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1-1-1974

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SEDIMENTARY AND SLUMP STRUCTURES OF CENTRAL MAINE

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Introduction

The rocks of central Maine are turbidites and distal turbidites of predominantly Silurian age. They are metamorphosed to chlorite, or in places biotite, zone rocks. A variety of tectonic structures have been superimposed on the primary sedimentary and slump structures. The two processes of turbidite deposition and slumping tend to be associated because rapid deposition on a slope and water-saturation will aid both. Some structures observed are difficult to assign to either depositional or slump processes, and may be mistaken for some structures of tectonic origin (such as isoclinal folds and shears).

Acknowledgements

Field work was supported by the Maine Geological Survey. Thanks go to A.J. Boucot, Oregon State University, and E.M. Moores, University of California, Davis, for helpful suggestions which improved the manuscript.

Lithologic Units

Lithologies to be visited on Trip A-2 include the Vassalboro formation and an unnamed unit informally referred to as the "Kenduskeag formation". These units are described in detail by Ludman and Griffin in Trip B-4.

Distinguishing features of the Vassalboro formation are its massive and homogeneous character and thick to very thick bedding. Its composition is predominantly fine quartzite and coarse metasiltstone with minor phyllitic interbeds. Turbidite structures and slump structures are rarely observed in the Vassalboro formation, except at Peaked Mountain (Stop 1). Graded bedding and braided laminae are common.

Rocks of the "Kenduskeag formation" are characterized by extreme variation in bedding thickness and style, ranging from massive quartzites to zones of thin alternating metasiltstone and phyllite. Turbidite features are relatively common, as are slump folds and associated structures. An important characteristic of this unit is the chaotic zones in which bedding is totally disrupted.

Other units in central Maine are the "Sangerville formation", "Solon formation", and Waterville formation. The "Sangerville formation" exhibits excellent turbidite features and some slump structures. The "Solon formation" exhibits excellent turbidite features and locally well-developed sole markings. The Waterville formation exhibits fine internal laminae and cross-laminae, and good slump folds. The maroon and green phyllite member of the Waterville formation contains trace fossils, nerites facies (bathyal), similar to those described by Seilacher (1962, 1964, 1967).

Sedimentary Structures

In this paper, sedimentary structures are those structures associated with the deposition of the unit. They include features summarized in the first part of Table 1. Most of these features are the result of turbidite flow. Graded bedding and cross-laminae are common in rocks of central Maine, but the other features are relatively rare.

Slump Structures

Slump structures are those structures resulting from downslope movement prior to lithification (summarized in the second part of Table 1). The processes of slumping and of turbidite flow may produce similar structures in some cases.

Slump Folds

It is not always possible to distinguish isoclinal slump folds from tectonic isoclinal folds. Slump folds in central Maine usually occur as a set, that is, an anticline and a syncline, thus producing an asymmetric sigmoidal structure which appears as a minor structure superimposed on the major tectonic structures. Throughout the area slump folds are usually right-laterally asymmetric (z-folds, Ramsay, 1967, p. 351). Typically a slump fold set is not continuous through a thick stratigraphic sequence but tends to die out or to end abruptly. The stratigraphic thickness affected is generally 2.5 centimeters to 3 meters. A single outcrop 10 meters square in area may exhibit as many as eight different and distinct slump folds.

Slump folds appear to have deformed plastically while saturated with water. Individual beds often thicken in the crests and troughs, indicating that material flowed from one portion of the bed to another. The boundaries of most isoclinal slump folds consist of a sedimentary welded contact above and a sedimentary decollement surface below (Figure 1).

The criteria used to distinguish sedimentary slump folds from tectonic folds are: 1) that the slump fold is a flexural-flow fold formed by plastic deformation, 2) the shape of the fold changes from bed to bed, 3) the nose of the fold is usually blunt-shaped, but the folding is tight, 4) slump folds are usually found in a set of an anticline and a syncline, producing a disharmonic structure that is restricted to a stratigraphic horizon between undisturbed beds, 5) portions of a slump can be classed as a similar fold, 6) slump folds often have sedimentary welded upper contacts and sedimentary decollement lower contacts, 7) slump folds are usually associated with other soft-sediment flow structures, and 8) the axial lines of slump folds have a more variable plunge than those of tectonic folds.

Sedimentary Welded Contacts

Helwig (1970) proposed the term "welded contact", following the usage of Jones (1937), to describe a primary sedimentary relationship consisting of a penecontemporaneous depositional contact of continuous strata overlying a slump fold (Figure 1). The sedimentary welded contact is not a sharp, knife-edge contact; rather, the contact is indistinct, and internal

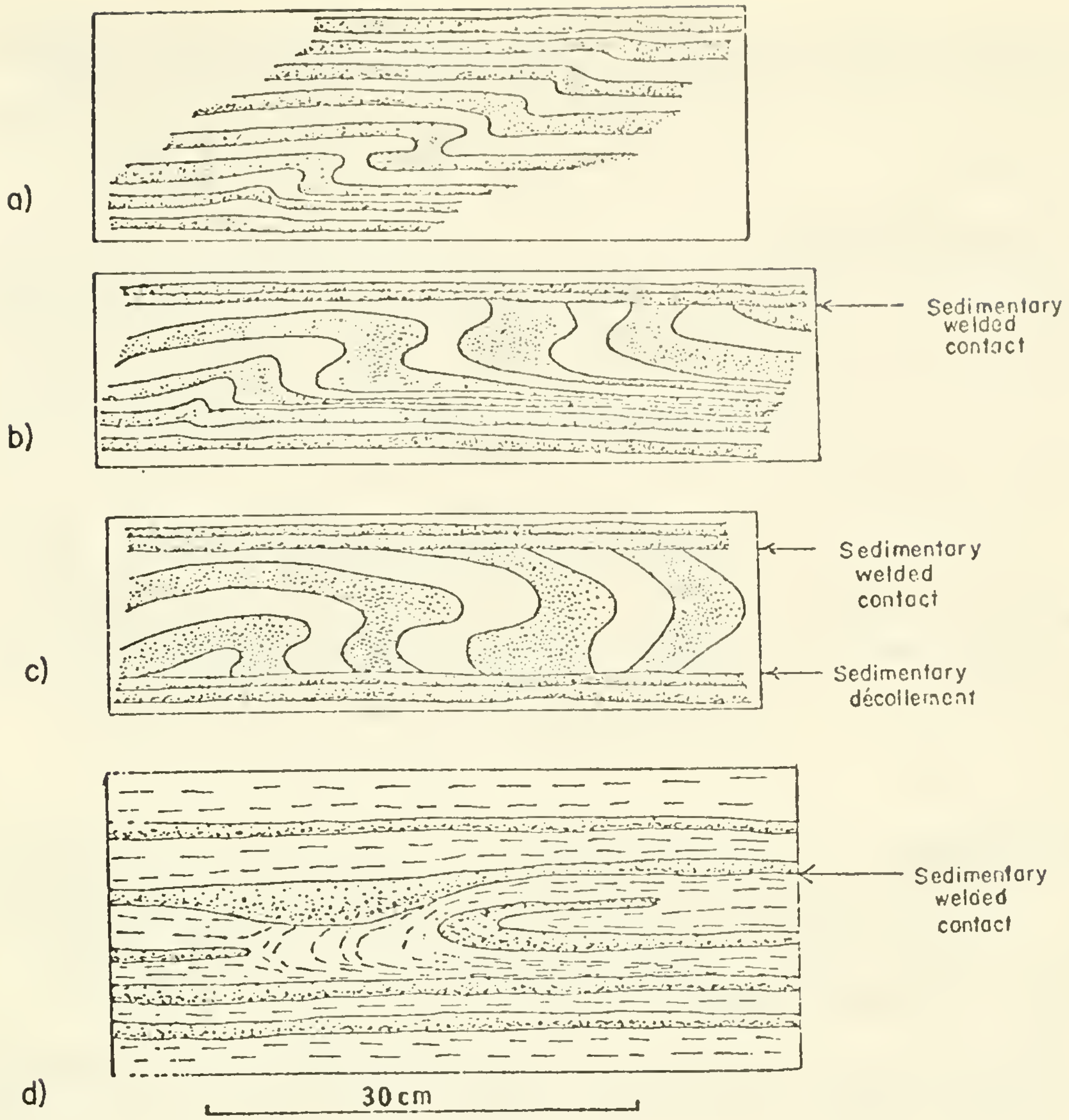
Table 1. Sedimentary, slump, and tectonic structures of central Maine.

Sedimentary Structures (resulting from, or associated with, turbidite flow)
- Graded beds
- Cross-laminae and cross-bedding
- Discontinuous bedding
  - Wedge-outs
  - Pull-aparts
- Sedimentary lenses
- Slate chips
- Siltstone balls and deformed pebbles
- Flow casts
- Sole markings

Slump Structures (resulting from submarine slumping and sliding)
- Slump folds
- Sedimentary welded contacts
- Sedimentary decollements
- Discontinuous bedding
  - Wedge-outs
  - Pull-aparts
- Sedimentary lenses
- Siltstone balls and deformed pebbles
- Chaotic bedding or sedimentary breccia

Dewatering structures
- Flame structures
- Load casts
- Braided laminae or "false bedding"

Tectonic Structures
- Tight, upright isoclinal folds (F_1) & axial plane cleavage (S_1)
- Open, asymmetrical folds (F_2) & both horizontal and vertical fracture cleavage (S_2)
- Open, small amplitude crenulations (F_3) (In Harmony area)
- Left- and right-lateral kink bands (F_4)
- Minor tectonic shears and faults (S_5)



<u>Figure 1.</u> Features of slump folds.

(a) Slump fold which continuously changes its shape and dies out both upward and downward so that underlying and overlying beds are undeformed.

(b) Slump fold with a sedimentary welded contact at its top. The structure dies out to the lower left.

(c) Slump fold with a sedimentary welded contact at its top and a pronounced sedimentary décollement at its base.

(d) Diagram of flap fold in thin 0.3-1.2 cm interbedded phyllite (dashes) and quartzite (stipples) layers of the Waterville formation. Flap fold is overlain by a sedimentary welded contact. Quartzite layers are graded.

laminae are wispy and feathery where they intersect the contact, due to the unconsolidated nature of the sediments when the contact was formed. In most cases, a welded contact forms a zone 3 to 6 mm thick. Unlike tectonic shears and bedding plane faults, which exhibit a similar geometry, welded contacts do not weather more readily than the surrounding bedding planes.

Sedimentary Decollements

The lower contact of most slump folds is a surface of decollement along which the slump moved downslope (Figure 1c). This surface of sedimentary decollement is not a sharp distinct plane. Typically, laminae on either side of the decollement surface are feathery and wispy, indicating that the sediments were saturated and flowed plastically at the time of slumping. The lower limb of the slump fold has been overturned so that beds on either side of the decollement surface have opposing directions (Figure 1c).

In some cases the lower or overturned limb has been sheared completely off so that there is no reversal of top direction across the plane of decollement. In extreme cases, only the curved nose portion of the lower limb remains, exhibiting an angular relationship with the underlying beds. As in the case of a welded contact, the surface of sedimentary decollement does not produce an easily weathered zone across the outcrop, and thus is readily distinguished from a tectonic fracture zone.

Chaotic Bedding

Outcrops containing numerous deformed pebbles exhibit a chaotic aspect. In such outcrops, long axes of the pebbles are randomly oriented to subparallel. There may be no discernible bedding, the outcrop consisting entirely of deformed siltstone or quartzite pebbles, lenses, and segments of beds in a matrix of phyllite.

In some cases, the long axes of pebbles are parallel to the trend of bedding; these are often isolated lenses (sedimentary lenses of Table 1). Individual fragments within a chaotic zone range from 2.5 to 60 cm in length and the same chaotic zone may contain spherical pebbles, elongate pebbles folded back upon themselves, and flat tabular segments of beds. In many cases both the pebbles and the surrounding phyllite and fine siltstone exhibit extremely complex soft-sediment deformation (as at Stop 9).

In large exposures it can be seen that chaotic bedding or sedimentary breccia have developed in particular stratigraphic horizons which are about one to 2.5 meters thick, and continuous bedding can usually be traced along both sides of the chaotic zones.

Dewatering Structures

The authors believe that in central Maine, folding (F_1) and the development of cleavage (S_1) began while the sediments were still saturated with water, as suggested by Maxwell (1962) for the Martinsburg formation of New Jersey and Pennsylvania. Evidence for this is the digitations on fold noses, the plastic nature of deformation, and the features referred to as braided laminae or "false bedding" (Table 1).

Braided Laminae

Black clay-size muscovite and chlorite grains are concentrated along the foliation planes of the medium-grained massive quartzites, producing a faint lamination. These foliation planes are separated by 6 to 12 mm, and the indistinct, faintly colored laminations are about 3 mm thick. The fine-grained material making up these laminae weathers more readily than the surrounding quartzite, thus producing a grooved appearance on the surfaces of weathered pavement outcrops.

In most cases it is difficult to determine whether the faint laminae of phyllite found in massive quartzites of the area are primary sedimentary features or are related to the foliation, because of the general parallelism between bedding and cleavage. In a few cases, such as at Stop 2, it can be conclusively demonstrated that the faint laminae are related to foliation (S_1). In these few cases the foliation is a few degrees divergent from bedding and the quartzite contains phyllite beds 10 to 20 cm thick. The laminae or "false bedding" intersect the trace of bedding at an angle of as much as 15°.

Tectonic Structures

Five tectonic deformations have been recognized in central Maine. The first deformation (Acadian) produced most of the tight vertical isoclinal folds (F_1) seen in outcrop, and rotated the slump folds to vertical. It also produced the northeast-trending regional folds, and the vertical axial plane cleavage (S_1).

The second deformation produced the open right-laterally asymmetric folds (F_2) whose average orientation is N 15 E, vertical, and a complimentary horizontal set that is less well-developed. Associated with these folds are horizontal and vertical fracture cleavages (S_2), that often produce horizontal and vertical lineations (L_2).

The third deformation (F_3) is recognized only in the Harmony area of Skowhegan quadrangle (to be visited on Trip B-4, Ludman and Griffin).

The fourth deformation produced both left- and right-lateral kink bands (F_4), the majority being left-lateral. Their axial planes (S_4) are commonly oriented in an east-west direction.

The final stage of deformation is represented by minor but widespread tectonic shears (S_5). Probably the large-scale faults observed in the northern part of the area are related to these.

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Itinerary

Mileage	
	Meet in parking lot at Bangor Auditorium (behind the Paul Bunyan statue on Maine Street). Begin mileage at south exit of parking lot. Starting time is 8:30 A.M. The route as well as the regional geology are shown on Figure 2.
0	Turn east out of parking lot onto Dutton Street.
0.1	Turn south onto Main Street (Route 1A).
0.2	Turn west onto I-395.
0.7	Take the Hampden exit onto U.S. 202 West, and drive west.
3.2-3.5	Outcrops on west side of road of the "Kenduskeag formation".
4.8	Soudabscook Stream.
5.6	At stop sign, turn west onto Route 202/9 towards Unity.
7.4-7.7	Outcrops of Vassalboro formation on north side of road.
9.1	Soudabscook Stream.
9.3-13.3	Outcrops of massive Vassalboro formation.
14.8	View of Peaked Mountain straight ahead.
15.5-17.0	Outcrops of Vassalboro formation.
17.2	Dixmont town line.
17.7	Turn north onto dirt road at crest of hill and continue west on old asphalt road.
17.8	Turn north onto gravel road.
18.1	Proceed uphill to bend, turn around, and park on shoulder of road.

Stop 1. Peaked Mountain.
Pavement outcrops of Siluro-Devonian Vassalboro formation, consisting of low biotite zone massive quartzites with minor interbeds of blue-black phyllite and rusty-weathering blakc carbonaceous phyllite. A few brown-weathering calcareous lenses are present.

Sedimentary features include graded beds, flute casts (? or load casts, flame structures or injections, pelitic intraclasts, and cross-laminae.

Slump structures, near the south end of the outcrop, include slump folds, wedge-outs, sedimentary decollements, and disrupted bedding. There is local development of "false bedding" or braided laminae parallel to axial plane cleavage (S_1).

Tectonic structures include an isoclinal syncline (F_1), two well-developed cleavages at about N 70 E (S_1) and N 10-15 E (S_2), a poorly developed cleavage of unknown origin at about N 35 E, and left-lateral kink bands (F_4).

Return to U.S. 202.

18.5 Turn west onto U.S. 202.

18.6-19.2 Outcrops of Vassalboro formation along the road.

19.8-19.9 Outcrops of "Kenduskeag formation" along the road.

20.8 View of Mt. Harris straight ahead.

21.3 Outcrops of Vassalboro formation.

21.7 Dixmont Hills picnic area.

22.0 Outcrop of Vassalboro formation south of road.

22.8 Town of Dixmont. Turn north on U.S. 7 towards Newport.

23.4-25.1 Outcrops of Vassalboro formation.

26.7 Plymouth town line.

27.9 Road crosses a kame, currently being mined for gravel.

28.1 Here the road follows an esker.

28.4 Plymouth Pond visable east of road.

29.6 Town of Plymouth. Turn sharp left and cross bridge above dam. Proceed southwest.

29.7 Pavement outcrop of "Kenduskeag formation" in house yard.

30.0 Turn west at "Y" (away from Round Pond) and proceed uphill.

31.2 Turn south onto dirt road.

31.5 Farm house. Park off road behind garage.

Stop 2. Plymouth Hill road traverse.
After viewing the outcrop behind the garage walk south along the woods road to the brow of the hill (about .4 miles), observing outcrops in the road and along both sides of it.

Pavement outcrops of Siluro-Devonian Vassalboro and Silurian "Kenduskeag formation". The latter consists of chlorite zone interbedded quartzites and blue-gray phyllites, characterized by zones of disrupted bedding and slump folds.

The first outcrop (Vassalboro formation) exhibits "false bedding" or braided laminae produced by injection of pelite along surfaces of axial plane cleavage at an angle to true bedding. Graded beds and left-lateral kink folds are also present.

The rest of the outcrops ("Kenduskeag formation") exhibit graded bedding, folded pebbles, slump folds, sedimentary breccia, pull-aparts, and wedge-outs. Note that the axial plane cleavage (S_1) cuts across the folded pebbles in the sedimentary breccia.

Other tectonic structures include folds (F_2), fracture cleavage (S_2), kink bands (F_4), and minor tectonic shears (S_5).

Although isoclinal folds are present it is not always possible to distinguish those of tectonic origin (F_1) from those of slump origin.

Return to asphalt road.

31.8 Turn east onto asphalt road and proceed slowly.

32.1 Just west of the Southern Gospel Mission Headquarters building pull as far off the road as possible and park.

Stop 3. Southern Gospel Mission outcrop.
A small pavement outcrop of "Kenduskeag formation".

Sedimentary structures include graded beds and cross-laminae. Slump structures include slump folds, sedimentary breccia, rotated pebbles, and sedimentary decollements.

Axial plane cleavage (S_1) is poorly developed, however, slump structures are deformed by open right-handed asymmetric tectonic folds (F_2).

Continue east on asphalt road.

32.7 View of Plymouth Pond and the Dixmont Hills.

32.9 At the "Y" bear left (north) towards Plymouth.

33.3 At stop sign in Plymouth bear east onto Route 169 towards Carmel.

33.3-35.0 Outcrops of "Kenduskeag formation".

35.1 Etna town line.

35.6 Outcrop of "Kenduskeag formation".

35.8 Dirt road to north. Continue east on Route 169.

35.9-37.8 Outcrops of "Kenduskeag formation". Open asymmetrical folds (F_2) visable in places.

38.0 Park on shoulder of road near large outcrop.

Stop 4. Etna interchange.
Roadcut outcrop of "Kenduskeag formation", with polished pavement outcrops on top.

Sedimentary features include graded beds and cross-laminae. Slump structures include slump folds, sedimentary breccia, balls and pebbles, pelitic injections, and pull-aparts.

Tectonic structures include axial plane cleavage (S_1), open asymmetric folds (F_2), both horizontal and vertical fracture cleavage (S_2), and tectonic thinning of beds (probably associated with F_1).

It is not clear in all cases whether the isoclinal folds and the breccia are of sedimentary or tectonic origin.

Continue east on Route 169.

38.8 Turn north onto State Highway 143.

39.0 Cross I-95 overpass.

40.3 At power line crossing park on shoulder of road, and walk back to the outcrop.

Stop 5. Power line outcrop.
Roadcut and pavement outcrops of a coarser facies of the "Kenduskeag formation".

This outcrop is distinguished for its excellent development of sedimentary breccia. The wispy nature of the pelite concentrations suggests deformation during dewatering similar to that discussed by Alterman (1973).

Calcareous pebbles with internal laminae can be observed on both glacially polished and blasted surfaces.

Continue north on State 143.

41.2 Intersection of State 143 and U.S. 2. Gas and food available. Turn east onto U.S. 2.

41.7 Outcrop of "Kenduskeag formation".

41.8 Carmel town line.

42.1 Turn right into Etna Pond Picnic Area.

Stop 6. Lunch.
The outcrops here are poor pavement exposures of the "Kenduskeag formation", typical of the bulk of outcrops in central Maine. Features which may be observed here are graded bedding and cross-laminae.

Turn west on U.S. 2.

43.0 Intersection with State 143; remain on U.S. 2.

43.7 Outcrop of "Kenduskeag formation".

43.9 Outcrop of "Kenduskeag formation" with isoclinal fold visible at southwest end of outcrop.

44.9 Outcrop of "Kenduskeag formation".

45.2 Just beyond crest of hill, bear left (southwest).

45.3 Turn southeast onto dirt road. Park on shoulder of road in vicinity of fourth telephone pole. The outcrops to be viewed are on the west side of the road between the fourth telephone pole and the top of the hill.

Stop 7. Washington School traverse.
Pavement outcrops of "Kenduskeag formation".

Sedimentary features here include graded bedding, cross-laminae, and possible flute casts or load casts.

Slump structures include discontinuous beds and lenses, sedimentary breccia, pelitic injections, slump folds, sedimentary decollements, and detached slump fold noses.

Tectonic features include axial plane cleavage (S_1), open asymmetrical folds (F_2), and kink bands (F_4).

It is uncertain whether many of the folds observed here are of slump or tectonic origin.

Return to U.S. 2.

46.0 Turn west onto U.S. 2.

46.7-46.8 Outcrops of Vassalboro formation.

47.4 Turn north onto side road at sign advertising the Sebasticook Valley Snowmobile Club.

47.5 Newport town line; outcrops of Vassalboro formation.

48.1 Maine Central Railroad crossing.

49.0 At stop sign turn northeast.

49.5 Outcrops of Vassalboro formation.

50.2 Stetson town line.

50.6 Stop by the small swamp (south of road) and park on shoulder. The outcrop is on the other side of the swamp.

Stop 8. Quarry outcrop.
Pavement outcrop of "Kenduskeag formation".

Sedimentary features include very good graded bedding, cross-laminae, convolute laminae, and possible load or flute casts.

Slump structures include slump folds, pull-aparts, wedge-outs, sedimentary decollements.

Tectonic features are poorly developed, except for the axial plane cleavage (S_1).

Return to vehicles and continue driving northeast.

52.5 Stop sign at intersection with State 143. Continue straight across.

53.6 Bear north (left) at "Y".

55.0 View of Pleasant Lake to left rear.

56.8 At stop sign turn east onto State Highway 222.

57.4 Levant town line.

59.6 Stop sign in town of West Levant. Leave State 222 and continue straight on Kenduskeag Road.

61.7 Kenduskeag town line.

63.9 Cross bridge over Kenduskeag Stream.

64.0 Turn south onto State Highway 15 at town of Kenduskeag. Gas available.

66.3 Outcrop of "Kenduskeag formation".

66.8 Turn east onto side road. Kenduskeag Stream visible to the south.

68.4 Bangor and Aroostook Railroad tracks.

68.9 Stop sign at intersection with Maine State Highway 221. Continue straight across.

70.7 Stop sign. Turn south.

71.3	View of Pushaw Lake to east.
72.3	Outcrop of "Kenduskeag formation". Turn east.
73.8	Stop sign. Go straight across intersection (towards Villa-Vaughn Campground).
78.2	Stop sign. Turn northeast onto Stillwater Ave.
79.0	I-95 overpass. Gas available here. Continue on Stillwater Ave.
79.5	Turn north onto State Highway 16 West (Bennoch Rd.) at blinking yellow traffic light.
80.2	Road is on esker.
81.9	View of Stillwater River and Marsh Island to east.
82.4	Esker.
83.3	Pushaw Stream.
85.2	Town of Pea Cove. Turn east onto Route 116 and proceed slowly.
85.4	Park on shoulder of road. Please do not park across driveways or on lawns. The outcrops to be viewed are in the field behind the row of houses.

<u>Stop 9</u>. Pea Cove.
Excellent pavement outcrops of "Kenduskeag formation".

Sedimentary features include graded bedding, cross-laminae, cross-bedding, and possible flame structures.

Slump structures include slump folds and dismembered slump folds, sedimentary breccia in all stages of formation, deformed and broken pebbles. Some clasts within the sedimentary breccia are themselves sedimentary breccia, suggesting that brecciation is a repetitive process. Pelitic injections in a variety of orientations, not parallel with tectonic structures, may also be seen.

Tectonic structures include isoclinal folding (F_1) shown by reversal of tops, open asymmetrical folding (F_2), axial plane and fracture cleavages (S_1, S_2), and tectonic shears (S_5) distinguished from sedimentary features by lack of pelite injections.

85.6	Return to State 16 and turn north towards Milo.
86.4	I-95 overpass. View of Alton Bog to the northeast.
86.5	Turn left onto I-95 South. All outcrops between here and Bangor are "Kenduskeag formation".

92.8	Stillwater Road exit. Orono and the University of Maine.
103.5	Exit onto I-395.
105.5	End of freeway. Turn immediately south onto Dutton Street and return to parking lot of Bangor Auditorium.

END OF TRIP

Thank you.

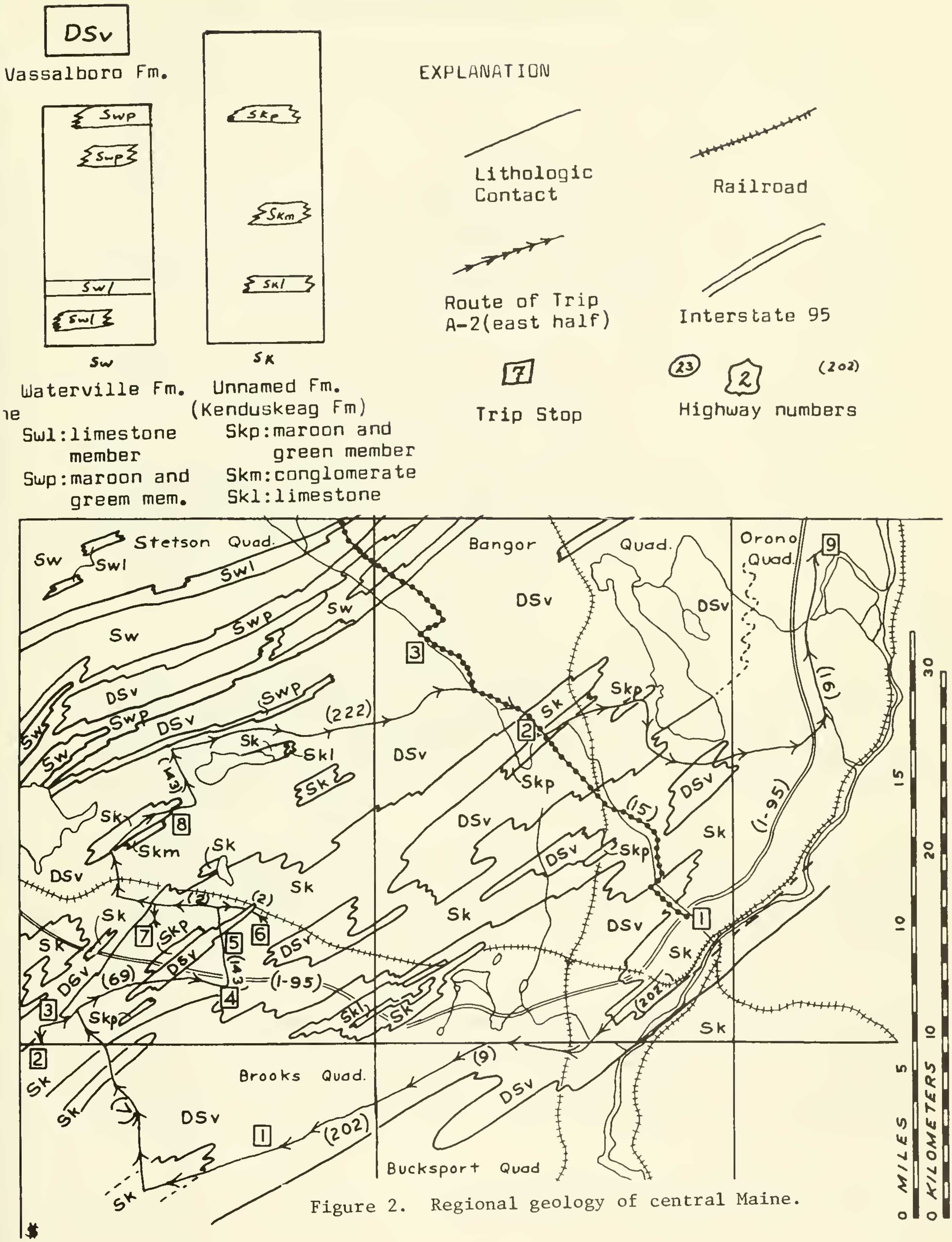

Figure 2. Regional geology of central Maine.