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Postglacial Faulting in the Vicinity of the Norumbega Fault Zone, Eastern Maine

by

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Introduction

At least six earthquakes of intensity V or greater on the modified Mercalli scale have occurred in the vicinity of the Norumbega fault zone in eastern Maine during historical times (Earthquake Information Bulletin, 1973). Figure 1 shows the locations of the earthquake epicenters in relation to the fault zone, and Table 1 gives other pertinent information. The strongest shock was the 1904 earthquake, which had an intensity of VII and toppled chimneys in Calais and Eastport, Maine, and St. Stephen, New Brunswick. The epicenters on Figure 1 are located approximately, and only half of them are actually within or very close to the Norumbega fault zone. Most of the six earthquakes could equally well be related to other directional trends when the earthquake distribution within the whole state is considered. Nevertheless, the occurrence of recent earthquakes in the vicinity of the fault zone warranted an examination of Quaternary features in the area to determine whether there is evidence of Holocene movement along the Norumbega Fault. The section of the fault zone that was examined for this study extends from the Penobscot River (in Orrington, 8 km south of Bangor) northeastward to the St. Croix River (T (Township) 1 R (Range) 1 and T2R2).

Quaternary Deposits and History of the Fault Zone

Pre-late Wisconsinan continental glaciers presumably covered eastern Maine, but the present study revealed no deposits that definitely could be attributed to these earlier glaciations. The late Wisconsinan continental ice sheet advanced across Maine about 20,000 yr B.P. (Schafer and Hartshorn, 1965) and covered the state until about 13,000 yr B.P. (Stuiver and Borns, 1975). Bedrock striations in the study area indicate that the ice flowed toward the southeast. The ice sheet left widespread deposits of both basal and ablation till. The till in the central part (lakes region) of the study area is very sandy and bouldery because of the local prevalence of granitic bedrock. Numerous drumlins occur in the region between U.S. Route 1 and the St. Croix River. These glacially streamlined hills appear to be composed mostly of till, and they obscure much of the bedrock geology.

The deglaciation of southeastern Maine began about 13,000 yr B.P. and was interrupted by the Pineo Ridge Readvance about 12,700 yr B.P. (Borns, 1973). The ice margin probably had not retreated far from the coast prior to this event. The present study revealed no stratigraphic

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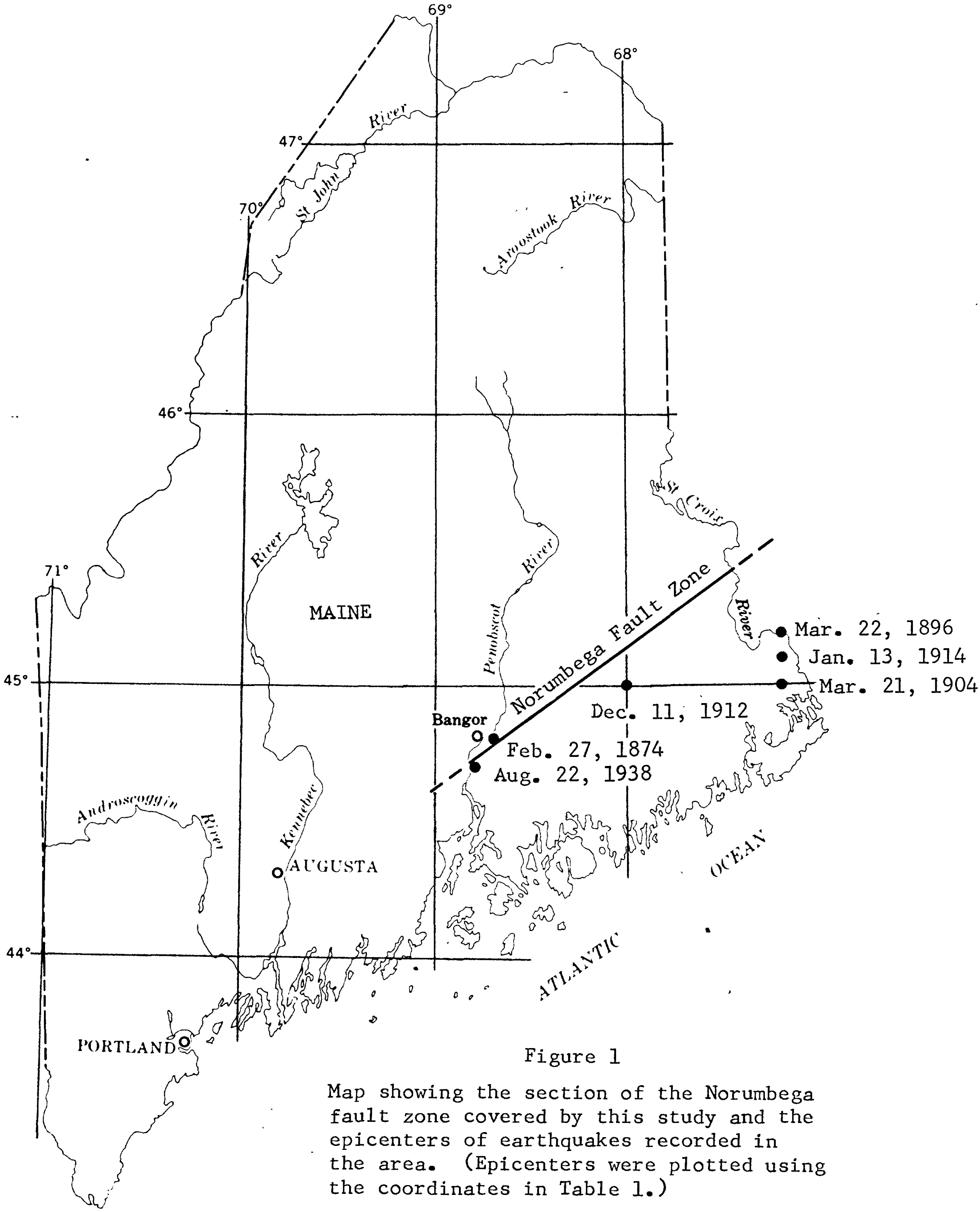

Figure 1

Map showing the section of the Norumbega fault zone covered by this study and the epicenters of earthquakes recorded in the area. (Epicenters were plotted using the coordinates in Table 1.)

TABLE 1
EARTHQUAKES RECORDED IN THE VICINITY OF THE NORUMBEGA FAULT ZONE

Date	Time (EST)*	Latitude (degrees)	Longitude (degrees)	Intensity**
Feb. 27, 1874	22:40	44.8	68.7	V
Mar. 22, 1896	19:56	45.2	67.2	IV-V
Mar. 21, 1904	01:04	45.0	67.2	VII
Dec. 11, 1912	05:15	45.0	68.0	V-VI
Jan. 13, 1914	03:00	45.1	67.2	V
Aug. 22, 1938	07:48	44.7	68.8	V

SOURCE: Coffman and von Hake, 1973.

* Eastern Standard Time
** Modified Mercalli scale

evidence of widespread deglaciation followed by readvance of the ice. However, there are numerous outcrops where striations indicate ice flow toward the south. The northwest-southeast set is also present on some of these ledges and appears to be older. Thus, the north-south striations probably indicate the shift to a more southerly ice flow that is known to have accompanied formation of the Pineo Ridge moraine near the coast.

The retreat of the late Wisconsinan ice sheet resulted in the deposition of water-laid sediments. The Penobscot Valley experienced marine submergence, and glaciomarine silt, clay, and sand of the "Presumpscot Formation" were deposited at low elevations (generally less than 60 m). Ice-contact sand and gravel were laid down in abundance throughout the study area. Many of the gravel deposits are poorly sorted and have been deformed by collapse caused by melting of supporting ice blocks. The somewhat flat-topped, gently sloping landform (98-104 m elevation) southwest of Turner Mountain in the Great Pond quadrangle probably is a glaciomarine kame delta, but the majority of the ice-contact deposits are eskers. Some of the eskers consist of a single ridge of sand and gravel, which typically is 10-30 m high. However, most are complex landforms with multiple ridges and associated kames and kame terraces. The terrain in such areas is very irregular and dotted with kettles. A good example is the esker system west of Nicatous Lake in the Nicatous Lake quadrangle. Non-collapsed outwash plains are rare in the vicinity of the Norumbega fault zone because the glaciofluvial sediments were deposited in valleys that were choked by stagnant ice. Some of the deposits along the St. Croix River may be outwash.

Glacial lakes existed in local upland basins above the marine limit in late glacial time. Deltaic topset and foreset beds were noted in a few pit exposures of meltwater deposits. However, the author found no exposures of lake-bottom sediments, probably because borrow pits have been excavated only in ice-contact sand and gravel or in till.

Postglacial deposits in the vicinity of the Norumbega fault zone include stream terraces, flood plains, swamps, bogs, and colluvium. Most streams in the area are small and have narrow, discontinuous flood plains. Stream terrace deposits are also uncommon. A small deposit of terrace alluvium consisting of about 3 m of sand and gravel overlies the glaciomarine deposits on the east side of the Penobscot River in Orrington, and detailed surficial mapping might reveal terraces along the St. Croix and other rivers. Swamp deposits are abundant throughout the fault zone. The postglacial drainage pattern is somewhat deranged, and there are many poorly drained areas (such as kettles) where swamps and bogs have developed.

Colluvium -- including coarse talus and other slope deposits formed by mass wasting -- has accumulated in the hilly terrain of the Norumbega fault zone since the last glaciation. Modern sediments are also forming by the reworking of glacial deposits along lake shores. These include lake ramparts, which are ridges produced by the shoving action of lake ice. Beach deposits have resulted from wave attack, especially where the lakes border on kames and eskers.

Methods of Investigation

Several types of Quaternary features were examined for evidence of surface or near-surface movements along the Norumbega fault zone:

1. Glacially striated or polished bedrock outcrops, for vertical displacements of the outcrop surfaces and/or lateral displacements of striations and grooves.

2. Exposures of the bedrock-overburden interface, for faults that extend from the bedrock up into the surficial sediments.

3. Exposures of stratified glacial sediments that have not experienced ice-contact deformation, for faulting of bedding or other primary features.

4. Exposures of postglacial stream-terrace and flood-plain alluvium, for displacement of the bedding.

5. Glacial and postglacial landforms with linear or planar elements (such as esker ridges and flat terrace surfaces), for fault displacements.

6. Any other features, such as raised beaches, that may have resulted from recent faulting.

The landforms of the area were studied by means of topographic maps and aerial photographs, but most work was done in the field. It soon became apparent that bedrock outcrops that have been exposed for hundreds or thousands of years are generally too weathered to preserve glacial striations, so the search was narrowed to fresher exposures along roads, lake shores, and stream banks. Much of the project area is wilderness, but good outcrops were found along the numerous logging roads that cross the region. The author examined approximately 200 outcrops, of which about half are glacially polished and striated. The lithologies in the fault zone include a variety of granitic igneous rocks, metasediments, siltstone, and conglomerate. Bedrock maps by D. R. Wones (unpublished data) and A. Ludman (1978) were used to locate the traces of the Norumbega fault zone and the nearest outcrops.

Numerous borrow pits and road cuts in the study area provided an opportunity to examine the stratigraphy of some of the surficial deposits. Most pit exposures are in eskers and other ice-contact sand and gravel deposits (locally overlain by glaciomarine silt and clay along the Penobscot River). Several were found in till, and a very few pits have been excavated in stream-terrace sediments and outwash(?).

Examination of the Norumbega Fault Zone for Evidence of Postglacial Faulting

Of the various features that were listed above as potential indicators of recent fault movement, only the striated bedrock outcrops yielded definite evidence of postglacial faulting. The other features were either poorly exposed or not useful for reasons indicated below. Well-stratified surficial sediments are absent or poorly exposed over much of the study area. Many of the ice-contact deposits are stratified, but the bedding has been deformed due to melting of supporting ice blocks. Few of these deposits are exposed down to bedrock, so any faults that cut both the bedrock and surficial sediments cannot be distinguished from the common ice-contact disturbances.

An exposure of the glaciomarine "Presumpscot Formation" on the east bank of the Penobscot River in Orrington exhibits a sharp contact between brown oxidized clay and the underlying unoxidized blue-gray clay. This locality is situated between two traces of the Norumbega fault zone, but excavation over a short distance did not reveal any faulting of the oxidation boundary. Moderately well stratified stream-terrace alluvium overlies the clay just upslope from here. Nearly all the sand and gravel have been removed by a pit operation, though, and it was not possible to examine the deposit thoroughly for postdepositional faulting of either the bedding or terrace surface.

The Norumbega fault zone system has a clear topographic expression on maps, aerial photographs, and Landsat imagery. Its topographic prominence is due to the hilly terrain that lies immediately south of the fault zone over much of the distance between the Penobscot River and Grand Lake Stream (Wabassus Lake quadrangle). These hills are underlain by granite and other rock types that are more resistant to erosion than the conglomerate, siltstones, and metasiltstones that are common within the fault zone. Examination of maps and aerial photographs did not reveal any large-scale faulting of eskers or other landforms along the fault traces. Streams, eskers, and glacially streamlined hills generally cross the fault zone without apparent offset parallel to the fault traces. A few stream and esker segments are curved at their junctions with the fault traces or follow them for short distances (e.g., the segment of Dead Stream north of Little Turner Mountain in the Great Pond quadrangle). However, these deflections are most easily explained by modern adjustment of stream courses to preexisting faults or by diversion of glacial meltwater streams around hills.

Field work likewise failed to disclose any major postglacial faulting, especially in the surficial deposits. Several eskers were examined where they cross the Norumbega fault zone. It is likely that a postglacial fault scarp would survive longer in the highly permeable ice-contact gravels than in more easily eroded fine-grained material such as glaciomarine clay. The esker-delta southwest of Turner Mountain (Great Pond quadrangle) is the best landform for study because it is cleared of trees, crosses two of the principal fault traces, and has fairly flat and even surface topography in the deltaic portion. However, no fault scarps were evident on the surface of this deposit.

This study showed that any recent fault displacements in the study area are not readily detected in the Quaternary sediments or landforms of the region. This conclusion prompted a close scrutiny of glacially striated bedrock outcrops, where displacements of as little as 1 or 2 mm might be recognized. Figure 2 shows a good example of one of the striated glacial pavements.

Of the more than 200 outcrops that were visited, six exhibit definite postglacial faulting of the bedrock surface. All the fault exposures are in the Vassalboro Formation or its equivalent, the "Flume Ridge Formation," along strike to the northeast. One to three principal faults were noted on each outcrop, and the maximum vertical displacement is 30 mm. Table 2 shows the data that were collected from the fault localities. Several generalizations can be made on the basis of field observations:

1. Most of the faults are bedding-plane faults. The others either follow joints or have developed along somewhat irregular fractures. One fault of the latter variety follows (in part) a minor Paleozoic fault.

2. The faults generally have vertical dips. Lateral displacement (1-2 mm) occurs only at locality 5.

3. The faults do not extend far along strike. The ones that are exposed along their entire length are no longer than a few meters. Vertical displacement along each fault ranges from a maximum value to zero at either end.

4. There is no consistent direction in which the fault scarps face. Scarps face in opposite directions at locality 4.

5. There is no apparent relationship between the faults and the topography of the outcrops.

6. The faults are tight, with little or no open space along the fault planes.

Localities 1, 2, 5, and 6 are within the Norumbega fault zone. None of them are situated directly on one of the fault traces mapped by Wones (unpub. data) or Ludman (1978). The only outcrop in the study area that is known to coincide with a principal trace of the Norumbega fault zone is on the east bank of the Penobscot River in Orrington. Here the bedrock is highly sheared and crumbly, and the glaciated surface of the outcrop is poorly exposed.

Localities 3 and 4 are approximately 8-10 km southeast of the Norumbega fault zone as defined by the three major faults that extend at

Figure 2. Striated outcrop of Vassalboro Formation at locality 2 (see Table 2). View is toward the northeast. A vertical displacement of 1.5 mm (not visible in the photo) offsets the ledge surface along the joint that parallels the hammer handle.

TABLE 2

DATA FROM FAULT LOCALITIES

Locality No., Quadrangle, and UTM Grid Coordinates	Attitude of Bedding in Rock		Fault Attitude		Raised Side	Exposed Length of Fault	End(s) Exposed	Direction of Slope and Steepness of Surface Topography	Glacial Striation Direction(s)
	Strike	Dip	Strike	Dip					
No. 1 Bucksport 4951500 m N, 513600 m E	N 60° E	90°	N 55° W (approx.)	steeply SW	SW (0-5 mm)	1.47 m	both	moderately to W	120°, 180°, 200°
No. 2 Bucksport 4951400 m N 513600 m E	N 45° E	75° SE	N 60° W	75° NE	SW (0-1.5 mm)	1.09 m	both	moderately to W	175°, 215°
No. 3 Big Lake 4993400 m N 601700 m E	N 40° E	90°	N 40° E N 40° E	90° 90°	SE (0-30 mm) SE (0-5 mm)	6.40 m 2.97 m	SW NE	essentially level	128°, 143°, 180°
No. 4 Big Lake 4992900 m N 598700 m E	N 40° E N 40° E N 35° E	90° 90° 90°	N 40° E N 40° E N 35° E	90° 90° 90°	NW (0-25 mm) NW (0-30 mm) SE (0-10 mm)	2.51 m 4.04 m 1.68 m	NE neither both	essentially level	180°
No. 5 Big Lake 5005450 m N 599800 m E	N 35° E	90°	N 35° E	90°	NW (0-4 mm)	5.44 m	both	gently toward the W to NW	173°
No. 6 Kellyland 5023550 m N 620450 m E	N 35° E	90° (approx.)	N 85° E (approx.)	steeply SE	SE (0-10 mm)	2.51 m	both	gently to WSW	155°

least as far northeast as the Grand Lake Stream area. However, locality 4 lies on or very close to a subsidiary fault, mapped by Ludman (1978), that parallels the Norumbega fault zone and is probably part of the same fault system. Similarly, locality 3 is situated between this fault and another one that lies 3 km to the southeast.

The faults at localities 3 and 4 are best examples of postglacial faulting that were found. They were exposed recently by removal of a thin cover of glacial till, and they appear very fresh and unweathered. Striations and grooves on the surfaces of both outcrops are clearly displaced as much as 30 mm along vertical bedding-plane faults (Figures 3 and 4). Vertical slickensides were noted on one of the fault scarps at locality 4. Similar markings on the scarps at locality 3 are probably a lineation produced by the intersection of bedding and cleavage.

Only one locality (No. 6) showed a clear relationship between faulting and overlying surficial sediments. The fault at this locality was partly concealed by a thin cover of compact basal till. Excavation along the strike of the fault revealed a vertical fracture that extended from the fault plane up into the till for at least 10 cm. This fracture was visible only by virture of the gray color of the till immediately adjacent to it, in contrast to the brown till on either side. The color difference probably was caused by ground-water movement and removal of iron oxides along the fracture. The fracture itself is believed to have been a continuation of the fault from the bedrock up into the till.

A contact between till and a disturbed glacial pavement was found at one other locality (not listed in Table 2), which is a roadside outcrop just north of Amazon Lake in the Scraggly Lake quadrangle. The granitic bedrock at this locality contains open fractures that are filled with veins of till. The fractures exhibit vertical offset of 5 mm or more but do not extend up into the till cover (Figure 5). The till veins probably originated from slight movement of granite joint blocks at the base of the last glacier, followed by injection of moist till down into the joints.

Discussion

Oliver and others (1970) located numerous postglacial faults in slaty rocks of southeastern New York, western New England, and southeastern Quebec. The faults in these areas likewise developed preferentially in a single rock type. Offsets occurred chiefly along the cleavage planes in the slates. The observed faults were steeply dipping reverse faults that had no strike-slip component. The measured amount of displacement was typically a few centimeters or less. However, the faults reported by Oliver and others (1970) differ in some respects from those described in the present study. Most of them dip south or east; the amount of displacement is generally uniform along the entire exposed length of each fault; and the scarps all face in the same direction of any particular outcrop.

Figure 3. Glaciated surface of the "Flume Ridge Formation" at locality 3. View is toward the south. Wide glacial groove to right of hammer shows slight vertical displacement along two northeast-trending bedding-plane faults (near and far sides of hammer). Both fault scarps face northwest.

Figure 4. Glaciated surface of the "Flume Ridge Formation" at locality 4. View is toward the northwest. Note bedding-plane faults (behind hammer) and small joint blocks pushed up by frost heaving (center).

Figure 5. Glaciated granite pavement overlain by basal till, just north of Amazon Lake in the Scraggly Lake quadrangle. View is toward the east. Fractures in rock (center to lower-right) are filled with till. Note that fracture to left of hammer does not extend into the till cover.

Oliver and others (1970) discussed several tectonic and nontectonic causes of postglacial faulting that warrant consideration in trying to determine the origin of the faults described here. The mechanisms that they suggested are: slumping; frost heaving; regional tectonic stresses; or rock expansion due to hydration, unloading of glacial ice, or some other cause. Frost heaving and slumping were ruled out because of the uniform height and orientation of scarps on each outcrop, the tightness of the fault planes, and the lack of topographic control. The authors favored the expansion hypothesis for two reasons. First, the postglacial faults that they described from various areas were all dip-slip displacements that followed local planes of weakness in the bedrock, regardless of the strike direction of these planes. Second, "...the uniformly small throw and close spacing of the scarps favor the mechanism of small rotations of individual slabs whose thicknesses are determined by the natural joint spacing of the rock. If a regional tectonic force were active, one might expect larger displacements to be concentrated on a few larger faults" (Oliver and others, 1970, p. 587). Nevertheless, the reasoning of Oliver and others left a strong possibility of a tectonic origin for at least some of the faults.

It is clear that the postglacial displacements along the Norumbega fault zone are not the result of slumping, creep, or other topographically related mass-wasting processes. The largest offsets occur on broad, generally level outcrop surfaces. In fact, the downhill sides of the faults have been raised on the moderately sloping ledges at localities 1 and 2.

Frost heaving has at least contributed to the movement of joint blocks at one fault locality (No. 4). The principal displacements of the outcrop surface do not exceed 30 mm, but small joint blocks have been pushed up by greater amounts. Figure 6 shows a block that has been elevated 80 mm along bedding-plane faults and joints that cut across the bedding. However, it is uncertain whether similar frost heaving was the cause of all the faults described in Table 2. Postglacial faults should be more common if they were caused by frost heaving, even if they are limited to the Vassalboro ("Flume Ridge") Formation. On the other hand, the formation of ground ice in subhorizontal joints, especially under permafrost conditions in early post-glacial time, may have been responsible for at least some of the faulting. Frost heaving would be expected to produce miniature horsts of the type that occur at locality 4, but it seems a less likely mechanism for causing displacements like the ones at locality 3 (Figure 3). Here there are two bedding-plane faults in a broad, flat, sparsely jointed outcrop, and the fault scarps face in the same direction. Frost heaving of the rock would have required not only the lifting of the very large slab or rock between the faults, but also greater uplift of the body of rock (of indefinite extent) that lies immediately to the southeast. However, Washburn (1969) observed that frost heaving in northeast Greenland has raised large, tightly held joint blocks (with glaciated tops) as much as 125 cm above the surrounding outcrop surfaces. Therefore, it is possible that even the displacement at locality 3 may be due to frost action.

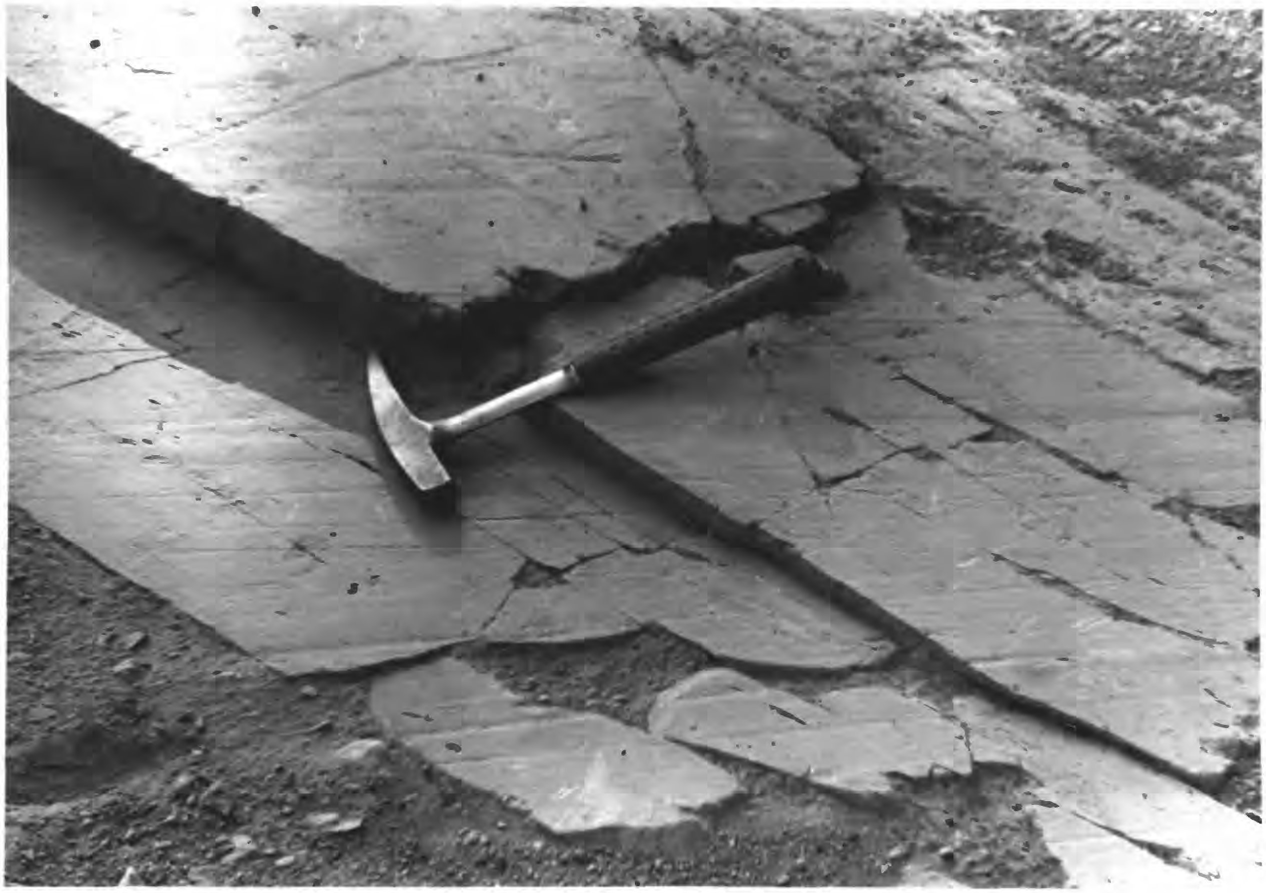

Figure 6. Close-up part of ledge surface at locality 4. View is toward the west. Bedding-plane fault (center to lower-right) displaces striations that trend 180^{o}. Joint block (upper left) shows greater elevation, probably because of frost heaving.

The expansion hypothesis cannot be discounted, but it is difficult to determine a probable cause of expansion. The Vassalboro ("Flume Ridge") is generally fresh and unweathered except where the bedrock has lain at or very near the ground surface during much of postglacial time. (A good example of differential weathering and erosion was seen on a shoreline outcrop at the south end of Fourth Machias Lake, where glacially striated quartz veins project 1-2 cm or more above the surrounding rock surface.) The slight amount of mineral alteration that may have occurred along joint planes in postglacial time is unlikely to have generated enough pressure to cause vertical fault displacements of up to 30 mm. Subhorizontal joints were noted in the Vassalboro Formation, but they appear to be few and widely spaced.

Crustal stress associated with postglacial uplift is another mechanism that may have caused the faulting. If this is the case, the stresses resulting from uplift selectively caused fault displacements in the Vassalboro ("Flume Ridge") Formation. The rock would be expected to have yielded readily along the vertical joints and bedding planes in this formation, in contrast to the sparsely jointed granites that occur over large parts of the study area. However, faults also should have developed in other well-jointed rock types in the Norumbega fault zone, but none were found.

It is possible that the postglacial faults resulted from tectonic activity, with a concentration of movement in the Vassalboro ("Flume Ridge") Formation. Any model that is built around this hypothesis must account for the various strike directions of the faults, the scarps that face in opposite directions, and the lack of strike-slip displacement.

It has been pointed out that there is not a strong correlation between the location of the Norumbega fault zone and the distribution of earthquake epicenters. It is equally uncertain that a causal relationship exists between the fault zone and postglacial faulting in the Vassalboro ("Flume Ridge") Formation. The localities with the largest displacements (Nos. 3 and 4) are 8-10 km southeast of the principal fault zone, but here the displacements may have been caused by movement along subsidiary faults that parallel the main fault zone. The results of the present study indicate that there is no evidence that the postglacial faults described in this report resulted from Holocene movement along the Norumbega fault zone.

Summary and Conclusions

Examination of landforms, surficial deposits, and more than 200 bedrock outcrops in the vicinity of the Norumbega fault zone revealed only six localities where definite postglacial faulting has occurred. All the faults are minor (1.5-30.0 mm) vertical displacements of glacially polished and striated outcrops of the Vassalboro ("Flume Ridge") Formation. They strike in various directions, but most of the faults (and the ones with the greatest displacements) are northeast-trending bedding-plane faults.

The cause of the postglacial faulting is unknown. The faults are not the result of creep or slumping, and it is unlikely that they were caused by any weathering process other than frost heaving. The development of ground ice along joints in the bedrock was probably much greater in late glacial time than under the present climatic regime, and this process was responsible for some of the vertical displacements of outcrop surfaces. However, it is possible that the faults developed as a consequence of regional stresses that produced minor faulting most commonly in the Vassalboro ("Flume Ridge") Formation. The origin and nature of these stresses (if they exist) are yet to be determined. They may be related to the seismic activity that has been recorded in the vicinity of the Norumbega fault zone.

Acknowledgments

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