Report
of the
STATE GEOLOGIST
1951 -1952

Joseph M. Trefethen
State Geologist

Maine Development Commission
Augusta, Maine   December, 1953

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and Professor of Geology
University of Maine, Orono

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JOSEPH M. TREFETHEN, State Geologist

Introduction

In the accompanying report are the results of the field work and laboratory investigations carried out by the Geological Survey staff in the biennium, 1951–1952.

In addition to the special field projects reported upon here, the usual work of specimen identification, information service, and field inspection of mineral properties was carried out.

An important extension of the work of the survey has been aerial magnetic surveys. The first of these covered the area around the Katahdin Iron Works area. The pyrrhotite (iron sulfide) comprising that great deposit, now owned by the General Chemical Company, is not magnetic, but it is found associated with a basic igneous rock, called gabbro, that can be identified by its magnetic characteristics. Consequently the magnetic work in this area delimits the parts of the area that may be most profitably prospected. This project was carried out in cooperation with the U. S. Geological Survey. A preliminary "red-ball" map was placed in the open file of the U. S. Geological Survey, and another copy in the open file of the Maine Development Commission at the State House in Augusta. Several companies made use of the data in planning field work in the region. These flights were made in the summer of 1951, and the map was released in the fall of that year.

In the field season of 1952, a second cooperative flight series was carried out with the U. S. Geological Survey. The maps and data for these flights, which were in the Dead River region, have not yet been received from the U. S. Geological Survey, but will be in the open file of the U. S. Geological Survey and the Maine Geological Survey as soon as they are compiled. In the field season of 1953, a third series of air borne magnetometer flights were made by the Aero Service Corporation of Philadelphia, under contract with the State. The results of this project, which covers a portion of the eastern part of the State have been placed in the open file of the State Survey.

It should be emphasized that these magnetic surveys do not in general locate ore bodies. They do narrow the target somewhat for certain types of ore bodies, and aid in the delimitation of certain geologic bodies; for example, it should be possible from these maps to localize granites, and distinguish between metamorphic and sedimentary rocks, and to distinguish basic from acidic igneous rocks. In this connection, it is interesting to note the extensive magnetic work that has been done in New Brunswick. In a state as large as Maine, it appears that this type of aerial survey is an excellent means for selecting specific areas for follow-up ground work.

NEW ENGLAND MINERAL RESOURCES*

JOSEPH M. TREFETHEN

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New England is as complex geologically as it is industrially and ethnologically. The rocks that comprise the area are of all types, igneous, sedimentary, and metamorphic, and the diversity of minerals corresponds. Throughout most of the region a cover of glacial debris mantles the surface. Broadly, New England is a region of worn-down mountains, a continuation of the Appalachian Piedmont. It owes much of its grandeur and charm of landscape to the complexity of its framework.

However, rich as the region is geologically, and diverse as are its minerals, economic concentrations of minerals are sparse and limited. This poverty of mineral resources is reflected percentagewise; collectively the New England states produce less than 0.5% of the United States total of mineral raw material. With 6% of the United States population, New England accounts for 11% of the total value of manufactured goods in this country. The relatively small portion of the mineral production, consequently, cannot be ascribed to an indolent or lethargic population. Nevertheless, there are some basic mineral resources in the region present in large supply. Some of these are currently drawn upon; and some are potential, waiting exploitation.

It is convenient in discussing mineral resources to separate metallics from nonmetallics. The bulk of New England production is from the nonmetallic group. These nonmetallics include gravel and sand, crushed stone, dimension stone, slate, feldspar, cement rock, agstone, structural clays, graphite, mica, asbestos, talc, and a few other minor commodities.

Nonmetals

Sand and Gravel. Reliable statistics on the production of sand and gravel are nonexistent, because of the widespread distribution of these resources and the resultant production from a multitude of large and small operations. Most of the sand and gravel, used for construc-

*Reprinted from *Industrial and Engineering Chemistry.*

tion purposes, is obtained from localized but widespread deposits of glacial outwash, especially in Connecticut, Massachusetts, and Maine. Vermont and New Hampshire have less adequate supplies. Perhaps the important item here is that at most places, at least in the first mentioned states, there are local sources of sand and gravel suitable to heavy construction.

Crushed Stone. Although natural aggregates supply the bulk of construction requirements, rock is crushed on commercial plant scale in each of the states. Massachusetts, Connecticut, and Maine lead. The total production is on the order of 3,750,000 tons per year.

Limestone. Limestone is utilized in various forms for many purposes. In the New England area are ten active plants that produce hydrated and quicklime, and other lime products. Four of these are in western Massachusetts, three in Vermont, two in the Rockland, Maine, area, and one in Connecticut. The Massachusetts plants produce about 100,000 tons of quick and hydrated lime per year and Vermont produces about 30,000 tons; production figures are not available for the other two states.

Production of limestone for chemical and metallurgical uses, in various forms, could undoubtedly be substantially increased, but distribution of pure limestone and marble is apparently very localized and there is little probability of large new tonnage districts entering the picture. Impure or siliceous limestones, possibly suitable for cement or glass wool, are more widespread.

Slate. Maine and Vermont are active producers of slate, and production could easily be expanded. If profitable, use could be made of ground slate; both states have large dumps of broken slate above ground. Minor use of this can be made for roofing granules and linoleum or other filler, but large tonnage uses in addition are needed.

Talc. The only talc production in New England is in Vermont—about 65,000 tons per year. The industry is well established and although estimates of reserves are not available, they appear to be adequate to support enlarged production.

Asbestos. Asbestos is produced, also, only in Vermont. This state is, indeed, the only large producer of asbestos in the United States. The product is mainly short fiber, and the annual tonnage is on the order of 50,000 tons per year. The reserves below ground are thought to be large.

Feldspar. Feldspar is produced in New Hampshire, Maine, and Connecticut in that order of importance. The total tonnage approximates some 60,000 tons per year, with New Hampshire accounting for about half. If the production methods were further modernized, total output could supply any demands.

Structural Clay. Structural clay products, mostly brick, are produced in all the New England states, from local clays. These clays are for the most part rock-flour clays of nonrefractory type. Raw, these clays are not adapted to higher quality uses, although small potteries are locally established, as at Blue Hill, Maine.

Graphite. Graphite, used for foundry facings, is produced only in Rhode Island from a metamorphic coal bed. Other parts of the region have graphitic schists that could produce large quantities of fine flake if economic conditions were favorable. The mineral is easily separated from the rock which contains it.

Mica. Mica is produced in New Hampshire, Maine, and Connecticut. Without support prices, the wartime production of mica fell off, and in this region no mines produced mica except as a by-product of feldspar operation. Some scrap and a little sheet mica are brought out in this way. A new price support program (1952) is reactivating mica mining, but production under this program so far has been small.

Metals

Copper is the only metal currently produced in New England. The Vermont Copper Co.'s Elizabeth Mine, in Orange Co., Vt., rehabilitated during the war after half a century of abandonment, ranked twentieth among the nation's copper mines in 1949. Production figures are not available, but the production is substantial. A plant is under construction at Berlin, N. H., to make sulfuric acid from iron sulfide gangue from Vermont Copper's operation.

A magnesium plant, based on local dolomite (calcium-magnesium carbonate) at Canaan, Conn., was operated during the war and is reported as now on a stand-by basis.

Undeveloped Resources

A number of potentially significant sources of mineral production exist in New England. Future development of some of these depends on market and technologic factors.

Manganese. In northern Maine, in two deposits known through drilling, are over 250,000,000 tons of manganese-bearing rock which averages about 11% manganese and 25% iron. The manganese is in considerable part in silicate compounds. These deposits constitute one of the two or three large-volume reserves of manganese on this continent, and in emergency these sources might be invaluable. In peacetime, if an economic process is developed for extraction of the manganese and iron, they could be a profitable basis for industry. They stand as a challenge to the chemical industry, for it is apparent that recovery of this manganese must be by chemical process.

Sulfur. With increasing demands for sulfur, and relatively few discoveries of new sources of brimstone, New England pyrite and pyrrhotite deposits may well come into production. One of the largest sulfide bodies east of the Mississippi River lies in central Maine, undeveloped. The search is on elsewhere for reserves of sulfur in sulfide form.

Others. Other types of deposit may eventually be tapped. It is possible, for example, that sillimanite (Al_2SiO_5) used in ceramic manufactures could be economically produced. It is certain that dolomite is locally available for production. New uses for peat might be developed.

The outlook for metals is not overbright, although the recovery of the Vermont copper district suggests that new discoveries may be made in other districts, as at Blue Hill, Maine. By and large, however, the known deposits of metals are too small to support operation.

Clay of the rock-flour rather than clay mineral type is abundant. If these blue and gray clays could be successfully treated to render them applicable to such large tonnage consumption as paper manufacture, or to higher grade ceramic uses, the raw clay present would support any tonnage demands.

Summary

The opportunities for expansion and development of mineral production, although limited, are nevertheless real and substantial. Development of the geological resources of this region depends in considerable measure upon learning how to use what is present in abundance, and how to improve or extract, within economic limits, both desirable and undesirable constituents.

PROGRESS REPORT OF LIMESTONE SURVEY

Knox County

By Henry W. Allen

Introduction

For the past three field seasons (1950–52) the writer has been in charge of the geologic investigation of the limestone resources of Maine. The investigation has been mainly centered in the Rockland, Rockport, and Union limestone belts with less detailed work extending over much of the county and adjacent areas.

Assisting with the mapping have been the following people: R. E. Meade in 1950, T. E. Lindsley in 1951, and H. F. Kyte during a portion of the 1952 field season.

A preliminary report (Allen 1951)[1] on this work was published in May 1951. The present report is concerned mainly with an evaluation of the principal limestone belts in terms of uses and amounts. An extensive treatment of the geology of the Rockland and Rockport limestone belts is now being prepared and will be published as a final report in the near future.

Limestone in its broadest interpretation includes any rock that is made up of at least 50 per cent calcium carbonate ($CaCO_3$). Classification can be made on most any convenient basis. For purposes of this report, the following will be used: (1) *high-calcium limestone* for limestone or metamorphosed limestone containing more than 92 per cent $CaCO_3$ (51.5 per cent CaO equivalent) and less than five per cent magnesia (MgO); (2) *calcium limestone* for limestone or metamorphosed limestone containing between 85–92 per cent $CaCO_3$ (47.6–51.5 per cent CaO equivalent) and less than five per cent MgO; (3) *low-calcium limestone* for limestone and metamorphosed limestone containing less than 85 per cent $CaCO_3$ (47.6 per cent CaO equivalent) and less than five per cent MgO; (4) *magnesium limestone* for a limestone or metamorphosed limestone with from five to ten per cent MgO; (5) *dolomitic limestone* for a limestone or metamorphosed limestone with an excess

[1]Allen, H. W. (1951), "Preliminary Report of Limestone Survey of a Portion of Knox County, Maine," *Report of the State Geologist* 1949-1950, Maine Geological Survey, pp. 78-90.

of ten per cent MgO; (6) *dolomite* for a limestone or metamorphosed limestone if the MgO:CaO ratio is about 1:1.

Description of Limestone Belts

Rockland Limestone Belt. The limestone formation that crops out in this belt is the Rockport limestone.[1] It extends continuously from Chickawaukie Pond north of Rockland city southwestward for approximately five miles to the St. George River at the west end of Thomaston village (see Map I). About a mile northeast of Thomaston village the belt attains its maximum width of slightly over a mile.

This rock is a fine to medium crystalline (metamorphosed) limestone. In general it is light to medium bluish-gray in color. Thin white calcite veins, mostly parallel to the bedding, give much of the rock a striped appearance when observed in close-up. Certain zones of varying width, such as those showing in quarries along Old County Road, are dolomitic and alternate with low-calcium, calcium, and high-calcium limestone zones. Some of these zones can be traced throughout most of the length of the belt. Table 1 shows 67 chemical analyses from Rockland, Rockport, and vicinity, the first 40 are from the Rockland limestone belt.

Repetition of certain zones across the strike together with minor structures suggest very tight isoclinal folding for the most part. In no place is it possible to determine the exact thickness of the limestone. Quarrying has reached depths commonly over 300 feet and occasionally in excess of 400 feet.

Rockport Limestone Belt. As in the case of the Rockland belt, the limestone which crops out is called Rockport limestone. The belt can be traced for a distance of about two and one-half miles from near the end of Beauchamp Point northward and thence northwestward almost to Route 137 (see Map II). North of Rockport village the belt has a width of nearly 1000 yards. Northwest of Simonton Corners (not shown on map) the limestone reappears at the surface over a relatively small area where in the past it has been quite extensively quarried.

The limestone differs in character from its occurrence in the Rockland belt in that a goodly portion of the rock is conglomeratic. The

[1]Bastin, E. S. (1908), *Description of the Rockland Quadrangle*, U. S. Geol. Surv. Folio no. 158.

TABLE 1---ANALYSES OF 67 SAMPLES FROM ROCKLAND AND ROCKPORT LIMESTONE BELTS AND VICINITY*

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Loss on Ign.	Total	Location
Ls-50-9	2.70	.70	.32	54.15	.25	41.97	100.09	East wall Crockett quarry, Rockland
Ls-50-11	2.86	.76	.48	52.85	1.59	41.64	100.18	East wall Achorn quarry, Rockland
Ls-50-13	5.22	1.56	.80	51.25	.91	40.52	100.26	Middle N. W. wall Bartlett quarry, Rockland
Ls-50-14	2.36	.94	.56	53.35	.79	42.35	100.35	Northeast corner Brown quarry, Rockland
Ls-50-17	4.78	1.10	1.28	49.65	3.20	39.64	99.65	South corner Engine quarry, Rockland
Ls-50-20	3.20	.72	.56	45.95	7.68	42.37	100.48	140′ west of Ls-50-17, Engine quarry, Rockland
Ls-50-22	1.52	.42	.16	54.05	1.17	43.10	100.42	Northwest side Hurley quarry, Rockland
Ls-50-26	5.22	1.46	.56	48.65	3.64	40.52	100.05	Paint hole quarry (150′ west Engine quarry), Rockland
Ls-50-30	.48	.10	.24	49.65	5.54	44.32	100.33	Syncline east side Mag quarry, Rockland
Ls-50-32	1.64	.36	.40	53.95	1.09	42.68	100.12	Southeast side O. B. Ulmer quarry, Rockland
Ls-50-35	.96	.34	.32	55.26	.17	43.23	100.28	"Softrock" northeast end, Sleeper Field quarry, Rockland
Ls-50-43	1.62	.46	.24	44.83	9.61	43.65	100.41	Across southeast half southwest end Austin Pasture quarry, Thomaston
Ls-50-45	1.06	.38	.40	40.28	13.58	44.71	100.41	South corner Austin Pasture, Thomaston
Ls-50-46	.80	.16	.40	36.43	16.96	45.61	100.36	Across S.E. half mid-way along Beech Woods St. quarry, Thomaston
Ls-50-47	2.98	.82	.40	40.58	12.33	43.25	100.36	Across N.W. half midway along Beech Woods St. quarry, Thomaston
Ls-50-49	2.48	.70	.40	52.52	2.11	42.31	100.52	Near S.W. corner Beech Woods St. quarry, Thomaston
Ls-50-51	5.90	1.90	.88	47.36	4.73	39.06	99.83	Small pit near east side Thomaston baseball field, Thomaston
Ls-50-61	7.20	1.52	1.52	48.58	2.40	38.73	99.95	Southeast side Maine State Prison quarry, Thomaston
Ls-50-62	4.04	1.20	.64	51.61	1.56	41.00	100.05	Southwest end Maine State Prison quarry, Thomaston
Ls-50-66	3.34	.90	.56	32.38	18.96	44.30	100.44	Northeast end Gay Farm quarry, Thomaston
Ls-50-74	2.76	.44	.40	52.83	1.36	42.37	100.16	East side northeast end Bog quarry, Rockland
Ls-50-76	.76	.30	.24	54.55	.92	43.58	100.35	Northeast end small quarry 300 feet east Beech Woods St. quarry, Thomaston
Ls-50-77	2.28	.62	.32	53.43	1.10	42.40	100.15	Northeast end Creighton quarry near U.S. #1, Thomaston
Ls-50-78	4.48	1.10	.80	49.39	3.23	40.75	99.75	Blackington Farm quarry, Thomaston
Ls-50-79	3.78	.76	.48	51.61	1.76	41.54	99.93	Surface exposure between Blackington Farm quarry and Old County Road, Thomaston
Ls-50-80	6.82	1.72	.64	49.59	1.14	39.57	99.48	50′ west of Ls-50-79 between Blackington Farm quarry and Old County Road, Thomaston

*Analyst: R. Hoch, Chief Chemist, Dragon Cement Co., Thomaston, Maine

TABLE 1---ANALYSES OF 67 SAMPLES FROM ROCKLAND AND ROCKPORT LIMESTONE BELTS AND VICINITY*
(Concluded)

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Loss on Ign.	Total	Location
Ls-50-82	1.84	.68	.24	53.23	1.65	42.72	100.36	Southwest end Gay quarry along Old County Rd., Thomaston
Ls-50-83	4.16	1.42	.72	49.59	3.26	40.75	99.90	Small quarry 40′ southwest of Gay quarry, Old County Road, Thomaston
Ls-50-87	2.34	.84	.64	41.29	12.02	43.00	100.13	Southeast edge Hardrock quarry, S.E. of Blackington Farm, Thomaston
Ls-50-88	5.94	2.24	.48	48.17	3.24	39.60	99.67	North facing slope Hardrock quarry just south Pleasant St. bridge, Thomaston
Ls-50-89	1.54	.32	.12	54.45	.53	43.25	100.21	Southwest end small quarry 0.2 mi. south Thomaston-Rockland line N.W. side Old County Road, Thomaston
Ls-50-90	2.18	.34	.32	41.49	12.28	43.86	100.47	Across southwest end Creighton quarry, intersection Dexter St. and Old County Road, Thomaston
Ls-50-91	4.10	.98	.40	50.80	2.83	40.99	100.10	Extreme west corner Nichols quarry, Thomaston
Ls-50-92	7.52	2.10	.64	46.45	4.63	38.63	99.97	Surface exposure mid-way between Gay and Hardrock quarries, Thomaston
Ls-50-93	1.44	.32	.32	52.83	2.41	43.10	100.42	North corner Williams quarry, Rockland
Ls-50-94	4.84	1.18	.56	48.47	4.02	40.95	100.02	Surface exposures 600′ northwest intersection Pleasant St. and Old County Rd., Rockland
Ls-50-95	3.50	.64	.56	47.36	6.27	42.10	100.43	Northeast end Snow quarry, Thomaston
Ls-50-96	1.80	.44	.40	52.12	2.93	42.84	100.53	Northeast end Creighton quarry between Snow quarry and Dexter St., Thomaston
Ls-50-97	6.76	1.58	1.12	49.39	2.09	39.20	100.14	Exposures north-northeast cemetery, Erin St., Thomaston
Ls-50-98	1.84	.30	.24	45.14	9.11	43.80	100.43	Pleasant Mt. quarry, Rockport
Ls-50-102	38.60	12.07	4.17	21.05	9.05	11.55	96.49	Lime silicate gneiss, highway roadcut (U.S. #1), 0.5 mi. northwest Rockport village
Ls-50-103	5.42	.90	.64	41.09	11.24	41.21	100.50	Limestone conglomerate, highway roadcut (U.S. #1), 0.5 mi. northwest Rockport village
Ls-51-6	22.92	.66	.96	25.20	16.81	33.99	100.54	Low tide exposure (limestone congl.), cove between Beauchamp Pt. and Deadman Pt., Rockland
Ls-51-20	13.64	2.32	1.04	32.59	16.15	33.98	99.72	Coastline exposure (limestone congl.), Henry estate, east side Rockport Hbr.
Ls-51-22	4.76	.66	.56	32.79	19.56	42.10	100.43	Coastline exposure (ls. congl.), Small Point west of end of Beauchamp Pt. east side Rockport Hbr.
Ls-51-23	15.70	4.42	1.92	41.90	2.05	33.19	99.18	Coastline exposure, Hog Cove, Rockport

Ls-51-30	2.90	.97	.73	31.37	20.64	43.85	100.48	Coastline exposure, N. 45 deg. E. Seal Ledge, east side Rockport Hbr.
Ls-51-77	11.72	1.73	.81	42.00	9.13	34.64	100.03	Ls. congl. 840 yds. due N.W. Rockport village, Simonds estate
Ls-51-80	13.72	2.21	.97	39.47	10.19	33.38	99.94	Ls. congl. Road cut on Union St., Rockport, 0.25 mi. north Rockport village
Ls-51-88	23.94	8.29	3.31	34.41	2.28	25.80	98.03	Middle northwest end Clam Cove, Rockport
Ls-51-97	19.22	3.81	1.05	35.51	12.26	28.42	100.27	Ls. congl. 350′ southeast intersection Calderwood Lane and Russell Ave., Rockport
Ls-51-98	14.82	2.87	.97	32.79	15.28	33.44	100.17	Ls. congl. southwest corner Lily Pond, Rockport
Ls-51-104	9.76	2.69	1.21	47.36	3.74	35.37	100.13	250′ southeast of southeast corner large quarry north-northwest Simonton Corners, Rockport
Ls-51-105	3.14	.62	.24	52.02	2.56	41.68	100.26	125′ south of southeast corner large quarry north-northwest Simonton Corners, Rockport
Ls-51-106	2.62	.48	.48	50.60	4.28	41.98	100.44	Near southeast corner large quarry north-northwest Simonton Corners, Rockport
Ls-51-109	10.90	3.05	.89	47.67	1.12	36.18	99.81	150′ north Miller barn, 0.45 mi. N.-N.W. Simonton Corners, Rockport
Ls-51-110	10.60	2.63	.89	48.07	2.57	35.60	100.36	600′ north Miller barn, 0.5 mi. N.-N.W. Simonton Corners Rockport
Ls-51-112	5.66	.92	.48	48.17	5.87	39.44	100.54	0.4 mi. N.W. point where Camden-Rockport line crosses Camden--Simonton Corners road, Camden
Ls-51-113	5.00	.72	.48	48.37	5.78	40.14	100.49	75′ south Ls-51-112
Ls-51-115	9.84	1.71	.81	46.75	5.12	36.24	100.47	Ls. congl. east corner Keene pasture, 0.25 mi. N.W. of where Camden-Rockport line crosses U.S. #1, Camden
Ls-51-116	63.60	14.41	7.43	6.07	3.29	1.20	96.00	Lime silicate adjacent on south to Ls-51-115, Camden
Ls-51-117	4.48	.93	.57	35.42	17.16	41.90	100.46	Ls. congl. 200′ south of Ls-51-115, Camden
Ls-51-118	7.70	2.03	.65	49.79	.75	39.35	100.27	Near south contact 500′ W.-S.W. of Ls-51-117, Rockport
Ls-51-120	1.32	.58	.40	42.10	12.22	43.78	100.40	West side of abandoned quarry 0.85 mi. south of Camden village, northwest side Union St., Camden
Ls-51-121	4.22	.72	.48	39.27	13.88	41.89	100.46	Ls. congl. 300′ west of west corner Lily Pond, Rockport
Ls-51-123	4.42	.67	.57	45.14	8.81	40.81	100.42	Ls. congl. 150′ south club house, Rockport golf course, 0.4 mi. due south Lily Pond
Ls-51-152	8.88	1.61	1.21	43.82	5.31	39.51	100.34	Coombs Point, Isleboro

*Analyst: R. Hoch, Chief Chemist, Dragon Cement Co., Thomaston, Maine inclusions, which are sub-angular to sub-rounded for the most part, are composed of both dolomitic and calcium limestones and vary from a fraction of an inch to several inches in diameter. Non-conglomeratic zones are common, and where this is so, the rock can hardly be told from some of the Rockport limestone in the Rockland belt. The Rockport belt has not been exploited as fully as the Rockland belt, hence the zonal aspect can not be clearly worked out. Sample analyses (Table 1) show dolomitic limestone with generally higher silica content than those at Rockland to make up the limestone formation for the most part.

The structure is believed to be similar to that of the Rockland belt with tight nearly isoclinal folds. The thickness of the limestone is unknown. Jacobs quarry, now abandoned, represents the greatest quarry depth attained in the whole area. Here limestone has been quarried from a depth in excess of 550 feet.

Union Limestone Belt. The Union limestone belt is a small metamorphosed limestone belt that crops out about 0.35 mile northwest of Union village (see Map III). It has a length of some 3200 feet in a north-northeast direction with an approximate width of 400 feet at its widest point.

Characteristically the rock is a soft medium crystalline limestone. It is light bluish-gray in color with thin darker gray seams parallel to the bedding. The following analyses (Table 2) is representative:

Table 2--Typical Analysis of Limestone from Union[1]

Constituent	Per cent
CaO	53.40
MgO	0.50
Insoluble matter, silica, etc.	2.50
Iron and aluminum oxides	0.80
CO_2	42.60
Moisture	0.20
Total	100.00

Rock of the above composition has been recovered to a depth of 165 feet in the present working quarry. Structurally, the belt appears to be a doubly plunging anticline.

[1]Communication from Knox Lime Co., Union, Maine.

Limestone Uses

The economic significance of limestone can not be overemphasized. Limestone, which is predominantly calcium carbonate ($CaCO_3$), and lime, which is calcium oxide (CaO) obtained by calcination of limestone, tonnage-wise play a very important role as we strive to increase our production capacity. The following table (Table 3) shows the approximate output of limestone sold or used for all purposes in the United States in 1949[1]:

Table 3--Limestone Sold or Used for All Purposes in the United States-1947-49, in Short Tons

	1947	1948	1949
Limestone	150,409,000	166,742,000	163,746,000
Cement	49,530,000	54,513,000	55,219,000
Lime	13,558,000	14,528,000	12,637,000
	213,497,000	235,783,000	231,602,000

Limestone in broken and crushed form and as lime find scores of uses in construction, agriculture, and chemical and other industries. Whereas, formerly lime was regarded primarily as a building and agricultural material, it is now regarded as a basic or industrial chemical. As a chemical reagent it ranks second only to sulphuric acid in the amount used.[2] The greatest consumption of limestone by far is in the manufacture of cement. Portland cement types are most widely produced.

Some of the important uses for limestone are presented in Table 4 on the following page.

It is beyond the scope of this paper to discuss even in a brief form how limestone is utilized in all of its many uses. Instead, five of the most important uses which the metamorphosed limestones of Knox County are well adapted to will be considered. These five are: (1) agricultural, (2) chemical, (3) fluxing stone, (4) cement, (5) rock wool.

Agricultural Limestone

In agriculture the greatest use for limestone and lime is in the "liming" of soils. Both high-calcium and dolomitic limestones are used

[1]Runner, D.G., and Jensen, N. C. (1951), "Stone", *Minerals Yearbook* 1949, U. S. Bur. Mines, p. 1155.

[2]National Lime Association (1951), *Chemical Lime Facts*, pp. 7-8.

Table 4--Some Important Limestone Uses

Uses	High-calcium limestone	Dolomitic and Magnesium-limestone	Dolomite	Impure limestone
Agricultural limestone	X	X		X
*Chemical:				
Alkali industry	X			
Calcium carbide & cyanamide	X			
Bleaches	X			
Magnesium oxides and hydroxides	X		X	
Trade waste treatment	X			
Crushed limestone (aggregate and road metal)	X	X	X	X
Dolomite refractories		?	X	
Fluxing:				
Open-hearth furnace	X			
Blast furnace	X	X	X	
Non-ferrous metal	X			
Glass manufacture	X	?	X	
Lime:				
High-calcium quicklime	X			
Low-magnesium quicklime		X		
High-magnesium quicklime		?	X	
Hydrated	X	X	X	
Hydraulic				X
Natural cement				X
Portland cement	X			X
Poultry grits	X	X	?	?
Pulp and paper:				
Sulphite pulp (Tower)	X		X	
Sulphite pulp (milk-of-lime)			X	
Soda pulp and sulphate (causticizing agent)	X			
Riprap	X	X	X	X
Rockwool	X	X	X	X
Sugar refining	X			
Water treatment	X			

*Lime is used for the most part.

either as ground limestone or as lime. Hydrated lime and burnt lime are extensively used where rapid neutralization is desired and where the calcium will be made immediately available to the plants. It has been recently shown by soil scientists that some acidity is desirable in the soil in order that certain other plant nutrients may be mobilized.

The trend now is to coarsely ground dolomitic limestone because of two main reasons[1]: (1) Application of coarsely ground limestone prevents the exchange positions of the soil colloids from being deluged by Ca^{2+} ions as appears to be the case when large quantities of finely pulverized limestone are applied. (2) A Ca:Mg ratio of 6:1 to 10:1 prevents Mg^{2+} ions from being crowded off the colloids. Otherwise the mass action effect of the Ca^{2+} ions will tend to produce deficiencies of other nutrients and may raise the pH to such a point as to immobilize other nutrients.

Since 1935 the Soil Conservation Program of the Federal Government has been largely responsible for a great increase in the use of agricultural limestone. At the present time about 93 per cent of all agricultural limestone is subsidized.[2] Hence, limestone delivered under this program must meet certain minimum requirements such as Ca:Mg ratio and size.

The Rockland-Rockport Lime Company of Rockland, Maine is the only producer in the county of agricultural limestone. Aroostook County in northern Maine is the principal market.

The Rockland and Rockport limestone belts hold good possibilities in meeting future increase demands for dolomitic limestone from Maine farms.

Chemical Limestone

Chemical limestone as broken and crushed stone or as lime represent an appreciable part of limestone production. In Table 4 some of the important chemical and industrial uses are indicated along with others. It should be noted that as a chemical reagent more high-calcium quicklime and hydrated lime are utilized than limestone in other forms.

Quicklime is produced by calcination of limestone and consists of lime (CaO) and/or magnesia (MgO). Carbon dioxide is driven off during the "burning." Table 5 is presented to show typical analyses of quicklimes.

Hydrated lime is a dry powder prepared by treating quicklime with sufficient water to form the hydroxide.

Example: $CaO + H_2O \longrightarrow Ca(OH)_2$

[1]Keller, W. D. (1951), "Industrial Minerals and Rocks as Plant Nutrient Sources," *Report of the State Geologist* 1949-1950, Maine Geological Survey, pp. 8-23.

[2]Kirk, R. E. et al (1952), Encyclopedia of Chemical Technology, The Interscience Encyclopedia Inc., New York, vol. 8, P. 376.

Table 5--Typical Analyses of Commercial Quicklimes[1]

Component	High-calcium Quicklimes Range* per cent	Dolomitic Quicklimes Range* per cent
CaO	93.25 – 98.00	55.50 – 57.50
MgO	0.30 – 2.50	37.60 – 40.80
SiO_2	0.20 – 1.50	0.10 – 1.50
Fe_2O_3	0.10 – 0.40	0.05 – 0.40
Al_2O_3	0.10 – 0.50	0.05 – 0.50
H_2O	0.10 – 0.90	0.10 – 0.90
CO_2	0.40 – 1.50	0.40 – 1.50

*The values given in this range do not necessarily represent minima and maxima percentages.

At the present time high-calcium limestone in the form of broken stone is being produced in the Rockland limestone belt by the Rockland-Rockport Lime Co. and in the Union belt by the Knox Lime Co. The greatest market is the pulp and paper industry of Maine. Lime for chemical uses is also produced by Rockland-Rockport Lime Co.

Fluxing Limestone

Because of the large tonnage of limestone used as a flux in the iron and steel industry, it is hereby singled out for special consideration. In 1949,[2] which are the latest figures available, blast furnaces used 23,350,000 tons of limestone, open-hearth furnaces used 6,000,000 tons of limestone and lime, and in excess of 1,000,000 tons were used in other metallurgical uses.

Lime and limestone play a very essential role as fluxes in the smelting of iron ore in the blast furnace and the refining of steel in the basic open hearth furnace. With constantly increasing steel production, the demands for insuring adequate supply of fluxing stone becomes ever greater.

In the blast furnace the limestone fluxes the silica from the ore, ash from the coke, and alumina in the raw materials forming a slag which separates from the molten iron. One-half ton of limestone is required on the average for each ton of pig iron produced.[3] In general high-calcium limestone is preferred, but stones with wide range of magnesia

[1]National Lime Association (1951), op. cit., p. 28.

[2]Runner, D. G., and Jensen, N. C. (1951), op. cit., p. 1155.

[3]Sergy, W. T. (1951), *The Use of Lime and Limestone in Iron and Steel Making*, Proceedings 49th Ann. Conv., Nat. Lime Assoc.

can be used. The silica should be under two per cent, alumina under one per cent, and sulphur under 0.035 per cent.

In open hearth furnaces large tonnages of lime as well as limestone are used. The lime serves to neutralize the acid impurities that are removed from the molten iron. Limestone materials make up about 13 per cent of the charge introduced into the open hearth furnace. The CaO content of the lime and limestone should be 95 per cent or above, the silica should be less than one per cent, and sulphur under 0.07 per cent.

At the present time no fluxing stone is being produced in Knox County although some has been produced in the past by the Rockland-Rockport Lime Co. from the Rockland belt.

Cement

Cement production in the United States has climbed steadily through the post World War II period. The latest figures available (1949)[1] show a production 211,700,000 barrels (376 pounds per barrel) for that year.

Raw material tonnages used in producing Portland cement in the United States for the years 1947–1949 is listed in Table 6.[2]

Table 6--Raw Materials Used in Producing Portland Cement in the United States, 1947-1949, in Short Tons

Raw Material	1947	1948	1949
Cement rock	11,728,062	13,046,856	12,628,494
Limestone	40,034,322	43,489,837	44,968,739
Marl	563,148	601,716	722,606
Clay and shale	5,373,591	6,440,584	6,698,408
Blast furnace slag	864,617	896,474	847,375
Gypsum	1,445,622	1,507,876	1,543,198
Sand and sandstone	821,017	723,769	724,624
Iron materials	257,048	318,106	346,542
Miscellaneous	147,056	133,716	140,999
	61,234,483	67,158,934	68,620,985
Average total wt. per barrel (376 pounds) of finished cement	pounds 657	pounds 654	pounds 654

[1]Runner, D. G., and Balser, E. V. (1951), "Cement," *Minerals Yearbook* 1949, U. S. Bur. Mines, p. 215.

[2]Runner, D. G., and Balser, E. V. (1951), op. cit., p. 216.

Portland cement is produced by calcining finely ground calcareous material (principally limestone) and argillaceous material (clay or shale) with the formation of clinker. Gypsum (approximately two per cent) is mixed with the clinker before grinding or between grinding and pulverizing the clinker. The resulting cement is composed essentially of 60–70 per cent lime, 20–25 per cent silica, 5–12 per cent combined alumina and iron oxide and lesser amounts of magnesia and other constituents.

The requirements of limestone for cement are not exacting although certain limitations must be observed such as: (1) Raw materials should not contain more than five per cent magnesia; (2) the ratio of the per cent silica to alumina should not be more than 5:1 and should preferably be between 3:1 and 4:1; and (3) the sulphur content should be low. Shale and/or clay, if added to high-calcium limestones together with quartz, sand and iron materials in the proper proportions, can adjust the resulting composition to proper limits. Cement rock is an argillaceous limestone or its metamorphic equivalent which contains enough silica and alumina to adapt it very well for the manufacture of cement with minimum addition of other materials. The Jacksonburg cement rock of the Lehigh Valley district of Pennsylvania is typical of such a rock. Table 7 shows the composition of this rock.

Table 7--Composition of Jacksonburg Cement Rock[1]

Constituent	Composition Per Cent	
	1	2
Calcium carbonate	69.00	74.05
Magnesium carbonate	5.70	4.09
Alumina	5.40	5.19
Iron oxide		1.87
Silica	19.82	12.66
Total	99.92	97.86

In the Rockland limestone belt at Thomaston, the Dragon Cement Co., with proper quarrying control, is utilizing a zone of so-called "lowrock" and a zone of so-called "highrock." The mixture analyzes at nearly cement "mix." Table 8 shows typical analyses of "lowrock" and "highrock."

[1]Myers, W. M. (1949), "Cement Materials," *Industrial Minerals and Rocks*, A. I. M. E., p. 165.

Table 8--Typical "Blast Hole" Analyses of "Highrock" and "Lowrock", Dragon Cement Co. Quarry, Thomaston, Me.[1]

Constituent	Composition Per Cent				
	"Lowrock"		"Highrock"		
	1	2	3	4	5
SiO_2	17.34	21.24	2.70	6.16	9.84
Al_2O_3	5.70	6.39	2.00 (Al₂O₃ + Fe₂O₃)	2.68 (Al₂O₃ + Fe₂O₃)	2.92
Fe_2O_3	1.54	2.25			1.38
CaO	39.93	37.41	53.14	50.25	45.52
MgO	1.93	2.48	0.84	1.41	3.03
Loss	30.53	28.36	41.58	39.34	35.70

Within or near the Rockland limestone belt there is an abundant supply of glacio-marine clays which can be combined with low silica and alumina limestones to adjust the composition of the raw material fed to the kilns. Often the clay is the overburden above the limestone. The composition of this clay is shown in Table 9 below:

Table 9--Analyses of Clay from Knox County, Maine[2]

Constituent	Composition Per Cent		
	1	2	3
SiO_2	62.80	62.33	61.59
TiO_2	0.87	0.79	—
Al_2O_3	17.36	17.70	19.10
Fe_2O_3	4.40	5.19	7.53 (Fe₂O₃ + FeO)
FeO	2.00*	1.72*	
CaO	0.88	1.00	1.68
MgO	1.58	1.53	1.87
Na_2O	1.48	2.38	—
K_2O	3.05	2.41	—
H_2O	5.70	4.92	5.51 (H₂O + CO₂)
CO_2	None	None	
	100.12	99.97	97.28

*The values reported for ferrous iron are questionable due to presence of small amounts of organic matter.

1. Clay from brickyards at Thomaston, Me., W. T. Schaller analyst, U. S. Geological Survey Laboratory.
2. Clay from Hayden Point near South Thomaston, Me., W. T. Schaller analyst, U. S. Geological Survey Laboratory.
3. Clay on property of the Rockland-Rockport Lime Co., near Rockland, Me.

[1]Communication from Dragon Cement Co., Thomaston, Maine.
[2]Bastin, E. S. (1908), op. cit., p. 13.

Rock Wool

Rock wool[1] is an artificial mineral wool composed of extremely fine fibers of silicate glass. It is widely used in insulation. It is produced by melting siliceous rock in water-jacketed cupolas with coke as fuel (4/5 to 5/5 of weight of raw rock materials). The molten material is subjected to shearing and tensile forces that draw out fibers. The fibers are chilled quickly below the softening point soon after they are formed.

Rock raw material can vary considerably. Table 10 shows the range of compositions as determined experimentally by Fryling[2] (1934) from which it is possible to produce rock wool.

Table 10--Calculated Range of Composition of Rockwool at 1500 Degrees C

Constituent	Range per cent
SiO_2	< 35 - 65
R_2O_3	0 - 33
CaO	< 5 - 50
MgO	0 - 32

The highly siliceous contact zones of the Rockland and Rockport limestone belts are believed to be suitable for probucing rock wool. Sample Ls-51-116 from Keene pasture, Rockport appears to have a composition suitable for this purpose.

Evaluation of Limestone Belts

An attempt has been made by the writer, based on available chemical analyses of samples (including drill cores), to evaluate the limestone resources of the Rockland, Rockport, and Union limestone belts. In order to keep the classification of the resources as simple and as meaningful as possible, the following categories have been chosen: (1) *Agricultural limestone* for dolomitic limestone averaging between ten and twenty per cent magnesia; (2) *high-calcium limestone* where rock has above 92 per cent $CaCO_3$ (51.5 per cent CaO equivalent) and less than five per cent MgO; and (3) *cement rock* to indicate rock approaching cement in composition.

[1]Lamar, J. E., and Machin, J. S. (1949), "Heat and Sound Insulators" *Industrial Minerals and Rocks,* A.I.M.E., pp. 452-458.

[2]Lamar, J. E., Willman, H. B., Fryling, C. F., and Voskuil, W. H. (1934), "Rock Wool from Illinois Mineral Resources," Illinois Geol. Survey *Bull.* 61, pp. 185-201.

The high-calcium rock sources are believed to be suitable for chemical and industrial uses such as metallurgical fluxes, pulp and paper manufacture, and water treatment. As for cement, it should be pointed out, that source rock for it is not restricted to the cement rock areas since higher calcium limestones could be utilized along with abundant clay reserves of the region. The reader is referred to the section, *Limestone Uses* for requirements for limestone in the various uses.

The designated areas of reserves are indicated with appropriate symbols on the accompanying maps, Maps I, II, and III.

Rockland Limestone Belt

Agricultural limestone—1. Beach Woods Street quarry north of Thomaston village—quarry extends across 200-foot wide zone of dolomitic limestone (samples Ls-50-46 and Ls-50-47) and is about 1400 feet long.

Estimated reserves: 1,000,000 tons down to 100 feet of depth.

2. Area adjacent to southeast side of Austin Pasture quarry on the east side of Dexter Street, Thomaston—triangular shaped unquarried area of dolomitic limestone 1400 feet x 300 feet. See analysis Ls-50-45.

Estimated reserves: 1,700,000 ton per 100 feet of depth.

3. Area adjacent to the southeast of Blackington Farm quarry between Dexter and Pleasant Streets, Thomaston—approximately 700 feet x 100 feet. See analysis Ls-50-87.

Estimated reserves: 600,000 ton per 100 feet of depth.

4. Area between present northeastern face of Mag quarry and Old County Road—approximately 500 feet x 100 feet.

Estimated reserves: 400,000 ton per 100 feet of depth.

Note: Considerable additional tonnage is available in Mag quarry since the present operation has reached a depth of less than 100 feet.

5. Other possible sources: Northwest of the northwestern edge of Sleeper Field quarry, Rockland—two dolomitic limestone zones separated by 300 feet of calcium and low-calcium limestones are indicated by drill core analyses. A 75-foot zone parallels the quarry 25 to 100 feet northwest of edge. The second zone (100 feet wide) is located farther northwest. No surface exposures are available for study and considerable depth of overburden is indicated.

Summary: Agricultural limestone reserves in the Rockland limestone belt exceed 5,000,000 ton for each 100 feet of depth. Abandoned quarries and geologic structure indicate that the deposits could be worked to two–three hundred feet economic conditions permitting.

High-calcium Limestone—1. Along southeastern edge of Crockett quarry between Cedar Street and Maverick Street, Rockland—unquarried area 800 feet x 100 feet with additional recovery possible from eastern side of quarry. Sample Ls-50-9 is believed to be representative. Clay borings indicate overburden may average 20–25 feet over the width of the zone.

Estimated reserves: 675,000 tons per 100 feet of depth below the surface of the limestone.

2. Adjacent to southeastern edge of Achorn quarry near southern corner (sample Ls-50-11) north of Maverick Street, Rockland—unquarried area 500 feet x 100 feet. Additional recovery appears possible from southeastern side of quarry which is now less than forty feet deep.

Estimated reserves: 500,000 tons per 100 feet of depth.

3. North-northeast extension of Sleeper Field quarry (samples Ls-50-35 and Ls-50-32) near intersection of Old County Road and Rankin Street, Rockland—100-foot wide zone which is now being recovered to a depth of nearly 200 feet in Sleeper Field quarry.

Note: Drill core analyses from the Sherer lot 400 feet north-northeast of quarry would be invaluable in estimating reserves and recoverability of limestone in this area. The survey understands that the core drill records of five holes put down by the Cowhan Engineering Co. of Chicago have been incorporated into the estate of the late George Cowhan. An agent for this estate does not know where these records are kept. A very conservative estimate based on observations in the Sleeper Field area would place the unquarried length of this high calcium zone at at least 400 feet.

Estimated reserves: 340,000 ton per 100 feet of depth.

Summary: High-calcium reserves in the Rockland limestone belt are limited. A total of slightly over 1,500,000 ton per 100 feet of depth believed available at the above described sites.

Cement rock—Investigation thus far indicates the greatest reserves of limestone in the Rockland belt should be classified as cement rock. Proper quarry control of the high and low grade limestones will keep additions at a minimum as is the case at the Dragon Cement Co. operation at Thomaston. Rock in which the $CaCO_3$ content falls below 85 per cent (47.6 per cent CaO) and in which the MgO is below five per cent show considerable silica and alumina contents in desirable ratio. High silica and alumina contents are due to presence of silicate and aluminum-silicate minerals.

1. Will Simmons pasture 0.3 to 0.4 miles north of Thomaston village —area 1700 feet x 500 feet on Simmons place (good surface exposures but no chemical analyses available at the present time).

Estimated reserves: 7,000,000 tons per 100 feet of depth.

Note: Additional probable reserves are available in the area between the Simmons pasture and Beach Woods Street to the northeast.

2. Northwest side of highway U. S. #1 near Dragon Cement Co. quarry, Thomaston—boring sample analyses indicate a large tonnage of suitable rock between Snow quarry and point northwest of west corner of Dragon cement Co. quarry.

Estimated reserves: 15,000,000 tons per 100 feet of depth.

3. Adjacent to west end Dragon Cement Co. quarry, Thomaston—drill core analyses show considerable tonnage of rock similar to that at 2.

Estimated reserves: 6,000,000 tons per 100 feet of depth.

4. East of intersection of Old County Road and Dexter Street, Thomaston—triangular-shaped area bounded by Old County Road, Dexter Street, and line of quarries. See samples Ls-50-79, Ls-50-80, Ls-50-82, Ls-50-83, and Ls-50-92.

Estimated reserves: 9,000,000 tons per 100 feet of depth.

Note: The area southwest of Dexter Street, which appears to be southwest extension of this zone probably holds additional reserves although little concrete evidence is available.

5. Intersection of Old County Road and Pleasant Street—area northwest and west of intersection extending from Williams quarry approximately 2400 feet along Old County Road x 600 feet wide.

Estimated reserves: 10,000,000 tons per 100 feet of depth.

Note: estimate based on surface exposures (sample Ls-50-94) plus drill core analyses across part of the area.

6. Other possible sources: (1) Area northeast of cemetery, Erin Street, Thomaston (sample Ls-50-97). Several million tons of rock believed available. (2) Approximately 100 feet northwest of northwestern edge of Sleeper Field quarry, Rockland, drill core analyses show a 300-foot wide zone of low-calcium limestone suitable for cement. No exposures are available and depth of overburden is unknown.

Summary: Cement rock reserves in the Rockland limestone belt exceed 50,000,000 ton per 100 feet of depth.

Rockport Limestone Belt

A study of analyses of samples from the Rockport limestone belt indicate two general trends; (1) magnesia and dolomitic limestones predominate, and (2) silica content runs quite consistently above four per cent. A noteworthy exception to this latter observation is the Jacobs quarry area 0.8 mile south-southwest of Camden village (see sample Ls-51-120.) South of Lily Pond it is doubtful whether the limestone will ever be quarried due to value of the land as summer estates.

Agricultural limestone—1. West of north end of Lily Pond—area 900 feet x 900 feet (see sample Ls-51-121). At west corner of pond a quarry face 500 feet long and 30–40 feet high exists. Numerous exposures in area indicate little overburden.

Estimated reserves: 6,000,000 tons per 100 feet of depth.

Note: To the north along both sides of Union Street overburden covers the bedrock. This area should be investigated by drilling.

2. Keene pasture between highway U. S. #1 and Route 137 about 2000 yards southwest of Camden village, Camden—area approximately 1500 feet x 600 feet.

Estimated reserves: 5,000,000 tons per 100 feet of depth.

Note: Little overburden is present. Belt occupies a ridge throughout this area.

Other possible sources. Adjacent to U. S. #1 on the west on the Rockport side of the Camden-Rockport line. Upwards to a million tons may be present here.

Summary: Agricultural limestones reserves exceed 11,000,000 tons per 100 feet of depth.

High-calcium limestone—No extensive occurrence in the Rockport belt.

Cement rock—Miller farm 0.45 miles northwest of Simonton Corners (not shown on map)—area approximately 1000 feet x 600 feet wide. See sample analyses Ls-51-109 and Ls-51-110.

Estimated reserves: In excess of 5,000,000 tons per 100 feet of depth.

Note: An additional million tons of low to high calcium limestones appear to be available southeast of large quarry 1.2 miles northwest of Simonton Corners. See sample analyses Ls-51-104, Ls-51-105, and Ls-51-106.

Union Limestone Belt

Agricultural limestone—No reserves indicated.

High-calcium limestone—1. Unquarried middle portion of entire belt probably averaging 200–300 feet wide.

Estimated reserves: Not sufficient data available to make a very meaningful estimate, however, upwards to 4,000,000 tons per 100 feet of depth below the surface of the limestone seems probable.

Cement rock—No reserves available.

Summary Statements

The limestone reserves in the Rockland limestone belt are the largest of any of the belts in Knox County. By far the greatest reserves are cement rock with agricultural limestone and high-calcium limestone in order of abundance.

In the Rockport limestone belt agricultural limestone reserves are greatest. A limited amount of cement rock is available in the Simonton Corners area. There is an almost complete absence of high-calcium limestone.

The Union limestone belt, although small, appears to be made up for the most part of high-calcium limestone.

In addition to the outlined areas the possibility of using the highly siliceous and aluminous contact zones of the Rockland and Rockport limestone belts for rock wool should not be overlooked. The northeast corner of the Keene pasture in the Rockport belt offers one such source. Large tonnages of material suitable for road metal is also available within the belts.

Acknowledgement

Excellent cooperation has been met with from all people within the areas mapped. The Rockland-Rockport Lime Co., the Dragon Cement Co. (formerly Lawrence Portland Cement Co.,) and the Knox Lime Co. have made their information and facilities readily available to the survey. Sixty-seven chemical analyses were made gratuitously by the Dragon Cement Co., which have been invaluable in this investigation.

MINERALOGICAL VARIATIONS OF THE ELLSWORTH SCHIST IN BLUE HILL, MAINE

By William T. Forsyth

Introduction

During the field season of 1952, the Maine Geological Survey carried on a mineralogical study of the rocks surrounding the known copper and iron sulfide deposits in and around the town of Blue Hill, Maine. Field work was conducted in two stages, (1) preliminary reconnaissance and (2) pace and compass traverses by W. T. Forsyth and H. F. Kyte, field assistant. The study disclosed that the known ore deposits of the Ellsworth schist are restricted to one of two readily separable zones representing different conditions of metamorphism.

Location

The area under discussion lies in the Blue Hill 15′ topographic quadrangle in the Penobscot Bay region. The town of Blue Hill is 18 miles southeast of Bucksport and 13 miles southwest of Ellsworth by way of Maine Route 15.

Areal Geology

Much of the area is covered by glacial drift and swamps; accordingly, bedrock exposures are moderately scarce. The best exposures are found along the shores and in road cuts, but inland, heavy mixed growth of hard and soft wood makes cross country travel difficult and obscures many outcrops.

Many geologists have visited this area in the past to study the copper and iron sulfide deposits located about two miles southwest of the village of Blue Hill. Bastin[1] described in 1907 the areal geology of a 30 minute rectangle, the northeast quarter of which is the Blue Hill quadrangle. In 1910, Emmons[2] described the sulfide ores of this area and Milan, New Hampshire, indicating that they were pre-metamorphic in origin because of their parallelism with local structures. In 1925, Lingren[3] compared this area with the high temperature metasomatic deposits of Orijarvii, Finland on the basis of similar mineralogy. Gillson and Williams[4] in 1929 described a zone of cordierite-anthophyllite mineralization around the border of the Ellsworth schist where it is in contact with a Devonian granite. One of the most recent works was a study of ore zoning by Ching-Yuan Li[5] in 1942 in which

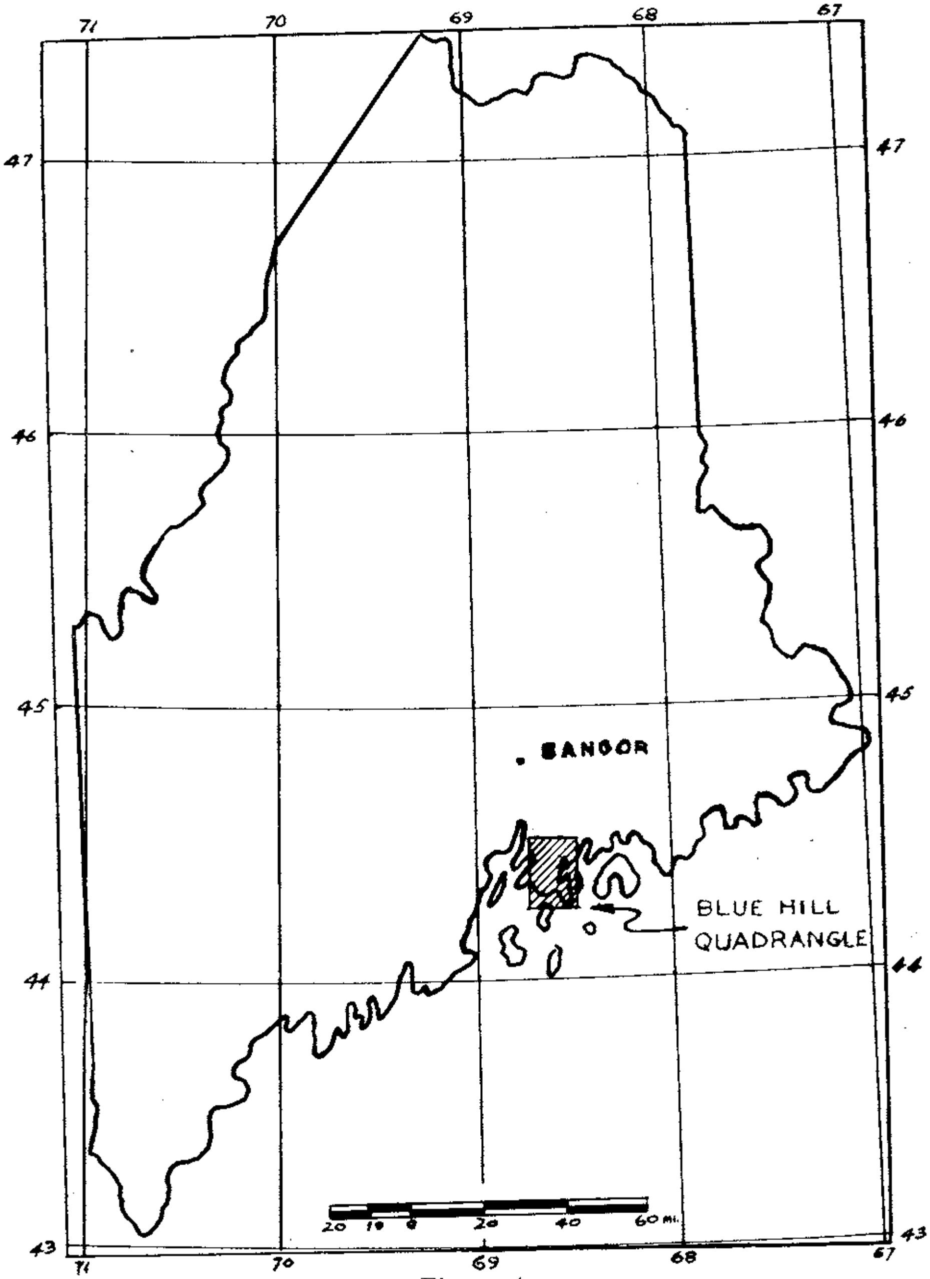
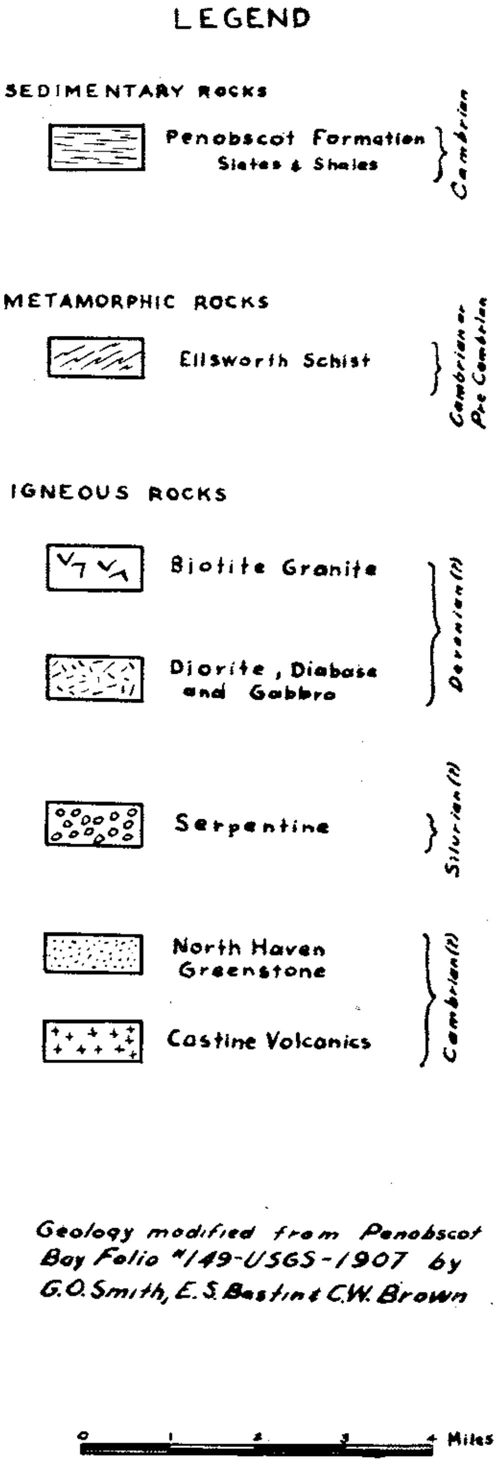
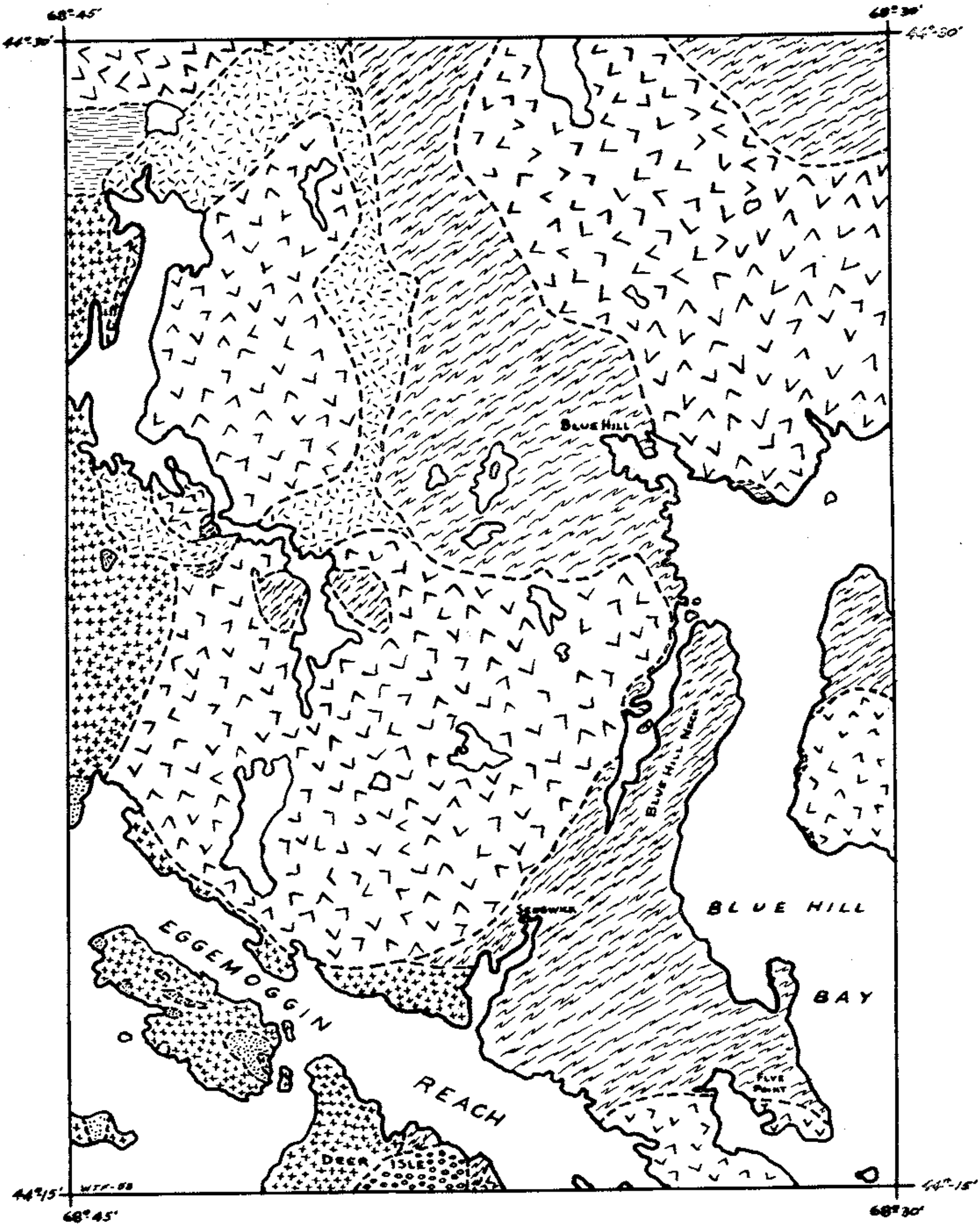


Figure 1
Location of Blue Hill Quadrangle



Legend for Figure 2



AREAL GEOLOGY OF BLUE HILL QUADRANGLE

Figure 2

he indicates that the sulfide ores are genetically associated with the intrusion of the Devonian granites. From 1948 to 1950 the United States Bureau of Mines carried on drilling programs in various parts of the Penobscot Bay region and published its findings in a series of pamphlets[6] dealing with the extent and metallurgical treatment of the ores.

It is the purpose of the present writer, however, to describe in more detail some of the variations in the lithology of the Ellsworth schist which have been lightly touched upon by the earlier writers. It is hoped that by denoting the differences between the ore bearing rock types and other facies of the same formation, certain areas might be eliminated from the scope of any further prospecting ventures which might be undertaken.

The Paleozoic formations found in the Blue Hill quadrangle are shown on Fig. 2 which is taken from Bastin (1907). As the present report is concerned with the lithologic variations superimposed on the Ellsworth schist by the adjacent granitic masses, the other metamorphosed sediments and volcanics will not be discussed.

The Ellsworth Schist

The Ellsworth schist is found in an arcuate north-south band extending practically the whole length of the quadrangle. Other outcrops are found in the vicinity of Surry and extend into Ellsworth, whence the formation derives its name. Smaller occurrences, presumably roof pendants in the granite, are found in the vicinity of North Brooksville.

The schist is a strongly crumpled foliate rock varying from light greyish green to black. In places original bedding is quite pronounced, but over the greater extent of the formation the bedding has been generally obliterated by metamorphism. Quartz veins of the pinch-and-swell variety are characteristic of this rock but are locally absent. Where present, they are parallel to foliation and being more resistant to weathering, give a banded appearance to the schist.

Two rather distinct varieties of the Ellsworth schist were observed in the field and will be discussed below in more detail. They are: (1) a low grade regionally metamorphosed rock characterized by its greenish color and well developed fissility, and (2) a dark gray to black rock varying from a gneissic to a hornfelsic texture. The areas in which these different types of rocks occur are called respectively the Chlorite Zone and the Biotite Zone.

The Chlorite Zone

The Chlorite Zone consists of quartz-muscovite-chlorite schists which occasionally may contain numerous helicitic porphyroblasts of albite-oligoclase approximately 0.65 mm. in length. Most of the fine quartz grains are elongated parallel to the preferred orientation of the micaceous minerals, and commonly show strained extinction.

A few lenses of quartz-muscovite schist have been found between Haven and Sedgwick, and microscopic examination shows them to be composed of fine granular quartz with sutured margins and undulatory extinction. Shreds of muscovite are present between the quartz and show a good parallel orientation. Occasionally angular grains of sodic plagioclase are found in the rock.

About 0.6 miles southwest of West Brooklin on Route 177 several eight inch thick layers of a calcareous schist were observed interbedded with the chlorite schist. The calcareous layers are white and have a pearly luster and consist of twinned calcite quartz, muscovite and chlorite.

The marked parallelism of the platy minerals in this zone suggests that the rocks developed under a dynamic type of metamorphism.

The Biotite Zone

Biotite begins to appear in the fissile chlorite schist near the granite contacts and according to Turner's classification of metamorphic rocks[7] represents a change of sufficient magnitude to warrant a subdivision in the formation. The term applied to this particular portion of the green schist is the Biotite-Chlorite subfacies, but in this report, all members of the Ellsworth schist containing biotite will be collectively grouped into the Biotite Zone, representing a higher grade of metamorphism.

In the region under discussion, the Biotite Zone is found in the immediate vicinity of the granite contacts whence it grades out into the Chlorite Zone. The contact zones at Long Island, Flye Point, Brooklin and the west shore of Salt Pond are relatively narrow compared to those of the northern part of the schist belt centered about the village of Blue Hill. In the latter area the contact zones are so broad that they overlap or merge, resulting in the complete elimination of the Chlorite Zone.

The first indication of the transition from the Chlorite to the Biotite Zone is the disappearance of the greenish cast of the schist due to the appearance of biotite. Closer to the contact the schist looses its fine fissility and becomes more like a hornfels. Relict banding in the form of alternating micaceous and quartzose layers is present in these rocks which have undergone higher metamorphism. In general it may be said that the texture of the rock has been coarsened and made more equigranular by recrystallization of the constituents of the chlorite schist.

Microscopic examination of several samples of the hornfelsic schist reveals that the most common mineral is quartz with sutured margins and strained extinction. Sericite and olive-drab to reddish brown biotite are present in random orientation throughout the slide. Andalusite or cordierite may be present in grains much larger than the other minerals. Various types of feldspar such as twinned or zoned sodic plagioclase, microcline, myrmekite, and microperthite also occur in these rocks. In plane light, a well developed linear structure is shown by trains of fine opaque magnetic minerals. The deformational patterns formed by these inclusions are quite similar to those found in the plagioclase porphyroblasts of the Chlorite Zone. Occasionally grains of chlorite showing alteration to or from biotite may be present. As the alteration proceeds laterally instead of concentrically, it was impossible to determine which mineral was the oldest.

Metamorphosed arkosic sediments are found around Blue Hill Falls and on the small island known as The Nub. These light colored rocks have an equidimensional granular texture but occasionally may be intensely deformed as is shown by granitic pebbles which are elongated three or four times their width. In addition to quartz, one of the more obvious minerals in the matrix is potash feldspar in the shape of angular grains about 3/16 inch across. Epidotization has been an important hydrothermal process in the arkosic areas and has produced a greenish coloration in many of the outcrops and especially along joints.

One of the hitherto unreported rock types in the Ellsworth schist is a massive pyritiferous quartzite occurring in steeply dipping beds parallel to the local relict foliation. One of the beds begins on the north side of the so-called Mines Road about ½ mile east of the Douglas Mine and outcrops over an area of approximately 25,000 square feet before grading out into a biotite hornfels bearing relict foliation. A similar quartzite of more impure composition and smaller areal extent was found immediately across from the Douglas Mine in a recent road cut.

The purer quartzite is light grey in color and shows only slight surficial oxidation. In thin section it is seen to be composed of fine uniformly sized interlocking grains of quartz with undulatory extinction. Many quartz grains are full of minute acicular inclusions in near perfect parallel orientation; however, the patterns present in different grains do not parallel each other. Andalusite, altering to sericite, forms braided patterns throughout the slide but is not apparent in the hand specimen. Euhedral to subhedral pyrite grains averaging 0.5 mm. constitute about 5.5 per cent of the rock by weight, and bear combinations of pseudo- cube and octahedron faces. Grain boundary relationships indicate that the sulfides developed later than the andalusite.

Beneficiation tests were conducted on this rock to determine if it would be satisfactory for use as a glass sand. The rock is amenable to gravity separation of aluminous silicates and sulfides following grinding to between 0.20 and 0.15 mm. Coarser grinding will not completely liberate the heavy minerals, and finer grinding seems to hinder a clean separation. Chemical analyses of the purified sand are not available but microscopic examination of this fraction indicates that it would probably meet glass manufacturers' specifications.

Ore Deposits

Sulfides in the Biotite Zone—An area around Second and Third Ponds was the scene of intense mining activity in the late nineteenth and early twentieth centuries. Two hundred or more test pits and shafts were sunk in an effort to locate copper and iron sulfide deposits similar to those on the shore of Second Pond. It was soon learned by those who ventured into the mining business that the distribution of these sulfide bodies was quite erratic. Where one claim might run into a massive ore shoot, the adjacent claims might be barren. Even those who did find a deposit running high in copper and iron were likely to lose all traces of it after a short period of operation. From the nature of many of the prospects, it seems as if they had been started on a hit-or-miss proposition, or on the basis of a few grains of sulfides showing in the bedrock. The literature on this district indicates that the ore bodies were thin, ranging from 5 to 12 feet thick and roughly parallel to the relict structure of the hornfelsic schist.

The Douglas Mine,[8] with the highest production and longest life, was worked along an inclined shaft parallel to the lode, with drifts and cross-cuts at lower levels. The uppermost 50 feet are still accessible during dry periods and show the following features. Both the foot and hanging walls of the shaft are very low in sulfide content. Occasionally slabs of massive pyrite are present and may be pried loose from the wall rock. The slabs seem to be a mass of compound pyrite crystals which have been cemented together by more pyrite. Quartz is intimately intergrown with these sulfides and may be replaced or corroded by them. Pegmatitic veins about two inches thick and bearing bundles of black tourmaline grains, muscovite and quartz have been found on the east end of the footwall, but could not be observed on the hanging wall. A fault of unknown displacement was observed on the footwall striking N80°E and dipping 80°S. The surface of this fault is covered by a cemented breccia of quartzose fragments which contain no sulfides. Massive quartz veins $\frac{1}{8}$ to $\frac{1}{2}$ inch wide crosscut the relict banding of the wall rock and also cut the replacement sulfides. Two vertical pyrite veins about $\frac{1}{2}$ inch thick were found on the footwall cutting directly across the bedding of the hornfelsic schist. Dump material contains pyrite, pyrrhotite, chalcopyrite, arsenopyrite, and magnetite in addition to the silicates.

A sample of sulfide bearing rock from this mine was examined microscopically and found to be exceptionally rich in quartz. These quartz grains occur in a mosaic pattern with sutured margins and undulatory extinction. Parallel trains of fine opaque inclusions are common within the quartz. Unidentified feldspar grains are somewhat rounded and have been thoroughly altered to sericite. Large grains of bleached biotite are scattered throughout the sample in random orientation, but smaller ones, intergrown with sericite, form crude braided patterns. Zircons are common and are surrounded by pleochroic haloes, yellow in the feldspar, but black in the biotite. Chalcopyrite shows marginal alteration to chalcocite and at the same time appears to be corroding and replacing quartz. A few grains of a greyish-green non pleochroic isotropic mineral are present and have been identified as gahnite.

At the Twin Lead mine, flakes of molybdenite were found in the hanging wall associated with chalcopyrite and pyrite. The presence of a sulfide vein cutting across the relict foliation in the footwall of this mine, as reported by Ching-Yuan Li[9] was verified.

The shaft of the Stewart mine is inaccessible but seems to be sunk at nearly right angles to the foliate structure. Ore from the dump shows intense replacement of the silicates by the sulfides. This particular sample contains so much pyrite that the silicates are mere islands. Rounded grains of quartz which show no undulatory extinction are corroded into embayed shapes by the pyrite while the bleached biotite and sericite are replaced along their cleavage planes.

Most of the samples from the Biotite Zone which were examined microscopically contain the fine trains of opaque magnetic inclusions which have been mentioned earlier. It is quite probable that such inclusions would cause anomalous readings on a magnetometer. The writer wishes to point out that it is possible to detect these grains which are too fine to be observed megascopically by means of an Alnico magnet suspended by a thread from some solid object. Where they are common in a sample, the suspended magnet will be deflected considerably, although the pull is too slight to be felt by a hand-held magnet. The relation of these inclusions to an ore body is not known, but they do seem to be found in the black hornfelsic schist surrounding the known mines. Whether or not they may be concentrated around the mines is a problem which has not been solved at this time.

Sulfides in the Chlorite Zone—Such sulfides as have been observed in the Chlorite Zone are rare and either porphyroblastic or crushed into sharp angular fragments. Porphyroblasts of pyrite from the shore of Blue Hill Neck near Carter Point have been deformed into rhombs $\frac{1}{4}$ inch on a side. Cubes of pyrite also crosscut the schistosity on Long Island and North Ellsworth but none have been observed in the Biotite Zone. Angular fragments of pyrite may be present in the cores of sugary quartz veins, but other than this and the porphyroblasts cited above, no other types of sulfide deposits are present in this zone.

It is the belief of this writer that the pyrite present in the Chlorite Zone had a pretectonic or syntectonic origin, while those ore bodies found in the Biotite Zone were deposited by late hydrothermal solutions originating in the crystallizing granite and migrating up-dip into the baked schist.

Manganese—A small deposit of manganiferous hornfelsic schist occurs about 500 feet east of the summit of Blue Hill. A sketch map of the mineralized area is shown in Fig. 2 (page 38). The manganese bearing mineral is pink rhodonite which occurs in irregular subhorizontal veins about $1\frac{1}{2}$ inches thick and also in fine grained clusters associated with garnet. The rock surrounding the pink bands is massive and dense, and although the minerals are too small for megascopic identification, a positive manganese reaction was obtained in a carbonate bead test. On all sides the deposit grades out into the folded dark hornfelsic schist

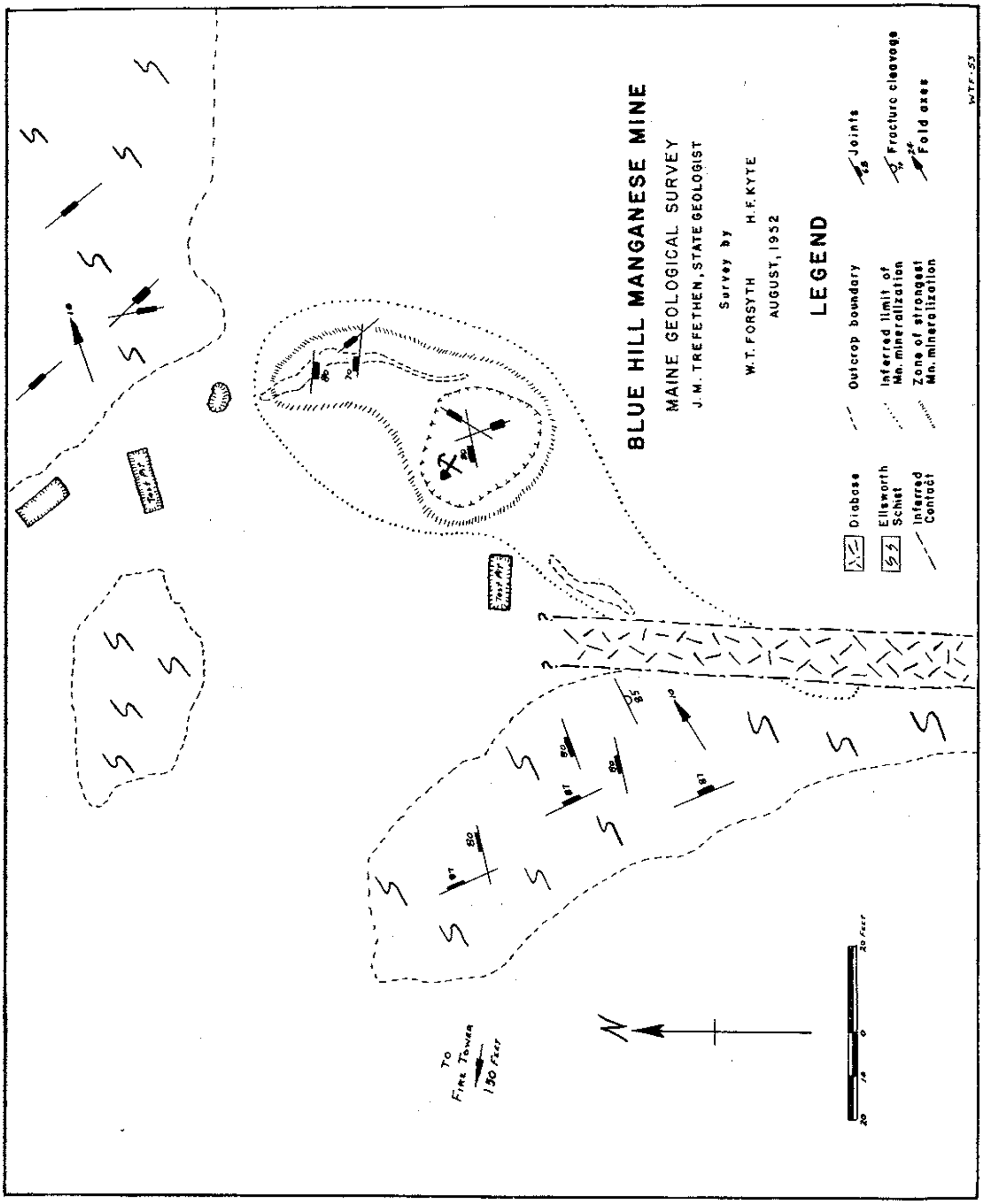

BLUE HILL MANGANESE MINE
MAINE GEOLOGICAL SURVEY
J. M. TREFETHEN, STATE GEOLOGIST
Survey by
W. T. FORSYTH H. F. KYTE
AUGUST, 1952
LEGEND
Diabase
Ellsworth Schist
Inferred Contact
Outcrop boundary
Inferred limit of Mn. mineralization
Zone of strongest Mn. mineralization
Joints
Fracture cleavage
Fold axes
Test Pit
Test Pit
TO FIRE TOWER 150 FEET
20 FEET
N

Figure 2

characteristic of the Biotite Zone. A highly fractured diabase dike about eight feet thick cuts through the mineralized rock but contains insufficient manganese to give a positive bead test. It is believed that this rhodonite deposit was formed later than the folding of the schist but earlier than the intrusion of the dike. Weeks[10] reports that 50 tons of the ore was shipped to the Katahdin Iron Works in 1881 for use as a flux and the size of the pit seems to indicate that very little more was ever mined out. Three analyses listed by Weeks average 20.61% manganese and 13.20% iron for this ore.

Structure

Bedding—As has been mentioned earlier bedding is poorly shown in the Ellsworth schist, supposedly having been largely destroyed during metamorphism of the original sediment. At Blue Hill Falls conglomerate layers however, are interbedded with more argillaceous rocks. Along the north side of the tidal entrance to Salt Pond a similar layer of rounded quartz pebbles grades downward into the argillaceous schist possibly indicating that the rocks are overturned. The calcareous zones within the chlorite schist are transected by schistosity at an angle which also suggests overturning. On the west side of Blue Hill mountain about 500 feet northwest of the intersection of the Mountain Road and Route 15 a strongly deformed conglomeratic layer consisting of a mixture of angular and rounded quartz fragments grades into a gritty schist. In this place the bedding-fracture cleavage relations indicate a normal position of the beds. The quartz-muscovite schist occuring in Brooklin has schistosity parallel to the trend of the bed, and the quartzites of Blue Hill are massive.

It is pointed out at this time that greenstone layers which might be confused with beds actually represent metamorphosed basic sills that cut the schistosity at a small angle.

Quartz veins—The quartz veins which parallel so perfectly the most intricate warping of the schistosity are believed to be older than the granite. As the mineralogical variations across the schist-quartz vein boundaries have not been studied in detail only an outline hypothesis of their origin can be offered at this time.

Within the Chlorite Zone the pinch-and-swell type veins are quite granular and may have fish-tail terminations. In some places there is a visable elongation of the component grains within the veins. All of the writer's observations point toward a conclusion that the present configuration of the veins was caused by crystallization under stress, probably associated with the deformation which produced the schistosity. There is no definite answer to the question of the nature of the original pre-metamorphic sediment although a possibility exists that the quartz was concentrated into the thick bands by a process of metamorphic differentiation. One of the pieces of evidence which seems to support this idea is that wherever the pinch-and-swell quartz veins are absent in the formation, the schist is composed of alternating layers of quartz, muscovite and chlorite about 1/16 to 1/8 inch thick.

Occasionally shear patterns are indicated by the arrangement of the quartz along the plane of foliation, and it seems probable that dilatancy could have been effective in forming these stringers during regional metamorphism. Whether the rocks were reduced to a condition conducive to metamorphic differentiation on a scale large enough to produce the larger quartz veins is a matter open to speculation.

A good indication that the veins may be associated with regional metamorphism and not Devonian igneous activity is that they often contain fragments of pyrite which have been crushed and sheared out parallel to the trend of the granulated vein. To the writer this implies that the pyrite and the quartz were crushed during a period of intense deformation and that subsequent thermal metamorphism did not heat the rock to a temperature sufficient to recrystallize the quartz as it did in the Biotite Zone.

Chevron folds on the southwest side of Blue Hill mountain seem to indicate that alternating quartzose and micaceous layers were formed during or prior to one stage of intense deformation. Microscopic examination of a polished section of a small fold shows that there has been flowage of the layers toward the crests and thinning on the limbs. Fractures fanning out from the axial plane of the fold are also present. As the folding grades out into gentle drags and crumplings in the foliation of the rock, the writer believes that the folds are secondary features developed at the same time as the folding of the schistosity.

Foliation—In a discussion of foliation it is first necessary to define the terms being used. This writer has used synonomously the terms "foliation" and "schistosity" in reference to the parallel elements of the fabric which produce a marked fissility in the rock. The term fracture cleavage will be used to denote finely spaced fractures roughly parallel to the axial planes of known folds.

It should be noted at this point that a well developed undulatory schistosity (fissility) is generally restricted to the Chlorite Zone. Apart from the outer limits of the Biotite Zone, thermal metamorphism, unaccompanied by strong rotational stresses, has caused nearly complete reconstitution of the schist minerals. In most places the delicate parallel fabric has been destroyed and replaced by a coarser granoblastic texture. Relict foliation in the form of alternating quartz veins and quartzo-micaceous bands is the only suggestion of the rocks' former fissile fabric.

As the schistosity of the Chlorite Zone is parallel with the quartz veins, one may assume that the same relationships hold within the Biotite Zone. The generalized structure lines shown in Map IV are based on this assumption. Outcrops on which structural measurements were taken are indicated by dip and strike symbols. No attempt has been made to form highly speculative interpretations of the structure necessary to connect the various traverses.

The strike and dip of the schistosity is extremely variable, unlike that frequently described in textbooks of structural geology. A frequent statement in these books is that schistosity has a fairly regular trend over large areas and bears a definite geometric relationship to the stresses of deformation. Clearly this is not true in the Ellsworth schist. Outcrops where the schistosity has been thrown into folds six feet high and eight feet long have been seen on the northwest shore of Long Island. A similar feature was observed on the east shore of the same island (Mt. Desert quadrangle) and on the east side of the Benjamin River at Sedgwick.

There seem to be two possible explanations of this phenomenon. The first begins with a stage of metamorphism which produces a uniform regional schistosity and partial or complete segregation of the quartz bands. A later stage of deformation then probably threw the schistosity into folds which may be overturned. The suggestion of isoclinal folding has been ruled out because wherever bedding-cleavage relations are found, the cleavage cuts across the bed at a high angle. The alternative suggestion is folded bedding schistosity but this does not seem probable because of the high dips of the foliation. By field correlation of a fine corrugation or wrinkling on the schistosity surfaces with the fold axes, and finding it to be a microscopic fracture cleavage in the laboratory, there is strong indication that the folds were formed after the schistosity had developed.

Metamorphism

It is not the purpose of this paper to discuss in detail the complexities of the physical and chemical changes resulting in the variations in the lithology of the Ellsworth schist. However, on the basis of field and laboratory studies, the writer feels that the rocks of the Chlorite Zone represent conditions of recrystallization under non-hydrostatic stresses such as might be encountered in regional metamorphism. The suites of minerals present in these greenschists are in accordance with those described by students of metamorphic geology as indicative of low grade metamorphism.

On the other hand, the rocks of the Biotite Zone represent a higher grade of metamorphism. Because of the presence of such anti-stress minerals as cordierite and andalusite, and the apparent recrystallization of the micas in random orientation, the writer feels that this higher grade of metamorphism is associated with the intrusion of the granites and directly related to the deposition of the ores.

Evidence of a hydrothermal stage following the baking of the schist by the granites is attested to by the replacement textures of the ores in the area, presence of such minerals as tourmaline and coarse muscovite, and the sericitization of albite in the schist near the granite contacts. As this hydrothermal stage tended to break down some of the higher temperature minerals, it might be considered a third stage of metamorphism, in a retrogressive sense.

The isograds shown on Map IV mark the appearance of biotite in the Ellsworth schist and indicate the outer limit of the conditions which would produce the alteration. Toward the granite contact, still higher temperatures would pervade the schist but the minerals which were produced are of microscopic size, a condition which is not conducive to their field detection. Because of the difficulty in making such an identification, the project was not undertaken hence the zoning cannot be considered complete. It is believed that those biotite bearing members of the Ellsworth schist which have a hornfelsic texture instead of being fissile are more likely to bear andalusite and/or cordierite, the higher temperature minerals.

Age of the Ellsworth Schist

The Ellsworth schist was considered to be of Pre-Cambrian age by Bastin because it is the oldest and most deformed rock in the area.

Niagaran fossils have been found in the Ames Knob Formation off Islesboro but any formations older than that have undergone so much deformation that paleontological evidence of age has not been seen. According to Ching-Yuan Li,[11] "A comparison with the rocks in the eastern part of the area [Blue Hill to West Pembroke], suggests that part of it may be early Paleozoic." On the basis of the law of superposition and the degree of deformation, it is agreed that the Ellsworth schist is the oldest rock in the Blue Hill region but no direct evidence of its age is known.

Granite

The granitic rocks found in this region underlie about one third of the area of Map IV, although they extend over a larger proportion of the quadrangle as a whole. As the field study was concerned more with the effects of the granite on the schist, little work was done on the central areas of the granite masses. For a complete description of these rocks the interested reader is referred to the previous works on the Blue Hill area. For this paper it is sufficient to say that the granite shows quite a bit of variability in texture and composition. One of the more significant features is that many of the contact zones grade into quartz monzonites which may contain minor amounts of molybdenite.

With the exception of a few basic dikes, the granite is the youngest rock in the area. The youngest metamorphic rock cut by the granite is Post Niagaran but no minimum age of the intrusion is available in this area.

Bastin made the assumption that the Blue Hill granites are equivalent in age to that underlying the Perry Basin in the northeastern part of the state. As no pebbles of the latter granite are found in the Silurian rocks of that region, but do occur in the basal conglomerate of the Perry Formation (Devonian), it seems probable that the granite was intruded during the Late Silurian or Early Devonian Period.

Conclusions

The purpose of this study was to examine the Ellsworth schist to determine if mineralogical data could be used as a guide to prospecting in the Blue Hill mining district. Field and petrographic work show that the schist can be subdivided into two metamorphic zones on the basis of megascopic mineralogy alone. The Chlorite Zone, consisting of green chlorite schist, was found to be devoid of sulfide deposits of economic significance. The Biotite Zone may be subdivided into Turner's amphibolite hornfels facies and the biotite-chlorite subfacies of the greenschist facies, but the division must be made on the basis of detailed petrographic sampling. All of the important replacement type sulfide ore bodies are found in the Biotite Zone but a difficulty arises in explaining why they have been found only in a limited area around Second and Third Ponds. The writer was not able to detect a key mineralogical assemblage associated with the sulfide ores but recommends that future examinations be concentrated in the hornfelsic portion of the schist up-dip from the central mass of granite.

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[6]a. S. B. Levin and R. S. Sanford. *Investigation of the Cape Rosier Zinc-Copper-Lead Mine, Hancock Co., Maine.* U. S. Bureau of Mines, Report of Investigations 4344, September, 1948.

[6]b. K. M. Earl. *Investigation of the Tapley Copper Deposit, Hancock Co., Maine.* U. S. Bureau of Mines, Report of Investigations 4691, May, 1950.

[6]c. K. M. Earl. *Investigation of the Douglas Copper Deposit, Hancock Co., Maine.* U. S. Bureau of Mines, Report of Investigations 4701, June, 1950.

[7]F. J. Turner. *Mineralogical and Structural Evolution of the Metamorphic Rocks.* Geological Society of America Memoir 30, New York, 1950.

[8]See Plate III for location of Mines.

[9]Ching-Yuan Li, *op. cit.,* p. 31.

[10]Joseph D. Weeks, 16*th Annual Report, Part* 3, USGS, 1894, p. 416.

[11]Ching-Yuan Li, *op. cit.,* p. 23.

PRELIMINARY REPORT ON EASTERN MAINE GRANITES

By Lawrence A. Wing

A general survey of the granites and associated ores of eastern Maine was started by the Maine Geological Survey during 1951. Four weeks of the 1951 field season and two months of 1952 have thus far been devoted to field work. Field and laboratory studies are incomplete but it was felt a preliminary report might be of use as a guide to exploration of the region.

Purpose of the Survey

Many small areas within the southeastern part of the state have been prospected or mapped in past years by both state and federal surveys as well as private interests. The purpose of this study is to examine the entire district in an attempt to explain the localization of different types of ores especially as related to the different granites of the region. If the ores can be related to structural, chemical, or mineralogical variations in the granites, future prospecting of the region could be more profitably directed.

The principal aim of this preliminary report is to point out the relationship of molybdenite to rather distinctive granite types. Other sulphide ores may follow the same pattern but additional work is needed before any useful generalizations can be made. Detailed descriptions of the sedimentary and metamorphic rocks enclosing the granite will be dealt with in a later report.

Mapping and Classification of the Granites

The map included in this report as Figure 1 has been compiled from various sources and from field studies by the writer. The map is of a preliminary nature and will undoubtedly require further modification as field work progresses. The area shown in Hancock County has been previously mapped by Trefethen.[1] The Blue Hill-Deer Isle area to the southwest of Ellsworth is taken in part from the work of Bastin[2] and in part from Forsyth.[3] The circular complex shown between Ellsworth

[1]Trefethen, J. M. (1944) Mt. Waldo batholith and associated igneous rocks, Waldo County, Maine, Bull. Geol. Soc. America, vol. 55, pp. 895-904.

[2]Bastin, E. S. et. al. (1907), Description of the Penobscot Bay Quadrangle, U.S.G.S., Geological Atlas, Folio 149.

[3]Forsyth, W. T. (1953) Metamorphic facies of the Ellsworth Schist in Blue Hill, Maine, Unpublished Masters Thesis, University of Maine.

and Cherryfield was mapped by the writer as was also the area shown as red hornblende granite south from Calais. The island of Mount Desert to the south of Ellsworth has been mapped and described by several authors. The present map is a modification of the work of Perkins[1] and Chadwick.[2] Further work is needed in this area. Rocks in the vicinity of Jonesport have been described by Terzaghi[3] in two separate papers. The extensions of the granite to the north of Ellsworth and Cherryfield are poorly known. The boundaries for this region are taken from Keith[4] with some minor modifications by the writer. A considerable number of papers have been written on the ore bodies in or near the granites of southeastern Maine. Reference will be made to these papers in a following section on ores.

The granites have thus far been classified into four types, all of which can be readily recognized in the field. A more detailed classification may be warranted as work progresses but does not seem necessary for the purposes of this report. A brief description and the locations of the four types of granite follows:

Porphyritic, gray biotite granite—This granite is chiefly a light gray color although shades of darker gray and light yellowish-gray are present. The rock is nearly everywhere porphyritic with potash feldspar phenocrysts up to 1 inch in length. The predominant feldspar is a potash feldspar with a smaller percentage of white plagioclase. Biotite is the only common dark mineral accompanied locally by hornblende. The entire Mount Waldo batholith to the north of Belfast is of this type and portions of the larger area between Mount Waldo and Ellsworth are of the same type, the relations between this and the Blue Hill area to the south are not known.

Red hornblende granite—The red hornblende granite is readily distinguished in the field from all other types by its color and lack of white feldspars. The reddish feldspar is chiefly microperthite and accounts for the distinctive color of the rock. Hornblende is present in

[1]Perkins, E. H. (1933) Geological map of Mount Desert Island, Mimeo by Arthur Stupka, Acadia Nat. Park.

[2]Chadwick, G. H. (1939) Geology of Mount Desert Island, Maine, American Jour. Sci., vol. 237, p. 355-363.

[3]Terzaghi, R. D. (1940) The Rapakivi of Head Harbor Island, Maine, Am. Min., vol. 25, p. 111-122.

——————(1946) Petrology of the Columbia Falls Quadrangle, Me., Maine Geol. Survey, Bull. 3, pp. 17.

[4]Keith, A. (1933) Preliminary Geologic map of Maine, Maine Geol. Survey, Augusta, Maine.

small amounts and usually somewhat altered. Contact zones with adjacent granite often show biotite in addition to hornblende. This granite is best seen on the eastern half of Mount Desert, the next point to the east (Schoodic Point), and in the vicinity of the town of Red Beach, south from Calais. The granite of the Red Beach area may be in part a pink biotite granite, as described later, but additional field work is needed here before detailed descriptions of locations can be attempted.

Pink biotite granite, zoned feldspars—This granite, showing strongly zoned feldspars, is perhaps the most distinctive of the entire region and certainly the easiest to recognize. It is characterized by an overgrowth of oligoclase on a core of pink microperthite, rarely with double or triple layers of each feldspar. The dark mineral present is always biotite. This granite appears to have a similar appearance to the Rapakivi granite of southern Scandanavia although the feldspars are generally smaller and more rectangular in shape. Granite of this type may be seen on Flye Point south of Blue Hill, in the circular complex between Ellsworth and Cherryfield, and in the vicinity of Jonesport.

Pink biotite granite, non-zoned feldspars—This granite has about the same composition as the pink granite showing the zoned feldspars but differs in texture. The pink perthite and white oligoclase are intimately mixed and very rarely show the overgrowth of oligoclase on perthite. The grain size is more variable than any of the other types but generally fine to medium. Small dikes and irregular knots of pegmatitic and aplitic material are common and the rock often shows tiny cavities where these dikes and knots are common or even profuse. The granite of Blue Hill is in part of this type but more field work is needed here. The western part of Mount Desert, the core of the circular complex east of Ellsworth, and an area southwest from Calais (Cooper) also are made up of this type of granite.

Granite Types and Mineralization

Some sulphide mineralization can be found with all of the granites of this region but commercial deposits as now known seem to be restricted to the non-zoned pink biotite granite. A number of small deposits in the Sullivan area, between Ellsworth and Cherryfield, may be associated with other types but further work is needed before this can be confirmed. The investigations thus far have been aimed primarily toward deposits of molybdenite of which there are several. Some trace of this mineral can probably be found in all of the granites but the non-zoned pink type appears to be the only host rock in which deposits of any importance are located. Two of these occurrences deserve mention, the Catherine Hill prospect located in the core of the circular complex east of Ellsworth and the Cooper Mine located southwest from Calais. The Catherine Hill deposit has been described by a number of writers, the most recent work by Trefethen[1] includes a plane table map. The molybdenite here seems to be mostly confined to joint surfaces although some is reported from small pegmatites. Recent assays by a private company reported chip samples across some of the test pits as carrying only a trace of MoS^2. The low percentage of molybdenite in this showing prohibits mining. It is possible that better concentration of molybdenite may exist in this area. Future prospecting should probably be confined to the core section mapped as unzoned pink granite on Figure 1.

The molybdenite deposit at Cooper, Maine has been described by Emmons[2] and Hess[3] and examined in detail by the writer. A plane table map was also prepared of the area and is included in this report as Figure 2.

Location—The workings are located on Cooper Hill about 22 miles southwest from Calais. The area is easily reached from route 191 and the workings lie near the crest of the hill and about 200 feet east of the highway.

History—The mine was opened in the early 1900's by the American Molybdenite Company of Boston. A mill was erected and reported as operating for about six weeks with the recovery of approximately one ton of concentrates. The workings consist of an open cut about 100 square and ten to fifteen feet deep and a shaft reported to be about 50 feet deep with a 200 foot drift along what was reported as an ore bearing zone.

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[1]Trefethen, J. M. and Miller, R. N. (1947) Molybdenite occurrence, Report of the State Geologist, 1945-46, Maine Geological Survey, Augusta, Maine, p. 54-56.

[2]Emmons, W. H. (1910) Some ore deposits in Maine and the Milan Mine, New Hampshire, U. S. Geol. Survey Bull. 432, p. 42.

[3]Hess, F. L. (1907) Some molybdenite deposits of Maine, Utah, and California, U. S. Geol. Survey Bull. 340, p. 234-235.

Granite and occurrence of Molybdenite—The granite is a fine textured light gray-to-pink biotite granite. The pink color seems to be in part due to weathering. Both orthoclase and plagioclase feldspars are present but exact determinations and percentages are not yet available. Molybdenite, pyrite, and purple fluorite are all present in small amounts. The granite is cut by many small pegmatitic seams and lenses as well as aplitic bodies of the same size and shape. Small miarolitic cavities are also common near the pegmatites and aplite dikes.

Molybdenite occurs mainly as a disseminated material but also appears on some joint surfaces and in some of the pegmatites. The grains of molybdenite are usually tiny, less than one-fourth inch, and thin. Larger grains are present but rare. Molybdenite is not disseminated throughout the area shown as a replacement texture on Figure 2 but appears erratically distributed. Surface exposures do not show the ore to be zoned in any definite pattern but exposures are rare outside the open cut and adjacent prospect pits. The concentration of molybdenite is considerably less than one percent. Drilling would be necessary to prove this deposit due to the scarcity of exposures in the immediate vicinity.

Summary and Conclusions

Of the four granite types mapped thus far in this investigation only one, the unzoned pink biotite granite, appears to be associated with molybdenite and possibly with other sulphide deposits as well. Any prospecting in this area for minerals of this type should be concentrated on this type of granite and the adjacent country rock.

Further work on the mineralogical composition of the granites as related to associated ores is currently under way and additional field work will also be carried out. Results of these findings will be published at a later date.

A PRELIMINARY REPORT ON THE GEOLOGY OF A PORTION OF THE RUMFORD QUADRANGLE

By Kern Jackson

This report consists of a summary of the work and observations made in the northern portion of the Rumford Quadrangle during the field season of 1951. Because this is only a progress report many of the interpretations and conclusions presented here are based on very incomplete observations. The author wishes to acknowledge the assistance of Mr. Sylvio Cyr, who acted as field assistant. Credit is also due to Dr. J. M. Trefethen who made valuable criticisms and suggestions with respect to structure and interpretation.

The field work was done by compass traverse and barometer. The U. S. Geological Survey quadrangle map was used as a basis for operations. However, it was not found to be very accurate particularly with respect to the courses and distribution of the small stream channels indicated on the hill sides. A number of these small streams were badly misplaced or too highly generalized to be of much value in the location of outcrops. The aneroid barometer was used to determine elevations after correction by checking in as often as possible at points of known elevations and bench marks. Daily variations of barometric pressure were obtained from the U. S. Weather Bureau station at Rumford and used to correct the elevations. The author considers the locations of points by this method to be accurate to within the contour interval.

Geology of the Region

Geologically the region can be divided into four basic units. These units are the schist wedge, the Noisy Brook gneiss mass, the Tumbledown gneiss mass, and a granite complex. The schist wedge is probably the oldest unit in the area and is composed of four metasedimentary units which have all been metamorphosed to garnet or staurolite bearing schists. The wedge occupies the central portion of the area mapped in Rumford quadrangle and is a triangular area. Further extension of the mass to the south in the quadrangle is probable but unknown at the present time. The rocks which make up this unit are as follows:

Two Mica Schist	thickness	4,200+	feet
Pyrrhotitic Schist		1,800±	feet
Byron Schist		5,000±	feet
Garnet-Staurolite Schist		6,800+	feet

The Byron Schist is the most prominent unit. It outcrops in a belt at least 9,000 feet wide, but is repeated by isoclinal folding. Its thickness is estimated at 5,000 feet. The two mica Schist and the garnet-staurolite schist may be similarly much overestimated in their actual thickness.

To the east of the schist wedge, there are two characteristic masses of gneiss. The Tumbledown gneiss mass appears along just the northern boundary of the quadrangle. This is the southernmost extension of a mass that is quite prominent in the Rangeley quadrangle to the north. The remainder of the eastern portion of the area mapped is underlain by the Noisy Brook gneiss mass. Stratigraphically the Noisy Brook gneiss is above the rocks of the schist wedge, but no contacts with the schists have been found so that its age relationships are unknown. Similarly, the age relationships between the Noisy Brook and Tumbledown gneisses are unknown.

The granite complex is the youngest unit in the area and is largely confined to the western portion of the area mapped. It is comprised of at least three penecontemporaneous intrusive bodies of granitic and granodioritic compositions, and has associated with it minor bodies of granitic pegmatite and aplite. It is definitely younger than either the schist wedge or the Noisy Brook gneiss as shown by intrusive relationships with both of these bodies. Good intrusive contacts with the Byron Schist are exposed on Old Turk Mountain and with the Noisy Brook gneiss in the bed of Noisy Brook. Smaller bodies of aplite and pegmatite are found all through the schist wedge and the Noisy Brook gneiss mass.

Each of the rock types found in the area are discussed below in as much detail as is possible at the present time. The structure of the region as a whole is discussed later.

The Garnet-Staurolite Schist

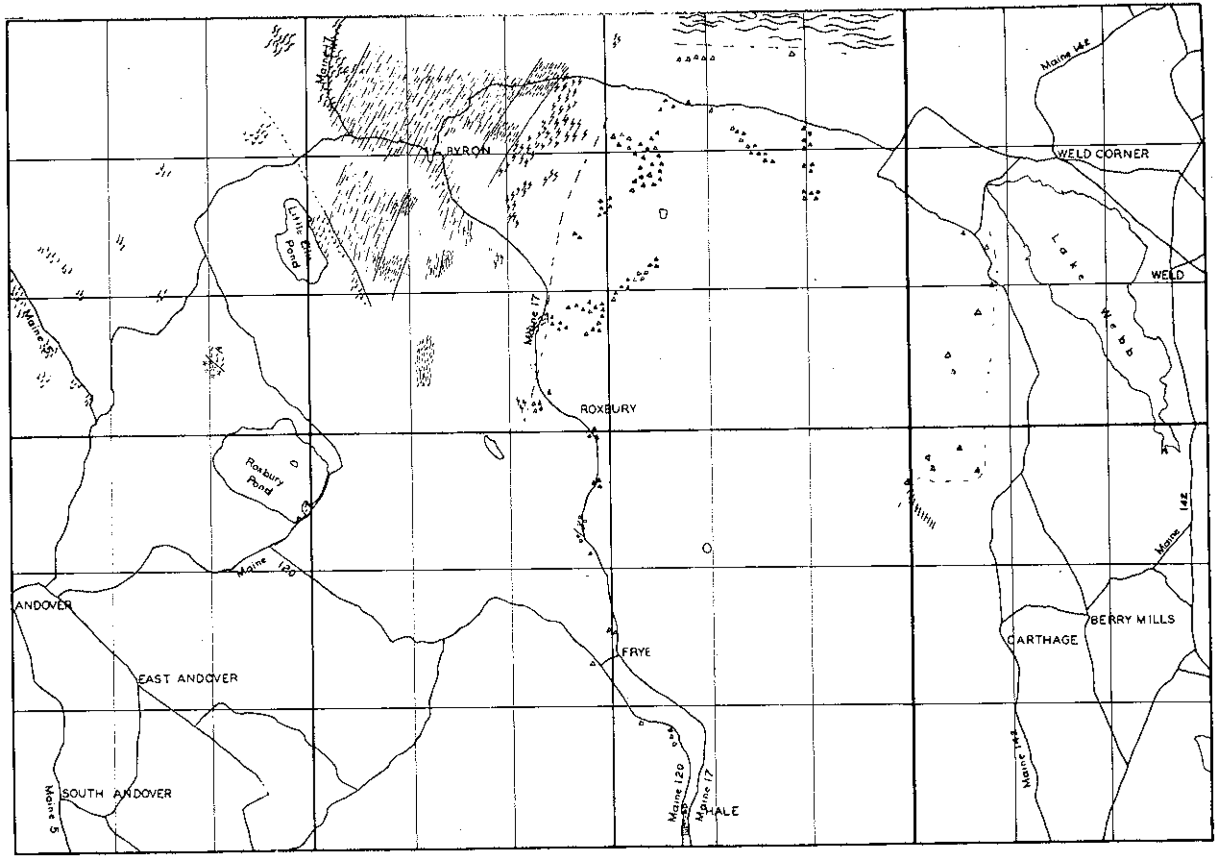
This schist is probably the oldest rock exposed in the region. This position in the stratigraphic sequence is based on the interpretation of the Byron schist which will be discussed later. Exposures of garnet-staurolite schist are found in only a limited portion of the quadrangle. The best exposures are along the beds of the Swift River and the East Branch of the Swift River. It is also poorly exposed in small scattered outcrops on the east face of Pleasant Mountain. In no place can its contacts with other rocks be seen, but they can be closely placed in the two river valleys.

Megascopically the rock is a silvery white to brownish schist showing very marked lineation. Muscovite is the predominant mineral occurring in small well oriented flakes which usually show fine crenulations in the plane of the schistosity and give the rock a strong lineation. Biotite is the second most important mineral and it occurs in the rock in two distinct habits each of which show lineation. The commonest form of biotite is as elongated discoidal flakes aligned in the schistocity and elongated parallel to the lineation. These flakes are generally 2 mm. in maximum dimensions. The second habit of biotite is with quartz in elongated cigar shaped pods up to 10 mm. in length and aligned in the lineation. The individual biotite flakes in these pods run transverse to the long axis of the pods.

The minor constituents are quartz, staurolite, and garnet. Quartz is probably more abundant than is apparent from a megascopic examination. It can be seen as small scattered grains through most of the rock. Occasionally it becomes abundant enough so that local lenses could be called a schistose quartzite and these may be relics of original bedding. Garnet is present in relatively minor amounts as small malformed euhedral crystals showing dodecahedron and trapezohedron faces. These crystals are pink and transparent, but rarely exceed $1\frac{1}{2}$ mm. in diameter. Staurolite is consistently present in small amounts as brown glassy euhedral crystals up to 5 mm. in maximum dimensions. These crystals are not oriented with respect to either schistocity or lineation.

The Byron Schist

The Byron Schist is important in the sequence because the stratigraphic sequence in the area is based on the interpretation of the origin of this formation. The Byron schist is named for the excellent exposures in the bed of the Swift River in the vicinity of Byron. This schist occurs in the area as a broad belt entering the quadrangle at the center of the north boundary and running south-southwest across Old Turk Mountain. The belt is terminated along the lower western slopes of Old Turk Mountain by an intrusion of granite. This belt has a maxi-



GEOLOGY OF A PORTION OF THE RUMFORD AND DIXFIELD QUADRANGLES

Miles

Geology by Kern C Jackson and Sylvio Cyr

Roads, ponds, rectangle lines, and subrectangle lines shown as well as geology

- Staurolite-Garnet Schist
- Byron Cyclical Schist
- Pyrrhotitic Schist
- Two Mica Schist
- Granite & Granodiorite
- Aplite & Pegmatite
- Tumbledown Gneiss
- Noisy Brook Gneiss
- Dense Sillimanite-rich Rock
- Schist & Quartzite

MAINE GEOLOGICAL SURVEY

JOSEPH M. TREFETHEN STATE GEOLOGIST

Field season of 1951

mum width of 9,500 feet, but this does not represent the true thickness of the formation. There is considerable repetition by isoclinal folding ond allowing for this, the probable thickness of the formation is on the arder of 5,000 feet.

In the field, the Byron Schist has a very striking appearance. It consists of alternating layers of dark staurolitic schist and light fine grained quartzite. On water polished surfaces, as the outcrops in the bed of the Swift River at Byron, this banding shows up very clearly as alternate dark and light stripes (Fig. 1). In weathered outcrops,

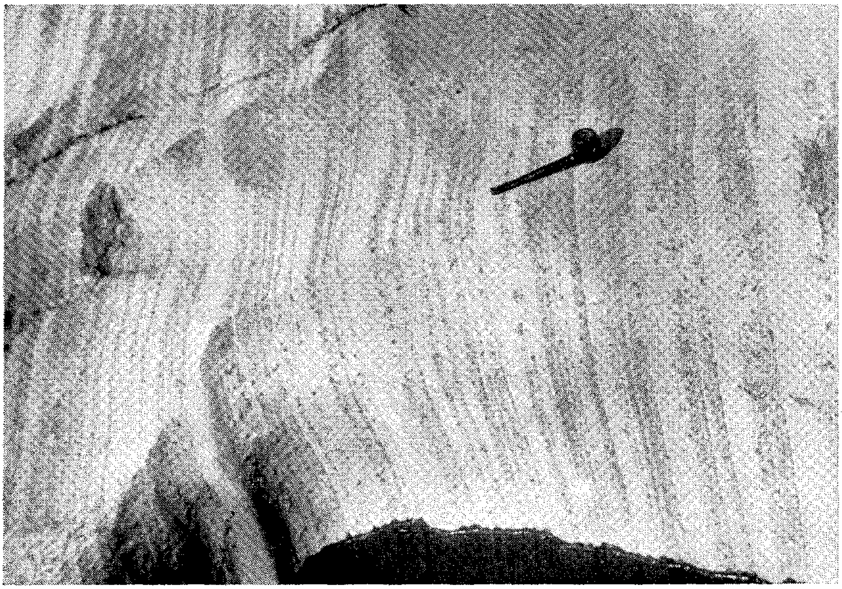


Figure 1

the staurolite schist lamellae are more readily weathered than the quartzite layers and the resultant surface has a wash board effect.

Megascopically, the two rock types which make up the dominant portion of this schist are very characteristic. They will be described separately and their relationships and origin discussed later.

The Quartzite Layers

The quartzite layers are very dense and fine grained. Quartz is the dominant mineral making up around 60% of the rock, in grains not commonly exceeding 0.2 mm. in diameter. Intimately associated with this quartz is a considerable amount of fine micaceous material of sericitic character. The sericite may be somewhat coarser than the quartz as some of the flakes are as large as 1 mm. in diameter. The bulk of the material, however, is as fine grained as the quartz.

Biotite is an important, though minor, constituent of the rock. It occurs as small euhedral books 0.5 to 1.0 mm. in maximum dimensions. It shows well marked elongation (parallel to 010?) and gives a clearly defined lineation to the rock. Garnet is the only other consistent constituent occurring in small euhedral crystals 1 to 2 mm. in diameter. Staurolite is only rarely present in the quartzite. When it is present, it appears as small subhedral brown crystals 2 mm. or less in diameter.

The Staurolite Schist Layers

Mineralogically the staurolite schist layers are very similar to the quartzite layers except for the relative proportions and sizes of the constituent minerals. Staurolite is the most striking mineral present. It occurs as euhedral single crystals and cruciform twins ranging from 2 to 15 mm. in maximum dimensions. The staurolite is a clear glassy brown with poikilitic inclusions of quartz and biotite. Most of the crystals have a soft thin altered marginal zone which give them a dull brown luster where unbroken.

Biotite is also a very prominent appearing mineral in the staurolite schist, occurring in two distinct sizes. One is identical in its appearance to the biotite in the quartzite layers and needs no further description. The second size is much coarser and occurs as roughly equidimensional flakes 2 to 3 mm. in diameter. This coarser biotite is aligned roughly parallel to the bedding of the rock and does not show lineation as does the finer sized biotite.

Quartz and sericite are important minerals of the rock making up as much as 50% of the bulk. They both have the same appearance as in the quartzite layers. Because of their finer size and light color, they are less conspicuous than either biotite or staurolite. Small euhedral garnet crystals are more abundant in the staurolite schist layers than in the quartzite, but are otherwise the same.

Relationships Between Quartzite and Staurolite Schist

Each quartzite layer is intimately associated with one adjacent staurolite schist layer and grades into it almost imperceptibly. Its

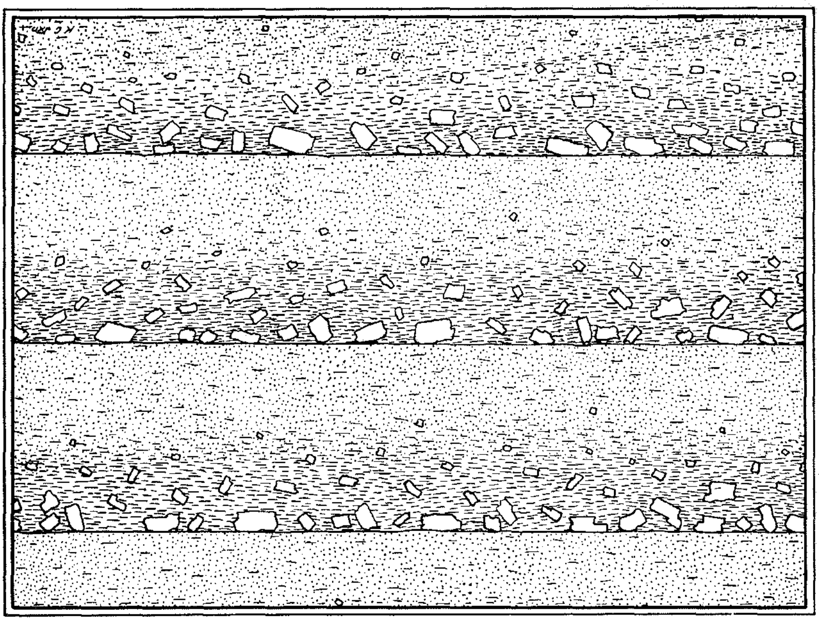


Figure 2

contact with the other adjacent staurolite schist layer is usually sharp with no gradation whatsoever. Beginning adjacent to the sharp contact the rock is pure fine grained sericitic quartzite. Passing through the quartzite toward the staurolite associated with it there is a gradual increase in the amount of biotite, but the rock remains relatively free of staurolite. When staurolite does begin to appear it is as small scattered grains in a quartz-sericite-biotite schist. Continuing on into the staurolite layer, staurolite becomes more abundant and of larger size until we reach the sharp contact to the next quartzite layer. The staurolite is coarsest and most abundant adjacent to this contact. Figure 2 illustrates this gradational relationship in an idealized way.

The Origin of the Byron Schist

The megascopic character and the relationships between the two rock types making up the Byron Schist would indicate that it had developed in a cyclical type of sedimentation similar to the varve structures of glacial-lacustrine deposits. The quartzite was apparently deposited as a fine silty material and its metamorphism has only resulted in recrystallization and the development of minor garnet and occasional staurolite. A staurolite-biotite-garnet-quartz-sericite schist would normally develop from the regional metamorphism of a silty clay. We can then visualize the original sediment as having been deposited in a quiet standing body of water. A supply of sediment must have been brought in periodically in the form of mixed silt and clay and added to the water. Silt, being the coarser and heavier material, would settle out first and accumulate on the bottom along with some clayey material. As time went on the silt was largely removed from the water and the dominant type of material settling out was the finer clay particles. Thus a gradational contact was developed between clayey silt and siltey clay. At some later date a new supply of sediment was brought into the body of water and a new cycle of sedimentation begun. As a result, in passing from quartzite through the gradational contact to the staurolite schist we should be going from older into younger sediment and hence up stratigraphically.

In order to test this theory a large number of cycles were measured in the vicinity of Byron. In 927 cycles measured it was found that 83% of them showed gradational contacts between quartzite and staurolite schist within the cycle and sharp contacts to the adjacent cycles. The gradation consistently showed the same direction as top except for cycles obviously involved in isoclinal folding in the formation. The complete cycles averaged 0.102 feet in thickness of which 54% was quartzite and 46% was staurolite schist. This consistency tends to substantiate the use of the gradational contact within the cycle for telling tops and bottoms.

Minor Features of the Byron Schist

A number of flattened cigar shaped masses of coarse muscovite have been found in the schist. These masses have maximum dimensions of 6″x1″x½″ and are commonly 4″x1″. Occasionally in the cores of these masses there are relict grains of pink andalusite; the muscovite is apparently a replacement of andalusite. The muscovite flakes are aligned parallel to the lineation shown by the biotite in the schist and usually cut diagonally across the length of the original andalusite crystals. The andalusite crystals developed parallel to the bedding plane but in a random orientation within the bedding plane. These crystals are invariably associated with healed, but still visible, fractures through the rock, which suggests that they may have developed by hydrothermal activity. Other similar healed fractures are frequently seen without the development of andalusite. In these cases small staurolite crystals are more abundant straddling the fracture than in the adjacent rock.

Cycles are occasionally seen that show evidence of erosion before the deposition of the succeeding cycle. In these the staurolite schist is largely lacking and in some it has been completely removed over portions of the cycle before the deposition of the next cycle, thus one quartzite rests directly on the next older quartzite. Another feature which frequently appears within the quartzite layers are relicts of small scale cross bedding or ripple marks. These relict structures appear as thin contorted layers with a higher biotite content than the rest of the quartzite. Any structures that might have caused their development have been destroyed by a plastic type of deformation within the layers during the upending of the whole sequence.

Several minor structural features are shown very well in the Byron Schist. Isoclinal folding has already been mentioned. The majority of the folds are small, generally affecting less than 50 cycles. Larger scale isoclinal folding is also present in the formation as a whole. This is particularly noticeable in going upstream from Byron and noting the direction of tops in the cycles. Quartz filled en echelon fractures are present in a few places in some of the thickest quartzite lamellae. In one section of the outcrop at Byron a small open warping of the schist has caused the cycles to separate and quartz has filled the fractures so developed along the bedding planes.

Pot hole erosion by the Swift River has been very effective in the cutting of Coos Canyon through the schist at Byron. Excellent examples of pot holes can be seen ranging from 1 foot to 15 feet in diameter and up to 40 feet deep. An eight foot granite boulder lodged at the foot of the falls immediately above the bridge at Byron is actively cutting a pot hole and, during the season, the boulder could be seen to have rotated.

The Pyrrhotitic Schist

The pyrrhotitic schist is the thinnest and most limited rock type in the schist sequence, but it is very widely distributed through the adjacent quadrangles to the north and east of the Rumford quadrangle and is very useful as a horizon marker. In the Rumford quadrangle it occurs in a belt about 1,800 feet wide immediately southeast of the Byron Schist. The best exposures of the formation are found in the bed of the East Branch Swift River two miles east-northeast of Byron.

In the field, the pyrrhotitic schist has a very characteristic appearance. It consists of alternate beds of a black pyrrhotitic phyllitic schist and dark dense pyrrhotitic quartzite. Both rock types are generally altered on the surface. The schist is altered to a depth of 6″ to 3′. The schist assumed a characteristic greenish, yellowish, or chocolate brown color depending on the amount of pyrrhotite originally present, the yellow color indicating the highest pyrrhotite content. The quartzite layers weather a uniform brown to a depth of $\frac{1}{4}$″. The black phyllite is the dominant rock type of the formation and quartzite only occurs as scattered beds 6″ to 5′ thick at various levels in the formation.

The characteristic minerals of the two formations are very similar and only the relative proportions of quartz and micas differ. Quartz is generally fine grained and granular giving a sugary texture to the quartzite beds. It is characteristically dark colored from many minute dark inclusions. These inclusions are opaque and may be of organic origin. In the micas, biotite is more abundant than either sericite or muscovite. In the quartzite, biotite occurs as well-formed oriented grains up to 2 mm. in maximum dimensions. In the phyllite both micas occur as highly irregular flakes which are folded into fine crenulations. Both micas contain the minute black opaque grains characteristic of the quartz. Aside from pyrrhotite, tremolite was the only other mineral observed. It occurred in a few of the quartzite specimens as fine accicular radiating crystals 2 mm. long and 0.2 mm. thick.

The pyrrhotite which is characteristic of this type occurs in both the phyllite and the quartzite. Its distribution, however, is rather irregular and there may be some tendency for it to be concentrated in the quartzite layers. It occurs as lense-shaped pods of granular aggregates. These pods are oriented parallel to the schistosity and range in size up to 20 mm. long and 3 mm. thick. Clear glassy coarse grained quartz is frequently associated with the pyrrhotite as lense shaped grains, or at the ends of the pods in an augen structure.

The contacts of the pyrrhotitic schist with its adjacent formations are exposed at various places. In all places the contacts both above and below are gradational. Excellent exposures of the contact with the Byron schist can be seen in two small stream beds on the east slope of Record Hill and Old Turk Mountain. In both of these localities the gradational zone extends for a thickness of about 75′ and appears as an intermixing of fairly typical Byron schist and typical pyrrhotitic schist free of quartzite beds. The contact between the pyrrhotite schist and the overlying two mica schist is best exposed in the saddle at the top of Whaleback Mountain. The gradation from one to the other is gradual and is accomplished by the loss of dark color and pyrrhotite and coarsening of the mica.

This high sulphide black schist is thought to have originated from a black highly organic shale of the Chattanooga type. The presence of organic material would depress recrystallization activity, thus resulting in a finer grained rock than the associated schists. Sulphide is considered an original constituent of the sediment—a result of organic decay and bacterial action. Pyrrhotite is the normal result of medium to high grade metamorphism of sulphur bearing rocks.

The Two Mica Schist

The two mica schist outcrops in only a few localities. The best exposures are on the south slopes and western peak of Whaleback Mountain. It is also exposed in one outcrop in the bed of the Swift River north of Roxbury and in one outcrop in the bed of the East Branch Swift River. The actual thickness of the formation is unknown because its relationship to the overlying Noisy Brook gneiss is unknown. The maximum known width of this rock in the area is about 4,200′.

This type is a rather typical garnet-muscovite-biotite-quartz schist. Quartz and muscovite are the dominant minerals, with biotite and garnet secondary in amount. The schist shows the original bedding very close to parallel to the schistosity in layers alternately richer in quartz and muscovite. When quartz is abundant in one layer, muscovite is a less important constituent and vice versa. The schist as a whole is fairly coarse grained with the mica flakes averaging 3 mm. in diameter. Quartz and garnet are finer, garnet averaging 1½ mm. in diameter; the quartz is fine and granular, giving a sugary texture to the quartz-rich layers.

The Noisy Brook Gneiss

The Noisy Brook Gneiss is the most puzzling rock in the entire area. It underlies an extensive part of the eastern half of the area of this report, but insufficient field and petrographic data are available to interpret the origin of the rock satisfactorily. The Noisy Brook gneiss is named for its exposures along Noisy Brook, a small tributary of the Swift River 1½ miles north of the village of Roxbury. In this area it is exposed almost continuously upstream from Highway 17 for a distance of two miles. Other excellent exposures can be seen intermittently along the bed of the Swift River from Hale to Roxbury.

The northwestern, northern, and eastern boundaries of exposure are fairly well established, but contacts with adjacent rocks have only been seen in two places. In each of these, the rocks in contact did not seem to belong to any of the sequence already discussed. The northern contact is on the lower southern slopes of Tumbledown and Jackson Mountains. The topography suggests that this may be a fault contact. The eastern contact is in Dixfield quadrangle and has been placed by the occurrences of outcrops of what will be described as a marginal facies of the gneiss. The northwestern boundary follows the strike of the schist sequence quite closely from the saddle between Whaleback Mountain and Brush Mountain south-southwest to a point one mile west-northwest of Roxbury. The southern boundary is exposed in the bed of the Swift River at Hale.

The Noisy Brook gneiss is composed of two facies. The first and most abundant is a central zone of coarse grained crudely banded gneiss with a more or less migmatic character. Quartz, feldspars, and micas are predominant minerals of this facies. The banding is highly irregular and in many places is so vague as to be almost indiscernible. There is no continuity in the banding suggestive of sedimentary bedding. The central facies grades into a marginal facies which is exposed in a discontinuous band around the margin. This rock is a silvery blue gray micaceous schist of an entirely different character from the central facies. Both facies are characterized by the uniform presence of coarse poikiloblastic and porphyroblastic muscovite flakes which are in complete random orientation. Each facies is discussed in detail below.

The Central Facies

Plagioclase feldspar is the dominant mineral and is probably in the oligoclase range of composition. It makes up 30 to 60% of the rock, in grains 3 to 8 mm. in maximum dimensions. The feldspar is grayish to bluish white, glassy, and in general rather poorly striated. Megascopically it shows little alteration. Quartz is the next most abundant mineral making up 25 to 50% in grains 1 to 10 mm. in diameter. The grains are anhedral, clear and glassy, and frequently are smoky. Biotite is the only important dark mineral. It occurs as subhedral brown flakes which are poorly oriented. It makes up 10 to 30% of the rock in flakes 1 to 5 mm. in diameter. The banding in the rock shows up as variations in the proportions of these minerals.

Muscovite is a very important mineral although it makes up a relatively minor proportion of the rock. Every outcrop of Noisy Brook gneiss contains numerous scattered flakes of muscovite. These flakes are large, up to 25 mm. in diameter, and are crowded with inclusions. Biotite is a commonly included mineral, quartz and garnet are less commonly included, and oligoclase is only rarely included in the muscovite. This indicates that the muscovite was the last mineral to crystallize. These flakes are the prime characteristic for recognizing the Noisy Brook Gneiss.

Minor minerals present in varying amounts are garnet, tourmaline, epidote, and sphene. Garnet is consistently present as pale pink subhedral granules 1 to 2 mm. in diameter. It was probably a very early mineral to form because it is included in quartz, oligoclase, and muscovite. Tourmaline occurs very sporadically as brown columnar euhedral crystals. It occurs more frequently as radial aggregates and separate crystals usually in vein like developments. These crystals are usually thin and prismatic with dimensions of 0.2 x 5 mm. Epidote and sphene occur together in the more granitic portions of the mass. Epidote is in anhedral clear glassy green granules 0.5 mm. in diameter. Sphene occurs as euhedral brown crystals 0.5 to 2 mm. in maximum dimensions.

The Marginal Facies

The most characteristic rocks of this facies are those immediately north of the bridge over the Swift River at Hale (rectangle 6.7). Mineralogically these rocks are quite similar to the central facies but the proportions and sizes of the constituents are very different. Oligoclase is much less abundant making up no more than 20% of the rock in grains 1 to 3 mm. in diameter. Quartz is much more abundant making 50 to 70% of the rock. These minerals have the same physical characteristics as in the central zone. Muscovite is similar to the muscovite in the central facies, but it is finer grained and more abundant in the rock as a whole. The flakes are mostly 10 mm. or less in diameter and do not seem to have as many inclusions as previously. It gives the rock its silvery appearance.

In the minor constituents garnet and tourmaline are present as before. The most unusual mineral is pyrite which is abundant in most of the specimens. There are several characteristic habits of pyrite. The most abundant form is as very finely crystalline aggregates scattered throughout the rock. The crystals in these aggregates seem to be well formed but are minute and give a sugary appearance. Thin films of pyrite are frequently seen coating some of the larger silicate minerals. These films are very commonly found within the biotite crystals parallel to the cleavage. Less commonly pyrite occurs as subhedral crystals 1 mm. or so in diameter. When the pyrite is weathered it leaves a light yellowish limonitic residue.

Inclusions in the Noisy Brook Gneiss

There are numerous inclusions scattered all through the Noisy Brook gneiss which complicate any interpretation of the origin of the rock. The inclusions are angular to subrounded in shape and are primarily of dioritic appearing rock or of biotite schist. Generally both types of inclusions are present in an outcrop and there seems to be no systematic arrangement of them. Where there is an elongated direction in these inclusions there is frequently, but not always, an alignment of the long axes of the inclusions parallel to the gneissosity of the host. In some cases there seemed to be a reaction rim developed between the inclusion and the host, but this is not the general case. These inclusions require a great deal more study in order to fully interpret the rock as a whole.

In addition to these inclusions there are numerous dikes and irregular masses of granitic pegmatite and aplite throughout the formation. These bodies vary in size from a few inches in thickness up to over one hundred feet in thickness. The best exposed contact of the Noisy Brook gneiss, which is immediately north of the bridge at Hale, is occupied by an aplite body 4 feet thick.

Origin of the Noisy Brook Gneiss

The origin of the Noisy Brook gneiss is as yet unsolved. There has been no petrographic work done and all mineral identification has been by megascopic means. Thorough petrographic investigation may well prove the presence of several critical minerals which are as yet unsuspected, and may indicate an entirely different bulk composition than this report would indicate. Field megafrabric studies would be most useful in the interpretation of the emplacement of the body. At the present time two possible explanations of the origin of the rock present themselves, but neither is wholly satisfactory.

The first possible explanation is that the rock developed by a metasomatic granitization process from preexisting rock, probably sedimentary. The process would involve the metasomatic introduction of soda first with the development of the plagioclase. At some time during or immediately following this phase of alteration, the mass became plastic and was deformed and more or less kneaded. At this time the inclusions, which were unaltered relicts, were kneaded through the rock and any original continuity in them was destroyed. Following this phase of plastic deformation a late and rather minor potash metasomatism took place during which time the randomly oriented muscovite flakes were developed. The aplite and pegmatite bodies would then represent the final phases of the activity during a time when the rock was relatively cold and stable. The marginal facies of the formation would be a basic front and would represent the limits of metasomatic alteration. The weakest point in this theory is the explanation of the inclusions, and causes the author to feel that this theory is not completely adequate.

The other explanation offered is that the rock was formed by the metamorphism of an original igneous mass. This will adequately take care of the inclusions as original xenoliths. The bulk composition of the rock, however, will not fit into any original igneous rock. This is particularly true of the marginal facies. Metasomatic introduction of material into an original igneous rock is a possibility, but does not seem a probability considering the composition of the product. Much more detailed field and petrographic work obviously needs to be done before a full understanding of this gneiss is possible.

The Tumbledown Gneiss

The Tumbledown gneiss makes up the bulk of Tumbledown and Jackson Mountains. The gneiss is a very coarse banded metasedimentary gneiss. The bands are alternately a micaceous quartzite and muscovite schist each of which has accessory biotite and garnet. The regional strike of the formation is east-west but it is intimately contorted (Fig. 3). The formation was first thought to be a higher metamorphic facies equivalent of the Byron schist, but the banding is consistently coarser than the banding in the Byron Schist. The only basic igneous rocks found in the area occur as dikes in this formation. The dikes are basaltic in appearance and cut across the gneissic structure. The dikes are about one foot thick and are undeformed and are obviously much later than the gneiss.

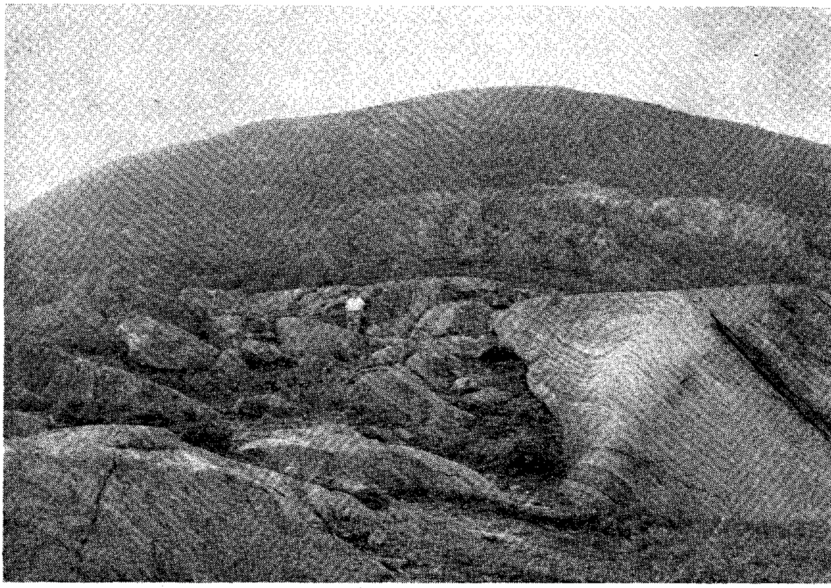


Figure 3

GRANITES

Granite and related igneous rocks seem to underly most of the area of the northwestern part. Several varieties of granite and granodiorite have been observed, but exposures in this area are poor and widely scattered, so that the relationships between the different rock types cannot be worked out in detail. The area is in the Ellis River Valley and is an area of relatively low relief, which forms a topographic basin. This basin is surrounded on all sides by hills that stand up at least 1,000 feet above the basin. Within the basin most of the hills have no more than two hundred feet of relief with one hill (Hedgehog Hill) having a relief of 500 feet. Granite seems to underlie all of this basin and to lap up on the lower slopes of some of the surrounding hills.

One very characteristic type of granodiorite is that exposed along the east shore of Little Ellis Pond and the Western slopes of Old Turk Mtn. Plagioclase is the predominant mineral in this rock and is probably an oligoclase in composition. Biotite is the only ferromagnesian mineral and is quite prominent in the rock. This biotite is considerably chloritized in places. Quartz and orthoclase are minor primary constituents. The most characteristic mineral of the granodiorite is abundant euhedral accessory titanite. These small crystals make up about 5% of the rock and are evenly distributed throughout every outcrop of this granodiorite. Other accessory minerals are pyrite and minute zircons.

Two more characteristic varieties are exposed in a number of very interesting outcrops in the bed of Beaver Brook and at Silver Ripple Cascade on Black Brook. Here there is a contact breccia between two igneous rocks. The older rock is a biotite granodiorite which occurs as highly angular blocks a few inches to six feet in maximum dimensions. These blocks apparently would fit together if the intervening material were removed. The matrix of the breccia is a white biotite granite in which orthoclase and quartz are the predominant minerals. The veins of the matrix vary in width from one inch to two feet. Neither of these rocks carries any appreciable amount of titanite and thus are not the same as the rocks at Little Ellis Pond. Another interesting series of outcrops of these two rocks is exposed in the bed of Black Brook running south-southeast from the west border of the quadrangle for a distance of one half mile. In this series of outcrops the contact breccia is exposed three times with intervening masses of unbrecciated material. Down stream the sequence is: contact breccia, granite, contact breccia, granodiorite, contact breccia, granite.

A schistose biotite granodiorite very similar to that just discussed except for its schistosity is well exposed at Hedgehog Hill. The interesting portion of this outcrop is the presence of two masses of a sillimanite gneiss. This rock is dark, very tough, and banded. It is made up of an unknown dark mineral which shows very poor cleavage, minor micas and garnets, and finely fibrous sillimanite usually in radiating tufts. In the larger outcrop of the gneiss on the crest of Hedgehog Hill there is a gradation of this sillimanite gneiss outward into a muscovite schist where it comes into contact with the granodiorite. The author feels that these masses are probably roof pendants or very large xenoliths in the granite, but can correlate them with none of the adjacent sequence of metamorphic rocks.

Granite pegmatite and aplite are very common throughout the entire area of the quadrangle. They cut rocks of every part of the sequence, but are most abundant in the granites and the Noisy Brook gneiss. There is only one large pegmatite in the area and that is in the Noisy Brook gneiss about 150 feet north of the bridge at Hale. This pegmatite consists primarily of microcline perthite, quartz, muscovite, and some graphic granite. No zoning was noted in it. All of the other pegmatites are small bodies generally less than four feet in thickness. There are several of the larger bodies of aplite in the area, however, and six of these are shown on the geologic map. These are normal granite aplites with no unusual characteristics.

STRUCTURE

The structure of the region is not simple, and outcrops are lacking in critical areas which would clarify the structure. The schist wedge is essentially an isoclinal block which has been complicated by faulting. In the northern portion, the strikes in the schists follow the regional structural trend in a north-northeast direction, but in the southern portion of the wedge the strikes are more nearly in a north-south direction. The strike of the schistosity and the strike of the bedding are parallel. The dips of the bedding and schistosity are invariably steep, usually greater than 80 degrees. The normal dip is to the southeast, although beds are occasionally overturned and dip steeply to the northwest. Small scale folding is commonly seen and in most of these folds the axial plane are vertical or nearly so, and the plunge of the folds is generally rather gentle to either the northeast or southwest. The lineation in all of these rocks is quite consistent and dips to the northeast at angles between 40 and 50 degrees and lies in the plane of the schistosity.

A number of faults obviously cut the schist wedge causing the offsetting of the pyrrhotitic schist. In only one place has any direct evidence of this faulting been observed. That one place is in the bed of the Swift River immediately north of the bridge at Byron. Here there is a conspicuous shear zone that cuts across the canyon running almost parallel to the bedding in the Byron schist. This shear zone would connect up in line of strike with the two aplite bodies shown on the map on the southeast slope of Old Turk Mountain. This suggests that the aplite bodies were emplaced along the weakened shear zone.

The overall structure of the region suggests the possibility that it is the result of batholithic intrusion from below. The complex faulting accompanied by intrusion along the weakened shear planes is characteristic of roof zones immediately above batholiths. The metamorphics in at least part of the region are underlain at relatively shallow depths by an extension of the granite complex which is exposed in the western part of the area. The topography of the region also suggests this, for the schists and gneisses are largely confined to the areas of higher elevations while the granites are largely exposed in the Ellis River Basin and along stream valleys where erosion of the metamorphics is the greatest.

CONCLUSIONS

The following conclusions have been drawn from the field data:

1. The Byron Schist is the metamorphic equivalent of a rock which showed cyclical sedimentation of the varve type, and its character can be used to determine the stratigraphic sequence in the schist wedge.

2. The pyrrhotitic schist has been developed by the metamorphism of a black, highly organic shale. The sulphides present were originally present in the sediment and may be important as a low grade source of sulphur.

3. The Noisy Brook Gneiss probably developed by the metasomatic alteration of preexisting sedimentary rock, but may have developed by the metamorphism of an igneous rock.

4. The structure of portions of the region is characteristic of the roof areas of batholithic intrusions and the granite complex may extend a considerable distance further east under the metamorphics at a very shallow depth.

CERTAIN ASPECTS OF THE ECOLOGY OF *VENUS* AND *MYA* AT MORGAN BAY AND AT BUNGANUC, MAINE

By ROBERT M. ZINK

ABSTRACT

At Bunganuc the littoral sediments are derived from a 30 foot high brown marine clay bank, which at the high tide line changes to a blue marine clay, which underlies the whole area. The littoral sediments grade seaward from a soupy, clayey silt near high tide to a sandy silt, to a silty sand near low tide. At Morgan Bay the littoral sediments are derived from a silty clayey glacial till bank 5 feet high. Wave and current action has left coarser sediments adjacent to the till bank. Currents carry the finer material toward the center of the bay which makes a soupy, clayey silt the main sediment type of the area.

The survey shows that both clams (*Mya arenaria*) and quahogs (*Venus mercenaria*) can live in the same general area; however, each lives in a different type of sediment. At Morgan Bay commercial quantities of *Venus* live in the large expanse of homogeneous soupy, clayey silt, while only a few *Mya* live near high tide in a pebbly sand containing boulders and cobbles. At Bunganuc both *Venus* and *Mya* live in commercial quantities, although there are many more *Venus* than *Mya*. Venus live in all the different types of littoral sediments, whereas *Mya* live near high tide and only in the homogeneous blue marine clay, which may or may not have a thin covering of soupy clayey silt.

Many *Venus* at Bunganuc live in a concentration known as the seedbed. Due to overcrowding *Venus* in the seedbed are stunted, and many die each winter because they are unprotected from extreme winter temperatures. The winter mortality in the seedbed results in a great monetary loss to the state. Recommendations for reducing the heavy mortality are made in this paper.

PREFACE

This paper presents field and laboratory results of projects undertaken at Morgan Bay, Surry, Maine and at Bunganuc Point, Brunswick, Maine. The purpose of comparing the areas is to cover an environmental range that indicates how the type of sediment correlates with the growth rate and presence of *Venus mercenaria* and *Mya arenaria*.

The procedure in the field consisted of mapping the relief and surface sediments at the above places, collecting sediment samples and data concerning them, and collecting biological specimens and data. The laboratory investigation consisted of a more detailed analysis of the samples and biological specimens than was possible in the field and an attempt has been made to correlate the geologic data with the biologic data.

Acknowledgements

The writer is under obligation to a number of persons and organizations for their cooperation and assistance, especially to the Maine Department of Sea and Shore Fisheries.

INTRODUCTION

During the field season of 1950, Philip W. Stackpole and Clyde Grant made a topographic and geologic survey map of a portion of Morgan Bay, Surry, Maine. They also collected samples of bedrock, surface sediments and subsurface sediments to be used in a laboratory investigation of the area which was undertaken and completed by the author.

During the months of July, August and part of September, 1951, the writer made a field investigation of the littoral[1] sediments of Bunganuc Point, Brunswick, Maine for the Maine Geological Survey in cooperation with the Maine Department of Sea and Shore Fisheries. This field investigation was supplemented by a detailed laboratory investigation of the sediment samples collected in the field.

ELEMENTS OF THE COASTAL ZONES

In this discussion the coastal zone is divided as follows: The coastline corresponds to the high tide line. Above and landward from the coastline is the coast or cliff. Any point lower or seaward from the low tide line is designated as off shore. Between the high tide line and the low tide line is the littoral zone, or the beach. The beach is divided into 2 parts by an arbitrarily chosen shoreline. The portion of the

[1]Littoral sediments may be defined as those sediments deposited between the high and low tide marks.

beach between the shoreline and the high tide line is the backshore. The portion of the beach between the shoreline and the low tide line is the foreshore. (Figure 1)

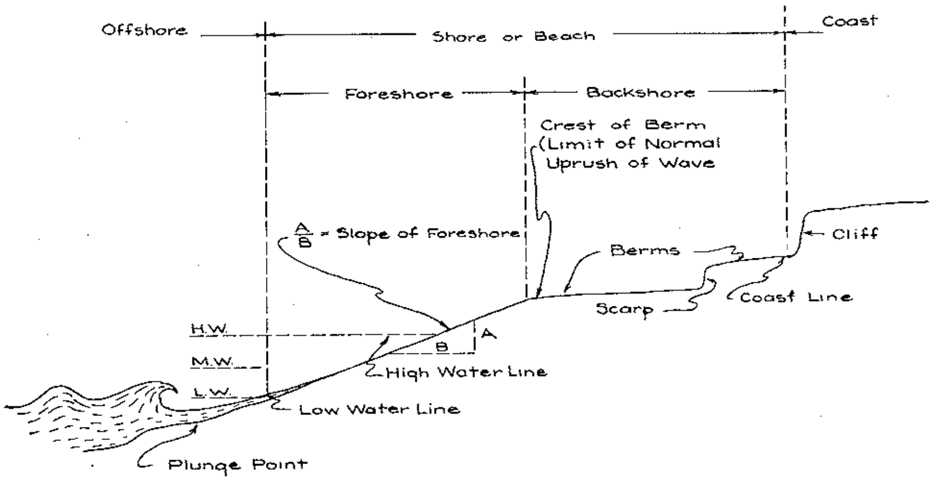


Figure 1. Coastal Zones.

TABLE I---ANALYSIS OF SURFACE SEDIMENTS FINER THAN 0.2 MM. IN DIAMETER

Sediment	Location	Color	% Sand	% Silt	% Clay	% Organic Content	Plastic Limit	Remarks
Brown Marine Clay	Cliff at northern edge of map above high tide	Brown	3	45	52	4	19	Cliffs are mostly tree covered. The clay has fine sandy horizontal partings 2 to 4 inches apart. The clay becomes the same blue color as the blue marine clay when salt water is added.
Blue Marine Clay	At the base of the cliff and at the bottom of all test pits	Grayish blue to dark gray	3	44	53	5	18	When dried it becomes a hard light gray substance which is crushed with difficulty, and which regains its blue color when water is added.
Clay Pebbles	At the base of the brown marine clay cliff	Dark gray		40	60	3	17	Discussed on page 84
Clayey Silt	On Bunganuc Shore from Bunganuc Ledge to Station H	Brownish gray	14	44	42	5	22	Its surface is tough and leathery. It supports a heavy growth of grass (*Spartina*). It becomes a hard light gray substance when dried.
Sandy Clayey Silt	On Bunganuc Shore from station H to Bunganuc Point	Medium gray	26	46	28	4	26	When dried artificially it becomes a light gray, hard, friable substance. When water is added to dry sediment it regains its original color.
Wattenschlick (tidal mud) from Hantzschel in Trask (1939, p. 195)	On the foreshore from the shoreline 400 to 1400 feet toward Bunganuc Rock	Black	7	59	34	8	23	Wattenschlick has a high water content (50-60%), which makes walking difficult, as one may sink more than a foot when wading through it. It dries to a hard, tough, light gray substance which is crushed with difficulty. It returns to its original form and color when water is added.
Sandy Silt	From seaward edge of wattenschlick, 300 feet toward Bunganuc Rock	Gray	35	46	19	4	27	This is a transitional zone between the wattenschlick and the silty sand. It has the same characteristics as the sandy clayey silt.
Silty Sand	From edge of wattenschlick to Bunganuc Rock	Light gray	55	32	13	4	0	There is always water covering it even though it is above low low tide. It has the same characteristics as the sandy clayey silt.

TABLE 2---FIELD MEASUREMENTS OF SURFACE SEDIMENTS COARSER THAN 0.2 MM. IN DIAMETER

Sediment	Location	% Boulders	% Cobbles	% Pebbles	% Sand	Remarks
Sand	In patches on backshore				100	The sand is 0.2 mm. in diameter. The color is tan both wet and dry. The grains are angular to sub-angular and pitted. Most of the grains are quartz and feldspar with some muscovite, biotite and hornblende. The sand appears to have gathered in small patches at a slightly lower level than surrounding sediments due to its being washed from sandy, silty clay.
Boulders, Cobbles and Pebbles	As units on backshore Adjacent to coastline	10	20	30	40	They rest on a surface of sandy clayey silt.
	Near Bunganuc Ledge	20	20	40	20	All sediments are angular and relatively flat, and consist of bedrock.
	Fifty feet west of mouth of fresh water stream	75	25			There are 12 boulders and cobbles in this group. They are glacial erratics resting on sandy silty clay.
	At mouth of fresh water stream	5	50	35	10	The largest boulder is 5′ x 2′ x 8″. Cobbles 5″ are the most common. The larger sediments rest on a tan sand 0.2 mm. in diameter.
	Fifty feet east of mouth of fresh water stream	5	50	35	10	Some sediments are on backshore and some on foreshore. The 4″ pebble is most common. They are glacial erratics.
	Near Bunganuc Point	10	20	30	40	They are not from the diabase bedrock. They are glacial erratics and rest in sand and sandy silt.
	As unit on foreshore Near station K	20	30	40	10	They are diabase and glacial erratics. They rest on silty sand.
Cobbles and Pebbles	20′ west of Bunganuc Point on the shoreline		10	10	80	Largest cobble is 4″ in diameter. The larger sediments rest on a tan sand 0.2 mm. in diameter.
	Halfway between stations A and B		15	30	55	Angular to sub-angular particles. The most common grain size is the pebble.
	Station B adajcent to shoreline		10	35	55	24″ in diameter. Larger sediments rest on tan sand 0.2 mm. in diameter.
	40′ east of Bunganuc Ledge		30	30	40	This group grades from a boulder, cobble, pebble group which is adjacent to Bunganuc Ledge.

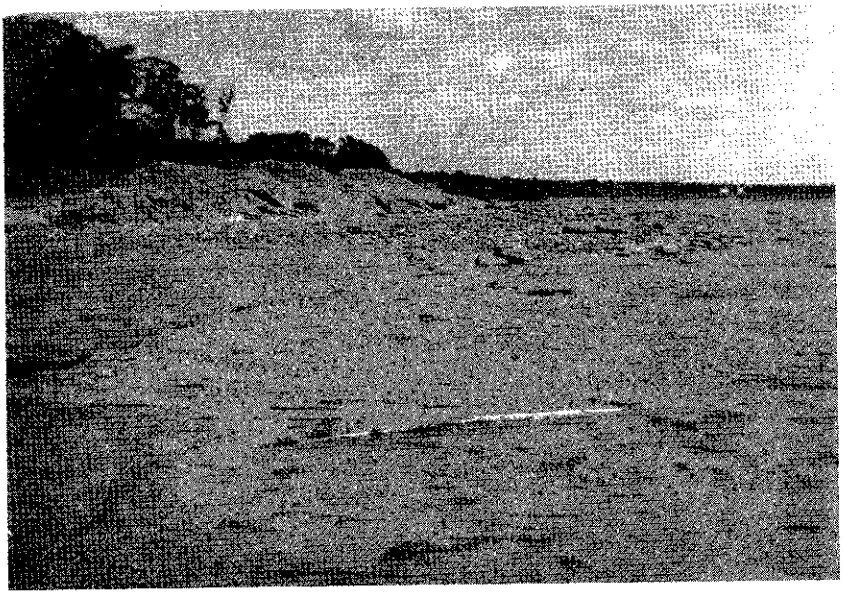


Figure 2. Bunganuc Point showing boulders, cobbles and pebbles around the bedrock.

Figure 3. Bunganuc Ledge partially covered with seaweed.

LABORATORY INVESTIGATION

The Morgan Bay and Bunganuc areas have been used primarily in an attempt to correlate the sedimentary environment with the density and growth of *Venus mercenaria* and *Mya arenaria*. The time spent in the laboratory investigation has been concerned with determining the range of particle size of the sediment samples by mechanical analysis, the plastic limit and the organic content of the sediments.

Forty samples were collected for laboratory analysis from the Bunganuc area. Seventeen samples were collected for laboratory analysis from Morgan Bay. See Tables 1 and 2. Data for these including hydrometer and sieve analyses, dispersion ratios, centrifuge moisture equivalents, lower liquid limits, plastic indices, plastic limits, and organic contents are on file at the University of Maine Library, Orono, Me.

BUNGANUC

Location of the Area

The Bunganuc area is located in the town of Brunswick about 6 miles southwest of the business district of Brunswick in Cumberland County, Maine. The detailed area (Plate 1A) is south of Bunganuc Landing along the shore of Maquoit Bay just east of where Bunganuc stream empties into Maquoit Bay. (See Index Map on Map VII).

For convenience in this paper the following named places will be designated as below: The bedrock exposed at the most easterly edge of the area is designated Bunganuc Point (See Fig. 2). The bedrock exposed at the most westerly edge of the area is designated Bunganuc Ledge (See Fig. 3). Bunganuc Shore is between Bunganuc Point and Bunganuc Ledge. Bunganuc Rock (See Fig. 4) is the bedrock exposed at the most southerly portion of the mapped area. (See Map # 1)

Topography

The relief in the vicinity of Bunganuc Shore consists of marine clay banks which have fine sandy and silty horizontal partings (See Fig. 5) in contact with the coastline. The littoral zone exhibits a smooth relief with the slope of topography growing gradually steeper from the low tide line to the shoreline. Between the shoreline and the clay banks

Figure 4. View of Bunganuc Rock taken at mean low tide from pit A-10.
Notice that water surrounds the rock at mean low tide.
At "low" tide water does not reach the rock.

Figure 5. View of the bare brown marine clay bank taken from station F.

the slope becomes quite steep and just at high tide line the banks rise steeply 25 to 35 feet above the high tide line, at which elevation they level off to a smooth rolling surface.

The difference between the mean low tide and the high tide is 8.9 feet in vertical drop in a horizontal distance of 2,700 feet. The difference between the "low" low tide and the "high" low tide is 3 feet vertically, but covers a horizontal distance of 1500 feet, while the difference between the "low" high tide and the "high" high tide is still 3 feet vertically but covers a horizontal distance of only 20 feet. On the foreshore the slope is 0.2 percent. On the backshore the slope is seven percent. The slope of the clay bank is roughly 40 percent.

The Backshore

The shoreline is extremely irregular, highly indented, and marked at its seaward extent by an irregularly carved wave cut bench ranging in height from 0.5 to 3 feet, and by a thick growth of grass (*Spartina glabra*). The landward extent of the backshore is marked by a combination of tree growth and a sudden increase in slope of the marine clay bank. The width of the backshore varies from 75 to 125 feet. It rises 7 feet from the shoreline to the coastline. The rises in elevation sometimes take place in ridges of 6 inches to 1 foot which are about 20 to 40 feet apart.

DRAINAGE

The tidal drainage is by way of Maquoit Bay into Casco Bay. There are two permanent fresh water streams that drain into the mapped area, Bunganuc stream at the west end of the area and a smaller stream located in the center of the area. Maquoit Bay is on the eastern side of the area.

There are also several small intermittent fresh water streamlets that flow out of sandy patches at the base of the shore and that flow into the Bay only at low tides. Ground water percolating through the sand is the source of water for these streamlets.

Bunganuc Stream

Bunganuc Stream is the largest fresh water stream draining into Maquoit Bay. It follows a rather meandering course and enters Maquoit Bay about 200 feet west of station A. At high tide this stream is about 400 feet wide and about 13 feet deep at its mouth, while at low tide (Plate IV A) the stream is only 5 feet wide and 2 feet deep at its mouth. The whole channel and its banks are composed of silt except the center of the channel which is composed of coarse sand.

Bench Marks

Semi-permanent and temporary bench marks were set along the backshore at convenient locations so that future surveys at the area could relocate the station position, contours, and sediment types, etc. shown in this survey.

Temporary bench marks were set in trees along the bank to tie in as many stations as possible. The trees used as bench marks were notched with an x and a nail was driven into the base of the tree.

Semi-permanent bench marks were set in each of the three bedrock outcrops in the area. These bench marks were noted (designated) by cutting an x one half inch deep and three inches long into the bedrock. Aluminum paint was then put over the x to make it more easily distinguishable.

The semi-permanent bench marks are designated as follows:

Bench Mark #1, elevation 11.21′ above the "low" low tide line of July 25, 1951, is located on Bunganuc Ledge.

Bench Mark #2, elevation 10.90′ above the "low" low tide line of July 25, 1951, is located on Bunganuc Point.

Bench Mark #3, elevation 9.46′ above the "low" low tide line of July 25, 1951, is located on Bunganuc Rock.

Location of the Grid and Test Pits

The three outcrops of bedrock were used as corners of a grid system. The grid system was used to establish elevations from which contours were drawn and to locate points from which sediment samples could be taken, and test pits dug.

Lines were drawn between these three outcrops. Then lines were drawn along lines of sight between stations A, B, C, D, E, F, G, H, I, and J to the bench mark on Bunganuc Rock. Along the line of sight between station G and Bunganuc Rock distances of 200 feet were measured until the rock was reached. Then lines were drawn at these points parallel to the base line. At the points where these two sets of lines intersected, stakes, 3 feet long, were driven into the ground marking the grid system.

Figure 6. Bunganuc Stream at low tide as taken from 1000 feet north of Station A, where steeply dipping bedrock cuts the channel.

Figure 7. Station R, a typical shell boulder formed by gulls dropping Venus on the boulder to break the shell to reach the meat of the animal.

Making the Grid Corners and Pits

Since pits were dug for several different reasons, a method of numbering the pits had to be used which would indicate the location of the pit, the reason for digging the pit and the depth at which the data is gathered.

In an effort toward obtaining simplicity the following method was chosen: The lines between the station and Bunganuc Rock were given the same designation as the letters of the stations. The lines of the grid parallel to the shore were numbered 1, 2, 3, etc. increasing from the shoreline outward; so, the location of the grid corners are designated A1, A2, B1, B2, etc.

Adjacent to the shoreline *Mya* pits were dug. For these, the reverse order was used. The first pit located from A was called 1A, the second 2A, and so on for each *Mya* pit located from each station.

In the *Venus* seedbed the pits were marked with a letter followed by the density of the *Venus* as determined by Dow and Wallace in 1950.

The samples of the clay bank were marked similarly to the marking of the grid corners from station F except that they had an "O" interposed between the station letter and the grid number.

To designate the zone from which a sample was taken, the plot location is followed by a dash and a number representing the appropriate zone.

Method of Digging and Analyzing Test Pits

Adjacent to the stake marking each test pit a 1 x 2 foot rectangle was drawn on the sediment surface. The surface was examined for the type and color of the sediment and for microscopic plant and animal life.

Beneath the surface the profile zones were noted along with any H_2S odor rising from the zone. The animal life in each zone was recorded. *Venus* in the test pits were measured for size and for age. *Mya* in the test pits were measured for size and depth at which they were found. The information gathered in the test pits is on file at the University of Maine Library, Orono, Me.

All test pits were dug with a hand trowel to a depth of eighteen or twenty-four inches. Deeper test pits were prevented because slumping of the pit resulted in contamination from the above zones.

Hydrogen-ion Concentration Recordings

During the summer and fall measurements of hydrogen-ion concentration were recorded on the foreshore. Most of these determinations were made by Ganaros.

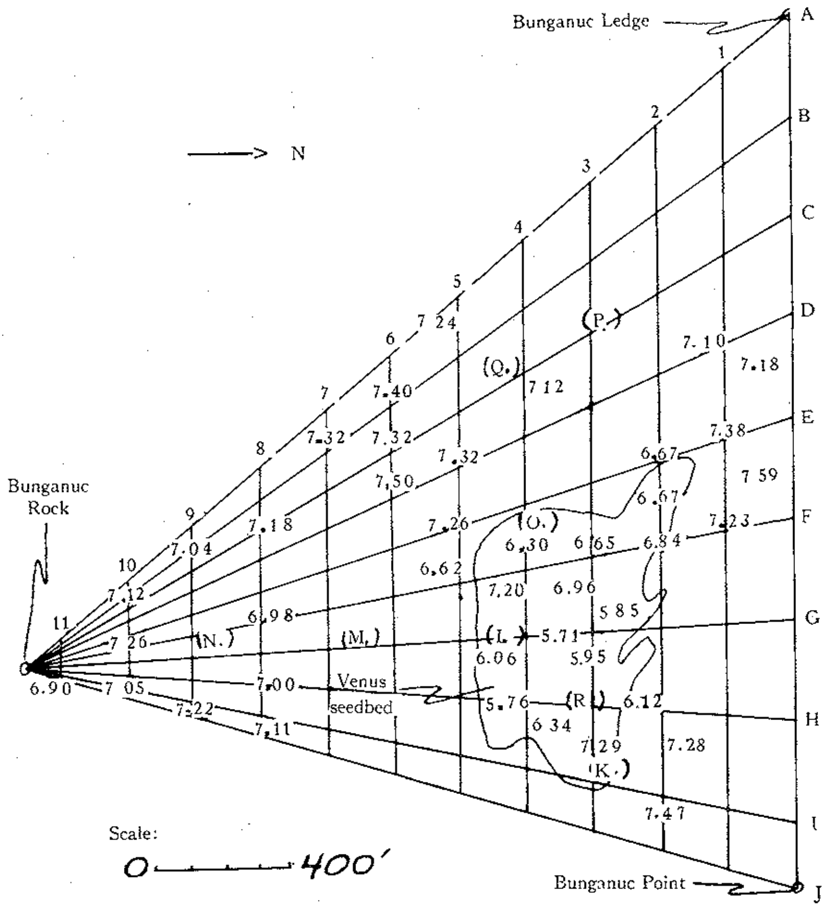


Figure 8. Diagram of the mapped area showing the location of the stations and the grid pattern. The approximate location and shape of the seedbed is depicted. The pH determinations are given at the points at which they were taken.

A Beckman pH Meter[1] was used to determine the hydrogen-ion concentration. The instrument was taken onto the clam flat, and the

[1]Laboratory type, Beckman Model G, manufactured by Central Scientific Co., Chicago, Illinois.

pH was determined by inserting electrodes in a beaker of the surface sediments. The beaker was mounted on a wooden stand to prevent grounding. In order to protect the meter from the salt water and silt, it was completely encased in copper with the exception of a few dials which had to be left exposed so they could be read.

A total of 43 pH readings were made. Fourteen of these, taken in the seedbed, showed a range of 5.71 to 7.29. Twenty seven readings, taken outside the seedbed, had a range of 7.00 to 7.50. Two readings taken in the *Mya* growing region had a range of 7.18 to 7.49. The individual measurements are shown in Figure 8.

GEOLOGY OF THE AREA

The geology of Bunganuc is described by its bedrock and its surface and subsurface sediments. Unusual formations and the origin of all geological features are discussed.

Figure 9. View showing the typical structure of the clay beds at several places adjacent to Bunganuc Shore. This picture shows the clay beds dipping west between stations E and F.

The Bedrock

Bunganuc Ledge is a bedrock outcrop of a quartz-feldspar-biotite-gneiss interbedded with a granite pegmatite. The bedrock has a strike of N 10°E with a dip of 65°E.

Bunganuc Point is a bedrock outcrop of a greenish gray fine-grained diabase. The long direction of the diabase is N 45°E. The dike is intersected by two sets of joints. One set of joints has a strike of N 65°E with a dip of 50°NW. The other set of joints has a strike of N 45°W with a vertical dip.

Bunganuc Rock is a bedrock outcrop of dark gray, fine-grained diabase. The long direction of the diabase is N 25°E. The dike is intersected by two sets of joints. One set of joints has a strike of N 60°E with a dip of 65°NW. The other set of joints has a strike of N 45°W with a vertical dip. According to Keith (1933) the diabase is Pennsylvanian in age.

Surface Sediments

The surface sediments have been classified into the groups in Table IV and V. Each group was mapped as a unit in the field. The sediments are divided into two groups. Those finer than 0.1 mm. in diameter, and those coarser than 0.1 mm. in diameter. Result of the field and laboratory determinations are given for the former group while only field determinations are recorded for the latter group. Possible origin of all the sediments in the tables are given.

Clay Anticline

At three places on the foreshore adjacent to the shoreline, the clay beds show an anticlinal structure (Fig. 9). At station F the clay beds form the crest of the anticline, with the strike of the axis being N 5°E. Between stations H and I the clay beds dip westerly 5°. Between stations B and C the clay beds dip easterly 5°.

There are various explanations which would account for the formation of this clay anticline. One is that the clay and its partings reflect the configuration of the rock surface beneath the clay. Another is that the anticline could be caused by differential compaction, by the weight of the marine clay that was laid down over the present area, which has subsequently been eroded away. More work will have to be done in the area before any definite conclusions can be made regarding the origin of these structures.

Clay Pebbles

Halfway between Bunganuc Ledge and Bunganuc Point at the base of the bare marine clay bank and 2 feet below the contact between the brown and blue marine clay are numerous clay pebbles (Plate IV B) from ½ to 3 inches in diameter. The clay pebbles are well rounded and are made up entirely of silt and clay, the average proportion being 60% clay to 40% silt.

It is interesting to note that the size and number of the pebbles vary with the tide. It was noticed that there were more and larger pebbles during and immediately after the highest tides with the pebbles almost disappearing during the low tide periods of the month. The reason for this is apparent from the origin of the clay pebbles, Haas (1927, p. 150). During the higher high tides the water reaches farther up the marine clay bank washing the fine sand out of the horizontal partings (Plate IV A). According to Twenhofel (1950, p. 593) pebbles

> form from dry chunks, which after being wetted on the outside become impervious, and entrance of water into the interior is retarded. Ultimately water penetrates the interior which expands and compels cracking of the outside.

This frees pieces of clay from the marine clay bank causing them to fall onto the shore where the water rounds the fallen pieces of clay into clay pebbles.

During the lower high tides, the water is unable to reach high enough up the marine clay bank to make pebbles; so, it reduces the size of the clay pebbles already formed by washing some of the silt and clay from the pebbles until they finally disappear.

The formation and washing away of the clay pebbles are the only signs of erosion noted during the field season.

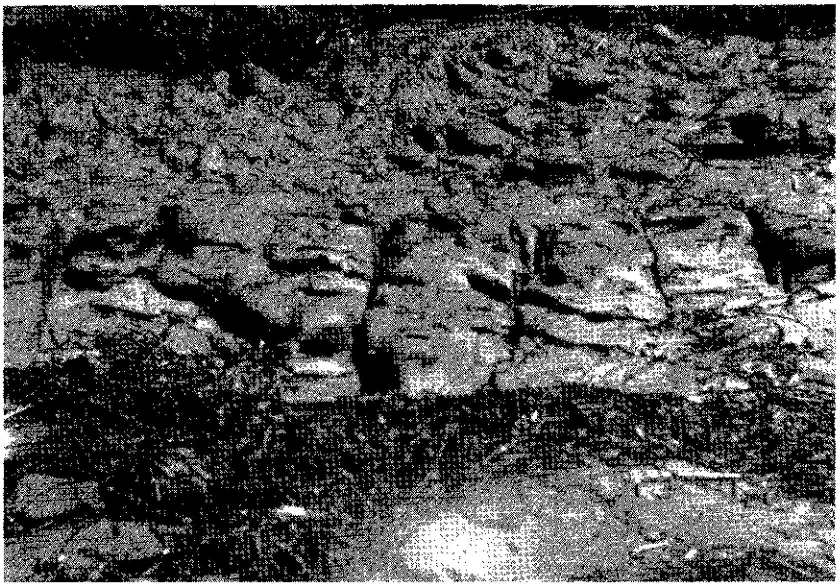


Figure 10. Close-up of the base of the marine clay bank showing an intermediate stage in the formation of the clay pebbles. Sand has washed out of the horizontal partings and vertical openings have formed, which will soon allow lumps of clay to fall onto the backshore, where they will be formed into clay pebbles.

Figure 11. Clay pebbles on the shore below the area pictured above. The white shell fragment on the right is one and one-half inches in its longest dimension.

ORIGIN OF THE SEDIMENTS

Origin of the Marine Clay

The marine clay is assumed to have accumulated during the Pleistocene epoch as the sea invaded coastal New England. At the time of the formation of the clay the seaward edge of the ice sheet was located inland and was adjacent to the sea, which covered the present coastline. Glacial marine clay is a rock flour clay, (Perkins 1930, p. 76), which is the product of mechanical grinding of rocks into very fine fragments, mainly by overriding ice. These fragments are composed of many diverse minerals.

The clay is considered to be marine because at many places marine fossils have been found in it. The clay in this area is a blue clay overlain by a brown clay. The transition in color between the two clays is a highly irregular surface located at the high water line. According to Goldthwait (1950, p. 26) the graded zone contact is typical of a weathering zone, as the brown clay works irregularly down into the blue clay. The brown clay appears to have been partially oxidized from the original blue clay at about the water table.

Trefethen (1946, p. 13) reports that both brown and blue marine clays are more or less interbedded with sandy and silty layers and have silty partings.

According to Bastin (1906, p. 430) marine clays represent old clam flats. Streams flowing from melting glaciers were heavily laden with sediment, coarse gravel and sand were deposited on land or in the ocean close to shore, but the finer portions were carried farther out and deposited as marine clay. The old clam flats differ from those of today only in the greater rapidity with which the muds were deposited.

Origin of Wattenschlick

Wattenschlick occurs where the sea attacks marsh coasts or coasts made up of very fine grained unconsolidated sediments. The sea destroys the previously deposited sediments and redeposits them at favorable localities. Accordingly in these areas the sediments are reworked deposits, not new ones. Most of the detritus that is deposited in the tidal mud comes from reworking of Pleistocene sediments, (Hantzschell 1939, p. 201).

The animals of the tidal region participate considerably in the formation of *wattenschlick* through the production of excrement. Mussels and other marine organisms filter silt and clay through their shells and through thread-like attachments, which aid in the formation of wattenschlick, (Kuenan 1950, p. 318).

According to Hantzschell (1939, p. 200) the black color of the sediment is due to FeS (hydrotroilite), which is present in a very finely divided state. According to Russell and Kuenen (1939 p. 170 and 354) the black color of the sediments is caused by H_2S gas resulting from decaying organic matter.

Origin of Boulders, Cobbles and Pebbles

There are many different sources of the boulders, cobbles and pebbles at Bunganuc. Some of these are given below.

Although there are occasional coarse, orange brown, sandy pockets in the marine clay, there is no glacial till on top of the clay. It is possible, although very unlikely that till may have overlain the clay (Perkins & Leavitt 1935, p. 33) and that the boulders, etc. are remnants of this till.

A more logical origin for the boulders, cobbles and pebbles is Trefethen's (1946, p. 15) observation that brown clay often contains numerous pebbles and cobbles presumably rafted in by floating ice. Then, as the icebergs melted, the rocks fell into the marine clay. In the process of erosion the marine clay was removed by washing by the wave action of the sea. The boulders, cobbles and pebbles were too large to be moved by ocean waves and currents so the larger sized particles, when once exposed on the surface, remained in place on the surface sinking vertically as the marine clay was washed away from beneath them. In this way there may have been a grouping of larger sediments into mappable units, such as around Bunganuc Ledge, Bunganuc Point, Station K and west of the fresh water stream.

At Bunganuc no signs were seen of sediment transport by the flotation method of McKelvey (1941) or by seaweed holdfasts as reported by Fairley (1950, p. 30) at Great Bar, Jonesport, Maine.

Origin of the Foreshore Sediments

The writer believes that a large portion of the finer sediments in the littoral zone is derived from the brown marine clay cliff adjoining the area. In an effort to discover the origin of the finer littoral sediments five samples of brown marine clay were obtained for laboratory analysis. Mechanical analysis, plastic limit and organic content determinations of the bank and littoral sediments show a close correlation between the sediment types. The formation and washing away of the clay pebbles and slumping of the clay cliff show that much of the finer sediments of the littoral zone are derived from the clay cliffs.

The finest sediments occur mostly near the high water line. In the middle part of the clam flat the fine sandy silt is found which forms the transition to the silty sand, which predominates near the low water line.

The author believes that the following are factors in the formation of the finer littoral sediments. At high tide the waves free particles of sand, silt and clay from the clay bank. The currents pick up these free particles and carry them seaward on the ebb tide. The grain sizes of the clay bank are 0.2 mm. or less in diameter. According to Fig. 17–2 in Trefethen (1949, p. 395) the particles 0.2 mm. in size are picked up before the smaller particles, and are also deposited first; so some sand remains on the backshore, but most of it is able to be carried quite a distance onto the foreshore. The silt and clay when picked up are able to be carried farther into the bay by the ebb tide, which would leave a condition just the reverse of what is found on the clam flat.

The flood tide then is probably responsible for the pattern of deposition found here. In advancing over the relatively dry flats, the waves are not able to transport the sand but they are able to pick up and transport the silt and clay of the areas over which they travel; so that, by the time the water reaches the shoreline, it contains the finest sized particles. These are deposited near the high tide line at the turn of the tide when the currents are weakest and the water is stagnant (Hantzschel 1939, p. 202).

Because the finer particles are wet they are not easily picked up by the ebb tide to be carried out into the bay, but the sand grains are small and have no cohesion so they are able to be picked up by the currents and carried toward the low tide line. Here most of the sand grains are deposited when the tide is changing and the water is stagnant.

SUBSURFACE SEDIMENTS

Beneath the surface there is a definite pattern of sediment deposition; each layer is distinct from the other by some characteristic, such as, color, texture or mineral composition. Throughout this investigation texture and presence or absence of shells were used as basic criteria for distinguishing the respectivc layers. For purposes of clarification, certain terms are defined from Donohue (1949, p. 25).

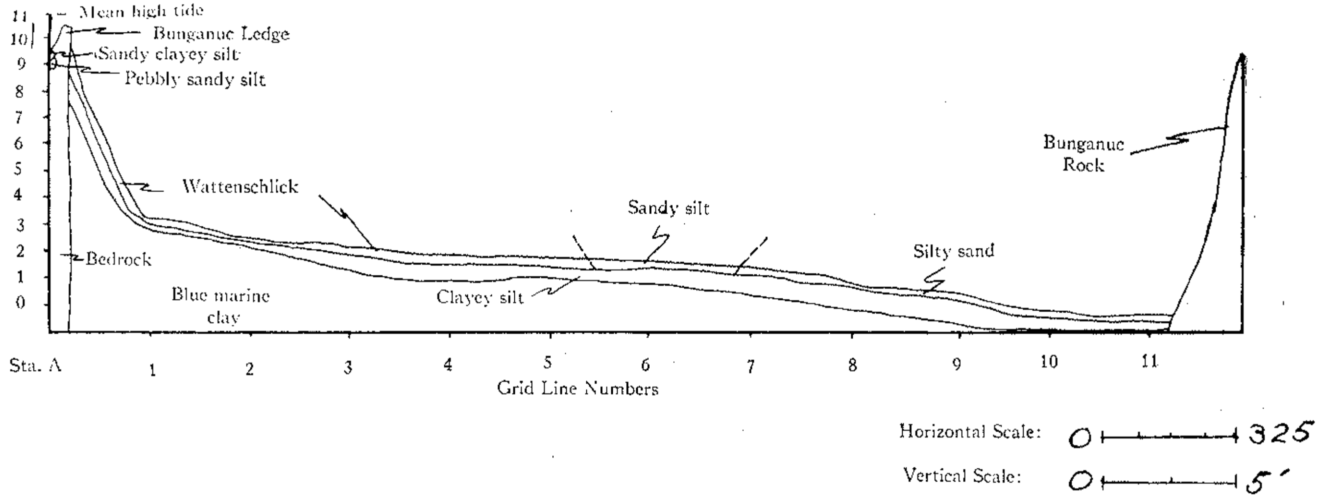


Figure 12. Sediment Profile of Line A from Bunganuc Ledge to Bunganuc Rock

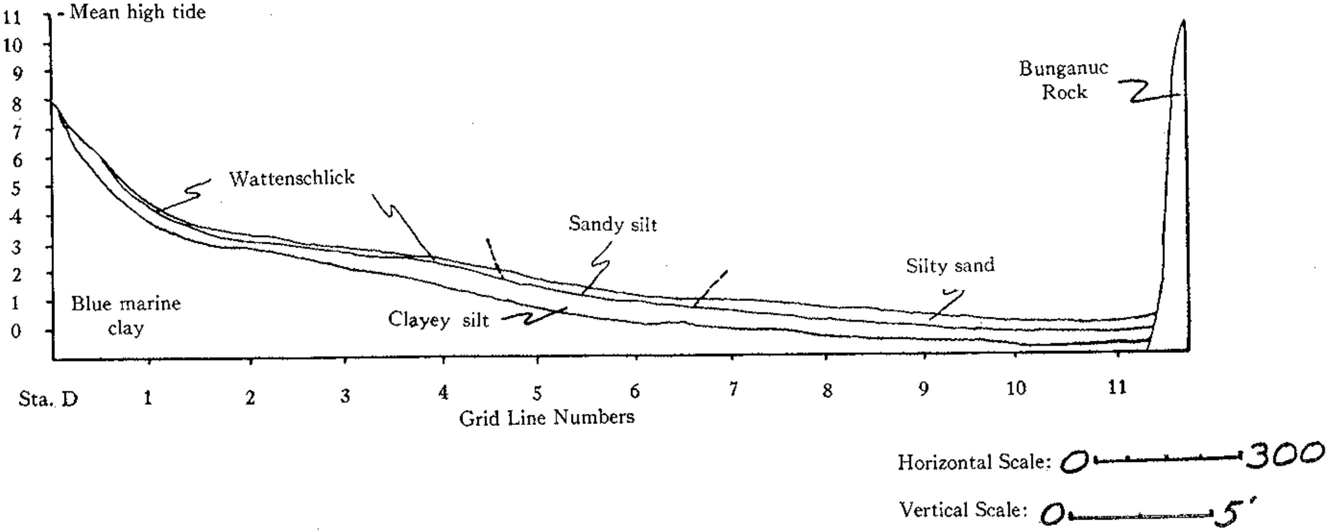


Figure 13. Sediment Profile of Line D from Bunganuc Shore to Bunganuc Rock

The sediment profile is a vertical section through an unconsolidated sediment exhibiting successive layers of varying thickness.

A profile zone is one of the several layers of sediment making up the profile. The profile zones are designated in the order in which they appear from top to bottom of a vertical exposure by the numbers 1, 2, 3, etc. Where the term "profile" is understood, "zone" alone may be used followed by the proper number, as in "zone 2."

Sediment texture is a term referring to the grain size composition of a given profile zone.

The thickness of each profile zone was measured independently, so that, to find the depth at which zone 3 starts, the thicknesses of zones 1 and 2 must be added together. Four profiles from Bunganuc Shore to Bunganuc Rock are included in this report. (See Figures 12, 13, 14, 15).

Profile zone 1 consists of the surface sediments previously described. These sediments may be only a surface covering, as they are on the backshore, or they may extend some distance below the surface, as they do on the foreshore, where they vary in thickness from one to four inches.

Beneath the top profile lies profile zone 2 which is always of finer texture and more compact than the sediment above it. On the backshore zone 2 consists of blue marine clay, beneath which no other type of sediment was found. On the foreshore zone 2 consisted of a silty clay, which contained much shell. The shell content of the silty clay varies considerably, being almost absent in some places and in other places being more abundant than the sediment. There seems to be no pattern to the distribution of shell in zone 2.

On the foreshore profile zone 3 is a blue marine clay. Zone 2 was delineated when the sediment no longer felt gritty or no longer contained any shell. Blue marine clay was the lowest zone exposed in the profile. The bottom of the deepest pit was two feet below the surface of the area which was the limit a hole could be kept open without slumping taking place. The composition and form of the blue marine clay underlying the foreshore is the same as the blue marine clay underlying the backshore and the cliff. It also has the same fine sandy partings.

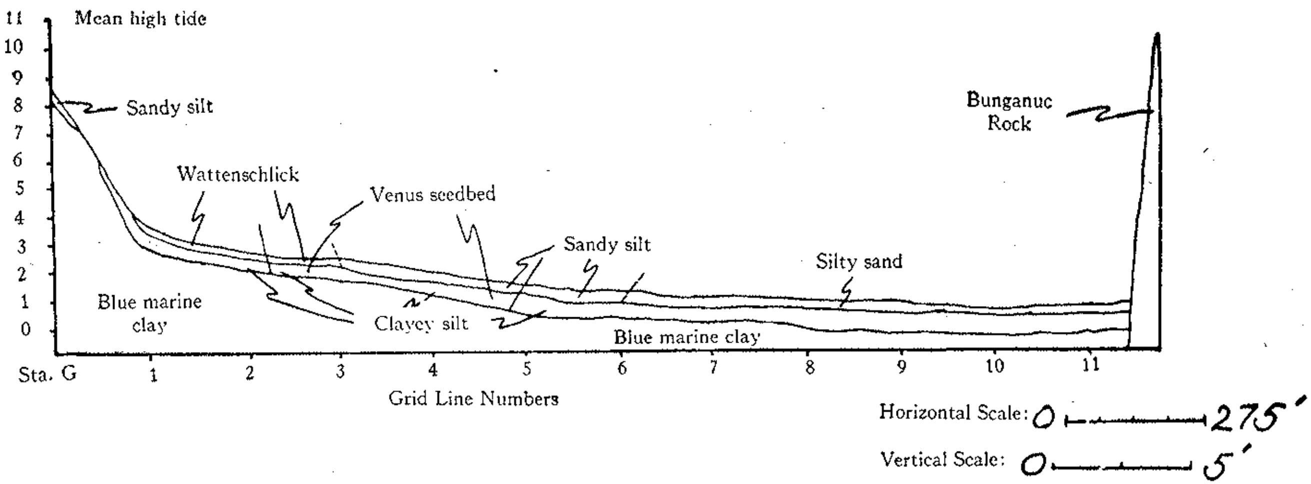


Figure 14. Sediment Profile of Line G from Bunganuc Shore to Bunganuc Rock

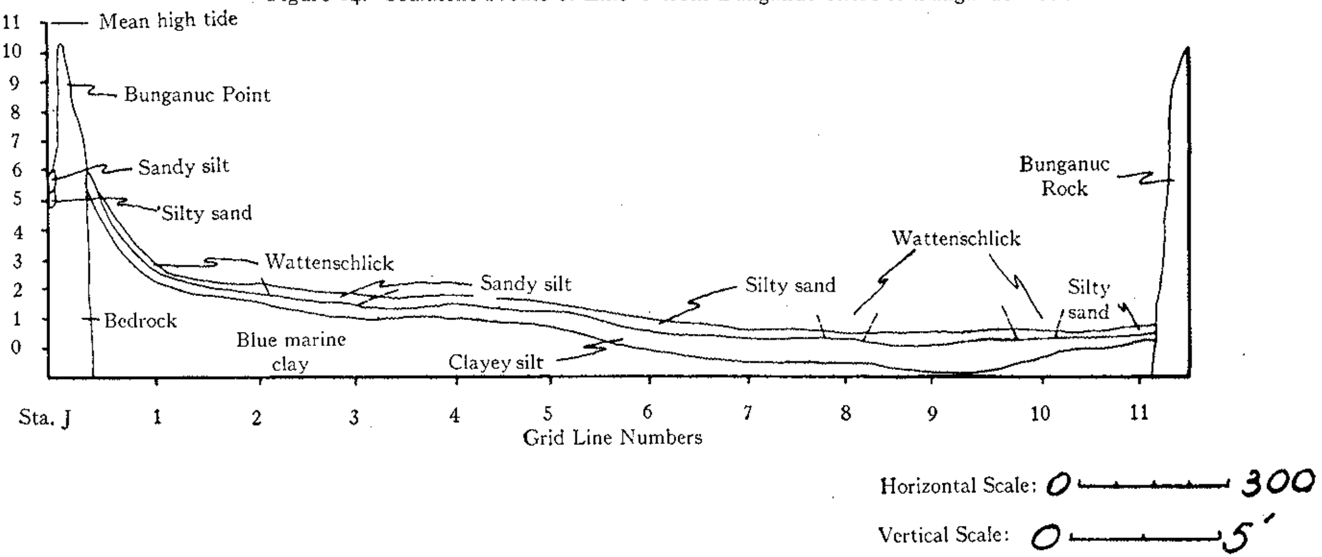


Figure 15. Sediment Profile of Line J from Bunganuc Point to Bunganuc Rock

BIOLOGY OF BUNGANUC

Bunganuc was chosen as an area of study because a large natural set of quahogs had become established in such a concentration that they were being forced toward the surface of the flats. This resulted in a slow growth rate during the summer and in a high mortality rate during the winter (Dow and Wallace, 1951).

The *Venus* Seedbed

The area in which *Venus* is most numerous is called the seedbed. The seedbed is located near the eastern edge of the detailed area and is approximately one-third of the distance from the shoreline to Bunganuc Rock (see Map #2).

In the seedbed the population is so great that many *Venus* are unable to burrow into the flat but rest on the shells of lower layers. The *Venus* that are unable to burrow into the flat live in the homogeneous, firm, gray sandy silt of zone 1. This sediment varies from $\frac{1}{2}$ to 2 inches in thickness and is not the natural habitat of *Venus*. The majority of the *Venus* live in profile zone 2, which is a homogeneous firm, gray clayey silt. The seedbed overlies a clayey silt that contains many *Mya* shells. The shelly, clayey silt overlies blue marine clay.

One of the main reasons for the high winter mortality rate is the fact that the seedbed is not perfectly smooth and flat. Within the seedbed there are variations of 0.2 of a foot from a smooth plane. These small differences in elevation have a great monetary value, in that in the lower areas or depressions the quahogs have a much lower mortality rate than they do in the higher areas, or ridges.

The ridges and depressions are important mainly during the winter, because it is then that freezing occurs on the clam flat at low tide. The quahogs in the depressions have a layer of water covering them (Figure 16) which provides some insulation and thus a measure of protection against freezing. The ridges (Figure 17) have no protection from the wind and cold weather so they freeze quite readily. Therefore, there is a higher mortality rate in the ridges than in the depressions. According to Dow and Wallace (1951, p. 20), the average mortality in the depression was 14% while the average mortality in the ridges was 54%.

During the winter of 1950–51 the highest mortality was in January, when the weather was more extreme than during other winter months,

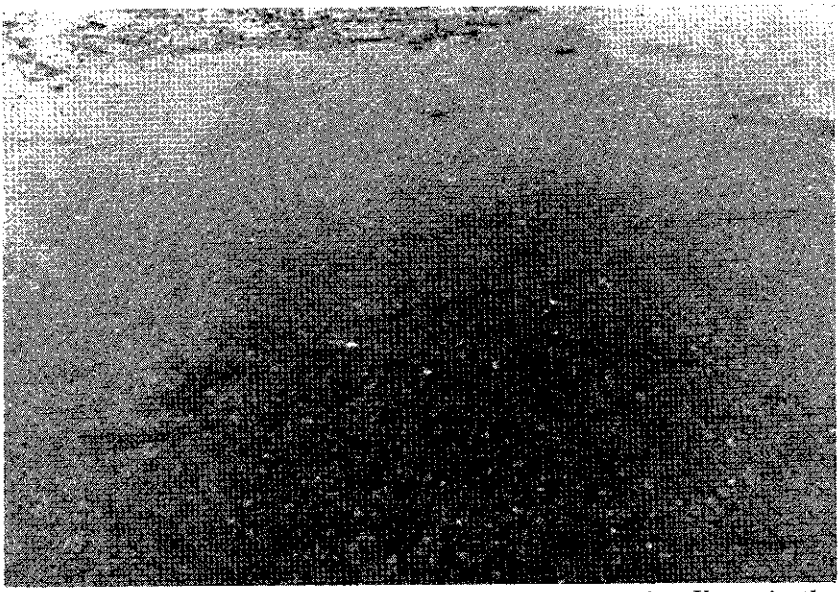


Figure 16. Close-up of a depression showing water covering *Venus* in the depressions protecting them from freezing temperatures.

Figure 17. Close-up of some gaping shells in a ridge caused by winter killing of *Venus* in the seedbed during January, 1951.

(Dow and Wallace 1951, p. 16). This leads the writer to believe that death was caused by daily alternate freezing and thawing of *Venus* in ridges over a period of several months. The writer also believes that the length of time that it takes to cause the death of *Venus* depends on the severity of the weather. The temperatures were lower and had a wider variation during the winter of 1950–51 than during the winter of 1951–52. In the former winter the majority of deaths took place in January, while in the latter winter the majority of the deaths took place in March.

The possibility that ridges formed because of a greater concentration of *Venus* in some areas than in others was eliminated by the fact that the average density of *Venus* in the depressions was 73 per square foot, while in the ridges it was 75 per square foot.

Trefethen suggests that such minor irregularities are inherent surface features on any natural deposit of this type, and that they become noticed only when there is an attractive reason. On re-examination of the detailed area the writer found evidence supporting Trefethen's statement. The writer found that there were ridges and depressions on the entire surface of the detailed area. He also noticed that the ridges and depressions were more pronounced in the seedbed and in the silty sand than in the *wattenschlick*. The ridges in the seedbed and in the silty sand are 0.2 foot higher than the depressions, while the ridges in the *wattenschlick* are 0.1 foot higher than the depressions.

The author attributes the difference in height of the ridges of the seedbed and of the *wattenschlick* to the greater solidity of the seedbed. The *wattenschlick* contains more water, so that it flows more readily and tends to flatten and assume a smoother surface under wave impaction than the silty sand.

Venus Outside the Seedbed

The *Venus* living and growing outside the seedbed are found in colonies, with from three to ten individuals in each colony. These *Venus* are larger and have a faster growth rate than the *Venus* in the seedbed. The average age of the *Venus*, both inside and outside the seedbed, is 4 years. The average size of *Venus* in the seedbed is 48 mm., while the average size of *Venus* outside the seedbed is 64 mm.

The author believes the difference in growth rate is due to the greater amount of food available per *Venus* outside the seedbed than in the seedbed. Due to overcrowding in the seedbed, most of the *Venus* have been stunted and have lost about one year's growth in four years.

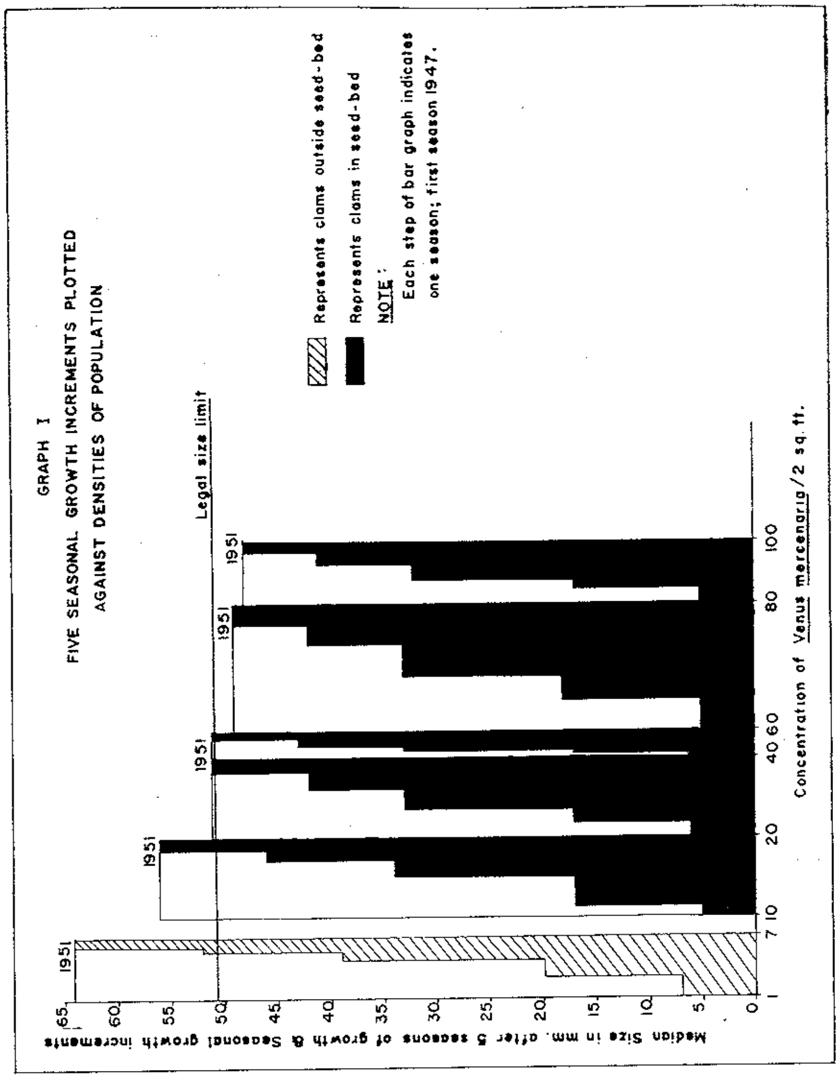

GRAPH I
FIVE SEASONAL GROWTH INCREMENTS PLOTTED
AGAINST DENSITIES OF POPULATION
Legal size limit
1951
Represents clams outside seed-bed
Represents clams in seed-bed
NOTE:
Each step of bar graph indicates
one season; first season 1947.
Concentration of Venus mercenaria/2 sq. ft.
Median Size in mm. after 5 seasons of growth & Seasonal growth increments

Figure 18

Mya arenaria

Many *Mya* live near the shoreline both on the backshore and on the foreshore. On the backshore the *Mya* live in a blue marine clay. On the foreshore *Mya* live in a blue marine clay which is covered by a layer of *wattenschlick* 2 inches thick. This shows that *Mya* can live under the *wattenschlick* when it is 2 inches thick, but the *Mya* itself must be in a firm compact sediment.

Biologic Discussion

It should be pointed out that all the animal and plant life discussed in each zone may not be included in the pit samples. This is because of the method of sampling. A grid system such as this does have its limiting factors. By incorporating a system of random sampling and observing, a truer picture of the area was gained.

For example, by looking at the pit tabulations it would be difficult to determine from these tabulations only such a vast concentration of quahogs as was found in zone 3. A hint to this area is suggested in pits F4, G4 and H4. However, by taking random samples around these stakes, it became possible to draw a much more accurate picture of the area. These non-grid pits were taken and only the *Venus* populations were counted and yearly growth increments were measured and tabulated.

In Figure 18 the median size of *Venus mercenaria* and their seasonal growth increments have been plotted against concentrations. This data was summarized from the grid pits and the 20 unit increments along the abscissa were arbitrarily chosen for the seed bed. The concentration of 1 to 7 represents the concentration found outside the seed bed. This shows that on the average these clams would reach the legal size of 2″ at the end of their third season of growth; whereas, in the extreme concentrations of the seed bed this would not occur until approximately in the middle of the 6th season of growth. This means that the clams in these dense concentrations require almost twice as long to reach legal size and will be subjected to the hazards of two additional winters.

In average densities of 20 to 40 clams per 2 square ft. the legal size limit was not reached until the end of the 1951 growing season. This coincides with the commercial digging in this area.

Figure 19 compares the seasonal growth increments of clams in and outside of the seed bed. In the first season the clams outside of the

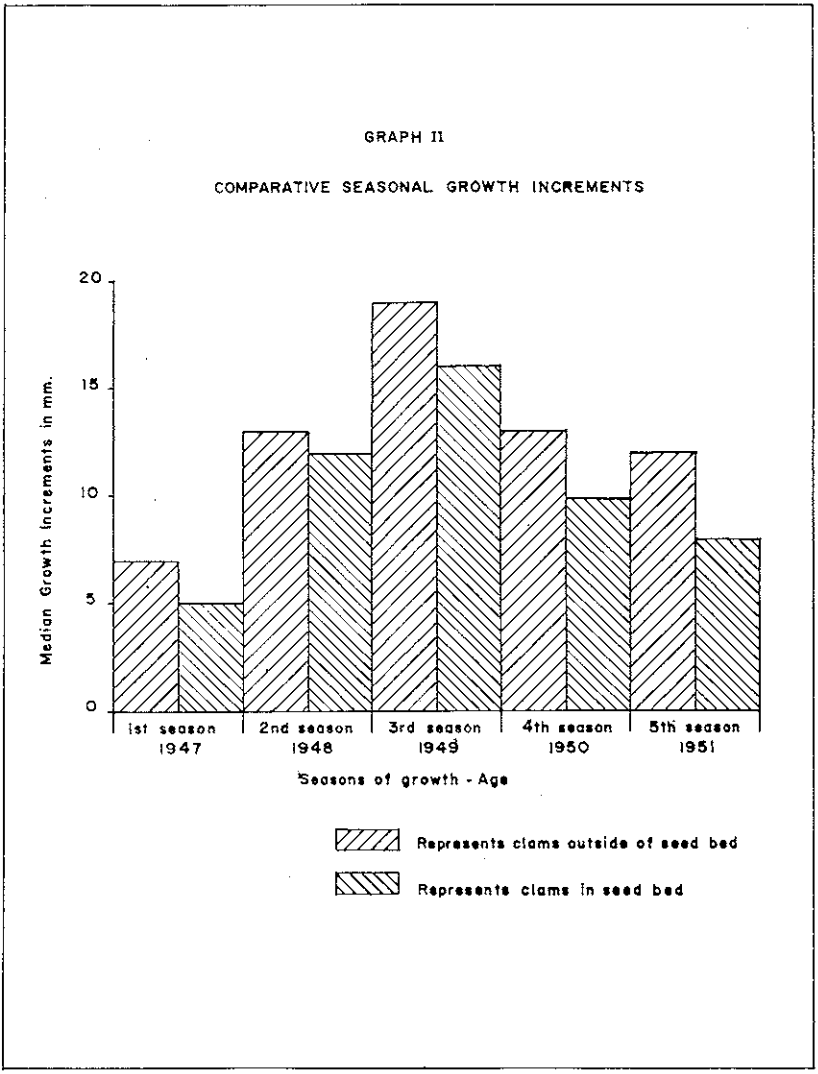
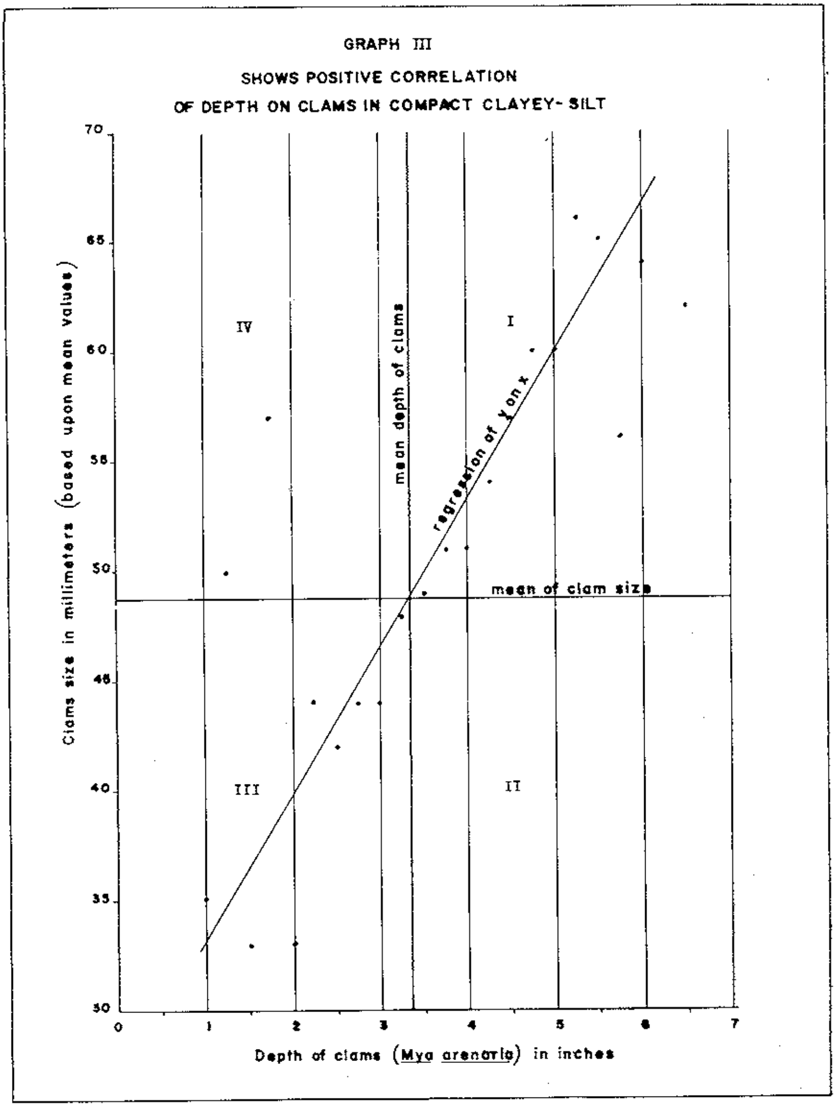

GRAPH II
COMPARATIVE SEASONAL GROWTH INCREMENTS
Median Growth Increments in mm.
20
15
10
5
0
1st season 1947
2nd season 1948
3rd season 1949
4th season 1950
5th season 1951
Seasons of growth - Age
Represents clams outside of seed bed
Represents clams in seed bed

Figure 19



GRAPH III
SHOWS POSITIVE CORRELATION
OF DEPTH ON CLAMS IN COMPACT CLAYEY- SILT
70
65
60
55
50
45
40
35
30
0
1
2
3
4
5
6
7
IV
I
III
II
mean depth of clams
regression of y on x
mean of clam size
Clams size in millimeters (based upon mean values)
Depth of clams (Mya arenaria) in inches

Figure 20

seed bed experienced on the average 40% more growth. During the third season of growth both show the greatest increment of growth and the average difference between the clams outside and inside of the seed bed has decreased to 18%. These growth measurements are based upon the total samples from the survey.

Figure 20 shows the correlation of clam depth in compact silty-clay with clam sizes is highly significant for the sample taken. A total of 324 measurements were made from this area. It is found that a deviation of +1 from the mean depth of $3\frac{1}{2}''$ is equivalent, on the average to a deviation of +6.8 mm from the mean size of 49 mm. These clams were entombed in this compact marine clay and appeared to be stunted in growth. The age of these clams was difficult to estimate because of the many interruption lines on their valves.

EFFECT OF WINTER WEATHER AT BUNGANUC

In March of 1952 the writer revisited Bunganuc to view the effect of winter weather on the clam flat. Winter erosion at Bunganuc was much more pronounced than summer erosion.

A few days previous to the writer's trip to the area a landslide which had slumped about 1000 tons of brown marine clay onto Bunganuc shore had taken place in a tree covered area adjacent to the bare, brown marine clay bank. (Figures 21 and 22). Due to the depth and thickness of the slide it is doubted that alternate freezing at night and thawing during the day could have been the cause of the slide. The author attributes the slide to a heavy layer of snow on the seaward side of a plane of weakness in the clay.

On close examination of the brown marine clay bank, it was noticed that a considerable degree of surface slumping had taken place along the whole bank, making much new material available to erosion by the action of waves. It was also noticed that the shoreline had receded from 3 to 6 inches during the winter causing the *Spartina* to slump over the edge of the shoreline (Figure 23). Even disregarding landslides during freeze and thaw season, the writer judges that at least 75% of the erosion of the clay banks at Bunganuc takes place during the winter, because of heavier storms, stronger winds, highly variable temperatures and alternate freezing and thawing of the clay bank. This heavier winter erosion could tend to cause an increased mortality of the *Mya* by depositing so much silt and clay over the area in which *Mya* live that it would smother them.

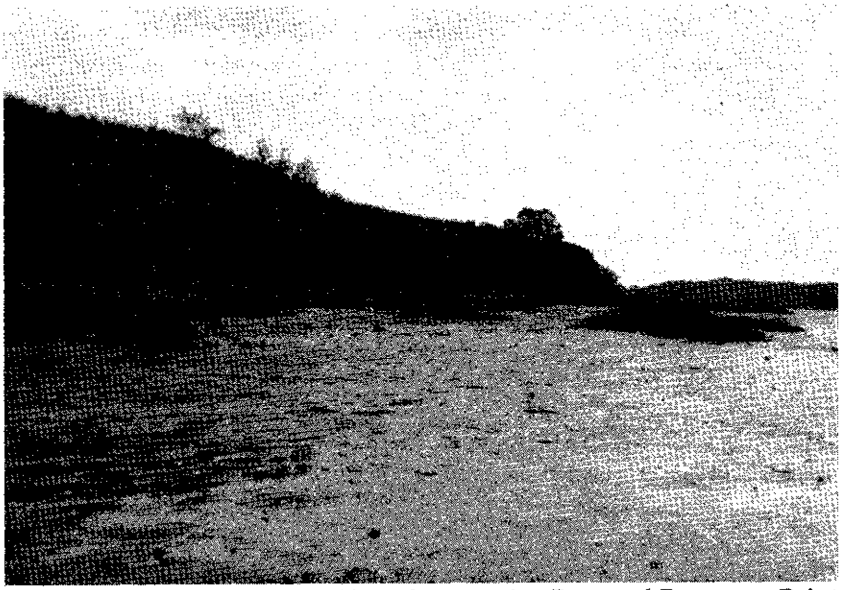


Figure 21. View of Bunganuc Shore from station D toward Bunganuc Point showing how the shoreline looked before the landslide occurred.

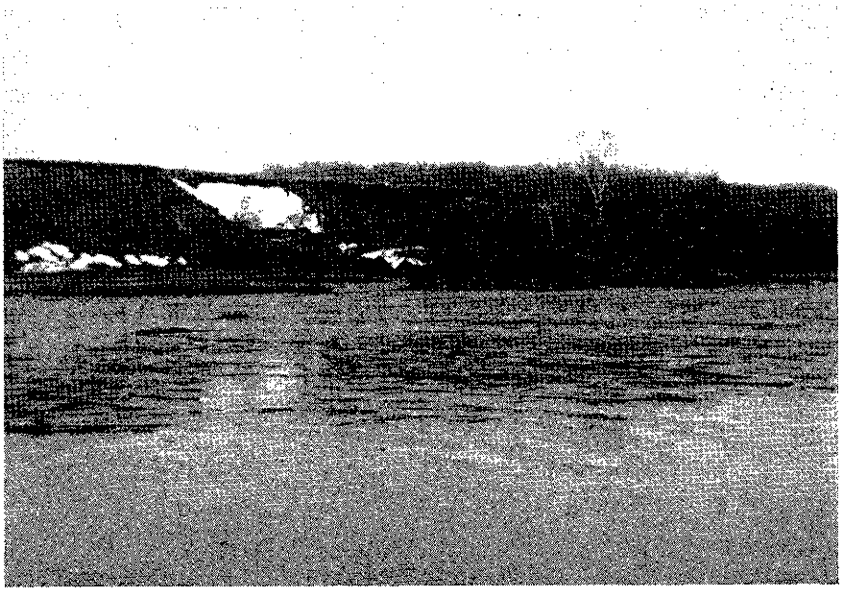


Figure 22. View of the landslide that took place on March 21, 1952. Notice the pocket of snow in the cuplike depression left by the landslide. This snow is believed to have been a prime cause in producing the slide.

Another effect of the winter weather is the change in color of the seedbed. During the summer, the seedbed can be immediately distinguished by its green color, caused by seaweed (*Ulva*) which is thicker on the seedbed than on the rest of the clam flat. During the winter, the seedbed can be immediately distinguished by its white color, caused by winter killing of quahogs in the ridges of the seedbed. The winter mortality is serious and measures should be worked out to conserve the *Venus*.

Figure 23. View of the grass roots that have slumped over the shoreline due to erosion of the shoreline during the winter of 1951-52. This picture is taken looking toward the mouth of the fresh water stream between stations D and E. The heavy concentration of mussels (*Modiolus plicatulus*) causes the white caste to the clump of grass roots in the foreground.

RECOMMENDATIONS

1. The seedbed should be closed to digging during the winter.

2. Digging should be carried on outside the seedbed in both the *Venus* and *Mya* producing areas during the winter.

3. As many *Venus* should be transplanted from the seedbed as is possible. This transplanting should take place in the fall or in the spring, preferably in the spring.

CONCLUSIONS

1. The marine clay is probably a product of glacial erosion deposited in Pleistocene seas.

2. Blue and brown marine clay have the same composition and physical properties. The difference in color is believed to be due to the partial oxidation of blue into brown clay above the water table.

3. Boulders, cobbles and pebbles were brought into the mapped area by:
   a) ice rafting by icebergs during Pleistocene time.
   b) farmers who carried them to the edge of the clay cliff.
   c) ice rafting during modern time by stream and bay ice.

4. Clay pebbles are formed due to erosion of the marine clay cliff and are larger and more numerous immediately following the highest tides in the summer.

5. The sediments of the littoral zone are derived from the marine clay cliff as indicated by:
   a) direct observation of clay slumping onto the backshore.
   b) similarity in grain size distribution of sediments in the clay bank and in the littoral zone.
   c) similarity of plastic limits and organic contents from both places.

6. The *wattenschlick* is reworked material from the marine clay bank, which owes its color to FeS or H_2S or both. It has a high water content and is formed by the combined workings of tides and small animal organisms which add excrement and help precipitate silt and clay into the *wattenschlick*.

7. About seventy-five percent of the total erosion of the clay banks takes place during the winter, due to the increased severity of winter storms and due to increased bank slumping caused by alternate freezing and thawing of the bank.

8. The formation and washing away of clay pebbles was the only sign of erosion during the summer.

9. The seedbed contains ridges and depressions which were formed before the concentration of *Venus* took place. Most of the mortality

takes place in ridges because *Venus* in the ridges are exposed to extreme winter temperatures and to alternate freezing and thawing while *Venus* in the depressions are protected by a layer of water.

10. *Venus* grow in most of the mapped area. There are fewer *Venus* outside the seedbed; however, they are larger and have a faster growth rate.

11. In the seedbed many *Venus* are stunted due to lack of food and due to competition caused by too many *Venus* living in the seedbed.

12. *Venus* appear to be able to live in a more acid sediment than *Mya*.

13. pH in the ridges is lower than pH in the depressions, possibly due to greater mortalities in the ridges.

14. Winter mortality in the seedbed is raised by digging, due to:
  a) jarring of the frozen *Venus* which results in tearing the frozen tissues causing death of the *Venus*.
  b) exposing more *Venus* to the surface and freezing weather than normal.

15. *Mya* live in commercial numbers in the mapped area. *Mya* do not inhabit the same environment as *Venus*. The real cause for *Venus* and *Mya* living in different environments is not yet apparent. More work in the field and the laboratory by both geologists and biologists is needed before any conclusions will be available to explain the different environments in which *Venus* and *Mya* live.

16. Transplanting *Venus* from the seedbed into other areas reduces winter mortality and raises growth rates of both the transplanted *Venus* and the *Venus* remaining in the seedbed, because fewer *Venus* are left to be exposed to the winter weather and because there is more food per *Venus* after transplanting some of them.

MORGAN BAY

Location of the Area

The area mapped on Morgan Bay is in the township of Surry in Hancock County, Maine. It is located at the head of Newbury Neck five miles south of the town of Surry and half way between Surry and South Surry at the narrowest point of Newbury Neck, which is locally called Carrying Place (see Index Map on Map No. III).

Topography

A glacial till plain surrounds the detailed area. In some places on the western side of the area, the till rises as vertical banks five to ten feet high above the 12-foot contour line before it levels off to a smooth rolling plane. On the eastern side, and also on the remainder of the western side, of the detailed area the till rises only one or two feet before levelling off to a smooth rolling plane.

Below the high water line the backshore is quite steep. On the eastern side of the area the slope of the backshore is roughly 8%. On the western side of the area the slope of the backshore is roughly 4%. The slope of the foreshore varies from 0.5% in the inlet to 0.3% farther out into the bay. At Morgan Bay the coastline corresponds to the contact between the bedrock and the glacial till. The backshore lies between the contact of the *wattenschlick* and the cobbly, pebbly sandy area and the contact between the bedrock and the glacial till.

Drainage

The drainage of the mapped area is into Bluehill Bay by way of Morgan Bay. One stream flows continuously into the largest inlet of the mapped area. In addition there are four intermittent streams that flow into the mapped area. One of these streams is on the eastern side of the area and three of the intermittent streams are on the western side of the area (see Map VIII).

Field Procedure

The field procedure consisted of making a map of the area on which the location of the stations and bench mark and test pits were plotted. The test pits were dug and analyzed for sediment type and for plant and animal life. Sediment samples were collected from the test pits and from the till bank.

Mapping the Area

The area was mapped with a telescopic alidade and plane table on a scale of 1:1200 (1 inch equals 100 feet), with a contour interval of one foot. The completed topographic map served as a base for mapping:

A. Distribution of surface sediments.
B. Distribution of test pits from which sediment samples and biological data were taken.
C. Contouring the *Venus* growing area.
D. Locating the *Mya* growing area.

Location and Digging the Test Pits

After the topographic map had been completed, a grid system was established for locating test pits from which samples and field data could be collected. A square grid system was laid out in an effort to keep the spacing of the test pits uniform and because the littoral zone narrowed at the head of the bay.

A two foot square plot was dug at each grid corner and all living organisms were recorded. Special attention was paid to the *Venus mercenaria*; each specimen was measured for size and yearly increment of growth in mm. In addition to attempting to correlate clam populations with geology an attempt was made to include as much of the biological environment as was possible.

Most of the pits were dug only to a depth of ten inches because the area was so soft that the pit walls collapsed and the pits quickly filled with water.

Collecting Sediment Samples

Sediment samples were secured from all profile zones in the profile section. The samples are representative of the immediate *Venus* and *Mya* environment and of layers both above and below the *Venus* and *Mya* environment. Two sediment samples were collected from the banks of the cove area. One sample was from the upper portion of the bank and one sample was from the lower portion of the bank. To avoid collection of slump material the bank was cut back one foot before the sample was collected.

In marking the collected sediment samples the first two characters refer to the location in the grid system, and the number following the dash refers to the depth below the surface of the soil at which the sample was gathered.

GEOLOGY OF THE AREA

Glacial erratics, striated bedrock, and the presence of glacial till adjacent to the area and resting on the bedrock make it apparent that the Morgan Bay area has been glaciated.

Bedrock

The bedrock of the area is Ellsworth schist which in some places has been injected by quartz. The schist is greenish gray in color and highly foliated. Much of the schist has the appearance of a greenish gray phyllite. The strike of the schistosity is N 55°E and the dip of the schistosity is 20°NW. According to Smith, Bastin and Brown (1907) the Ellsworth schist is the oldest formation in the area being either early Cambrian or pre-Cambrian.

The bedrock is cut by two sets of joints. One set strikes N 70° W and is vertical, while the other set of joints strikes N 20° E and is vertical. The glacial striae on the bedrock strike N 30° W.

Except for one short stretch on the western side of the area bedrock completely surrounds the outer fifty feet of the detailed area. About half of the bedrock in the area is exposed as bare bedrock or as bedrock with a thin film of silt. The other half of the bedrock is almost completely covered with a dense growth of grass (*Spartina glabra*). The *Spartina* is growing in a sandy clayey silt which has the same composition as the till bank.

Surface Sediments

The surface sediments consist of pebbles with some boulders and cobbles, pebbly sand and cobbles, and *wattenschlick*. There is some shifting of the sediments over part of the area. For example, it was noted that on July 10, 1950, an area roughly 5 feet by 15 feet, approximately 20 feet northwest of BM #1, had a pebble surface with dark gray sand beneath it. On July 25, 1950 the same area was covered with a layer of brownish gray, clayey silt about 3 inches thick. Apparently the silty material had moved in over the pebbles.

Subsurface Sediments

At Morgan Bay the different profile zones were determined mainly by a difference in the moisture content of the sediment. On the backshore the surface sediments of profile zone 1 are underlain by glacial

TABLE VI---FIELD MEASUREMENTS AND MECHANICAL ANALYSES OF SURFACE SEDIMENT

Sediment	Location	Color	% Boulders	% Cobbles	% Pebbles	% Sand	% Silt	% Clay	Organic Content	Plastic Limit	Remarks
Glacial till	Surrounding the southern side of the detailed area above high tide line	Tan	–	1	2	5	45	47	5%	37	The glacial till rises from one to five feet above the coastline before levelling off as a flat rolling till and grass covered plain. The largest cobble found in till was 3 inches in diameter.
Pebbles with Boulders and Cobbles	On western side of mapped area adjacent to glacial till bank	Many different colors	15	20	40	10	10	5			Bedrock outcrops are on 3 sides of this group, which is about 100′ x 50′. Sediments are angular to sub-angular. Some pebbles are rounded. Sediments are pieces of local bedrock and glacial erratics.
Pebbly Sand and Cobbles	Extends 50 to 200 feet from edge of bedrock to shoreline	Many different colors	3	10	22	45	10	10			Cobbles and pebbles usually rest on a layered tan sand which varies in thickness from 0.2 to 2.0 mm. Sand grains are angular to sub-angular. The most common minerals of the sand are quartz, feldspar, biotite, muscovite and hornblende.
Wattenschlick	Seaward from shoreline in center of detailed area	Black	–	–	–	5	40	55	10%	38	This wattenschlick has the same grain size, appearance and color and organic content as the wattenschlick at Bunganuc. It does have a different plastic limit, which might be due to a different mineralogical content or different degree of sorting or to a different degree of angularity or shape of the sediment grains, or to many other causes.

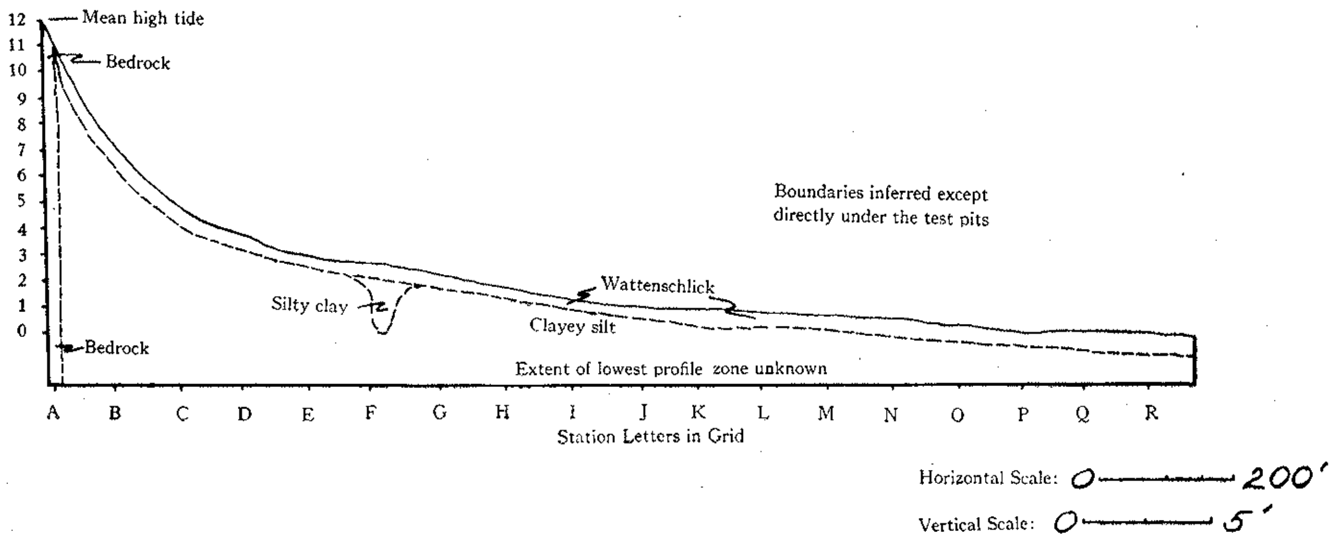


Figure 24. Sediment Profile along Grid Line Number 6 from Grid Letter A to Grid Letter R

till. On the foreshore, the *wattenschlick* of zone 1 is a clayey silt containing about 50 percent water. It varies in depth from 4 to 8 inches. Zone 2 is a compact clayey silt containing about 20 percent water. The contact between the zones is gradational, in some instances the *wattenschlick* becomes coarser as it approaches the contact and in other cases it becomes finer. It is believed that zone 2 of the foreshore is a glacial till similar to the other glacial till in the area, because they both have the same characteristics.

BIOLOGY

It has been a general observation along the Maine coast that where *Venus* occur in particularly large numbers *Mya* are usually absent. Morgan Bay was chosen as an area of study primarily because it was supposed to support thriving colonies of both *Mya* and *Venus*. Examination of the area disclosed that many *Venus* live in the large expanse of *wattenschlick*. The examination failed to disclose any large quantities of marketable clams. Instead only numerous small colonies of stunted *Mya* were found near the high tide line in firm sediments classified as bedrock with pebbly sand, cobbles and occasional boulders.

In pit I 15, in a pebbly, sandy area, 19 *Mya* were found alive and 26 were dead. The dead *Mya* were intact and in the normal vertical position. The live *Mya* ranged from 37 mm. to 55 mm. in length and were from 5 to 8 years old. The dead *Mya* have the same size and age range as the live *Mya*. Most of the shells were rough and disfigured. The largest number were dying from unknown causes. In all probability, their relation to the high water line provided a very short feeding time, and in addition, the incoming water contains a great deal of suspended material which possibly clogs the gills of the *Mya*. A parasite may be the cause of the *Mya* death, but no cases of such have been reported in these waters. There was no evidence that they were preyed upon by any predator such as crabs or worms. A few tube worms, (*Clymenella torquata*) were present in the pit, which substantiates observations that *Clymenella* is indicative of poor *Mya* growth.

At some time in the past this area supported an extensive *Mya* colony. Evidence of this is found by digging 8-18 inches in the silt where large numbers of *Mya* shells are found in the vertical position. The sediment supporting these *Mya* is a firm silt containing much sand and many pebbles. *Mya* appear to demand a sediment firm enough to allow them to maintain a siphon hole without the hole collapsing or filling in as it would in the *wattenschlick*.

Venus prefers the *wattenschlick* although occasionally some of them extend up to the sand and pebble border. *Venus* appears to live in colonies with from 3 to 15 per colony (Plate XIV). *Venus* ranges in size from 20 mm. to 65 mm. within each colony. They range in age from 2 to 5 years within each colony. The *Venus* colonization appears to end at the mean low tide line. The quahogs require approximately four years to attain a size of 2 inches in length.

Venus can travel horizontally over the surface as much as a foot at a time; so it has the power to migrate short distances wherein it could travel from a less favorable to a more favorable environment. *Venus* spat (seed) were found in the area, but few small *Venus* were found.

On the eastern side of the bay close to the head of the bay a large shell heap was found partially covered with sod grass. The shells were largely *Venus* shells. The *Venus* must have been shucked or steamed there many years back, possibly by Indians. This evidence attests to the fact that *Venus* have also inhabited the area for a long time. Which came first, *Venus* or *Mya*, and which died out can only be guessed.

Another possibility is that *Venus* and *Mya* follow one another in cycles. To illustrate, an area supports a heavy *Mya* population, then, due to slight but steady emergence of the land and the consequent wearing away of till banks by the tide, the area begins to silt in, covering and smothering the *Mya*. Since a heavy silt probably favors *Venus*, a set of *Venus* establish themselves. In time, the silt could possibly settle and pack itself thereby becoming firm and capable once more of supporting *Mya*, only to have the cycle repeated.

In the Morgan Bay area the *Mya* and *Venus* have several predators beside man. The most destructive of these are the seagulls which eat many *Mya* and *Venus* every day.

Lesser predators are the horseshoe crab (*Limulus polyphemus*), the green crab (*Carcinidea maenas*) and the starfish (*Asterias vulgaris*).

On the west bank of the cove, few *Venus* were found, and at the same time here the greatest number of horseshoe crabs were found. The horseshoe crab may be the reason why the *Venus* appear to be dying on the western side. Several dead *Venus* were found which had their shells chipped open and their meat was not cleanly removed, as it would have been had a seagull eaten the meat.

The green crab (*Carcinidea maenas*) is found in large numbers hidden in among the boulders and cobbles. This crab constitutes a serious menace to the *Mya* and *Venus* spat, as it is capable of digging well below the surface of the flats and is capable of cracking and crushing *Mya* shells as large as $1\frac{1}{2}$ inches. This crab may also be the reason why no *Venus* spat and only a few small *Venus* were found in the area.

Small starfish (*Asterias forbesi*) were numerous over the surface of the silt. The largest found were about 4 inches in diameter. Because of the size of *Venus* and the depth to which it burrows, it is doubted that these starfish constitute any serious threat to *Venus*.

A few "clumps" of the black mussel (*Mytilus edulis*) are found in the area. They are not numerous enough now to cause any serious damage to the clams.

Thousands of the gastropod *Nassa obsoleta* live on the clam flats. They appear to indicate areas of good *Venus* growth.

The razor clam (*Ensis directus*) seems to prefer the soft silty area which the *Venus* inhabits. The razor clam is usually found individually, probably because it has a greater degree of locomotion than the *Venus*, being able to move 15 to 20 feet across the flat at one time.

CONCLUSIONS

1. Because the bank sediments have roughly the same grain size and the same plastic limit as the littoral sediments, it appears that the bank sediments are being eroded by wave and current action. The sediments coarser than 2.0 mm. remain on the backshore while sediments finer than 2.0 mm. are carried onto the foreshore.

2. The *wattenschlick* is reworked material from the till bank, differing from the bank and from the underlying sediment only in having a higher water content, higher organic content and a darker color.

3. A winter visit to Morgan Bay disclosed that there is almost as much erosion during the summer as during the winter. Ridges and depressions about 0.1 foot high occur in the *wattenschlick*, but the *Venus* were not thick enough for the ridges and depressions to affect them.

4. *Mya* live near the high tide line in only one small area. *Venus* live in the *wattenschlick* from the shoreline to the low tide line. The greatest number live slightly seaward from the mean tide line.

5. Transportation by seaweed holdfasts moves pebbles and cobbles up to 4 inches in diameter into the detailed area eventually depositing them onto the backshore. In this way some coarse material is being added to the backshore so that it is becoming slightly coarser.

6. It takes 4 years for *Venus* to grow 50 mm. in size.

SUMMARY

Although Bunganuc and Morgan Bay support both *Mya* and *Venus* and have somewhat similar biological relationships, there are geological differences in the two areas. At Bunganuc the littoral sediments are derived from a glacial marine clay bank which is higher than a glacial till bank at Morgan Bay. Because the clay bank is higher, it has a greater volume of sand than the till bank, which, at Bunganuc has resulted in *wattenschlick* being deposited adjacent to the shoreline near high tide line, which grades out into a sandy silt and finally into a silty sand near the low tide line. At Morgan Bay the lower till bank does not have enough sand in it to follow such a depositional pattern; so *wattenschlick* is deposited in the whole area between the shoreline and the low tide line.

The *wattenschlick* in both areas has the same grain size composition, water content, color, organic content and appearance. Their plastic limits differ, probably due to the fact that one was derived from a glacial marine clay.

It appears that the grain size of a sediment does not have too much effect on where *Mya* lives, because at Morgan Bay it is found in a coarse pebble and cobble area with some boulders, while at Bunganuc it is found in a very fine grained silty clay. It does appear that the *Mya* prefers living in a slightly alkaline firmly packed sediment. *Venus* appears to prefer a slightly acid fine grained soil. The soil in which *Venus* lives may be watery (as the *wattenschlick*) or it may be firm (as the silty sand). *Venus* growth rate at Morgan Bay is more rapid than *Venus* growth rate in the seed bed, but not so rapid as the *Venus* growth rate outside the seedbed at Bunganuc.

Many problems involving the life, growth and death of *Venus* and *Mya* have not been included in this thesis, but some information has been gathered as to how the geology of an area can affect its environment and ecology, and this study may be helpful in future work on this or similar areas.

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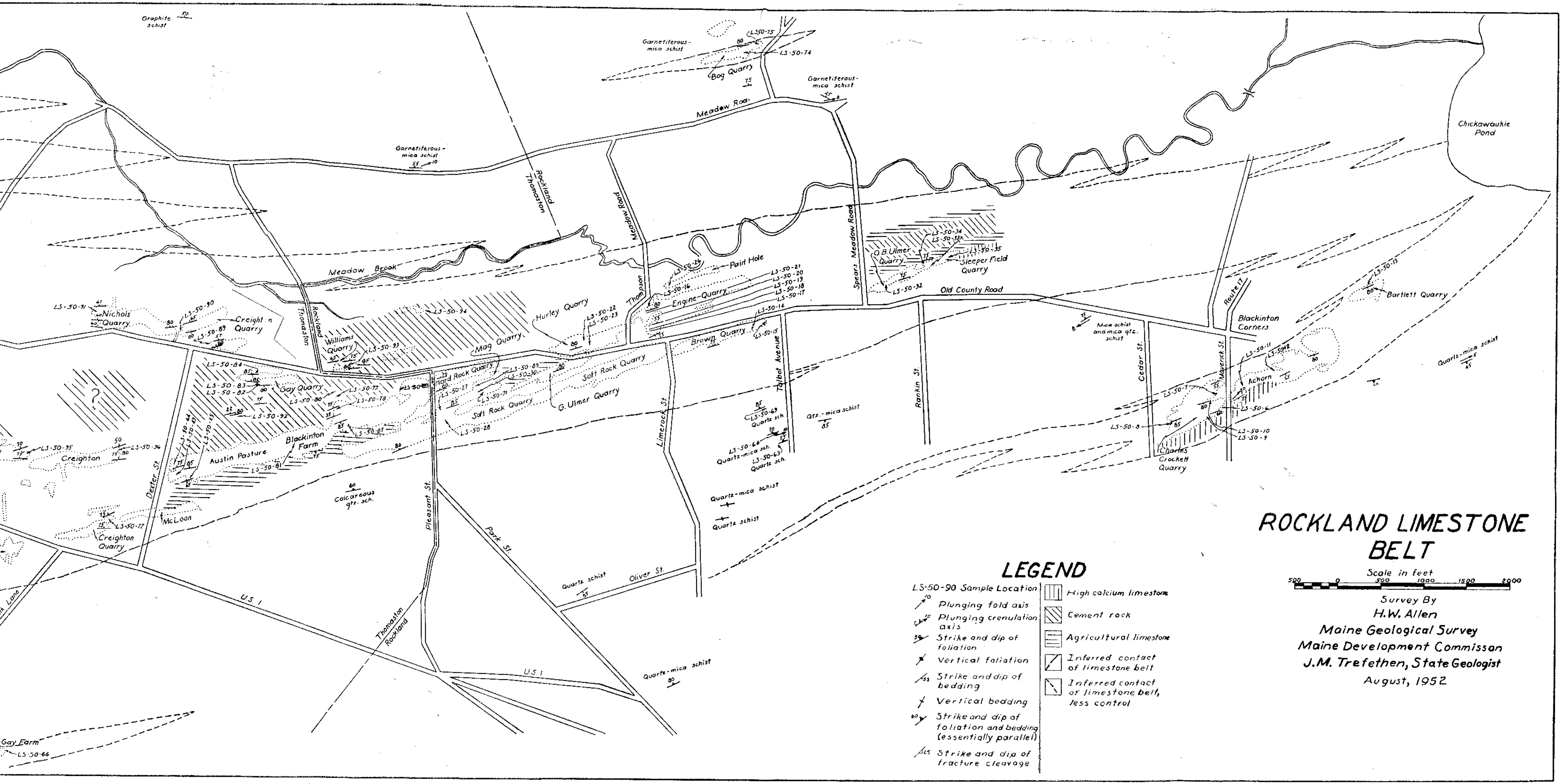
Maine
Report of the State
geologist


ROCKLAND LIMESTONE BELT
Scale in feet
500 0 500 1000 1500 2000
Survey By
H.W. Allen
Maine Geological Survey
Maine Development Commissan
J.M. Trefethen, State Geologist
August, 1952
LEGEND
LS-50-90 Sample Location
Plunging fold axis
Plunging crenulation axis
Strike and dip of foliation
Vertical foliation
Strike and dip of bedding
Vertical bedding
Strike and dip of foliation and bedding (essentially parallel)
Strike and dip of fracture cleavage
High calcium limestone
Cement rock
Agricultural limestone
Inferred contact of limestone belt
Inferred contact of limestone belt, less control
Chickawaukie Pond
Meadow Road
Meadow Brook
Rockland
Thomaston
Bog Quarry
Garnetiferous-mica schist
Graphite schist
Spears Meadow Road
Old County Road
O.B. Ulmer Quarry
Sleeper Field Quarry
Pair Hole
Engine Quarry
Hurley Quarry
Thompson
Nichols Quarry
Creighton Quarry
Williams Quarry
Mag Quarry
Gay Quarry
Hard Rock Quarry
Soft Rock Quarry
G. Ulmer Quarry
Brown Quarry
Talbot Avenue
Limerock St.
Rankin St.
Cedar St.
Maverick St.
Route 17
Blackinton Corners
Bartlett Quarry
Achorn
Charles Crockett Quarry
Mica schist and mica qtz. schist
Quartz-mica schist
Quartz schist
Qtz.-mica schist
Calcareous qtz. sch.
Creighton
Austin Pasture
Blackinton Farm
McLoon
Dexter St.
Pleasant St.
Park St.
Oliver St.
U.S. 1
Gay Farm
LS-50-66
LS-50-74
LS-50-75
LS-50-94
LS-50-93
LS-50-90
LS-50-89
LS-50-91
LS-50-84
LS-50-83
LS-50-82
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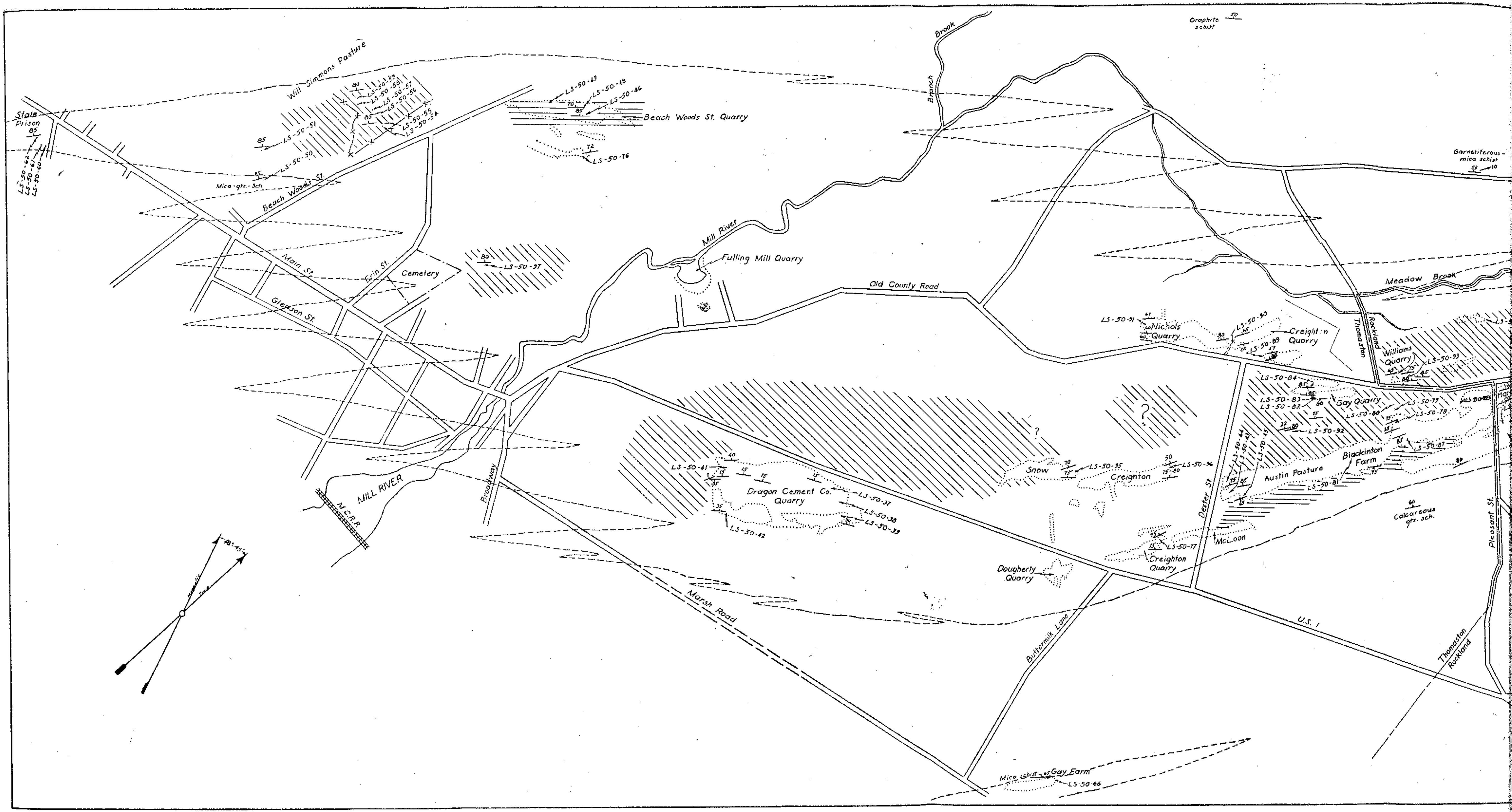
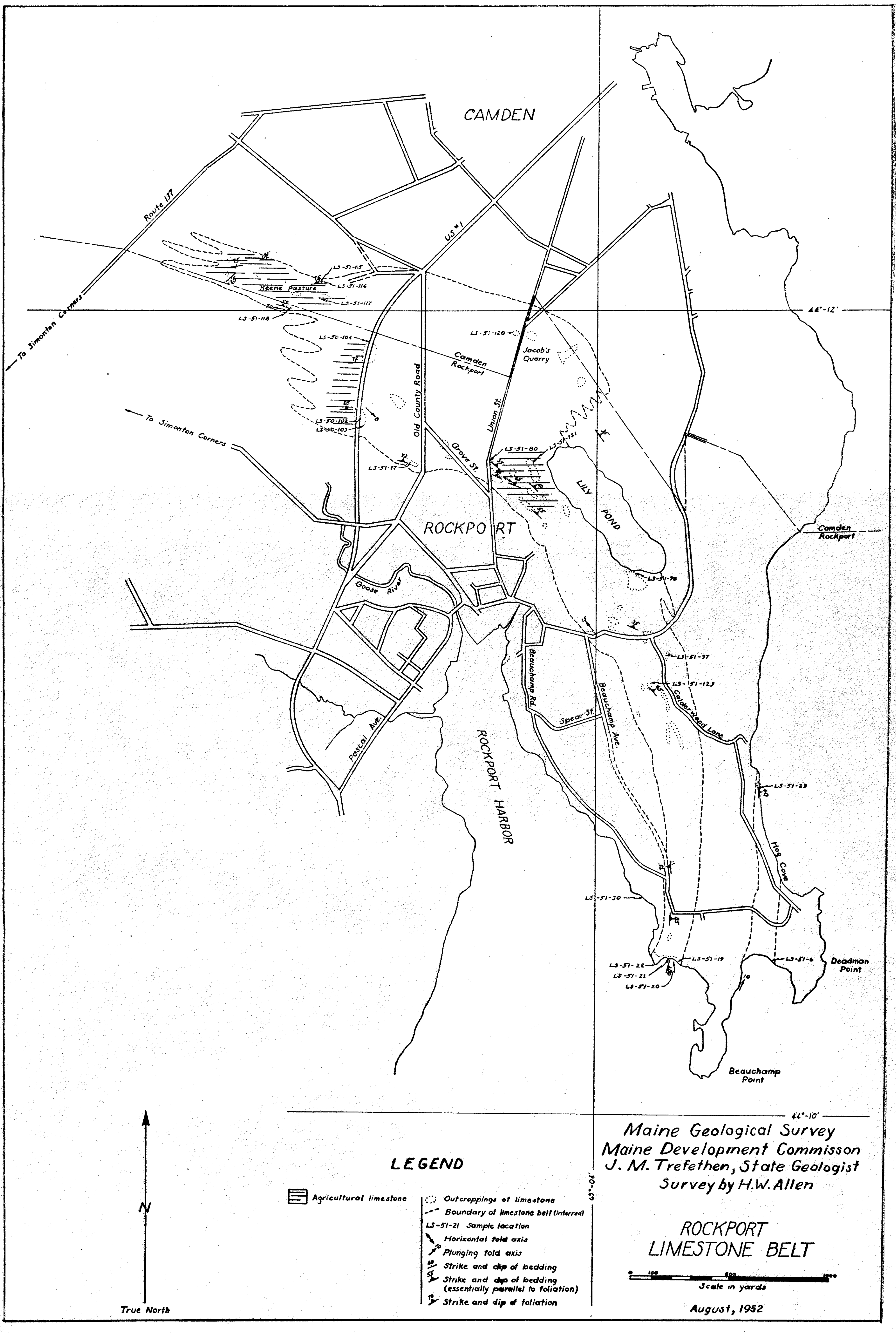
LS-50-9



State Prison
Will Simmons Pasture
Beach Woods St.
Beach Woods St. Quarry
Mica-qtz.-Sch.
Main St.
Erin St.
Cemetery
Gleason St.
MILL RIVER
M.C.R.R.
Broadway
Marsh Road
Mill River
Fulling Mill Quarry
Branch Brook
Old County Road
Graphite schist
Garnetiferous-mica schist
Meadow Brook
Nichols Quarry
Creighton Quarry
Thomaston
Rockland
Williams Quarry
Gay Quarry
Blackinton Farm
Austin Pasture
Dexter St.
Snow
Creighton
Dragon Cement Co. Quarry
Dougherty Quarry
McLoon
Creighton Quarry
Calcareous qtz. sch.
Pleasant St.
U.S. 1
Buttermilk Lane
Mica schist
Gay Farm
Thomaston Rockland

MAP I


CAMDEN
ROCKPORT
Route 137
US #1
To Simonton Corners
To Simonton Corners
Keene Pasture
Camden
Rockport
Jacob's Quarry
Old County Road
Union St.
Grove St.
LILY POND
Goose River
Beauchamp Rd.
Spear St.
Beauchamp Ave.
Calderwood Lane
Pascal Ave.
ROCKPORT HARBOR
Hog Cove
Deadman Point
Beauchamp Point
44°-12'
44°-10'
LS-51-115
LS-51-116
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LS-50-104
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LS-50-103
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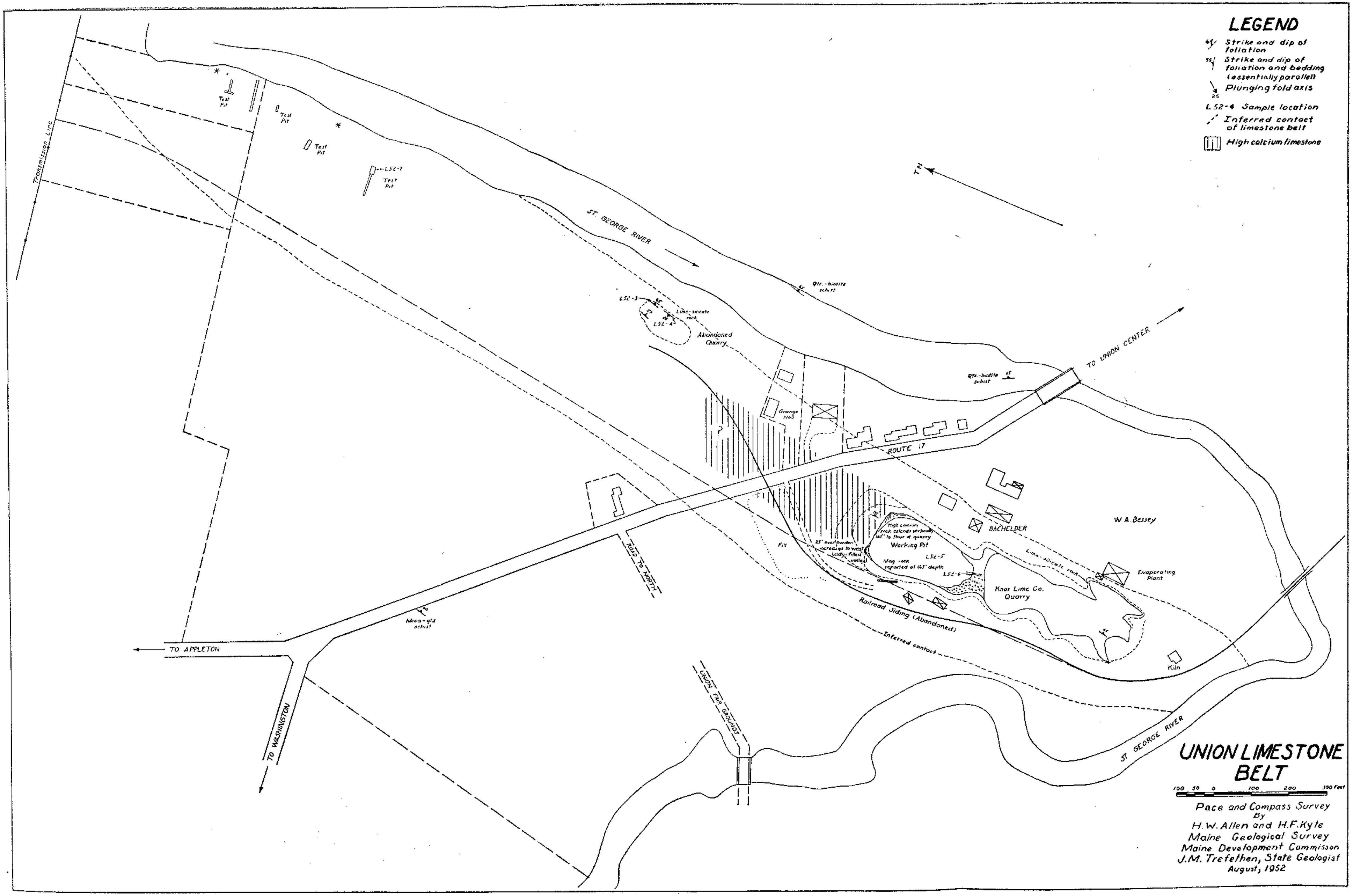
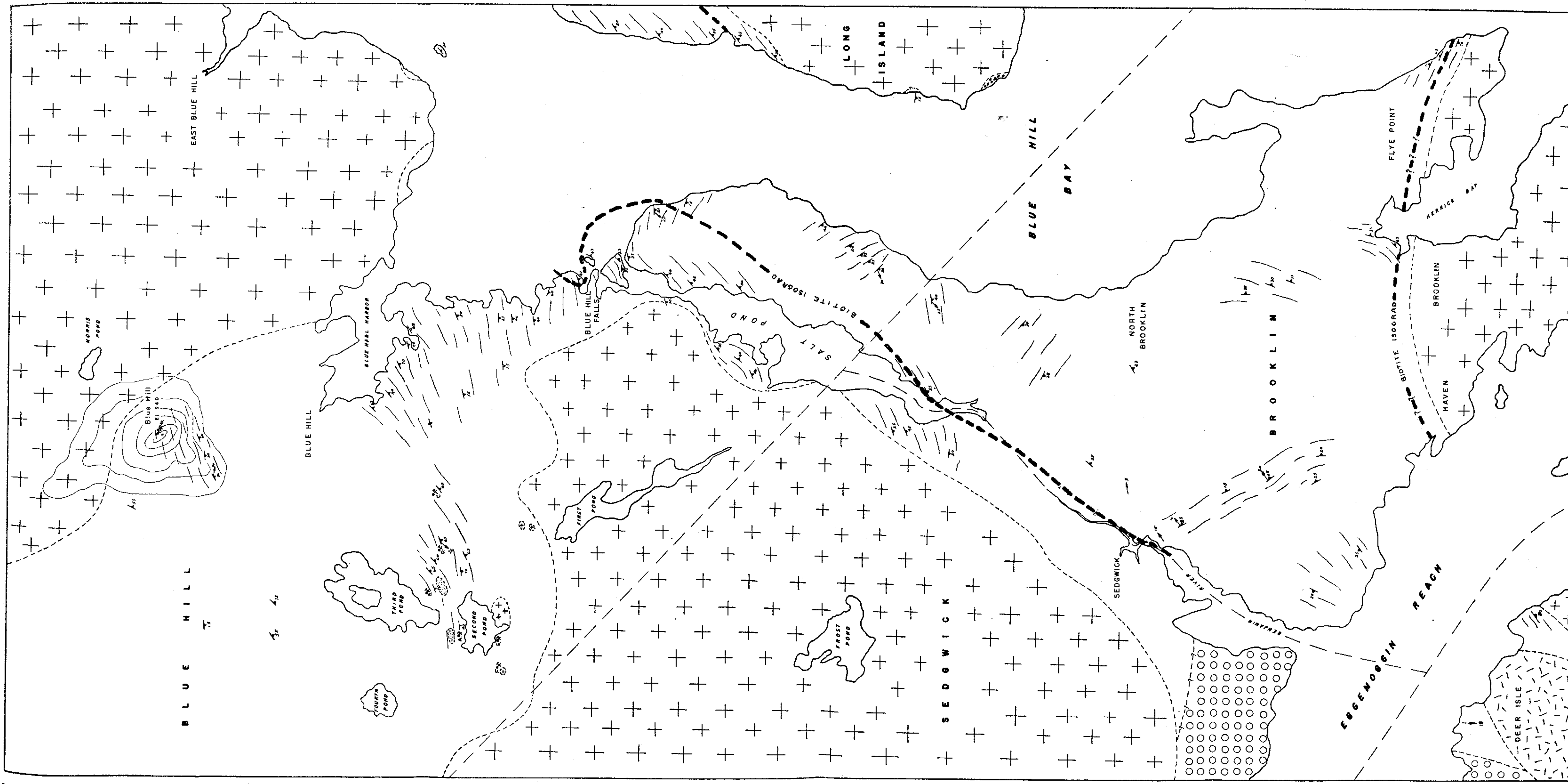
LS-51-20
LS-51-19
LS-51-6
Maine Geological Survey
Maine Development Commisson
J. M. Trefethen, State Geologist
Survey by H.W. Allen
LEGEND
Agricultural limestone
Outcroppings of limestone
Boundary of limestone belt (inferred)
LS-51-21 Sample location
Horizontal fold axis
Plunging fold axis
Strike and dip of bedding
Strike and dip of bedding (essentially parallel to foliation)
Strike and dip of foliation
ROCKPORT LIMESTONE BELT
Scale in yards
August, 1952
N
True North

MAP II

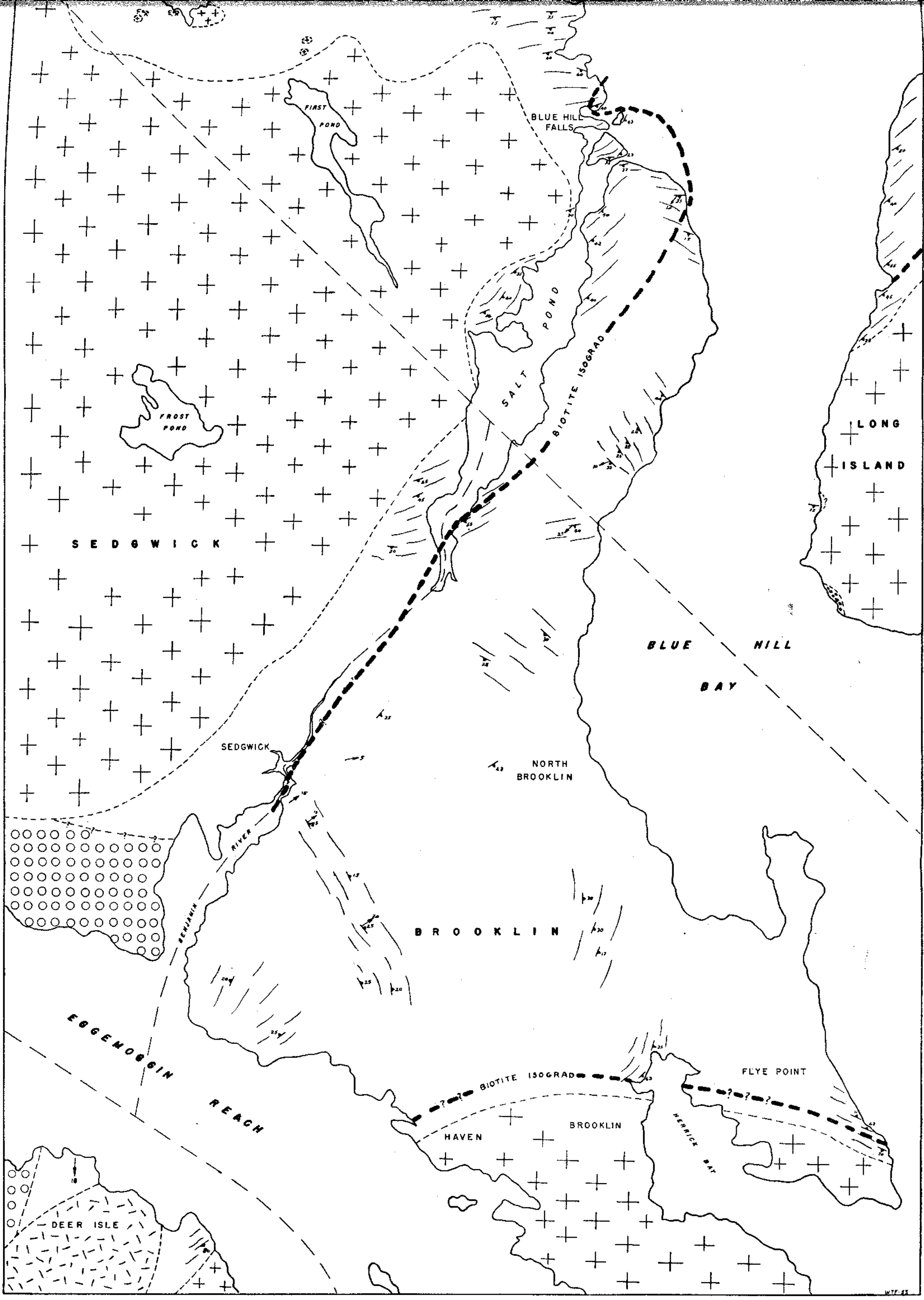

LEGEND
Strike and dip of foliation
Strike and dip of foliation and bedding (essentially parallel)
Plunging fold axis
L52-4 Sample location
Inferred contact of limestone belt
High calcium limestone
T N
Transmission Line
Test Pit
Test Pit
Test Pit
L52-7
Test Pit
ST. GEORGE RIVER
Qtz.-biotite schist
L52-3
L52-4
Lime-silicate rock
Abandoned Quarry
TO UNION CENTER
Qtz.-biotite schist
Grange Hall
ROUTE 17
W A Bessey
BACHELDER
High calcium rock extends vertically 165' to floor of quarry
Working Pit
L52-5
Mag rock reported at 165' depth
25' overburden increases to west (clay-filled valley)
Fill
L52-6
Lime-silicate rock
Evaporating Plant
Knox Lime Co. Quarry
Railroad Siding (Abandoned)
Inferred contact
Kiln
ROAD TO NORTH
Mica-qtz schist
TO APPLETON
TO WASHINGTON
UNION FAIR GROUNDS
ST GEORGE RIVER
UNION LIMESTONE BELT
100 50 0 100 200 300 Feet
Pace and Compass Survey
By
H.W. Allen and H.F. Kyte
Maine Geological Survey
Maine Development Commisson
J.M. Trefethen, State Geologist
August, 1952

MAP III



EAST BLUE HILL
LONG ISLAND
BLUE HILL BAY
FLYE POINT
HERRICK BAY
NORRIS POND
Blue Hill
El 940
BLUE HILL
BLUE HILL HARBOR
BLUE HILL FALLS
SALT POND
BIOTITE ISOGRAD
NORTH BROOKLIN
BROOKLIN
BIOTITE ISOGRAD
BROOKLIN
HAVEN
FIRST POND
THIRD POND
SECOND POND
FOURTH POND
FROST POND
SEDGWICK
SEDGWICK
RIVER
EGGEMOGGIN REACH
DEER ISLE
BLUE HILL

MAP IV



GEOLOGIC MAP
OF A SECTION OF THE
BLUE HILL QUADRANGLE
HANCOCK CO., MAINE

SURVEYED BY W.T FORSYTH and H.F KYTE FIELD SEASON 1952

MAINE GEOLOGICAL SURVEY, MAINE DEVELOPMENT COMMISSION

J.M.TREFETHEN, STATE GEOLOGIST

1 3/4 1/2 1/4 0 1/2 1 MILE

LEGEND

IGNEOUS ROCKS

- Biotite granite and Quartz monzonite — DEVONIAN
- Serpentine — SILURIAN
- Greenstone — CAMBRIAN
- Castine volcanics

METAMORPHIC ROCKS

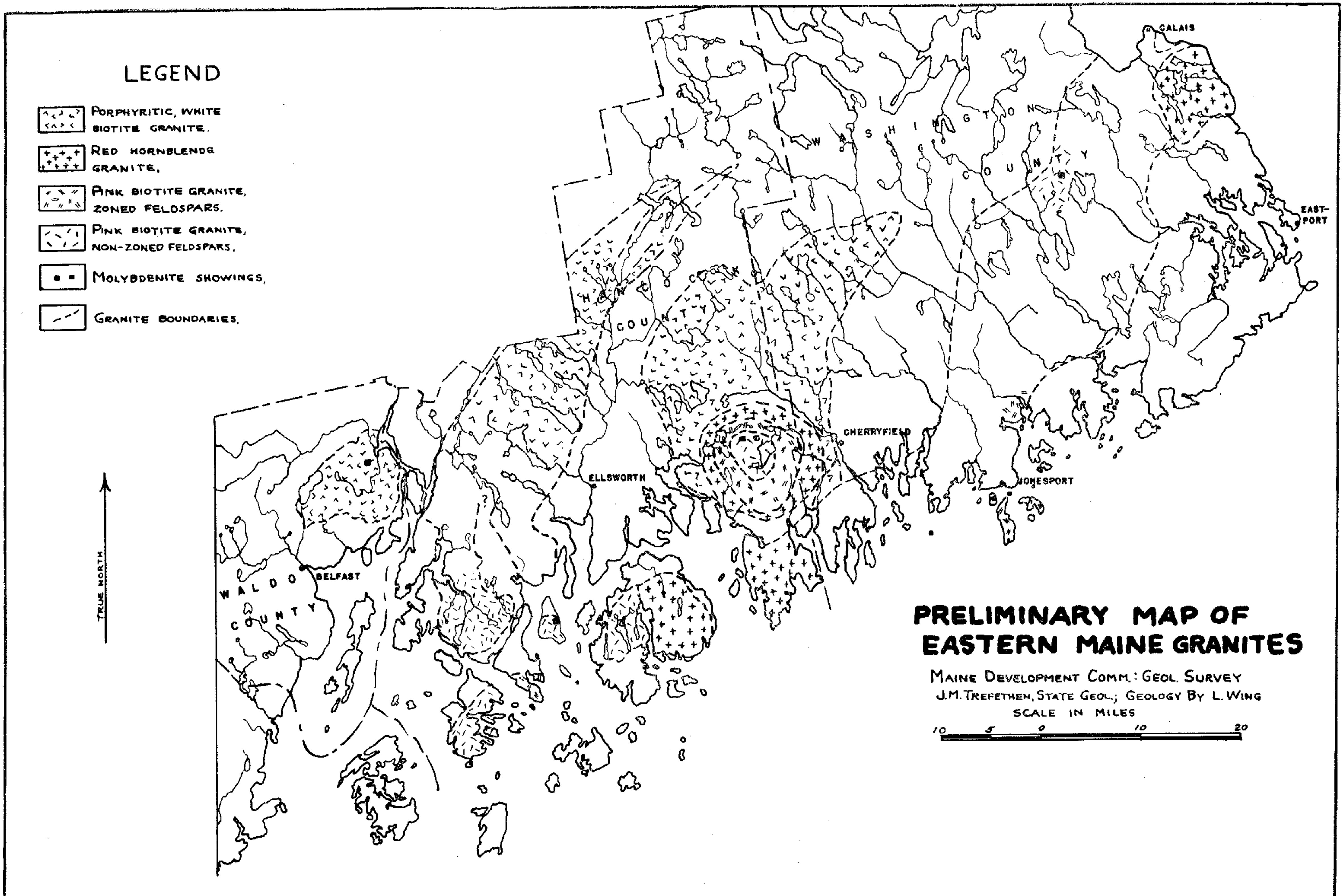
- Ellsworth schist — CAMBRIAN
- Quartzite lenses in schist

N

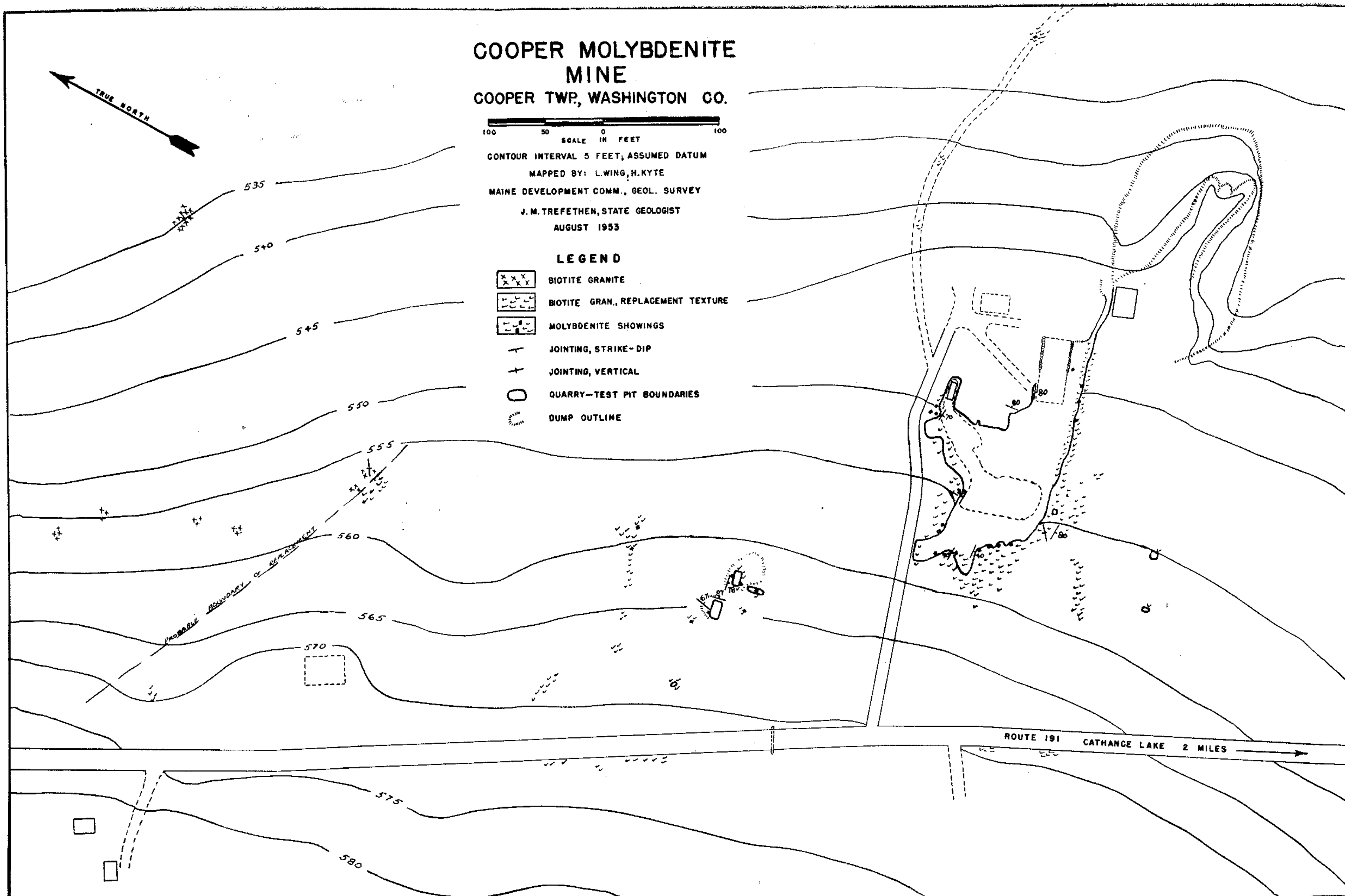
19°

Magnetic Declination 1941

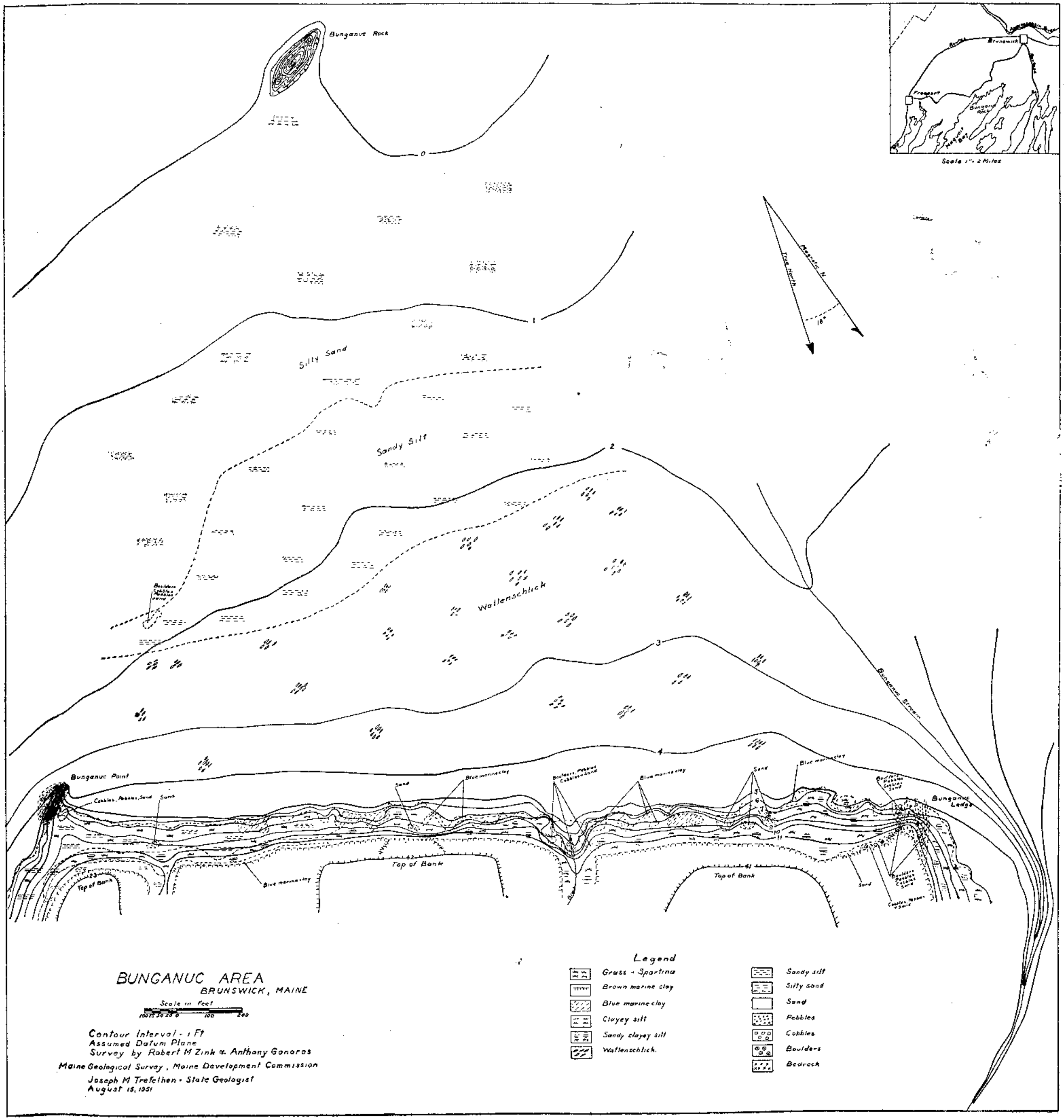
- Dip and strike of schistosity
- Direction and plunge of fold axes
- Formation boundaries modified from Penobscot Bay Folio
- Mineralogical isograd
- Mines
  - A. DOUGLAS
  - B. STEWART
  - C. STOVER
  - D. TWIN LEAD
  - E. MAMMOTH
  - F. OWEN LEAD
  - G. BLUE HILL MANGANESE


LEGEND
Porphyritic, white biotite granite.
Red hornblende granite.
Pink biotite granite, zoned feldspars.
Pink biotite granite, non-zoned feldspars.
Molybdenite showings.
Granite boundaries.
TRUE NORTH
CALAIS
WASHINGTON COUNTY
EASTPORT
HANCOCK COUNTY
CHERRYFIELD
ELLSWORTH
JONESPORT
BELFAST
WALDO COUNTY
PRELIMINARY MAP OF EASTERN MAINE GRANITES
Maine Development Comm.: Geol. Survey
J.M. Trefethen, State Geol.; Geology By L. Wing
SCALE IN MILES
10 5 0 10 20

MAP V

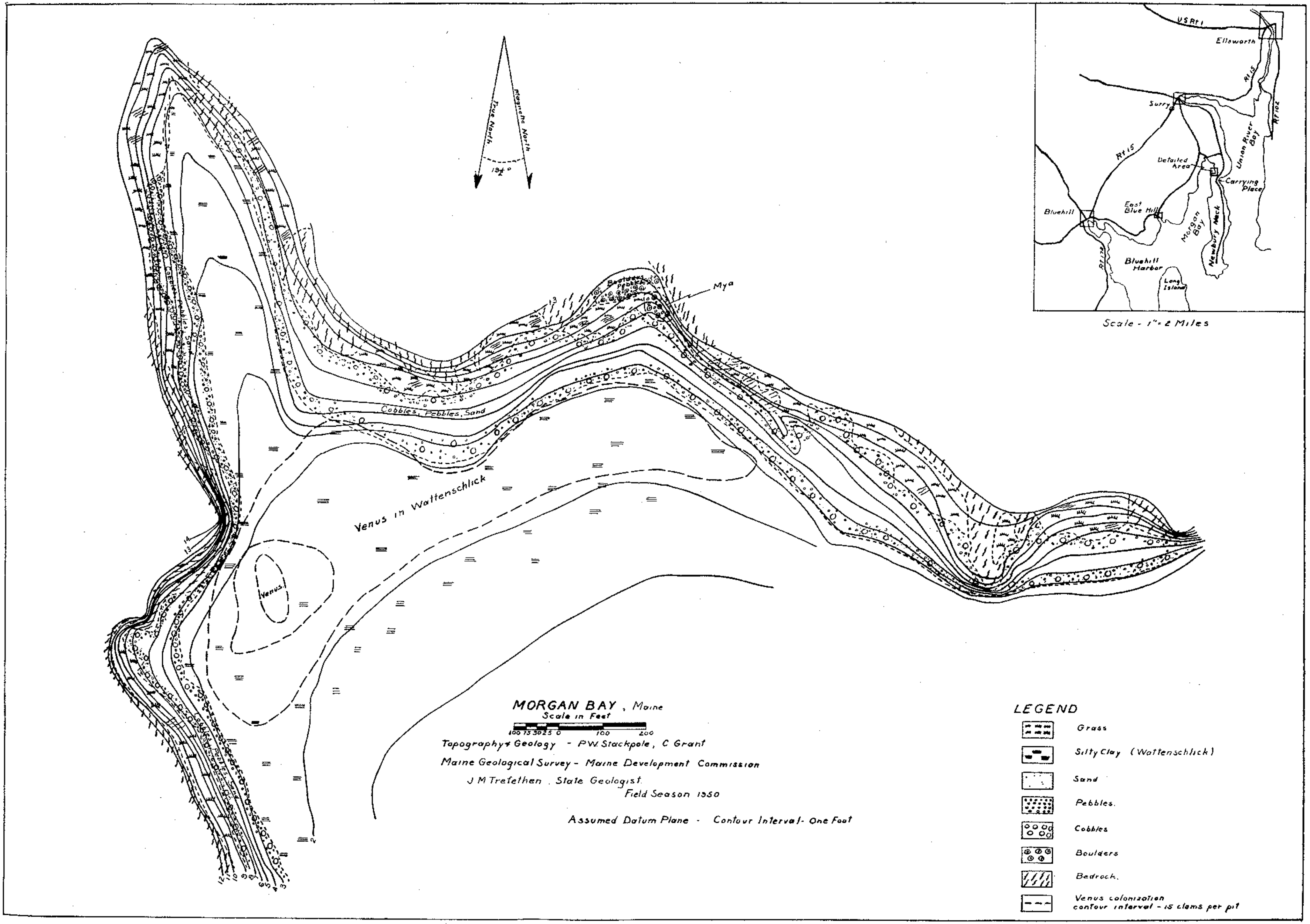

COOPER MOLYBDENITE
MINE
COOPER TWP., WASHINGTON CO.
100 50 0 100
SCALE IN FEET
CONTOUR INTERVAL 5 FEET; ASSUMED DATUM
MAPPED BY: L. WING, H. KYTE
MAINE DEVELOPMENT COMM., GEOL. SURVEY
J. M. TREFETHEN, STATE GEOLOGIST
AUGUST 1953
LEGEND
BIOTITE GRANITE
BIOTITE GRAN., REPLACEMENT TEXTURE
MOLYBDENITE SHOWINGS
JOINTING, STRIKE-DIP
JOINTING, VERTICAL
QUARRY—TEST PIT BOUNDARIES
DUMP OUTLINE
TRUE NORTH
535
540
545
550
555
560
565
570
575
580
PROBABLE BOUNDARY OF REPLACEMENT
ROUTE 191 CATHANCE LAKE 2 MILES

MAP VI



Bunganuc Rock
Silty Sand
Sandy Silt
Wattenschlick
True North
Magnetic N
Bunganuc Stream
Bunganuc Point
Bunganuc Ledge
Top of Bank
Blue marine clay
Scale 1" = 2 Miles
BUNGANUC AREA
BRUNSWICK, MAINE
Scale in Feet
Contour Interval - 1 Ft
Assumed Datum Plane
Survey by Robert M Zink & Anthony Ganaros
Maine Geological Survey, Maine Development Commission
Joseph M Trefethen - State Geologist
August 15, 1951
Legend
Grass - Spartina
Brown marine clay
Blue marine clay
Clayey silt
Sandy clayey silt
Wattenschlick.
Sandy silt
Silty sand
Sand
Pebbles
Cobbles
Boulders
Bedrock

MAP VII


True North
Magnetic North
18½°
US Rt 1
Ellsworth
Rt 15
Rt 102
Surry
Union River Bay
Rt 15
Detailed Area
Carrying Place
Bluehill
East Blue Hill
Morgan Bay
Newbury Neck
Rt 176
Bluehill Harbor
Long Island
Scale - 1" = 2 Miles
Boulders Pebbles
Mya
Cobbles, Pebbles, Sand
Venus in Wattenschlick
Venus
MORGAN BAY, Maine
Scale in Feet
100 75 50 25 0 100 200
Topography & Geology - P.W. Stackpole, C. Grant
Maine Geological Survey - Maine Development Commission
J. M. Trefethen, State Geologist
Field Season 1950
Assumed Datum Plane - Contour Interval - One Foot
LEGEND
Grass
Silty Clay (Wattenschlick)
Sand
Pebbles
Cobbles
Boulders
Bedrock
Venus colonization contour interval - 15 clams per pit

MAP VIII