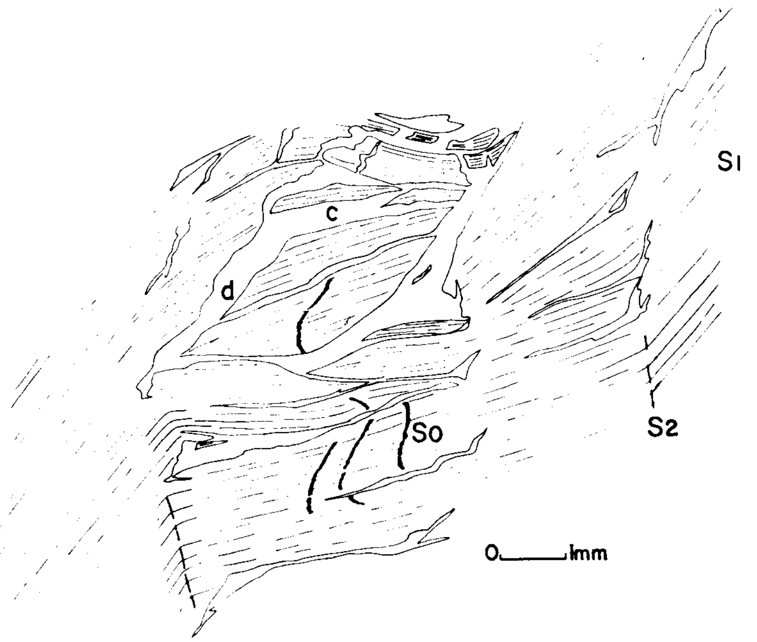


Figure 2-11. Kink band with associated discordant (d) and concordant (c) veins in an approximately rhomboidal veins array. The vein-bounded blocks have rotated different angles (clockwise sense) in the same sense that the kink band (SL) did with respect to the LL domains. Foliation (S1), Bedding (So), KBB's (S2).

are fragmented into sigmoidal segments and occur in several different inclined sets (Figure 2-7D).

<u>Crenulation Cleavage</u>: This foliation is better developed in the SL domains; it is almost imperceptible in the LL domains. It occurs parallel to the hinge line of the kink bands and forms a small angle or is parallel to the KBB's. When the enveloping surface trace of the foliae in the SL domain forms an acute angle with the KBB's bigger than the acute angle of the external rotation of the non-cleavage domain (N) with respect to the LL domains, the crenulation cleavage is a negative (Figure 2-12). On the other hand, when the enveloping surface trace of the foliae in the SL domain forms an acute angle with the KBB's smaller than the acute angle of the external rotation of the N domains with respect to the LL domains, the crenulation cleavage is a positive type and the cleavage frequency increases (Figure 2-13).

Occurrence

The distribution of kink bands throughout the Chathan fault zone is uneven. They occur forming dense arrays and generally oriented at angles of 55° - 80° to the foliation. They fall into two groups: NE negative and SW negative kink bands. Both groups possess subhorizontal SW-NE hinge lines (Figures 2-14 and 2-15, respectively). The NE negative kink band poles plot in a spot with a maximum striking N35E and dipping 35N; this group occurs in rocks with more gently dipping foliation (Figure 2-14). On the other hand, the SW negative kink band poles define a partial girdle extending NW-SE across projection and occur mainly in rocks with steeply dipping foliation (Figure 2-15).

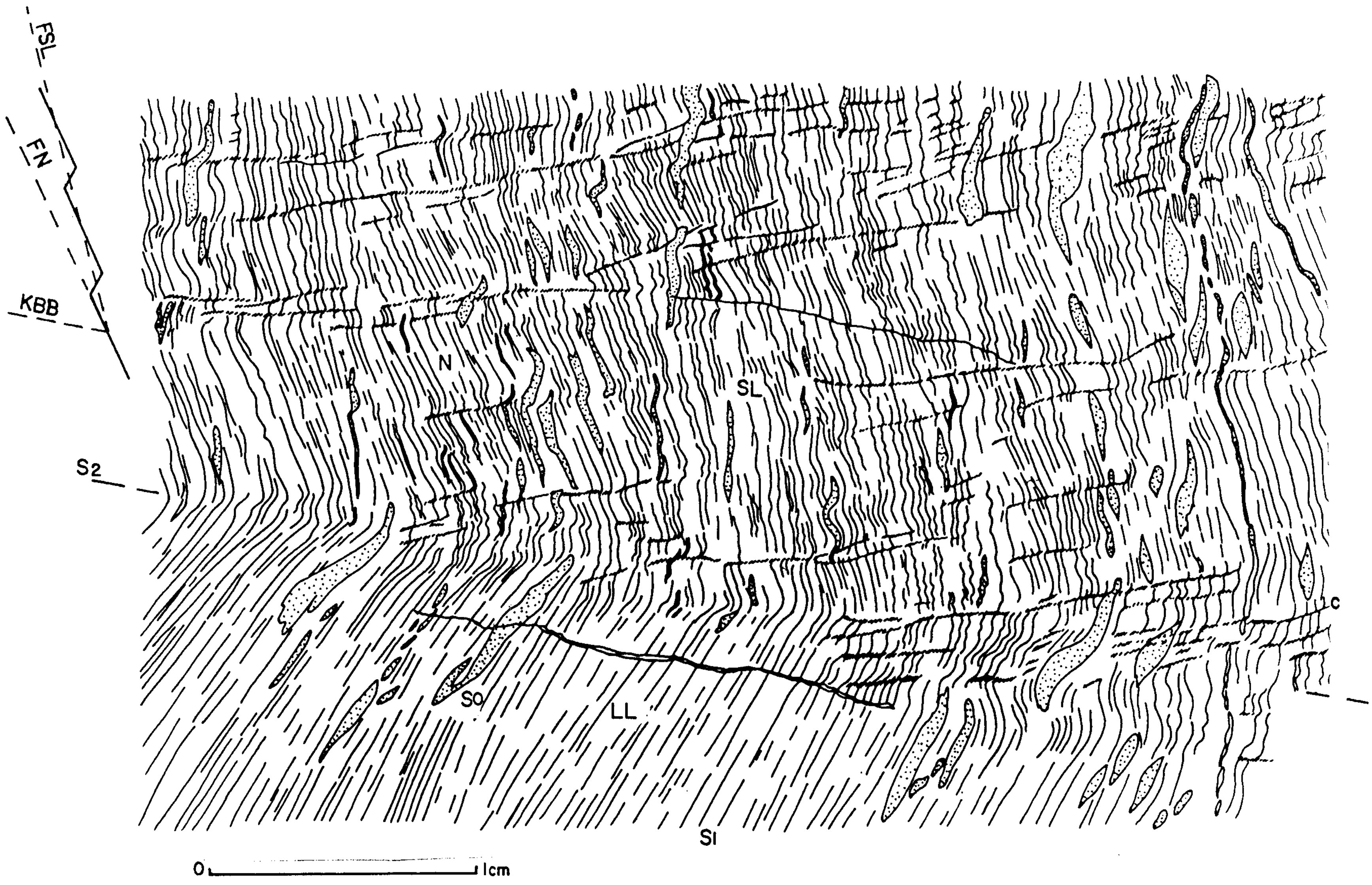


Figure 2-12. Portion of a NE negative kink band with associated SW negative crenulation cleavage. Enveloping surface trace of the foliae in the SL domain (FSL). Foliae in the N domain of the crenulation cleavage (FN). KBB (S2). Non-cleavage domain (N). Cleavage domain (C). Intrafolial fold in So (bedding).

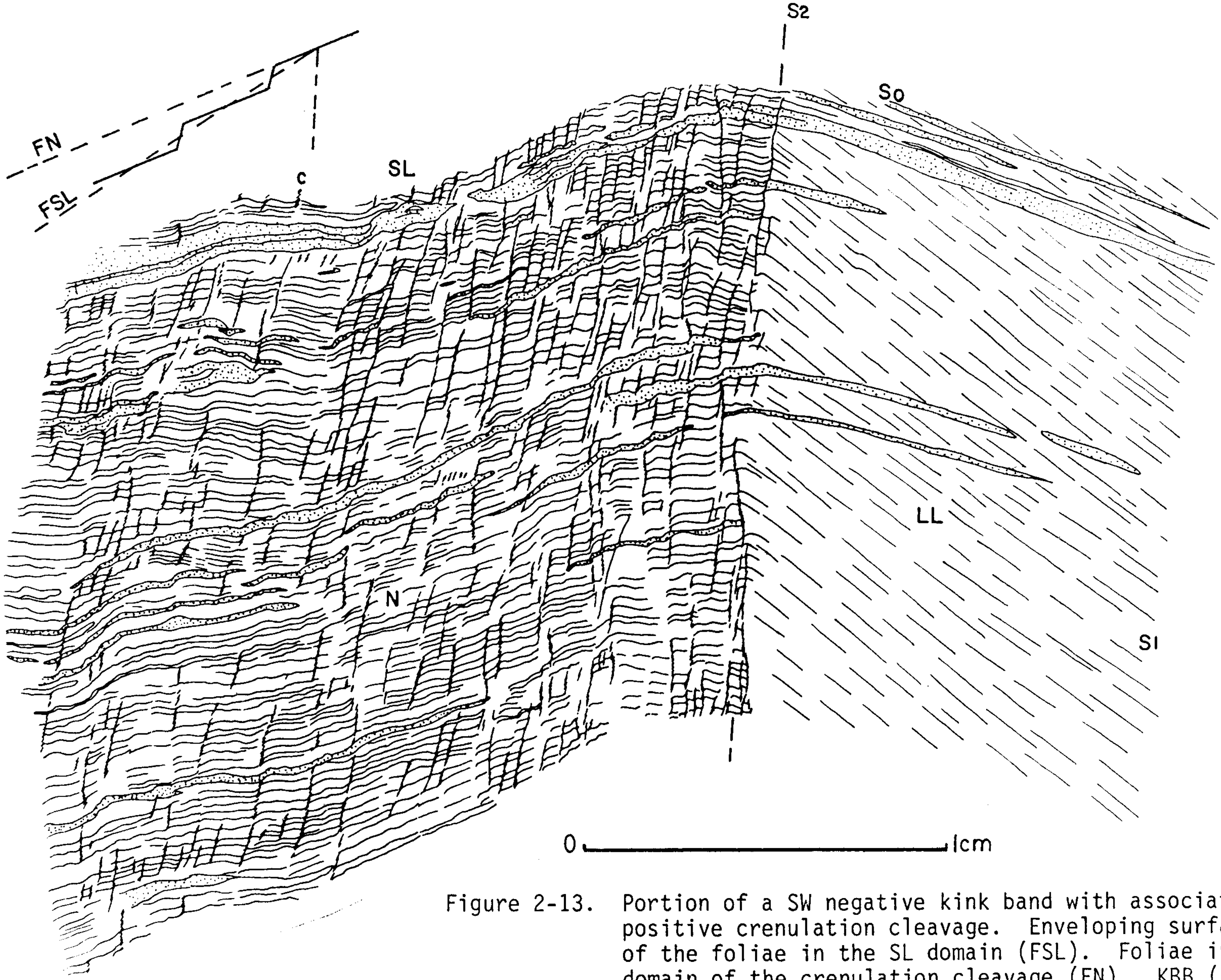


Figure 2-13. Portion of a SW negative kink band with associated SW positive crenulation cleavage. Enveloping surface trace of the foliae in the SL domain (FSL). Foliae in the N domain of the crenulation cleavage (FN). KBB (S2). Non-cleavage domain (N). Cleavage domain (C).

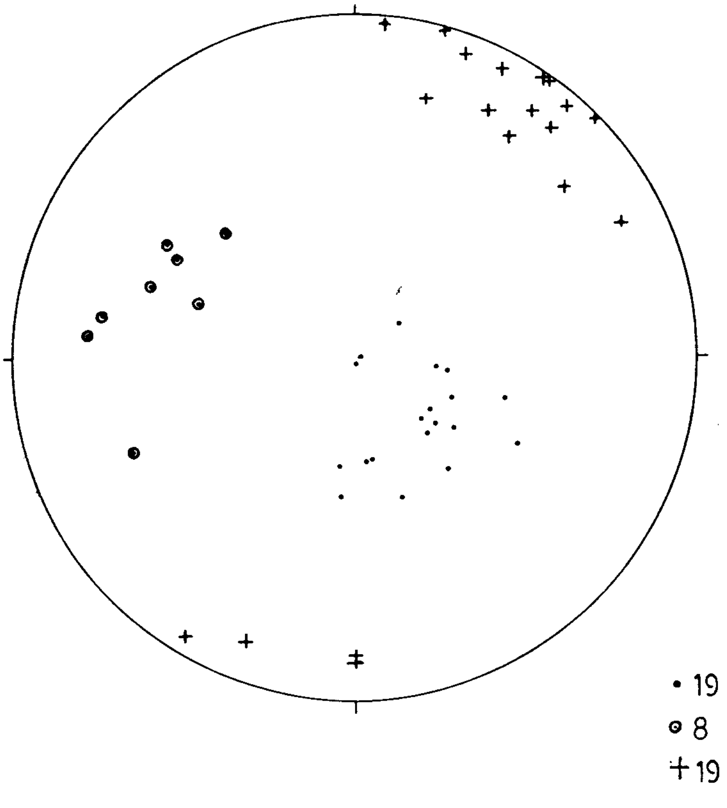


Figure 2-14. Orientation data of NE negative kink bands and regional foliation (S1) folded by them, plotted on the lower hemisphere of an equal area projection. Black dots represent poles of the KBB's (S2), crosses indicate hinge line (L1) and circles with a dot in their center are the regional foliation poles (S1). Numbers to the right of this diagram are numbers of point plotted.

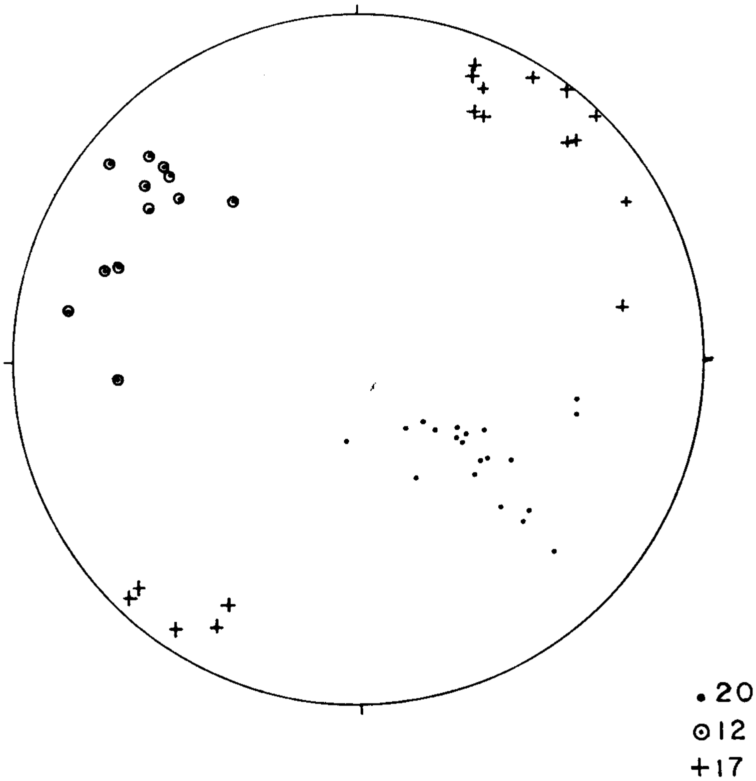


Figure 2-15. Orientation data of the SW negative kink bands and the regional foliation (S1) folded by them, plotted on the lower hemisphere of an equal area projection. Black dots represent poles of the KBB's (S2), crosses indicate hinge lines (L1) and small circles with a dot in their centers are the regional foliation poles (S1).

2.3 Concentric Folds

Concentric folds are those folds in which the thickness of the folded layers, measured normal to the layer is constant and in profile define approximately circular arcs. A combination of terms used in the description of folds as seen in profile (Hobbs *et al.* 1976, p. 170) and Ramsay's dip isogon classification (Ramsay 1967, p. 365) will be used to group these folds.

Morphology

Concentric folds occur commonly in metapelites. They are rarely present in metapsammitic layers and commonly die out before reaching the contact between an adjacent psammitic layer. They are generally cylindrical, harmonic, open rounded folds, with interlimb angles varying between 110° and 150°. Low amplitude and long wavelength are characteristic (Figure 2-16).

Where concentric folds are associated with fault terminations, they show many parasitic folds related to the deformation at these terminations (Figure 2-3). Sometimes, they are associated with kink bands with only one sense of vergence (Figure 2-17). Small folds in the metapelites commonly show microcrenulations, which in many cases present at their limbs a well developed crenulation cleavage forming small angles (5° - 15°) with the axial plane (Figure 2-18).

Figure 2-16. Sketch from an outcrop located between 65 m and 75 m of the cross section AA'. Concentric folds (class 1C) with their axial plane foliation (S2) dipping NW and their hinge lines striking NE and gently plunging SW.

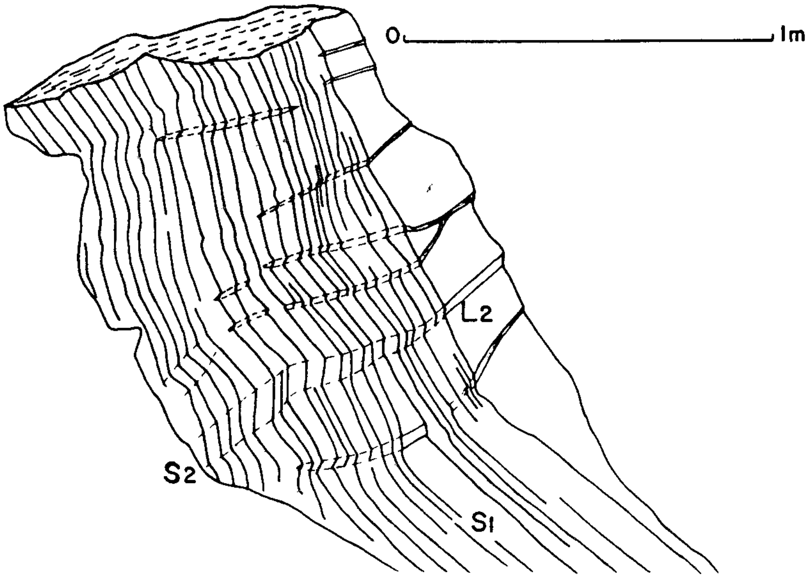


Figure 2-17. Outcrop located at 18 m of the cross section AA'. NE negative kink bands dipping NW approximately parallel to the axial plane of a concentric fold. Notice that all the kink folds present the same vergence.

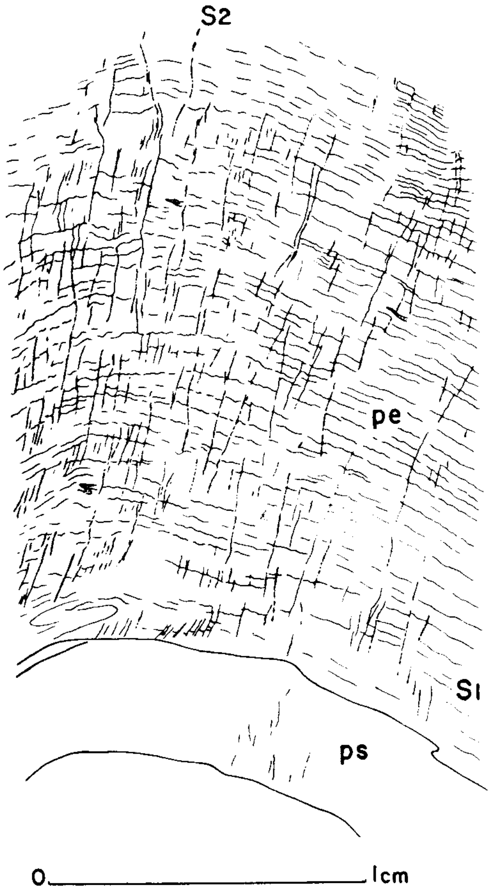


Figure 2-18. Small concentric fold cut perpendicular to its hinge line. Crenulation cleavage (S2) subparallel to the axial plane is better developed in the metapelitic layer (pe) than in the metapsammitic layer (ps).

Occurrence

Concentric folds occur mainly in rocks with a very well developed pre-existing foliation. Although this planar anisotropy is widespread through the Chatham fault zone, the concentric folds are scattered. Orientation data for concentric folds in the area are presented in Figure 2- 19. These folds plunge shallowly toward the NE and SW. They show the same axial plunges as the kink bands, and axial planes with the same strike. Their axial plane, however, dip mainly toward the SE, at angles between 35° and 90°.

2.4 Crenulation Cleavage

Crenulation cleavage is particularly well-developed in rocks rich in micas of medium to low grade metamorphic environments. The main feature which distinguishes it from other cleavages is the association with a microfolded pre-existing fabric. Concentration of phyllosilicates at the microfold limbs produces the cleavage. Thus, a microfolding can exist without crenulation cleavage, specially if it is weakly developed, but crenulation cleavage cannot exist without microfolds.

Classification

Crenulation cleavage displays a diversity of morphologies (Gray 1977a), and this probably was the reason why earlier workers (Dennis 1972, Williams 1972, Durney 1972 and Trouw 1973) used different nomenclature, sometimes implying a particular genesis. Gray (1977b) discussed this problem and proposed a morphological classification based in the cleavage microfabric. He employed the term crenulation cleavage, initially introduced by Rickard (1961, p. 325), modified by the prefix discrete or zonal, and defined these end members as follows:

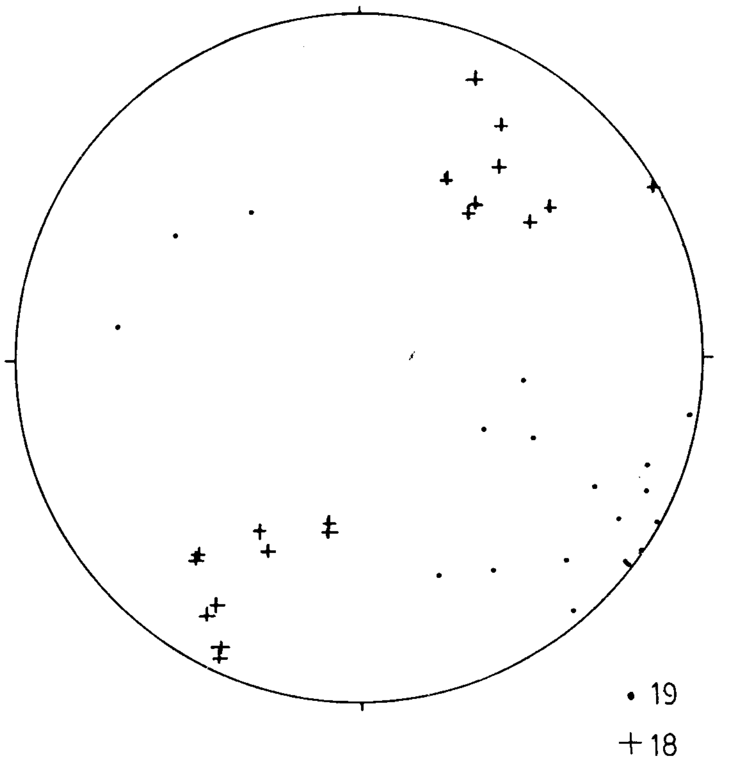


Figure 2-19. Orientation data of concentric folds, plotted on the lower hemisphere of an equal area projection. Black dots represent the axial plane poles (S2) of the concentric folds. Crosses are the hinge lines (L2). Numbers to the right of this diagram are numbers of point plotted.

"Discrete crenulation cleavage. - The cleavage has sharp, distinct boundaries which truncate the initial fabric", and "Zonal crenulation cleavage. The cleavage is a zone and has diffuse somewhat arbitrary boundaries through which the initial fabric is continuous" (c.f. Gray 1977b, p. 235).

Later, Powell(1979, p. 5) included these types of crenulation cleavage in a broader group termed "spaced cleavage". In this work I will adopt Gray's classification.

Microstructures

Discrete and zonal types in the Chatham fault zone are gradational classes, as is also pointed out by Gray (1977), and they can occur together in the same specimen. Often the cleavage morphology changes gradually from one type to the other, along the length of the cleavage planes (Figure 2-20).

A very common feature is a strong deflection of the cleavage traces near bodies with different mineralogical composition and/or bigger grain sizes. Where the cleavages approach the bodies (veins, bedding, lenses or layering) they become more discrete types, their traces rotate in the opposite sense that the cleavage domains (C) do with respect to the non-cleavage domains (N), and the acute angle between phyllosilicates in the C domains and C domain boundaries decreases. Usually, when the bodies are thick lenses or layers with coarse grain size, the cleavage does not cross them but ends at their boundaries (Figure 2-21).

Discrete crenulation cleavage: These cleavage are thin dark differentiated zones formed by aggregates of subparallel phyllosilicates making a small angle (less than 5°) with the cleavage domain boundaries (Figure 2-22). This type of cleavage has been considered a discontinuity in the

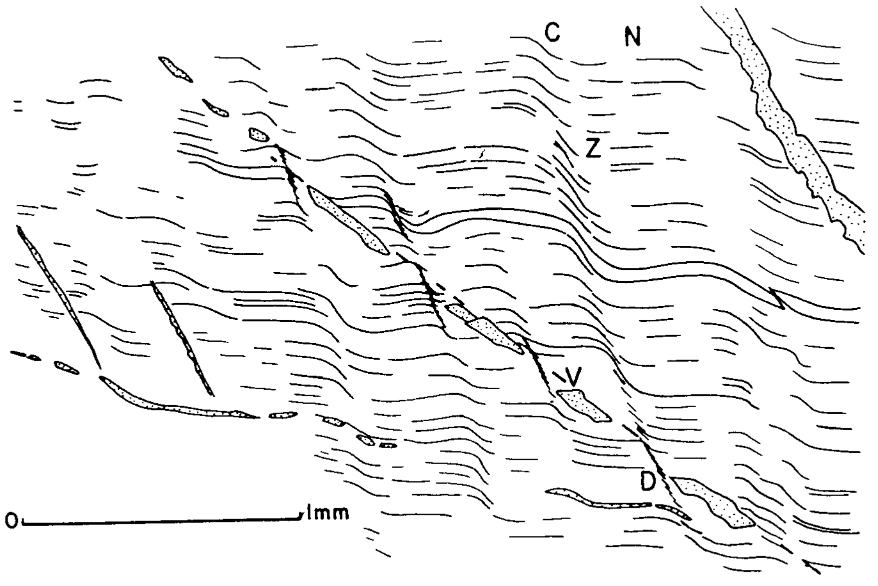


Figure 2-20. Crenulation cleavage changes gradually from zonal (Z) to discrete (D) while the cleavage approaches the segmented vein (V). The dashed line that connects the different segments of the vein V has not undergone offset parallel to the crenulation cleavage plane. Cleavage domain (C), Non-cleavage domain (N).

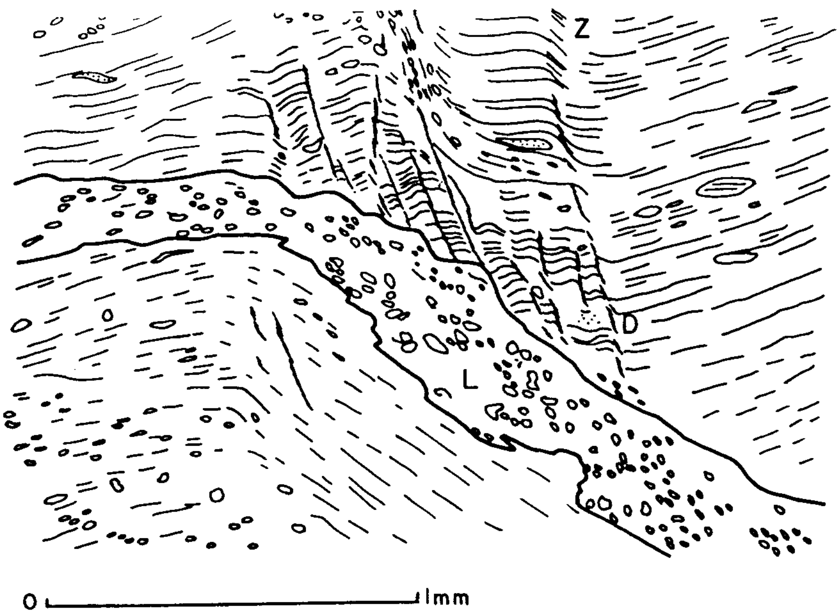


Figure 2-21. Crenulation cleavage changes gradually from zonal (Z) to discrete (D) type, while the cleavage approaches the quartz-rich layer (L). Notice that the cleavage does not cut through the layer.

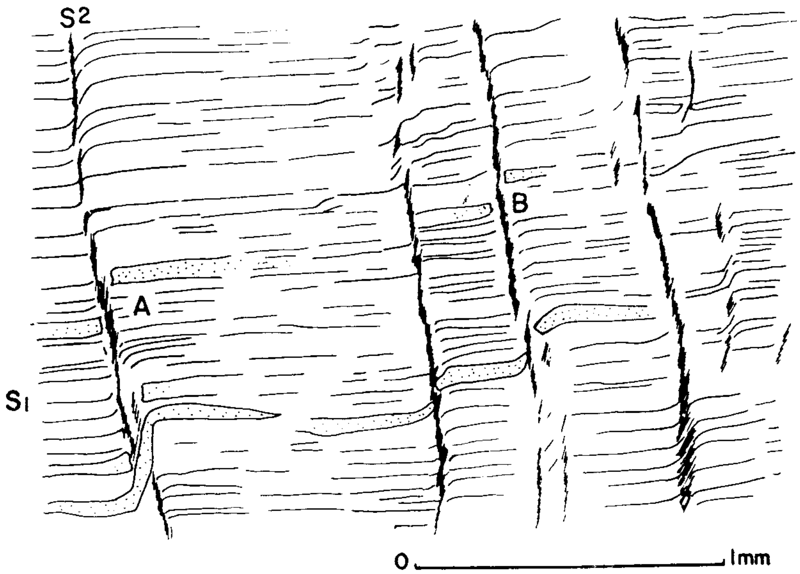


Figure 2-22. A and B show dark discrete crenulation cleavage (S2) along which a pre-existing lithological layering (S1) has been offset.

crenulated fabric and they are often shown truncating and offsetting both layering and veins (Williams 1972, Hobbs et al. 1976, p. 218). In the particular specimen showed in the Figure 2-20, the pre-existing layering (L) is offset at the cleavage, but the dashed line connecting the wall traces of the pre-existing vein (V) has not undergone offset parallel to the crenulation cleavage plane. However, there are cases where both pre-existing layering and veins are truncated and offset at the discrete crenulation cleavage (Figure 2-23).

Where the cleavage shows a strong deflection, evidence of cracking or fracturing at the truncated terminations has not been observed and the quartz is not particularly undulose. Phyllosilicate grains along discrete crenulation cleavage show no kinking of individual grains. The phyllosilicates defining the discrete cleavage domains are more closely packed than those in the N domains. The C domains have a different mineralogy to that of the N domains. They show a deficiency of quartz and preponderance of mica, carbonaceous material and opaques relative to the N domains.

Zonal crenulation cleavage: Zonal cleavage correponds to phyllosilicate domains coincident with the limbs of microfolds (Figure 2-20). This cleavage consists of parallel, closely packed phyllosilicates grains, which sometimes enclose thin lenticular quartz grains. Those cleavages whose morphology change gradually from zonal to discrete show a decrease in the quartz/phyllosilicate + opaques ratio, where they become more discrete. The quartz grains show the same intensity of undulose extinction in both C and N domains.

In a crenulated multilayer fabric, the quartz-rich layers at the C domains become thinner or they are gradually pinched (Figure 2-20). In other cases, the C domains die out at the quartz-rich layers and

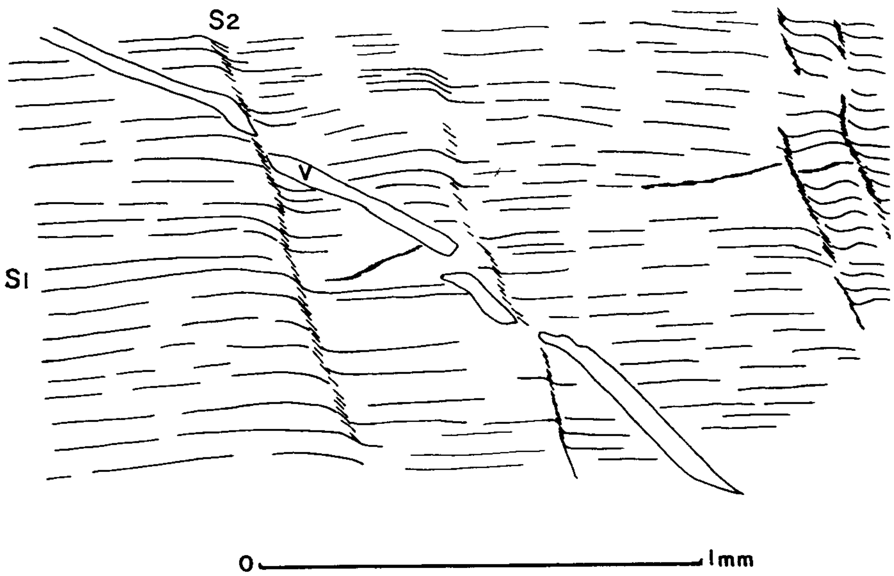


Figure 2-23. Dark discrete crenulation cleavage (S2) across which pre-existing vein (v) and layering (S1) is offset.

these conserve their thickness and are not deflected. Where quartzose layer thickness or the microfold interlimb angle decreases, the cleavage development and the deflection and pinch out of the quartzose layer are more evident.

Orientation Data

Crenulation cleavage (S2) has a variable strike from NS to EW, but the NE strikes are the most consistent. The foliation typically dips to the SE at angles varying on 20° to vertical. The lineation at the intersection of the regional foliation (S1) and the crenulation cleavage planes strikes NE and plunges gently toward the NE and SW (Figures 2-24).

2.5 Slaty Cleavage

Early workers used this term to describe the fabric responsible for the fissility of slates. A distinctive feature of these fissile rocks is a planar orientation of inequant and/or platy minerals.

Slaty cleavage is an established term and in this work I will use it as a general term to describe the regional foliation, and in that way to include all morphological variation that this cleavage shows in the Chatham area.

Microstructures

Multilayer fabrics with contrast in layer competence: Rocks with multi-layer fabrics consist of alternating pelitic and psammitic layers with a well-developed cleavage marked by narrow dark film-like domains (F) in the pelitic layers. The cleavage morphology in folded pelitic layers depends on their location within the structure and the tightness of folds. In an incompetent pelitic layer folded between two competent

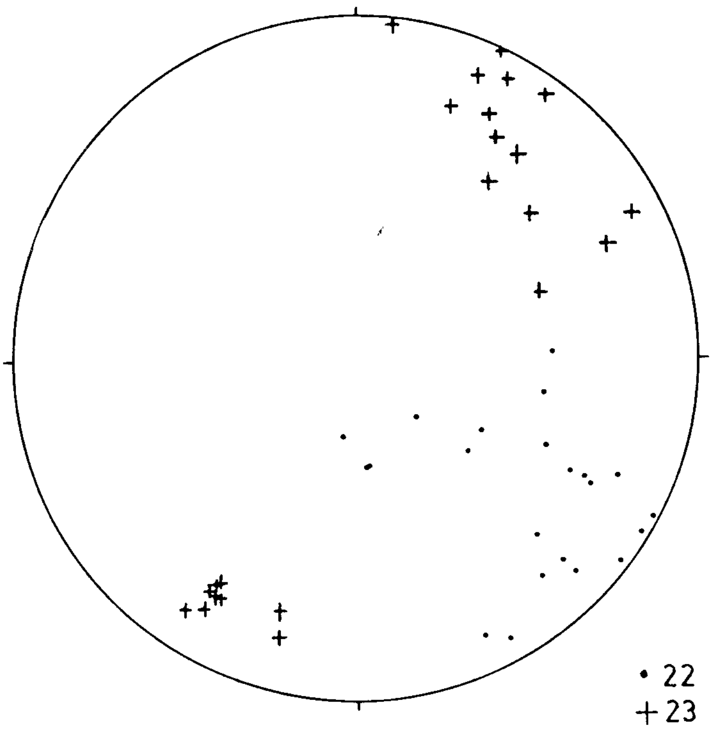


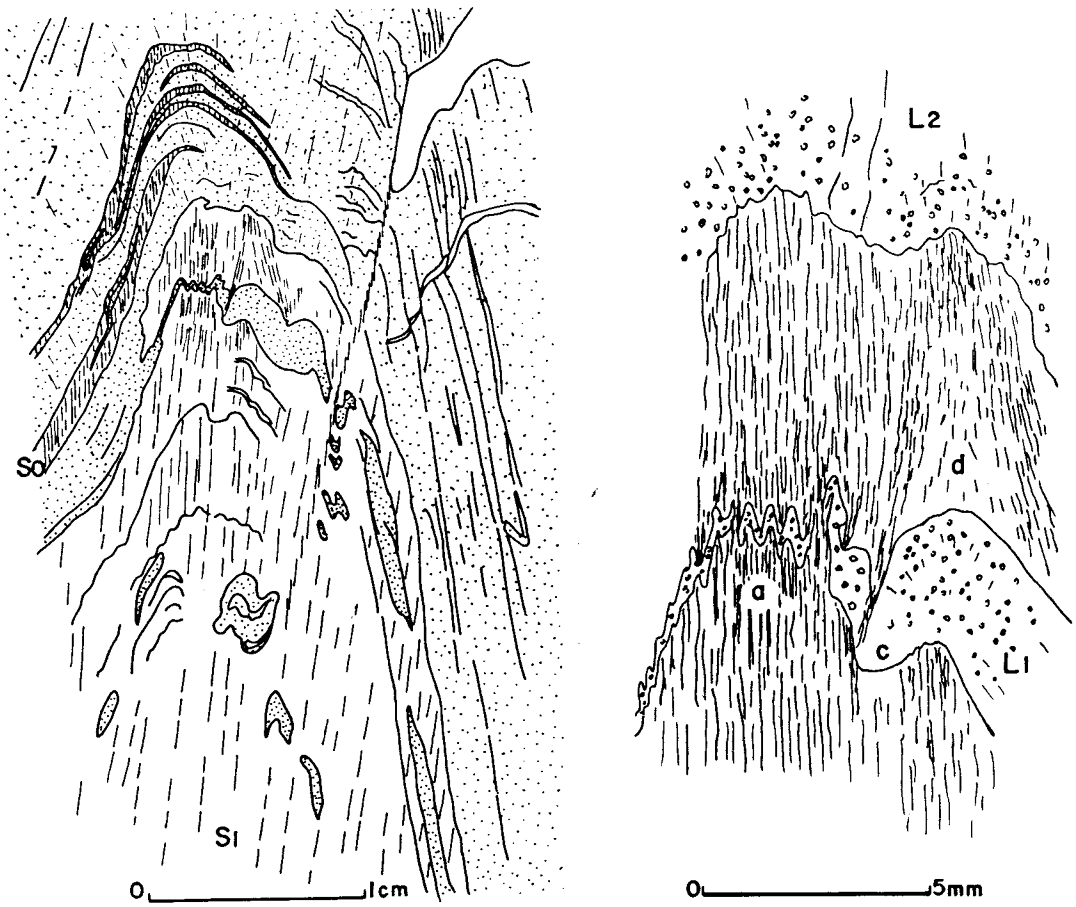
Figure 2-24. Orientation data of the crenulation cleavage, plotted on the lower hemisphere of an equal area projection. Black dots represent the crenulation cleavage plane poles (S2), and the crosses the regional foliation-crenulation cleavage intersection line (L2). Numbers are the points plotted.

psammitic layers, the cleavage becomes more anastomosing and better developed from the external arc of the layer L1 to the internal arc of the layer L2 (Figure 2-25B), and from the hinge zones to the limbs. On the other hand, with increase in the tightness of the folds, the cleavage is better developed, and the divergent fan fabric showed in open folds changes to an axial plane fabric in tighter folds (Figure 2-25B, letters d and a, respectively).

In the vicinity of the inner arc of a folded psammitic layer, several film-like domains coalesce to eventually form a single, very dark, wide film-like domain which in some instances cuts through the psammitic layers (Figure 2-25B, letter c). While the cleavage becomes more penetrative the number of film-like domains increases forming an anastomosing fabric (Figure 2-26). It shows lenticular domains (L) consisting mainly of chlorite, muscovite and quartz with small amounts of plagioclase. Chlorite pods are present in about 10% of these domains. The pods have within them interleaved micas. Most pods show evidence of deformation, mainly bending and kinking of the grain (Figure 2-27). These deformed grains sometimes coexist with unstrained grains. In some of these grains the mica composition changes along the same grain (Figure 2-28). The quartz grains,on the other hand, show no changes in their undulose extinction from one domain to the other.

Some psammitic layers contain fine pelitic bands. Their micas and chlorites are kinked and the cleavage bisects their limbs parallel to the axial plane of the fold (Figures 2-25B letter c and 2-29).

<u>Multilayer fabric without contrast in layer competence</u>: In those rocks where bedding is expressed by faint color differences and subtle



A B

Figure 2-25. A) Disharmonic approximately similar fold (class 3) develops in a multilayer with contrast in layer competence. B) Detail of the folding at the hinge zone of the above fold. Divergent fan cleavage is characteristic in open folds with thick psammitic layers (d). Axial plane cleavage is related to tight folds developed in thin psammitic layers (a). Film-like domains sometimes cuts through psammitic layers.

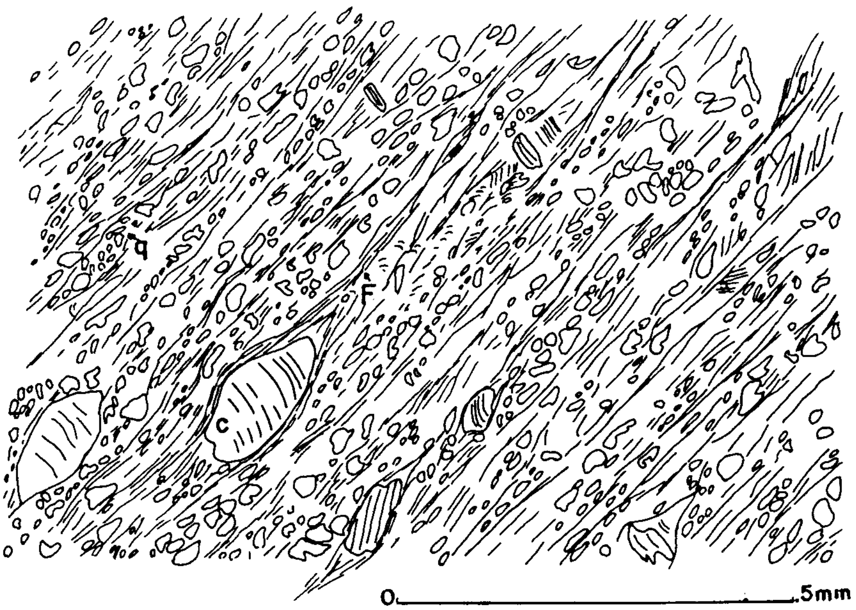


Figure 2-26. Slaty cleavage in phyllite. Layer-silicate-rich domain anastomose around large chlorite grains (c) and aggregates consisting of quartz grains (q). Film-like domain (F).

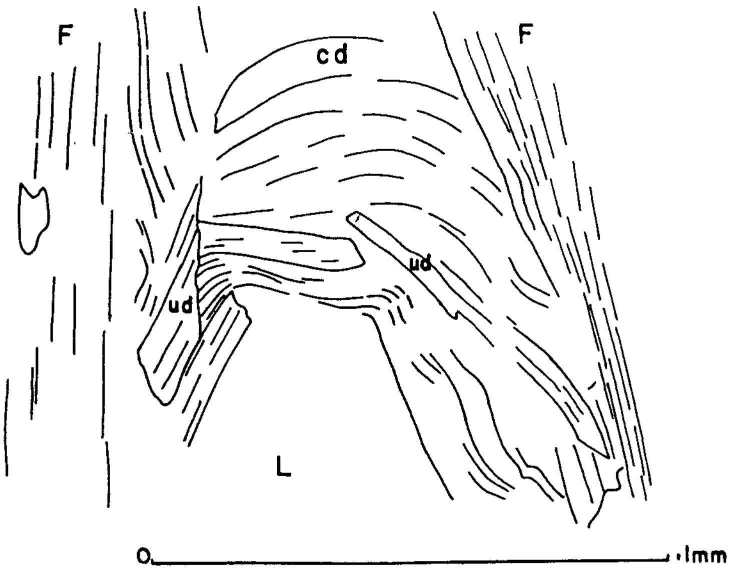


Figure 2-27. Chlorite pods show several deformed grains (cd) and unstrained grains (ud) in lenticular domain (L) between layer-silicates-rich domains (F).

Figure 2-28. Large mica grain forming a lenticular domain surrounded by anastomosing layer-silicate-rich domain. Notice that this grain changes its composition from its center (biotite (?) Bi) to its edges (muscovite, Mu), along its length.

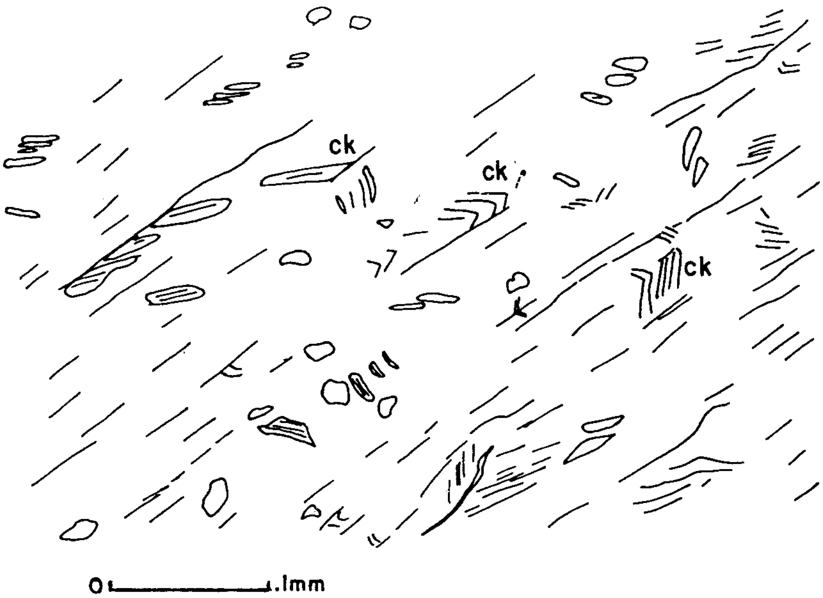


Figure 2-29. Pelitic layer containing kinked chlorite (ck) grains whose KBB's are parallel to the cleavage.

compositional layering (Figure 2-30), there is not a strong contrast in the mechanical properties of the different layers, and the cleavage morphology is more homogeneously developed throughout the specimen. The L domain (lens domains) become less prominent and the F domains broader. A characteristic feature of this type of rock is a strong preferred orientation of micas.

Small pyrite crystals are common in layers with abundant carbonaceous material. They may form agglomerates with associated mica beards strongly oriented parallel to the cleavage. Other common minerals are calcite and quartz with undulose extinction.

Occurrence

Slaty cleavage is the regional foliation of the Chatham area. It is steeply SE-E dipping, commonly between 45° and 90°, and strikes mainly NE with small deviations to the E and N. In general, this foliation is oriented striking roughly perpendicular to the direction of tectonic transport indicated by fault striations, and parallel to the strike of the fault set F1 (Figures 2-1A and 2-31), but dipping at steeper angles to the SE than the fault set F1 does.

2.6 Folds with the regional foliation as their axial plane foliation

The style of these folds varies considerably. They are commonly cylindrical, but in those outcrops where they are exposed for several meters along their hinge lines, they show non-cylindrical shapes. The interlimb angle (Fleuty 1964) varies from 20° to 90° and increases in the direction of displacement of upper blocks as indicated by fault striations, i.e., from SE to NW. The amplitude and wavelength of these folds are difficult to determine due to the intense disruption of the fold systems by faulting or erosion.

Figure 2-30. Similar fold (class 2) in a phyllite with slaty cleavage as its axial plane foliation. Reverse fault (f) forms small angle with the cleavage.

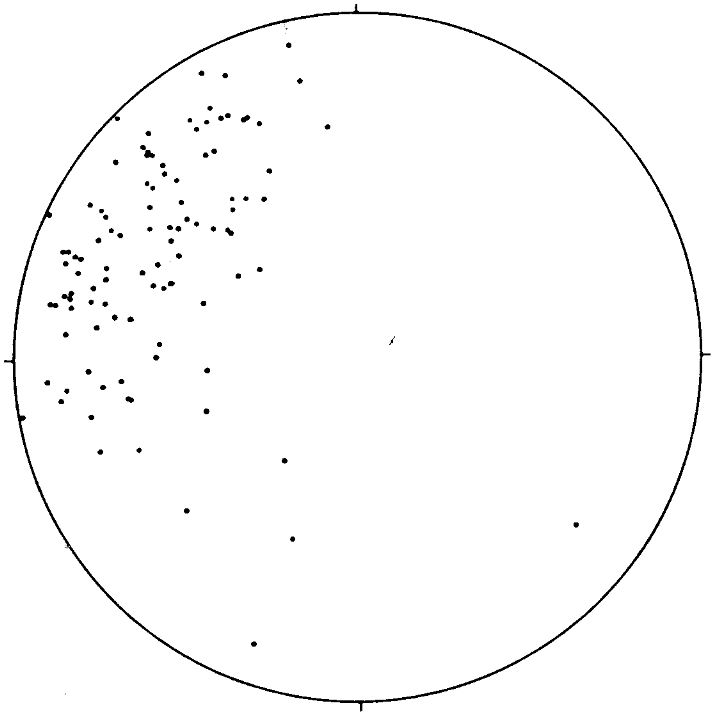


Figure 2-31. Orientation data of the slaty cleavage (regional foliation, S1), plotted on the lower hemisphere of an equal area projection. Black dots represent the poles of the slaty cleavage planes. Number to right of the diagram are the points plotted.

Folded multilayer complexes with contrast in layer competence: In the psammitic layers the folds approximate commonly to the rounded concentric style (Figure 2-32). Parasitic folds developed in competent layers show more acute interlimb angles while the layer decreases in thickness laterally (Figure 2-25B).

Where larger fold systems are exposed, the folds are mainly asymmetrical and non-cylindrical with their plunge reversing along their length, this type of fold is better developed in psammitic layers and commonly the fold system is disrupted by faulting parallel to the layers at the fold limbs (see cross section CC' at 165 m).

In these multilayer complexes the thick pelitic layers show axial plane cleavage, whereas the thin ones divergent fan cleavage. In psammitic layers the cleavage is divergent fan type (Ramsay 1967, p. 405). Folds in alternating psammitic and pelites show fanning and "refraction" of the axial plane foliation.

The psammitic layers show convergent fan patterns of veins (Ramsay 1967, Figure 7-65) which are commonly offset by microfault zones or micro faults parallel to the layering (Figure 2-33). The sense of displacement at these shear zones is the same as that predicted by Donath (1962) in his model of flexural-slip fold development. These veins are filled by recrystallized quartz grains with strong undulose extinction. The microfaults are filled by quartz with undulose extinction also, but the grains show cataclastic textures (fractures). In the brittle shear zones the foliation parallel to the layering shows a closely-spaced fabric, and it becomes more penetrative toward the external arc of the folded layer.

Other evidences of shear parallel to layering (So) has been observed in several outcrops. These surfaces show slickensides, whose striation-

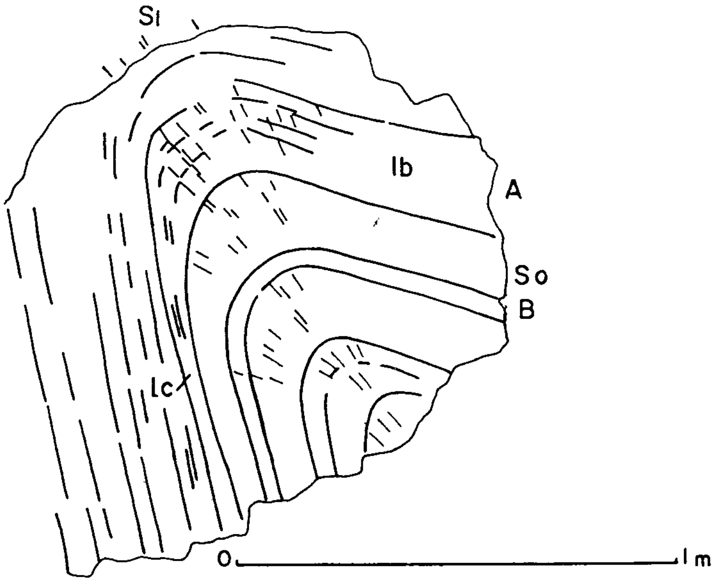


Figure 2-32. Sketch of an approximately concentric fold located at 165 m of the CC' cross section. Notice that the layers belong to different isogon classes, the layer A has one limb class 1b and the other 1c, on the other hand the layer B is fold class 1b.

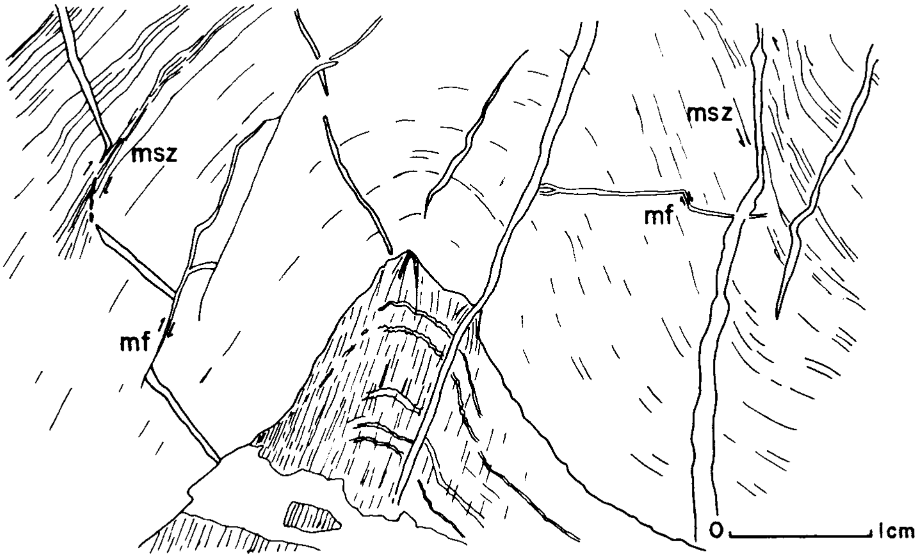


Figure 2-33. Concentric fold in psammitic layer showing a convergent fan pattern of veins, which are offset by microfault zones (mz) and microfaults (mf) parallel to the layering (So).

step combination present the same sense of shear given by the microfaults and microbrittle shear zones of the above example.

Folded microlayer complexes without contrast in layer competence: The folds developed in this type of fabric show the same style in all beds and this is approximately similar (Figure 2-34). Those folded multilayer complexes where the carbonaceous beds are closely spaced present better developed parasitic folds than those with more broadly spaced beds.

Occurrence

These folds are commonly better exposed in psammitic rocks or in the mica-quartz-carbonaceous material-calcite phyllites. The psammitic layers are poorly exposed in the Chatham area, but a good outcrop where these folds are well displayed is located on the New York State Thruway (west bound) in the cross section CC' between 160 and 180 m.

The hinge line of these folds and the lineation product of the intersection of the pre-existing layering (bedding and foliation ?) with the regional foliation (S1), have been considered parallel to the fold axis and plotted together (Figure 2-35). These lineations define approximately a great circle (N42E, 50S) with two maximum in N56E, 20N and N28E, 20E.

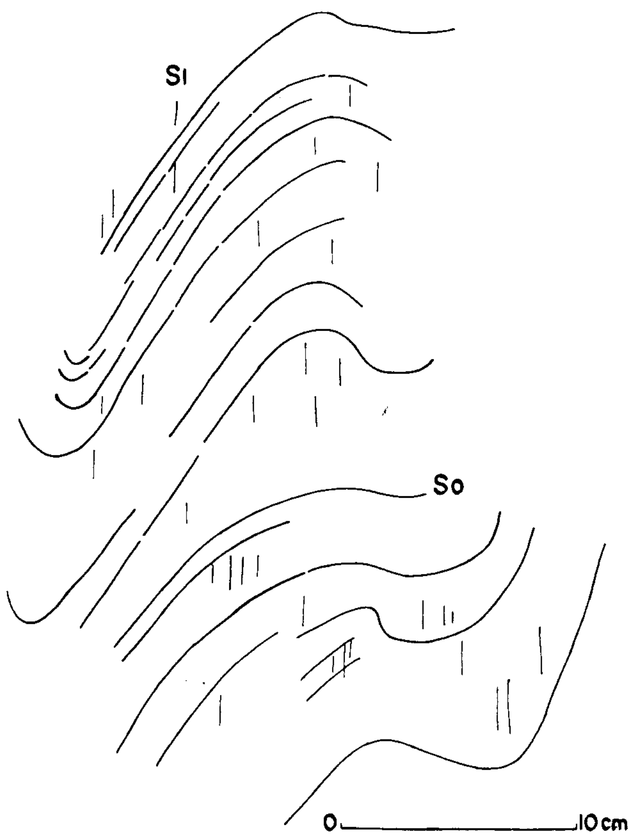


Figure 2-34. Disharmonic approximately similar folds with assymmetrical configuration.

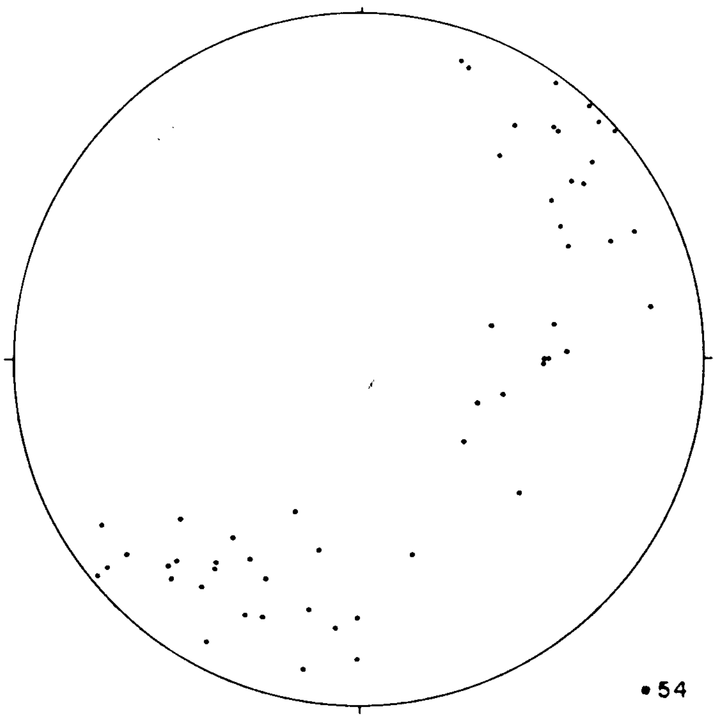


Figure 2-35. Orientation data of the hinge lines of the folds with the regional foliation as their axial plane foliation, and the S1-So intersection line. Number to right is the number of points plotted.

CHAPTER 3

CHRONOLOGY OF STRUCTURES

The Chatham fault zone is a multiply deformed region, and it is the subject matter of this chapter to distinguish generations of structures and to establish the order in which they formed.

In the determination of a generation of structures it is necessary to establish the structures believed to belong to the same phase of deformation and use the style criteria to group, throughout the area, the structures of each particular generation. The use of style for correlation in areas of discontinuous outcrop, such as the Chatham area, has been criticized (Means 1963, 1966; Williams 1970) on the basis that folds belonging to different generations can show the same style and orientation, and folds of the same generation may show different styles. In the determination of the relative age between different Chatham structures the overprinting and the style concepts were the criteria used.

3.1 Generations of Structures

First Generation of Structures

The first generation of structures (G1) includes the oldest folds of the Chatham area, designated here F1, and their associated foliation (slaty cleavage S1). They are refolded and faulted by the second generation of structures, but they do not fold any earlier tectonic structure*

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*However, in this work I could not demonstrate that the layering in the psammitic rocks is indeed bedding. On the other hand, one specimen showing disrupted layering (So) presents evidence of a possible earlier folding for the psammitic rocks of the Nassau formation (Figure 3-1, letter f). Another possible example is provided by the specimen illustrated in the Figure 2-25A.

(Figures 2-30, 3-1, 3-2, see the cross section EE' between 105 and 110 m).

These folds show a considerable variation in style, but all present: (1) as their axial plane foliation the regional foliation, (2) the same metamorphic grade (chlorite zone of green schist facies), and (3) similar orientation patterns.

All the folds with the above characteristics belong to G1, but it does not mean that all of them were simultaneously generated during the deformation event in which they were developed, or that all G1 structures are older than all G2 structures (see chronological significance of the generation concept in Hobbs et al. 1976, p. 354).

Second Generation of Structures

The second generation of structures (G2) includes kink bands, concentric folds and the fault systems of the Chatham fault zone. Kink bands and concentric folds, termed F2 folds, were grouped under this generation for the following reasons: (1) they show associated crenulation cleavage and in both fold style it is not an ideal axial plane foliation, (2) both kink bands and concentric folds show the same orientation pattern, (3) both fold the regional foliation.

The conjugate fault systems of the Chatham fault zone are considered here structures developed synchronously with the folding of the regional foliation (S1) at least during an interval of time. The duration of the faulting and the folding (F2) and their overlapping in the time scale could not be determined with available information. Evidences that both faults and F2 folds are related to the same deformation event are: (1) these fault systems cut and offset the G1 structures (see cross sections), (2) these faults also cut and offset kink bands (Figure

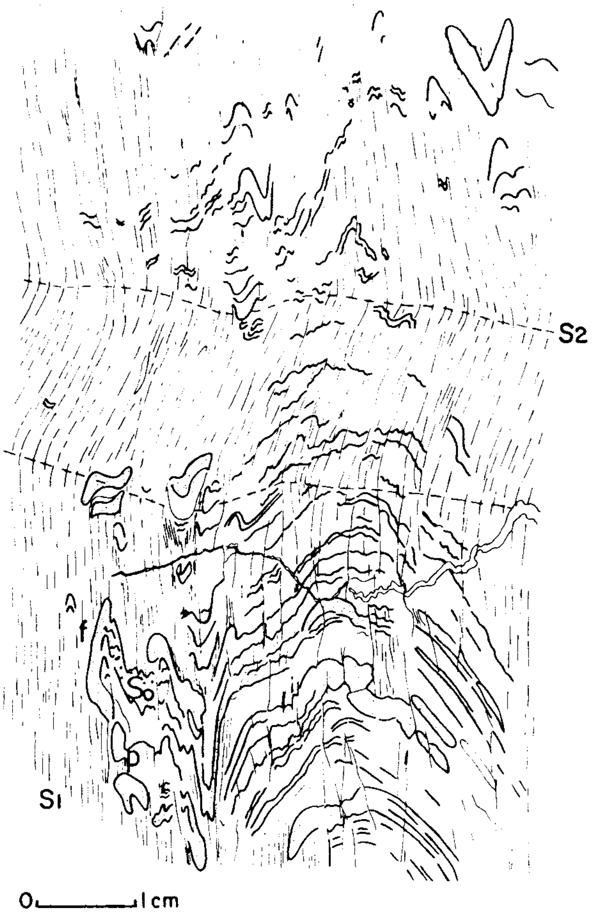

Figure 3-1. Similar fold (f1) in rocks of the Nassua formation folded by kink band (f2). Layering (So) is intensely disrupted. In the left-bottom corner (f) of the figure a psammitic layer (p) show a fold-like feature, which probably represents an earlier folding event for these rocks. Slaty cleavage (S1), KBB's (S2).

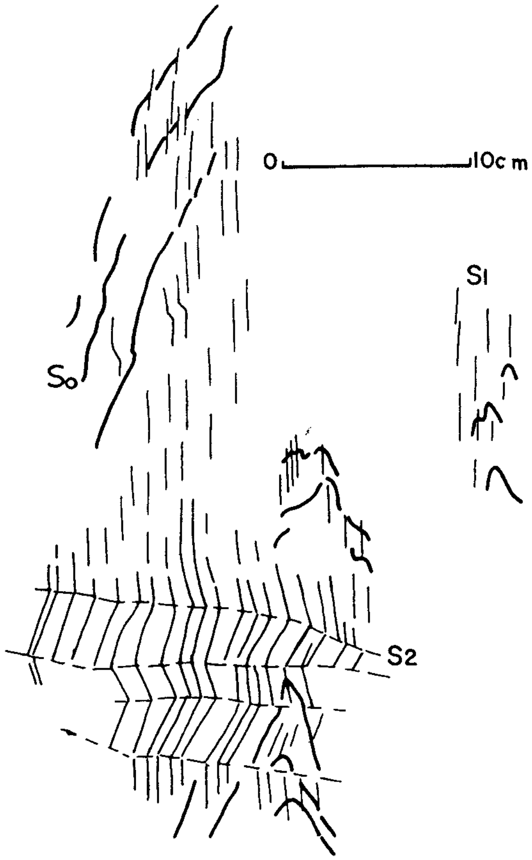

Figure 3-2. Similar fold (f1) in rocks of the Wallomsac slate folded by kink band (f2).

3-3 and cross section EE' at 170 m) and (3) kink bands fold these faults (Figures 3-4, 3-5 and cross section AA' between 85 and 90 m, and between 50 and 55 m).

3.2 Geometrical Analysis

G1 Structures

The hinge lines of F1 folds and the lineations produced by the bedding (So)-regional foliation (S1) intersection, designed here L1 lineations, plot in a great circle whose average orientation is N42E, 50S (Figure 2-35). The F1 folds show gently curved hinge lines (Figure 3-6)and their non-cylindrical geometry must be partially responsible for the changes in F1 axis orientation, but it alone could not explain the large change in the strike of these lineations from NE to NW. These lineations are also contained in the regional foliation (S1), and the changes in orientation of this surface (Figure 2-31) must affect their attitude. The combination of these two geometries may explain the orientation pattern of the L1 lineations.

The regional foliation and the axial plane of F1 folds are parallel, and they are designed S1. The poles of these planes describe roughly a family of great circles striking N20E and plunging toward the NW at angles mainly greater than 45°. The regional foliation traces describe on the terrane a curved pattern which is similar to the fault set f1 trace pattern suggested by Bell (1978), see Geological Map and Figure 1-1.

G2 Structures

The phase of deformation related with the generation of F2 folds includes the following geometrical features: (1) three different types of lineations: hinge lines of the kink bands and concentric folds, and

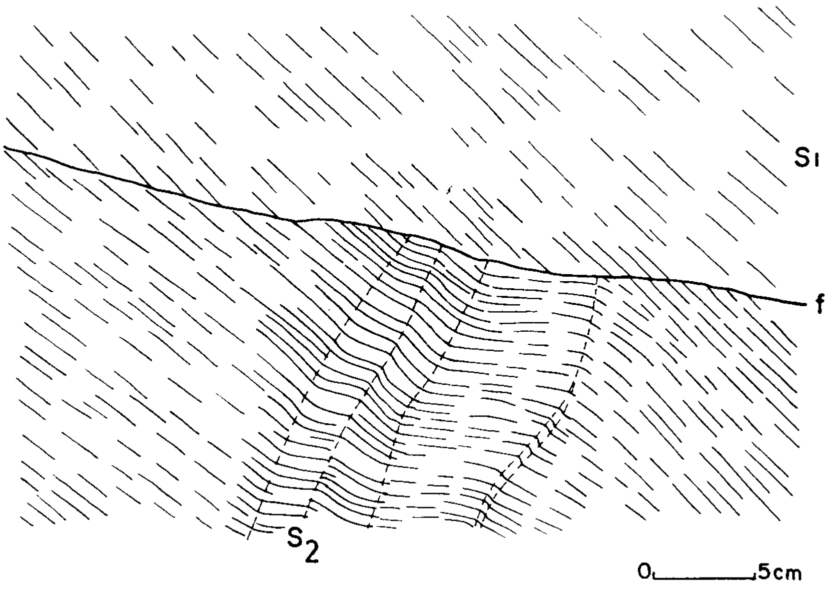

Figure 3-3. Sketch of a thrust fault (f) belongs to the set F1, where it cuts and offsets several kink bands (f2). This point is located at 87 m of the cross section AA'.

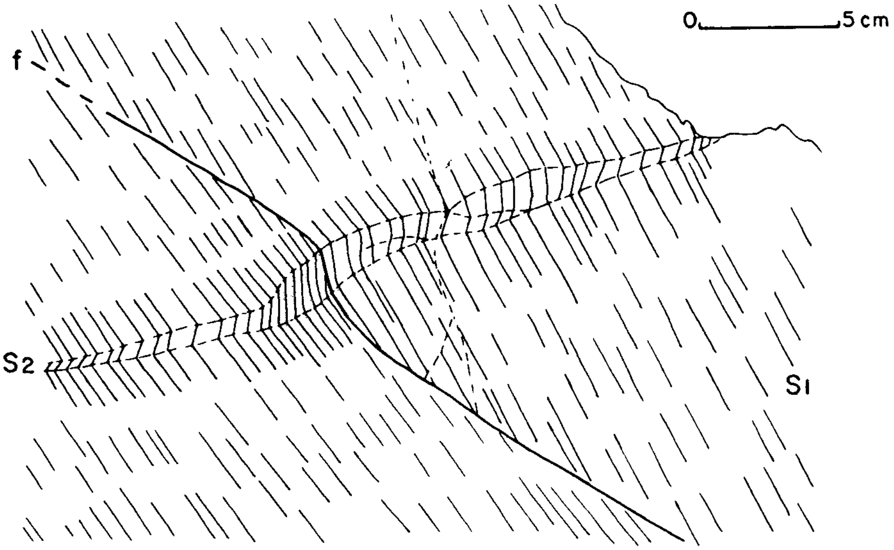

Figure 3-4. NE negative kink band folds a thrust fault (f) that belongs to the fault set F1. This point is located at 52 m of the cross section AA'.

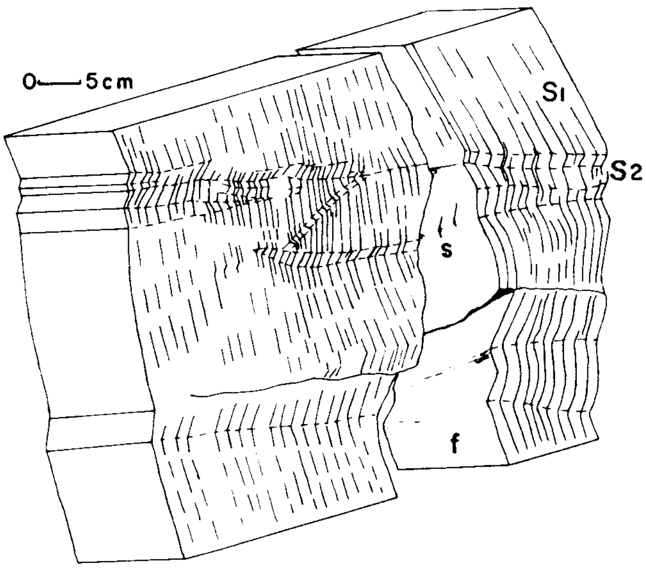

Figure 3-5. Several kink bands fold a fault parallel to the regional foliation. Fault (f), Striations (s).

the lineations produced by the crenulation cleavage-regional foliation intersection; these lineations are grouped here under the symbol L2a, where "a" means F2 fold axis. Another geometric feature related to these folds are: axial plane of the concentric folds, KBB's and crenulation cleavage planes; they are assigned here S2. L2a lineations strike NE and plunge gently toward the NE and SW. The S2 planes strike NE and dip mainly toward the SE with angles between 0° and 90°, and their poles define a partial girdle extending NW-SE across projection, (Figures 3-6 and 3-7, respectively).

The F2 folds have been developed in a gently folded pre-existing regional foliation (S1) (see Geological Map). The orientation of the L2a lineations reflects this gentle folding in an incomplete great circle (Figure 3-6).

The fact that the direction of displacement indicated by striations faults of f1 (Figures 2-1A) symmetrically divides the F1 and F2 axis orientations (Figures 2-35 and 3-6, respectively) probably indicates that the direction of tectonic transport of the rock bodies in the Chatham area was more or less constant and from SE to NW, during the deformation events that produced the G1 and G2 structures.

The fault set f1 often cuts and offset faults of the same set that are located ahead of them in the direction of displacement (see cross section AA' between 20 and 25 m, and from 60 to 65 m; and CC' between 110 and 120 m). This seems to indicate that the younger thrust faults are mainly developed in the hanging-wall of the older thrust faults. This type of stacking sequence has been termed overstep by Dennis 1967 (c.f. Elliot and Johnson 1980, p. 90).

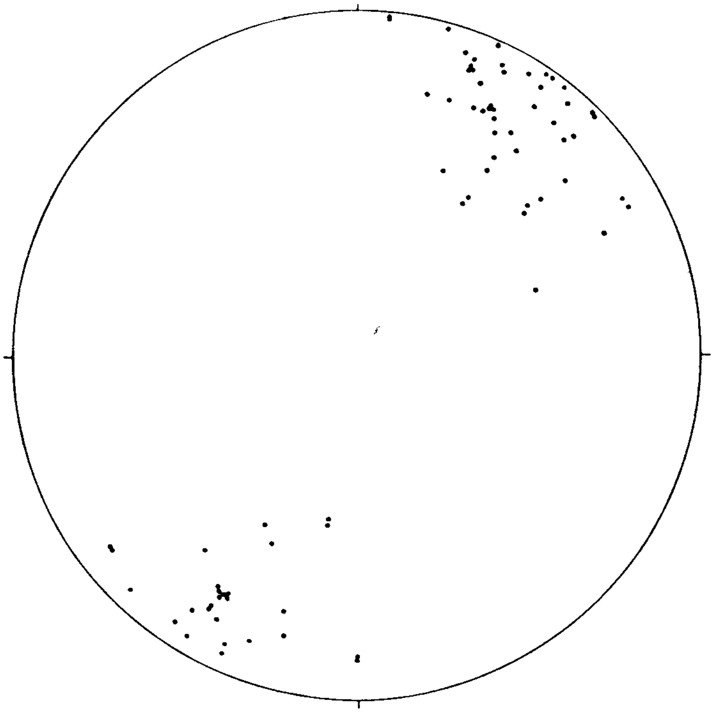

Figure 3-6. Orientation data of L2a lineations plotted on the lower hemisphere of an equal area projection. Black dots represent the F2 axis. Number to right indicates points plotted.

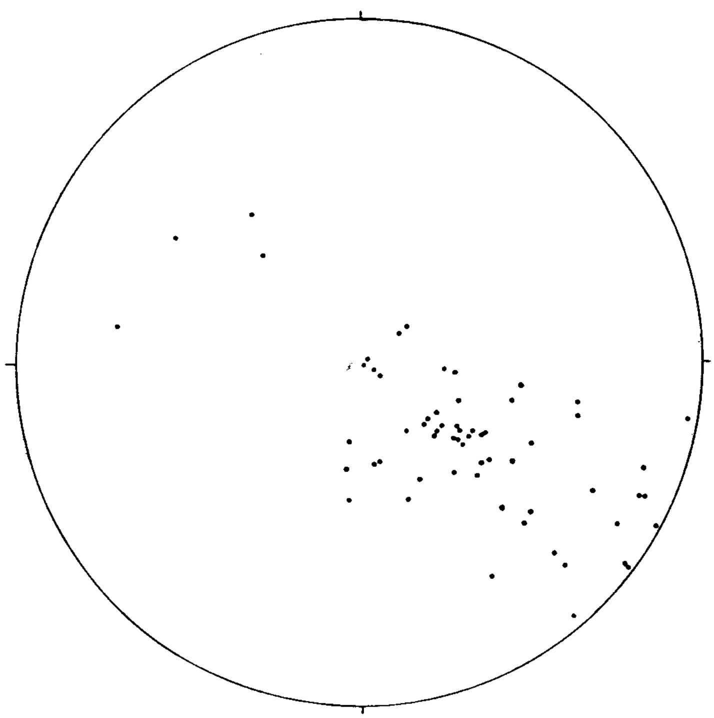

Figure 3-7. Orientation data of S2 planes plotted on the lower hemisphere of an equal area projection. Black dots represent the poles of the S2 planes, and the number to right of the diagram indicates the points plotted.

3.3 Correlation of the Chatham structures with structures elsewhere in the Taconic region

Zen (1972) has recognized three deformation events in the Taconic region. The first episode involves allochthonous rocks, which according to him were emplaced in unconsolidated to semiconsolidated state as submarine gravity slides into a sea receiving muddy sediments; evidence of this deformation are slump folds in the allochthon. Rowley (1983) recognized, in the Bomoseen area, this syn-depositional deformation, which he called D_0 deformation; he grouped under this deformation event, slump folds, chaotic disrupted sequences involving unsolidated or poorly consolidated sediments and normal faults to explain stratigraphic truncations within the allochthon. Rowley (1983) does not relate these syn-depositional deformation features with a major tectonic event as Zen (1972) does, but he considers that these structures occurred at virtually any time and any place during the deposition of the sediments. Syn-depositional structures have not been recognized in the Chatham area during the present work.

Syn-depositional structures and folds that pre-date the regional foliation and post-date the syn-depositional deformation are the most difficult structural features to recognize because they have been obscured by the intense deformation and recrystallization during the regional metamorphism (Taconic orogeny). Zen and Ratcliffe (1971) and Ratcliffe (1969, 1974a, 1974b) reported the existence of post-syn-depositional and pre-regional foliation minor folds both in the autochthon and allochthon. Rowley (1983, D_1 deformation) has claimed that this generation of folds was only developed in the allochthon during the assembly and obduction of the accretionary prism. The age of this deformation event has been constrained (Rowley 1983) between N. gracilis

(Fisher 1977) and O. ruedemanni (Riva 1974). Pre-slaty cleavage structures in the Chatham area are rare; only in some rocks of the Mettawee slate (Nassau formation) have they been recognized. Examples of them are fault crosscut by slaty cleavage (S1) and folded by F1 folds, and intrafolial folds developed in the metapsammitic layers of this formation folded by f1 folds (Figure 3-1, letter f).

The main regional deformation within the allochthon and subjacent para-autochthon (c.f. Zen 1972, p. 70) involves large, kilometer scale, tight to sometimes isoclinal west-verging folds, with an associated axial surface slaty cleavage. This event recognized by Zen (1972) as the second tectonic event is called D2 deformation by Ratcliffe (1979) and Rowley (1983), and occurred synchronously with the regional metamorphism of the Taconic orogeny. In the Chatham area both allochthon (Mettawee slate) and paraautochthon (Walloomsac slate) were deformed and metamorphosed during this event, named in this work G1. The age of this tectonic episode is given by the age of the metamorphism (Middle to Late Ordovician time) (Harper 1968 and Ratcliffe 1979).

Post-regional foliation structures (Zen 1972, 3rd tectonic event) are common throughout the Taconic region. Ratcliffe (1979) has recognized two generations of folds F4 and F5 trending NW and NE, respectively. The relative age between these two generations of folds changes from place to place (Ratcliffe 1979); sometimes F5 refolds F4 and in other cases F4 refolds F5. Rowley (1983) has also recognized two deformation events (D3 and D4) post-regional foliation; he assigned crenulation cleavage, mesoscopic and macroscopic folds and several thrusts including the Frontal thrust to the D3 deformation event; and vertical kink bands and normal faults to the D4 deformation. Rowley (1983) has related the crenulation cleavage development to his F3 folds and post-slaty cleavage (T3) thrusts; he has pointed out that at macroscopic scale, crenulation cleavage development appears to correlate spatially with T3 thrusts. In the Chatham fault zone the crenulation cleavage (S2) is oriented subparallel to the axial plane of the concentric folds and KBB of the kink bands; the kink bands fold the thrusts and they are cut by the thrusts (Figures 3-4 and 3-3, respectively). These evidences are consistent with Rowley's idea about the generation of the crenulation cleavage during the thrusting (T3).

The F2 folds of the Chatham area trend mainly NE and based on their orientations they could be correlated with the NE-trending folds (F5) of Ratcliffe (1979). No NW-trending minor folds were observed in the Chatham area, however the regional foliation (S1) in this area has been gently folded in a NW-trending macrofold, which reflects the geometry of the Chatham fault zone. This macrofold probably belongs to the F4 generation described by Ratcliffe (1979).

The Chatham fault zone post-dates the regional metamorphism of the Taconic orogeny, but how long after this significant part of the event it was developed is not clear. Ratcliffe and Bahrami (1976) and Ratcliffe (1979) based on stratigraphic and structural information and on the isotopic age of a phyllonitic muscovite (374 my) collected from the imbricated thrust zone at the contact between the Chatham and Everett slices, have suggested a Devonian (Acadian orogeny) or younger age for this fault zone. Bell (1978) based in the structural relationship between the Giddings Brook, Rensselaer and Chatham slices has proposed a post-Taconic age for the development of the Chatham fault zone. On the other hand, Rowley, Kidd and Delano (1979) have pointed out that the presence of a second cleavage (crenulation cleavage associated to T3 thrusts) is not necessarily associated with or indicative of a second, wholly separated and later event, in this case the Acadian orogeny. They suggest that the structures belonging to the D3 deformation (Rowley 1983) could have developed in a progressive deformation during the Taconic orogeny, and these structures represent the late stages of this orogeny. In the Chatham fault zone I did not find evidence to discriminate between the two opinions suggested above.

CHAPTER 4

CONCLUSIONS

The Chatham fault (Ratcliffe _et al._ 1975 and Bell 1978) is an anastomosing fault zone 0.4 to 1.4 km wide, dipping mainly between 80°SE and the horizontal with a 45°SE average dipping angle. Striations and steps on the fault planes indicate a predominantly NW direction of displacement of the hanging wall blocks during the thrusting. This fault zone juxtaposes rocks from the Walloomsac slate (Giddings Brook slice) and Mettawee slate (Chatham slice).

Two generations of structures are clearly recognized in the Chatham fault zone. The first generation (G1) is considered synchronous with the Taconic orogeny and includes mainly similar west-verging folds whose axes describe a great circle (N42E, 50S) symmetrical to the direction of later thrusting displacements. The regional foliation (slaty cleavage, S1) is the axial plane of these folds. This cleavage dips toward the SE, at angles between 45 degrees and vertical.

The second generation of structures (G2) are considered at least partially synchronous with the thrusting and they clearly overprint the pre-existing G1 structures. Two different styles of folds are present, kink bands and concentric folds. Both are associated with the development of the second generation of cleavage (S2) in the area. This cleavage (crenulation cleavage, S2) is locally developed in fine-grain rocks with a closely-spaced foliation. These structures are also symmetrically oriented with respect to the direction of thrust displacement. An important feature of these structures is the consistent NE trend of their gently NE-SW plunging fold axis (L2a) and the NW dip of their S2 planes.

Rocks belonging to Mettawee slate probably underwent an earlier deformation. This suggestion is based in an isolated case where I could observe an intrafolial fold folded by a F1 fold.

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