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Thrust and Strike-slip Faults near Jackman, Maine

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ABSTRACT

The Marie Petuche fault, exposed at the international border station north of Jackman, Maine, is interpreted as a northwest-directed thrust. Evidence for this conclusion includes repetition of section, overturning of beds in the footwall, coincidence of a zone of kink folds, and outcrops which show southeast-dipping shear surfaces and fractures parallel to bedding and cleavage. This fault extends at least 25 km to the northeast.

The Thrasher Peaks fault is a major fault which extends for nearly 200 km from northern New Hampshire into western Maine. Along most of its length the fault strikes northeast-southwest and has a vertical sense of displacement. Outcrops of the fault northeast of Jackman indicate that the primary displacement on this east-west striking segment of the fault is right-lateral strike-slip. A fault gouge which contains cataclastically deformed clasts of Attean pluton in a slate matrix and kinematic indicators ornamenting shear surfaces are the primary evidence for this interpretation. The minimum demonstrated displacement is 10 km. This fault was probably active through much of the Acadian orogeny.

The association of thrust and strike-slip faults is interpreted as a positive flower structure related to two factors: the curvilinear nature of the strike-slip fault and its unusual east-west strike in this region.

The implications of this interpretation are that the overall displacement on the length of the Thrasher Peaks fault has been oblique and that the fault may continue for a considerable distance to the northeast. Possible candidates for the continuation of the fault toward the northeast are the suite of reverse faults in the Caucomgomoc Lake area.

INTRODUCTION

Since detailed bedrock investigations were first conducted in northwestern Maine during the 50's and 60's, the area which includes the junction of three major tectono-stratigraphic features, the Connecticut Valley - Gaspé and the Moose River synclinoria, and the Boundary Mountains anticlinorium (Fig. 1), has been recognized as a broad, structurally complex zone of significance (see Boone et al., 1970; Albee and Boudette, 1972). Recent investigations have concentrated in particular on the fault which bounds the Chain Lakes massif on its northwest side, referred to as the Thrasher Peaks fault.

Interpretations of the nature of the Thrasher Peaks fault have been nearly as numerous as the number of investigators owing to paucity of outcrop and difficulty of access. Albee and Boudette (1972) recognized a zone of cataclasis representing unknown translation in the northern part of the Attean pluton. In his investigations of the zone, Westerman (1979, 1980) proposed a normal fault dipping steeply to the northwest. Boone et al. (1970) and Boone (1978, 1980) suggested that the fault zone is a series of northwest-dipping thrust faults.

The objectives of this paper are to present field evidence bearing on the nature of this structurally complex zone, to consider structural associations within it, and finally to propose a structural model for the region. This paper will consider two faults within the broader zone. The first, the Marie Petuche fault, is a zone of thrust faulting which includes a number of imbrications. The second, the Thrasher Peaks fault, is interpreted to be

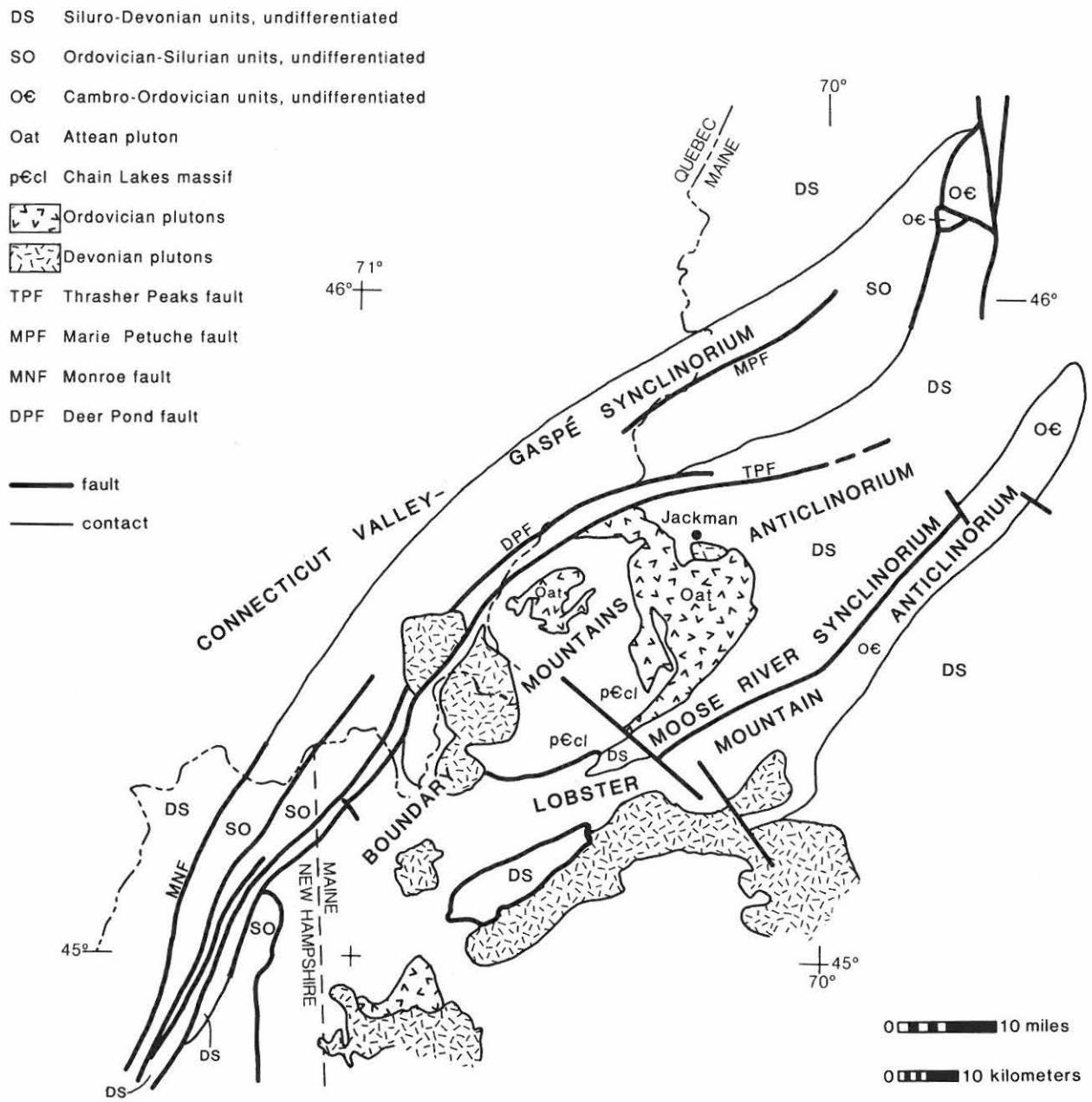

Figure 1. Generalized bedrock geologic outline map of western Maine and northern New Hampshire (modified from Moench, 1984).

of oblique movement along its entire length, but to be primarily a right-lateral, strike-slip fault along the segment studied in Maine (Fig. 1).

REGIONAL SETTING

Of the three tectono-stratigraphic features in the region, the Boundary Mountains anticlinorium exposes the oldest rocks. These include the Middle Proterozoic Chain Lakes massif, the Boil Mountain Complex, interpreted as a Cambrian(?) ophiolite suite (Boudette, 1982), and an Upper Cambrian(?) mélange and overlying Cambrian(?) and Lower Ordovician flysch carapace (Boone et al., 1984). Intruding the older rocks of the anticlinorium is the Ordovician Attean pluton (443 Ma; Lyons et al., 1986), a mottled pink and green porphyritic quartz monzonite. With the exception of this pluton, all of the rocks of the anticlinorium are deformed. Recent work (Boone and Boudette, 1989; Boone, this volume) suggests that the deformation was part of the mid-Cambrian to Early Ordovician Penobscottian orogeny.

The Moose River and Connecticut Valley - Gaspé synclinoria contain primarily Silurian and Devonian metasedimentary and metavolcanic rocks in Maine although toward the southwest in Vermont apparently older rocks are exposed in the latter (Bothner and Berry, 1985). Most folding and faulting in the synclinoria can be related to the Acadian orogeny. The metasedimentary units within the synclinoria of most importance to this study are: the Frontenac Formation, a thick sequence of interbedded wacke and slate, and mafic volcanic rocks (Canada Falls Member) of probable Silurian age (Marvinney, 1986); the Upper Silurian or Lower Devonian Ironbound Mountain Formation, a dark gray mudstone- and siltstone-slate unit (Marvinney, 1986); and the Lower Devonian Northeast Carry Formation, a dark gray siltstone-slate and metasandstone unit. The last two formations are constituents of the recently defined Seboomook Group (cf. Pollock, 1987). The Frontenac and Ironbound Mountain Formations are exposed in a broad anticline along the southeast margin of the Connecticut Valley - Gaspé synclinorium which has been sliced by northwest-directed thrust faults including the Marie Petuche fault (Fig. 1). These units are of importance in establishing translations on each of the faults.

The metasedimentary units present a particular difficulty to structural interpretation in that they lack distinct, regionally extensive, stratigraphic sequences. This is especially true of the Frontenac Formation which contains packages of coarse-grained, proximal turbidites (Marvinney, 1986) which vary in stratigraphic position and tend to be laterally discontinuous. Only a general trend of upward-increasing frequency and thickness of interbedded slate has been recognized (Marvinney, 1986). Due to the lack of stratigraphic markers, the regional structural interpretation draws heavily from analysis of cleavage, minor structures, and, in the case of faults, several outcrops which show their nature, rather than on map patterns of stratigraphic units.

THRUST FAULTS

Marie Petuche Fault

Several thrust faults are mapped in the study area, the longest of which is the Marie Petuche fault (Fig. 2). This fault extends from the international border station on U.S. 201 - Quebec 173 (#1 on Fig. 2) northeastward along the international border and the southeast side of Green Mountain (#2 on Fig. 2) to the vicinity of Comstock Mountain (#3 on Fig. 2) for a total length of 25 km. At its current level of exposure it is an intraformational fault within the Frontenac Formation. Its extent beyond the map area is unknown; it has not been recognized to the northeast in the Caucomgomoc Lake area (Pollock, 1983) nor to the southwest in Quebec (S. R. Chevé, pers. commun., 1982).

The existence of the fault is supported by several lines of evidence. First, there is a stratigraphic discontinuity across the fault. On the southeast side, beds in the Frontenac Formation face to the southeast; lower stratigraphic levels are encountered as the fault is approached. The frequency of interbedded slate increases gradually toward the southeast as the contact with the Ironbound Mountain Formation is approached. On the northwest side of the fault, beds face mostly northwestward. The bedding style and frequency of interbedded slate on the northwest side are similar to that of the transition zone with the Ironbound Mountain Formation encountered well to the southeast.

Second, the orientation and style of structural features changes across the zone. On the southeast side, asymmetrical minor folds are numerous, tight to isoclinal, and verge to the northwest. On the northwest side, minor folds are less numerous, open, and most often neutral in vergence. When interpreted as parasitic folds to a major structure and when considering the repetition of Devonian units on the northwest and southeast sides of the field area (Fig. 2), the northwest vergence of the minor folds on the southeast initially seemed to indicate that this area was within the southeast limb of a major northeast-trending anticline. The abruptness of change in style and vergence of minor folds across a narrow zone, however, suggests that the minor folds are related to a fault. The change in vergence is also important in establishing the translation on the fault.

Third, a narrow zone of kink folds, perhaps several hundred meters wide, exists along the southeast side of the fault zone. The kink folds (definition of Hobbs et al., 1976) are upright, tight, have amplitudes and wavelengths of a few to tens of centimeters, and have northeast-trending axes. They generally occur in sections where the interbedded slate is thick. An important feature in many parts of the kink zone are near-vertical, thin pseudobeds which result from the redistribution of quartz from the kink fold limbs into their hinge zones. This suggests that the axis of maximum shortening was nearly horizontal during development of the kink folds. Folds of this form commonly occur with their axial planes perpendicular to the axis of maximum compression as a consequence of 50% shortening in fine grained rocks (Paterson and Weiss, 1966).

In several areas the Marie Petuche fault is exposed, but nowhere as well as in the roadcuts at the international border station on U.S. Route 201, shown in Figure 3 (#1, Fig. 2). Here the fault cuts thick wackes and interbedded slate of the Frontenac Formation in a zone of nearly continuous exposure 160 meters wide. Through much of the roadcut, especially the western end, the dominant structures are numerous fractures which are subparallel to both bedding and cleavage, and other shears developed at a low angle to bedding. Individual wacke beds cannot be traced across the exposure due to a combination of sedimentary discontinuity and displacement along shears. The intersections of the fractures and shears with cleavage and bedding results in an extensively fractured exposure.

The intensity of deformation increases from southeast to northwest across the border roadcut. The following discussion refers to sketches at each of several stations from southeast to

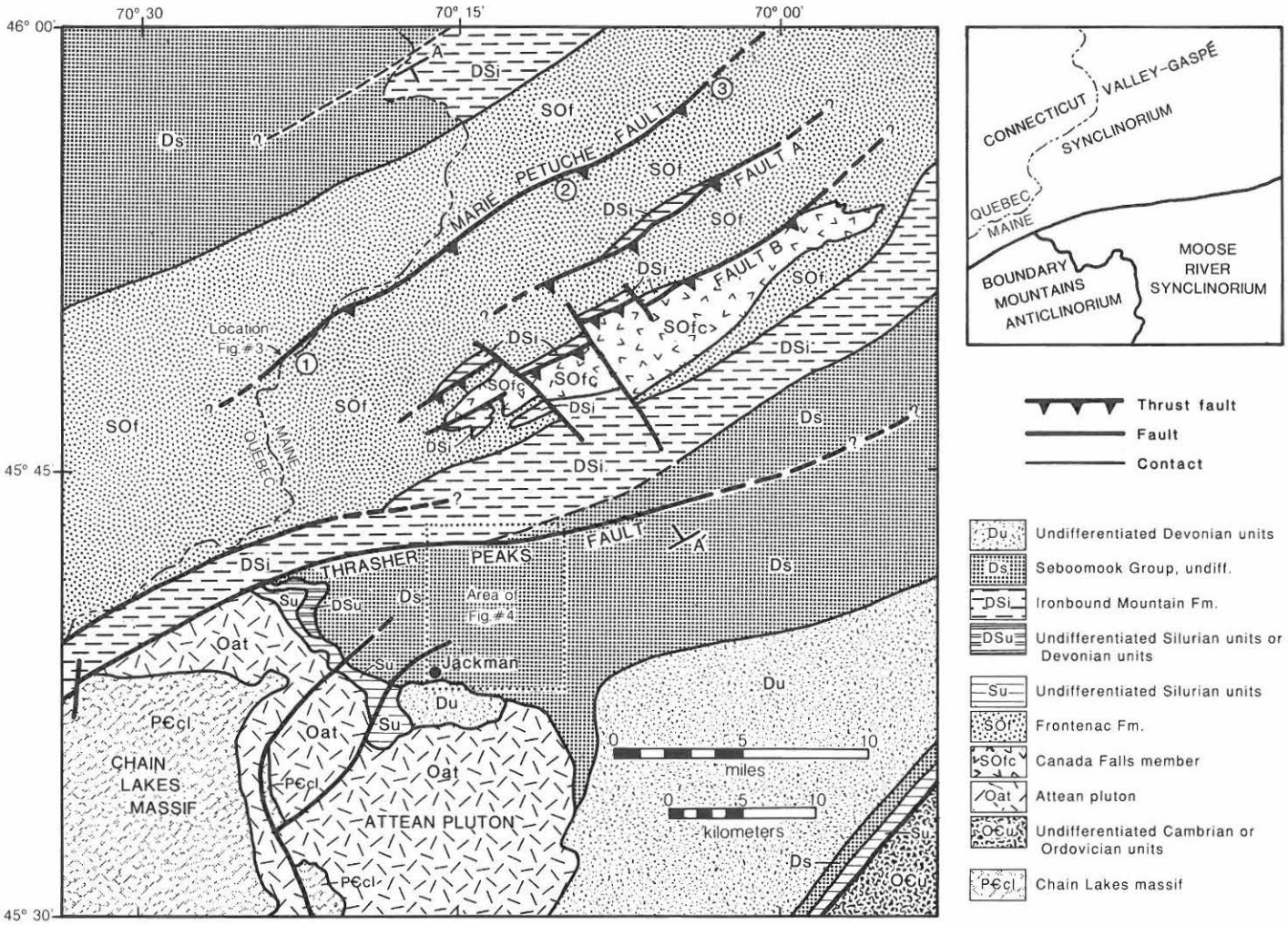

Figure 2. Bedrock geologic outline map of northwestern Maine and adjacent Quebec (modified from Osberg et al., 1985). Locations dicussed in text: (1) International border station; (2) Green Mountain; (3) Comstock Mountain. Faults A and B discussed in text.

northwest along the roadcut (Fig. 3). Starting in the southeast (station 1), bedding is fairly regular and dips steeply to the southeast. Penetrative, nearly bedding-parallel cleavage of presumed Acadian origin is prominent. At the left (northwest) side of this station bedding is discontinuous. It is segmented by a steeply dipping spaced cleavage which displays some dip-slip movement, but which has the same general orientation as the penetrative cleavage. Whether this is a change in the style of Acadian cleavage, reactivation of cleavage surfaces, or a younger fabric is uncertain.

Another 50 m to the northwest, bedding is again recognizable as it dips gently to the southeast (station 2). This gentle dip persists for the remainder of the roadcut. Cleavage through most of the remainder of the roadcut dips moderately to the southeast. Fractures parallel to bedding and cleavage are common. In this part of the outcrop, shear surfaces oriented N45°E 50°SE are locally ornamented with fine mineral lineations and mullions bearing approximately 120° and plunging 50°.

This general style of deformation continues across the outcrop to the northwest. In places bedding is quite obvious and penetrative cleavage is similar to Acadian cleavage seen elsewhere. In others, two cleavages are evident. The regional cleavage strikes approximately N45-60°E and dips moderately to steeply southeastward. Distinct lithons in which cleavage is penetrative are bounded by spaced fractures along which some slip has occurred. A later, near-vertical spaced cleavage is only locally developed.

At the northwestern limit of exposure the extent of brittle deformation is great (stations 3 and 4). Fractures sub-parallel to bedding and cleavage have reached their maximum development. While a number of more competent beds can be identified here, they cannot be traced laterally for more than a few tens of meters. Small sections of competent beds are offset in a vertical sense by southeast-dipping shears. Competent beds are bounded by zones of intense fracturing. In these zones bedding is discontinuous and there is considerable quartz veining, mostly bed-

ding-parallel. The fractured zones also are moderately kinked, similar to the fashion of kink folding noted elsewhere along the fault, including northwest vergence. These impart a northwest dipping fabric to the roadcut.

Additional, less extensive examples of this type of deformation can be observed through a belt extending a few kilometers south of the border station. These occurrences are separated by sections of relatively undeformed rocks of the Frontenac Formation indicating that faulting occurred along a number of narrow zones rather than along a single discrete plane.

The Marie Petuche fault is interpreted as a northwest-directed thrust for several reasons: (1) southwest dipping shears offset bedding at the border station; (2) the asymmetry and northwest vergence of minor folds on the southeast suggest northwest-directed compression, but no corresponding major fold has been recognized; (3) the associated zone of kink folds suggests that the axis of maximum compression was sub-horizontal and oriented northwest-southeast; and (4) beds overturned toward the northwest are present in the footwall and are well exposed at Comstock Mountain (#3, Fig. 2). The increased fracturing at the border station roadcut could be explained by deformation in the upper plate of a thrust ramp as described by Elliot (1976), Sanderson (1982), and Butler (1982), for example.

Other Thrust Faults

Although faulting occurs entirely within the Frontenac Formation along the Marie Petuche fault, in two other areas faulting of the same nature has resulted in stratigraphic repetition of other units (labeled faults A and B in Fig. 2). Fault A is in the central part of the Penobscot Lake quadrangle (Fig. 2) where a thin wedge of Ironbound Mountain Formation is in depositional contact with the underlying Frontenac Formation on the northwest and structurally beneath it on the southeast. All units dip and face southeastward. Extensive kinking and "pencil" cleavage (Ramsay, 1981) are developed in the Ironbound Mountain Formation. Because the style of deformation is similar to that seen along the Marie Petuche fault, this fault is believed to be an imbrication of northwest-directed thrusting.

Fault B is inferred along the northwestern limit of the Canada Falls volcanic member where it is in contact with excellent mudstone slate of the Ironbound Mountain Formation. Bedding in the latter faces southeastward into the volcanic rocks, but it was not possible to determine bedding attitude in the volcanic rocks near the contact. The fault trace is represented by a narrow topographic low in which there is no outcrop. Kink folds are only locally developed along this trace. Although outcrop evidence for the style of faulting is lacking here, stratigraphic repetition is in the same sense as that of the other thrust faults suggesting that this, too, is a northwest-directed thrust.

Several other factors are important in establishing the fault type. On the southeast side of fault B, the southeastward facing limbs of many of the minor asymmetric folds are overturned to the southeast. This is especially apparent in rocks of the Ironbound Mountain Formation adjacent to the volcanic rocks immediately above the fault. The frequency of overturning decreases away from the fault toward the southeast such that beds are upright within several kilometers. Similarly, cleavage dips toward the northwest in this belt, whereas throughout most of the field area it is vertical or dips toward the southeast. The frequency of northwest dipping cleavage also diminishes toward the southeast. These relationships suggest that the rocks in the belt adjacent to and southeast of fault B have been rotated to the southeast, either during or following cleavage and fold development. Such rotation might develop in response to northwest-thrusting along an upward-steepening fault surface.

In addition to the overturning there are two small areas of Frontenac Formation within the belt of Ironbound Mountain Formation southeast of fault B (too small to be shown on Fig. 2). Faulting is noted on the southeast side of one and has been inferred for the other. These are interpreted as reverse faults which have brought the Frontenac Formation up to higher structural levels. They are thought to be back-thrusts related to volume accommodation along fault B.

Additionally, an aeromagnetic map of the region (Boucot et al., 1964) shows a marked magnetic gradient coincident with fault B. The strong magnetic signature of the volcanic rocks on the southeast is abruptly terminated at the fault. The Ironbound Mountain and Frontenac Formations on the northwest side are represented by a broad magnetic low. The abruptness of change supports a fault interpretation for this contact.

Based on the mapped distribution of units alone (Fig. 2), other models are possible for fault displacement. The three thrust faults could be interpreted as normal faults with their northwest sides down-dropped. While such a model easily explains the juxtaposition of Frontenac and Ironbound Mountain Formations, it is inadequate to explain other structural features, such as the associated zone of kink folds, the change in style of minor folds across the fault, overturning in the footwall, and rotation of structures southeast of fault B. Because of the near-horizontal orientation of maximum compression in a thrust fault setting, these features are more easily accommodated in a thrust model.

Age of Faults

The maximum age of the thrust faults is Early Devonian. The faults must be younger than probable Lower Devonian rocks of the Ironbound Mountain Formation which they cut, but the minimum age is unconstrained. However, because of the close association with folds - both the zone of kink folds and minor asymmetric folds - the faults are considered to be syntectonic with these ductile features. Inasmuch as Acadian folds are the youngest folds in this part of Maine, the faults are probably also of Acadian origin.

NORMAL FAULTS

Within the field area are several northwest-trending faults of probable normal displacement (Fig. 1). They are inferred from the displacement of strike belts and are younger than thrust fault B which they crosscut. Similar faults may crosscut the Marie Petuche fault, but have not been recognized because of the difficulty in assessing offset in the Frontenac Formation. These faults are probably similar to those which crosscut the Moose River synclinorium and Lobster Mountain anticlinorium to the south (Osberg et al., 1985).

THRASHER PEAKS FAULT

The Thrasher Peaks fault is a major feature which extends from northwestern Maine near Jackman (Fig. 2), across the Eastern Townships of Quebec Province, into northern New Hampshire. The mapped length of the fault, from outcrops described herein to its southern termination about 10 km south of Magalloway Mountain, New Hampshire, is approximately 200 km. Along much of its length in New Hampshire and Maine the Thrasher Peaks fault trends northeast-southwest and juxtaposes pre-Silurian rocks of the Boundary Mountains anticlinorium on its southeast side with Silurian and Devonian rocks on its northwest side (Moench, 1984; Osberg et al., 1985). The fault dips steeply toward the northwest along this segment and shows mostly dip-slip movement although it is not certain whether it is of normal or reverse displacement (R. H. Moench, pers. commun., 1987).

Along the continuation of the fault east of the Chain Lakes massif and Attean pluton, the structural and stratigraphic relationships are distinctly different. There the Thrasher Peaks fault trends nearly east-west and is bounded on both sides by Silurian and Devonian rocks of the Moose River and Connecticut Valley - Gaspé synclinoria. Strike belts in this region are relatively broad and structures relatively open. These observations suggest that the nature of the fault changes along this segment of its length.

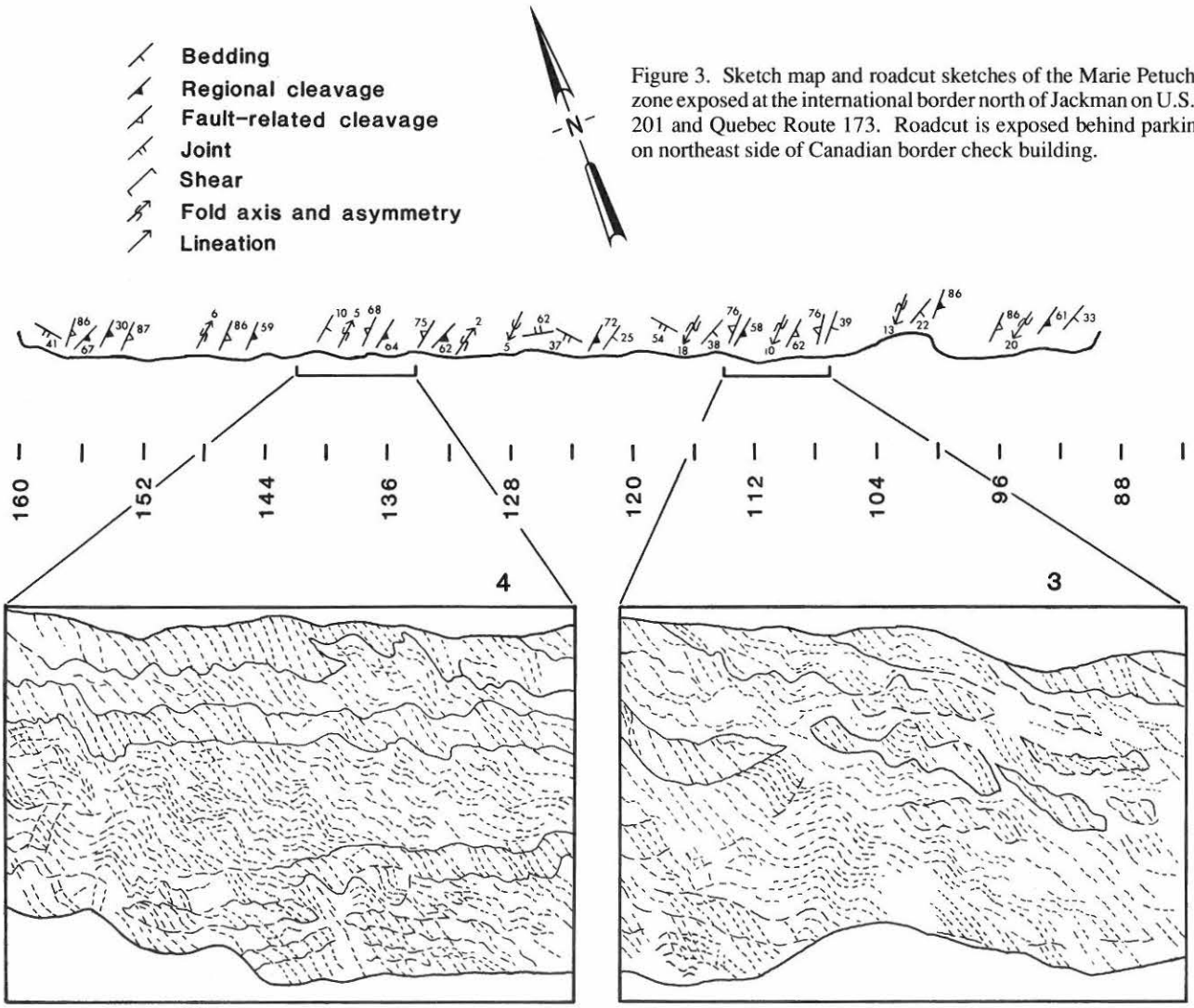

Figure 3. Sketch map and roadcut sketches of the Marie Petuche fault zone exposed at the international border north of Jackman on U.S. Route 201 and Quebec Route 173. Roadcut is exposed behind parking area on northeast side of Canadian border check building.

Outcrop Description

The Thrasher Peaks fault is exposed in two outcrops located northeast of Jackman (Fig. 4), informally referred to as the northern and southern outcrops, which are separated across strike by a 100 m wide topographic low with no exposure. Each outcrop exposes clasts and shear traces in a matrix of dark gray slate and is interpreted as fault gouge. The gouge, which on first appearance looks like a conglomerate, probably underlies the entire zone between the outcrops. The characteristics of this tectonic pseudo-conglomerate provide much information about fault displacement and duration. Figure 5 shows a representative portion of each outcrop.

The most striking similarity in both outcrops is the nature of the clasts in the gouge. They are dominantly granitic, with a mineralogy consisting of euhedral quartz, powdery white altered plagioclase, K-feldspar, green biotite forming pseudomorphs after hornblende, and some chlorite. The coarse-grained mineralogy imparts a green and white mottled appearance to the clasts. The clasts usually have a pronounced mineral foliation parallel to their long axes. Their mineralogy, texture, and color in both hand specimen and thin section are identical to rocks of the Attean pluton, described in detail by Albee and Boudette (1972), which is located approximately 15 km westward along the fault trace.

While the clast types in each are quite similar, the outcrops differ notably in clast size, style of deformation, and degree of structural overprinting. In the southern outcrop, clasts are relatively small and elongate, with long axes ranging from 2 to 10 cm and short axes about half that (Fig. 5a). Incipient necking in some clasts suggests that ductile deformation may have been important at some period, although this phenomenon is not well developed. However, numerous anastomosing, near-vertical shear surfaces contain abundant phyllosilicates and poorly formed pressure shadows have developed at the terminations of some clasts (Fig. 5a). These phenomena support the possibility that ductile deformational mechanisms were active. Furthermore, the pressure shadows are commonly asymmetrical about the clasts (Fig. 5b). The asymmetry is indicative of dextral translation, based on the criteria set forth by Simpson and Schmid (1983).

The last important characteristic of the southern outcrop is that the gouge zone is folded. A line drawing of the outcrop (Fig.

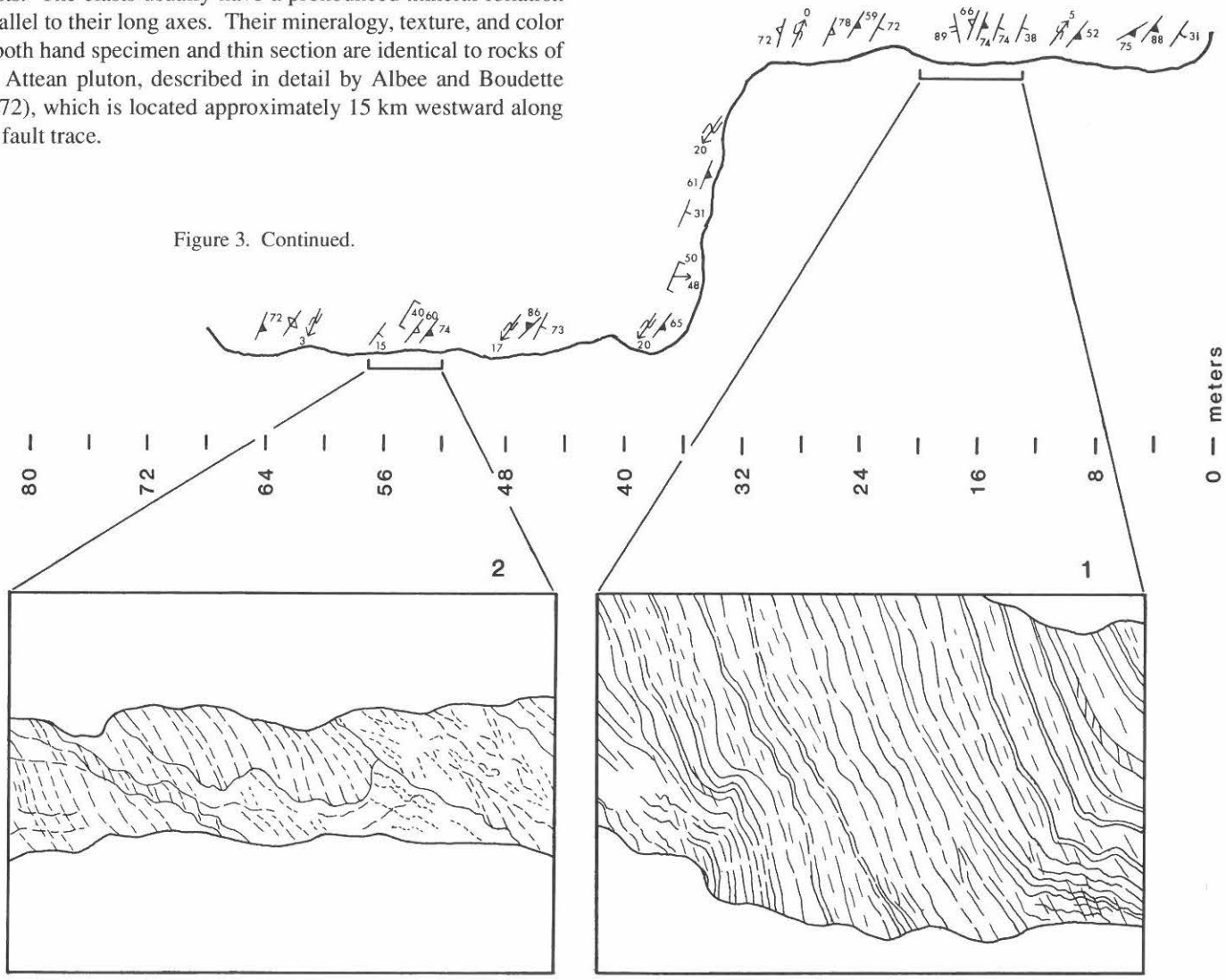

Figure 3. Continued.

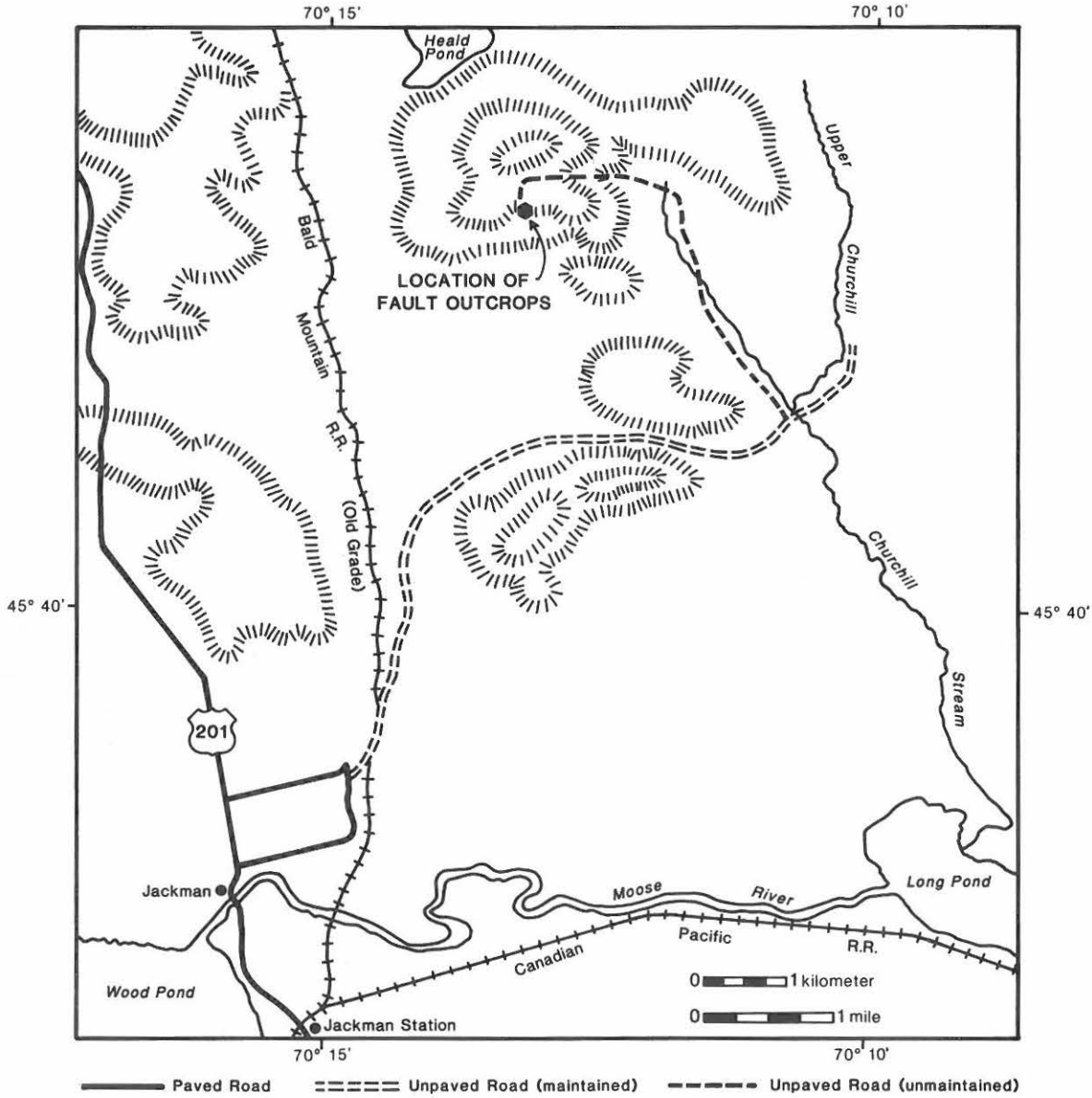

Figure 4. Sketch map showing location of Thrasher Peaks fault outcrop northeast of Jackman discussed in text and illustrated in Figures 5 and 6.

6), shows clast-rich gouge zones folded in antiforms and synforms which trend east-northeast, and are cut by an east-northeast-trending axial plane cleavage. The style and orientation of these structures are similar to others of inferred Acadian origin throughout the region.

By contrast, clasts in the northern outcrop are large, ranging from 5 through 30 cm in length, and are less elongate. The dominant deformational style in this outcrop is cataclastic. Near-vertical, brittle shear surfaces cut many of the large clasts, resulting in intersheaved slices of granite and dark gray slate (Fig. 5c), and a hackly outcrop surface. The texture of most clasts is dominated by anastomosing fractures. No post-fault folds were observed in this outcrop.

Shear surfaces in the northern outcrop are exceptionally well ornamented with kinematic indicators. A hand specimen (Fig. 7) shows the orientations of some of these structures on a sub-vertical shear surface. First, the specimen contains a number of granitic clasts which have been elongated along a sub-horizontal axis. Second, narrow mullions related to shearing around the more competent clasts are nearly horizontal on this surface. Third, a sub-horizontal lineation caused by smear of clast minerals is parallel to the mullions. Fourth, the shear

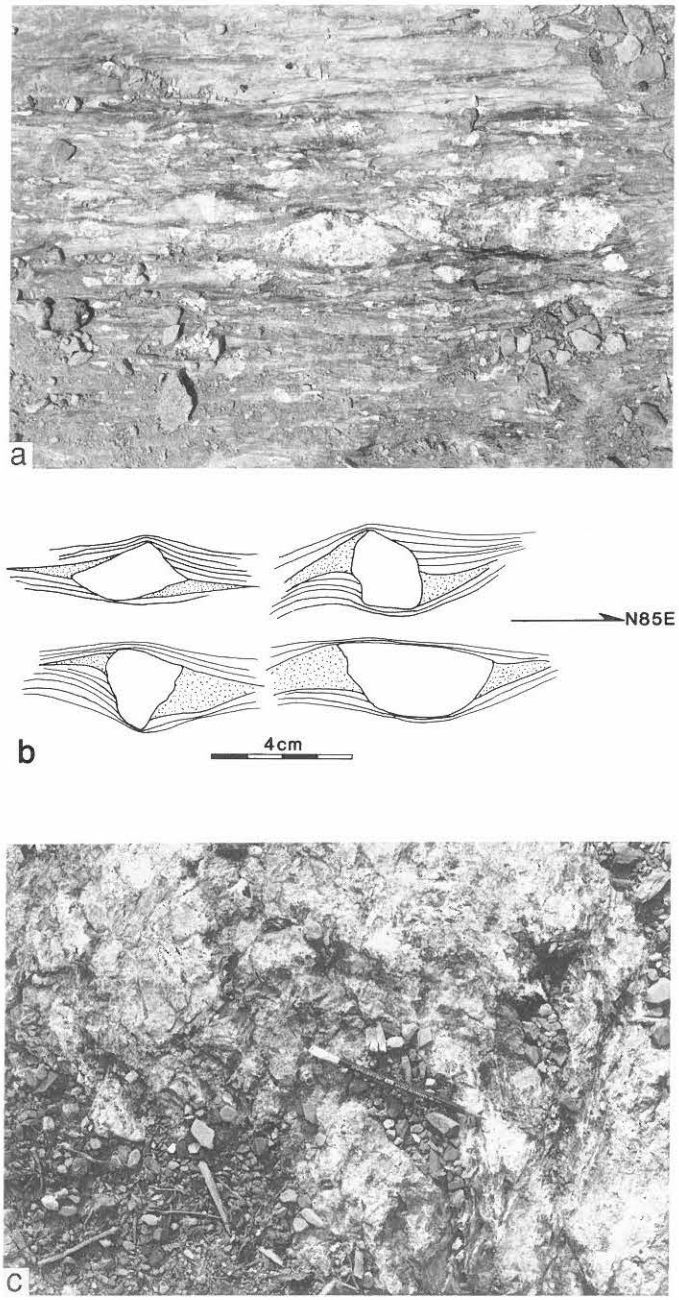

Figure 5. Examples of Thrasher Peaks fault outcrop characteristics. (a) Southern outcrop. Granitic clasts are attenuated and set in a sheared and mylonitized matrix of dark slate. Field of view: 40 cm. (b) Sketch of several clasts in southern outcrop showing asymmetry of pressure shadows (stippled). (c) Northern outcrop. Hackly texture resulting from brittle shearing, and intersheaving of slate and large granitic clasts. Pencil is 15 cm long.

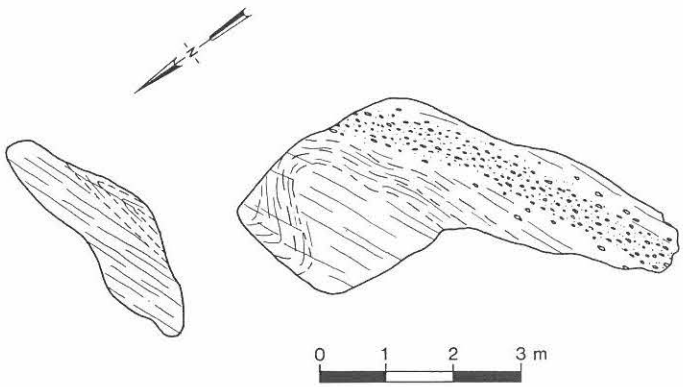

Figure 6. Line drawing of southern Thrasher Peaks fault outcrop. Clast-rich mylonitic zone is folded and cut by regional Acadian cleavage.

Figure 7. Hand specimen of cataclastic rock in the Thrasher Peaks fault zone. View shows south-facing, near-vertical surface; east toward right. A number of granitic clasts (center and top-center) are smeared out in a sub-horizontal orientation (E-W). Surfaces are ornamented with sub-horizontal mineral lineations and mullions as well as slickenside steps, the risers of which face west.

surface has slickenside steps, the risers of which on the south-facing plane of this sample face west. This phenomenon may or may not indicate right-lateral movement (Hobbs et al., 1976). All these observations suggest that sub-horizontal shear within a vertical plane is important in this fault zone.

Clast comminution through shearing is evident in the northern outcrop. In a slabbed sample, cut along a horizontal plane, the origin of small clasts is well shown (Fig. 8). The large granitic clast on the left contains many anastomosing shears. Throughout most of the clast these shears show little displacement, but in its upper right corner movement was sufficient to displace small fragments of the clast. Movement separated some lozenge-shaped fragments from the clast and distributed them within the slate matrix. Many fragments of similar shape can be seen throughout the sample, but it is not clear whether they were derived from the large clast or some other. Anastomosing shear surfaces can also be seen. A broad and diffuse pressure shadow has developed at the right end of the large clast. In this shadow,

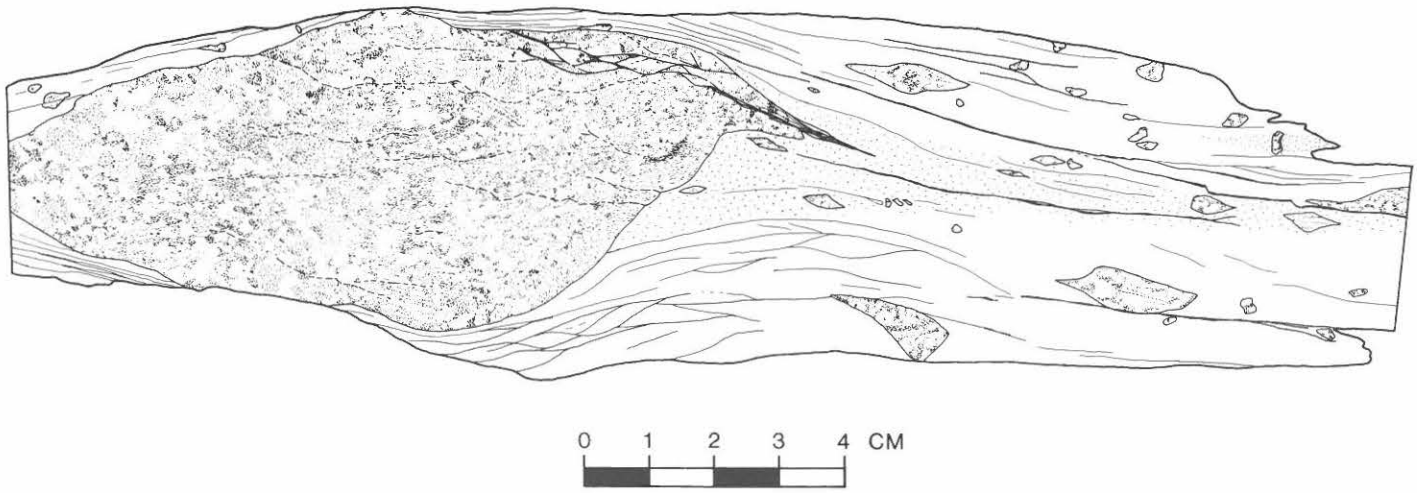

Figure 8. Sketch of slabbed sample of cataclastic rock from the Thrasher Peaks fault zone (map view). Large Attean clast (left) is fragmented by anastomosing shears, especially in its upper right corner. Lozenge-shaped granitic fragments are scattered throughout disrupted slate matrix. Stippling in pressure shadow of large clast where matrix grain-size is larger and shears fewer.

the grain size in the matrix material is slightly larger, presumably due to exsolution of minerals in this area. Poorly defined pressure shadows can be found on the ends of a number of clasts. Similar clast-rich gouge zones have been reported by Westerman (1979, 1980) in the fault zone where it bounds the north side of the Chain Lakes massif.

Age of Faulting

The constraints on the timing of the Thrasher Peaks fault, while better defined than those pertaining to the thrust faults, do not provide a consistent picture of movement. Observations from the fault outcrops suggest that part of the fault was active prior to Acadian folding since the fault gouge itself is folded in the style of Acadian deformation in the region. Acadian deformation probably occurred prior to 400 Ma, the age of the undeformed Lexington pluton which punctures folded rocks of the Seboomook Group farther south (Gaudette and Boone, 1985). However, the fault can be no older than the Lower Devonian Ironbound Mountain Formation which it cuts, unless it is a reactivated older structure. To the southwest the fault truncates the Spider Lake pluton, dated at 371±1 Ma (hornblende ^{40}Ar-^{39}Ar; Lux, 1983). The Deer Pond fault (Fig. 1), felt to be related to the Thrasher Peaks fault because of its proximity, parallelism, and similar length, is intruded by the pluton, however. Apparently, different segments or strands of the Thrasher Peaks fault and other related faults were active at different times and for different durations.

Interpretation

The following summary points about the Thrasher Peaks fault can be made from these observations: (1) The dominant displacement on this section of the fault zone is right-lateral, as demonstrated by kinematic indicators and the source of the clasts. (2) Clasts in the gouge were derived through shearing of the Attean pluton *in situ*, presently exposed 15 km to the west, and were then dragged along the fault to their current location. (3) The dark gray, fine grained matrix of the gouge is derived from slates of the Seboomook Group. (4) Movement on this fault continued throughout the Acadian orogeny and may, in part, postdate it. This is suggested because faulting in the northern outcrop postdates folding. However, this may represent more recent reactivation of the fault.

The distance of 15 km along the fault trace to the nearest outcrop of the Attean pluton may be considered an upper limit on the transport distance of the clasts. If the Attean pluton has a laccolithic shape similar to many other Maine plutons (Osberg et al., 1985), then it likely extends eastward beneath the Moose River synclinorium, although the magnitude of this extent is unknown. A crude estimation can be made of its possible position based on present outcrop location and relationships with overlying rocks. The Attean pluton crops out 15 km west of the fault locale and is unconformably overlain by sedimentary rocks which dip eastward (Albee and Boudette, 1972). The magnitude of dip is variable due to later folds, but an average of 20 degrees is reasonable and is assumed to be close to the dip of the unconformity. Since this is an erosional surface, it probably dips less steeply than the actual intrusive contact. Using 20 degrees as a minimum, then, the Attean pluton can be projected to a depth of at least 5 or 6 km beneath the fault outcrop, though such an extent for the pluton is not supported by aeromagnetic (Boucot et al., 1964) or gravity evidence (Bothner, 1985). Since movement on the fault seems to have been within 10 degrees of horizontal, the clasts may have been derived from as near as 10 km to the west.

Some alternative interpretations can be made from these data. One is the possibility that the outcrop represents a sheared conglomerate or debris flow within the Ironbound Mountain or Northeast Carry Formations. While this cannot be entirely refuted, there are a number of factors which make this unlikely. The lozenge shape of clasts is characteristic of clasts originating through shearing of larger fragments (Mitra, 1984; Sibson, 1977). Clasts in debris flows of similar age elsewhere in the area (e.g., in the Ironbound Mountain Formation) and conglomerates (Upper Silurian conglomerate of Albee and Boudette, 1972; Hobbstown Formation of Boucot and Heath, 1969; Rangeley Formation of Moench and Boudette, 1970) are generally polymictic and subrounded unless part of a shear zone. But perhaps the best evidence opposing this interpretation is that the clasts, especially the large ones of the northern outcrop, are penetratively fractured in similar fashion to *in situ* rocks of the Attean pluton near Turner Ponds. It seems unlikely, given the competency contrast of granitic rocks and slate (Jaeger and Cook, 1976), that clasts freely floating in a ductile matrix would be so fractured by shearing of the conglomerate. More probable is the possibility that the granitic clasts were cataclastically deformed while part of a large body. Large blocks were dragged along the fault zone to their present location, fragmenting en route (see Fig. 8). Presumably, the same characteristics could develop through shear of a debris flow containing cataclastically deformed clasts, requiring a more fortuitous combination of debris flow transportation direction, composition, and locus of later faulting.

Another alternative is that the granitic clasts were derived from the Attean pluton at depth and brought to their present location largely by vertical fault movement, indications of lateral movement having resulted from a late phase of faulting. If the pluton extends this far east it would probably be deeper than 6 km. In order to develop the relationships observed in outcrop from the pluton at depth a fairly complex scenario is required. Near-vertical movement on the fault would have to be first in one sense and then in the opposite in order to drag granitic fragments into the fault, but show little vertical displacement in the units exposed at the surface. Polarity reversal of this type would be required a number of times to develop the contrasting northern and southern outcrops. Only the latest movement would be strike-slip, accounting for the kinematic indicators. This seems less likely than simple, continuous, right-lateral strike-slip.

STRUCTURAL SYNTHESIS

The preceding sections show that movement on the Thrasher Peaks fault occurred during the Acadian orogeny and that movement on the northwest-directed thrusts probably occurred during a similar time frame. A structural model for the region, therefore, must incorporate the development of these differing fault styles within a limited time period. The hypothesis proposed here is that the thrust faults and perhaps even the northwest-trending high-angle faults are ancillary structures within a strike-slip regime. Figure 9 is a schematic representation of the strain ellipse associated with east-west, right-lateral strike-slip faulting including the relative orientations of ancillary structures which can develop in this regime. While the relationships shown are only applicable for incremental strain in the strict sense, they can be used loosely to define the quadrants of tension and contraction within a right-lateral strike-slip setting.

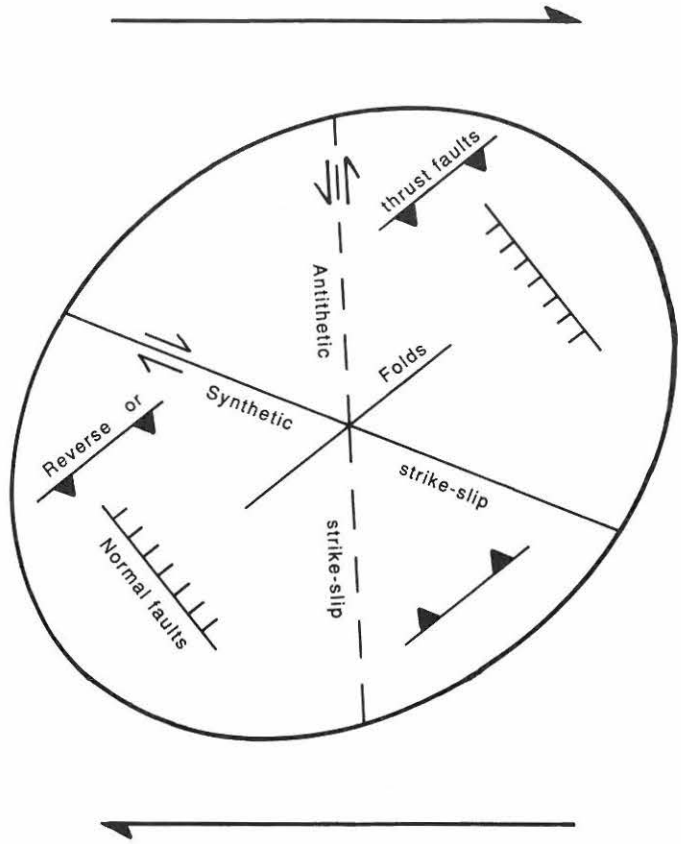

Figure 9. Strain ellipse for right-lateral strike-slip regime showing typical orientations of ancillary structures developed in this setting. Modified from Sylvester and Smith (1976), Harding (1974).

In general, reverse and thrust faults in the setting shown in Figure 9 strike northeast-southwest; normal faults strike nearly perpendicular to these. Such structures develop when the principal compressional axis is oriented obliquely to the strike-slip fault, which is a common occurrence when the fault trace is curvilinear. This results in a component of compression or tension oriented at an angle to the fault. All of these structures are not normally developed along one portion of a strike-slip zone, but each may be locally developed along different portions (Crowell, 1974; Harding and Lowell, 1979). The Marie Petuche and the other northwest-directed thrust faults in the region may represent northeast-striking ancillary faults to the Thrasher Peaks fault, as shown in cross-section (Fig. 10).

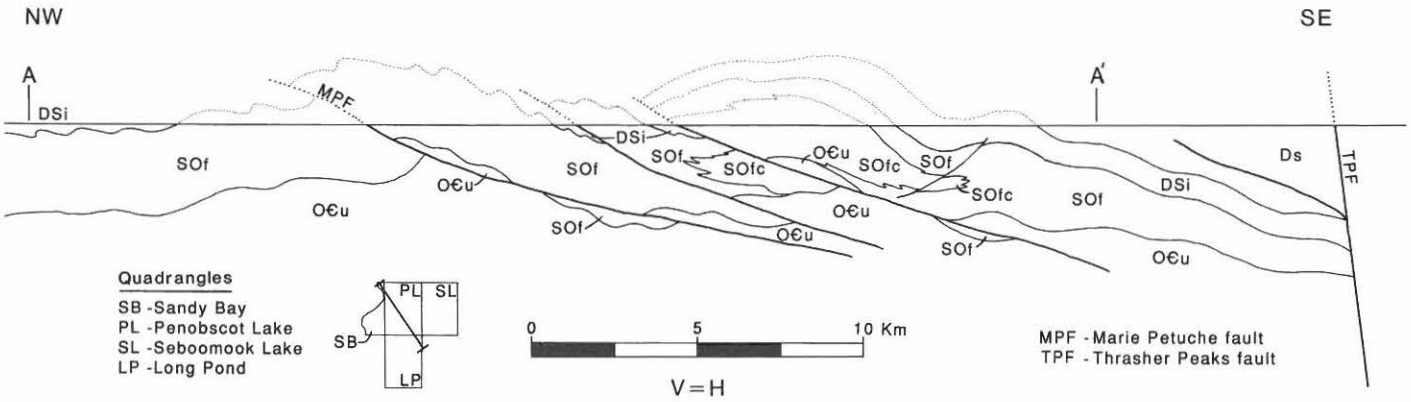

Figure 10. Interpretive cross-section through the Thrasher Peaks fault illustrating its relationship with thrusts. Unit descriptions and section location shown on Fig. 2.

The configuration of ancillary reverse or thrust faults about a strike-slip fault, viewed in cross section, has been termed a flower structure by Harding and Lowell (1979). At variable depths dependent on level of exposure, the thrusts and reverse faults are interpreted to merge with the strike-slip fault. While in many settings flower structures are symmetrical about the main fault zone, they need not be (Harding and Lowell, 1979). It is uncertain whether a symmetrical set of thrust faults exists on the south side of the Thrasher Peaks fault in the Moose River synclinorium; none have been recognized in earlier mapping by Boucot and Heath (1969). Hence, the Thrasher Peaks fault and ancillary thrusts are configured in a half flower structure, similar in size, style, and displacement to structures mapped by Lowell (1972) in a strike-slip zone in Spitsbergen and by Gates (1987) in the Piedmont of southwestern Virginia.

Proposing that the northwest-directed thrusts share their origin with right-lateral strike-slip faulting provides an explanation for a perplexing problem related to the thrusts. Specifically, continuations of the thrusts both to the northeast and southwest have not been recognized in recent mapping (Pollock, 1983; S. R. Chevé, pers. commun., 1982). It is possible that they have not been recognized in those regions because the Frontenac Formation lacks distinct stratigraphic markers. It is more likely, given the nature of the Thrasher Peaks fault, that these northwest-directed thrusts are local phenomena related specifically to oblique movement along a strike-slip portion of the fault and thus would not be expected to extend for great lengths.

The natures and configuration of the faults may also be related to their strikes. Along most of its length, in particular in New Hampshire where it is a high-angle fault of probable dip-slip movement, the Thrasher Peaks fault strikes northeastward. Northeast of Jackman it strikes nearly due east while the Marie Petuche fault has a northeast strike. If motion along the Thrasher Peaks fault in New Hampshire were oblique, then the faults in Maine may have resulted from resolving the oblique motion into its vertical and strike-slip components. The argument for oblique convergence is enhanced by recent work on major Acadian faults of the Gaspé Peninsula by St-Julien et al. (1988). They found evidence for significant right-lateral strike-slip along east-west-striking segments of the faults and argue that Acadian convergence, which produced the predominant northeast-southwest structural grain, was oblique. In terms of the overall scheme of displacement along the Thrasher Peaks fault, the differences between the nature of faulting in the Jackman area and northern New Hampshire suggests that the fault is neither purely strike-slip or purely dip-slip; it is most probably of oblique slip. In east-west-striking sections, strike-slip predominates. In northeast-southwest striking sections, dip-slip predominates.

CONCLUSIONS

Outcrop evidence along the Thrasher Peaks fault northeast of Jackman, Maine, indicates that the primary displacement along the fault in this vicinity is right-lateral strike-slip. Based on crosscutting relationships with Acadian structures and intrusions, the fault was probably active during much of the Acadian orogeny. Thrusting along the Marie Petuche fault and its imbrications may have been related to right-lateral faulting because the principal axis of compression tends to be obliquely oriented along curvilinear sections of strike-slip faults.

The implications of this interpretation of the Thrasher Peaks and related faults in northwestern Maine concern the extent of this style of faulting, and its duration. Given the magnitude of displacement documented near Jackman, it seems likely that the fault continues for some distance to the northeast. Possible candidates for its extension include the suite of faults mapped by Pollock (1983, 1985) in the Caucomgomoc area. In the monotonous slates beyond, the fault zone may be quite cryptic.

The recognition of a significant strike-slip component along a major fault in western Maine suggests that other faults may exhibit oblique slip as well and that their reevaluation is warranted.

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