Maine Geological Survey
DEPARTMENT OF CONSERVATION
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OPEN-FILE NO. 83-6

Title: Analysis of Structural Features in Southern Piscataquis County, Maine

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Date: 1983

Financial Support: Preparation of this report was supported by funds furnished by the Nuclear Regulatory Commission, Grant No. NRC-04-76-291.

This report is preliminary and has not been edited or reviewed for conformity with Maine Geological Survey standards.

Contents: 17 page report

INTRODUCTION

The present study, done during a ten-week period in the summer of 1981, was initiated to determine if recent observations of seismicity in central Maine could be correlated with evidence of brittle failure as seen in bedrock structural relationships. A correlation, if found, might then explain the crustal motions responsible for both the structural features and the periodic energy releases documented by earthquakes. The study was confined mainly to a detailed examination of outcrops in the Sebec Lake, Sebec, and Schoodic 15-minute Quadrangles. In addition, some work was done in the Dover-Foxcroft and Guilford Quadrangles north of the Piscataquis River. Figure 1 shows the location of the study area with respect to previously identified and named topographic lineaments, as well as some earthquake epicenters.

PREVIOUS WORK

The area studied has not been mapped although several workers have done reconnaissance and/or detailed work in parts of the three quadrangles. Philbrick (1936) mapped the Onawa pluton, concentrating particularly on the well-exposed contact aureole that surrounds it. Miller (1945) described the occurrence of pyrrhotite at the Katahdin Iron Works and outlined the Ore Mountain pluton with which the sulfide mineralization is presumed to be genetically associated. Loiselle (pers. com.) mapped the Schoodic and Ebeemee plutons in a reconnaissance study in which he also described other granitic plutons as well as the gabbroic and dioritic rocks of Norway Point at the south end of Schoodic Lake in the Schoodic Quadrangle.

Griffin (1973) studied a broad area to the south underlain by sedimentary and metasedimentary rocks of the Merrimack Group of presumed Siluro-Devonian age[1] (Griffin, 1973, p. V11-V111). His work dealt with the problem of discriminating between syndepositional, soft-sediment deformation and subsequent Acadian deformation. Despite the detailed work of Griffin this problem remains. The definition of Acadian structures is extremely difficult precisely because of the soft-sediment

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[1]The thick sequence of sandstones, calcareous siltstones, and shales with minor limestone and conglomerate which comprises the several named stratigraphic units of the Merrimack Group are considered to have been deposited in a tectonically unstable and rapidly subsiding basin. These sediments, deposited mainly by turbidity currents, are of post-Taconic and pre-Acadian age. They were deformed and metamorphosed to varying degrees during the Acadian Orogeny. In recent discussions (see, for example, Hussey, 1981, p. 39-41) it is suggested that the Merrimack Group may include units as old as Late Ordovician. A Late Ordovician age was first suggested by Osberg (1980, p. 280) for units belonging to the Vassalboro Formation.

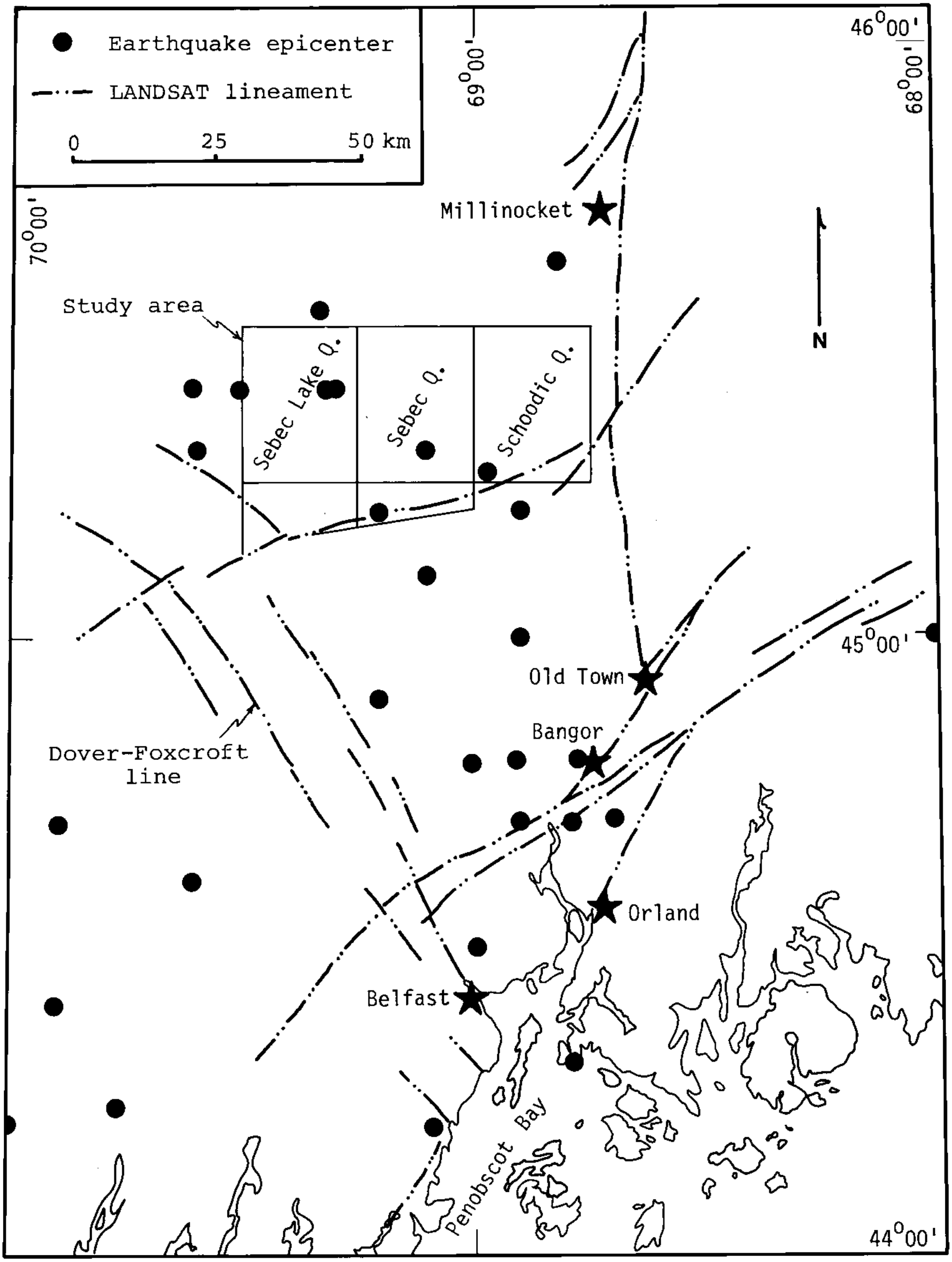


Figure 1

Map showing location of study area, topographic lineaments, and earthquake epicenters (Boston Edison Co., 1976; Figure 16 of Barosh, 1978) slump and other features Griffin documented so clearly and because of the facies changes he suggested. A Maine Geological Survey open-file map by Griffin (1976) contains data for portions of the Sebec Lake, Sebec, and Schoodic Quadrangles (Figure 2).

Pankiwskyj (1979) studied a large area in southern Piscataquis County (including a portion of the area described here). He concentrated on Acadian and post-Acadian deformation structures, modifying the pattern of map units and the structural features recognized earlier by Griffin. Pankiwskyj recognized no "recent offsets" in the area studied.

Westerman (1980) continued study of a portion of the area examined by Pankiwskyj and suggested that the Dover-Foxcroft line (Lee and others, 1977 and Figure 1) correlates, at least with respect to its orientation, with a "NW trending set of brittle fractures, which can be seen as the youngest deformational features in the area" (Westerman, 1980, p.67). These features are kink bands with generally steeply plunging axes. A left-lateral rotation sense is indicated by the configuration of deformed bedding and/or early cleavage within the kink zones. Fracture surfaces bounding the kink bands strike NW and dip steeply NE or SW.

The present study involved a review of previously identified Acadian structures in the study area, as well as evaluation of the "late" structural features, in addition to the primary task of examining the brittle structures evidenced in outcrop in the three-quadrangle area. Each of these will be discussed separately below.

STRUCTURAL FEATURES OF PRE-ACADIAN OR ACADIAN AGE

The oldest stratigraphic units in the area belong to the Sangerville Formation of Silurian age. The Sangerville includes generally thick-bedded, weakly calcareous, poorly-graded graywacke, sandstone and siltstone. It includes an argillaceous to silty limestone and a coarse-grained, poorly to well sorted, polymictic conglomerate. These were referred to by Pankiwskyj (1979, p. 33) as the "metalimestone" and "granule metaconglomerate" members respectively. Both units are well exposed along the Piscataquis River near Dover-Foxcroft and along the river in the SE 1/9 of the Schoodic Quadrangle west of Howland. The Fall Brook (Madrid) Formation conformably overlies the Sangerville. In many outcrops it resembles portions of the Sangerville but is distinguished from the latter by its buff, non-rusty color on weathered surfaces, and dark gray color on freshly broken surfaces. The Fall Brook lacks the bedding plane fissility of the Sangerville, has a much more "angular break", and is generally better sorted and cemented. The Carrabasset Formation, consisting mainly of dark gray, graphitic slate (which has been extensively quarried between Monson and Brownville) overlies the Fall Brook. The Carrabasset is typically thin bedded and where silty consists of rhythmically graded beds. These are distinctive on glacially polished surfaces, consisting of white "bottoms" grading sharply up into dark gray phyllitic "tops". Within each graded bed the percentages of silt and clay vary considerably.

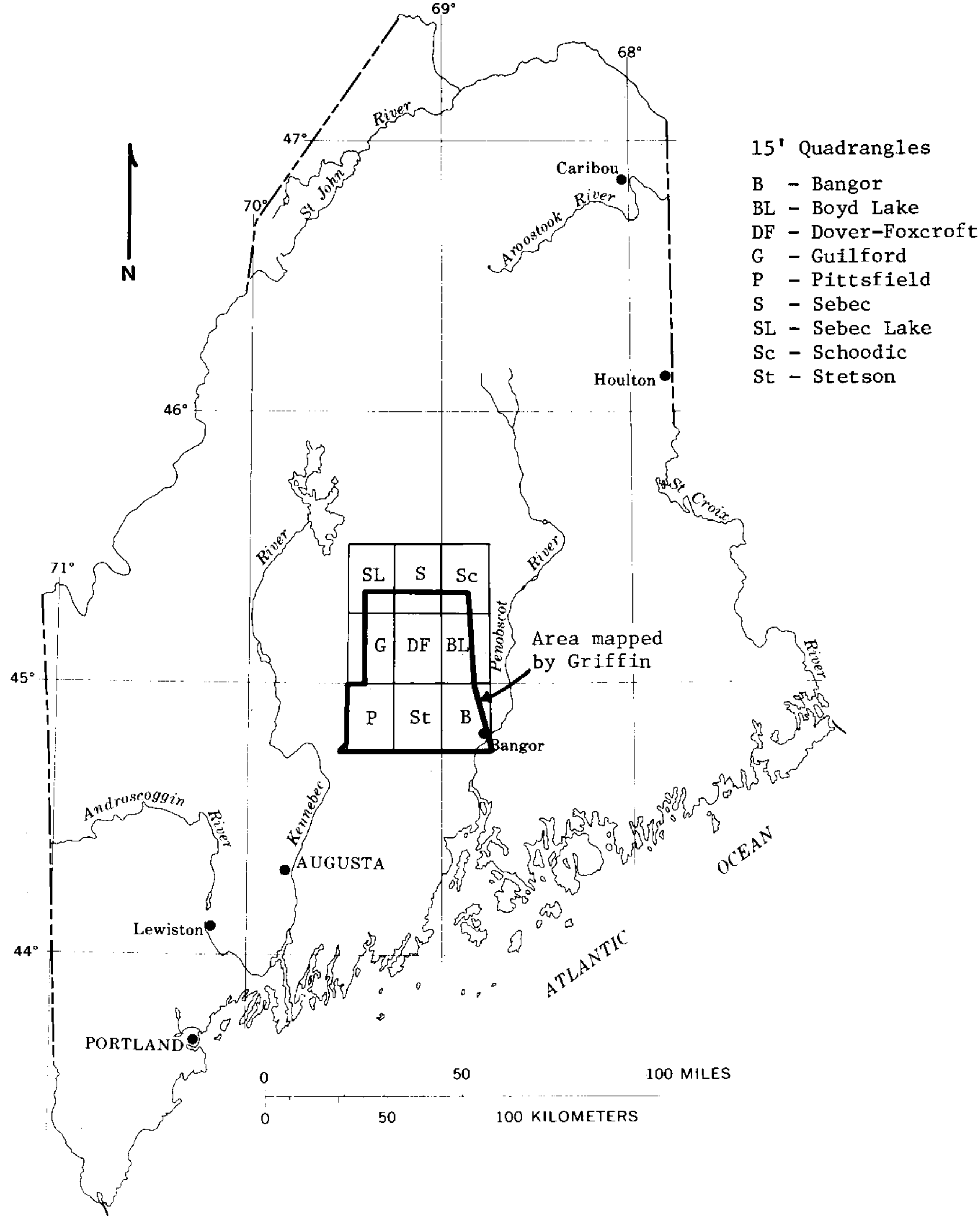


Figure 2

Index map of Maine (Figure 2 of Griffin, 1973, p.4)

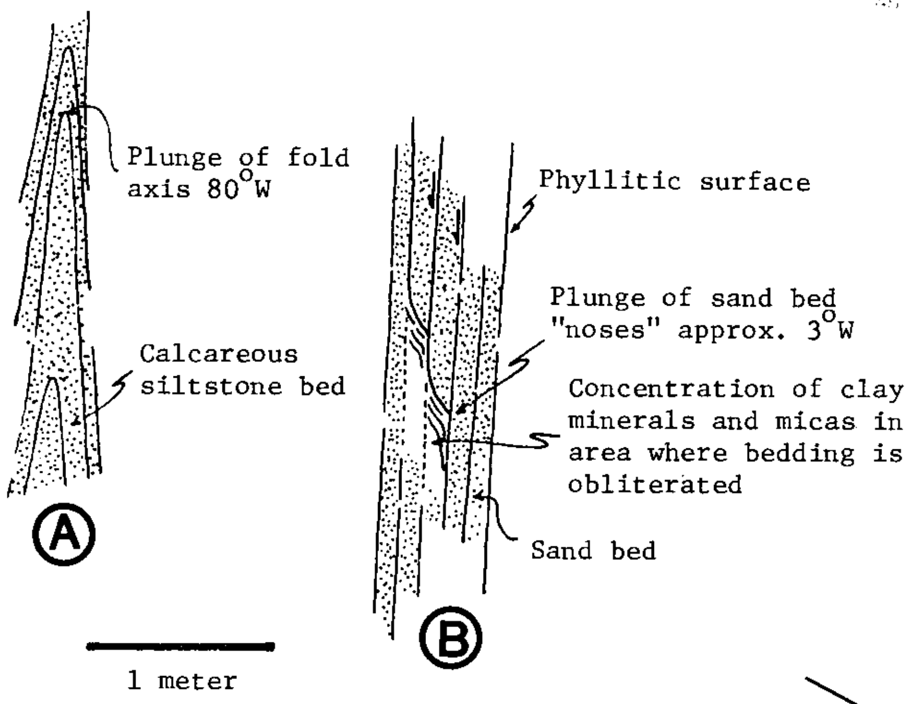
The presence of graded bedding in all three formations allows the determination of stratigraphic topping sense in many exposures. On the basis of this information and the regional map pattern, fold axes and a great number of bedding plane faults have been identified by Ludman (1978; Maine Geological Survey open-file reports), by Griffin (1973; Maine Geological Survey open-file reports), and by Espenshade and Boudette (1964). The major structural features have been shown by Pankiwskyj and others (1976). A curious feature of the structural pattern is that while the rocks are generally steeply dipping, implying tight isoclinal folding, strong axial-plane foliation is absent. In the more argillaceous intervals of the Sangerville a foliation appears to be present, but it is everywhere parallel to bedding. Nowhere has a demonstrably early cleavage been identified which cross-cuts the bedding.

The lack of distinct cleavage defined by parallel orientation of platy minerals implies that the rocks were deformed by flexural slip along bedding surfaces. Furthermore, it seems likely that deformation occurred soon after deposition, possibly when the sediments were not yet lithified.

As mentioned previously (see Griffin, 1973) there are numerous examples, mainly in the Sangerville but also in the Carrabassett Formation, evidencing penecontemporaneous deformation--that is, deformation essentially contemporaneous with deposition. While stratigraphic intervals thus disturbed can be mapped to a certain extent, and while individual slump folds and sedimentary decollement surfaces can be identified in outcrop, the scale of such features is unknown. However, it seems possible that omission of stratigraphic intervals and the repetition of portions of stratigraphic units is due to instability in the depositional environment and not to post-lithification response to directed tectonic stress. Thus, identified fold axes and faults essentially parallel to bedding (see references above) are probably discontinuous early features. It is noteworthy that none of the faults has any topographic expression, nor are they characterized by brecciation and shearing of the rocks.

Figures 3, 4, and 5 are included here to demonstrate the degree to which stratigraphic "omission" and "repetition" occurs. Figure 3 is a sketch of an outcrop on the south side of the Piscataquis River near the fish ladder at Brown's Mill in Dover-Foxcroft. Notable is the fact that the sand beds in the Sangerville Formation pinch out along lines plunging 3° W while the axes of nearby slump folds plunge nearly vertically. A possible explanation is that the former are nearly parallel with the axis of rotation (or folding) while the latter, initially developed in a horizontal plane, are at an angle to it. The axis of the slump fold has therefore been rotated into a near-vertical position.

Figure 4 is a sketch of a portion of a glacially polished horizontal surface in the CE 1/9 of the Schoodic Quadrangle. It shows a sedimentary decollement surface developed in a distinctly graded, thinly (0.5 cm) bedded interval of the Carrabassett Formation. The surface along which



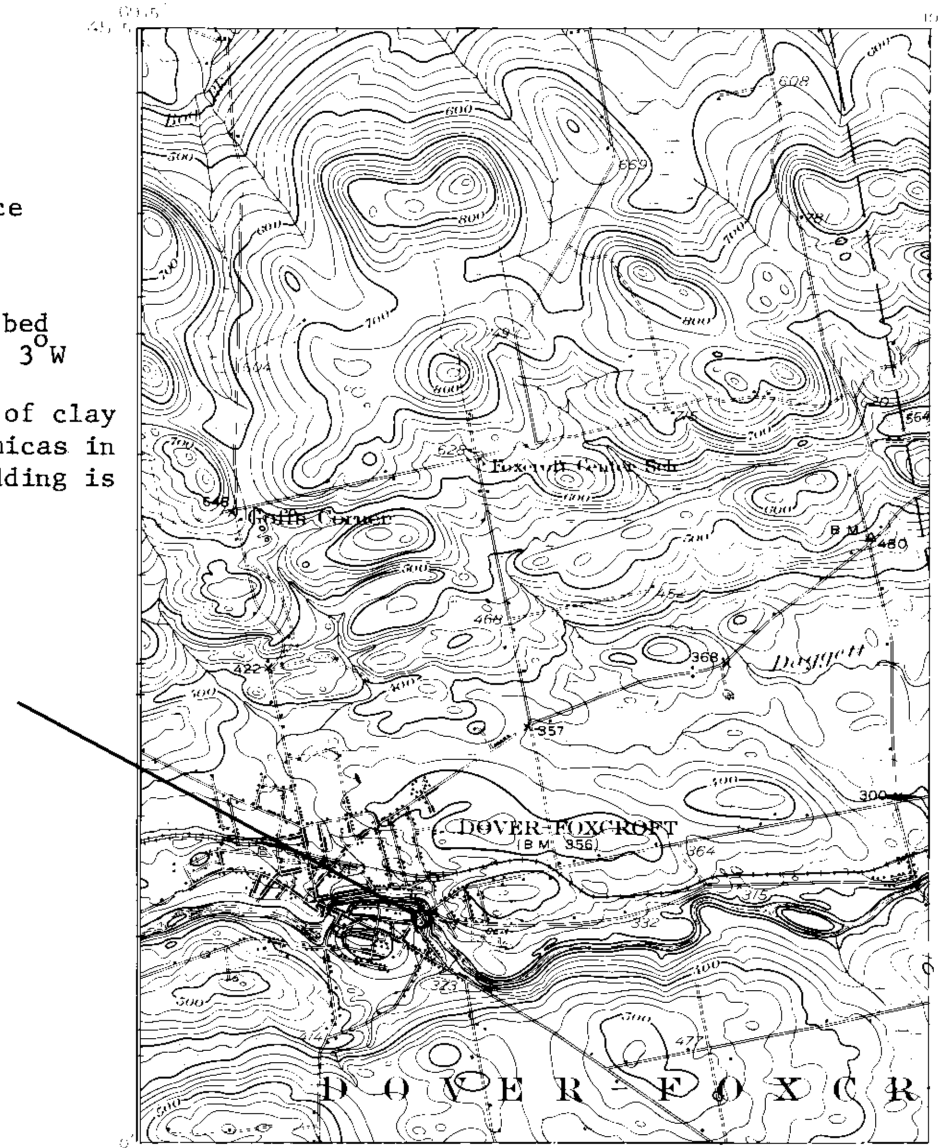


Figure 3

Soft-sediment deformation features observed at Brown's Mill, Dover-Foxcroft, Maine. (A) slump fold as seen in vertical view looking east; (B) imbrication resulting from bedding-plane decollement (Vertical view looking east .. 5 ft. south of "A").

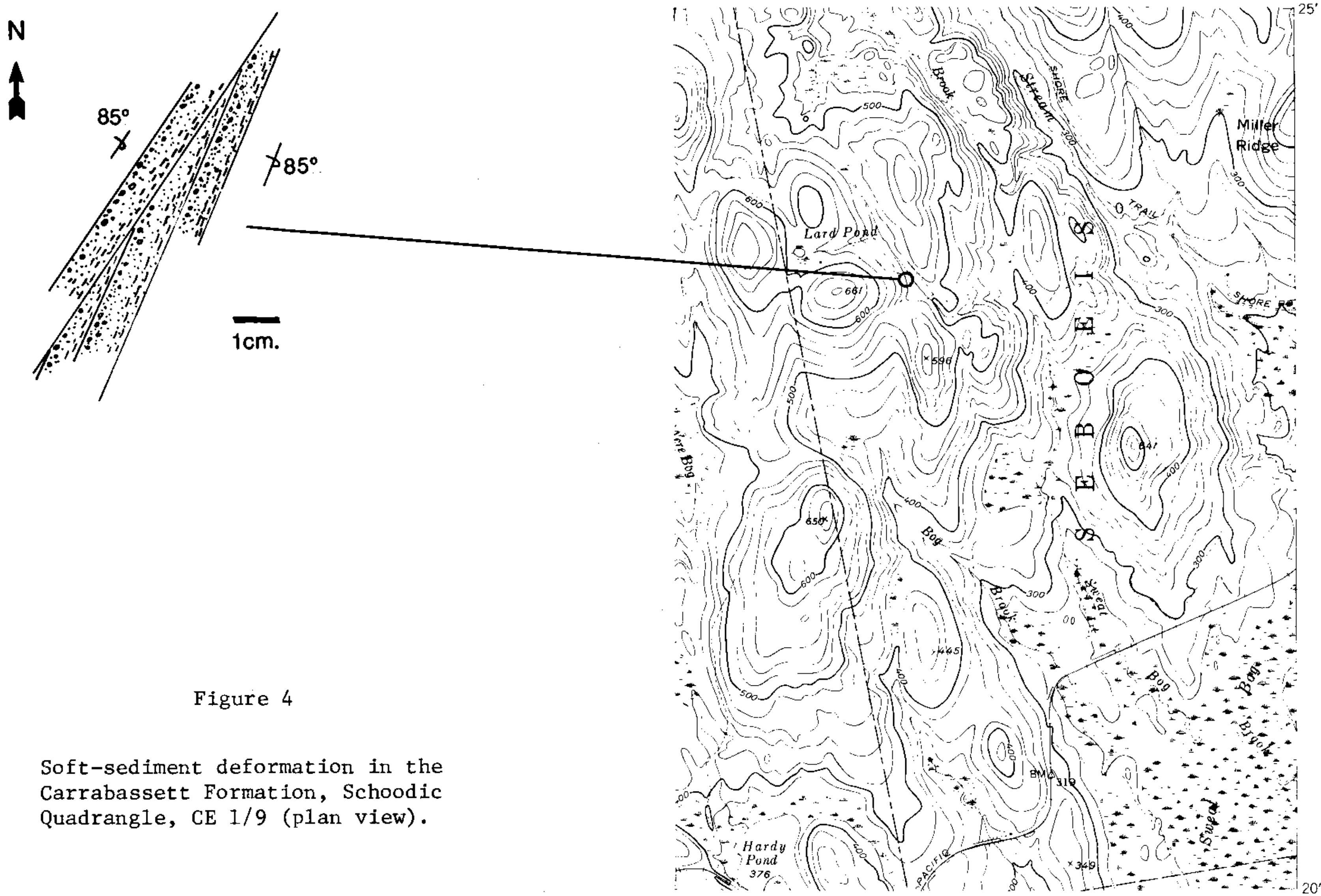
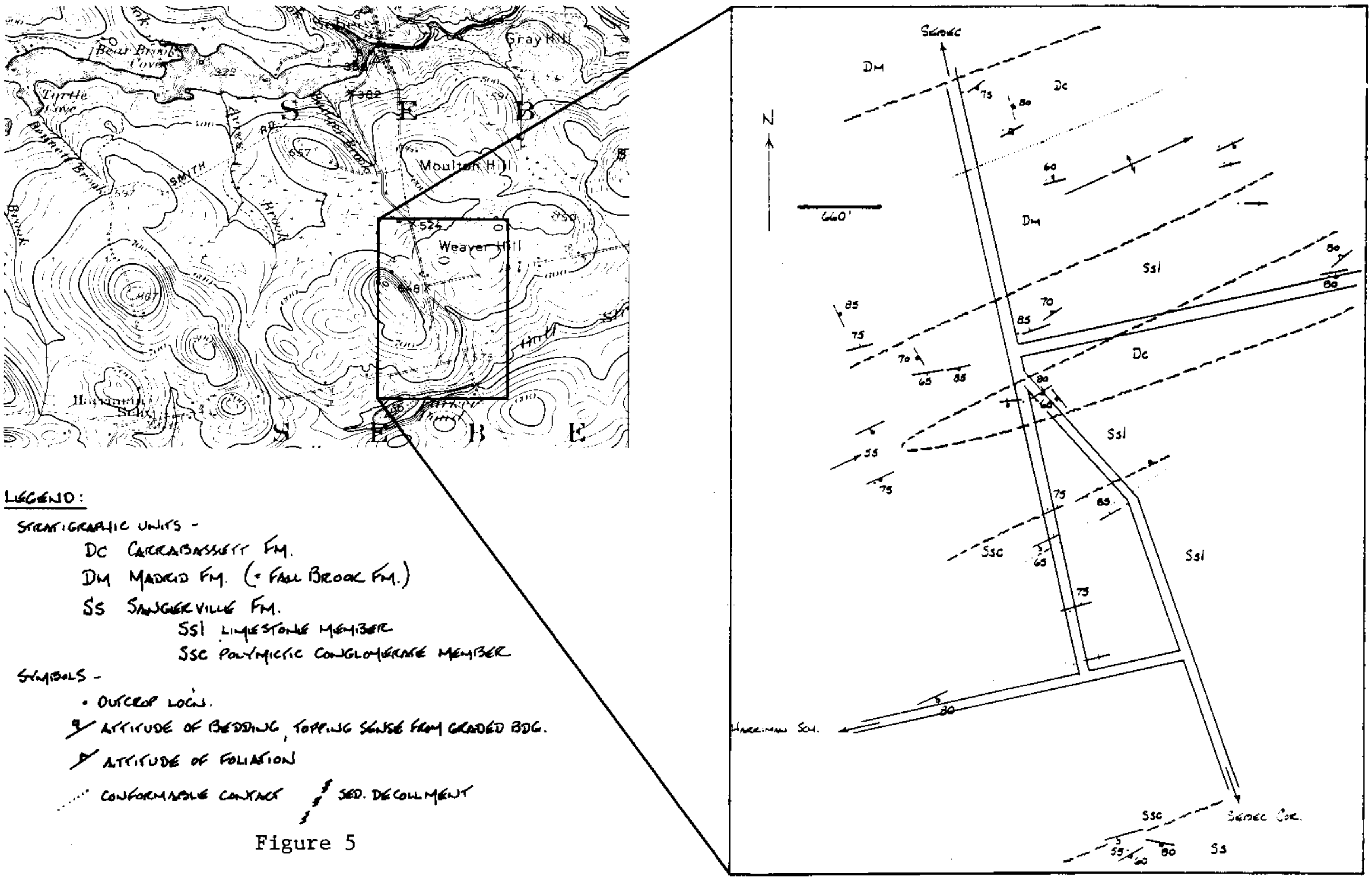


Figure 4

Soft-sediment deformation in the Carrabassett Formation, Schoodic Quadrangle, CE 1/9 (plan view).



LEGEND:

STRATIGRAPHIC UNITS -

Dc CARRABASSETT FM.

DM MADRID FM. (= FALL BROOK FM.)

Ss SANGERVILLE FM.

Ssl LIMESTONE MEMBER

Ssc POLYMICTIC CONGLOMERATE MEMBER

SYMBOLS -

• OUTCROP LOCN.

ATTITUDE OF BEDDING, TOPPING SENSE FROM GRADED BDG.

ATTITUDE OF FOLIATION

CONFORMABLE CONTACT

SED. DECOLLMENT

Figure 5

Detailed map of a portion of the Sebec and Dover-Foxcroft 15' Quadrangles.

there is angular discordance in the attitude of bedding is perfectly straight over an exposed distance of approximately 20 feet, and the truncation is sharp. Elsewhere in the same outcrop rolled and ripped-up silty beds can be seen.

Figure 5 is a detailed map of a portion of the Dover-Foxcroft and Sebec Quadrangles. Bedrock exposure in the area shown is very good and, although time did not permit the search for and precise location of all contacts, the control for the relationships shown is considered very good. The area illustrates the problems encountered in structural interpretation of the regional relationships.

LATE ACADIAN (?) KINK BAND FOLDING

Westerman (1980) has previously discussed kink bands developed in the various units of the Sangerville Formation south of the Piscataquis River. These features are generally of outcrop scale and have been superimposed upon the earlier large-scale fold structures that determine the map pattern in the region. The observation of Westerman (1980, p. 65) that kink bands with a right-handed rotation sense ("Z" folds) are earlier than a set of similar structures with a left-handed rotation sense ("S" folds) is supported by observations made along the Piscataquis River in the southeastern portion of the Schoodic Quadrangle. There, cross-cutting relationships of the kinked zones in the argillaceous limestone member of the Sangerville support his suggested chronology. Despite this suggested temporal sequence, the two sets of structures are considered to represent a conjugate pair of deformation structures developed diachronously over a limited interval of time.

Orientations of the kink bands seem to be different north of the Piscataquis River although they are considerably less common and data are insufficient to examine their orientation in a statistical manner. "Z" kink bands, which Westerman found to have an average trend of N 32° E south of the river (Westerman, 1980, p. 65), have similar north to northeast trends north of the river. However, "S" kink bands, for which Westerman found orientation maxima of N 36° W and N 68° W trend essentially east-west along both the north and south sides of the river. Away from the river to the north, kink-band folding was not observed except in outcrops of the Carrabassett Formation along the Canadian Pacific Railroad south of Schoodic Lake.

The character, frequency, and orientation of kink bands is highly variable over the region as a whole. They are most frequent and apparently consistent in orientation within the Sangerville Formation south of the Piscataquis River. This suggests that the lithologic character of the deformed unit exerts a strong control upon their development. Argillaceous intervals in the Sangerville seem to be most affected by kink band development whether the sediments are argillaceous limestones or argillaceous siltstones. Kink bands are rarely seen in the thick bedded grits or conglomerates of the Sangerville. Similarly they are absent in the predominantly thick-bedded calcareous siltstones of the Madrid Formation. However, lithology alone is insufficient to account for kink band distribution because of the similarity of the Carrabassett shales, which generally do not display these structures, to intervals of the Sangerville which do.

The stress orientations responsible for kink band development had an unknown relationship to the attitude of bedding and earlier-developed cleavage in the deformed rocks. Hence the character of "Z" and "S" folds might be expected to be different and this appears to be so. The former are larger features, often large drag folds with pronounced axial-plane fracture cleavage which may have a spacing as close as 1 cm in the hinge of the structures. Definition of these requires the mapping in some cases of several outcrops in an area, although in other cases they can be seen in individual outcrops. Some outcrops in the southern portion of the Sebec and Schoodic Quadrangles show a closely spaced fracture cleavage which is "refracted" as it "passes" from one sedimentation unit to another. In several instances observations of fracture cleavage were made without identification of the "Z" fold with which it was presumably associated. Closely spaced fractures mineralized with quartz were also observed. These have north to northeast trends and probably represent the same deformational event that elsewhere produced discrete kink bands.

The "S" folds, in contrast, are generally observable in a single outcrop and are sharply defined zones up to a foot wide bounded by parallel planar fractures. Within the fracture-bounded zone, bedding and/or cleavage orientations are distinctly different than they are outside the deformed zone.

JOINTS

Figure 6 summarizes the orientations of joints in the study area. All measured fractures were more or less planar, locally mineralized with quartz, and showed no slickensides or other features suggestive of displacement. The diagram shows that joints generally strike NW and have steep NE and SW dips. The joints are presumed to post-date the development of the kink bands noted above, although definitive observations bearing on their temporal relationship were not made.

Figure 7 is a similar plot of measured joints along the West Branch of the Pleasant River within the Gulf Hagas Reserve (northeast corner of the Sebec Lake 15-minute Quadrangle). The deep gorge developed by the West Branch may in part be explained by an apparent zone within the Carrabassett Formation in which a greater number of joint orientations made the rock more erodable (by the action of ice and water). However, data are insufficiant to establish a hypothesis to explain both the location and the form of Gulf Hagas.

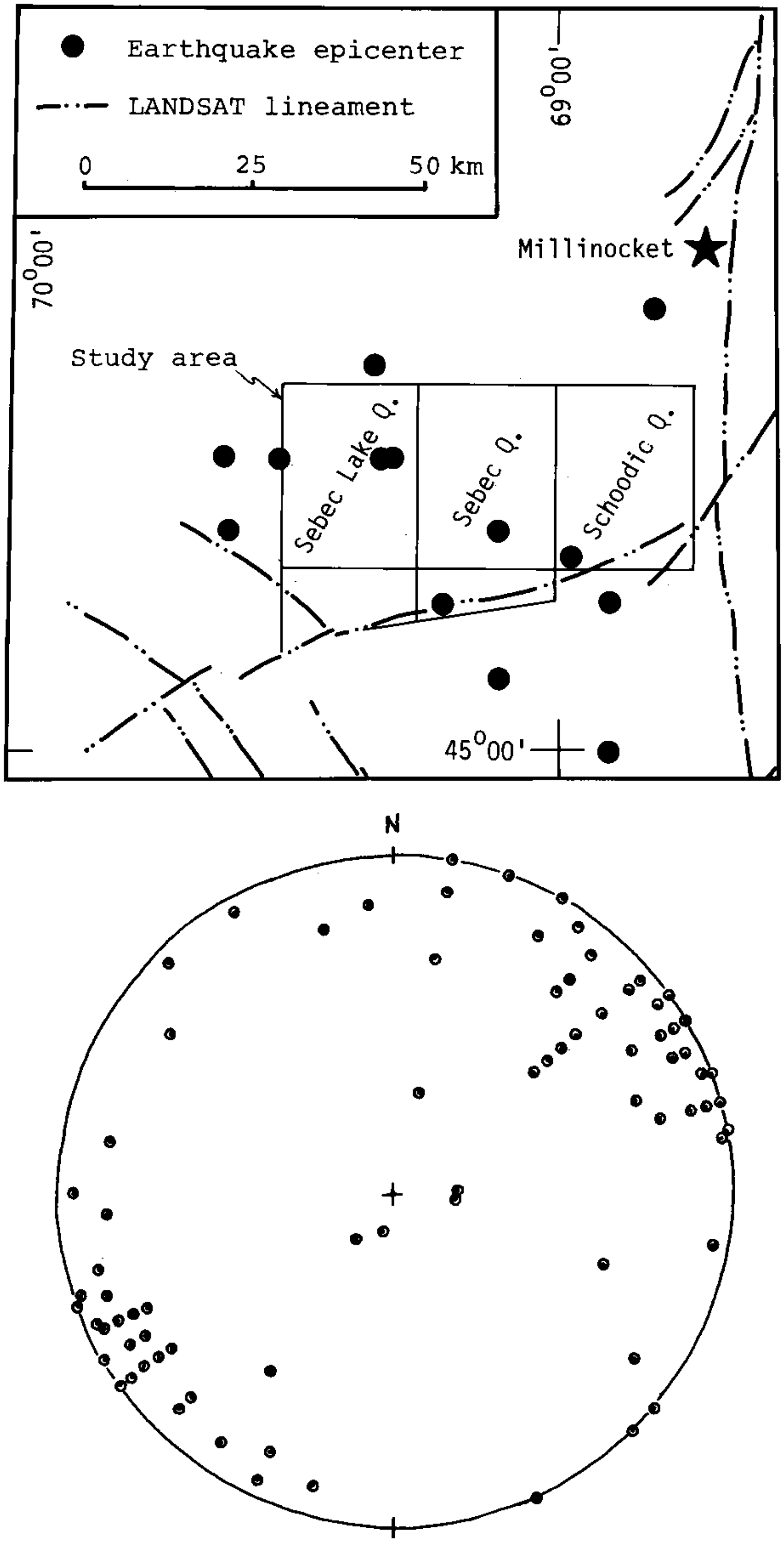
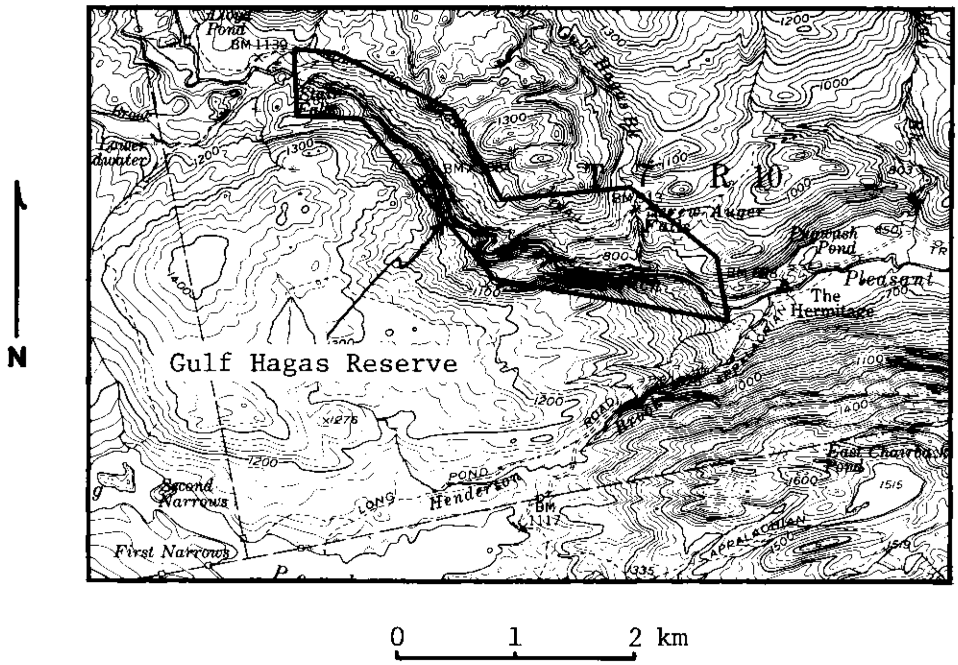


Figure 6

Uncontoured southern hemisphere equal-area projection of the poles to joint surfaces (entire study area: N=77)



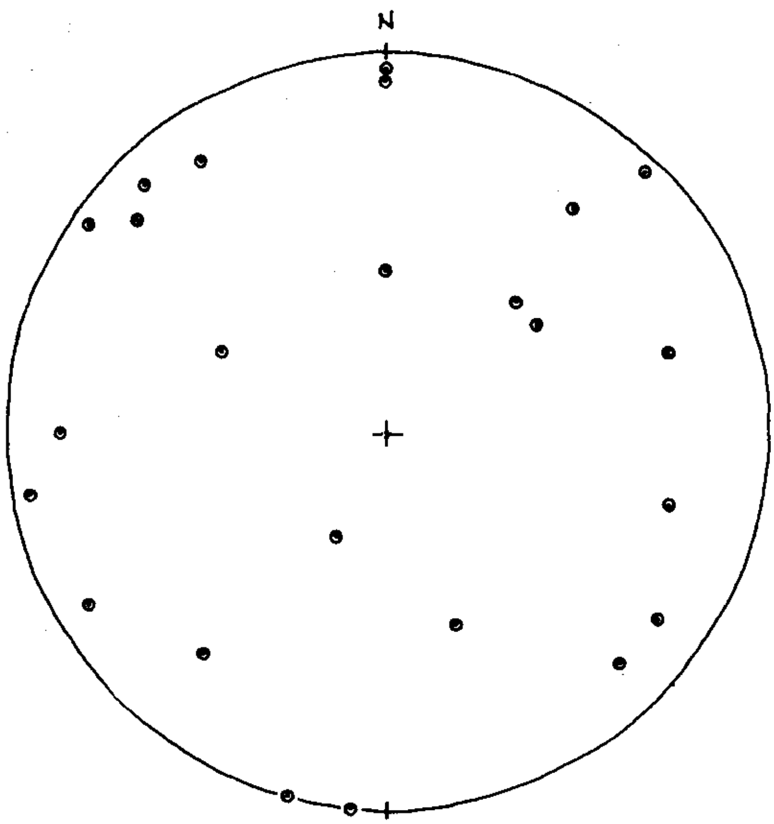


Figure 7

Uncontoured southern hemisphere equal-area projection
of the poles to joint surfaces (Gulf Hagas Reserve: N=24)

RECENT (?) TECTONISM

The area studied is characterized by a notable lack of evidence of brittle failure of possible geologically young age. Few slickensided surfaces, breccia zones, or mylonites were observed. Only two outcrops contained evidence of brittle failure post-dating the development of kink bands and the regional jointing. The first is on the north side of a large outcrop in the Piscataquis River below the dam at Howland. There, graded siltstone beds of the Sangerville Formation as well as the late fracture cleavage related to the "Z" folds as discussed above, are dragged along a steeply dipping right-lateral fault whose trace is characterized by a 0-8 cm wide breccia zone which can be traced for 10-15 m across the outcrop. The fault trace trends 320°.

The second outcrop is located 2 km west of the first on the west side of the southbound entrance ramp to I-95. The outcrop contains a glacially polished interval of thinly bedded siltstone and shale of the Sangerville Formation. Silty intervals contain cross-bedded ripples and the general trend of the bedding is N 70° E, 85° S, with the sequence topping NW. A fracture cleavage trending N 10° W, 90°, is noticeable in the silty beds. A series of at least a dozen sub-parallel surfaces trending N 25° E, 90°, cut the outcrop over an interval at least 5 m wide. All surfaces are strongly slickensided with the plunge of the slickensides consistently 0°. Associated drag folds indicate that an indeterminate amount of right-lateral offset has occurred along the zone.

CONCLUSIONS

The Landsat lineaments shown on Figure 1 can be evaluated in light of the structural data discussed above. The Penobscot lineament of Barosh (1978) remains a difficult topographic feature to correlate with identifiable bedrock structural features. The outcrops near Howland are suggestive of the possibility that the Penobscot River occupies the locus of a presently active tectonic zone.

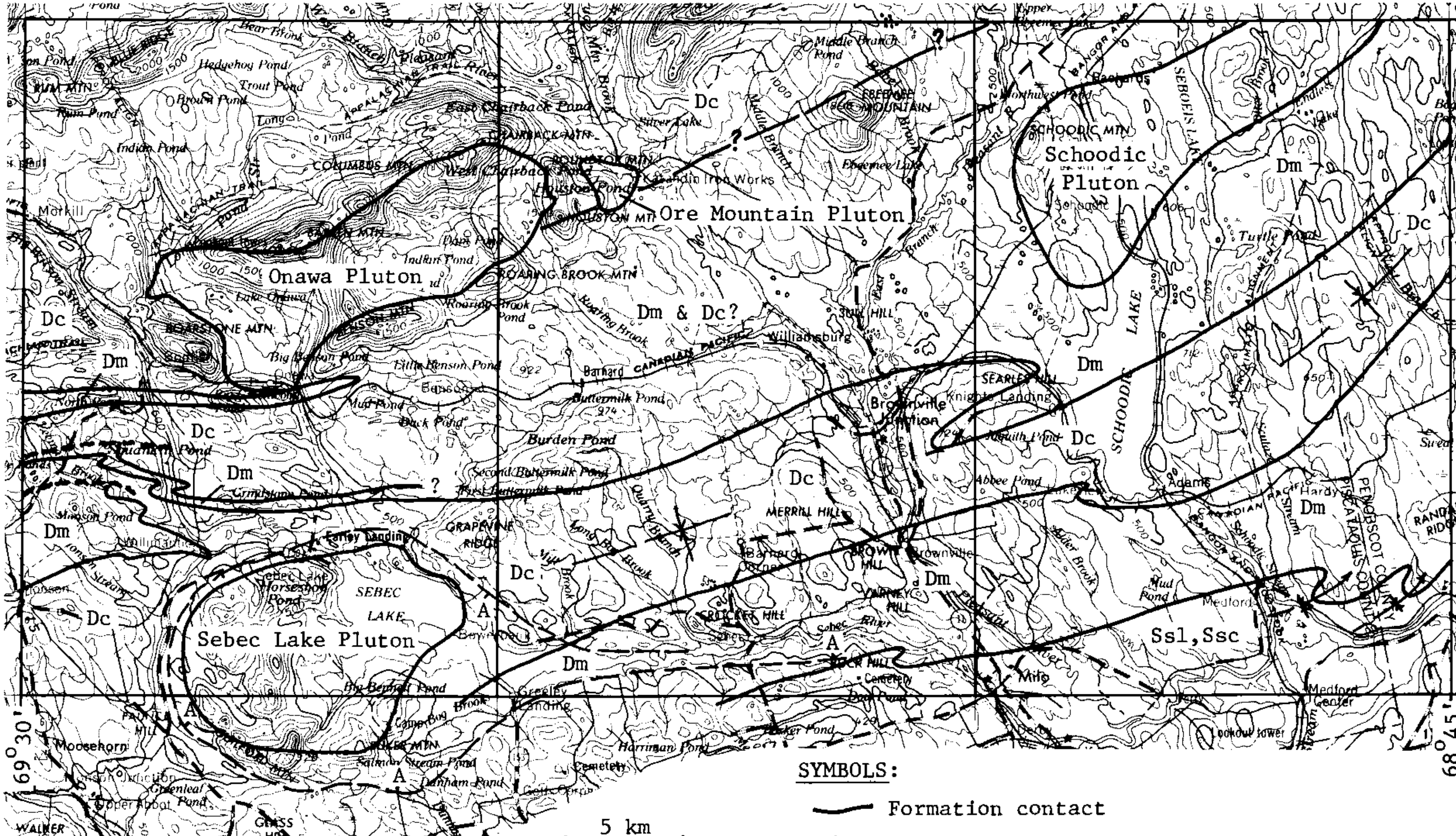
The east-west lineament (Figure 1) marked by the course of the Piscataquis River is a topographic low that is primarily stratigraphically controlled. The valley, particularly in the Dover-Foxcroft area, is underlain by the limestone member of the Sangerville, which is more readily eroded because of its lithologic character and because of the greater frequency of kink bands within it. More resistant (and less deformed) conglomerate outcrops both north and south of the river, further controlling the morphology and location of valley development. In the eastern portion of the Schoodic Quadrangle, litho-stratigraphic control of the course of the river is less obvious. While a considerable amount of limestone outcrops in the river bed, near Schoodic the river has breached an interval of conglomerate and flows at an angle to the bedding within it. It is possible that east-west trending "S" kinks exert a primary control over the course of the stream.

The topographic low occupied by Garland, Harriman, Parker, and Dow ponds in the northern portion of the Dover-Foxcroft Quadrangle parallels the Piscataquis River valley (Figure 5). Like the latter it is underlain by limestone with more resistant conglomerate outcropping both north and south of the valley.

The Dover-Foxcroft line of Lee and others (1977) is readily visible on Landsat imagery, but does not stand out at a scale of 1:62,500 on either the Guilford or Greenville Quadrangle. The line corresponds to the general direction of movement of late Wisconsin ice in the area, and in some places there are eskers and esker controlled subsequent streams paralleling its trace. The fact that the predominant joint orientation direction and "S" fold directions parallel the lineament is interesting. It seems likely that patterns of ice deposition and erosion, controlled perhaps to some degree by these bedrock structural features, are responsible for the generation of this linear topographic feature. More curious is the regional change in the attitude of formational units and large scale Acadian structures--a change which seems to be "hinged" by this line (see Westerman, 1980, p. 61). The flexure itself is not unusual in view of the Appalachian-Caledonian reentrants and recesses (see, for example, Williams, 1978) which exist along the axis of the fold belt. But the identification of a linear feature on satellite imagery along a zone where the change in the strike of the units is most abrupt is striking. It may be that the lineament is perceived because the flexure is there and not that the flexure is created by a tectonically active zone evidenced by a lineament.

The Sebec River flows from Sebec Lake east across the Sebec Quadrangle and joins the Piscataquis River southeast of Milo at Derby. The Sebec Lake pluton underlies a portion of the lake and has been mapped as a circular body roughly 9 km in diameter. The thermal aureole surrounding the granite has a very curious shape suggesting that the granite may be similarly different. Contact metamorphic effects are not observed in the rocks 1 km west and north of the contact, yet are obvious in the rocks both north and south of the Sebec River 15 km to the east (Figure 8). If the pluton has a pollywog shape--as these observations seem to suggest--then the question is what, if anything, this unusual shape has to do with observed seismicity in the Milo area.

In summary, two topics seem to warrant further study in an effort to understand the seismicity in the area. First, the outcrops near Howland (see above discussion) should be examined in detail. Additional outcrops near the Penobscot River should be sought. Second, a gravity study should be done in order to model the shape of the Sebec Lake pluton. Such a study might establish faulting as an important control of the orientation of the Sebec River valley and of seismicity in the Milo area.



STRATIGRAPHIC UNITS:

Dc - Carrabassett Formation
Dm - Madrid Formation (Fall Brook Formation of Pankiwskyj, 1979)
Ssl, Ssc - Sangerville Formation (undifferentiated)
 l - limestone member
 c - conglomerate member

SYMBOLS:

Formation contact
Synclinal axis, direction of plunge as shown
Fault
A — Contact metamorphic isograd, area of andalusite-bearing pelitic assemblages as indicated (thermal aureoles around Onawa, Ore Mountain, and Schoodic plutons are omitted)

Figure 8: A portion of the Millinocket 2° Quadrangle (Geology modified from Griffin, 1973 and Pankiwskyj, 1979)

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