



# THE MAINE GEOLOGIST

THE NEWSLETTER OF THE GEOLOGICAL SOCIETY OF MAINE

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## SPRING MEETING '79

It was a full and abundant day on March 16th when about 70 GSM members and guests gathered in Chase Lounge at Bates College for the 5th annual Spring Meeting of the Geological Society of Maine. The meeting got under way around 1:15 PM with introductory remarks by Prof. Roy Farnsworth, and was then given over to Profs. John Creasy & Bill Forbes to preside over the afternoon's Special Program, a series of technical presentations by 9 Maine college students, following G.S.A. format.

The Program and abstracts of papers are reproduced elsewhere in this Newsletter. All of the speakers did excellent jobs in their preparations and presentations of papers; their slides were informative (and upside-right); and they are to be commended for their fine efforts in geologic research. We who were in attendance wish also to express our appreciation to members of the Bates Geology Club for their substantial work in providing logistical support for the meeting, in passing out programs, selling meal & bar tickets, providing punch-coffee-donuts-and-cookies, and generally keeping us all aimed in the right direction. Finestkind. Anew Tradition, the Spring Meeting Student Program, was launched successfully on March 16th, and we can look forward with warm anticipation to next year's Program.

Following the Student Program, a business meeting was held (more-or-less intervened by the opening of the cash bar) to announce the publication and availability of the Society's Bulletin No. 1 of MAINE GEOLOGY; to note that papers are now being received for Bulletin No. 2 of MAINE GEOLOGY; to ponder over how to get up a list of nominations for 1979-80 GSM Officers; and to outline preliminary plans for summer field trips. The forces of thirst and hunger thereupon moved the group to adjacent facilities in Chase Hall for Happy Hour and supper.

To round out the day, the Featured Speakers for the evening session were Dee Caldwell on "Drumlins in York County containing stratified drift that may relate to the Kennebunk Re-advance" and Lindley Hanson on "Recessional moraines in the Jackman area that may postdate the Champlain Sea transgression".

Very briefly to summarize the evening's discussions: Dee has found drumlins in southwestern York County characteristically to contain deltaic deposits on their north ends, with the source of deltaic materials derived from the south. All of these deposits were deformed subsequent to deposition by ice over-riding from the north, ap-

parently at the time of the Kennebunk re-advance, something like 13,200 years ago. In the Jackman area, Lindley has found evidence for an ice advance from the N50-80°W subsequent to the major Laurentide glaciation. Moraines of this later advance overlie lacustrine clays in the lowlands, and are particularly interesting in that around 90% of the moraine clasts are of the (local) Attean quartz monzonite pluton, with few clasts derived from the metamorphic rocks of the region.

## Maine College Student Program GEOLOGICAL SOCIETY OF MAINE

SPRING MEETING, MARCH 16, 1979

CHASE HALL - BATES COLLEGE, LEWISTON, MAINE

### PROGRAM OF TECHNICAL SESSIONS

#### BEDROCK GEOLOGY AND EXPERIMENTAL STUDIES

Chase Lounge, 1315 hours

*John Creasy*, Presiding

- 1 *John M. Pechenham, Donatd J. Wagon\**: Bedrock geology of the Merrill Hill and North Leeds area, Turner Center 7½' Quadrangle, Maine ..... 1315
- 2 *Peter L. McSwiggin*: Stratigraphy, structural geology and metamorphism of the northeast extension of the Liberty - Orrington antiform, South-Central Maine ..... 1335
- 3 *Merit W. Bean, Jr.*: The bedrock geology of the West Milan area, Percy Quadrangle, New Hampshire ..... 1355
- 4 *Jane A. Gilotti*: A finite strain analysis of limestone and quartzite conglomerates, Rockport, Elaine ..... 1415
- 5 *George H. Swihart*: Experimental freeze-thaw weathering of granite ..... 1435

#### GLACIAL GEOLOGY AND PALEONTOLOGY

Chase Lounge, 1515 hours

*William H. Forbes*, Presiding

- 1 *Michael P. Bingham*: The structure and origin of washboard moraines in coastal Elaine ..... 1515
- 2 *Kristine J. Crossen*: Paleocology of marine fossil faunas from an exposure of the Pre sumpscot Formation, Cumberland, Maine ..... 1535
- 3 *Nick T. Colas \**, *William H. Forbes*: Silurian *Acrotretidea* from northern Maine ..... 1555
- 4 *Jane Jones \**, *Kelly Clinton*, *William H. Forbes*: A new fossil plant from the Devonian of Dalhousie Junction, New Brunswick ..... 1605

\*Speaker

# ABSTRACTS

## Maine College Student Program

### THE BEDROCK GEOLOGY OF THE WEST MILAN AREA, PERCY QUADRANGLE, NEW HAMPSHIRE

BEAN, Merit W. Jr., Department of Geology, Bates College, Lewiston, Maine 04240 The Albee Formation, Ammonoosuc Volcanics and the Oliverian Series are examined at West Milan, New Hampshire. The Albee Formation, a fine-grained micaceous quartzite, is characterized by pinstripping, caused by alternating quartz-feldspar rich and mafic rich laminations. Graded bedding and soft-sediment deformation are observed. Modal analysis yields 41% quartz, 37% biotite, 13% chlorite, 5% feldspar and 2% pyrite.

The Ammonoosuc Volcanics consist primarily of black to dark green, medium-grained massive amphibolite. Natrolite is found in amygdaloidal fillings. Modal analysis reveals 65% hornblende, 31% feldspar, 3% quartz and 1% pyrite.

The Oliverian Series consists primarily of medium-grained gneiss of intermediate to granitic composition. Mafic content (biotite) increases with depth, and a transition from a two-feldspar granite to a one-feldspar gneiss is noted with increasing depth.

The Albee Formation and Ammonoosuc Volcanics occur as northeasterly striking, northwesterly dipping beds. The Oliverian Series is a northerly continuation of the Cliverian Dome as mapped by Billings (1975) in the Gorham Quadrangle. An actual contact between the Oliverian Series and the Ammonoosuc Volcanics is seen, and no cross-cutting relationships are seen. The Albee Formation-Ammonoosuc Volcanics contact appears to be gradational, based on an increase in mafic material in the Albee Formation as the Albee-Ammonoosuc contact is approached. This gradation seems to represent a transition from predominantly mafic volcanic activity to deposition of an impure sandstone, with reworked volcanic detritus forming the impurities.

### THE STRUCTURE AND ORIGIN OF WASHBOARD MORAINES IN COASTAL MAINE

BINGHAM, Michael P., Department of Geology, University of Maine, Orono, Maine 04469

Washboard moraines are asymmetric, evenly spaced and occur in clusters of up to 50 moraines. These minor moraines may range from 2 to 5 meters in height and 10 to 20 meters in width. Two areas in Coastal Maine were studied in detail: 1) Sedgewick and 2) Cherryfield. In both, the moraines were formed by ice confined in a bedrock valley. Moreover, the moraines were formed as the ice retreated up bedrock hills. A large trench (45 meters long X 2 meters wide X 4 meters deep) excavated through two moraines in Sedgewick shows units of flow till interbedded with stratified sediment. Between the moraines the drift is covered by as much as 3 meters of marine clay (Presumpscot Formation). Flow till grades into turbidite beds that flowed from the distal side of one moraine onto the proximal side of the downstream moraine.

Field relationships in Sedgewick show that the moraines: 1) consist of interbedded flow till and stratified sediment, 2) were not formed beneath an ice shelf, 3) were formed in shallow marine water, 4) were formed in part by sheet flow of subglacial water, and 5) were formed by temperate basal ice. Furthermore, the thickness of the ice at the time of moraine deposition (about 13,000 years B.P.) was no more than 50 to 150 meters.

### SILURIAN ACROTRETIDAE FROM NORTHERN MAINE

COLAS, Nick T. and FORBES, William H., Department of Geology, University of Maine at Presque Isle, Presque Isle, Maine

Brachiopods of the family Acrotretidae are now reported for the first time in the Early Silurian rocks of the Appalachians. Several species of phosphatic inarticulate turbidites of the Frenchville Formation in Northern Maine. The specimens, which show variation from previously described Silurian forms, are very well preserved and exhibit a wide range of growth development stages.

Found in association with the acrotretids are conodonts; the recovery of which was the original intent of the acid digestion process that eventually yielded the brachiopods. The conodonts, *Spathognathodus cellioni* Walliser and *Spathognathodus pennalus angulatus* Walliser are both restricted in range to the Cellonii Zone, which correlates approximately with the interval C<sub>2</sub>-C<sub>4</sub> of the Llandovery (Lower Silurian).

### PALEOECOLOGICAL STUDY OF MARINE FOSSIL FAUNAS FROM AN EXPOSURE OF THE PRESUMPSCOT FORMATION, CUMBERLAND, MAINE

CROSSEN, Kristine J., Department of Earth Sciences, University of Southern Maine, Portland, ME 04103 Marine fossils were examined from a 13-meter composite section of Pleistocene sediments exposed in a gravel pit in Cumberland, Maine. The lower two units correlate with the Presumpscot Formation and consist of nonfossiliferous compact mud (Unit A) overlain by silty clay (Unit B). Unit B also contains sand lenses, scattered marine fossils, a strong "salty" odor, and gray to black stains indicating reducing conditions. An overlying Unit C contains marine fossils within intercalated beds of sand, gravel, and mud. The uppermost Unit D is composed of bedded sands and devoid of fossils. The two fossiliferous strata have yielded seventeen species. Numerically dominant in both strata is the Arctic Wedge Clam (*Mesodesma arctatum*), accounting for 86% and 73% of all individuals in Units B and C, respectively. Other numerically important species include the bivalves *Mytilus edulis*, *Macoma balthica*, *Hiatella arctatum*, and *Serripes groenlandicus*. These and all other fossils encountered show boreal affinities and were deposited well within their present-day geographic ranges. Sediment types in which the fossils were found also agree with known substrate preferences for living representatives. Sediments and fossils of Unit B suggest a moderately shallow environment or a moderately deep environment into which shallow water species were crashed. Similarly, a shallow depositional environment is suggested for Unit C. These data, together with the attitude of the beds in Unit C (N168, 12H) and earlier mapping of a delta front 0.5 mi. south, indicate the former existence of a sandy delta (possibly derived from outwash sediments) which prograded into a previously muddy estuary.

### A FINITE STRAIN ANALYSIS OF LIMESTONE AND QUARTZITE CONGLOMERATES, ROCKPORT, MAINE

GILOTTI, Jane A., Department of Geological Sciences, University of Maine at Orono, Orono, Maine 04473 The finite strain ellipsoid is determined for seven oriented samples of limestone conglomerate and three oriented samples of quartzite conglomerate from Rockport, Maine. Both conglomerate units outcrop in the normal limb of a recumbent fold in Rockport and in the reversed limb at Beauchamps Point. Two graphical methods (Dunnet, 1969; and Elliot, 1970) for measuring strain from deformed fabrics of sub-ellipsoidal markers are used to establish the deviatoric strain ratios for planar sections; and the three-dimensional ellipsoid is constructed from measurements made on three orthogonal cuts through each sample. The ten resultant strain ellipsoids have a flattened shape which is proportionally similar from sample to sample. The axial ratios of these ellipsoids are approximately equal to 1.3 : 1 : 0.3. The orientations of the strain ellipsoids vary in relation to the structural geology. In general, the flattened plane of the ellipsoid lies in the schistosity plane of the major recumbent fold. Subsequent F<sub>2</sub> folds have modified this trend.

A NEW FOSSIL PLANT FROM THE DEVONIAN OF  
DALHOUSIE JUNCTION, NEW BRUNSWICK

JONES, Jane, CLINTON, Kelley and FORBES,  
William H., Department of Geology, University of Maine at Presque Isle, Presque Isle, Maine 04769

The unnamed plant, under investigation occurs in dense light gray, slightly calcareous, reworked volcanic tuffs of early Middle Devonian age at Dalhousie Junction in northern New Brunswick, Canada. Abundantly represented in at least two widely separated localities, this plant is unique from all other genera thus far described from the Devonian. Major differences are characterized by a highly wrinkled surface texture with associated spines that appear to be helically coiled about an axis. Sparsely dichotomously branching, the second order branches toward the distal ends, appear to have small ovoid masses that are provisionally determined as sporangia. No spores have been recovered from these masses. On the carbonized axes, a central vascular strand can be observed.

STRATIGRAPHY, STRUCTURAL GEOLOGY AND  
METAMORPHISM OF THE NORTHEAST EXTENSION OF THE  
LIBERTY-ORRINGTON ANTIFORM, SOUTH-CENTRAL MAINE

MCSWIGGEN, Peter L., Department of Geological Sciences, University of Maine at Orono, Orono, Maine 04473

The northeast extension of the Liberty-Orrington antiform lies in the Orrington-Bucksport area of south-central Maine. The core of the antiform contains the Precambrian(?) Passagassawakeag Formation, and is flanked by three stratified formations: the Cambro-Ordovician Copeland and Rider Bluff Formations, and the Latest Ordovician to Silurian Vassalboro Formation. The Ordovician Winterport Granite and Stricklen Ridge pluton, and the Devonian Lucerne and Mt. Waldo plutons intrude this sequence of formations.

Rocks of the Orrington-Bucksport area have been multiply deformed, recording at least four generations of minor folds, three of which have been correlated with major fold features. These features were sequentially formed during a single orogenic event during the Upper Silurian to Lower Devonian Periods. Unconformities in the stratigraphic record indicate two earlier events, one in the Ordovician and the other in Precambrian(?) time.

Three major metamorphic events have affected the rocks of the area. A regional metamorphic event accompanying the formation of the Liberty-Orrington antiform in Upper Silurian to Lower Devonian time produced low-grade greenschist facies in the northeastern, and high-grade greenschist facies in the southwestern part of the area. Rocks beneath the Ordovician unconformity display low- to high-grade amphibolite facies. These rocks have been both regionally and contact metamorphosed before the Siluro-Devonian event. The contact metamorphism occurred in Ordovician time at the margins of the Winterport Granite and the Stricklen Ridge pluton. It is not known whether the regional metamorphic event occurred in the Ordovician or Precambrian(?) time. Isograds have been mapped in the Copeland and Vassalboro Formations, but the precise reactions which formed the isograds were not determined.

THE BEDROCK GEOLOGY OF THE MERRILL HILL AREA,  
TURNER CENTER 7½' QUADRANGLE, MAINE

PECKENHAM, John M., Department of Geology, Bates College, Lewiston, Maine 04240

The rocks of the Merrill Hill area have been metamorphosed to the amphibolite facies. Representative lithologies include biotite-garnet gneiss, calc-silicate granulite, and graphite-bearing sulphidic schist. These lithologies correlate with the lower part of

the Sangerville Formation (Pankiwskyj and others, 1976). The stratified rocks are intruded by two lenticular bodies of foliated biotite granite. Mineral assemblages in the biotite gneiss are indicative of metamorphism within the range of  $P=4-5.5\text{kb}$ ,  $T=550^{\circ}-675^{\circ}\text{C}$ , and  $X_{\text{H}_2\text{O}}=0.5-0.7$ . The textural and compositional variations in the granite suggest at least three possible origins: 1) pre- or syn-tectonic intrusion of granite with subsequent metasomatism; 2) recrystallization of or 3) partial anatexis of a feldspathic wacke.

EXPERIMENTAL FREEZE-THAW WEATHERING OF GRANITE

Swihart, George H., Department of Geology, Colby College, Waterville, Maine 04901

The freeze-thaw process has traditionally been regarded as an effective rock weathering mechanism in cold regions. Recently some question has arisen as to whether the weathering assumed to be the result of frost action is not in reality due to hydration shattering or water adsorption.

This paper attempts to deal with the query on the rock weathering mechanism in cold regions and also provides data on experimental freeze thaw weathering rates of granite. Experimental data is analyzed for three stages of the weathering of granite. Petrographic description is included for observed compositional changes. Data is compared with results of related experiments by other investigators. After a review of weathering mechanisms it is concluded that, theoretically, it is likely that physical weathering in cold regions depends mainly on the freezing of water on and in rocks to produce bond weakening and rupture. Experimental attrition rates of granite are found to be comparable to those of Wiman who conducted a similar project in 1963. Fresh granite, immersed in water, lost .210 of its original weight after 32 fluctuations across the freezing point from  $8^{\circ}\text{C}$  to  $-5^{\circ}\text{C}$ . Granite which had been exposed to natural weathering for about 100 years lost 5.22% of its original weight. From this data rates of rock attrition were calculated. Fresh granite lost about  $37\text{g}/\text{m}^2\text{-year}$ , whereas the weathered granite mentioned above lost  $920\text{g}/\text{m}^2\text{-year}$ .

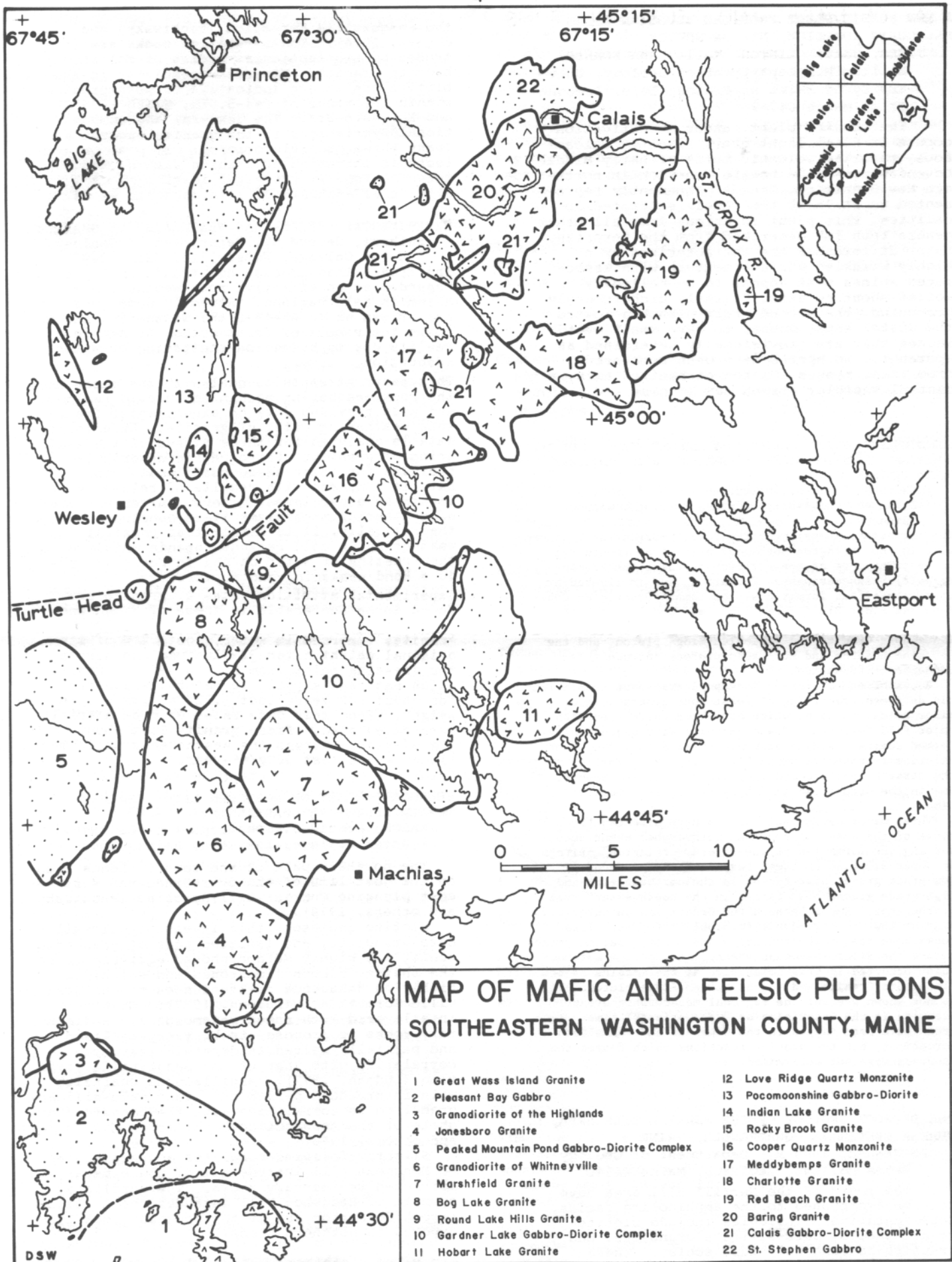
BEDROCK GEOLOGY OF NORTHERN LEEDS, MAINE,  
TURNER CENTER 7½ QUADRANGLE.

WASON, Donald J., Department of Geology, Bates College, Lewiston, Maine 04240

The northern part of the town of Leeds lies on the west limb of the overturned and north-east plunging Currier Hill Syncline (Pankiwskyj and others, 1976).

Biotite gneisses, thin layers of calc-silicate granulite, and isolated pods of graphitic schist are highly metamorphosed equivalents of the shales, ribbon limestones and sulphidic, highly carbonaceous pelite lenses of the Sangerville Formation. (Ludman, 1977). Granite interlayered with these metamorphosed sedimentary rocks is proposed to be recrystallized and partially melted feldspathic graywacke correlative with that of the Sangerville Formation (Ludman, 1977). Argillaceous quartzite with interbedded pelite and minor calc-silicate granulite is correlative with the sandstone and shale of the Anasaguticook Formation (Pankiwskyj and others, 1976).

Slightly foliated tonalites and adamellites of Monument Hill intrude all of these metamorphosed sedimentary rocks. The unfoliated syenite of Hedgehog Hill intrudes the Anasaguticook Formation and is the youngest rock type exposed in northern Leeds.



# MAP OF MARC AND FELSIC PLUTONS

## PLUTONIC ROCKS IN WASHINGTON COUNTY, MAINE

By David S. Westerman  
University of Southern Maine

Mapping during the past decade by workers of the Maine Geological Survey has resulted in a clearer understanding of the distribution of individual plutonic masses in southeastern Washington County, Maine. The adjoining map shows the spatial relationships of these plutons and provides the current working names of each body. This compilation was prepared for Dave Wonea to be used in his portion of the U.S. Appalachian-Caledonian Project (International Geological Correlation Program) Map on Plutonism in the Appalachian Orogen. Additional information on that map will include Streckeisen modal classification, ages, and reference numbers for additional data. Work is currently in progress to compile that additional information and any input from interested persons will be appreciated.

The present status of mapping suggests that the Turtle Head Fault as mapped in the Penobscot Bay area by Stewart and Wonea (1974) continues eastward through Washington County. Those workers refer to the rocks south of the Turtle Head Fault as belonging to the "coastal volcanic" block which includes the Castine volcanics resting unconformably on the Ellsworth Schist. They refer to the rocks north of the fault as belonging to the Penobscot block and place the time of faulting in the Devonian.

In the Wesley Quadrangle, the extension of the Turtle Head Fault separates the Cookson (Penobscot) Formation on the north from the Ellsworth Schist on the south, on which Siluro-Devonian volcanics rest unconformably. The northernmost (basal) member of the Ellsworth-type rocks in the Wesley Quadrangle is a polymictic conglomerate which is very similar to conglomerates in the same stratigraphic position to the west in the Tug Mountain Quadrangle (R.A. Gilman, personal communication) and to the east where they are mapped as the Oak Bay Conglomerate. Earlier workers have consistently cited the Oak Bay Conglomerate as having a maximum age of early Silurian based on a single pentamerid brachiopod from a limestone pebble found and reported by Cummings (1967). Unfortunately, that pebble is lost (W.H. Poole, written communication).

In summary, the coastal volcanic block appears to be continuous from Penobscot Bay to Oak Bay, N.B., and to be in fault contact with the Penobscot block over that distance. Certain plutonic rock types are restricted to those individual blocks in southeastern Washington County.

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Bedrock geology of northern Penobscot Bay  
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## *Glacial Item*

It was some time back we received a letter from Robert P. Gerath, Thurber Associates, 1623 McKenzie, Victoria, British Columbia V8N 1A5, one of our more remotely-situated members. Bob said that he will be publishing the results of his research on the glacial geology and geomorphology of four map areas adjacent to NW Maine in northern New Hampshire, and hopes to have them ready within the year. In the meantime, he will be pleased to hear from those with like interests, and if you should get out his way will welcome anyone who can stop in to call.

## THE PEOPLE'S CORNER

This is a public corner in the Newsletter to be devoted to observations, questions, answers and ideas. I would like members to contribute words, maps, sketches, important locations, cartoons or anything involving their current work, thoughts or hopes. An effort will be made to answer all questions, and there is no standard format to hold to.

I had a thought the other day which I think might be just enough to puzzle your mind for a bit. While I was teaching about methods of determining refractive indices with immersion oils, one of my students asked why the apparent thickness of mineral grains is less than the true thickness. Well it took a minute, but I figured that it was because the light from the bottom of the crystal got refracted away from the source when it immersed into air, so it appeared to be coming from a shallower depth than its true depth. The example that popped into my mind was how people generally get their sleeve wet when reaching into a wishing well to steal the money. I got to thinking that if a fish in water looks closer to us than he really is, then we must look farther away to the fish than we really are since the refractive index of air is less than that of water. That led me to wonder about the effect of the refractive index of air being greater than that of space. Maybe the stars are really close and they just look far away.

A wandering mind is a dangerous thing.

D. S. Westerman, Pres., GSM  
University of Southern Maine

## SURFICIAL GEOLOGY HANDBOOK

The Maine State Planning office has recently published Woodrow B. Thompson's "Surficial Geology Handbook for Coastal Maine". The first part of the Handbook describes the origin of surficial deposits in southern Maine, and the characteristics by which they can be recognized. This section is illustrated by numerous photographs and topographic maps that show good examples of each type of deposit. The following chapter explains how surficial maps are developed, and the remainder of the Handbook discusses some major applications of surficial geology in land-use planning. Emphasis is placed on the widespread occurrence of surficial earth materials and their importance in locating water supplies and waste disposal sites. (Continued on Page 6)

The first printing of the Handbook has been exhausted. However, it is expected that it will be reprinted this year by the Maine Geological Survey. Meanwhile, copies are available at many libraries and planning agencies around the state. (WBT)

## POSTGLACIAL FAULTING ALONG THE NORUMBEGA FAULT ZONE

By Woodrow B. Thompson  
c/o Maine Geological Survey  
Department of Conservation  
Augusta, Maine 04333

During the summer of 1978 the author searched for evidence of postglacial faulting along the Norumbega Fault Zone that lies between the Penobscot River and the Maine-New Brunswick border. The project was a co-operative effort of the USGS and the Maine Geological Survey. It was prompted by the occurrence of earthquakes in the vicinity of the Norumbega Fault, particularly in the Bangor and Calais areas. Several earthquakes of intensity V (MM) or greater have been recorded from this region during historical times.

The features that were examined for recent faults included landforms (such as delta surfaces), internal exposures of well-stratified glacial and postglacial sediments, the bedrock-overburden interface, and glacially striated or polished bedrock outcrops. It soon became apparent that little information was available from landforms and pit exposures. Eskers are the most common glaciofluvial deposits in the study area. They are characterized by ice-contact faulting and poorly developed stratification, both of which tend to conceal any recent faulting that may be present. The heavy forest cover and relative scarcity of other types of stratified deposits also hindered the search:

Glacially striated bedrock outcrops are fairly common along the fault zone. They are relatively fresh on lake shores and where exposed by logging road excavations. (Most ledges in the woods are too weathered to preserve striations.) Approximately 100 striated outcrops were located and studied. Six of these outcrops exhibit minor vertical displacements (1.5 - 30.0 mm) of the bedrock surface. Most of these displacements are northeast-trending bedding-plane faults in the Vassalboro Formation or its apparent equivalent-the Flume Ridge Formation. Four of the localities are within the Norumbega Fault Zone, but not directly on any of the principal fault traces mapped by D. R. Wones. The other two are located on or close to subsidiary faults (mapped by A. Ludman, 1978) that parallel the Norumbega system and lie 8-10 km southeast of it. The postglacial faults generally do not extend more than a few meters along strike, and there is rarely a lateral component of movement. The scarps face in various directions, creating miniature horsts on at least one outcrop surface. At one locality a fault extends from the bedrock up into the overlying till for a vertical distance of 10 cm or more.

The cause of the minor postglacial faulting is not known. However, mass wasting has been ruled out. Some of the outcrop surfaces are

broad and level, while in other cases the down hill side of the fault has been raised. More likely mechanisms include frost heaving, regional tectonic stresses, or isostatic uplift due to melting of the last glacier. Frost heaving may have at least contributed to the faulting at some localities, especially in late-glacial time (when permafrost was present in parts of New England). Any model that incorporates regional forces -- tectonic or otherwise -- should account for the preferential faulting of the Vassalboro Formation and the various strike and facing directions of the faults. A cause-and-effect relationship of the postglacial displacements to the Norumbega Fault or to recent earthquakes is not apparent at the present time.

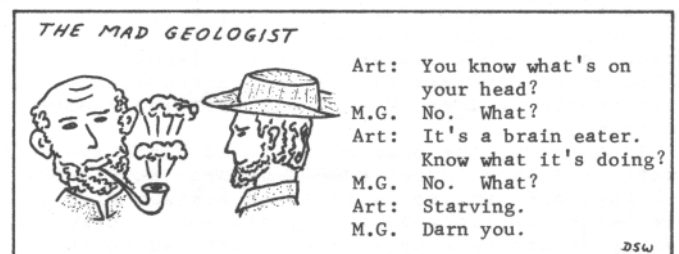
A more detailed account of this study will be published in an article by Wones and Thompson.

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## HILLSLOPE HYDROLOGY

By Robert G. Gerber  
Cons. Geologist & Civil Engineer  
South Harpswell, Maine 04079

A new book (Kirkby, 1978a) contains a collection of articles on the subject of "hillslope hydrology" which is the study of the process of precipitation travel over and through geologic terrane and the manner in which this travel shapes that terrane. In the calculation of stream-flow from a given rainstorm, test runoff models simply divide precipitation between runoff and infiltration. Many models consider the runoff portion to travel to a surface stream by sheet flow and this is commonly called overland flow or "Hortonian flow" after R.E. Horton who developed his classical model of surface runoff in 1933 (Chorley, 1978). Recent research has shown, however, that the route that precipitation follows from impact to stream-flow is usually much more complicated. Whitley and Kirk-

by (1978) summarize the various means of hillslope water flow as follows:

1) Infiltration excess overland flow. This occurs as overland flow when rainfall intensity exceeds soil infiltration capacity.

2) Saturation overland flow. This occurs as overland flow over soils having no infiltration capacity because of saturation.

3) Return flow. This consists of subsurface flow--not necessarily occurring in saturated soil--that comes to the land surface after a short distance of travel in the upper soil horizon (A-horizon). This subsurface flow returns to the land surface when permeable soil thins in a downslope direction, flowlines converge in a hollow, or a hillslope flow turns from convex to concave upward.

4) Saturated subsurface flow. This is a subsurface flow in a zone of saturated soils--often as a perched water table in the B-horizon--that enters a stream directly. It may feed ephemeral streams.

5) Unsaturated subsurface flow. This is subsurface flow that occurs above or between water tables and often enters a stream through the upper stream banks.

6) Ground water flow. This is similar to saturated subsurface flow, but is usually at greater depth in the soil or bedrock and has a smaller hydraulic gradient.

Each of the above flow types contributes to a stream hydrograph as a function of various terrane parameters. On Maine soils of glacial origin ranging from ice-contact to till, most rainstorms do not produce much Hortonian flow. The three major streamflow-generating processes are subsurface flow, return flow, and direct precipitation on streams and saturated soil areas. The frequency, timing, and relative importance of these three processes vary, depending on soil and topography.

Kirkby (1978b) developed a hillslope hydrology model to express the relationships between rainfall, topography, soil properties, and overland flow. Where overland flow is a small percentage of precipitation, the total annual overland flow contribution,  $Q_{OF}$  from a point on a hillside can be estimated as follows:

$$Q_{OF} = R \cdot e^{-h_c \div r_o} \cdot \Phi(i \cdot a \div s), \quad (\text{Eq. 1})$$

where R = total annual rainfall  
 $h_c$  = daily average soil water storage (e.g., 10 mm on bare ground, 40 mm under grass, 100 mm under forest cover)  
 $r_o$  = average rainfall per rainday, or  $R \div N$ , where N is the number of raindays per year  
 $e$  = 2.72 (natural antilogarithm of 1)  
 $\Phi$  = "hillslope hydrology function" which for a vertically uniform soil is assumed to be equal to  $e^{i a \div s}$   
 where a = the area drained per unit contour length (when contours are straight and parallel, a = the distance from a drainage divide)  
 $K$  = lateral saturated soil hydraulic conductivity  
 $s$  = local hydraulic gradient (assumed to be equal to topographic gradient for near-surface flow)  
 $i$  = the daily rate of soil water accumulation which in turn =  $(R - E - Q_{OF}) \div 365$ ,  
 where E = deep percolation and evapotranspiration losses  
 $Q_{OF}$  = overland flow contribution averaged to the site considered. Since this is a function of  $Q_{OF}$ , Eq. 1 becomes indeterminate. This term can often be ignored, however, until an area of perennial flow is reached.

Note: This formulation (Eq. 1) assumes that overland flow is produced when daily rainfall exceeds  $h_c$  and the number of days per year that this occurs is equal to  $N e^{-r_o \div h_c}$ , where N = number of raindays per year.

An extensive discussion of the implications of Eq. 1 is beyond the scope of this article. Please refer to Kirkby (1978b). If one uses typical values for Maine climate and assumes  $K = 25$  meters per day with Eq. 1, one finds that overland flow is created when  $a \div s$  reaches values on the order of 1 km or more and thus, flow and wash erosion only occur in hollows where  $a \div s$  is high.

If  $K$  is decreased to represent less permeable soils, overland flow becomes more frequent. Appreciable overland flow and appreciable erosion are considered to occur when  $N \cdot R \cdot Q_{OF}$  is greater than one day per year.

The sediment transport rate,  $S$ , in cubic meters per meter width of slope per year is given in Eq. 2.

$$S = (0.001 + 2 \times 10^{-8} \cdot Q_{OF}^2) \cdot s, \quad (\text{Eq. 2})$$

where  $Q_{OF}$  = accumulated overland flow discharge summed over a year (the integral of  $q_{OF}$  between two flowlines over the length of the slope)

A graph of  $S$  as a function of the distance from a drainage divide on a straight slope shows that there is a "throughflow critical distance" (on the order of several hundred meters for most Maine situations) at which the erosion rate increases dramatically. The graph would also show that with all other things constant, a decrease in slope gradient causes a smaller initial erosion rate but also a smaller throughflow critical distance. As one would suspect, these equations can be used to design an earth's slope in a road cut, for example, to minimize the erosion rate on the slope. Generally, short, steep and convex upward slope profiles will have the least tendency to erode.

The hillslope hydrology model also has application to the understanding of shallow landslides (i.e., skin flows) that occur as planar slides on silty glacial till and glaciomarine slopes. For a potential slide surface at depth,  $z$ , the factor of safety against slope failure, F.S., is given by Equation 3.

$$F.S. = \tan \psi \cdot \{ (1 - \{\gamma_w \div \gamma\}) + \{ (\gamma_w \div \gamma) \cdot (z_w \div z) \} \} \div \tan \beta \quad (\text{Eq. 3})$$

where  $\beta$  = slope angle  
 $\gamma_w$  = unit weight of water  
 $\gamma$  = total unit weight of soil  
 $z_w$  = depth to water table (in this case this is usually a perched water table where saturated subsurface flow occurs)  
 $\psi$  = friction angle of soil (effective cohesion is assumed equal to 0)

For an "effective" soil water accumulation rate,  $i$ , taken as 2 to 5 times the yearly average  $i$ , to approximate "wet" conditions and therefore the most likely time for landslides,

$$z_w = h_c - (r_o \log_e \{ \Phi(i a \div s) \}) \quad (\text{Eq. 4})$$

Failures generally occur in the A- and B-horizons where  $1P$  is at a minimum. Eq. 3 can be solved for the depth,  $z$ , at which F.S. is at a minimum and for a given  $z_w$ , there is a unique  $S$  for which F.S. = 1. One finds that for a given  $S$ ,  $z_w$ , and  $\sim$ , the depth to the F.S. minimum is slightly deeper than  $z_w$  and  $z_w$  in turn can be estimated from climatic, topographic, and soil conditions.

In summary, the routing of precipitation to streams is complex and in many Maine landscapes occurs as primarily subsurface flow and return flow. Hortonian flow only occurs during intense rainstorms, or in hollows, or on soils with A- and B-horizons of very low permeability. The rate of subsurface flow and the depth to the water table created by this flow has been modeled. Manipulation of the basic model equations provides insight into many terrane-forming processes.

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The Geological Society of Maine  
c/o John R. Rand, Cundy's Harbor  
RD 2 - 210A, Brunswick, Maine 04011

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Correspondence about this Newsletter, or about membership in the Society may be addressed to John R. Rand, Cundy's Harbor, RD2-Box 210A, Brunswick 04011.

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FIELD TRIPS: JULY 27-28-29

### SUMMER FIELD TRIPS - 1979

#### MAINE GEOLOGY - Bulletin Series

Bulletin No. 1, printed by UM-Farmington under Prof. Archie Berry's aegis with type-set cover and binding by the Newsletter's printer, J. H. French & Son, Brunswick, was delivered to the March 16th GSM meeting by A. M. Hussey II in time to sell 40 copies off the rack. It was determined to sell copies at \$3.00 apiece, which works out to \$2.85 for out-of-State purchasers and \$2.85 + 15%: Maine Sales Tax (\_ \$3.00) for in-State purchases. The price was set to cover costs of printing, binding, postage, announcements, damaged copies, etc., the totals of which remain to be seen. A Circular announcing the publication and providing an Order Form has been mailed to 811 addresses, including GSM members, geoscience libraries, geological societies and geological surveys throughout the U.S. and Canada. It was voted to send complimentary copies to each of the Bulletin authors, to the Maine State Library, to libraries of all Maine colleges, and to the Bulletin Committee, Messrs. A.M. Hussey II and D.S. Westerman.

For proposed Bulletin No. 2, anticipated for publication at least by next year about this time, some papers have already been received and more are solicited. The Bulletin Committee has been expanded to include Prof. Bradford A. Hall, UM-Orono. Please contact Bulletin Committee members directly if you wish to submit a paper.

1. DICKEY-LINCOLN - The GSM Annual Meeting and primary field trip program will be held this year on JULY 27-28-29 in Aroostook County, with the Annual Meeting on July 27th at a facility to be announced, and the field trips on July 28th and 29th in the area of the proposed Dickey-Lincoln hydroelectric site. On one day, Bob Gerber will conduct on-site discussions of surficial geologic materials and land-use problems pertinent to the proposed hydro facility. On the other day, Dave Westerman will conduct comparable discussions of bedrock lithologies and structures significant to the proposed project. Leading from the field discussions, it is hoped to publish a guidebook in which discussions and technical commentaries on the various features observed will be presented. The site area is not replete with Holiday Inns, and you may want to bring your own mountain tent, sleeping bag and peanut butter-and-jelly. FINAL DETAILS WILL BE MAILED TO YOU SOMETIME IN JUNE.

2. COASTAL TRIP - As a bonus, various Members are also working on the concept of a one-day trip in the south-central coastal area, for possibly just after Labor Day. It might be, for example, that Woody Thompson would agree to show us some important features of the surficial geology (maybe including some Washboard moraines!) down in these parts. We'll let you know when the plans indurate.