Maine Geological Survey
DEPARTMENT OF CONSERVATION
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OPEN-FILE NO. 81-89

Title: Report on Brittle Fracture and Bedrock Mapping in the Bangor - Brooks - Stetson Area of the Bangor 2 degree Quadrangle, Maine

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Date: 1981

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: 13 page report

ABSTRACT

Mapping in the Bangor-Brooks-Stetson area was carried out for the purpose of examining lineaments which may be related to recent seismic activity. Major faults of the Norumbega Fault zone were mapped across the southeastern half of the Brooks 15' Quadrangle, all trending approximately N50E and indicating right-lateral motion. This zone separates the Merrimack synclinorium from the Liberty-Orrington anticline, and represents the boundary between the Silurian turbidite sequence to the northwest and the Precambrian(?) and Cambro-Ordovician terrain to the southeast. Small-scale fracture systems suggesting movement are associated with Z-shaped asymmetric folds trending north of the primary cleavage in the region, and with S-shaped kink folds trending approximately E-W. Offsets were commonly observed in the hinges of these two types of folds, showing right-lateral and left-lateral movement, respectively. No evidence of post-glacial faulting was observed in the study area.

INTRODUCTION

The area of study is located in the southern portion of a wedge-shaped area north of Penobscot Bay, Maine, which is known to be one of low, but persistent, seismic activity (Boston Edison Co., 1976; Barosh, 1978). Bedrock mapping and lineament analysis was carried out in the Bangor-Brooks-Stetson area during the 1980 field season, and this study represents a continuation of previous work (Westerman, 1981a) in the central portion of the active area (see Figure 1). Emphasis was placed on 1) bedrock mapping, particularly in the Brooks Quadrangle where coverage by previous workers was incomplete, and 2) interpretation of faults, lineaments, and other structural or topographic features that may be related to the seismic activity that has been identified in the Penobscot Bay region by the Weston Geophysical Observatory. Figure 2 shows the geology and structure of the study area.

GEOLOGIC SETTING

Rocks in the Bangor and Stetson 15' Quadrangles and in the northwestern third of the Brooks Quadrangle have been previously mapped as formations belonging to the Merrimack Group (Griffin, 1976a), and they are structurally located on the southeastern flank of the Merrimack synclinorium. The stratigraphic interpretations of Griffin are in agreement with those of Pankiwskyj and others (1976). These authors suggest that the Waterville Fm.(S) is older than the Vassalboro Fm.(DS), but Osberg (1980) suggests the opposite based on fossil evidence reported in Pankiwskyj and others (1976). Lithologic descriptions of these rocks can be found in the references mentioned above and will not be repeated here; the entire sequence is part of a turbidite sequence containing minor limestone, conglomerate, and green and maroon slate.

The southeastern half of the Brooks Quadrangle is underlain by rocks of early Paleozoic (Cambro-Ordovician) and Precambrian(?) age which occur in the northeasterly trending Liberty-Orrington anticline of Osberg (1974) and the Passagassawaukeag block of Bickel (1976). Feldspathic gneisses and schists of the Passagassawaukeag Fm. occupy the core of the structure (Bickel, 1976) and are thought to be Precambrian in age (Stewart and Wones, 1974). In contact on the northwest side of the Precambrian rocks are schists and gneisses of the

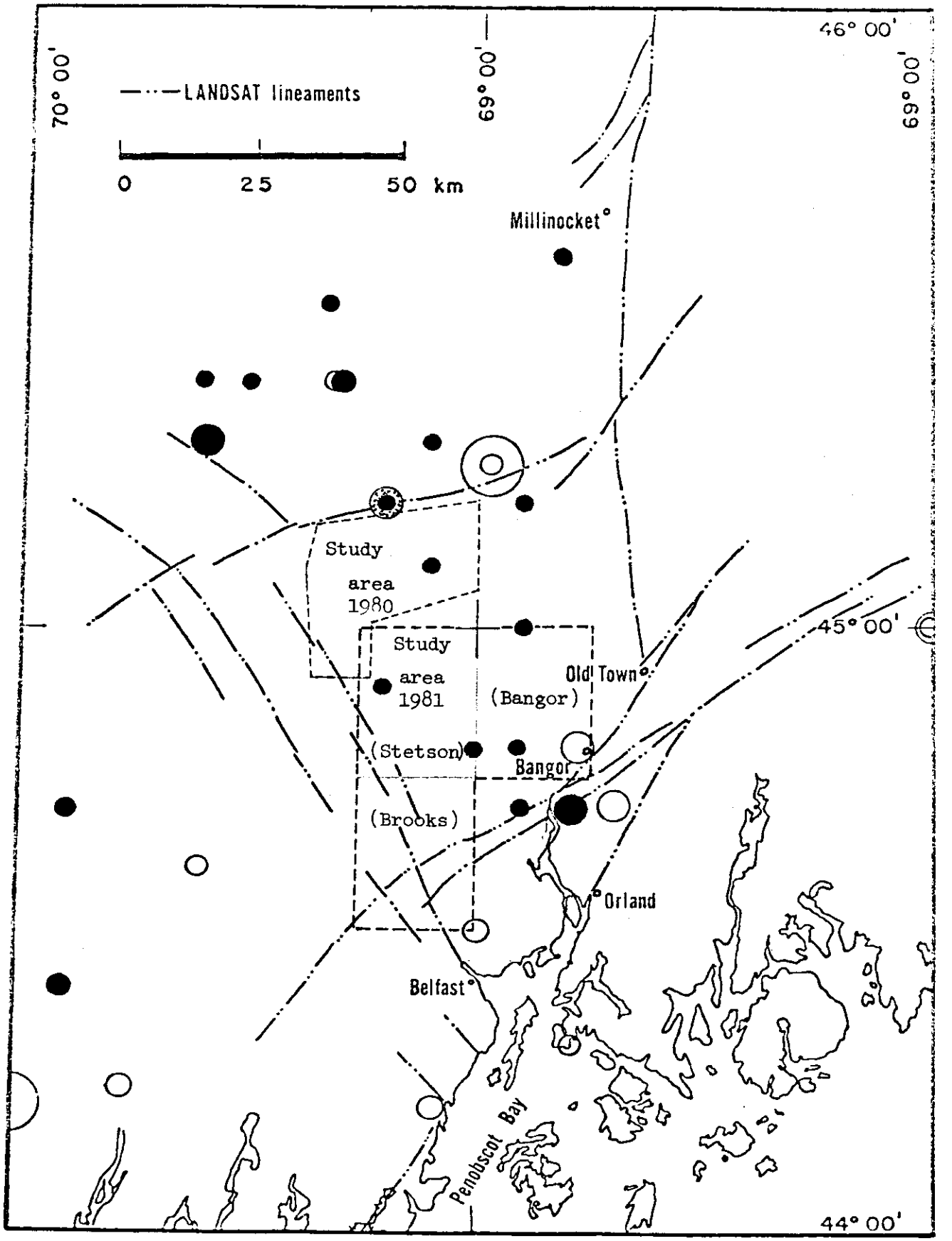
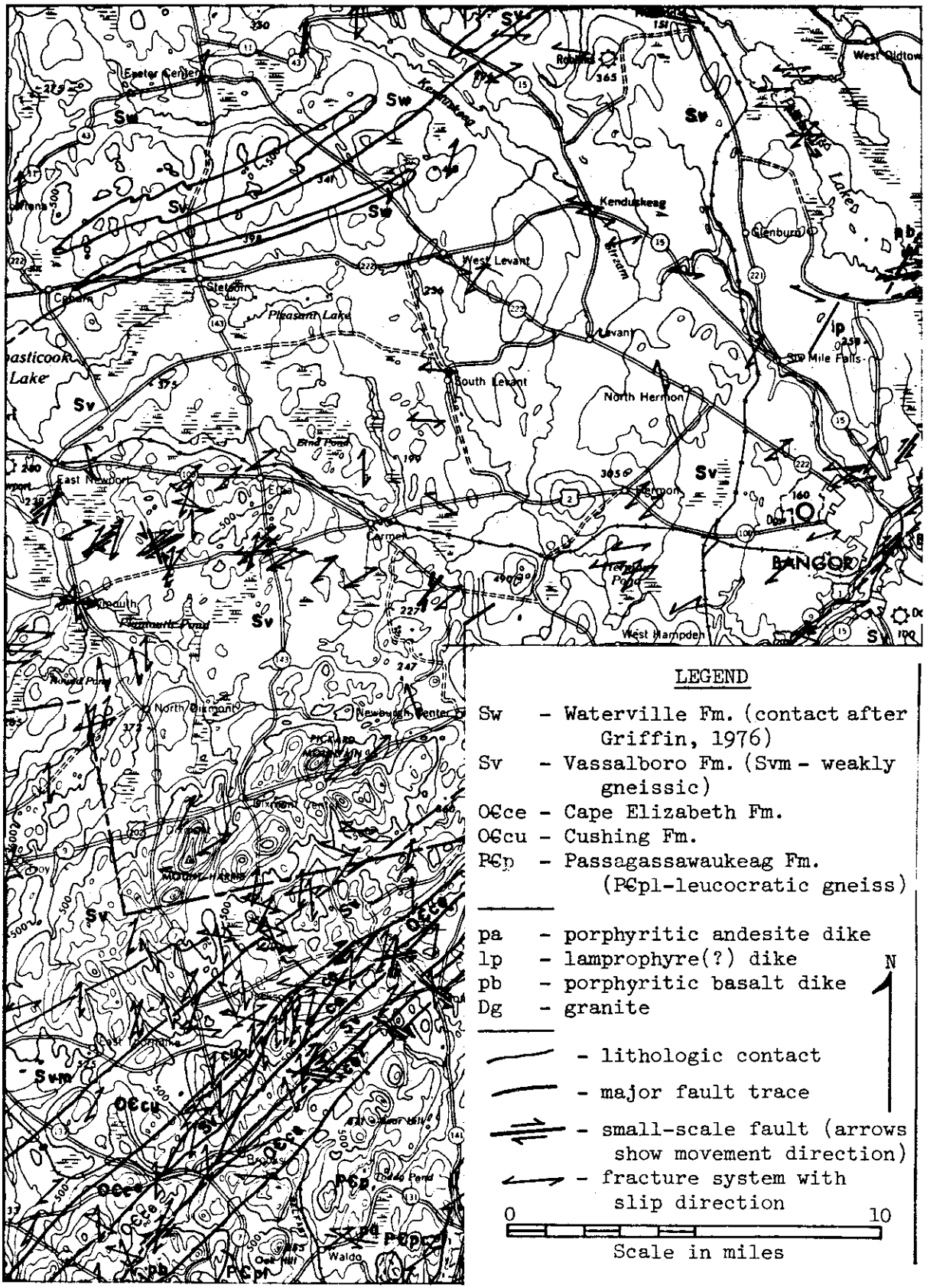


Figure 1. Wedge-shaped area of low, but persistent, seismic activity (Boston Edison Co., 1976; Figure 16 of Barosh, 1978)



LEGEND

Sw - Waterville Fm. (contact after Griffin, 1976)

Sv - Vassalboro Fm. (Svm - weakly gneissic)

OCce - Cape Elizabeth Fm.

OCcu - Cushing Fm.

PCp - Passagassawaukeag Fm. (PCpl-leucocratic gneiss)

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pa - porphyritic andesite dike

lp - lamprophyre(?) dike

pb - porphyritic basalt dike

Dg - granite

- lithologic contact
- major fault trace
- small-scale fault (arrows show movement direction)
- fracture system with slip direction

Hogback schist (Perkins and Smith, 1925; Jacobson, 1963; Bickel, 1976) which have been correlated with the Cape Elizabeth Fm. (Pankiwskyj, 1976). (The name Cape Elizabeth Fm. will be used for this unit in the remainder of this report.) On the northwest side of the Cape Elizabeth Fm. are rocks of the Cushing Fm. (Pankiwskyj, 1976), and both units belong to the Casco Bay Group. Within the study area, these formations of the Casco Bay Group are separated from each other , and from the older (SE) and younger (NW) units adjacent to them, by faults of the Norumbega Fault zone which trends N50E across this region. Fault-bound blocks of units from the Merrimack Group have been mapped within the fault zone in the Brooks Quadrangle.

Igneous activity in the study area includes the intrusion of the Mt. Waldo granite into the Passagassawaukeag Fm. during the Devonian (Brookins, 1976) and the emplacement of several dikes. A lamprophyre(?) dike trending N27E is located 0.15 mi. east of Pushaw Road in the Bangor Quadrangle on the Bangor-Glenburn township line; a basalt dike is exposed at the crest of the hill 1 mi. southeast of Roy Corner in the southwest part of the Brooks Quadrangle; and a porphyritic andesite(?) dike is exposed in a roadcut 1.5 mi. northeast of Waldo in the southeastern part of the Brooks Quadrangle. A faulted porphyritic basalt dike(?) is exposed at the south end of Pushaw Lake.

LINEAMENT ANALYSIS

The dominant large-scale lineaments in the study area trend northeasterly and are associated with 1) outcrop belts of distinctive lithologic units, and 2) traces of faults within the Norumbega Fault zone. A major set of lineaments which trend N35W from Belfast have been identified by Barosh (1978), and these cross the southwesternmost portion of the study area. Minor lineaments are observed generally as part of drainage patterns, and they typically trend NNW to NW. Detailed study of major and minor faults and of brittle fractures was carried out, with particular attention paid to evidence of movement on these fracture surfaces.

The existing map pattern of units within the Merrimack Group (northwest of the Norumbega Fault zone) appears to be the result of upright folding as has been suggested by Osberg (1980) for the area along strike to the southwest and has been implied by the mapping of Griffin (1976a) within the northern portion of the current study area. Lee and others (1977) noted a change in trend of the outcrop belts within the seismically active wedge-shaped area mentioned earlier, and they termed the hinge of this regional flexture "the Dover-Foxcroft line". Barosh (1978) called attention to the prominence of this flexture on Landsat imagery, observing the pattern as a giant drag fold cut off at its eastern margin by the northerly trending Penobscot lineament zone. The sense of motion required on a regional scale to produce such a fold would be right lateral which would be compatible with interpretations of the sense of motion within the Norumbega Fault zone to the northeast (Wones and Stewart, 1976).

Within the study area of this report, the wedge-shaped regional flexture narrows to the southeast, terminating at the Norumbega Fault zone. Units involved in this flexture include the Vassalboro Fm. and the Kenduskeag "unit" of Griffin (1976a), and they commonly exhibit right-lateral shear surfaces parallel to the bedding plane cleavage, suggesting that this sense of motion has been pervasive throughout the study area.

The second prominent set of northeasterly trending lineaments are those associated with the Norumbega Fault zone, and within the study area, these lineaments are restricted to the southern half of the Brooks Quadrangle and the southeasternmost corner of the Bangor Quadrangle. The continuation of these lineaments has been mapped to the southwest by Pankiwskyj (1976) and to the northeast in the Bucksport Quadrangle by Griffin (1976b) and Stewart and Wones (1974). Fault traces within the Norumbega Fault zone are generally eroded, producing topographic lineaments trending N50E, and exposures of the primary fault planes were not observed. Rocks adjacent to the fault traces generally exhibit features such as cataclastic and mylonitic textures, slickensides, silicification, and drag folds, all suggestive of faulting.

Mapping by Pankiwskyj (1976) indicates five major faults which extend northeastward from the Liberty Quadrangle into the Brooks Quadrangle. The northwesternmost fault of this group is the Hackmatack Pond Fault which separates the Vassalboro Fm. (NW) from the Cushing Fm. (SE), and is here interpreted to mark the northwest boundary of the Norumbega Fault zone. An exposure near this fault can be observed 0.25 mi. north of Knox Corner in the Brooks Quadrangle (southwest portion) where black siliceous mylonite(?) occurs within rusty sulfidic schist of the Cushing Fm. Right-lateral drag folds are present in the schist where it is in contact with the siliceous rocks. The Hackmatack Pond Fault is marked by a strong topographic low in the eastern half of the Brooks Quadrangle where it extends through the Vassalboro Fm. and presumably continues eastward through Burnt Swamp in the Bucksport Quadrangle. The Cushing Fm. has terminated along strike on the southern side of the fault, either by auxiliary faulting or by plunging beneath the Vassalboro Fm. Further study of this geometric configuration may support the hypothesis of Pankiwskyj (1976) that this is an older fault, but its apparent eastward continuation in the Vassalboro Fm. suggests that its time of activity was coincident with that of faults to the southeast.

The next major fault to the southeast is an extension of the Stantial Bog Fault of Pankiwskyj (1976) which enters the Brooks Quadrangle at its junction with the Burnham, Liberty and Belfast Quadrangles. This fault separates the Wilson Cove member of the Cushing Fm. (NW) from the Cape Elizabeth Fm. (SE) in the Liberty Quadrangle (Pankiwskyj, 1976). A garnet-rich schist is exposed in the central portion of the Brooks Quadrangle (see Bickel, 1974, Stop 4) between two splays of the Stantial Bog Fault, and these rocks may be correlative with the Wilson Cove member of Pankiwskyj. Exposures of sulfidic, gray schist of the Cape Elizabeth Fm. on the southeast side of the Stantial Bog Fault can be seen 1.7 mi. ENE of North Monroe in the east-central portion of the Brooks Quadrangle. These rocks vary in color from light to dark gray as a function of increasing cataclasis. Quartz occurs in these rocks as stringers and pods oriented parallel to the foliation, and crenulation drag folds indicate right-lateral movement at the time of faulting. Rocks immediately north of this fault belong to the Vassalboro Fm.

The Sandhill Corner Fault is the next major fault to the southeast, entering the study area from the Belfast Quadrangle. Along the eastern half of its length within the Brooks Quadrangle, rocks of the Cape Elizabeth Fm. are present on the northwest side and younger rocks of the Vassalboro Fm. occur on the southeast side as a fault-bound block. This block is thought to have formerly continued to the southwest, but its southwestern portion has been offset to the north by right-lateral movement on a fault trending N20E through

the central portion of the quadrangle within the Norumbega Fault zone. In the Bucksport Quadrangle to the east, the Sandhill Corner Fault joins with the Stantial Bog Fault, pinching out the rocks of the Cape Elizabeth Fm.

Southeast of the Sandhill Corner Fault is the Sunny Side Fault of Bickel (1974). Within the Brooks Quadrangle, this fault can be best observed in Marsh Stream near the Knox-Brooks township line where outcrops of different members of the Cape Elizabeth Fm. are exposed within 25 meters of each other. Biotite-muscovite-quartz-garnet schist (SE side) contains abundant quartz veins, and rough, undulating cleavage with chattery surfaces suggests right-lateral motion. Calc-silicate "gneiss" (NW side) is exposed upstream, exhibiting well-developed lithic layering disturbed by complex multiple folds. This fault splays to the northeast with the northwestern splay marking the southern margin of the fault-bound Vassalboro block.

The southeastern margin of the Norumbega Fault zone is located at the contact between the Cape Elizabeth Fm. (NW side) and various members of the Passagassawaukeag Fm. (SE side). This contact was considered by Bickel (1976) to be an unconformity or perhaps a fault, but the interpretation that the Cushing Fm. is older than the Cape Elizabeth Fm. (Hussey and Newberg, person. comm.) suggests that the Cape Elizabeth Fm. is in fault contact with the Precambrian rocks to the southeast.

SMALL-SCALE BRITTLE FRACTURE ANALYSIS

The types of small-scale brittle fractures which were studied in detail include:

1) cleavage parallel or nearly parallel to bedding or lithologic layering (S_{0-1}),
2) axial plane cleavage of small-scale, asymmetric Z-shaped folds,
3) axial plane fractures of small-scale, s-shaped kink folds,
4) small-scale faults, and
5) joints.

Nearly all rocks in the study area exhibit a well-developed cleavage oriented approximately parallel to the lithologic layering. The degree of development of this cleavage increases with decreasing grain size and increasing phyllosilicate content, being expressed as a bedding plane parting in the courser-grained rocks of the Merrimack Group. This cleavage is thought to have developed at the time of upright folding which produced the regional map pattern in the Merrimack Group. Shearing parallel to this cleavage is commonly suggested by mineralized surfaces with poorly- to well-developed slickensides indicating right-lateral movement.

Superimposed on the S_{0-1} cleavage are younger cleavages associated with small-scale folds. These folds are generally of two types which tend to occur individually within areas, but can be observed together at certain locations. The first type, which may be the older of the two, is seen as near-vertical, axial plane cleavage of tight, small-scale, asymmetric Z-shaped folds whose axes plunge steeply. The sense of motion indicated by these folds is right-

lateral, and offsets of 1 to 20 mm. can commonly be observed in the hinges of the folds. This cleavage is particularly well-developed in the northwestern third of the Stetson Quadrangle within rocks of the Waterville Fm., trending N0-15E, and in the southern thirds of the Stetson and Bangor Quadrangles and northwestern half of the Brooks Quadrangle within the Vassalboro Fm. and Kenduskeag "unit", trending N20-45E. Similar fractures and folds are very prominent within portions of the Norumbega Fault zone, trending N0-10E, particularly in the central portion where the fault-bound block of Vassalboro Fm. has been offset laterally on a N20E fault. (See Figure 3.)

Axial plane fractures associated with S-shaped kink folds constitute a second and distinctively different set of brittle fractures. These fractures are also near vertical, and axes of their folds dip steeply. The sense of motion indicated both by the shape of the folds and by dislocations in the hinges is left lateral. This is a prominent type of small-scale deformation in the northern half of the Bangor Quadrangle, and is common in the southwestern three-fourths of the Brooks Quadrangle as well. (See Figure 4.)

Small-scale faults were observed at 38 locations in the study area; 10 indicated apparent left-lateral movement, 15 apparent right-lateral, and 13 showed normal, thrust, combination of dip- and strike-slip, or undetermined sense of motion. No observed faults exhibited evidence of post-glacial movement. Orientations were highly variable with maximum concentrations (34%) between N30E and N60E; eight of these showed right-lateral movement and none showed left-lateral movement. In most instances, these NE trending faults are thought to be related to the regional, right-lateral strain with slip parallel to lithologic layering and on splays off these surfaces. Left-lateral, small-scale faults occur in two weakly preferred orientations; 50% are between N60E and N90E, and the remainder are between N40W and N30E. (See Figure 5.)

Joints are most commonly oriented at high angles to bedding, schistosity, and gneissic foliation. Figure 6 illustrates the orientations of joints in the study area, none of which showed evidence of movement. Precisely one third of the joints are between N40W and N70W, and an additional third occur within the two 30° segments adjacent to that maximum region. No joints were observed within the black, sulfidic schists of the Cushing Fm., and these units are thought to have experienced large amounts of strain subsequent to the development of joints.

In summary, the brittle fracture history of the Bangor-Brooks-Stetson area involves extensive faulting, predominantly on high-angle, northeasterly trending surfaces, with right-lateral movement. During times when strain was not occuring on these surfaces, stress was released by strain producing small-scale Z-shaped folds, typically oriented N10-40E, and small-scale S-shaped kinks, typically oriented N80-90W. These same styles of deformation occur thoughout the study area, and it is thought that the stress field which produced the Norumbega Fault zone persisted to the northwest in the Merrimack synclinorium. Recent seismic activity within the Norumbega Fault zone suggests that stress continues to be released (see Figure 1, Newberg, 1981, and Westerman, 1981b). A major dislocation on a N25E trending, right-lateral fault through the Norumbega Fault zone resulted in the northward transport of Vassalboro-type rocks which were formerly attached to the fault-bound block of Vassalboro Fm. within the zone. Small-scale Z- and S-folds may have developed from a secondary stress field produced when faults of the Norumbega system were locked.

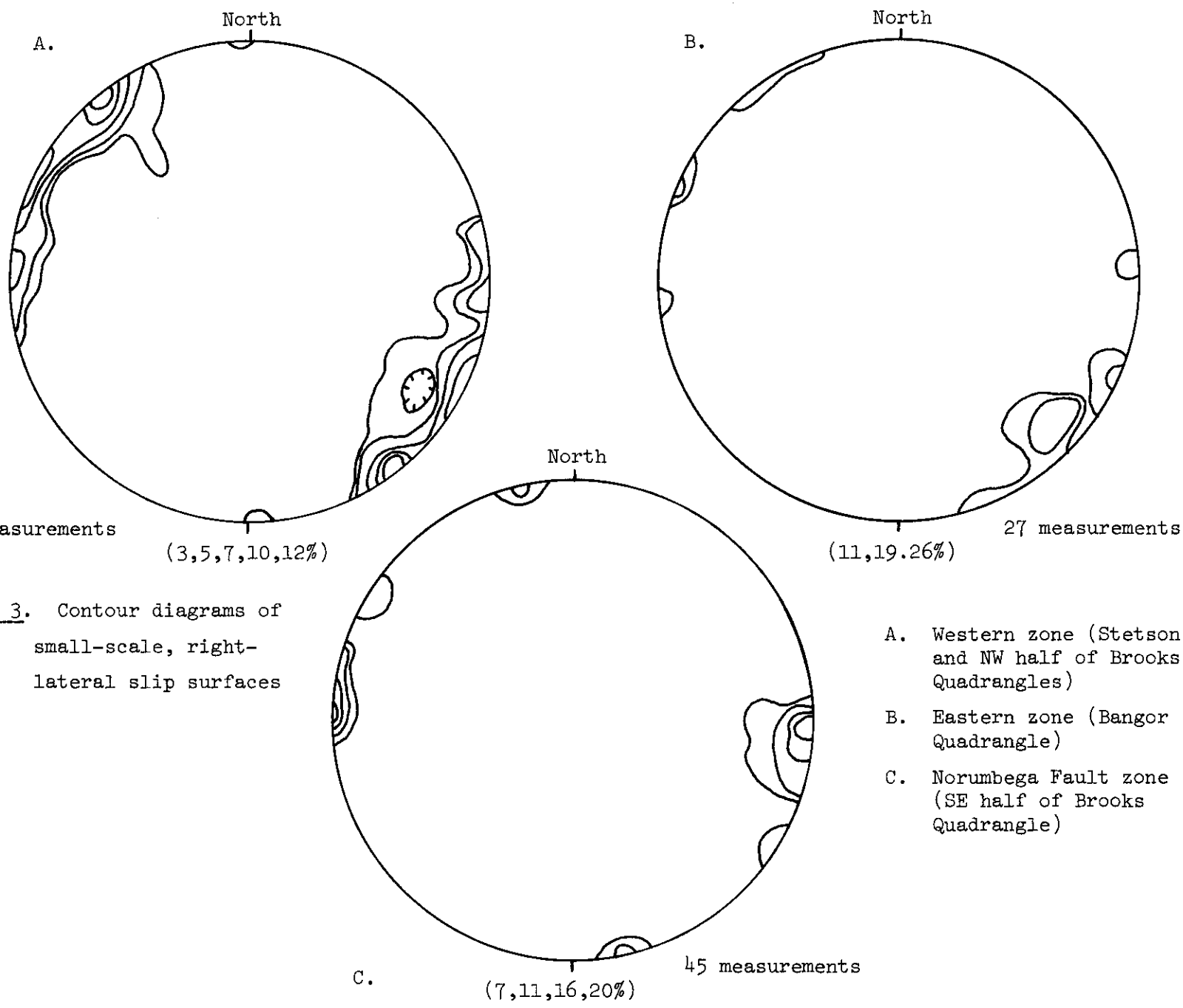

Figure 3. Contour diagrams of small-scale, right-lateral slip surfaces

A. Western zone (Stetson and NW half of Brooks Quadrangles)

B. Eastern zone (Bangor Quadrangle)

C. Norumbega Fault zone (SE half of Brooks Quadrangle)

Figure 4 A.

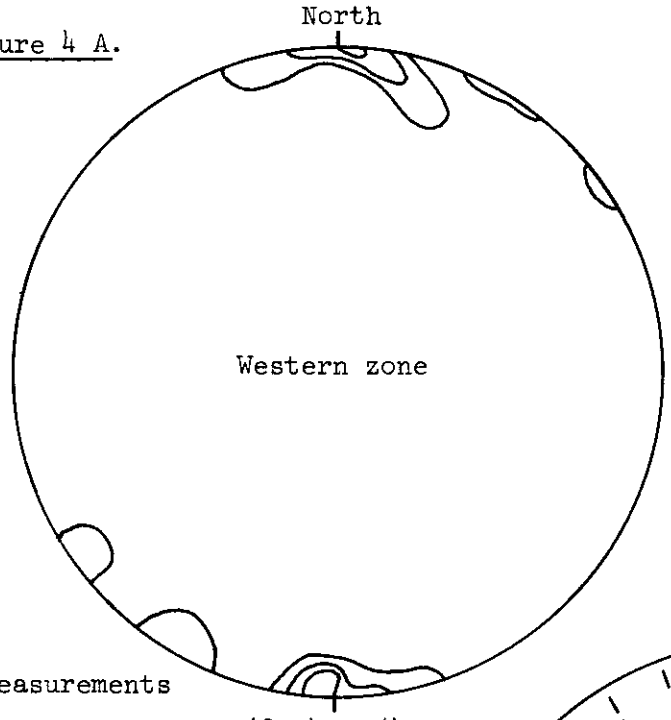

Figure 4 B.

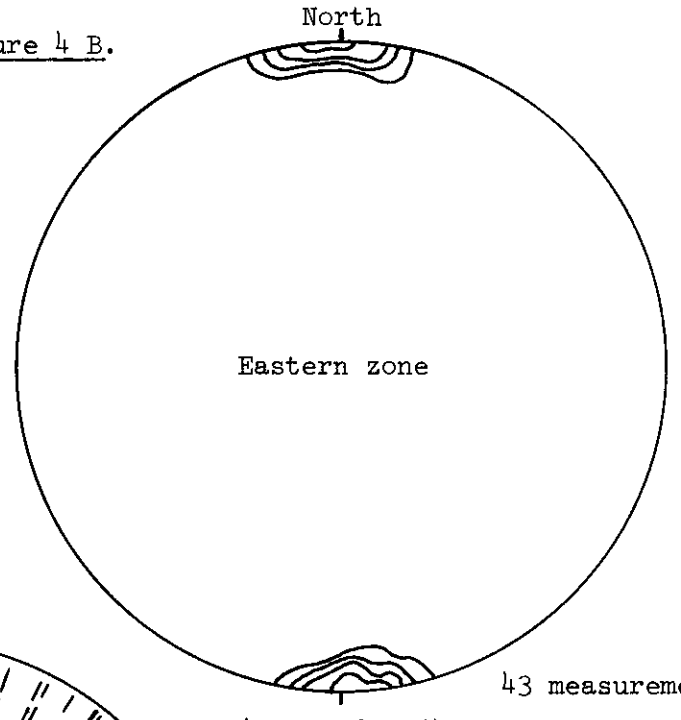

Figure 4. Contour diagrams of small-scale, left-lateral slip surfaces (zones as in Fig. 3)

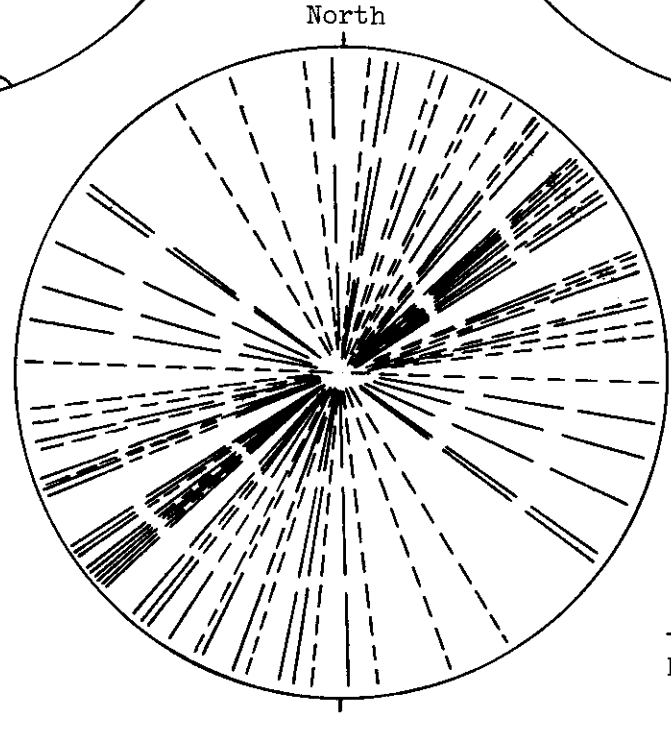

Figure 5. Small-scale faults

Right lateral

Left lateral

Normal, thrust, dip- and strike-slip, and undetermined

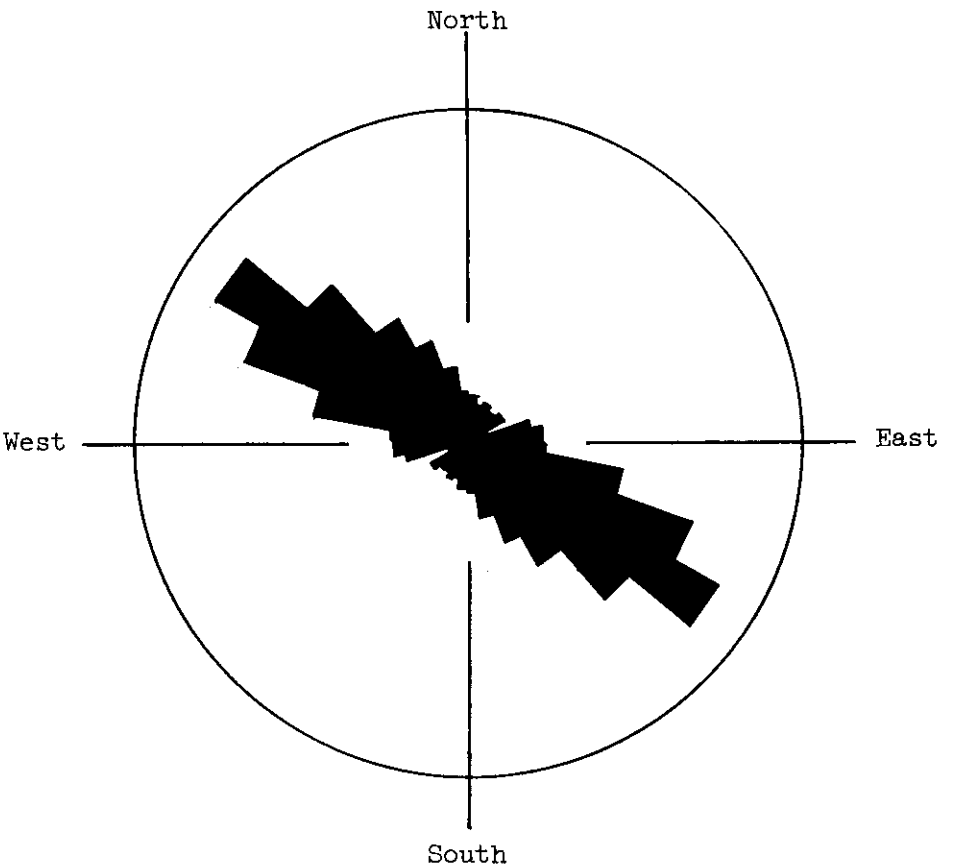

Figure 6. Rose diagram of joints

The author suggests that, in view of the frequency of seismic activity in the Bangor area, detailed study of the Norumbega Fault zone should be continued in the northern half of the Bucksport Quadrangle. A radiometric date on the faulted dike or sill exposed at the south end of Pushaw Lake, located at the Villa Vaughn Campground, would also be informative.

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