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REPORT

of the

STATE GEOLOGIST

1949 - 1950

May 1951
Maine Development Commission
Augusta, Maine

MAINE GEOLOGICAL SURVEY

Orono, Maine

Joseph M. Trefethen, Ph.D., Director and State Geologist

PERSONNEL

1949

L. W. Goldthwait	Geologist
Richard Ordway	Geologist
L. A. Wing	Geologist
V. E. Shainin*	Geologist (U. S. Geological Survey)
J. J. Donohue	Assistant Geologist
Philip Stackpole	Assistant Geologist
William Fairley	Field Assistant
William Linton	Field Assistant
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Herbert Schneider	Field Assistant
Wayne Plummer	Draftsman

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1950

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L. A. Wing	Geologist
Henry Allen	Geologist
Henry Woodard	Geologist
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MAINE DEVELOPMENT COMMISSION

Augusta, Maine

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ACTIVITY OF THE MAINE GEOLOGICAL SURVEY 1949-1950

By JOSEPH M. TREFETHEN, State Geologist

The Maine Geological Survey, carrying out a part of the Maine Development Commission's program, has a fourfold function:

1) to give **service to landowners and prospectors** through the identification and examination of mineral and rock specimens and prospects;

2) the **exploration and mapping** of areas which appear to have economic prospects for mineral development;

3) **laboratory research** directed towards the discovery of new or improved techniques that may make possible economic advances in the commercial development of our mineral resources; and

4) **the dissemination of information** on the geology and mineral resources of Maine, through publication, correspondence, and talks before various groups. A review, therefore, of the Survey's activity includes a variety of geological work, and is conveniently summarized by following in outline these four functions—service, exploration, laboratory research, and information service.

Service

As in the past few years, many specimens have been received for identification, nearly one a day. Many of these are "fools' gold" to be sure, but anyone who has had the experience of picking up some shining yellow particle from the earth knows the prospector's thrill, but also knows the uncertainty as to the value of the discovery. It is through such curiosity that many new discoveries have been made. Some minerals are easily named; others, especially in this state where the numbers of rare minerals are large, require much patient work to identify correctly. Identifications of local rocks and minerals are made for state residents at the Orono Laboratory. If the specimen requires considerable time for identification a nominal charge is made.

As in past years, also, requests to examine mineral prospects have come in from nearly all parts of the state. The continued dryness of the 1949 and early 1950 field season brought more requests for aid and advice on well locations and development. Ground water is, indeed, our most valuable mineral resource, and its value, of course, increases with scarcity.

In the field seasons of 1949 and 1950 the Maine Survey had parties in various parts of the state.

The detailed investigations of selected parts of the shorelines begun in 1948 in cooperation with the State Department of Sea and Shore Fisheries were continued cooperatively. Progress reports on this project are incorporated in this report.

Field work and mapping of certain of the Newry-Red Hill feldspar areas, (a cooperative project of the Maine Geological Survey and the United States Geological Survey) were completed in 1949 field season by Vincent E. Shainin, of the United States Geological Survey. Because of the untimely death of Professor Shainin in June, 1950, the final report on this work has been delayed.

Professor Goldthwait continued studies of the distribution and significance of glacial-marine clays in the Portland-Sebago Lake Region. Results of these studies are incorporated as a part of this report.

Further investigations of the serpentine rocks of Maine, with special reference to asbestos possibilities were continued, and are reported upon in a paper by Mr. Wing. The possibility of utilization of serpentine rock to rebuild soils deficient in magnesium, as pointed out in the highly significant pioneering paper of Dr. Keller published in this report, should not be overlooked.

The studies of shoreline processes and sediments, in areas selected by the Sea and Shore Fisheries Department of the state, are progressing. The particular economic reason for these studies is to evaluate the environmental factors which bear on clam production.

In the summer of 1950, L. A. Wing made a reconnaissance of the St. John and Allagash Valleys. Recent geological information on this part of the state has been wanting up to the present.

PREFACE TO ROCKS AS FERTILIZER

J. M. Trefethen

The following article, "Industrial Minerals and Rocks as Plant Nutrient Sources" by Dr. W. D. Keller, Professor of Geology at the University of Missouri, makes a highly significant contribution to an economic application of geology. The significance of this will be quickly apparent to those engaged directly or indirectly with agriculture.

In certain parts of Maine, as is well known, the soil lacks magnesia. This deficiency is supplied by using a magnesian or dolomitic land lime. In Aroostook County, our area of largest demand for land lime, the magnesia deficiency requires importation of magnesian lime. There is suitable calcium stone locally available. It would seem, therefore, that if the magnesium deficiency could be remedied through application of Mg, possibly in the form suggested by Dr. Keller, the local limestone could be used without "sweetening" with imported dolomite, and at the same time introduce other benefits to the soil.

It will be noted that Mr. Wing's paper on the "Serpentine Rocks of Maine," also in this report, calls attention to large bodies of serpentine rock in this state (Deer Isle, for example) that contain twenty-five to thirty-five per cent MgO. Perhaps fertilizer and lime producers will do well to consider the implications and possibilities suggested by Dr. Keller's paper.

INDUSTRIAL MINERALS AND ROCKS AS PLANT NUTRIENT SOURCES

By W. D. KELLER

Professor of Geology, University of Missouri and
Consultant to Maine Geological Survey

Abstract

Industrial minerals and rocks constituted most of the raw materials for the 750 million dollars worth of soil fertilizers sold in 1948. The demand for fertilizers is expanding. Hitherto unused rock products are potential sources of plant nutrients. Geologists will be better equipped to develop new and additional industrial rock sources as fertilizers when they understand the underlying requirements for soil rebuilders.

Introduction

Agricultural fertilizer sales totalled about $750 million in 1948. That is a big sum from anybody's viewpoint, and it should be particularly significant to the economically minded geologist for most of the raw materials used in these fertilizers are obtained from industrial minerals and rocks. Moreover, demands and expenditures for fertilizers will increase greatly in the future, not only for nutrients now being exploited but in addition for new substances which soil research is indicating to be necessary. Herein lies an expanding demand for rock products which will be recognized and filled by the geologist who appreciates the problems confronting the soils specialist and the farmer.

Hence, a major purpose of this paper is to orient the perspective to parallel that of the soils scientist who needs and is looking for untried geologic sources of plant nutrients. From this wider viewpoint the geologist will be much better able to recommend and supply his rock products. Therefore much of this discussion will deal with soil processes as related to rocks and minerals rather than with geologic descriptions of rock occurrences. It is hoped that the paper will be provocative and stimulating, rather than an historic recital of operating examples. Some of the concepts expressed herein are pioneer in character and may be controversial in degree. Progress commonly arises from diversified, out-of-the-rut thinking, and it is hoped that both pedologists and geologists will benefit by exchange of new ideas and new utilization of rock products.*

In keeping with the expressed intention of emphasizing the soils perspective, the mechanism by which the rocks of the geologist end up as beefsteak or spinach on milady's chinaware will be first reviewed.

The Ionic Exchange Concept Common to Both Plant Nutrition and Rock Weathering

Plants grow in the soil (and above it) because the soil acts as a mechanical support, and because it furnishes inorganic nutrients to their roots. The total soil water is a complex fluid medium through which the nutrients move from soil to plant, or *also* from *plant to soil.* Nutrients commonly move from roots to leaves, but also from leaves to roots (potatoes, peanuts, and legumes with nitrogen tubercles on roots, etc.). Hence, nutrients may move about according to their activity gradients in all directions through the water between soil and plants. The nutrient ions move like fish which swim both up and down in the watery stream while it flows dominantly but not always in the direction soil to roots to leaves as the transportation medium.

These inorganic nutrients are conveyed dominantly and most efficiently from the soil to the plants by way of intermediate colloids (organic and clays) through the mechanism of ion exchange. The latter is commonly known as base exchange where restricted to base-forming cations, but plant nutrition includes as well the various complementary anions. The colloidal transfer is so general that the role of simple molecular solution in soil water probably is of secondary importance in plant nutrition, except in the practice of hydroponics.

Hence, the nutrient ions derived from a rock or mineral fertilizer which has been added to the soil usually pass through an intermediate stage of colloidal absorption enroute to being acquired by the plant rootlet. For example, the calcium from a particle of limestone (or other Ca-bearing rock particle) is first taken up by H^+ clay or H^+ organic colloid in exchange for its H^+. This is a step in the process called weathering by the geologist. Incidentally, weathering of rock-

*The writer is especially fortunate in having the fullest privilege of soliciting information and advice from his colleagues in the Soils Department of the University of Missouri. The material in this paper pertinent to soils has come from them in one way or another. It has been read by Professor Albrecht and its contents discussed with others.

forming minerals by acid clay in the soil has been quantitatively studied by Graham[1] in the laboratory. The now calcium-bearing clay of the example cited above holds the calcium in an exchangeable position ready to give it up to a plant rootlet which may search its way in and take away the calcium only as this Ca is replaced by the equivalent in hydrogen. The plant then has acquired the calcium, and the clay colloid is restored to a hydrogen clay which is chemically ready to attack another particle of decomposable rock in order to obtain K, Ca, Mg or any other cation that may meet with chemical equilibrium.

This example has been described in detailed steps in order to bring out important phases of the transfer: (1) weathering of a nutrient-reserve mineral, (2) the importance of H^+ ions (acidity) in the soil, (3) colloidal absorption, (4) ionic exchange of nutrient, (5) active behavior of the root, (6) chemical equilibrium, and (7) aggressive action of the acid clay toward a cation-possessing rock or mineral which is thereby a possible reserve of plant nutrient. Although most of the phases listed above are usually artificially classified as lying within the field of agriculture, those pertaining to the rock and mineral particles (the reserve nutrients) are of immediate and intrinsic interest to the industrial mineralogist. The opportunities and possibilities for furnishing inorganic plant foods widen tremendously after one realizes that any rock is a potential fertilizer provided it can furnish efficiently to a chemically active clay or humus soil colloid an element which is needed by plants.

Trace Elements, and native rocks as Fertilizers

No longer are nitrogen, phosphorus, and potassium (the N-P-K trio) the only elements to be considered in the category of fertilizer. They are merely the first to have been recognized as deficient in depleted soils. Deficiency of calcium, which from a human and animal nutritional standpoint may be more important or serious than that of either N, P, or K, was commonly and erroneously diagnosed as a condition of high soil acidity, along with soil shortages of N, P, and K. Currently magnesium soil reserves are rapidly becoming depleted, and the micro-nutrients, or trace elements are needed worse in many soils than their bulkier companions. Indeed, the most spectacular responses by plants to any of the soil additives has come from the trace elements when added in quantities of a few parts per million. All of them are plant foods and merit attention as such. More than a score of elements are listed as indispensables in plant and animal nutrition and most of them are derived from rock products. The more obvious inorganic nutrient elements (rock-and mineral-derived) include P, K, Ca, Mg, Mn, Cu, Co, Mo, B, Zn, and S.

The geologic sources of the plant foods will be considered in terms of the elements. However, it should be recognized at the outset that plant nutrients may be added to the soil in two contrasting ways. One practice is to add them in the form of the conventional commercial fertilizer by which processed, concentrated, relatively soluble salts of the desired elements become immediately available to the plants and are usually quickly depleted by plant use, by becoming insoluble in the soil, or removed by ground water leaching within a couple of years. This method has much to recommend it for it is speedy in action, requires the handling of minimum bulk of material (unless too much low-priced, inert, silica sand filler is added to "improve the working properties" of the fertilizer), and saves money on the cost of freight or truck haulage. Certainly industrial rocks and minerals are the raw materials from which most of the processed end products are derived.

The other procedure (not much advertised) to restore soil reserves is to add in clay, silt, and sand-sized particles selected rocks and minerals, or blends thereof, which will weather and decompose in the soil (rapidly from a geological viewpoint, but slowly compared to laboratory reactions) and release in a more natural way the desired nutrients.[2]

This scheme of fertilization is exemplified by the current profitable addition of crushed limestone, and of raw rock phosphate, which are only sparingly soluble in ground water, but which are decomposed by soil acids, bacterial action, and other weathering agents so that the nutrients are released at a natural rate. This later practice closely simulates the way that Mother Nature would replenish soil nutrient reserves.

It is proposed that various natural and industrial (the latter used in a double sense) rocks and mineral carbonates, silicates, sulfides, sulphates, phosphates, slags, and other compounds known to geologists but hitherto little used or unused for this purpose may be employed. Artificial processing of fertilizer would expect to be held to a minimum. Low grade ores, too low for metallurgical recovery in some cases; ore concentrates diverted from refining; and various nutrient-containing bulk rocks are the proposed potential materials for plant food use.

There are advantages and disadvantages to each practice of adding the soil supplements, and the extent of these varies with soil needs and circumstances. Practically in many instances it appears best to combine a small amount of artificially prepared, quickly soluble "starter" with the bulk of slower-acting, longer-lasting natural rock product as soil restorative.

Minerals Serve in Soil Restoration rather than as Starter Fertilizers

The addition of fertilizer in the form of native rocks and minerals is to be recommended for several reasons. One is that a more natural ratio or balance of nutrients is supplied to plants than where an excessively high concentration of soluble fertilizer substance is imposed upon the soil-plant system. In the latter case, when a soluble fertilizer is added, the soil colloids are apt to be deluged, at least in local spots, with solutions of only a few ions of high concentration. Their mass action effect forces other nutrient elements off the colloids causing the plant rootlets in the vicinity to take on mainly the fertilizer solution as it is present, rather than in the ratio between several nutrient ions as the plant needs them. This factor of nutrient balance usually is highly important. Instances have been recorded where an imbalance has resulted in both toxicity due to one nutrient ion in excess, and simultaneously a deficiency of another. Therefore it is not to be dismissed as being only of academic interest. Artificial imbalance becomes more acute or apparent as production is pushed toward its maximum limits, and as the reserve organic matter, the natural shock absorber for fertilizer mistakes, becomes less and less. Danger of excessively high or toxic concentration of one nutrient ion is practically eliminated by the addition of most natural or bulk rock products to the soil. In these native materials the large nutrient reserve is locked up in a sparingly soluble silicate, carbonate, etc., which breaks down slowly through weathering and thereby delivers for a relatively long time the smaller volume of soluble ions as needed.

Another point of paramount importance in the method of addition centers about the privilege of selective feeding by the plant roots. Different plants need different ratios of nutrients. Plants cannot be regimented successfully in their feeding any more than can human beings. In a rich, virgin soil, like that on which plant life evolved before man took over and disturbed equilibrium, a heterogeneous distribution of nutrient loci is the normal pattern. Plants can send their roots and take up nutrients where, and in the optimum quantities, that will make for most efficient nutrition. This picture has been clearly described by Albrecht:[3]

"These facts support the concept that the soil need not be a uniform medium as to degree of acidity or as to the distribution of all the essential plant nutrients. Rather, the soil may be a mixture representing a heterogeneous collection of foci of each of these in the mineral or rock forms weathering slowly while in contact with the acid clay. Plant growth may then represent the summation of root contacts with all these different centers of fertility as the roots move to and get from them all that is needed for maximum crop productivity. . . . .

"It seems more reasonable to believe that the plant is growing much better if its advancing roots find one area around a limestone particle that may be nearly neutral but providing much calcium, then at some distance another area more acid, where iron can be taken, then another where around some feldspar its potassium is slowly made available, then another where the acidity is mobilizing the phosphorus, and still others where manganese and the different essential nutrient elements are on the clay in exchangeable form because the clay is in contact with some mineral fragment and maintains itself in a weathering equilibrium with it."

Heterogeneity in nutrient foci within the soil is best achieved by adding silt-sized sparingly soluble fertilizer grains. On the other hand, a mixture of highly soluble fertilizer gives rise to a concentrated, relatively homogeneous solution which blots out selective, variety, and balanced feeding by plant roots.

A disadvantage to the use of native rock products is their greater weight and consequent cost of transportation. Obviously the geographic extent out from a deposit to which they can be practically sold and used is a matter of economics and simple arithmetic.

Geological Sources of Calcium

In the preceding part has been described the mechanism by which the soil provides inorganic nutrients to plants, and the concept of using relatively unprocessed (crushing or concentrating excepted) rocks or minerals for plant food reserves. With these notions in mind, geologists can utilize their background of knowledge of earth materials and of occurrences of deposits with suitable compositions, to propose to soil scientists the trial of selected rocks and minerals as soil supplements. Such cooperation is welcomed because foremost pedologists are asking for assistance.

We will next consider some of the rock sources of the inorganic nutrient elements. Agricultural limestone, the use of which has increased about tenfold in the last decade, is in still increasing demand. Calcium is needed in adequate amounts in the synthesis of protein and in the full growth of strong bodies, bone, and virility of animals which feed on plants. Legumes in particular, and other plants do not survive where calcium is deficient. In spite of the earlier erroneous opinion that soil acidity was bad, the attempt to correct it by adding limestone was beneficial because calcium and magnesium were added in the limestone. High acidity means an overäbundance of replaceable H^+ ions on soil colloids in places where Ca (or other cations) is deficient. The main purpose in adding limestone to soil therefore is to supply calcium, but not in excess to the point where all H^+ is removed. It is now definitely recommended that some acidity be retained or even developed in the soil. Referring to the quotation from Albrecht, certain foci of acidic character are indispensable to mobilize efficiently phosphate, manganese, and certain other nutrient ions. Some precautions even with liming need to be observed.

Current recommended specifications for agricultural limestone incline toward crushing into coarser sizes. Finely pulverized limestone which is applied in large quantity deluges the exchange positions of the soil colloids with Ca, and can produce deficiencies in other cations and may raise the pH so high as to immobilize the nutrients dependent upon acid for their availability. Therefore it is possible to over lime a soil, but if the stone is applied in coarser particles (8 to 10 mesh and finer) a heterogeneous mixture of acid and Ca^+ colloid is maintained from which the plant root can make its own selection.

In regions of alkali soils, especially in the arid and irrigated regions where Na is in excess and natural high pH (alkaline) prevails, no acid may be available on the colloid to react with or dissolve Ca from limestone. Here is needed a Ca salt of higher solubility in pure water so that the Ca^+ ions will go in and competitively displace the excess Na^+ from the colloids. Two functions of Ca^+ absorption follow: the delivery of Ca^+ as nutrient, and the improvement of soil texture due to the flocculating effect of the divalent Ca^+ ion on the clay which had been highly dispersed by the Na^+ ion.

Gypsum (land plaster) has been used extensively and usually successfully for this purpose. Very recently, Axtell and Doneen[4] described good results from the use of gypsum applicators which promote the solution of gypsum in irrigation water. Recommended quantities for different alkali conditions are given in their article. The sulphate ion in gypsum also plays a beneficial part in many cases, but deleterious in others. Wider use of gypsum in place of limestone may be explored where the economics of the situation indicates the possibility.

Calcium chloride, because of still higher solubility, may be applicable under certain high alkali conditions. However, excessive chloride ion may prove detrimental to seed germination and must be guarded.

Slags from metallurgical furnaces rich in Ca may be excellent sources of calcium[5] for soil. Usually they are glasses, also rich in various metals, which are highly susceptible to hydrolytic weathering and oxidation so that release of the nutrients is fairly rapid in the soil. If the metals include Mn, Zn, Cu, Co, Mo, and possibly others, the slag becomes a source of trace elements which may be sorely needed. Magnesium is usually present in greater or lesser quantity in slags, and this element is becoming deficient in many localities.

In areas where limestones do not occur, but where high calcium silicates (Ca plagioclase, for example) are in the rocks, the latter are possible sources of Ca for they weather with moderate speed as shown by Graham.[1]

Processed or by-products of calcium preparations like slaked lime or cement clinker should find a market as agricultural stone.

Magnesium Sources

Magnesium is an essential component of the plant's chlorophyll molecule, hence there is no question of the seriousness of a magnesium deficiency wherever it exists. That deficiency is now evidencing itself in many localities. Over-liming (using high Ca limestone) is contributing to Mg deficiency in some cases by (a) crowding Mg off the colloid exchange complexes by sheer mass action, and (b) exceeding the tolerable Ca/Mg ratio which preferably ranges between six and ten Ca to one Mg. Dolomite[6] comes to mind as the usually most abundant rock source of Mg and it is usually the most practical one in regions where it occurs. Land that has been limed to excess with high Ca lime may have lost almost all capacity (acidity) to react with dolomite and absorb magnesium. To restore a temporary favorable balance of magnesium to such a soil it may be necessary to add a very soluble Mg salt like Epsom Salts, or one of the potassium-magnesium evaporite minerals. Magnesite is obviously an excellent source of Mg; olivine weathers more slowly but can be used. Impure MgO developed as a by-product from manufacturing processes utilizing magnesium-bearing earth materials may be a practical soil supplement.

The purity of limestone, dolomite, or other nutrient source has been stressed far more than can be justified. What should be of more importance to the consumer is the cost per unit nutrient on his land. For example, a limestone testing 85% $CaCO_3$ equivalent which is produced nearby and bears low transportation cost may easily be more economical than one testing 95% or more which has to be trucked 15 miles. A mine dump or tailings pile made up of impure dolomite, calcite, or trace element gangue may stand out in a non-sedimentary, non-limestone agricultural area like an oasis on the desert.

Magnesium may be derived from its silicates olivine and serpentine, even in a water soluble compound, by mixing those pulverized minerals with commercial superphosphate fertilizer. This discovery should go a long way toward solving the problem of Mg deficiency in soils within igneous and metamorphic areas and far removed from dolomite. It may save farmers large sums, and may open new business for quarry operators.

A Russian, I. V. Druschinin[10,11] used dunite (olivine), and later workers in New Zealand,[12] obtained even better results from pulverized serpentine. Excerpts from the abstract of the New Zealand article, and from a letter to the Oregon State Department of Geology and Mineral Industries from the New Zealand Mines Department, are taken from the May 1945 issue of the "Ore.-Bin"[13] as follows:

(Ref. 13) "Fine ground serpentine is used in the preparation of serpentine superphosphate which is prepared by mixing 1 part of ground serpentine with 3 parts of hot superphosphate. The resulting mixture has many advantages on the straight superphosphate in particular the drying of the serpentine and superphosphate mixture due to the binding of hygroscopic water into water of crystallization of the new phosphate compounds formed during the reaction between the components of the mixture, facilitates the application of the fertilizer to the ground by the drilling machine, preserves the containing bags and generally makes for easier handling. Again the reaction results in the reduction of water soluble phosphoric acid to less than 4 per cent while the content of citric acid soluble phosphoric acid remains unchanged. The reduction on content of water soluble phosphoric acid is accompanied by a marked increase in the water soluble magnesium while silica and iron also appear in a readily soluble form. As the result of extensive field trials, it has been established that serpentine superphosphate is in all cases equal in value to standard superphosphate while in many cases it possesses greater value. . . . .

(Ref. 12) Results of experiments conducted in Russia showed that when from 8 to 9.5 per cent dunite was added to the superphosphate, plant growth was greater than with straight triple superphosphate. This extra boost is attributed to the magnesia and colloidal silicon dioxide provided by the addition of the dunite. Raw, commercial triple superphosphates and the concentrated superphosphates are difficult to handle due to excess moisture, which being acidic, attacks the containing bags. Also, the same moisture tends to make lumps which cause difficulty when distributed by means of a drill. The reduction of the excess acidic moisture is accomplished in two ways: first, the acid is neutralized by the dunite, and second, the excess moisture is taken up by rendering the material less hygroscopic. Although the Russians were merely attempting to neutralize their superphosphate without destroying any of its beneficial effects, the New Zealand process causes wholesale reversion of calcium superphosphate by addition of as much as 25 per cent serpentine. This reversion, resulting in a lessening of water soluble P_2O_5 without any decrease in the citrate-solubility, does not affect the fertilizing value of the serpentine-superphosphate. The unusual feature of this reversion is that the complex chemical reactions can take place in a dry, or nearly dry state, and at normal temperatures. The serpentine is merely finely ground (92.4 percent-100 mesh; 81.5 percent-165 mesh) and intimately mixed with three or four times as much superphosphate. When mixed dry the reaction between the two constituents was virtually complete at the end of two weeks. When 5 percent water was added during mixing, the reaction was greatly accelerated and was practically complete in four days.

A comparison of the water-soluble constituents of commercial superphosphate, dry mixed serpentine and superphosphate (1:3), and wet mixed serpentine and superphosphate (1:3) is given in the table below:

Water-soluble constituents

	P_2O_5	CaO	MgO	SO_3
Superphosphate	20.5%	14.5%	0.3%	10.6%
Serpentine-superphosphate, dry mix 14 days after mixing	7.90	3.3	2.2	3.6
Serpentine superphosphate, wet mix 14 days after mixing	1.68	2.23	1.05	3.70
Small factory sample, wet mix (1:3) 12 days after mixing	6.46	2.23	2.05	2.76 "

The research quoted above is notably significant for two reasons. It illustrates a way by which Mg can be obtained from its silicates, which conventionally have been considered to be insoluble. It illustrates also the mixing of an otherwise relatively inert rock or mineral with an aggressive commercial fertilizer, thereby enhancing the effectiveness and value of both. This principle may well be extended to other combinations.

Potassium, Phosphorus and Sulphur

Potassium-bearing rocks and minerals which have plant food possibilities are the leucite-rich ones, glassy phases of potassic rocks, illite, alunite, glauconite, potash feldspar, and granite. In the case of potassium-bearing igneous rocks, the best tried example is the leucitic volcanic ash and cinders of the Vesuvius potash petrogenic province which quickly decompose sufficiently in Italy to furnish enough nutrients to grow grapes, tree fruits, and vegetables. No doubt the high glass content of these volcanic products is partly responsible for their rapid hydrolysis, and their subsilicic (feldspathoid) chemical composition conduces to easy decomposition. Orthoclase and microcline are decidedly more resistant to weathering than is leucite, and have been less promising as potash sources for the soil. However, potash feldspars occur more widely than does leucite, and are available commercially as pulverized by-products or down-graded products. Experiments are under way at the University of Missouri[14] to explore the possibility of accelerating the availability to plants of potassium from feldspar by various heat treatments.

Granite has been used as a soil supplement, with excellent results reported from it in growing tobacco.[15] Geologists recognize, however, that the amount of potasssium which can be obtained from granite is at once limited by its relatively low K_2O content (an average value for granite is about 4% K_2O. Syenite is richer in potassium than granite and should therefore be preferred. Granite and syenite weather relatively slowly unless very finely pulverized.

Illite (6% K_2O) is undoubtedly the source of potash reserves in many soils. Illite-rich shales which occur widely are therefore, potential sources of potash.[14]

Alunite (11% K_2O) and alunitized rock occur in a few localities but are relatively rich in potash. The potassium in alunite is rendered water soluble upon heating.

Glauconite has long been used as a soil supplement at various points on the east coast near where the greensand crops out. After an interlude of decreased application, it is now being produced and used in increasingly greater quantities. Glauconite contains appreciable amounts of the trace elements. It possesses high base exchange properties which may be advantageous when added to the soil.

Phosphorus is added to the soil as a phosphate. The use of highly soluble, processed phosphate fertilizer has so thoroughly demonstrated its value that no further comment is necessary. During the past 5 years or so the use of raw rock phosphate has expanded rapidly and widely. It can be expected to show even greater increase. Units of P_2O_5 in the form of raw rock can be placed on the farm at a highly favorable competitive cost with respect to the acid treated fertilizer over many areas. Because the most effective utilization of phosphate apparently requires a high concentration of it, the extra quantity of raw rock obtainable per dollar stands in favor of raw phosphate. Usually a delay of about a year, or one weathering season, passes before much nutritive response can be seen after application. The phosphate reserve lingers longest with raw rock. A combination of a quick-acting, processed phosphate as a "starter," supplemented with a major application of raw rock satisfies many phosphate deficiencies. In the development of an untried phosphate deposit the fluorine content, which might be excessive, must be considered.

Sulfur has been added to the soil in both elemental form and as the sulphate. Presumably the main function of elemental sulphur is to oxidize and give rise to one of its acids, eventually terminating as sulphuric acid. Excess alkalinity can thereby be corrected. It is also probable that the "nascently" formed acid or the sulphate ion possesses higher chemical effectiveness than externally applied sulphate, possibly because of the locus of its conversion to acid and its intimate association with other reaction substances. Certain hot spring deposits of sulphur (which are commonly mixed with gypsum), or other surface deposits too badly mixed with other rock to compete in the production of pure sulphur may be located close enough to an agricultural market to work at a profit. Sulfides not suitable for metal extraction are a potential source of acidity as a soil supplement. If the associated metals can serve as trace elements the entire sulfide becomes functional. A sulfide-bearing tailings or gangue would appear to be a valuable substitute for silica sand filler in fertilizer.

Trace Elements

Manganese when added in trace amounts produced phenomenally spectacular results in increased production of crops in Florida. Deficiencies of it have been found elsewhere. Indications have been found that resistance to certain diseases, and improvement of general health rise remarkably in both plants and animals when adequate amounts of manganese, with copper and cobalt, are ingested. Probably the oxides of manganese are so sparingly soluble, except in highly acid soil, that they may fail to become available to plants. Artificial acid treatment of manganese oxides will increase their solubility. Manganese carbonate was found by Konnur,[7] working under Graham, to free manganese readily to acid clay. At once, geologists envisage a market for manganese ore deposits which are too low grade (like the Arkansas deposits) for metallurgical purposes. Because of transportation costs various low grade deposits throughout the country should command markets around them.

In the paragraph above the statement was made that manganese *with copper and cobalt* had proven beneficial. A vitally important fact, only implied there, should be elaborated, namely: that the effectiveness of one element or nutrient may be greatly enhanced when it is in combination with others. Moreover, some elements known to be needed by plants are tolerated in only exceedingly small amounts unless accompanied by one or more specific others. It is still unknown for certain whether they exercise a joint catalytic effect, whether a balanced ratio is necessary within a combination, or if some other factors are decisive in their utilization and the well being of the organism. Iron and copper, molybdenum and copper, iron and manganese, and the Mn-Cu-Co trio previously mentioned apparently enhance one another's effectiveness. Doubtless other relationships exist still unknown and unsuspected. Until we can discover all of the necessary combinations the sure way of supplying the entire plant needs is to add trace elements with "shotgun" coverage. Preferred application will be with moderately soluble natural compounds, i. e., rocks and minerals, which assures that no pronounced imbalance is likely. Industrial minerals and rocks seem to be the best materials available for that purpose.

Cobalt deficiencies have been very serious in Australia, New Zealand, Scotland and in the United States along the coastal plain from Texas to the Carolinas, in Illinois, Wisconsin, Michigan, California, and elsewhere. Although the deficiency is recognized in ill, stunted, and non-fertile cattle and sheep, the correction must come mainly by additions to soil and thence to the animals by way of plants and food. Cobalt bearing sulfides are potential raw material sources for soil supplements. Gradual oxidation of the sulfide and accompanying solution of the cobalt can be expected to furnish trace amounts for an extended time interval. Other cobalt compounds than sulfides will serve as well as they release the metal cation.

The use of copper has shown amazing increases in production of sugar cane in Florida, and has proved notably beneficial in the growth of citrus fruits in both California and Florida. It is being used with manganese and cobalt in Missouri in experiments to control Bangs disease in cattle and undulant fever in human beings. Copper appears to be very effective and absolutely indispensable in activating or promoting the utilization of other trace elements and probably even N-P-K in a combined action. Currently copper sulfate is being added to the soil and in the form of sprays on foliage. However, because of the high solubility of copper sulphate there is grave danger of it being leached away by rain and descending ground water so quickly that much of it is lost before being picked up by plants. Small scale experiments are the basis of this warning. The use of copper carbonate or sulfide ores in soil additions would eliminate the hazard of high solubility, and still free enough of the element in slow solution to be effective.

Zinc has been found beneficial to citrus groves (often sprayed on in Florida and California) and zinc deficiencies are also recognized in other soils, especially those which are old and long-weathered. Sphalerite and smithsonite will furnish zinc readily upon weathering; the rate of delivery from hemimorphite, willemite, or zincite might be slower.

Boron seems to be adequately supplied from borates and associated boron-containing minerals.

Molybdenum, which is needed in trace amounts, may be added as one of the few minerals in which it occurs.

The amount of each trace element needed by any particular soil depends in part upon the total content of that element in the soil, and the availability of it. These two occurrences may be radically different. For example, boron from borax is immediately available, whereas the boron in tourmaline silt particles is almost inextricably locked up. The availability may vary further with the acidity (pH) of the soil.

Manganese is commonly present in soils from 50 to several hundred parts per million. Copper is often present up to 50 parts per million, whereas cobalt is less abundant, perhaps 10 to 15 parts per million. Zinc varies widely in total content, probably because it may locate in the clay crystal lattice.

It is impossible to specify in this paper how many pounds of ore or rock constitute a replenishing or a therapeutic dose for soils in general. It is apparent however, that 100 pounds of Mn (elemental) will supply 50 parts per million of Mn per acre, taking the weight of the top soil (about 6.66 inches) as 2 million pounds per acre and therefore 1000 pounds of Mn ore supplying 10% elemental Mn will be required.

Similar examples may be set up for Cu, Co, Zn, Mo, and other elements.

Non-obvious Sources Need to be Explored

The sources enumerated previously for inorganic nutrient elements are mainly those which are obvious[8] to almost all geologists. The knowledge of other uncommon and unique deposits, special rocks, or unusual occurrences will fall within the special experience of most readers, and may be utilized accordingly.

Certain limestones now rejected because of their "impurities" may command a premium position because of those very accessories.[9] Phosphate, for example, can hardly be deleterious. Glauconitic dolomite will supply at least three cations (Ca, Mg, K). Spectrographic analyses of limestones in Missouri show their barium content to range from less than .00005 to 0.2 per cent of the rock, and strontium occurs up to 0.3 per cent. Manganese is present up to .06 per cent, copper up to .01 per cent, zinc rarely, but up to .01 per cent, chromium up to .05 per cent, and boron up to .01 per cent, all expressed as the element analyzed for, in the bulk stone. Other elements which occur infrequently, and usually only in thousandths of per cent of the limestones, include Ni, Pb, Mo, Cd, V, Sn, and Ag. Wide variations in composition occur within a single limestone formation; it seems probable from one set of rather meager data that trace element compositions may be more constant in a section vertically within one region (because of risen mineralizing solutions?) than laterally within a single bed. Hence, numerous analyses of formations may reveal local deposits of stone which have unique compositions peculiarly valuable for agricultural purposes.

Because most soils within the intensive agricultural belts require periodic liming it is suggested that minerals containing trace elements be added at the same time in an agstone blend to produce a "fortified" agstone. Just as concentrated commercial fertilizers may be "tailor-made" for a particular agricultural need, so may native rock and mineral plant foods be similarly blended. The practice of adding inert, almost useless silica sand as a dilutent filler in commercial fertilizers should be discontinued, and some crushed rock or low grade ore (like low grade manganese ore, glauconitic dolomite, phosphatic limestone, slag, K-feldspathoid rock, etc.) be substituted.

Optimum blends and combinations will result when there is close cooperation between soils men who have determined their plant food needs, and geologists who know what they can furnish within a certain area. For instance, in one locality a dolomite formation may be the best source of Ca and Mg, in another it may be rock from a mine dump, a furnace slag in a third, and in a fourth it may be calcium limestone and magnesium from one of the K-Mg-sulfates of the evaporites. We must realize that the objective is to furnish nutrient elements rather than rocks (Ca instead of limestone) as the end, and that the various rocks and minerals are the means toward the end. By proceeding from that idea, wide combinations of many rocks, minerals, and by-products become feasible and potential marketable products. Increased utilization of industrial minerals and rocks in the field of plant foods will be accelerated by geologists who are alert, offer their assistance to the agricultural consumers, and take advantage of the rapidly expanding market in soil supplements.

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MARINE CLAY OF THE PORTLAND-SEBAGO, MAINE, REGION

By LAWRENCE GOLDTHWAIT

Introduction

A study of the marine clay in the Portland-Sebago region has been carried out as a continuation of the more general clay survey of the State of Maine. This general survey was made by Miller and Savage in the summer of 1946 and by Koons and Donohue the following summer. In 1948 the southwestern portion of the State particularly was studied by Goldthwait and E. Cormier. A summary of this work may be found in the Report of the State Geologist 1947-1948.

The purpose of the earlier surveys was primarily to determine the general distribution of clay in the State. Because of the many problems raised by earlier fieldwork it was felt that a more detailed study of a selected area was essential to a better understanding of the clay, its distribution, and its origin. For a month during each of the summers of 1949 (by Goldthwait and C. Robbins) and 1950 (by Goldthwait and F. Haley) such a program was carried out on clay in the Portland-Sebago region. This report attempts to summarize the two month's fieldwork.

A somewhat similar survey of the marine clay of southwestern New Hampshire is being carried out by Goldthwait for the New Hampshire State Planning and Development Commission.

Discussion of the Clay

General Considerations. Fieldwork covered the Portland quadrangle, most of the Gray quadrangle, and small portions of the adjoining Sebago, Buxton, and Freeport quadrangles. These are all of the 15-minute series. Emphasis was put on the relationship of the various glacio-fluvial deposits to the clay. Clay is found from the ocean to about 24 miles inland near the northwest edge of Sebago Lake. Occurring particularly in the valleys, the elevation of the clay increases to the northwest generally reaching about 300 feet above sea level at the highest.

Generally the clay rests on bedrock, till, or gravel although many cases of gravel and sand overlying the clay were observed.

No map of the clay has been made beyond the generalized map in the 1947-1948 Report. In order to work out the bounds of the clay and gravel in detail, fieldwork much beyond the scope of the present survey would be required. The reason for this lies in part in the fact that much clay is hidden beneath other deposits.

Analyses of 43 clay samples were made by E. Cormier in the spring of 1949. Results indicate that the clay actually averaged 39% clay, 37½% silt, and 23½% sand. Individual samples varied considerably from these figures. Of the clay-silt fraction alone 51% was clay. This compares with earlier analyses of 45% clay in the clay-silt fraction for samples collected widely from the coastal part of Maine.

Field methods. In order to discover the general distribution of the clay, most of the roads in the region were traversed. This was supplemented by a considerable amount of footwork. Verification of the limits of clay, thickness of clay, depth below the surface, and characteristics of deeper clay were derived in part from literally hundreds of auger holes from 3 to 21 feet deep. All available exposures of clay, such as gravel pits, roadcuts, etc., were studied. 41 clay samples taken during the summer of 1948 have been analyzed for grain size, specific gravity, liquid limit, and plastic limit. 4 special samples were studied for organic content and carbonate content. These analyses are available from the State Geologist. More samples have been taken, but have not yet been analyzed. Diatoms have been separated from the clay, but have not yet been positively identified.

Special mention should be made of a continuous exposure from three to twelve feet deep made in the construction of a pipeline from Portland to Montreal. This pipeline extends from Portland through the center of the region under study and passes the east side of Sebago Lake. Observations along this entire section of exposure were made.

Color. In many of the deeper sections of clay there are two colors evident. The upper is brown, with the blue-gray beneath. In some localities only one color is found.

Analyses of the clay samples include both brown and blue clay from each of five different localities. The following comparisons indicate, on the bases of these few samples, few consistent differences except in color.

A comparison of grain sizes shows that in 3 of the pairs of samples (of brown and blue clay) the blue contained more clay than the brown. Samples from the other two localities showed more clay in the brown. Quick examination in the field often suggests that the blue characteristically contains more clay than the brown, but such observations have often proved erroneous against laboratory analysis. It is obvious however that at many localities there are marked variations in grain size in the clay in small vertical distances. The analyses bear this out.

At one locality there was opportunity to collect brown and blue clay samples as well as samples from a modern marsh only 10 feet away. Analysis indicated that while the marine brown and blue clay contained 45 and 47 per cent clay, the modern marsh had only 30 per cent.

The only consistent difference between the brown and blue clay for the five localities analyzed was in specific gravity. The blue always ran somewhat higher, averaging about .04 higher and with the maximum difference in one locality of .07.

Liquid limit comparisons indicate that the blue had the higher liquid limit than the brown at two localities, lower at two localities, and equal at the fifth. There was likewise lack of consistency in the plastic limit for the brown and blue clay, with the lower blue having a higher plastic limit in three of the five cases.

Comparisons of the brown and blue clay showed similar organic content in both cases while the carbonate content was variable.

These few samples indicate that there are not consistent differences between the upper brown and the lower blue clay except in color, specific gravity and perhaps organic content. To be sure, there have been only five localities used in these tests, (two in the case of the organic content), but the general lack of consistent differences is worth noting. The brown and blue clays seem to be much alike, and highly variable.

At exposures where both colors are seen in the Portland-Sebago region, the contact often consists of a mixed or graded zone between the two colors. This zone often is typical of weathering, with the brown working down into the blue somewhat irregularly. There may be found in places a somewhat higher concentration of limonite in this boundary zone. The colors of the limonite, and the nature of the mixed zone all strikingly resemble conditions found between the brown and blue glacial till in New Hampshire. Both types of deposits, although much different in origin, appear to have been partially oxidized from the original blue into the brown of the upper clay or till. The depth of the oxidation in the field always appears to be related to the depth of water table, the bottom of the brown approximates the water table. In swamp areas where the water table is at or near the surface, the brown clay is absent.

Upper clay limits. Marine clay has been found as high as 440 feet above sea level in the State (near the northern edge of the town of Farmington) and up to about 300 feet in the Portland-Sebago area north of Raymond between Panther Pond and Thomas Pond and in a kettle hole two miles south of Raymond.

During the summer of 1949 an effort was made to locate the highest reach of the clay in various sections of the Portland-Sebago region. The upper limit of the clay was checked by many auger holes and elevations were taken by barometer at approximately 75 localities. An isarithmic map showing the highest elevations of the clay was made. In constructing the map it became evident that the edge of the clay was not always uniform even at nearby places although a general increase of elevation toward the northwest showed. Also the effect of topography was evident particularly in the Presumpscot Valley and on the higher hills northwest of Gorham and in Windham.

The fact that the clay limits were not always uniform in nearby places, that they lacked a uniform increase of elevation to the north or northwest, as well as the relationship to topography, all suggest that the clay does not mark the upper reach of water in which the clay was laid down. If the marine clay had been laid down as it is today in our present salt marshes, one would expect to find a much more uniform pattern of the upper clay limits. Either the clay was not laid down up to the water level or it has been washed and removed unevenly following deposition. And the utter lack of clay above 300 feet suggests that the ocean did not reach appreciably higher than 300 feet in this region.

Washing. Ultimately the ocean retreated from the land to its present position or perhaps lower. While this emergence was going on, the unconsolidated sediments were exposed to wave and current action. It is to be expected that signs of washing are found.

Generally, the clay today is found in valleys, depressions, and pockets, and less commonly in the more exposed sites. Gently sloping bedrock knobs protruding only a few feet above the sand, gravel, or clay are washed free of unconsolidated mantle. This is quite generally the case. Knobs of till protrude through sand, gravel, or clay. There are several conspicuous localities where the till is fairly thick above elevations of 300 feet in situations where one would expect excessive washing if exposed to wave and current work.

As mentioned above, the fact that the upper reaches of clay often are not uniform within short distances may also be the result of washing and removal of clay from the upper slopes.

The relationship of the gravel and sand to clay is particularly suggestive of washing. For example, a sandpit near Cash Corner in South Portland located at the edge of a large level sand plain has exposed the inclined contact where clay from the nearby valley overlaps the sand. The clay, the sand, and the inclined contact have been cut off at the top to produce a level surface. (See Figure 1.)

Literally scores of sections and auger holes indicate that sand and gravel have been washed down from nearby higher deposits on top of the clay. This cover thins away from the sand and gravel source until there is no cover over the clay. Such a sequence was repeatedly observed in the continuous section along the pipeline. Such washing can be found not only in the lower more coastal sections of the region but also in the Sebago and Gray sections.

Waterplanes. Fossils as well as the distribution, and nature of the clay indicate a marine origin. It is reasonable therefore to expect to find evidence of wave and current work in the form of spits, beaches, cliffing, etc. A careful lookout for clear-cut shoreline features has been kept and very few have been found. It has long been the experience of others in Maine and New Hampshire to remark upon the lack of clear evidence of wave and current work on unconsolidated sediments in exposed positions. The scarcity of wave work has been attributed to constantly fluctuating sea level and to possible protection by ice. Shoreline features, if made, certainly would have been modified by frost, creep, and other forms of mass-wasting.

However there are two or three places in the region studied that look as though they are traces of waterplanes. The topographic appearance is supplemented by the sequence of sediments.

The best example was located in East Gray. A large nearly level plain of sand and gravel extends eastward to the valley occupied by the Royal River which is roughly 200 feet lower. The upper edge of the gravel plain is at an elevation of 325 feet. From this edge there is a steep slope dropping to about 305 feet. (See Figure 2.) Beyond this for about 970 feet there is a very gentle slope of sand and gravel down to the highest elevation of clay (here at 266 feet). A vertical section at this point shows 2½ feet of sand, 2 inches of clay with sand and gravel beneath. 50 feet farther downslope there is three and a half feet of sand over four inches of clay, with sand beneath. At 57 feet beyond this, and from here on, there is clay to depths of more than 15 feet, the bottom of the clay beyond the reach of augering. The photograph (Figure 2) shows the flat sand and gravel plain on the right, the steep slope changing to a gentle slope below.

About 6 miles south of the village of Gray there is a drumlin-like hill known as Poplar Ridge. It is fairly even-sloped, and from all observations made, appears to be entirely of glacial till, at least to depths of more than ten feet in places. This hill rises abruptly out of a fairly level apron of sand and gravel around the northeast, east, south, and southwest sides, the elevation of which is about 300 feet. Down the gentle slope to the east clay is found as high as 227 feet. This suggests that the ocean reached to approximately the level of the apron, depositing the clay in the deeper water. The rather uniform slope of the hill and lack of evidence of washing suggests that the ocean did not reach as high as the till. The elevation of the apron at Poplar Ridge is about the same as the possible waterplane recorded at East Gray, a distance of about 4½ miles.

If these two localities do represent work by waves and currents the question is raised whether they represent the highest reach of the ocean in this area, or whether they indicate temporary halts as the ocean was receding. So far, in this region, clay has not been found at higher elevations than the possible strandline, in spite of a rather intense search. Since there are many favorable spots for clay at elevations above 300 feet where no clay has been found it may be that the upper reach of the ocean has been marked. It is felt that, of the possible evidence of marine advance, the marine clay is the best proof. Terraces and deltas, as well as raised beaches, which are used by some to indicate marine levels in Maine, may be interpreted to be of non-marine origin.

An interesting relationship exists between the clay and a large kettle at East Gray, within a mile of the described strandline and within the same large gravelly plain. This kettle, called by Perkins[1] the largest in Maine, is roughly ¾ of a mile long by ¼ of a mile across and has a

[1]Perkins, E. H. (1935) "*Glacial Geology of Maine*," Maine Tech. Exper. Sta., Bull. 30, Vol. 2, p. 50.

maximum depth of roughly 100 feet. The sides are steep, mostly at the angle of repose, and eskerlike ridges surround smaller kettles on the sides and floor. A threshold of gravel separates the kettle from the valley of the Royal River. Clay extends up the side of this valley to an elevation of 254 feet. Since the lowest part of the rim is 308 feet above sea level the bottom of the kettle is about 54 feet below the upper reach of the clay less than $\frac{1}{4}$ mile away, and about 66 feet below clay a mile distant. An extensive search within the kettle supplemented by considerable augering failed to find any trace of clay.

This lack of clay in the kettle suggests either that the ocean did not reach to 308 feet so as to flood the kettle, or that ice remained in the kettle during the time that the ocean might have been higher. If the ocean did not reach as high as the kettle rim so as to flood it, then the possible strandline nearby, with its related clay, represents the highest reach of the ocean in post-glacial time in this region.

The possibility that the kettle was ice-filled for the duration of the highest submergence appears unlikely. The steep slopes and pitted sides of the kettle are not suggestive of washing. It has been mentioned that clay generally is found in the valleys, and parts or most of many of these valleys have been cut in plains of outwash gravels. Perhaps the best example is the valley of the Nonesuch River which is, in places, over 80 feet deep, and less than $\frac{1}{4}$ mile wide, having short, steep-sided tributaries. Almost the entire river is cut into a large outwash plain of gravel and sand. Clay is found in many patches in the valley but the bulk of the surrounding plain appears to be of sand and gravel. Other shallower valleys are similar. Such a relationship of the clay to outwash deposits suggests that the outwash was laid down and eroded by subaerial erosion before marine invasion and resultant clay deposition. It would seem that any ice which produced the large kettle at East Gray would have disappeared well before valleys, such as the Nonesuch, would have been carved. If the sequence of outwash deposition and subaerial erosion came before marine submergence then it seems likely that the kettle at East Gray was above the marine limit, and the supposed strandline represents the uppermost extent of the sea in post-glacial time.

It should be mentioned that one of the highest places where clay was found in this region was in a smaller kettle near the northwest end of Sebago Lake. The ice in this smaller kettle melted out before the ocean retreated to lower elevations.

Depth of water. The described strandline takes on added significance if it represents the highest reach of the ocean. As mentioned above, the base of the steep slope of the strandline is about 305 feet, so that the sea level must have been close to that elevation. The highest clay immediately down the gentle slope is 266 feet in elevation. This would mean that the clay could be deposited in water as little as 35 to 39 feet deep. Possibly it could have been deposited in shallower water, and the upper portions having been removed as the ocean level dropped. But again, it appears unlikely that the clay was laid down in the fashion of modern salt marsh deposits.

Time of deposition. The marine clay presumably is made of fine sand, silt, and clay washed into the ocean, at the time of melting of the ice sheet, by melt water streams flowing from the north or northwest. In every instance that the relationship of clay to till has been observed the clay has always been on top, therefore the clay is younger. Also the clay generally rests on gravel. Sand and gravel are found on top of clay only to a limited extent and the thickness is usually a matter of a few feet. It is believed that it was washed onto the clay from nearby higher ground. The continuous section provided by the pipeline indicates this to be the case over and over again.

In the coastal portions of Maine and New Hampshire, where there is only slight relief to the land, much of the sand and gravel takes the form of outwash plains. There is a complete lack of eskers, steep-sided kames, and other ice-contact deposits at the surface. There is a possibility that such deposits are buried beneath the clay and gravel. Ice contact deposits are found in areas of greater relief in the northerly sections of this region. In the Gray and Windham sections there are kames, kame terraces, and crevasse fillings. The clay laps onto the sides of such deposits or covers them, and there is never any extensive gravel overlying the clay. The record consistently shows the clay to be younger. In a number of these cases the clay has been removed from the crests, presumably by wave wash, while it remains on the sides.

Some kettles have clay in them, suggesting again that the clay was laid down after the gravels. If the Sebago Lake basin may be considered a kettle, and the deposits around the fringes of the lake suggest this, then the ocean apparently invaded this depression. Since the 1948 report, clay has been found at several localities around the lake as well as on Fyre Island in the lake. There are many reports of clay on the lake floor in a variety of locations.

The hypothesis of a readvance of the ice to partially cover the clay with outwash sands and gravel has been entertained, but extensive readvance appears very unlikely. There is apparently only one till age. Stratification in the lower gravels shows no disturbance. Stratification in the marine clay, which is not at all uncommon, has shown disturbance at only a few of the hundreds of good sections observed. From the nature of the disturbance it is clear that it was caused by slumping of the clay down slope.

Again, relative to the time of deposition of the clay it seems very likely that this followed at least a short period of subaerial erosion. This is an exceedingly important concept, for it implies the possibility that some of the gravels were laid down on land, and not in the ocean as had been thought by some. Following this deposition and erosion of sand and gravel came the invasion of the sea and subsequent wave wash of some of these materials over the clay.

One point concerning the time relationship of the clay deposition to gravel should be clearly made. And that is, that the above sequence and timing applies strictly to the Portland-Sebago area, and not to the whole coastal area of Maine submerged by the ocean in portglacial time. Reconnaissance fieldwork suggests that what applies to the Portland-Sebago area applies to the coastal area southwestward through New Hampshire, but very likely may not apply to deposits to the east.

Warping. The nature of warping in post-glacial time has been considered in the field, but little help has come in the study of this area. It is known that the ocean reached an elevation inland of about 300 feet. But the only answer as to the depth of water in which the clay was laid down is near the northern border of marine invasion at East Gray as described. No evidence has been found to suggest whether the clay in the lower portions of the area was laid in deep or shallow water. Therefore it is not known whether the ocean came onto the land, or retreated, with no tilting of the land or whether the upwarping became progressively greater inland. Only submergence is evident.

Clay mounds. A nest of kamelike mounds, consisting entirely of clay, approximately 15 feet high and with gentle slopes was found about a mile west of Gray. (See Figure 3.) A four-foot excavation failed to show any bedding and none was apparent in the auger cores. True gravel kames veneered with clay had been found in the vicinity. The clay mounds did not follow any pattern to suggest that they were carved by streams, but a series of seven auger holes indicated rather that they reflected the irregular bedrock beneath, which was at a depth of eight to twelve feet and greater. It seems therefore that these mounds have neither gravel nor the structure to suggest a kame origin. Rather the undulations seem to be an expression of the uneven bedrock beneath.

Two tills. A large pit at Pleasant Hill in the town of Scarboro was described by Perkins[1] to consist of two layers of till separated by fine foreset sand. This locality was repeatedly visited during the last two summers and extensive exposures have been observed. On the north, east, and south sides exposures of a maximum depth of nearly 70 feet and a bedrock floor could be seen. As excavations progressed there was no trace of glacial till except for one 20′ patch in gravel which was removed by later excavation. Sand and gravel were generally patchy and irregular, although stratification was well preserved, and clay lapped onto the edge of the deposit.

The other exposure of till located in a pit ¼ mile E. of W. Kennebunk is about 4 miles from the locality where Sayles and Antevs[2] described three tills. About three feet of till showed for about fifteen feet along the floor of the pit. This was covered by steeply dipping well stratified sandy gravel. Two small patches of till completely surrounded by gravel were nearby. There was no trace of other till and excellent exposures were observed on all sides of the large pit.

It appears that at least some of the exposures of till over gravel are small isolated masses and do not record a general readvance of the ice.

Summary. Based on recent fieldwork the late glacial and early postglacial history of the Portland-Sebago region appears to be as follows. With the melting of the glacier, kames, crevasse fillings, kame terraces, and particularly outwash plains of sand and gravel, were laid down. This was followed by a short period of subaerial erosion of the gravel deposits. Then came the marine invasion to a maximum elevation of about 300 feet and deposition of the clay. As the ocean receded there was extensive washing by waves and currents. The clay was deposited in water as shallow as 40 feet deep or less. Since the clay was laid down oxidation has changed the color of the blue clay to brown above the water table. The nature of warping cannot be worked out on the basis of field observations at present.

[1]Perkins, E. H. (1935). "Glacial Geology of Maine," Maine Tech. Exper. Sta., Bull. 30, Vol. 2, p. 89.

[2]Sayles, R. W. and Antevs, E. (1927). Bull. Geol. Soc. Amer. Vol. 38, pp. 142-143.

Figure 1. Sandpit near Cash Corner, S. Portland. Clay overlying sand (contact marked by broken line).

Figure 2. Possible strandline at E. Gray. Gravel plain surface in foreground. Steep slope changing to gentle in background, to left of barn.

Figure 3. Clay mounds 1 mile west of Gray.

ASBESTOS AND SERPENTINE ROCKS OF MAINE

By LAWRENCE A. WING

Introduction

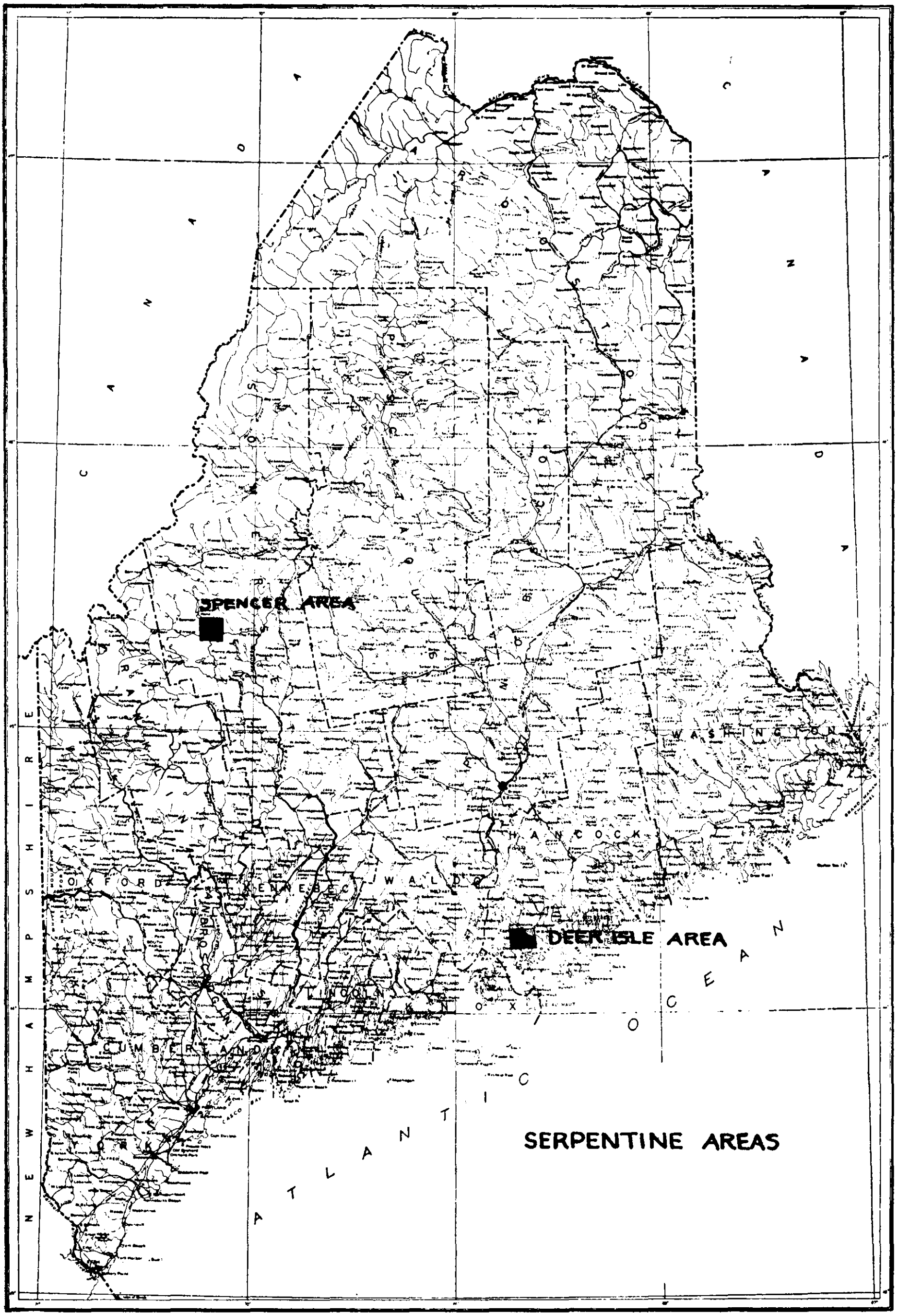
Occurrences of asbestos have been reported in the past from several sections of the state. An investigation of the reported occurrences and other similar areas has been carried on by the Maine Geological Survey during the field seasons 1947 through 1950. A preliminary report covering the work of 1947 and 1948 has been previously published in the Report of the State Geologist for those years. Field work is now completed and this report is a summary of the findings.

The field parties for this project were under the direction of Dr. Joseph M. Trefethen, State Geologist, and consisted of Lawrence A. Wing of the Maine Geological Survey with Robert Chase as field assistant in 1947, Raymond Woodman, Jr., in 1948, William Linton in 1949, and Sylvio Cyr in 1950. Arthur S. Dawson, geologist for the Canadian Pacific Railway Company, worked in cooperation with the survey during the seasons of 1947 and 1948. Final drafting of the maps was done by the author and Frank Nickerson.

The purpose of the investigation was to map and evaluate the known occurrences of asbestos as well as examine additional areas that might be favorable for the presence of this mineral. The work was accomplished by pace and compass mapping of a reconnaissance nature on a scale of about one inch to the mile. Plane table mapping and larger scales were used in the more promising localities.

Field Problems

Asbestos is a term used to identify several fibrous forms of the mineral serpentine. Commercial deposits of asbestos are known to occur only within large masses of serpentine. Small deposits, of no economic significance, may occur in other rock types. However, many large masses of serpentine are known to exist that do not carry asbestos. This association clearly points out a two-fold problem of exploration: first, the examination of known occurrences of serpentine to discover the presence, if any, of asbestos; second, the search for new areas of serpentine and possibly associated asbestos.


NEW HAMPSHIRE
CANADA
SPENCER AREA
DEER ISLE AREA
OXFORD
CUMBERLAND
YORK
WALDO
HANCOCK
WASHINGTON
ATLANTIC OCEAN
SERPENTINE AREAS
Figure 1

In early phases of the field work it was noted that bodies of serpentine were located in close proximity with the rock greenstone. No geological relationship is known to exist between these two rock types but considerable reconnaissance work was carried on in and around the greenstones. The work on the greenstones is summarized in another part of this Report, see page 47.

General Locations

Large masses of serpentine have been mapped at two places within the state, designated as the Spencer Area and the Deer Isle Area for the purposes of this report. The Spencer Area lies about in the center of Somerset County in the vicinity of Little Spencer Stream, the Deer Isle Area covers part of Deer Isle and Little Deer Isle in the southeastern portion of Hancock County. These areas are outlined on the map shown in Figure 1 and are described under separate headings.

Additional occurrences of serpentine have been noted in other parts of the state. Those examined were too small to warrant detailed mapping.

THE SPENCER AREA

This area straddles the Little Spencer Stream about three miles below the outlet of Spencer Lake. It is accessible by trails and logging roads passable to horses and tractors. The asbestos prospect may be approached from both east and north. A passable truck road, starting from Route 201 about three miles north from The Forks, passes westerly to within about ten miles of the Little Spencer Stream. The remaining ten miles are served by logging roads. A good private road exists from Route 201 to the northern end of Spencer Lake and a logging road from the south end of the lake connects to the deposit.

Previous Work

The sediments and greenstone of the area are shown on the Preliminary Geologic Map of Maine by Keith.[1]

Wing[2] and Dawson reported on the asbestos and associated rocks in 1948. The results of an airborne magnetometer survey of the area

[1]Published by the Maine Geological Survey, Orono, Maine, 1933.

[2]Wing, L. A. and Dawson, A. S.: "Preliminary Report on Asbestos and Associated Rocks of Northwestern Maine"; Report of the State Geologist 1947-48; Maine Geological Survey, Orono, Maine.

have been reported on by Hurley[1] and Thompson. Woodard[2] has reported on an area a few miles to the north.

The serpentine body on Little Spencer Stream has been prospected and diamond drilled by two asbestos companies in 1948 and 1950 but results of their work have not yet been published. Work has not progressed beyond the exploration stage.

General Geology

Rocks of the Spencer Area consist of the greenstone volcanics, Siluro-Devonian sediments, and a series of minor intrusives.

The sedimentary rocks have been mapped as two formations, the Moose River Sandstone of lower Devonian age (Oriskany) and the Silurian (?) sediments that have not yet been correlated to any known formation.

Most common to the region are the Silurian sediments made up chiefly of sandstones and shales with thin beds of quartzite and some limey shale. This formation is confined to the central and southern portions of the map. The Silurian age has been adopted from Keith.[3]

Perkins[4] has also tentatively placed corresponding sediments to the south of the Moose River Sandstone as of Silurian age. He states that the rocks to the south are in apparent structural unconformity with the Moose River Sandstone and are much more highly metamorphosed.

The less extensive formation, the Moose River Sandstone, crosses the northern limits of the map but the boundary here has not been clearly defined either by location or its nature.

The volcanics of the mapped area consist of two belts of greenstone trending east-west through the central portion of the map. This rock is believed to be of Silurian age and is discussed in detail in the report on greenstones found in another section of this report.

Minor intrusive bodies in the form of dikes and sills are found throughout the area of Silurian rocks. They seem somewhat more common in the southern part of the mapped area. Granite, diorite, quartz diorite, and some diabase are the rock types present. The serpentine bodies may have originally been intrusive sills.

[1]Hurley, P. M. and Thompson, J. B.: "Airborne Magnetometer and Geological Reconnaissance Survey in Northwestern Maine"; G.S.A. Bull., Vol. 61, No. 8, 1950.

[2]Woodard, H. H.: Published in this report, page 68.

[3]Op. cit.

[4]Perkins, E. H.: "Contributions to the Geology of Maine, Number 2. Part I, The Moose River Sandstone and its Associated Formations"; Am. Jour. of Sci., Vol. X, October, 1925.

Structure

The area mapped has not yielded enough information to give a complete picture of structure. The major structure as stated by Perkins[1] would be a syncline with the Devonian sandstone to the north occupying the core section. Hurley[1] has interpreted the southern contact of the Devonian as a thrust fault. The sediments in the vicinity of the serpentine bodies show a fairly consistent strike slightly north of east with steep dips both north and south. Slaty cleavage in most sections is about parallel to bedding.

A well developed fold was found in the Spencer Stream a short distance below Spencer Gut. The fold axis strikes sixty-five degrees east of north and plunges about forty-five degrees to the northeast. This reading is confirmed by the bedding and cleavage relations shown on the Little Spencer Stream both above and below the occurrence of serpentine on the stream. The relationship between bedding and cleavage in the vicinity of the serpentine body show the area as an anticline plunging to the east with the serpentine somewhere in the central section. The steepness of the beds and the scarcity of outcrops in critical areas leave room for much error in any interpretation of structure.

Several small faults have been mapped in detail in the serpentine and many others may exist. Major faulting is not indicated from the surface outcrops with the possible exception of the southern contact of the Devonian as indicated by Hurley.[1]

Structure, insofar as it can be determined, and the geologic contacts are shown on the map in Figure 2.

Serpentine and Asbestos

Two large bodies of serpentine and several small bodies are indicated on Fig. 2. Outcrop maps by pace and compass on a scale of one inch to two-hundred feet were made of the two larger bodies. The detailed map of the serpentine on Little Spencer Stream is shown in Map I. The detailed map of the Stony Brook Mountain serpentine is included in the Report of the State Geologist for 1947-48 but is not reproduced in this report.

Typical serpentine of all the bodies mapped is a dense, dark green to blue material with a greasy luster. It is intersected by closely spaced fracture planes in nearly every conceivable direction. Many

[1]Op. cit.

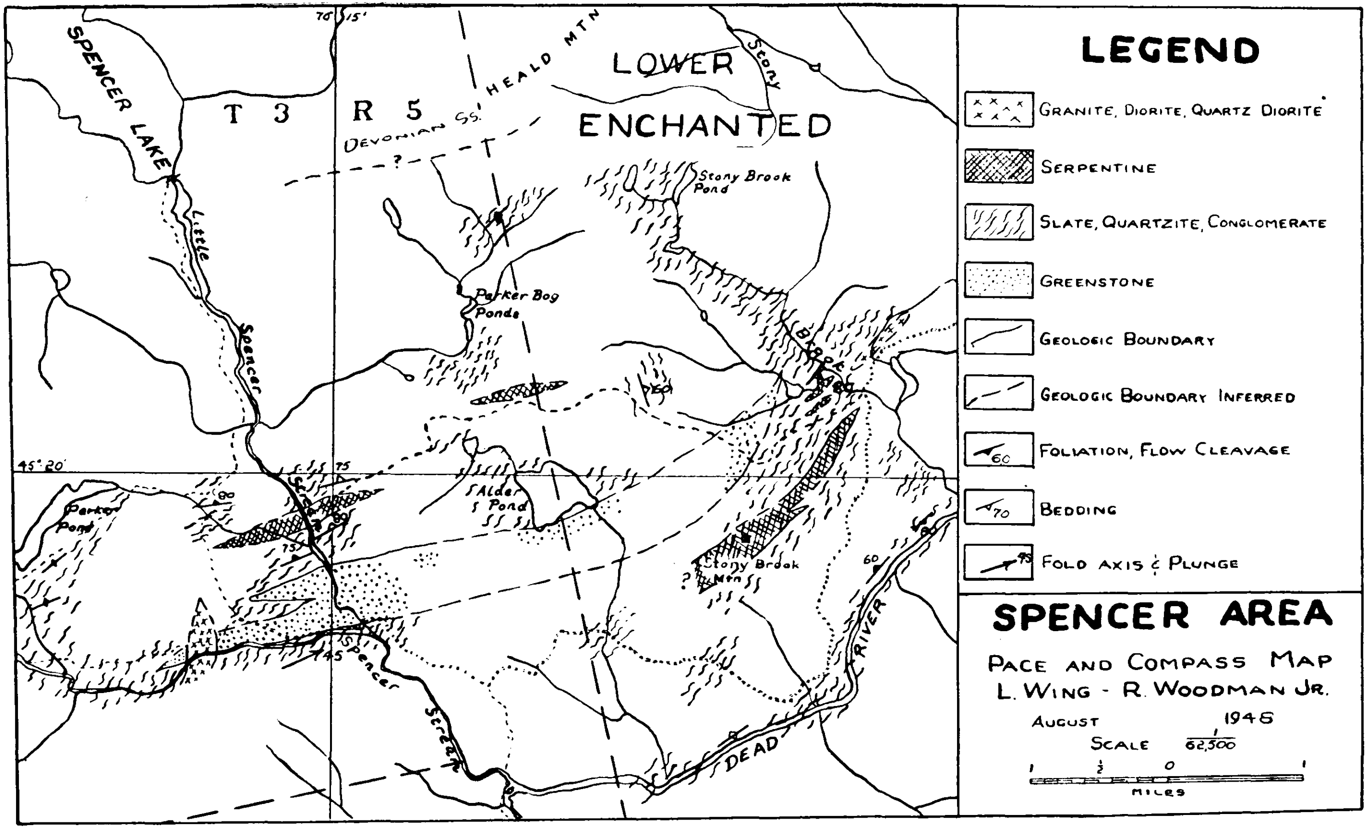

LEGEND
Granite, Diorite, Quartz Diorite
Serpentine
Slate, Quartzite, Conglomerate
Greenstone
Geologic Boundary
Geologic Boundary Inferred
Foliation, Flow Cleavage
Bedding
Fold Axis & Plunge
SPENCER AREA
Pace and Compass Map
L. Wing - R. Woodman Jr.
August 1948
Scale 1/62,500
1 ½ 0 1
Miles
SPENCER LAKE
T 3 R 5
Devonian Ss.
HEALD MTN
LOWER ENCHANTED
Stony
Stony Brook Pond
Little Spencer
Parker Bog Ponds
Alder Pond
Parker Pond
Stony Brook Mtn
Spencer Stream
DEAD RIVER
45° 20'
70° 15'

Figure 2

of these fractures show evidence of slight movement and often contain asbestos in the form of a shear-fiber. Some of the fractures show asbestos as a vein material in the form of cross-fiber.

The only noticeable change in the serpentine is found near the southern contact of the Spencer body and in the isolated outcrops near the south end of Lower Enchanted Pond. At these locations the color of the rock becomes a greenish-grey with many small cleavage planes visible. Thin section study of this rock shows it to be mostly made up of dolomite, which accounts for the cleavages, with talc and serpentine as the next most common constituents. Magnetite and pyrite are present in small amounts. Textural relations would indicate that the dolomite has been partially altered to serpentine and talc, the extent of the original dolomite bed is not known. The magnetite as noted in this rock is also present in the normal serpentine and accounts for the magnetic anomalies of the region.

A sample of serpentine from the western end of the Spencer body was analyzed and showed 0.11 per cent nickel and 0.48 per cent chromium.

Some trace of fiber is present in all of the bodies examined in the Spencer Area. The only body that appears to have asbestos present in concentrations and in large enough volumes to be worth consideration is the one found on the Little Spencer Stream.

Little Spencer Stream Body

The detailed map of this area shown on Map I indicates a body of quite uniform width, 800 to 900 feet, striking slightly north of east and conformable in dip with the surrounding sediments. It can be traced over a length of at least 3000 feet. To the east, under heavy overburden, it is lost to view but may be cut off by a northeasterly trending fault as assumed from dip needle readings. There is no indication of pinching on this end of the body. To the west the serpentine also passes under an area of heavy overburden. One small outcrop was located in 1949 about 2000 feet southwest from the western end of the mapped body, it may be a separate mass or a continuation of the larger mass.

Sediments adjacent to the Spencer mass strike slightly north of east and dip steeply to the north. The serpentine is structurally conformable with the sediments and apparently lies in an anticlinal fold pitching to the northeast.

The origin of the serpentine is obscure. It is possibly a highly altered sill of ultrabasic intrusive material such as a dunite, or an originally thick formation of dolomite almost completely altered, or replaced by serpentine. The dolomite along the southern contact has suggested the latter explanation but this may have been only a thin bed altered along the contact with an intrusive body.

Description of Asbestos.—At least two areas within the serpentine body are appreciably richer in fiber than the remainder of the mass. One area, about 800 feet east from the stream and in the center of the body, shows a width in the north-south direction of about 150 feet and a length of about 200 feet. The second area is about 1400 feet west of the stream and slightly to the south of the center of the body. This zone is about 100 feet wide and 200 feet long. The intervening area between the fiber rich sections is mostly drift covered. The possibility of a continuous fiber bearing zone in the center of the body has been suspected and recommendations to interested parties have pointed out this possibility. Personal communications with members of the drilling crews seem to indicate that such a zone has not yet been proven and the tonnage of known ore is not yet great enough to warrant development in this remote region.

The asbestos of the Spencer area is of the chrysotile variety commonly referred to by the industry as cross-fiber. It may occur in this area in two ways. The least common occurrence is as very small veins with the fiber at high angles to the vein walls. The fiber length in such veins rarely exceeds one-quarter of an inch and the average is closer to one-sixteenth. Veins of this type may be found sparingly in nearly any part of the body but they have not been seen in commercial concentrations. The more common occurrence for the asbestos, and the one that merits consideration from an economic viewpoint, is that referred to by the asbestos industry as shear-fiber. This is the type of material found in the areas mapped as fiber-rich zones. The shear-fiber of the Spencer Area is believed to have been formed by shearing movements on original veins of cross-fiber. Hand specimens give the appearance of a smear or coating on the planes of movements. The individual fibers in this type of occurrence are about of the same length as those noted in the undisturbed veins. Slip-fiber, a more brittle variety of asbestos, is not present in noticeable amounts.

The reason for localization of the fiber-rich areas is not known. It may be structural, compositional, or both. Fracturing is more intense in the fiber-rich areas.

Milling tests on samples taken from the easternmost fiber-bearing zone are reliably reported to have contained a fiber content up to eight per cent, all of short lengths, but good quality. Field examination of both east and west occurrences lead to the belief that percentages of fiber and uniformity would run about the same for both.

THE DEER ISLE AREA

Two separate bodies of serpentine occur in this area, one each on Deer Isle and Little Deer Isle. The location of the bodies is shown on the map Figure 3. Work in this area by the Maine Geological Survey has been restricted to detailed mapping on the serpentine and rocks immediately adjacent. Both bodies are easily accessible by highway.

Figure 3

Key map showing locations, see Map II for Deer Isle andMap III for Little Deer Isle Areas.

Previous Work

The earliest known report on this area mentioning the presence of serpentine is by Jackson[1] in 1838. The next work in the serpentines was done by Merrill[2] in which he described the occurrence on Little Deer Isle. This was followed by the work of Bastin[3] in the Penobscot Bay area published in 1907. The serpentine on Deer Isle has also been indicated by Keith.[4]

A small quarry on the northeastern shore of Deer Isle was operated for building and ornamental stone in the later part of the nineteenth century. A fairly extensive quarry was recently developed on Little Deer Isle for use as a fill material in building the causeway between the islands.

General Geology

The serpentine bodies occur as stock-like masses for the most part surrounded by older rocks. The granite forming a short section along the southern contact on Deer Isle may be younger than the serpentine as noted by the porphyritic texture in the granite close to the contact. The actual contact here is not visible. The small body on Little Deer Isle is completely surrounded by the Castine formation of Bastin[4] which he has mapped as of Cambrian (?) age. This rock also makes up all of the northern contact on Deer Isle with the exception of a short section on the eastern end where the Ellsworth Schist, Cambrian or Precambrian of Bastin, is present for a short section along the shore. The southern contact of this same body has been shown by Bastin as mostly the Castine formation with some granite and some Ellsworth Schist on the eastern end. The Ellsworth Schist here has not been relocated in the current mapping and it appears the contact may well be entirely granite on this end of the body on the south side. The granite appears to be the younger rock, probably Devonian. The Castine formation in the vicinity of the serpentine bodies is predominantly made up of rhyolites ranging from pink to dark grey in color.

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[1]Jackson, C. T.; "Second Report on the Geology of Maine", 1838.

[2]Merrill, G. P.: "On a peridotite from Little Deer Isle, in Penobscot Bay, Maine"; Proc. U. S. Nat. Mus., 1888.

[3]Bastin, E. S.: "Geologic Atlas of the United States, Penobscot Bay Folio, No. 149"; Dept. of the Int., U. S. Geological Survey, Washington, D. C.

[4]Op. cit.

Serpentine and Asbestos

Detailed mapping on the scale of one-hundred feet to the inch was done on the Deer Isle body and on the scale of two-hundred feet to the inch for the Little Deer Isle body. A Lake Superior Model dip needle was used in both areas in the hope that the magnetite associated with the serpentine might make this method useful in determining the location of the contacts in the drift covered areas. Small variations in magnetic readings were noted in the vicinity of the contacts and these are shown on Map II and Map III.

Typical serpentine of this area is a dark green color with a waxy appearance, intersected by bands of nearly black serpentine and occasional bands of lighter colored serpentine. Very fine veins of chrysotile asbestos are present in some localities on the Deer Isle body where they occur as minute discontinuous fracture fillings. The length of the fiber seen did not exceed one-sixteenth of an inch.

Thin sections studied by Bastin[1] and Merrill[1] indicate the serpentine was derived from an igneous rock composed of olivine and pyroxene or olivine and amphibole and that serpentine is now the major constituent of the rock. Some sections show grains of the original minerals that are only partly altered. Considerable magnetite is scattered throughout both bodies and accounts for the small magnetic anomalies.

The asbestos in this area is entirely in the Deer Isle body and even here it is limited to a few local areas near the contacts. The asbestos occurs as a fracture filling with individual veins less than one-sixteenth inch thick and seldom more than a few inches long. The veins generally are closely spaced and parallel. The concentration of fiber in this area is not of any economic significance.

Dip needle mapping around the stock on Little Deer Isle disclosed a peculiarity in magnetic readings that cannot at the time be explained. It can be seen from Map III that a small area on the northern side of the outcrop strongly repels the dip needle to a value of minus twenty degrees, or the needle was pushed twenty degrees above the horizontal. A few feet to the south of this point, in an area too small to plot on the map, the reverse is true. Here the needle swings to a positive value in the order of fifty degrees. Both of these areas differ greatly from the normal readings of the serpentine which ranges from a positive twenty to thirty degrees.

[1]Op. cit.

Conclusions

Field exploration on serpentine and asbestos point out that at the present time the only deposit known to exist within the state that might be worth development is located on Little Spencer Stream in the Spencer Area. Here the rock shows a good percentage of asbestos in some areas and the fiber is of a fair quality. The tonnage of ore, as known to the author at the time of writing, is not sufficient to warrant operation. It is possible that the tonnage figure may be improved by future exploration by interested parties and the possibility of additional bodies within this area cannot be completely discounted.

The other areas of serpentine examined show fiber in small quantities but with little indication of commercial deposits. Reports of fiber of good lengths have long persisted from the Jim Pond Area a few miles west from the town of Eustis. This area has been covered in considerable detail in the course of the survey but no asbestos of value has been seen in the field.

SUMMARY REPORT ON MAINE GREENSTONES

By LAWRENCE A. WING

During the field investigation of asbestos in Maine it was noted that bodies of serpentine and asbestos-bearing serpentine always seemed to occur close to bodies of greenstone. No geological relationship is yet known to exist between these rock types. Considerable exploration was carried out in the greenstone areas during the search for asbestos, many of the areas proved to be barren of asbestos but the information gathered concerning the greenstone and other rock types found in the same regions may be of aid in any future exploration or interpretation of these sections of the state.

The purpose of this report is to describe, in more detail than seemed advisable in the serpentine report, the locations, structural features, and mineralogy of those greenstone bodies seen during the course of the serpentine investigations.

Previous Work

Literature on the greenstones of Maine is not abundant. The only reference used on a state wide basis is the Preliminary Geologic Map of Maine by Keith.[1] Other works used as a reference are applicable to local regions and are mentioned in appropriate sections of the report.

Locations

The northwestern section of the state shows many bodies of greenstone. They seem concentrated in a northeast trending belt about seventy miles wide. The belt extends from the northern ends of Oxford and Franklin Counties to the northeastern part of Aroostook County. Minor areas of greenstone are shown by Keith[2] in the coastal areas around Deer Isle, Mount Desert, and Eastport. These coastal areas have been described in early works by Bastin[3] and are not reviewed in this report.

[1]Published by the Maine Geological Survey, Orono, Maine, 1933.

[2]Op. cit.

[3]Bastin, E. S.; "Geologic Atlas of the United States, Penobscot Bay Folio, No. 149"; Dept. of the Int., U. S. Geological Survey, Washington, D. C.

——————— "Geologic Atlas of the United States, Eastport Folio, No. 192"; Dept. of the Int., U. S. Geological Survey, Washington, D. C.

Mapping

Four of the greenstone bodies shown on Map IV have been mapped on a scale of one inch to the mile while investigating reported occurrences of serpentine in those areas. The Parmachenee Area, the Jim Pond Area, and the Spencer Area have been previously reported on in the Report of the State Geologist for 1947-48. Detailed maps of these areas have been published in this earlier report and are not reproduced here. The Patten Area is new and the map is included in this report as Map V. The remaining areas of greenstone were not mapped in detail but rapid reconnaissance surveys were carried out on and around the bodies and some samples were taken.

Descriptions of Rock Types and Occurrences

The term greenstone has been used as a name for what probably represents several rock types. As used in this state the name implies a dark green, schistose rock, usually of volcanic origin. The rocks are now partially metamorphosed but the original composition probably ranged from basic to intermediate eruptive rocks. Keith lists them as diabase and amygdaloid altered to epidote chlorite schist. This description is too general for many of the rocks as seen in the field.

The numbers and names on Map IV correspond to those following in the text. In some localities thin section study has been done, in others, the rocks are described from megascopic inspection only. The boundaries and structure are described for those regions where they have been studied in detail.

Parmachenee Area—Asbestos was reported from the extreme northern part of Oxford County and exploration was undertaken on the basis of these reports. The region is not easily accessible and is relatively unexplored in a geological sense, therefore, reconnaissance mapping, on the scale of one inch to the mile, seemed more likely to turn up valuable information than any other method.

The greenstone body of this region is well defined as a northeasterly trending belt, about five miles wide where it crosses the New Hampshire boundary and tapering to about one mile on the northern end where it crosses into Quebec. The detailed map of this region may be found in the Report of the State Geologist for 1947-48, where it is described as the Parmachenee Area.

Structure for the region has been determined from the position of flow tops in the greenstone and from the bedding and cleavage relationships in the surrounding sediments. The greenstone occupies a position about in the center of an anticlinal fold plunging twenty to thirty degrees to the northeast. The strike of the axis of the anticline is about twenty degrees east of north and the fold appears to be overturned to the southeast. This structure has also been indicated by Harvie[1] although no description was given in his report.

The volcanics and sediments of the Parmachenee Area were both mapped as Ordovician in the Report of the State Geologist 1947-48. The structural interpretation places the volcanics as slightly older than the surrounding sediments. More recent work indicates a possible Silurian age for these rocks.

The greenstone commonly occurs as a fine-textured, often massive, dark green rock. Well defined pillows and banded flow structure can be seen at a few places. Flow tops can be seen on some exposures where they are characterized by irregular thin bands of dark green to brown chert. Along zones of movement the rock is locally sheared to a highly fissile chlorite schist.

Microscopic examination of the rock shows it to be a highly altered material. Zoisite, epidote, and carbonate are common constituents. The principal ferromagnesian minerals are hornblende, chlorite, and pyroxene. Some sections show small amounts of serpentine. Quartz, biotite, olivine, magnetite, ilmenite, titanite and pyrite are common accessory minerals. A section of the rock from the International Boundary close to the southeastern border of the belt, shows zeolite amygdules of microscopic size.

The greenstone of this region is undoubtedly of volcanic origin and probably represents an original rock somewhere between andesite and olivine basalt in composition.

The Jim Pond Area, like the Parmachenee Area, was mapped on the basis of reported asbestos. Mapping of the region on the scale of one inch to the mile was undertaken with considerable time devoted to the particular area that was reported to have yielded good samples of asbestos. It was concluded that asbestos in commercial quantities was not likely to be found in this area. The map showing this work may be found in the Report of the State Geologist 1947-48.

[1]Harvie, R.: "Asbestos Deposits of the Province of Quebec," Guidebook No. 2, Excursion A9, Can. Dept. of Mines.

One large belt of greenstone passes about through the center of the mapped area. It seems to taper out on the eastern side of the map but the western boundaries are unknown. Within the belt of greenstone are found several occurrences of slate and some rhyolite. The slate and rhyolite occur either as several interbeds or a few beds repeated by tight folding of the entire belt.

Structure of the region has been tentatively described as an anticlinal fold plunging to the southwest. This interpretation is based on minor folding found on Eustis Ridge and on the outcrop distribution. Intense shearing has occurred in some areas and some beds are displaced. Faulting seems likely on this basis but information is not sufficient to determine the position and attitude of the faults.

If a southwesterly plunging anticline is the correct interpretation of structure, the greenstone is slightly older than the sediments. Interbedding is common along the contacts and both sediments and greenstone are taken as Silurian (?) age.

The greenstones of the Jim Pond Area seem to show two distinct rock types. The northern and central part of the belt is made up of a dark green rock, schistose in many places, that closely resembles the greenstone of the Parmachenee Area. Poorly defined pillows are present in many places. Amygdaloidal textures are occasionally seen and pebbles or lenses of jasper are not uncommon in the vicinity of the pillows. This rock is then most likely an original volcanic flow now partly metamorphosed. Thin section study has not been done on this rock but from megascopic study it would appear to be much similar to that seen in the Parmachenee Area.

The greenstone found in the southern part of the belt is a much lighter green in color with minute spots of darker green material. No flow structure or pillow structure was noted in this material. Small veins of intergrown calcite, epidote, and minute quantities of asbestos are found in many places throughout the region showing this light green rock. The veins are not uncommon but are widely spaced. The relations between this light green material and the darker colored greenstone to the north are not known. Field association and mapping would lead to the belief that they are closely associated, but microscopic study is needed before any final conclusions can be drawn.

The Spencer Area, like the two preceding areas, was mapped on a basis of reported serpentine. Here, the results were more encouraging and large bodies of serpentine were mapped. The detailed descriptions are given in another part of this report. Mapping was done on the scale of one inch to the mile and the results may be seen on Figure 2 of the Serpentine Report.

One belt of greenstone was mapped in this area showing a width of about one-half mile and a length of about five miles. The southern edge of the belt passes through the junction of the Spencer Streams and the greater part of the mass lies to the east of this confluence. A general continuation of this belt, or one closely allied, has been noted about two miles to the east of the mapped area.

Structure in this region is complicated by close folding and interpretation is rendered difficult due to the scarcity of outcrops in many of the critical areas. Regional plunge in the vicinity of the greenstone body seems to be from forty-five to sixty degrees in a northeasterly direction and the strike of the fold axes is about sixty-five to eighty degrees east of north. An anticline is indicated from the bedding and cleavage relationship in the vicinity of Little Spencer Stream and another anticline is indicated in the vicinity of Stony Brook where the greenstone belt takes a decided turn to the north and strike of the sediments becomes more nearly north and south. Additional field work in surrounding areas might aid in the structural interpretation of the region.

The greenstone is generally a fine textured, light-to-dark green rock with well defined flow structure present, but rare. Amygdaloidal texture with calcite filling is noted around the southern end of Alder Pond. In all other ways this rock very closely resembles that seen on the southern margin of the belt in the Jim Pond Area, even to the occurrence of the small veins of intergrown calcite, epidote, and asbestos. A volcanic origin for this rock seems likely. Final naming would require thin section study.

1. The greenstone body located on the eastern end of Seboomook Lake and indicated on the Preliminary Geologic Map of Maine was examined very briefly. The greenstone is characterized by a dark green color with strong flow structure present. The flow structure is parallel to bedding, about sixty degrees east of north, and both the sediments and the greenstone are about in a vertical position. Some outcrops of the greenstone show textures somewhat coarser than normally encountered in this type of rock and should afford good opportunities for thin section study.

2. Reconnaissance work was carried out along the lake margins in northern Piscataquis County. The outcrops along part of the shores

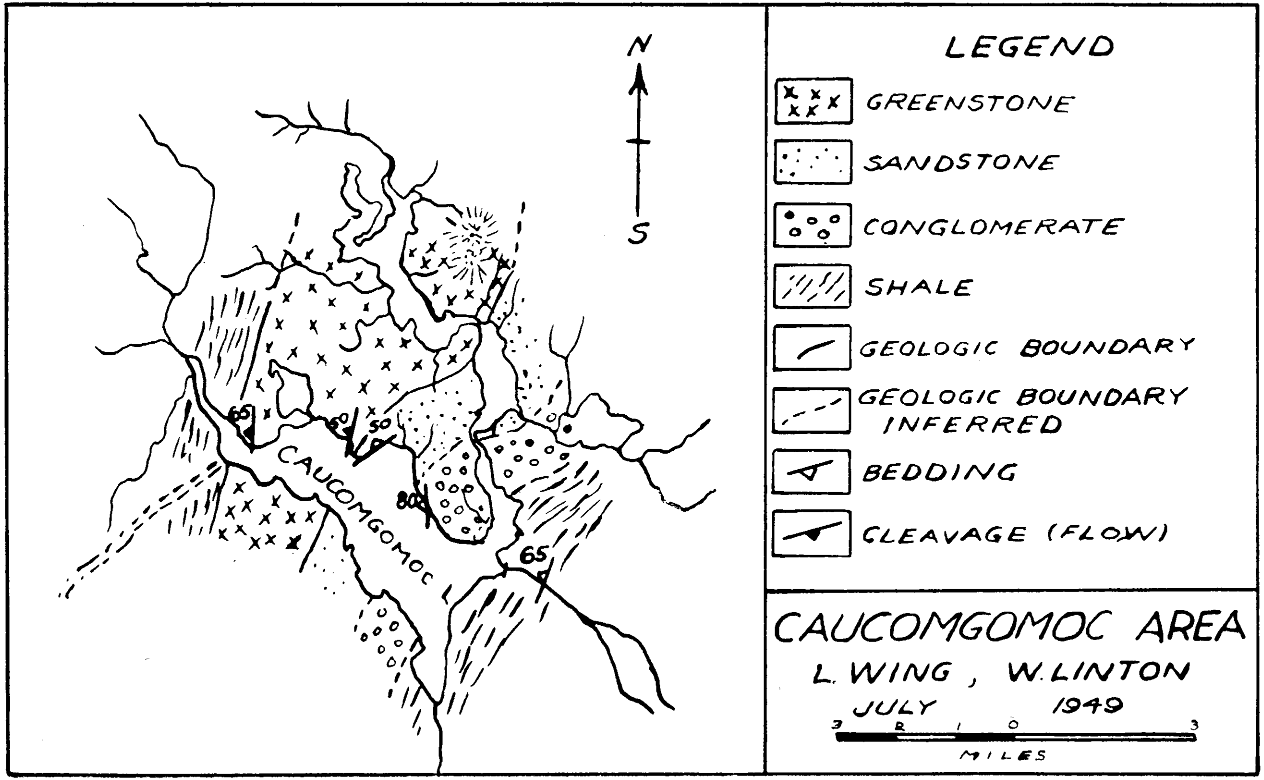
N
S
CAUCOMGOMOC
LEGEND
GREENSTONE
SANDSTONE
CONGLOMERATE
SHALE
GEOLOGIC BOUNDARY
GEOLOGIC BOUNDARY INFERRED
BEDDING
CLEAVAGE (FLOW)
CAUCOMGOMOC AREA
L. WING , W. LINTON
JULY 1949
MILES

Figure 1

of Caucomgomoc Lake, Round Pond, and Poland Pond show a greenstone belt to occur about in the position indicated by Keith. A considerable variety of sedimentary rocks are also present. These rock types and boundaries are indicated on the sketch map shown in Figure 1.

Outline of the bodies, or beds, and structure of the region cannot be determined from the limited amount of work done in this area. Bedding and flow structure range in strike from fifteen degrees west of north to forty degrees east of north. Readings less than twenty degrees from north are most common. The beds and the flow structure dip rather consistently about sixty-five degrees to the west with ranges from fifty to eighty degrees present.

The greenstone is generally fine textured with strong flow structure nearly everywhere present. Pillow structures are common but usually so deformed as to be useless in interpreting top and bottom of the flows. Many small areas show coarser textures much like the rock seen at Seboomook Lake.

Grey slate, grey sandstone, red sandstone, and grey conglomerate are the sedimentary rocks noted. Of these sediments, the red sandstone seems worthy of mention in that it is not a common rock type in this part of the state. Two occurrences are seen in the region on the north shore of Caucomgomoc Lake about in the central portion. The thickness of the beds does not exceed one hundred feet and they may represent a single folded bed. They appear to be structurally conformable with the adjacent grey sandstones which are slightly limey. They are bordered a short distance to the east by the grey conglomerate with pebbles up to three inches in diameter.

3. A pace and compass traverse was carried down Ripogenus Gorge from the foot of Chesuncook Lake for the purpose of locating and studying the contact between the mapped greenstone and the granite to the east, both shown on the Preliminary Geologic Map of Maine. A dip needle traverse was first tried to locate the position of the contact from magnetic variations but this proved unsuccessful. Detailed work in the gorge itself showed the contact to be about one-half mile down the gorge from the dam. The actual contact is not visible here but lies in a weathered depression about thirty feet wide. The greenstone close to the granite shows a lighter color than that some distance away and is appreciably softer. This may be due to effects from the younger granite and also probably accounts for the easily weathered

zone that represents the contact. The normal greenstone away from the contact is a dark green, fine textured rock showing very little structure. The rock could more properly be labeled a diabase rather than a greenstone.

The origin of this rock is obscure but only the contact area was examined. No unusual mineralization was noted in the vicinity of the contact of the diabase with the granite.

Keith has also indicated a greenstone body on the east side of the Katahdin Granite, about due east from the Ripogenus body. An attempt was made to locate this body without success from the northeastern corner of Millinocket Lake. Mud Brook flows into Millinocket Lake at this point and exploration was limited to this brook valley extending about six miles up from the lake. This entire region is covered by glacial drift. Large boulders of the Katahdin Granite are scattered over the surface in great abundance. Deep weathering, sometimes referred to as "rotten stone" is found on the south and southwest side of nearly all the boulders seen and the sand of this region contains grains of feldspar as a common constituent and is mostly a product of disintegration of the granite.

4. A road cut south from Portage Lake, near the point where the town line crosses the highway, shows an outcrop of greenstone. The body here is probably very small, as indicated by Keith. The rock is of a dark green color and porous on the weathered surface. The pore spaces are seen to contain calcite in the fresh samples and the rock is probably of volcanic origin.

Black and dark grey slate is found along the east shore of Portage Lake about one-half mile north of the town of Portage and makes up the northern contact of the greenstone. This slate shows no traces of bedding. Flow cleavage strikes seventy degrees east of north and is about vertical. The cleavage planes show slight traces of manganese stain.

5. Two large greenstone bodies are shown by Keith as occurring about fifteen and thirty miles west from the town of Ashland. A traverse was run to the west from Ashland in the hope of crossing these two bodies. The outcrops seen on this limited traverse would indicate the bodies have been shown in about the correct position by Keith. The largest body, indicated by number five, shows a greenstone of mottled light and dark green color. Considerable calcite is present in the rock both as vein material and disseminated patches. The patches

may be deformed amygdaloidal fillings. The rock probably is of volcanic origin but evidence had not been seen to prove this.

6. The northern end of the body about thirty miles west from Ashland was crossed by the traverse mentioned in the previous paragraph. The greenstone on this end of the body is a fine textured material showing no flow structure in the few outcrops seen. The southwestern extention of this body is shown by Keith as continuing almost to Churchill Lake and passing between Harrow Lake and Pleasant Lake. This region was later examined and the position as indicated by Keith is about correct. Amygdaloidal texture is common here showing calcite and epidote as amygdule fillings.

THE PATTEN AREA

Rumors concerning the occurrence of asbestos have also persisted from this region and mapping of Chase Mountain and the surrounding area was carried out on the scale of one inch to the mile. Mapping was done on a base map compiled from the Island Falls Quadrangle and from timberland and property maps of the area. The results of mapping are shown on Map V.

General Geology

Results of field work show the central and eastern portions of the mapped area to be underlain by Silurian volcanics and sediments and the extreme western portion to be underlain by Devonian sediments. Fossils have not been collected from the immediate area and correlation is based on lithologic and structural evidence.

Silurian sediments of the Ashland region, a few miles to the north, have been described by Williams[1] and Gregory in 1900. The same region was revisited and described by Twenhofel[2] and this work has been used by the author in reference to the Patten Area. Twenhofel has described the sediments of the Ashland Area as lower or middle Silurian in age.

The volcanics of the region appear to be interbedded with the Silurian sediments and an equivalent age is taken for them.

A major belt of lower Devonian rock is shown by Keith[3] as passing

[1]Williams, H. S., and Gregory, H. E. "Contributions to the Geology of Maine"; U. S. Geol. Survey Bull. 165, pp. 1-212, 1900.

[2]Twenhofel, W. H.: "The Silurian of Aroostook County, Northern Maine"; Jour. of Paleontology, Vol. 15, No. 2, March, 1941.

[3]Op. cit.

a short distance west of the mapped area. It seems probable that the Devonian rocks present in the Patten Area represent the eastern boundary of this belt.

The classification of the formations adopted as a result of this study is shown in Table I.

TABLE I

Lower Devonian	Moose River Sandstone	Massive sandstones
	Unconformity	
Middle and Lower Silurian	Volcanics	Rhyolite Greenstone
	Ashland Formation	Interbedded shales, sandstones, limey shales, and including lenses of the Ashland Limestone

Description of Formations

The rocks of this region have not been studied in thin section. For this reason the descriptions of the rock types will necessarily be brief.

Volcanics

One folded belt of volcanic rocks lies in the center of the mapped area. Two rock types are present within the volcanic belt. Greenstone is the most common rock type with thin flows of rhyolite occurring on the inside of the fold, or stratigraphically, above the greenstone. The rhyolite and greenstone are separated to some extent by a thin section of shale but interbedding of all three rock types is common in this transitional zone. On the map the contacts have been drawn on a basis of the most predominant rock type present. Therefore, in crossing from greenstone to rhyolite, the rock types would appear as follows: massive greenstone, greenstone showing a few thin flows of rhyolite and thin beds of shale, shale with thin flows of rhyolite, massive rhyolite. The thin beds and flows referred to above generally range from three feet up to fifty feet in thickness.

The greenstone occurs as a dark green, fine textured rock, generally showing a strong foliation which is about parallel to the slaty cleavage of the surrounding sediments. Locally, considerable textural variations are present. Small areas of medium textured rock, showing crystals of feldspar up to three millimeters in length, are found about halfway up the fire-trail on Mount Chase. In the same vicinity, fine textured rock showing almost no structure, is present. These textural ranges probably represent variations in the main body of greenstone. There are no definite indications that they are different in either composition or mode of occurrence. Poorly defined pillow structure is present and flow tops are often marked by small lenses of dark grey chert that are generally confined to the depressions between pillows. The pillow structure and chert lenses are best exposed on the peak of Chase Mountain under the tower and for several hundred feet to the west.

Flows of rhyolite appear stratigraphically above the greenstone, although interbedding with greenstone and shale is common. This rock shows a dark grey color with a few phenocrysts of feldspar and quartz visible to the naked eye. The rhyolite has been considerably sheared in some areas and other mineral constituents appear to be present in such occurrences. Microscopic study is necessary before these variations can be properly described.

The interbedded relationship of the volcanics to the surrounding shales places them as about the same age, probably Silurian.

Sediments

The sediments of the Patten Area can be subdivided on a basis of age into two formations. The Ashland formation of Silurian age and the Moose River Sandstone of lower Devonian age.

Ashland Formation—This formation consists chiefly of thinly interbedded shale and sandstones with minor occurrences of limey shale and limestone. This formation was first studied in the vicinity of the town of Ashland a few miles to the north by Williams[1] and Gregory. At the time they subdivided the rocks as the Ashland shale and the Ashland limestone. Twenhofel[1] later applied the name Ashland formation to include both rock types. Fossils from the shale and limestone are similar and as the limestone occurs as small lenses within the shale, the formational name seems more appropriate. The shales and sandstones may occur from thin to massive beds with grey shale being the most predominant rock type. The limestone is grey in color with many grains of white calcite present. In places the rock is a conglomerate with limestone pebbles in a limestone matrix. Very few fossils were

[1]Op. cit.

located in the Patten Area and these have not yet been studied. The limestone is found in the shape of lenses enclosed by shale. Limits of the lenses were not seen but outcrops of shale in the vicinity could indicate that they probably do not greatly exceed one hundred feet in thickness and probably not more than three hundred feet in length. These figures represent close to maximum sizes and the lenses may be considerably smaller.

The limey shale is not common to the Patten Area and seems to occur along the strike from the lenses of Ashland limestone. This rock is possibly the Ashland limestone considerably contaminated by admixtures of clay.

Moose River Sandstone. The extreme western portion of the map shows a massive sandstone lithologically similar to that mapped to the west as Devonian. Fossils were not collected in the mapped area but the lithologic similarity and similarity in structure leave little doubt that this represents the eastern boundary of the Devonian belt. Field study was limited to fixing the boundary between this formation and the Ashland formation to the east.

Structure

The major structure of the region is a large synclinal fold whose axis strikes about eighty degrees east of north and plunges seventy-five degrees to the east. The greenstone belt serves as an excellent marker horizon in tracing the fold, and bedding and cleavage relationships in the Ashland formation consistently substantiate the attitude mentioned above. The Silurian rocks are bounded on the west by the younger sandstones and an unconformity seems likely here. Folds in the sandstone show strike of the axes of minor folds to be about ten degrees east of north and plunges from twenty to thirty degrees to the south.

Conclusions

Two sedimentary formations and a volcanic belt are recognizable in the Patten Area. The Ashland formation of Silurian age underlies much of the area and is in the form of a large syncline plunging steeply to the east. The Moose River sandstone is present in the western portion of the mapped area and folds plunge rather gently to the south. An unconformity probably separates the two formations. Within the Ashland formation, and of the same age, a belt of volcanic greenstone and rhyolite occurs with a total thickness in the order of 5000 feet. The composition of the greenstone, both as it now exists and as it originally occurred, has not been determined. Thin section study, and possibly chemical analyses, are necessary before questions on origin and composition can be answered.

The only rock type of possible economic importance seen in the Patten Area is the Ashland limestones occurring as small lenses in the township of Moro. Those lenses studied appear to contain limestone of fairly high purity but chemical analyses would be necessary in order to properly evaluate the uses to which this material might be applied. The outcrops seen by the field party are in a low swampy area and drainage would be a major problem in any quarrying operation. It is possible that further prospecting along the strike of the known limestone lenses might show additional deposits to exist. The occurrence in lenses would indicate that any deposit of economic significance must be either a large lens or several smaller lenses located in a favorable position.

Summary and Conclusions on Greenstones

The field work on greenstones has been accomplished during the survey for serpentine and asbestos. As a result of the secondary importance of the greenstones as compared to the serpentine and asbestos, the work in many areas is purely of an exploratory nature. When the possibility of the presence of serpentine was reasonably well ruled out in any particular region, further field work was generally considered inadvisable. This report is intended to present the information gathered that was not of interest in the serpentine report.

The field work to date indicates that the large bodies of greenstone shown by Keith[1] are mapped in about the correct position and the outlines of the bodies are generally about as indicated. The rock, for the most part, seems to be of volcanic origin. A few bodies have not been studied enough to indicate the origin and some of these may be intrusive rather than volcanic.

All of the bodies in the interior part of the state have been mapped as Silurian, or the same age as the rocks which nearly always border them. The single body in the Parmachenee Area is considered as of Ordovician age in the Report of the State Geologist for 1947-48 on a basis of correlation with Quebec deposits of a similar nature. No proven correlation exists in the Parmachenee Area and it may well be that this body is also Silurian.

At least two broad subdivisions are indicated from a megascopic examination of the greenstones and from textural relationships. The most common occurrence is as a dark green, schistose rock rich in chlorite and epidote. This rock often shows pillow structure and amygdaloidal textures are not uncommon. The second rock type is a light green, generally massive rock in which amygdaloidal textures have not been seen. This rock is also rich in epidote and small veins of intergrown epidote, calcite, and chrysotile asbestos are common. Pillow structures have been seen in this rock but are rare. Chlorite is much less abundant than in the darker colored rock.

These two greenstones seem to be closely connected and may occur in the same region and possibly in the same formation. This close relationship points out the possibility that the darker, more schistose material may be a more metamorphosed equivalent of the lighter more massive variety. Detailed thin section study of these rocks and a few chemical analyses would possibly answer the questions of origin and association. Thin section study in the fine textured and highly altered greenstones would be difficult but rocks such as those found in the Patten Area, with considerable variations in texture, may be more easily studied and supply a basis for further study of the other bodies.

GEOLOGICAL RECONNAISSANCE OF THE ST. JOHN AND ALLAGASH RIVER VALLEYS

By LAWRENCE A. WING

A reconnaissance survey was carried out in the extreme northwestern part of the state during the months of July and August, 1950. Work was principally confined to the main rivers and tributaries in the upper portions of the St. John Valley and the Allagash Valley. The survey was under the direction of Dr. J. M. Trefethen, State Geologist, and consisted of the author assisted in the field by Sylvio Cyr. Coverage of more ground than earlier anticipated was made possible by early reconnaissance flights over the area with Captain Harold Chapman, USAF, and later flights by Joel Daigle of St. Francis carrying the field party with full equipment to inaccessible areas.

Purpose of the Survey

The section of the state covered by this survey has been virtually unexplored in a geological sense. Several greenstone bodies border the region on the east and south, serpentine and asbestos are known from the southern limits, and manganese occurs to the east. It seemed possible that any or all of these rock types might continue into the Allagash and St. John regions. As the geology of this area is, for the most part, poorly known, the possibility of other economic deposits could not be discounted. It was decided that a survey along the principal rivers would turn up the most information in the time available.

General Character of the Area

The area covered by the survey embraces the extreme northern portions of Somerset and Piscataquis Counties and the northwestern part of Aroostook County. Seventy townships are included in the region making up a total of about 1,600,000 acres. The region is shown on Map VI.

Topography is generally hilly to rolling with no mountains of exceptional elevation. Those mountains rising somewhat above the surrounding terrain serve as distinct landmarks in the rolling countryside.

Major rivers flow to the north and northeast with many small tributaries generally flowing in a northwest-southeast direction. The western portion of the area is drained by the St. John River and the eastern portion by the Allagash River. Both rivers are readily navigable by canoe as are many of the tributaries. The shallow waters of the rapids make any craft larger than a canoe impractical for any of the rivers or streams of the region.

The St. John River is completely uncontrolled in the mapped region, no dams exist and the only lakes present are found at the headwaters of its tributaries. It is generally shallow with high current velocities and many strong rapids. Width varies greatly but probably averages three to four hundred feet for that portion shown on the map.

The upper part of the Allagash drainage is characterized by many large lakes while the lower portions are devoid of them. The river proper starts at the outlet of Churchill Lake, although waters from as far south as Allagash Lake and Chamberlain Lake drain into this system. The lakes downstream from Churchill Lake are generally long and narrow, partially due to the dam at the north end of Long Lake. With the exception of a few short sections, the river is swift with one series of rapids following another. Allagash Falls, located in Township Fifteen, Range Eleven, is the only true falls on the river. The Allagash River is smaller than the St. John with a width up to two hundred feet and generally shallow.

The entire region shown on the map is heavily timbered and in the past lumbering has been the only economic activity carried on other than the seasonal fishing, hunting, or canoe trips that are well known to this region.

Method of Mapping

The majority of the outcrops in this region seem to occur along the rivers and streams. The gently rolling divides do not, as a rule, show many outcrops. As a result of this fact, nearly all traversing was done by canoe, with short pace and compass traverses in some regions near the streams. Three topographic quadrangles, Umsaskis, Allagash Falls, and Allagash, are available for portions of the mapped area. The remaining areas are well covered by timberland maps on a scale of one inch equals three miles. The rivers and streams are generally mapped in enough detail to make location fairly easy and accurate. Township lines are poorly marked, with a few exceptions, and of little help in locations.

Previous Work

This region is shown on the Geologic Map of Maine by Keith.[1] Hitchcock[2] reported on the results of a survey through portions of the St. John and Allagash valleys. The work by Hitchcock is of little use at the present time although interesting reading.

General Geology

The work of the present survey is not detailed enough to allow many generalizations on formations or major structures. Much more field work would be necessary before any such conclusions could be drawn. A description of the rocks noted on this survey are given below in the order in which they were studied. Structural relations and some generalizations of both structures and rock formations are described in a following part of the report.

St. John River—The traverse of the St. John River was started by canoe from Nine-Mile-Bridge in Township Twelve Range Sixteen and continued downstream to the town of Allagash. The rocks along the St. John River itself are composed of alternate thin beds of sandstone and shale with very little variation in texture and color for the entire region. The only noticeable unusual feature of these sediments is the textural relations between the sandstones and shales. Small flakes of shale, up to several inches in length, are very often embedded in the sandstone and very irregular lenses of sandstone are found in the shale. The latter occurrence is less common than that first mentioned. This texture is illustrated in Figure 1. Where sandstone is found in the shale it appears that the older rock type was eroded to an irregular surface prior to, and perhaps during, the deposition of the younger rock. Structure is uncertain where such phenomena have been noted, but generally the shale appears to be the eroded surface and the sandstone the subsequent deposit. Where thin shale particles are embedded in the sandstone they are often seen as very thin flakes, some partially curved. Here it seems the original soft clayey flakes were carried along with the sand and deposited contemporaneously. They appear to have been torn from some earlier deposited clay strata. Where this texture is noted the total thickness of sediments involved seldom exceeds a few feet but the texture itself is characteristic of a major per-

[1]Op. cit.

[2]Hitchcock, C. H.: "Geology of the Wild Lands," 6th Annual Report of the Maine Board of Agriculture, 1861.

centage of the outcrops as far downstream as St. Francis and to some extent is present in the Allagash valley. The above explanation is suggested from the examination of the limited number of outcrops available along the streams, but further study and an understanding of structure are necessary before a complete explanation of this texture can be known. The texture alone might serve as an excellent marker horizon for future work.

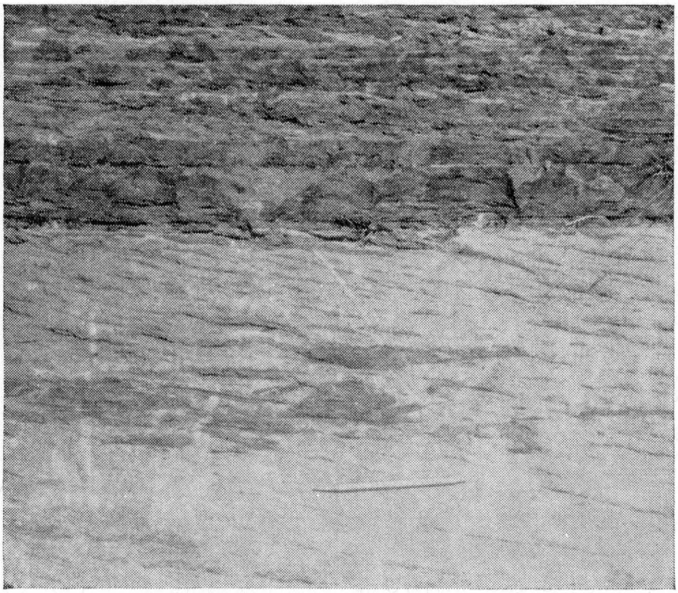

Fig. 1. Cleavage-Bedding Relations

Little Black River—This river was traversed by canoe from the St. John to the mouth of Rocky Brook, about fifteen miles upstream. Additional foot traverses were run north to the vicinity of Rocky Brook Pond in Township Nineteen Range Twelve and west up the Little Black River for a distance of about five miles.

The rock types on this traverse change from the interbedded sandstones and shales of the St. John River to predominantly dark grey shales showing little trace of stratification. Outcrops are not numerous in the region near the St. John but the shaley rocks are persistent eastward to within about four to five miles of the river. Very thin beds of limestone were noted in the upper reaches of the Little Black about two miles west from the mouth of Rocky Brook. Cubes of pyrite are common in the shale and limestone at this locality but not noted elsewhere. A considerable quantity of red shale was noted in the overburden about five miles up Rocky Brook from the Little Black but the rock was not seen in place. The outcrops around Rocky Brook Pond are massive grey sandstone with no indication of stratification.

St. Francis River—A canoe traverse was run on this river from the northern end of Beau Lake downstream to the St. John. The topography of the entire valley seen in this traverse is strongly influenced by glacial deposits and bedrock outcrops are relatively scarce. An esker exists at the southern end of Beau Lake and continues with many interruptions all the way downstream to the St. John River. Numerous kames and short sections of kame terrace are also present.

The rocks in the vicinity of the southern end of Beau Lake and on to the south through Glazier Lake are similar to those seen on the upper portions of the Little Black River, mostly shales with a few thin beds of sandstone. The outcrops near the St. John are thinly bedded sandstones and shales.

Allagash River—A canoe traverse was carried out on this river from Churchill Lake to the town of St. Francis. Additional foot traverses were run in the vicinity of Cliff Lakes, Harrow Lake, and Priestly Lake.

Keith[1] has shown the region around Churchill Lake as Devonian sandstones with small areas of rhyolite to the south and southeast and the southern end of a body of greenstone to the east near Harrow Lake. Rhyolite is much more common in this region than indicated by Keith. Outcrops in Cliff Lakes, the eastern shore of Churchill and the western end of Harrow Lake are all rhyolite. The contact between the rhyolite and greenstone lies about midway down Harrow Lake on the south side. The position of the northern end of this body was determined from an earlier survey and is described in the report on greenstones.

Outcrops between Churchill Lake and Umsaskis Lake to the north are extremely rare. About two miles north from Churchill Lake an outcrop of shale with rare lenses of sandstone was noted. Bedding appears to strike forty-five degrees east of north and dip about seventy degrees south. This rock is similar to that seen on the St. John river, both in appearance and attitude. This locality is within the belt mapped as Devonian by Keith. The only evidence of the age relations

[1]Op. cit.

lies in the fact that outcrops further north in the vicinity of Umsaskis and Priestly Lakes show shale and some phyllite and are generally more metamorphosed than the sediments near Churchill Lake.

The outcrops noted from Umsaskis downstream to within about five miles of Allagash Falls are all of a dark grey shale in which bedding is not distinguishable. A short distance above Allagash Falls the thinly interbedded sandstones and shales, so characteristic of the St. John valley, appear and continue on down to the end of the river. The peculiar textures noted in the St. John are also present in the outcrops seen on this portion of the Allagash.

Structure

In a region as large as the area covered by this survey and in which relatively complex folding is known to exist, any generalizations of structure based on the work of a single field season must be incomplete. The relationship between bedding and cleavage in many of the outcrops noted in the St. John valley make it possible to determine local folding. In sections where outcrops are fairly numerous anticlinal and synclinal axes are determinate for short distances. Where these short distances are aligned and not widely separated, they have been connected on the map. This gives some of the axes lengths up to twenty-five miles.

The most likely solution of structure from the information available shows the St. John River following an anticlinal axis from a short distance north of Nine-Mile-Bridge, downstream about two miles north from Seven Islands. North of Seven Islands the river crosses in a northeast direction for about five miles to the east side of Township Fourteen Range Thirteen then northeasterly about six miles along a synclinal axis. Another anticlinal axis apparently is encountered at the mouth of the Little Black River and possibly continues to the northeast through the southern end of Glazier Lake. A synclinal axis passes through the Allagash a short distance above Allagash Falls and continues northeasterly to the mouth of the St. Francis River. The northern end of Glazier Lake is in a synclinal area and it is possible that this axis may continue to the southwest and connect with the synclinal axis shown on the upper St. John. Plunge, as indicated by minor folding and the relationship of bedding and cleavage, varies considerably but ranges between twenty-five and seventy degrees to the northeast. The steeper plunges are located in the southern half of the mapped area and become more gentle in a gradual manner as the northern limits are approached.

It is possible that folding is closer than indicated by the fold axes shown on the map, but until definite marker horizons are located, or until more outcrops are studied, further inference does not seem warranted. The axes shown, while very incomplete, may serve as a guide to any further exploration of the region.

Evidence of major faulting was not seen in the field, but as much of the area remains unknown the possibility should not be discounted.

Economic Geology

Mineral deposits of economic significance were not seen by the field party. The sandstones and shales occupying much of the area studied are not likely to contain much of value. Limey shales and some thin beds of limestone were noted in the headwater regions of the Little Black River and Hitchcock[1] mentions limestone as reported to the west of the St. John River between Big Black and Little Black Rivers. The extreme remoteness of the entire section makes such a deposit uninteresting from any economic viewpoint. A deposit of any type situated in this region would require considerable expenditure for development of transportation facilities.

Summary

From the work of a single field season, it would seem that deposits of economic significance are unlikely to be found in those portions of this region covered by the traverses. Much of the area remains unstudied and it is possible that future work may turn up new deposits.

Much of the area studied is underlain by thinly bedded sandstones and shales that show a very uniform appearance and attitude. These sediments have been mapped by Keith[1] as Silurian; no evidence was seen to either confirm or disaffirm this age. The northern boundary of a major belt of Devonian rock probably passes northeasterly through the region a short distance to the north of Churchill Lake. Much field exploration under extremely difficult conditions of transportation and supply would be necessary to establish the contact between the Silurian and Devonian sediments.

The greenstone bodies within the area are probably quite well defined on the map, but areas of rhyolite in the vicinity of Churchill Lake need further field work before boundaries can be established.

Structure in this section of the state is poorly known. It is hoped that the plotted strikes and dips of bedding and cleavage and the fold axes shown on the map may be of aid to any future exploration or interpretation of this remote region.

[1]Op. cit.

REPORT ON THE GEOLOGY OF A PORTION OF THE SPENCER LAKE AREA, MAINE

By H. H. Woodard

Introduction

The Spencer project as set up, was to include a detailed study of the rocks in the Spencer quadrangle, Maine, in the hope that they would provide evidence of the nature and extent of the asbestos-bearing serpentine body on the Little Spencer Stream.

The project was under the guidance of Dr. Joseph Trefethen, State Geologist, and Dr. Robert Balk, University of Chicago. Thanks are due Mr. Arthur Boucot of Harvard University for his identification of fossils which were collected in the area. The author thanks his wife, Helen Herald Woodard, for her assistance in the field.

The length of time spent in the field was approximately five weeks. Practically all of this was spent in working around the immediate vicinity of Spencer Lake. The author was never in the western ninths of the quadrangle. The last two weeks of work were financed by a grant from the Development Commission, State of Maine. After five weeks the project was discontinued owing to the extremely poor exposures in the area. Owing to limited time there were no thin sections made of the rocks, and all descriptions are, therefore, of a megascopic nature.

Location and Access

The Spencer quadrangle lies in the western part of Maine close to the international boundary and approximately halfway between Moosehead Lake and the Rangeley Lakes. Spencer Lake lies in the eastern part of the Spencer quadrangle.

Spencer Lake is accessible by automobile via twenty miles of gravel-surfaced logging road. This road turns west off U. S. Route 201 at Parlin Pond, which is 12.5 miles south of Jackman Station, Maine. The southeast corner of the quadrangle may be reached via a logging road from the town of Eustis, Maine. This road extends into the middle ninth of the Spencer quadrangle, ending at King and Bartlett Lake.

Previous Work

Little detailed work has heretofore been done in this area. Wing and Dawson[1] have published a preliminary report on the Spencer serpentine body. Hurley and Thompson[2] have reported on the results of combined magnetometer and field reconnaissance work in this area. This publication is essentially the same as an earlier publication by Hurley.[3] Keith[4] has indicated on his Preliminary Geologic Map of Maine the presence of certain rock types in the area.

Reports on work from surrounding areas are not plentiful. The reader is referred to the bibliography at the end of the paper by Hurley and Thompson for a complete coverage.

Geology

The rocks of the Spencer Lake area are a series of rhyolites and Siluro-Devonian sediments which overlie, unconformably, older igneous rocks. The sedimentary rocks can be subdivided into at least three lithologic units. They are: Moose River sandstone, probable Seboomook Slate, and calcareous-arkosic sediments west of Spencer Mountain. The igneous rocks are rhyolites, granites, and diabase to quartz diorites(?).

A belt of sediments in the southern part of the area trends northeast-southwest. The northern part of the area is underlain by igneous rocks except immediately west of Spencer Mountain where an isolated "basin-like" deposit of sediments occurs. The geology is shown on Map VII.

Sedimentary Rocks

The Moose River sandstone enters the Spencer quadrangle at approximately the middle of the eastern quadrangle boundary. It is typically exposed at the south end of Spencer Lake, where large outcrops control the lake level. As the formation is traced southwestward its breadth of outcrop narrows markedly, and apparently just southwest of Lost Pond it disappears completely.

[1]Wing, L. A. and Dawson, A. S., Preliminary report on asbestos and associated rocks of northwestern Maine: Maine State Geologist Ann. Rept., 1947-1948, pp. 45-58, 1949.

[2]Hurley, P. M. and Thompson, J. B., Airborne magnetometer and geological reconnaissance survey in northwestern Maine: Geol. Soc. America Bull., vol. 61, no. 8, pp. 835-841, 1950.

[3]Hurley, P. M., Airborne magnetic survey in Maine: Eng. and Min. Jour., vol. 150, no. 8, pp. 52-55, 1949.

[4]Published by the Maine Geological Survey, Orono, Maine, 1933.

The Moose River sandstone as exposed in this area is not a typical sandstone type of sediment, but is actually a dirty, dark green, fine-grained siltstone with a few minor beds of dark grey-black slate. Grain size is usually so small that no actual grains can be observed with a handlens. The dark green color of the rock is apparently due to the abundance of interstitial chlorite.

Fossiliferous beds are common. When present, these beds are virtually fossil coquinas. Probably all the original carbonate shell material has disappeared. In fresh exposures it can be seen that the fossil surfaces are often coated by a gold-colored, platy mineral which Boucot[1] has identified as stilpnomelane, and the original carbonate of the shells now contains much iron as evidenced by the spongy limonite found in weathered material. In weathered exposures the fossils occur as impressions and molds. Ellipsoidal black shale fragments are common in the fossiliferous beds.

It is usually not possible to distinguish bedding in the Moose River if fossil beds are absent. However, a strong foliation is everywhere developed.

Boucot[2] working northeast of the Spencer Quadrangle, has found that he can subdivide the Moose River sandstone into four major lithic units and three faunal units. These embrace the lower Devonian (Oriskany and lower Onondagan). Fossils, collected by the author in the Spencer area, were sent to Mr. Boucot for identification. A preliminary identification[3] indicates that the Moose River sandstone in the Spencer area is Oriskany, and that the Oriskany can be split into upper and lower faunal units. The upper faunal unit probably is restricted to the far eastern boundary of the Spencer quadrangle, while the lower unit comprises that part of the formation exposed along the shores of Spencer Lake and southwestward to the point where the formation pinches out.

The Moose River sandstone is bordered on the southeast by a series of grey-black slates, and dense, grey-black tuffs and tuffaceous slates. The relationships of these rocks with the Moose River are unknown. No exposures of this contact could be found. Strike and dip of foliation and bedding on the Moose River side of the contact are apparently the same as strike and dip of foliation and bedding southeast of the contact. Hurley and Thompson[4] believe that this is a thrust contact.

[1]Personal communication, 1950.

[2]Written communication, Sept. 15, 1950.

[3]Written communication, Nov. 6, 1950.

[4]Op. cit.

The northwest border of the Moose River sandstone is underlain conformably by a series of grey-black slates interfingered with rhyolites. This contact was observed in only one locality, and even here the actual contact is covered by a strip of glacial overburden 20 feet wide. However, the contact appears conformable and gradational.

Slates and associated rhyolites—Hurley and Thompson[1] apparently regard the slate in the Spencer area which borders the Moose River sandstone on the northwest as an equivalent of that described by Perkins[2] north of the Spencer Lake area (named by him the Seboomook slate). The present author also believes that this formation must be an equivalent of the Seboomook.

The upper 50-100 feet of this formation in the Spencer area is rich in quartz. This grades downward into the typical calcareous, grey-black slates, which commonly contain thin quartz-rich beds. The slates are interfingered with dense, cherty, dark green rocks which Hurley and Thompson[3] classify as rhyolites. They are probably similar to the rhyolites described by Smith,[4, 5] which are of two types: garnet bearing and non-garnet bearing. The rhyolites in the Spencer area contain no megascopic garnets. The Spencer rhyolites are highly fractured, and openings produced during fracturing have in many cases been filled with late calcite. In fact the whole rock contains interstitial calcite.

The relationships of the rhyolites with the surrounding slates are not clear. Only one outcrop showed contact relations. At this locality a poorly developed flow structure in the rhyolite approximately parallels the strike and dip of the contact and the strike and dip of the bedding in the slates. Thus the rhyolite appears conformable. However, on the eastern edge of the Spencer area there is some indication that the rhyolites may not exhibit concordant relations with the slates. Outcrops of rhyolite occur in close proximity to the Moose River sandstone. If these rhyolites are equivalent to those occurring in the Seboomook slate, and they appear to be, then they lie much higher in the stratigraphic section than they do where exposed on the shores of

[1]Op. cit.

[2]Perkins, E. H., The Moose River sandstone and its associated formations: Am. Jour. Sci., 5th Ser., vol. 10, pp. 368-375, 1925.

[3]Op. cit.

[4]Smith, E. S. C., The igneous rock of Mt. Kineo and vicinity: Am. Jour. Sci., 5th Ser., vol. 10, pp. 437-444, 1925.

[5]Smith, E. S. C., An occurrence of garnet in rhyolite: Am. Jour. Sci., 5th Ser., vol. 25, pp. 225-228, 1933.

Spencer Lake. This condition could be accounted for by: (1) assuming an intrusive cross-cutting relationship, or (2) assuming an interfingering of rhyolite flows through most of Seboomook and possibly part of Moose River time. It is well known that rhyolite bodies occur within the Moose River sandstone.[1,2,3] However, none of these rhyolites have been observed transgressing formational boundaries. Owing to the scarcity of exposures in the Spencer area the author is unable to say which of the above two possibilities is a correct interpretation for the rhyolite-sediment relationships.

The interfingering of rhyolite with slate is considerably more complicated than Hurley and Thompson[4] have indicated on their map. The rhyolites have been mapped separately (Plate 1).

The lower part of the slate becomes more calcareous, and thin beds of impure dark grey limestones become apparent. At the extreme base of the formation is a thin, white to light grey orthoquartzite which is cemented in part by calcite. This basal orthoquartzite lies unconformably on an older granite complex. The author observed the actual contact at only one locality. This exposure is on the west side of Spencer Lake at Lat. 45° 27′ N, Long. 70° 18.6′ W.

Fossils were observed in the slate formation at only one locality. No age determination could be made. Perkins[4] has noted a Silurian graptolite from the Seboomook slate. If this age determination is correct then part or all of the formation in the Spencer area could be Silurian.

Immediately west of Spencer Mountain is an area of fossiliferous sedimentary rocks. According to Hurley and Thompson[4] these are completely surrounded by igneous rocks. As these two authors point out the sediments of this area are in part lithologically similar to the lower part of the Seboomook slate.

The western half of this "basin-like" area is composed essentially of dark grey slates and limestones interbedded with medium to coarse grained arkoses. The eastern half of the area contains interbedded black slates, dark grey limestones, white pure limestones, thick-bedded green conglomerates, and considerable light to dark green arkosic

[1]Smith, E. S. C., The igneous rock of Mt. Kineo and vicinity: Am. Jour. Sci., 5th Ser., vol. 10, pp. 437-444, 1925.

[2]Smith, E. S. C., An occurrence of garnet in rhyolite: Am. Jour. Sci., 5th Ser., vol. 25, pp. 225-228, 1933.

[3]Hurley, P. M. and Thompson, J. B., Airborne magnetometer and geological reconnaissance survey in northwestern Maine: Geol. Soc. America Bull., vol. 61, no. 8, pp. 835-841, 1950.

[4]Op. cit.

material. The clastics are all cemented with calcite. Bedding in the eastern half is highly irregular and almost any direction of strike or degree of dip can be measured. This almost random orientation of bedding is apparently an original feature of the sediments. One gains the impression that the sediments were laid down on a very steep surface, and that during storms conglomeratic and arkosic beds were washed out over limey muds. Considerable slippage of the sediments seems to have taken place on the steep surface, and thus limestone and arkose beds are commonly folded and mashed together. The fragments of folded and ruptured beds of limestone, only slightly or not at all rounded, are suspended in arkosic beds. These fragments can be fitted together perfectly into their original form.

The arkoses and conglomerates contain many pebbles and boulders of the underlying granite, along with numerous schist and felsite fragments. Thus there can be no doubt that the sediments overlie the surrounding granite unconformably. The reason for the concentration of arkosic material in this area is obvious when one observes the granite exposed immediately to the east on Spencer Mountain. Here the granite is highly sheared and brecciated, and it is at times impossible to tell granite from arkose.

Fossils are numerous in this whole series of sediments. The preliminary identification by Mr. Boucot of a collection from this area only indicates that the sediments are Siluro-Devonian.

Igneous Rocks

The granites exposed in the Spencer area are all overlain unconformably by Silurian and/or Devonian sediments. The granites vary considerably in texture and probably in mineral composition. Mafic minerals present may be hornblende, chlorite, or biotite. Two local areas which contained garnet were observed. On the northern point of land which forms "the narrows" in Spencer Lake, an outcrop of granite contains numerous lenses of diabasic rock. Basic xenoliths are also present in many localities.

The north end of Spencer Mountain is underlain by a dark green, fine- to medium-grained rock which megascopically appears to be gabbroic to quartz dioritic in composition. Considerable quantities of pyrite and magnetite are present. This body has been mapped separately (Plate 1). The rock exposed on the north and east side of the mountain is quartz-rich, and resembles quartz diorite. The rock on the west side and top of the mountain is finer-grained, contains little quartz and has a texture resembling a diabase. This material is highly epidotized. The quartz diorite (?) apparently grades into the finer-grained diabase-like rock. This whole basic body is cut by large granite dikes as much as 100-300 feet wide.

Only one outcrop was observed which exhibited contact relations between these basic rocks and the surrounding granites. A few feet from the contact granite stringers cut across the basic rock, and at the contact the basic rock appears to be sheared and altered. These features, plus the high degree of epidotization in the basic rock possibly indicate that the granite is younger in age.

Structural Geology

Sediments—Where present, bedding is easily observed in all sedimentary rocks of the Spencer Lake area. The bedding in the southeastern sedimentary belt strikes N 45°-75° E and dips 35°-70° SE. Foliation is well developed in all these rocks and in general trends more to the north than does bedding. The dip of the foliation is usually steep and ranges from 60° NW through vertical to 60° SE. Wherever foliation and bedding were observed together in an outcrop, the relationships indicated that tops of the beds were to the southeast. Thus this section of sediments lies on the northwest limb of a syncline. In every case, with only one exception, foliation-bedding relations indicate that the syncline plunges southwestward. The only exception to this plunge was observed on the far eastern boundary of the Spencer quadrangle where the township line between T4-R6 and T3-R5 intersects the quadrangle boundary. At this locality foliation-bedding relations indicate a syncline to the southeast, and a plunge to the northeast. Hurley and Thompson[1] have shown that the Moose River sandstone occupies a broad syncline which plunges northeastward. The subdividing of the Moose River sandstone in the Spencer Lake area into upper and lower Oriskany, where the upper Oriskany occurs to the northeast of the lower Oriskany, also indicates that the syncline plunges northeastward. The reason for the apparently anomalous foliation-bedding relationships on the southwestern extension of this syncline is not known.

The southeast contact of the Moose River sandstone remains a mystery. Hurley and Thompson[1] believe that this is a thrust contact

[1]Op. cit.

because in the vicinity of Moosehead Lake the Moose River sandstone on the southeast limb of the syncline appears to be too thin. Also at Tarratine, and about the foot of Spencer Lake, the rocks are sheared. The present author finds that the rocks near the southern end of Spencer Lake are highly sheared. Crinkling and chevron folds are common in the slates and tuffaceous slates southeast of the contact, in the Moose River sandstone northwest of the contact, and in the upper part of the Seboomook slate northwest of the Moose River. The axial planes of the chevron folds in these rocks strike northeastward and dip gently (10°-20°) southeast.

Two small shears, one on the southwest shore of Spencer Lake in the Seboomook slate, the other on the southeast shore of Spencer Lake in the Moose River sandstone, approximately parallel to the southeast contact of the Moose River sandstone. These shears show only small displacements (probably a few feet at the most). Their strike and dip is indicated on the map.

The bedding in the sediments west of Spencer Mountain varies markedly depending on the location. In general the beds in the western half of the area strike N 30°-40° E and dip 30°-55° SE. In the eastern half of the area the bedding is erratic owing to deformation contemporaneous with deposition. Foliation is developed in these rocks, especially in the more slaty beds. However, foliation is also developed in some arkosic and even conglomeratic beds. In these beds the foliation is produced by alignment of chlorite in the matrix, and often these foliation planes extend through granite pebbles and boulders as parallel fractures. The fractures were later filled with quartz. These quartz crystals have their "c"-axis oriented perpendicular to the fracture walls.

Igneous rocks—Structure in the igneous rocks is not pronounced. However, in the granites and the Spencer Mountain basics a foliation or banding is locally developed.

Foliation is produced in the granite through alignment of micaceous minerals and quartz blebs. This foliation trends northeastward and dips 45°-70° NW. Basic lenses, which occur locally in the granite, always parallel the strike and dip of the foliation. It is not known whether the foliation is primary or secondary. Jointing in the granites is locally well developed. Throughout most of the area there appear to be two main sets of these joints. One set strikes approximately north-south, while the second set strikes east-west. Both sets are essentially vertical.

Banding in the Spencer Mountain basics is locally developed, especially on the eastern side of the body. The banding is produced by an alternation of dark, basic bands and lighter, less basic bands. This banding trends northeastward and dips 40°-75° NW. If this is a primary feature of the rock, it possibly indicates that these basic rocks are a northwest-dipping sheet.

Paleontology

Boucot[1] finds that he can divide the lower Devonian Oriskany (of the Moose River sandstone) into upper and lower faunal units. The upper unit contains a new terebratuloid similar to *Mutationella* together with *Antispirifer*, while the lower unit contains *Beachia aff. thunii. Leptocoelia* sp. has not been found in Onondagan rocks of this district but only in Oriskany rocks. It is, therefore, presumed to be only Oriskany in this district.

The fossil localities noted on Plate 1 are in many cases identical with those noted by Hurley and Thompson.[2] However, several new localities were observed, and representative collections were made. As noted earlier a preliminary identification has been made by Mr. Boucot. The localities and his identifications are listed below. The reader is referred to a copy of the U. S. Geological Survey, Spencer quadrangle, Maine, for locating the following fossiliferous outcrops.

In the southeast corner of the north ninth of the Spencer quadrangle, 200 feet northwest from the top of the 2160 foot hill:

> *Gypidula*, sp. (resembles lower Helderberg species but the genus is a long ranging Siluro-Devonian one)

In the east ninth of the Spencer quadrangle on the south shore of Spencer Lake, 2675 feet northeast from the top of the 1540 foot hill:

> *Beachia* cf. *thunii* (lower Oriskany)
> *Leptocoelia flabellites*
> *Spirifer murchisoni*
> *Platyostoma* sp.
> *Chonostrophia* sp.
> *Leptostrophia* sp.
> *Loxonema* (?)

[1]Written communication, Nov. 6, 1950.
[2]Op. cit.

In the east ninth of the Spencer quadrangle on the extreme eastern quadrangle boundary, 880 feet due south from the intersection of the eastern quadrangle boundary and the township line which separates T3-R5 from Hobbstown township:

terebratuloid aff. *Mutationella* (upper Oriskany)
Leptocoelia flabellites
Chonostrophia sp.
Leptostrophia sp.

In the east ninth of the Spencer quadrangle near the south end of Spencer Lake, 360 feet north of the "5" in 1593 foot hill:
Leptocoelia flabellites (Oriskany)

In the east ninth of the Spencer quadrangle near the south end of Spencer Lake, 3400 feet due north of the "8" in B. M. 1098:
Leptocoelia flabellites (Oriskany)

In the east ninth of the Spencer quadrangle near the south end of Spencer Lake, 1060 feet due north from the top of the 1593 foot hill:
Leptocoelia flabellites (Oriskany)

PRELIMINARY REPORT OF LIMESTONE SURVEY OF A PORTION OF KNOX COUNTY, MAINE

By HENRY W. ALLEN

Introduction

This limestone survey of a portion of Knox County, Maine, was made by Henry W. Allen with Russell E. Meade as field assistant, from July 10 to September 7, 1950. Mapping was for the most part confined to the so-called main Rockland-Thomaston limestone belt (Bastin 1908).[1] However, this work was extended to the northeast through Rockport village into the area of the second largest limestone occurrence in the county.

Limestone has been known to occur in Knox County since before 1733. In that year the first lime was shipped from the area to Boston by Samuel Waldo. Today, the many quarries both large and small attest to the tremendous volume of limestone that has been quarried in the area. For the most part the quarries are long and narrow, with depths varying from a few feet to as much as the 550 foot depth of the Jacob's Quarry in Rockport. There remains still a large volume of limestone available, most of which can be utilized for one or more of the many limestone products, provided selective quarrying with proper chemical control is practiced.

The geology of the Rockland Topographic Map Area, which takes in much of Knox County, was mapped by Edson S. Bastin[2] of the United States Geological Survey in 1905.

It was the purpose of the present survey in the limited time available to restudy certain areas of the quadrangle to evaluate existing limestone resources in terms of the availability, use, and amounts. The principal products for which the limestone of Knox County is and can be used, are: (1) agricultural lime, (2) calcium flux stone, (3) high calcium stone for chemical purposes, and (4) cement. Final estimation of available amounts of limestone in the areas mapped suitable for these various uses must wait the results of chemical analyses of limestone samples collected by the party.

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

[2]Bastin, E. S. (1908), op. cit.

Location and Size of Main Rockland-Thomaston Limestone Belt

The main Rockland-Thomaston limestone belt is the most important occurrence of limestone in the State. It extends from Chickawaukie Pond, one and one-half miles north of Rockland, southwestward for nearly five miles to the St. George River at the west end of Thomaston village. This belt consists of two elongate fingers of what Bastin termed the Rockport limestone. The fingers merge into one at about one-half mile southwest of Chickawaukie Pond. The northwestern finger is by far the most extensive and is the one in which most of the quarries are located. About a mile northeast of Thomaston village this finger has its maximum outcrop width of slightly over a mile, which is also the greatest outcrop width of the whole belt. The southeastern finger has a maximum width of about a thousand feet at a point six to seven tenths of a mile due south of Chickawaukie Pond. The limited number of exposures along the southeast finger makes it very difficult to determine just how far to the southwest the limestone extends continuously. Stratigraphic, structural, and topographic relationships make it reasonable to assume that the limestone of the southeastern finger extends nearly to Limerock Street, which is approximately one and one-half miles south of Chickawaukie Pond. At no place could the true thickness of the limestone strata be determined due to repetition of strata by intense folding, therefore the outcrop width at any given place may be many times greater than the stratigraphic thickness of the limestone beds.

Stratigraphy

Bastin[1] in the Rockland Folio gives the following sequence, oldest to youngest, for the metamorphosed sedimentary rocks occurring in the area of the Rockland quadrangle; (1) Islesboro formation containing the Coombs limestone member at the top; (2) Battie quartzite; (3) Penobscot formation; (4) Rockland formation consisting of the Weskeag quartzite member at the base, a siliceous limestone member above the quartzite, and the Rockport Limestone member at the top.

For a description of each of the formations found in the area, the reader is referred to the Rockland Folio. This preliminary report is mainly concerned with the Rockport limestone member of the Rockland formation in the main Rockland-Thomaston limestone belt. A Cambro-Ordovician (?) age was assigned to the Rockport limestone by Bastin.

[1]Bastin, E. S. (1908), op. cit.

Description of Limestone in the Rockland-Thomaston Belt

The Rockport limestone is for the most part a medium-textured crystalline light bluish-gray metamorphosed limestone (marble). Thin white calcite bands many of which parallel the bedding give much of the rock a striped appearance when observed in close-up. Certain zones of varying width, such as those seen in many of the quarries along Old County Road west of Rockland, are actually a dolomitic marble. In fact, more magnesium limestone has been quarried in the past from the area for use as plastic limes than strictly high calcium limestone for flux stone and other chemical uses. Excellent high calcium limestone appears to occur in limited amounts as compared to magnesium limestone.

Some rather characteristic narrow zones of light brownish-gray and brown thin striped iron-bearing limestone usually bordered by light bluish-gray and white striped limestone containing less iron have been noted. The multiple occurrence of these phases across the strike is probably for the most part the result of repetition through very tight isoclinal folding.

No conglomeratic zones were observed in the limestone in the main Rockland-Thomaston belt such as occur in the limestone of the Rockland belt about 0.4 miles north of Rockport village.

Bastin states that the Rockport limestone has a thickness of at least 400 to 500 feet and may have a thickness several times greater than that. In no place is it possible to make a good approximation of the thickness due to repetition by folding. It is quite apparent, however, that the greatest part of the Rockland formation in the Rockland-Thomaston limestone belt consists of the so-called Rockport limestone.

The relationships of the Rockport limestone member to the siliceous limestone and Weskeag quartzite can be worked out structurally in the Rockland-Thomaston belt although no actual contact exposures were observed. The present survey checks the sequence worked out by Mr. Bastin: the Rockport member is above the siliceous limestone member, which in turn is above the Weskeag quartzite.

Structure

Investigation by the writer indicates the possibility that the main Rockland-Thomaston limestone belt may have an anticlinorium structure rather than a synclinorium structure as determined by Bastin.

The key to the anticlinorium is believed to be present in the area of the so-called Bog quarry at the southern tip of Mt. Battie about one and one-half miles west-northwest of Rockland. This quarry is located a short distance west of the main limestone belt on the crest of an outlying fold. Here the limestone can be seen plunging to the northeast under manganiferous quartzitic mica schist. The contact between the limestone and the schist is well exposed in the western face of Bog quarry.

Bastin has mapped the outlying fold in which Bog quarry is located as synclinal, plunging southwest at this point whereas, actually since the limestone plunges to the northeast under the schist the fold is anticlinal. Northeast plunges of axes of minor folds in the northeastern part of the main limestone belt are fairly common. Structurally it would appear that the absence of the Weskeag quartzite along the northwest side of the main limestone belt is not by reason of an unconformity, but rather by the fact that it is the upper contact between the Rockport limestone and the overlying formation.

More field work especially along the east-southeast edge of the belt is necessary in order to determine the exact nature of the structure. It might be well to point out here that the structure of the limestone has a direct bearing on the determination of limestone reserves of the area. If it can be shown that the structure is anticlinal, then the area to the northwest and southeast has limestone underlying present surface rock. The same limestone if in a synclinal structure would not extend out to the northwest and southeast under the surface rock, but is limited to the non-eroded part of the trough of the area.

The rocks of the area, both in the main limestone belt and adjacent to it, have been subjected to intense pressure. Consequently the structure consists of many minor folds superimposed on larger folds of an isoclinal type. Many second order folds are exposed in the quarries of the belt. The axial planes of most of these folds are overturned either to the west-northwest or to the east-southeast depending on the position relative to the axis of the major structure. The southern corner of the Engine quarry in Rockland shows a syncline and anticline whose axial planes are about 40 feet apart and are overturned to the west-northwest. An anticline with west-northwest overturned axial plane is well displayed in Mag quarry. The limestone is highly fractured with many small faults and joints. Many of the fault surfaces show nearly horizontal movement parallel to the trend of the axial planes of the faults.

Economic Geology

At the present time high calcium limestone is being quarried by the Rockland and Rockport Lime Co., of Rockland, for use in paper manufacturing. This company is also set up to produce agricultural lime in which magnesia is a desirable constituent.

The Lawrence Portland Cement Co. of Thomaston has been producing cement from cement rock taken from a quarry adjacent to their plant 0.3 mile east of Thomaston village for over twenty years. A minimum of foreign material has to be added to bring the cement up to "mix"; however, strict chemical control of the quarrying operation is necessary in order to avoid high magnesia percentages and at the same time to maintain proper proportions of lime, silica, alumina, and iron. Raw materials for use in cement should not have over four percent magnesia. The ratio between silica and alumina in limestone should not be over 5:1, and ratios between 3:1 and 4:1 are desired.

On the location map a few zones of limestone suitable for the following general uses have been indicated by number: (1) agricultural lime, (2) calcium flux stone for chemical purposes, and (4) cement. Although each location will be discussed in turn, a complete evaluation of the area must wait the results of chemical analyses of collected samples. For the most part the determination of the indicated area is based on the chemical analyses of drill cores furnished by the Rockland and Rockport Lime Co.

The exact location and size of these indicated areas are best shown on a large scale map of the limestone belt which is on file with the Maine Geological Survey, Orono, Maine.

Location 1*A*—High magnesia limestone suitable for agriculture lime is located adjacent to the Austin Pasture quarry on the southeast side of Dexter Street, Thomaston.

Drill core analyses show a zone of magnesia limestone with an outcrop width across the strike at this place of about 300 feet near the southern corner of the Austin Pasture quarry. An unquarried zone extends for some 800 feet to the northeast at this width. Beyond this point, Hardrock quarry cuts across the zone so that at a distance of about 1,600 feet northeast of Dexter Street the upper part of the rock has been quarried to a depth probably under a hundred feet across the entire width of zone. The dip of the strata is rather steep, for the most part between 65 degrees west-northwest and 65 degrees east-southeast. Near vertical dips are common. The zone consists of a series of tight

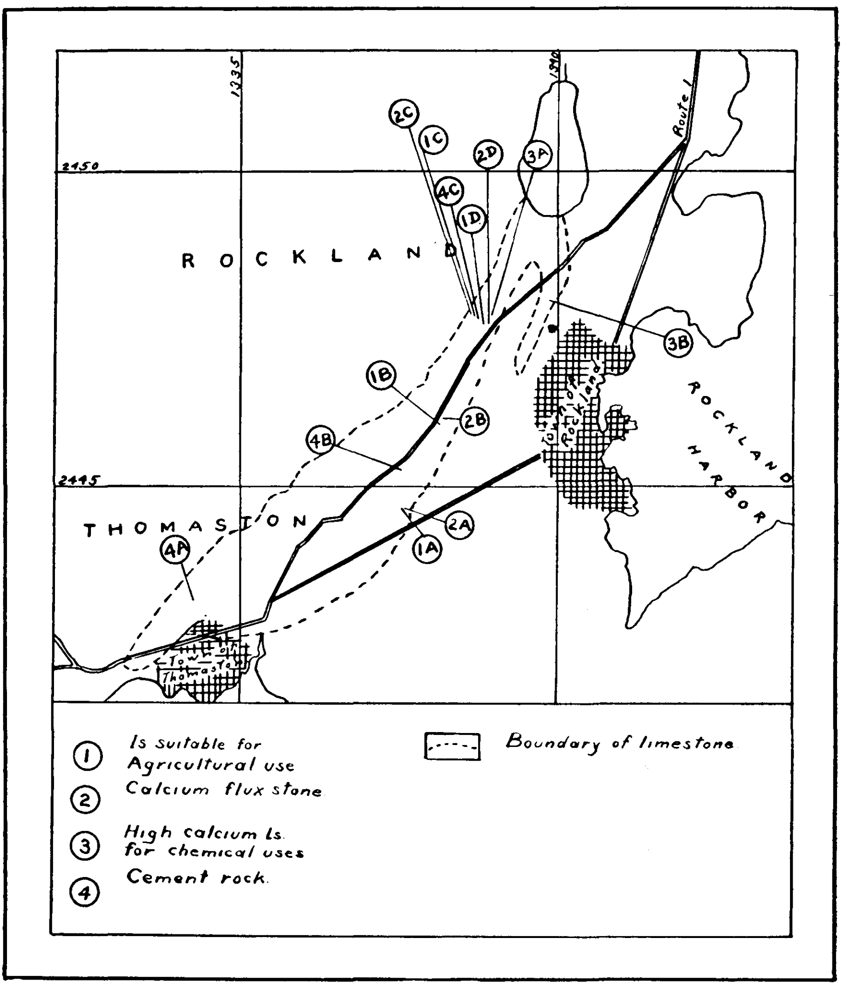

Figure 1

Location Map, Rockland, Maine Area

minor folds with trend of the axial planes being nearly parallel to the strike of the strata. Old quarries toward the northeast have been quarried to a depth of over 400 feet. It is reasonable to believe there is at least that much depth of limestone at this location. The abandoned quarry itself could be reworked to greater depth as well as a small unquarried area on the Blackington Farm between the southwest end of Softrock quarry and Hardrock quarry to the northwest.

Location 1B—A second location containing high magnesia limestone suitable for agricultural use lies some 4,200 feet northeast of Dexter Street between the present northeast working face of Mag quarry and Old County Road in Rockland. An unquarried area approximately 500 feet by 100 feet, is available here. In the adjacent Mag quarry considerable reserve of magnesia limestone is available since the present operation has reached a depth of less than 100 feet.

The limestone here appears to be in a northeast extension of the same zone as that described at location 1A above. The structure is also similar with the beds of both places having near vertical dips.

Location 1C and 1D—Location 1C and 1D are situated on the northwest side of Sleeper Field quarry on the northwest side of Old County Road near the head of Rankin Street in Rockland.

These zones are both rather narrow containing high magnesia limestone, and are about 325 feet apart separated by limestone of low magnesia content. Location 1D is about 25 feet northwest of the northwest edge of Sleeper Field quarry and has an outcrop width of about 75 feet across the strike of the strata, whereas, location 1C is about 400 feet northwest of the northwest edge of the quarry and has an outcrop width of 100 feet. The absence of exposures in the immediate area made it impossible to predict the length to which it would be economical to quarry these zones. However, it appears reasonable to expect on the basis of similar occurrences that these zones extend both northeast and southwest along the strike from these points. There may be considerable overburden over 1C since it is farther out in the valley toward Meadow Stream than is 1D. Most valleys in this coastal area have accumulations of glacial-marine clays with as much as 50 feet of depth not being uncommon. The clay is used in adjusting silica and alumina percentages in the manufacture of cement.

If the overburden can be removed with not too great an expense these two narrow zones of magnesia limestone can be quarried in conjunction with wider zones of high calcium limestone suitable for flux and other chemical uses from location 3B and a wide zone of impure limestone suitable for cement from location 4C.

The structure in the area of Sleeper Field quarry is similar to that discussed above at location 1A, which is indeed characteristic of the entire Rockland-Thomaston limestone belt.

Location 2A—In the immediate area southeast and adjacent to location 1A (magnesia zone) there is a parallel zone of good calcium limestone having a calcium carbonate content averaging above 86 percent.

The zone is at least 100 feet wide and extends for some 2000 feet northeast of Dexter Street to the southwestern edge of the abandoned Softrock quarry.

Quarrying conditions and structure that would be encountered could be expected to be similar to those at location 1A. The overburden is probably more than that encountered at location 1A, but is not believed to be excessive.

Chemically it would appear that the rock from this location would make good flux stone. In addition certain quantities of the rock may be of a quality suitable for other chemical uses where high calcium limestone is demanded.

Location 2B—The unquarried area lying just northeast of the present east corner of Mag quarry 800 feet northeast of the Pleasant Street iron bridge, between the northwest edge of Softrock quarry and the southeast edge of G. Ulmer quarry, is underlain by a zone of high calcium limestone according to drill core analyses.

This unquarried part of the high calcium zone is at least 100 feet wide and 500 feet long elongated parallel to the trend of the long axes of the quarries. The strata have very high dips at this point.

The zone is suggested as source of flux stone. Here again as at location 2A much of the rock may be also suitable for other chemical purposes.

Quarrying of this rock could be in conjunction with present operations in Mag quarry by extending the limits of Mag quarry.

Location 2C—Location 2C, which is a high calcium limestone zone having a calcium carbonate content averaging over 90 percent, is located about 550 feet northwest of the northwest edge of Sleeper field quarry on the northwest side of Old County Road at the head of Rankin Street, Rockland.

A width of outcrop for the zone has been determined at 250 feet. The length to which the zone could be quarried could not be determined due to lack of exposures, but it is reasonable to assume that this high calcium zone extends to the northeast and southwest parallel to magnesia zones discussed under Locations 1C and 1D. Core drill information obtained by the Cowhan Engineering Co. of Chicago in the area adjacent to Sleeper Field to the northeast would be invaluable in blocking out the limestone of the area. The survey understands that the core drill records of five holes put down by the Cowhan Engineering Co. have been incorporated into the private estate of the late George Cowhan; however, an agent for this estate does not know where these records are at the present time.

At location 1C, there is the possibility of thick clay overburden over this high calcium zone since it lies in the valley occupied by Meadow Brook. No information is available to the survey as to overburden depths in this particular area.

Quarrying of this high calcium limestone could be done in conjunction with operations for magnesia limestone at 1C.

The limestone from location 2C certainly could be used for flux stone and very likely for other chemical uses.

Location 2D—Between 75 and 100 feet southeast of the present southeast edge of Sleeper Field quarry, a high calcium limestone zone 175 feet wide is available near the intersection of Rankin Street with Old County Road.

This zone could be quarried at full width for about 100 feet to the southwest at which point Old County Road cuts diagonally across the limestone, however, there appears available a surface area of approximately 40,000 square feet between a line extending northwest from the head of Rankin Street to the edge of Old County Road. Undoubtedly the zone extends to the northeast, but here as in other parallel zones near Sleeper Field quarry the Cowhan drill records of the adjacent area to the northeast were not available and no exposures were present.

The bedding in the Sleeper Field area has a near vertical attitude so the outcrop width approximates the width of zone that could be maintained at depth. Quarries a short distance to the southeast have been excavated to a depth of over 400 feet. Apparently there is fully that much depth of limestone at this location, but it may not be economical to go that deep as a quarry operation.

It is believed that the rock here is a very likely source for flux stone, and it is possible that the rock would be acceptable in other chemical uses where high calcium limestone and lime are desired.

Location 3A—Present quarrying operation in the Sleeper Field quarry at the head of Rankin Street, Rockland, are in a high calcium limestone zone. The limestone is being utilized in the manufacture of paper. The quarry is being operated at a depth of slightly under 200 feet. Location 3A is used in this report to indicate the unquarried northeast extension of this zone from Sleeper Field quarry.

A 100 foot width is estimated for this zone and the distance that this zone can be followed to the northeast is subject to the same conditions as outlined for 1C, 1D, 2C, and 2D.

The rock from this zone could be used as a flux stone as well as for the manufacture of paper.

Location 3B—Along the southeast edge of the Charles Crockett quarry between Cedar and Maverick Streets, 0.7 mile south of south end of Chickawaukie Pond, Rockland, drill core records show an unquarried zone of high calcium limestone.

The zonal width has been estimated as at least 150 feet. It appears feasible that this zone extends for at least the distance between Cedar and Maverick street which is in excess of 800 feet. In addition the zone apparently parallels the southeastern edge of Achorn quarry to the northeast between Maverick Street and Old County Road along the southwest end of what is now the Rockland Golf Course.

Clay borings southeast of the Charles Crockett quarry indicate an overburden of clay averaging greater than 30 feet. The clay depth becomes greater toward the east. Apparently there is a clay filled valley at this point.

To recover the full width of this high calcium zone would require the removal of a great volume of clay unless it is found possible to mine the limestone. The possibility of underground mining should be thoroughly considered by a competent mining engineer.

It is believed that the limestone at 3B could be utilized for most chemical processes requiring a high lime content which would include use as a flux stone.

Location 4A—Location 4A is used to designate the area locally known as Will Simmons pasture. This pasture is located 0.3-0.4 miles north of the center of Thomaston village 400 feet west of Beech Woods Street near the intersection of Beech Woods and Erin Streets.

Visible exposures in the pasture show an outcrop width of at least 500 feet along a distance of over 1,000 feet for an impure limestone. Undoubtedly this length extends several hundred feet farther in both northeast and southwest directions. The rock that outcrops here consists of bluish-gray and white striped to light brown and brownish-gray striped limestone with light green, light brown, and light purple interbedded siliceous zones.

Topography here is controlled by the greater resistance of this impure zone, hence a gentle southwest sloping ridge of low height is present.

The analyses of collected samples from this area are not available at the present time, but it is believed that the location has possibilities in providing cement rock.

A length of 1,700 feet with a width of at least 500 feet is available on the Will Simmons place alone. This length probably could be extended at full width toward the northeast to Beech Woods Street. It is reasonable to assume here on the bases of structure and position in the limestone belt, that a depth of at least 200 feet is present. The average dip of the strata is 85 degrees to the northwest.

Before location 4A can be properly evaluated as a source of cement rock or for any other purpose, chemical analyses must be completed and it is recommended that coring borings be made.

Much of the brown striped rock at this location appears to also have possibilities for use as a flux stone providing the chemical analyses show sufficiently high lime content.

Location 4B—The 200 feet wide area adjacent on the east to the Gay quarry on the southeastern side of Old County Road near the Rockland-Thomaston town line, and extending along the strike of the strata from Dexter Street northeast to Old County Road (some 1,800 feet), has been designated as location 4B.

Limestone in this zone is for the most part not a high calcium rock but resembles in character much of the better limestone noted at 4A. On the bases of chemical analyses of the Blackington Farm drill core, the rock has the possibilities of meeting cement rock requirements.

In general the dips of the strata are very steep as is characteristic of much of the Rockland-Thomaston limestone belt. Abandoned quarry operations to the southeast would indicate over 300 feet of depth would be available.

Location 4C—Location 4C represents a 300 foot wide zone of impure limestone extending northwest from a point approximately 100 feet northwest of the present northwestern edge of Sleeper Field quarry. It represents the zone between magnesia zones 1C and 1D, but core drill analyses show this zone itself low in magnesia. The rock from this zone apparently has possibilities as cement rock.

The zone is subject to the same conditions as outlined above for parallel zones at locations 1C, 1D, and 2D, which are all situated in the area northwest of Sleeper Field quarry under the valley of Meadow Stream.

Conclusions

Conclusions that can be drawn for this preliminary report are as follows:

1. It is believed that the limestone of the main Rockland-Thomaston belt may hold a position in an anticlinorium rather than a synclinorium as proposed by Bastin. Additional field work along the southeast side of the belt may help solve the structural problem which is closely related to the stratigraphic problem. A petrofabric analysis of the Rockland limestone should be of great assistance in determining the regional structure. A limestone conglomerate with stretched pebbles, which is exposed near Rockport Village, appears to be especially adapted for this work.

2. Chemical analyses of collected limestone samples should be made in order to completely evaluate the limestone reserves in terms of uses and amounts. The various zones of limestone as described in this report and other zones not considered here appear to be related to the minor folds, being parallel to the trend of the axes of the major folds, hence a complete structural picture will aid in predicting these zones.

3. The possibility of underground mining should be considered. If economic, underground mining might considerably augment the quantities of good limestone available at the surface.

Acknowledgment

The survey thanks all owners of the properties visited for the excellent cooperation in allowing the field party to observe rock exposures on their properties. Especially are thanks due the Rockland and Rockport Lime Company of Rockland and the Lawrence Portland Cement Company of Thomaston as the two principal property owners and contributors of information. President Knott Rankin of the lime company and Vice-President John Pomeroy of the cement company have made available to the survey all their companies' maps, geological in-

formation, and chemical analyses. Much valuable information was obtained from the diamond drill core records of these companies. The use of these records has made it possible in this preliminary report to indicate certain unquarried zones of limestone suitable for several of the principal uses which otherwise would not have been possible until costly chemical analyses of collected samples had been made.

RADIOACTIVITY OF SOME MAINE PEGMATITES

By Richard J. Ordway

Introduction

During July and August of 1949 about six weeks of field work were spent investigating the radioactivity of some pegmatites in Maine. Field work had the following objectives:

(1) To study the radioactivity of pegmatites in an attempt to learn which of the various pegmatites contain radioactive elements—in particular, the element uranium; if possible, to identify these elements and the minerals in which they occur, and to determine the quantity and distribution of these minerals in the pegmatites.

(2) To consider the effect of overburden in measuring the radioactivity of pegmatites, and to explore the possibility of delineating zones in pegmatites on the basis of radioactivity. It was thought that possibly the radioactivity of different zones in some pegmatites might vary significantly. Potassium is feebly radioactive and abundant in some types of feldspars.

(3) To study variations in background readings in order to determine the minimum length of time for each count.

(4) In addition, a fourth objective involved the study of some of the pegmatites with the purpose of reporting on the history of the production of strategic mica in Maine during World War II and evaluating these pegmatites as future sources of mica. The main basis for this report is field work done by the author in Maine during 1943-1945 as a field engineer for a government agency, Colonial Mica Corporation. This report will be prepared separately in the future.

Field work was done in three general areas—Norway, Rumford, and Topsham. The following mines and prospects were checked with the Geiger counter for evidences of radioactivity: Albany township—Donahue, Wardwell, Guy Johnson, Fred Scribner, Ernest Wentworth, Stearns Mountain, Bumpus; Canton township—Reynolds; Greenwood township—Noyes Mountain, Nubble (Matti Waisenan); Hebron township — Hibbs; Newry township — Newry; Paris township — Mount Mica; Rumford township—Red Hill, George Elliot, Black Mountain; Stoneham township — Melrose, Foster Hill; Topsham township — Trenton Quarry, Quarry #1, Russell Brothers; Waterford township—Beech Hill; West Peru township—John Lobikis; Woolwich township—Trott Cove.

The following mines and prospects have been described in the *Report of the State Geologist* 1943-1944, published by the Maine Development Commission in March 1945 (geologic maps accompany some of the descriptions): Donahue, Guy Johnson, Fred Scribner, Wardwell, Ernest Wentworth, Noyes Mountain, Hibbs, Mount Mica, Russell Brothers, Beech Hill and Trott Cove. The names of these prospects or mines generally are based upon their locations or their property owners. Furthermore, the U. S. Geological Survey has mapped and reported upon many of these pegmatites. Copies of these maps may be obtained from the U. S. Geological Survey, Washington 25, D. C.

A battery-operated, portable Geiger-Mueller counter was used in the field work. This counter is a beta-gamma survey meter, whose probe has a 30-inch wire. Most beta radiation can be prevented by sliding the shield.

A Geiger-Mueller counter is an instrument designed to detect the presence of a radioactive substance. The principal part of the instrument consists of a partly evacuated metal tube which contains two metal electrodes kept at a constant difference of potential. No current passes through the gas in the tube from one electrode to the other because the voltage is so low. However, radiation from radioactive substances causes some of the gas particles to become charged (ionized) and to move toward one of the electrodes, thus causing a momentary current. This feeble current is amplified and can be made to operate a light, deflect a needle, or cause audible clicks.

The count consists in the number of pulses of electric current observed in one minute. This measures the magnitude of the radioactivity in the vicinity of the tube or probe. The counter records a number of pulses per minute even when uranium or some other radioactive substance is not present in noticeable quantities. Cosmic rays cause some of these and are more abundant at high altitudes. In addition, tiny amounts of radioactive elements are widespread in the rocks and mantle of the Earth. These pulses are called the background count and vary according to topography and rock types. Readings of a few minutes duration away from radioactive concentrations determine the background count. However, the background varies from place to place and somewhat from time to time at the same location.

A booklet called "Prospecting for Uranium" was published by the U. S. Atomic Energy Commission and the U. S. Geological Survey in 1949 (price 30c) to answer the many inquiries which prospectors and others had made to various government agencies on the occurrence, recognition, and sale of uranium-bearing ores. According to this booklet (pages 30-32):

> "After having first determined the background count for a general region, the prospector may proceed by merely walking with his Geiger counter over the area in which he is interested, meanwhile taking into account the general topography and geology of the land. At any place where the counter registers two or three times the background count, a close examination should be made with the counter probe in order to determine the precise source of the radioactivity. In particular, the prospector should try to determine whether the radioactivity is coming from a high-grade vein or from a mineral sparsely distributed through the rocks, since a relatively large area of weakly radioactive rocks will cause a response similar to that of a small crevice filled with high-grade ore.
>
> It is not possible to say what minimum reading a counter should give to indicate acceptable quantities or grades of uranium ore. A specific area that consistently gives readings of more than twice the background may well prove to be significant. The matter of primary importance is to obtain the reading in a specific area in terms of the background, and to select representative samples of the ore for assay. If the radioactivity of any particular rock is four times the background count, a sample should be taken.
>
> In prospecting with the Geiger counter, it is important not to cover ground too rapidly. Otherwise, the counter may not have time to register narrow veins that might be passed over. It is good practice to pause and take 1-minute readings at frequent intervals, especially in areas where preliminary testing indicates that radioactive minerals may be present. These readings should be taken by placing the counter probe on the ground.
>
> The question of how close a Geiger counter must be brought to uranium in order to detect it cannot be answered in terms of feet or inches. A counter's ability to detect a uranium deposit depends primarily upon four factors: the amount of radioactive ore, the richness of the ore, the amount of overburden, and the distance of the counter from the surface. The depth of overburden that rays from a radioactive mineral can penetrate depends upon the type of overburden. In some cases as little as 6 inches will conceal the presence of uranium. Naturally, high-grade ore will produce stronger rays than low-grade ore, and therefore may be detected at a greater depth beneath the earth's surface. Even high-grade ores, however, can rarely be detected under more than 2 feet of overburden."

In field tests the Geiger counter cannot distinguish radioactive rays given off by uranium from those of other radioactive substances. Potassium is feebly radioactive and may be one of the chief reasons that pegmatites in Maine give counts which are consistently above background. Radium, thorium, rubidium, and some carbon are examples of other radioactive elements.

Uranium-bearing Minerals

Uranium occurs in nature only in combination with other elements as mineral compounds. The most common uranium-bearing minerals are described in the booklet "Prospecting for Uranium"[9] (pp. 1-5) as follows:

"Uranium minerals are divided by geologists into two classes: primary and secondary. Primary minerals are those that have not been changed since they were originally deposited. Secondary minerals are those that have been formed from primary minerals by weathering or other natural processes. These are very different in appearance from primary minerals, and may be deposited at some distance from their point of origin by means of solutions that gradually seep through rocks. Both primary and secondary minerals are of interest to the prospector, since either may occur in concentrations of commercial value.

Primary Uranium Minerals

Primary uranium minerals are usually found in vein deposits or pegmatites. They are generally dark brown or black, are noticeably heavy, with a specific gravity of four or more, and frequently have a dull, pitch-like luster. Because they are easily decomposed to form secondary uranium minerals, they are not commonly found in surface rocks exposed to weathering. The more important primary uranium minerals are as follows:

Pitchblende

This is by far the most important uranium mineral. It is essentially uranium oxide, and is the chief constituent in virtually all high-grade ore . . . but to date has not been discovered in major concentrations in the United States. It usually is found in vein deposits, frequently in association with the sulphide ores of such metals as silver, cobalt, nickel, bismuth, and copper. It occurs in rounded, irregular masses, rather than as crystals, and breaks with a curved surface as does glass. Pitchblende is heavier than iron, about as hard as steel, and is grayish black, sometimes showing a greenish cast. It is practically never brownish black or reddish brown as are many of the other primary uranium minerals. When crushed into thin fragments or ground to a powder, pitchblende is always black, greenish black, or grayish black.

Uranite

This mineral has the same color, as well as most of the other properties and characteristics of pitchblende. Unlike pitchblende, it occurs in the form of small, cube-shaped crystals, rather than as rounded, irregular masses. It is sometimes found in association with pitchblende, but is most likely to be encountered in pegmatites. Although it has a high uranium content, it has not yet been discovered in significant concentrations except in close association with pitchblende.

Others

The other primary minerals are the uranium-bearing oxides of columbium, tantalum, and titanium, such as betafite, euxenite, and samarskite. In general, they do not occur in large enough concentrations to be considered as significant sources of uranium, although they have been mined for uranium on a limited scale in some parts of the world. These minerals, which usually occur in irregular masses of well-formed crystals, range in color from dark brownish red to black. In thin slivers or when powdered, they are decidedly reddish or reddish brown, which distinguishes them from powdered pitchblende. They are also less pitch-like than pitchblende, and are found for the most part in pegmatites.

Secondary Uranium Minerals

Secondary uranium minerals are characterized by bright yellow, orange, and green colors, and usually occur as earthy or powdery masses, as groups of very small crystals, or as flat plates. . . . The secondary minerals may occur in almost any type of rock, and may or may not be associated with primary minerals."

Field Procedure

A background reading was made at the car. In the vicinity of the pegmatite another background count was made. Next a tape-and-compass sketch map was made as a base upon which to plot the locations of reading stations and various notes on the geology. For some pegmatites, previous maps made by the U. S. Geological Survey, the Maine Geological Survey, or the author could be used. Following this, readings were taken on various parts of the pegmatite and surrounding rocks and recorded on the base map. Background counts were read periodically. Most readings covered a 2-minute interval, but some lasted 5 minutes and a few 10 minutes and 20 minutes. The longer readings were made chiefly to test fluctuations in background count and the reliability of the average 2-minute reading.

Several methods of taking readings were utilized. With the counter in operation, the probe was moved slowly over all accessible parts of the pegmatite and surrounding country rock. Where radioactivity seemed to be high, a search was made for the cause. Generally a small dark spot was located which was surrounded by stained feldspar or smoky quartz. Then a reading was taken on this spot. Frequently, when the probe was close to the spot, the radioactivity was too intense for the most sensitive range of the counter and a shift had to be made to a less sensitive range. The count was made by observing the number of deflections of a needle on a dial on the Geiger counter in a definite length of time. However, accurate counts seemed difficult on the less sensitive ranges, movement of the needle being less distinct.

In nearly all instances when the probe was moved a foot or so from the radioactive spot, a normal pegmatite reading was obtained. A high reading area thus could be surrounded by low reading areas. Normally this was checked by slow movement of the probe. A search was made in the field for high reading areas, and any such areas were noted on the maps. In addition, readings were taken on different pegmatite zones, along inclusions of wall rock and wall rock contacts, and along any areas of unusual mineralization. However, when the radioactivity of various pegmatite zones was tested, attempts were made to take representative readings and to locate the stations more or less at random within the zone areas. A few small sections of some pegmatites were found which gave high readings throughout. These are discussed in the descriptions of the individual mine or prospect.

All readings were compared directly with the background count. Instead of marking one spot on the map as a 45 count or another as a 38 count, these locations were labelled as 1.8 times the background or 1.6 times the background. If a reading could not be made on the most sensitive scale, then a plus sign was placed on that location, and the magnitude of the needle deflection noted.

Variations in Background Counts

Tables 1, 2, and 3 summarize results obtained by analysis of various background counts. Thirteen of the counts (Table 1) were taken for 10 consecutive minutes; four of the counts (Table 2) continued for 20 consecutive minutes. These readings were made at various times and places in the Norway-Rumford-Topsham areas. A record of individual 1-minute counts is given in Table 1 but is omitted in Table 2. Background counts were singled out for analysis since they are consistently lower than readings taken on pegmatites and thus may be read more accurately. A human error is introduced into counts of higher magnitudes because difficulty is experienced in noting each movement of the needle. This is especially true for readings several times the background. The needle may sometimes be deflected greatly and yet move with almost imperceptible jerks for a short time while deflected.

The chief emphasis in the Tables is upon the reliability (based on percentage variation from the average) of consecutive 2-minute counts. Figure 3 indicates that 66% of all the possible consecutive 2-minute counts analyzed fall within a 10% variation from the average, and that 21% of the remaining consecutive 2-minute counts fall within a 10-15% variation from the average. Thus 87% of all the possible consecutive 2-minute counts which were checked fall within a 15% margin of variation from the average. Therefore, counts of two minutes seem adequate in recording the radioactivity of various parts of a pegmatite. However, if greater accuracy is desired, then 3-minute, 5-minute, or longer counts must be taken. Furthermore, since considerable time is saved by taking counts of short duration, it is advisable to set limits of error at the beginning of a project, and then to select a time length for the count which conforms to this.

TABLE ONE

13 10-minute background counts	6	7	8	9	10	11	12	13	14	15	16	17	18	Averages for the 13 counts
First of 10 consecutive 1-minute counts	28	42	31	31	28	31	39	25	25	26	26	27	26	
Second count	27	31	33	23	41	34	33	36	39	28	26	29	24	
Third count	29	37	32	20	29	32	35	24	30	24	26	24	34	
Fourth count	27	28	25	24	42	29	36	19	29	26	25	20	24	
Fifth count	39	33	32	36	34	27	26	21	34	28	20	22	27	
Sixth count	30	39	36	31	41	30	27	33	35	33	24	24	25	
Seventh count	39	30	27	27	35	35	27	22	28	33	25	25	28	
Eighth count	29	35	37	24	40	37	35	27	27	25	25	21	24	
Ninth count	27	27	36	31	26	39	40	31	30	30	24	21	27	
Tenth count	30	30	37	23	33	30	39	17	27	30	27	25	23	
Average for the 10 minutes	30.6	33.2	32.6	27.0	34.9	32.4	33.7	25.5	30.4	28.3	24.8	23.8	26.2	29.5
Maximum percentage of variation from average in 1-minute counts	27%	26%	30%	33%	26%	20%	23%	41%	28%	17%	19%	22%	30%	26.3%
Highest consecutive 2-minute count	34.5	36.5	36.5	33.5	38	38	39.5	30.5	34.5	33	26	28	29	—
Lowest consecutive 2-minute count	27.5	28.5	28.5	21.5	30	28	26.5	20	27.5	25	22	21	25	—
Maximum percentage of variation from average in consecutive 2-minute counts	13%	14%	13%	24%	14%	17%	21%	20%	13%	17%	11%	18%	12%	16%
Number of consecutive 2-minute counts within 10% of the average (9 possible counts)	6 (67%)	8 (89%)	5 (56%)	5 (56%)	8 (89%)	5 (56%)	5 (56%)	4 (45%)	6 (67%)	7 (78%)	8 (89%)	5 (56%)	7 (78%)	68%
Number of consecutive 2-minute counts within 10-15% of the average	3 (33%)	1 (11%)	4 (44%)	1 (11%)	1 (11%)	3 (33%)	1 (11%)	2 (22%)	3 (33%)	1 (11%)	1 (11%)	3 (33%)	2 (22%)	22%
Number of consecutive 2-minute counts within 15-20% of the average	0	0	0	2 (22%)	0	1 (11%)	2 (22%)	3 (33%)	0	1 (11%)	0	1 (11%)	0	8%
Number of consecutive 2-minute counts more than 20% above the average	0	0	0	1 (11%)	0	0	1 (11%)	0	0	0	0	0	0	2%

TABLE TWO

Results obtained from four 20-minute background counts (Percentages carried to nearest whole number)	Average count for the 20 minutes (Range in parentheses)	Maximum percentage of variation from average for a 1-minute count	Maximum percentage of variation from average for consecutive 2-minute counts	Maximum percentage of variation from average for consecutive 3-minute counts	Maximum percentage of variation from average for consecutive 5-minute counts	Number of consecutive 2-minute counts within 10% of the average (19 possible counts)	Number of consecutive 2-minute counts within 10-15% of the average	Number of consecutive 2-minute counts within 15-20% of the average	Number of consecutive 2-minute counts more than 20% above the average
1	26 (16-34)	38%	23%	20%	13%	11 (58%)	4 (21%)	3 (16%)	1 (5%)
2	24 (15-32)	37%	29%	25%	17%	11 (58%)	3 (16%)	1 (5%)	4 (21%)
3	25 (16-32)	36%	24%	20%	8%	13 (69%)	3 (16%)	2 (10%)	1 (5%)
4	31 (23-36)	26%	21%	16%	13%	13 (69%)	5 (26%)	0	1 (5%)
Averages for the four 20-minute counts	26.5	35.5%	24%	20%	13%	63%	20%	8%	9%

TABLE THREE

	Percentage of 2-minute consecutive counts within 10% of the average	Percentage of 2-minute consecutive counts within 10-15% of the average	Percentage of 2-minute consecutive counts within 15-20% of the average	Percentage of 2-minute consecutive counts more than 20% above (or below) the average
Averages for 13 10-minute counts . . .	68%	22%	8%	2%
Averages for four 20-minute counts. .	63%	20%	8%	9%
Weighted averages representing 210 minutes of counting.	66%	21%	8%	5%

Granitic Pegmatites

Granitic pegmatites generally are light-colored rocks, commonly occurring in vein-like masses, which are characterized by very large and irregular grain sizes. In large part, they consist of the normal minerals which compose granite or granitic rocks with which they are often associated. Pegmatites have been a source of many valuable materials, among them being mica, feldspar, beryl, and spodumene. Some uranium-bearing minerals have been mined from pegmatites, but in general pegmatites contain such small amounts of uranium that they are not considered as important potential sources of that element.

Pegmatites have been studied and described for many years. However, the demand for pegmatite minerals during World War II stimulated study and systematic mapping of various pegmatite units and zones. This work has been described by a number of authors, among them being Cameron and others,[1,2] Shainin,[7,8] and Heinrich.[4] Heinrich[4] (pp. 438-439) has described primary units in pegmatites as follows:

"Many pegmatite bodies contain well-defined, mappable units of contrasting petrology (i. e., varying mineral content or texture or both) which, in the ideal case, occur as concentric layers around a central unit, or core. Such units, through recent usage, have been termed pegmatite zones (Shainin, 1946B). They are primary in the sense that they represent the original structural elements of the pegmatite body, formed in successive stages of crystallization from the walls inward. The structure and shape of zones reflect the attitude of the pegmatite body as a whole. Not only does their arrangement impart a rough bilateral symmetry in plan but in section as well. Pegmatites containing such units may be termed, *zoned pegmatites*, and those lacking these elements may be referred to as, *unzoned pegmatites.*

Recent usage has also suggested appropriate names for various zones. The outermost zone along the wall rock contacts is the *border zone.* Because these are commonly thin, they generally cannot be mapped separately, and because they are of relatively little practical importance to the pegmatite miner, they have been ignored. On the other hand some operators have distinguished an economically important *wall zone*, which name can conveniently be retained for the zone adjoining the border zone. The central units are known as *cores*, and a zone immediately surrounding a core is often referred to as a *core-margin zone.* Any zone that falls between the core and the wall zone may be termed an *intermediate zone*, of which the core-margin zone is one variety.

The designation of zones in actual practice is not always easy. Lack of pegmatite exposures, changes in relative position of units on different levels owing to the plunge of central and intermediate zones, incomplete development of zones, and disruption and destruction of zones by secondary material are factors that tend to complicate the deciphering of the zonal structure.

Although, in general, the configuration of zones reflects the over-all shape and attitude of the pegmatite, it should be noted that zones may be imperfectly developed, at least in the horizon under immediate observation. Cores, in particular, may occur as several isolated lenses or pods as well as single central bodies. Some intermediate zones will show a maximum thickness around the end of cores and may pinch out along its sides to form a hoodlike unit. Locally within the pegmatite border or wall zones may be discontinuous.

Page[5] (p. 34) has stated:

"In summary, potash-rich (perthite-rich) zones or pegmatites are the most likely sources of uranium minerals and soda-rich (albite-rich) or lithia-rich (lepidolite-rich) zones or pegmatites are somewhat less favorable. Furthermore, sheet-mica-bearing pegmatites are less favorable than the scrap-mica-bearing deposits. Uranium minerals from pegmatites probably will continue to be a byproduct of mining for other minerals, and appreciable production cannot be expected from this source."

Radioactivity of Some Maine Pegmatites

Brief comments follow on results obtained from a study of the radioactivity of some Maine pegmatites. Some pegmatites are discussed individually, others are grouped together.

Red Hill Pegmatites

The Red Hill pegmatites are located about 4½ miles west of the city of Rumford in the town of Rumford. A topographic-geologic map of these pegmatites and the surrounding area was prepared under the direction of Vincent E. Shainin.[8] In mapping the internal structure of the Red Hill pegmatites, Shainin recognized four zones: (1) border zone, (2) wall zone, (3) intermediate zone including the core-margin zone, and (4) the core zone. This map was used by the writer as a base in studying the radioactivity of the various zones in these pegmatites. Nearly 100 readings were made at various locations on the pegmatites and plotted on the map. All of these counts were of two minute duration or longer. In addition, nearly all the accessible parts of the pegmatites were covered by slow movement of the probe while the Geiger counter was in operation.

Results of this study are shown in Table 4. The background count averaged 26½ for 13 different readings. All other counts are expressed relative to the background count—a 2.5 count means 2½ times the background count. Brief comments on the geology accompany some of the counts listed in Table 4.

A number of small areas of greater radioactivity were discovered. Commonly a small black mineral grain (uraninite?) was found surrounded by smoky quartz and/or stained, discolored feldspar. The dark color of the quartz and feldspar fades out gradually away from the black mineral grain. In some specimens the characteristic octahedral shape of a uraninite crystal could be recognized, in others no definite crystal faces could be discerned. Undoubtedly, the invisible rays given off by the radioactive material have caused the quartz and feldspar to become dark in color. This association of smoky quartz

TABLE FOUR--RED HILL PEGMATITES [Base Map by Shainin[8] (Map VI)]

Core Zone Count	Core Zone Geology	Core—Margin Zone Count	Core—Margin Zone Geology	Intermediate Zone Count	Intermediate Zone Geology	Wall Zone Count	Wall Zone Geology	Border Zone Count	Border Zone Geology	Wall Rock Count	Wall Rock Geology	Aplitic Granulite Count	Aplitic Granulite Geology
1.4	Probe on perthite and quartz	3.2	Ass. smoky quartz and fine-grained muscovite	1.9	Perthite	1.4		2.5		1.8	Wall rock is schist and quartzite interbedded	1.5	
2.1	Probe on perthite	(+)	Ass. sm. quartz	1.0	Quartz	1.4		3.6		1.4		1.4	
1.3	Probe on quartz			1.8	Perthite	1.4		2.0		1.3		1.2	
1.8	Probe between perthite and quartz crystals	1.9	Perthite	1.5		(+)	Sm. Quartz and Uraninite (?)	1.6		1.3		1.8	
		3.3	Sm. quartz					2.0					
2.0	Perthite	3.1	Sm. quartz	1.7		(+)	Sm. quartz and Stained feldspar	1.8		1.6			
1.0	Quartz	1.9	Perthite	1.6									
2.3	Perthite	2.0	Perthite	1.3		(+)	Sm. quartz and Stained feldspar	1.6		1.6			
1.9	Perthite	1.2	Quartz					1.5		1.6			
2.0	Perthite	2.0	Perthite			(+)	Sm. quartz	1.3		2.3	Beryl zone in wall rock		
0.8	Quartz	0.9	Quartz			(+)	Sm. quartz						
2.0	Perthite	1.4				2.7	Sm. quartz						
0.7	Quartz	1.3				(+)	Sm. quartz						
1.7	Between quartz and perthite crystals	1.3				1.4							
		1.2				1.9	Graphic granite						
1.2		1.9	Perthite			1.6							
2.3	Perthite	0.8	Quartz			2.2							
						1.6							
1.6	Between quartz and perthite crystals					1.0							
						1.5							
1.3	Between quartz and perthite crystals					1.3							
						1.2							
2.0	Perthite					1.2							
2.0	Perthite					1.5							
0.7	Quartz					1.5							
2.2	Perthite					2.5							
1.2						1.5							
22 readings average—1.6		15 readings average—1.8 [one count (+) omitted from average]		7 readings average—1.5		18 readings average—1.6 [6(+)counts omitted from average]		9 readings average—2.0		8 readings average—1.6		4 readings average—1.5	

Note: The count is expressed relative to background, i. e., a 2.0 count is twice the background count. Background averaged 26.5 for 13 readings. Plus (+) readings could not be made on the most sensitive scale, the radioactivity was too intense.

and/or stained feldspar with radioactive minerals was found in nearly all the pegmatites studied.

Study of the radioactivity of various zones in the Red Hill pegmatites seems to have given few significant results. Table 4 indicates that the average count on the different zones ranged from 1.5 to 2.0 times the background count, plus (+) counts omitted. Eight readings on the schist-quartzite wall rock averaged 1.6 times the background. It is difficult to see how zoning in pegmatites can be delineated on the basis of such results. Perthite-rich sections of a pegmatite commonly give a count which is about double the background and higher than an average pegmatite reading. This evidently is due to the radioactive potassium which is abundant in the perthite. However, very low readings (equal to background or less) are obtained on large quartz crystals surrounded by perthite. Furthermore, a reading of about 1½ times the background is obtained when the probe is placed at the contact between the quartz and perthite crystals. Even though very little perthite (and thus potassium) is present in the border zone and wall zone, the radioactivity of these zones is approximately the same as the radioactivity of the perthite-rich core and core-margin zones.

Uraninite (?) grains in the Red Hill pegmatites seem to be confined largely to the wall zones and core-margin zones, with the wall zones furnishing about twice as many specimens as the core-margin zones.

Melrose

The Melrose quarry is located in the town of Stoneham about 5½ miles west-northwest of the village of East Stoneham on the southeast slope of Sugarloaf Mountain. The property was worked for feldspar within the last few years. The pegmatite is well zoned with very large crystals of quartz and perthite in its central parts.

Numerous small areas in the pegmatite were found too radioactive for reading on the most sensitive scale of the Geiger counter. Most of these areas were associated with masses of smoky quartz. In some instances small grains of a black mineral (uraninite?) could be seen in the smoky quartz. However, when the probe was moved a foot or so from such radioactive areas, a normal pegmatite reading was obtained. Most of these radioactive areas are associated with large quartz crystals in the central part of the pegmatite and probably are located ni core-margin zones. Average readings on large perthite crystals weer about double the background count, whereas average readings on large quartz crystals (not smoky) were about equal to the background count.

A sulfide vein, exposed for a length of about seven feet and having a maximum width of about one foot, was discovered cutting the pegmatite at one place.. This vein gave high readings consistently, being too radioactive for reading on the most sensitive scale of the Geiger counter. A 1-lb. sample of this zone was analyzed by the Trace Elements Section of the U. S. Geological Survey. The equivalent uranium content of the sample was reported to be only 0.09% uranium.

Nubble

This abandoned mica mine is located in the town of Greenwood on the northwest slope of the Nubble abour four miles southwest of the village of West Paris.

Two small veinlike zones, containing abundant biotite mica and garnet, and some smoky quartz and muscovite mica, were discovered. These were traced along the strike of the pegmatite, and gave high readings consistently throughout their extent, averaging more than 2½ times the background count. Other sections of the pegmatite gave normal pegmatite counts.

Noyes Mountain

This abandoned mica-gem quarry is located in the town of Greenwood on the south slope of Noyes Mountain about four miles southwest of the village of West Paris.

Several parts of the pegmatite containing abundant garnet and black tourmaline gave high readings consistently, some parts being too radioactive for reading on the most sensitive scale of the Geiger counter. Other sections of the pegmatite gave readings which were less than double the background count.

Ernest Wentworth

This pegmatite is located in the town of Albany about two miles west of Hutchinson Pond. Numerous pegmatites occur in the area and small prospect pits are numerous. A well-developed core zone is exposed in one small prospect pit. This core zone contains large crystals of quartz and perthite and is some 5 to 7 feet in width. Beryl crystals are abundant. The impression of one crystal had an exposed length of 3½ feet, a width of 15 inches, with the rest of the crystal projecting an unknown distance into the pegmatite. Two other crystals about nine inches in diameter were measured, and numerous smaller crystals were seen.

Several black mineral crystals (uraninite?) were found which were too radioactive for the most sensitive scale of the Geiger counter. These crystals were located in stained perthite masses. Some of the uraninite (?) crystals were located in a core-margin zone, others were found in big loose blocks of pegmatite on the pit floor, their mineral associations apparently indicating either core or core-margin zones.

Black Mountain

This abandoned mine is located near the top of Black Mountain in the town of Rumford about five miles west-northwest of the city of Rumford.

High readings were obtained on stained surfaces along joints which cut various parts of the pegmatite. Some of these stained areas were too radioactive for reading on the most sensitive scale, others gave readings considerably above the background count, and still others gave normal pegmatite counts. Typically the stained surfaces are shiny blue-black in color showing an irridescence, but some surfaces are dull and have a black sooty appearance.

Counts on large perthite crystals commonly were double the background count or more, whereas large quartz crystals gave readings about equal to the background count.

Pegmatite Groups

Some radioactive black minerals (uraninite?) were found at each of the following mines or prospects: Hibbs, Stearns Mountain, Trott Cove, Quarry #1, Russell Brothers, Donahue, Mount Mica, and Newry. Nearly all of the black mineral grains were surrounded by smoky quartz or perthite stained a dark color. In general the dark colors fade out gradually away from the black mineral in a manner similar to that seen in other pegmatites in Maine. All of these areas gave counts which were more than double the background count, most of the specimens being too radioactive for reading on the most sensitive scale of the Geiger counter. Probably the uraninite (?) crystals are associated with core-margin zones at Stearns Mountain, Quarry #1, Russell Brothers, and Newry. At Mount Mica several uraninite (?) crystals were found in loose blocks of pegmatite on the dump. Two others were located in the wall zone within $1\frac{1}{2}$ feet of the contact. At the Donahue prospect several uraninite (?) crystals were discovered within two feet of the granite wall rock, apparently in a wall zone.

Counts more than double the background were obtained on parts of the following mines: Scribner, Beech Hill, Wardwell, and George

Elliot. However, no specimens of uraninite were seen. At the George Elliot mine, numerous readings along schist inclusions or wall rock contacts gave counts about three times the background count. However, low readings were also obtained at other places along schist inclusions and wall rock contacts. At the Wardwell mine the highest readings were 2 to 2½ times the background count, the majority of these being located along the contacts of the pegmatite with the gneissic wall rocks or along the margins of inclusions of gneiss in the pegmatite. At Beech Hill only four readings were obtained which were more than double the background count. Three of these are located along the contact with the wall rock.

Foster Hill, Reynolds, John Lobikis, and the Bumpus mines gave very few readings which were double the background count, and most of these few counts were associated with large masses of perthite. However, much of the Bumpus mine was inaccessible because of water conditions.

Summary

This study of the radioactivity of Maine pegmatites produced results which are largely negative, although not entirely unexpected.

1. Statistical analysis of some 210 minutes of consecutive 10- and 20-minute background counts made with the Geiger counter indicate that 66% of all possible 2-minute counts vary 10% or less from the average, and that 21% of the remaining possible 2-minute counts vary 10-15% from the average. Thus 87% of all possible 2-minute consecutive counts vary 15% or less from the average. Therefore, 2-minute counts seem an adequate length for checking the radioactivity of pegmatites. If greater accuracy is desired, longer counts must be made.

2. No commercial concentrations of uranium-bearing minerals were found in any of the pegmatites studied. About two-thirds of all the pegmatites checked with the Geiger counter were found to contain black radioactive mineral grains, probably uraninite in most instances. Invariably these black mineral grains were found to be surrounded by smoky quartz and/or stained feldspar, with the dark color fading out gradually away from the radioactive mineral grains. Evidently the invisible rays given off by the radioactive material caused the quartz and feldspar to become dark colored. When the counter probe was moved a foot or so from these radioactive minerals, a normal pegmatite reading was obtained. Most of these uranium-bearing minerals were found in wall zones or core-margin zones.

3. Several pegmatites were found to contain certain areas which consistently were too radioactive for reading on the most sensitive scale of the Geiger counter. A sulfide vein cutting the Melrose pegmatite is representative of these areas. Analysis by the Trace Elements Section of the U. S. Geological Survey showed an equivalent uranium content of a 1-lb. sample to be 0.09%—very low.

4. An attempt was made to delineate zones in pegmatites on the basis of radioactivity. Potassium is feebly radioactive and is present in perthite which is abundant in core and core-margin zones; potassium is absent in the plagioclase feldspars which predominate in border and wall zones. Nearly 100 counts were made on different zones in the Red Hill pegmatites in Rumford with results which are summarized in Figure 4. The average count in each zone varied from 1.5 to 2.0 times the background count—the border zone giving the 2.0 count. These results appear not to be significant. Since the results were obtained on pegmatites exposed at the surface, little research was done in checking the radioactivity of pegmatites beneath overburden.

5. In every pegmatite checked with the Geiger counter, large masses of perthite gave readings which were about double the background count or slightly more, whereas large quartz crystals (not smoky) gave readings which were about equal to the background count or less.

6. Readings taken along the margins of inclusions of wall rock or along wall rock contacts with pegmatites were double the background count or more in parts of some pegmatites, but gave normal counts in other parts of the same pegmatites and in other pegmatites.

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SHORE STUDIES

By J. M. Trefethen

In any evaluation of Maine's natural assets, the shore zone ranks high indeed. Many will agree that nowhere else in the United States can be found its scenic equal. The potential of tidal power, and the utilization of our natural harbors and coastal thoroughfares are, of course, well known. In addition to these physical aspects, however, are biologic assets. Although perhaps less widely recognized, thriving and economically significant industries are based on the biological resources of the shore zone. Among these the harvesting of the soft shell clam, *Mya arenaria*, is outstanding. According to a bulletin of the Maine Department of Sea and Shore Fisheries ("The Maine Clam," by Robert L. Dow and Dana E. Wallace) the annual dollar value of the clam harvest has increased sevenfold in the past decade. Based on retail prices, the value of clam production is estimated by the Department of Sea and Shore Fisheries to be not less than $25,000,000, of which some one to two million dollars are paid directly to the producers.

During the course of its biological research, the Maine Department of Sea and Shore Fisheries has found that some clam flats have deteriorated and that others have improved as habitats for the clam. Because there are, possibly, factors of the physical environment which can be correlated with the productivity and growth of clams, geological investigations have been cooperatively undertaken by the Maine Geological Survey and the Maine Department of Sea and Shore Fisheries. The first of this projected series of cooperative geological investigations was begun in the field season of 1948, with the field and laboratory studies of the Stover's Cave, South Harpswell, Me., area by Mr. J. J. Donohue. In subsequent seasons investigations have been made of a portion of Sullivan Flats, Sullivan, Me., by Mr. Philip Stackpole; Great Bar, Jonesport, Me., by Mr. William Fairley; Medomak Cove, Bremen, Me., by Mr. Donohue, and Margo's Bay, Surry, Me., by Mr. Clyde Grant. Studies have also been begun of the Doctor's Creek Area, Wells, Me., and Western Beach, Scarboro, Me. Detailed studies of portions of the flats at Georgetown, Me., have been made by Dr. W. H. Bradley, Chief Geologist of the U. S. Geological Survey, with the same general objectives as those of the Maine Geological Survey shore studies. So far, these investigations are in the fact finding stage. When the detailing of the Doctor's Creek and Western Beach areas are completed, with possibly the addition of one more area, Musquoit Bay, detailed reviews and possibly remapping of the completed areas will be undertaken to determine the extent of changes brought about by the physical agents acting upon the area since the first mapping.

The areas selected for these detailed studies represent the major types of flats from which clams are taken. These "samples" include flats dominantly silt and clay mud, sand flats, sand and pebble or cobble areas, and complex beaches with a wide variety of sediment types. As the work progresses, it becomes increasingly apparent that the ecological complex, especially the biological factors, must be carefully studied, and the individual components of the complex properly correlated. Just as in the community of nations today, no one people is living unaffected by the milieu, so the reproduction and growth rates, thrift, and even survival of clam populations is a resultant of the physical and biological milieu in which they live.

Some of the techniques of the earlier studies have been abandoned or modified, and some new ones introduced as experience has indicated. Investigations of this type are in a pioneering stage. So far as known this is the first state sponsored investigation of this particular kind undertaken in this country.

SEDIMENTS OF MEDOMAK COVE, BREMEN, MAINE

By J. J. Donohue

Introduction

In the investigation of littoral sediments, bank sediments, and geological factors which may influence survival and growth of *Mya arenaria*, the Medomak Cove area was selected for detailing. The month of August 1949 was spent in this study.

Medomak Cove is approximately eight miles south of Waldoboro, Maine, and located on the eastern shore of the Bremen Peninsula. The cove is part of the western borderland of Hockomock Channel through which the Medomak River drains into the sea.

Field Work

The detailed study of this area consisted of:

Mapping: Topographic mapping of the area included the littoral and bank zones. Mapping was done on a large enough scale to permit detailed plotting of the surface geology and the location of test pits. Original map scale is 1:600 (1 inch equals 50 feet). The contour interval was one foot. (Map VIII)

Geologic mapping of surface sediment units, bed rock, and test pit locations was made by plotting such on the topographic map which served as a base.

Sampling: A grid system for establishing test pits, from which samples were collected, was used. A square grid system was laid out because of a narrowing littoral zone, and in an effort to keep the spacing of the test pits uniform.

Test Pits: Test pits of the littoral zone were dug to a depth of 24 inches. This is approximately the maximum depth to which one can dig here because of wall slump. Sediment samples were secured from all profile zones in the profile sections. *Mya* usually occupies a position a few inches below the surface to a depth not exceeding ten inches. Therefore, the sediment samples are representative of the immediate *Mya* environment and also of that environment both above and below *Mya* occupation.

Bank Sampling: Sediment samples were collected from the banks surrounding the cove area and also from several localities further inland from the immediate bank-littoral zone area, e. g.; *BS a, b, c.* Bank sampling consisted of two samples for each locality; one in the upper portion of the bank and one in the lower portion of the bank. To avoid collection of slump material the bank was cut back about two feet and a clean sample was secured for sediment analysis.

Field Interpretations: A field interpretation of sediment units, i. e., unit structure, texture of sediment, type deposit (glacial, marine, slump), source area, factors of deposition, and condition of porosity and permeability was made.

pH Data: As in the Stover Cove investigation, the littoral sediments were tested for pH. Conclusions drawn from the Stover Cove data, namely, that the sediment high in silt and clay content, contains much organic slime, is of low permeability and accumulated decomposed organic products—hence a reducing and highly acid environment—are verified by the findings in the Medomak Cove area.

Penetrometer Recordings: Proctor Needle recordings were taken to secure some information regarding the compactive resistance of the sediment. For most types of littoral sediment, however, tests of compactive resistance by this instrument are of little value. Substitution of the "cone-bearing" type of test device as described by Boyd[1] is suggested.

Permeability and Porosity Measurements: Since it is apparent that the pH of the littoral sediments varies with subsurface drainage, the writer recommends that a greater effort be made in securing porosity and permeability data in the field. To date, these data have only been estimated qualitatively by comparisons from pit to pit by observation of how rapidly the pit filled with water. Thus a rough measure of the relative permeabilities of the sediments is made. Dr. K. O. Emery[2] suggests the following field procedure for obtaining permeability data: Push a long glass rod, 6-50mm ID, into the previously undisturbed sediment so as to get a plug 5 to 10cm long in one end of the glass tube. Some gain is obtained by applying some suction at the time of pushing. Set the tube upright on a wet paper towel with the plug end

[1]Boyd, Keith; Suggested Method for Bearing Power of Soil by Means of a Cone Machine, Procedures for Testing Soils, ASTM, 1947.

[2]Dr. K. O. Emery; personal communication.

down. Apply a water head of 100 to 150cm by filling the tube with water. Put a drop of kerosene at the top to stop evaporation. The volume of water that passes through the plug can be determined by successive readings showing the change of head, to a maximum of, say, 15cm drop. These measurements of lapsed time, head, change of head, and plug length can be inserted into the usual permeability formula. The measurements will be in darcys.

General Description of the Medomak Cove Area

Major Sediment Units of the Littoral Zone: Beginning at the wave-cut bank and working toward low tide, a major pattern for the surface sediments can easily be seen in this area: This pattern is:

1. A boulder pavement with an average width of ten feet and an average relief of three feet can be seen on the southwest side of the cove. The majority of these boulders are probably derived from adjacent farm land as residents of the area report that for years boulders from the fields atop the southwest banks have been dumped over the southwest bank. The writer believes this to be true because holes drilled into the boulders for insertion of a metal pin for removal from the ground are visible in many of the boulders of the boulder pavement on the southwest shore. The bank has probably been actively eroded since the first concentrated dumping, and wave action has distributed

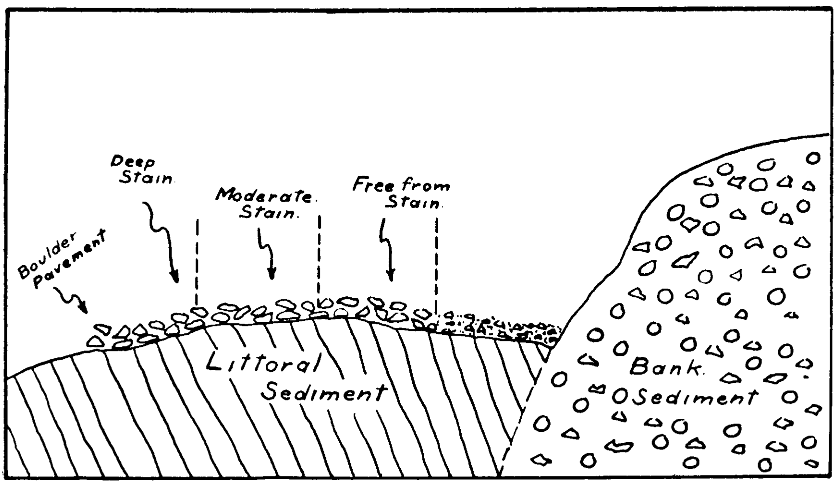


Figure 1

the boulders. Those boulders farthest from the bank are stained dark brown. On the other hand, the boulders at the base of the wave-cut bank are relatively free from stain.

Figure 1 shows the boulder pavement. The reason for the filled space between the boulder dump and the bank can be accounted for by the lack of boulder dumping in recent years, subsequent erosion of the bank by wave action, and then a deposit of mixed debris (sand, pebbles and small cobbles) by storm wave action. No boulders appear in the marine clay bank sediments.

The boulder pavement on the northeast shore appears to be a natural deposit from the bank which is comprised of glacial till. This boulder pavement is not as heavy nor as concentrated as that on the southwest bank.

2. Adjacent to the boulder pavement is a sediment unit of scattered pebbles, cobbles and boulders with silty-sand.

3. Seaward of the preceding is a sediment unit of silty-sand and pebbles.

4. Next seaward is a sediment unit of uniform silty-sand which is exposed at low tide.

Minor Sediment Units of the Littoral Zone

1. Black sandy-silt, rich in organic slime, fringes the cove area. At low tide it is exposed as lenses restricted to areas of the *Mytilus edulis* beds. The *Mytilus* beds trap part of the silt and other fine debris that would otherwise be transported to deeper water. A section through one of these beds is shown in Fig. 2.

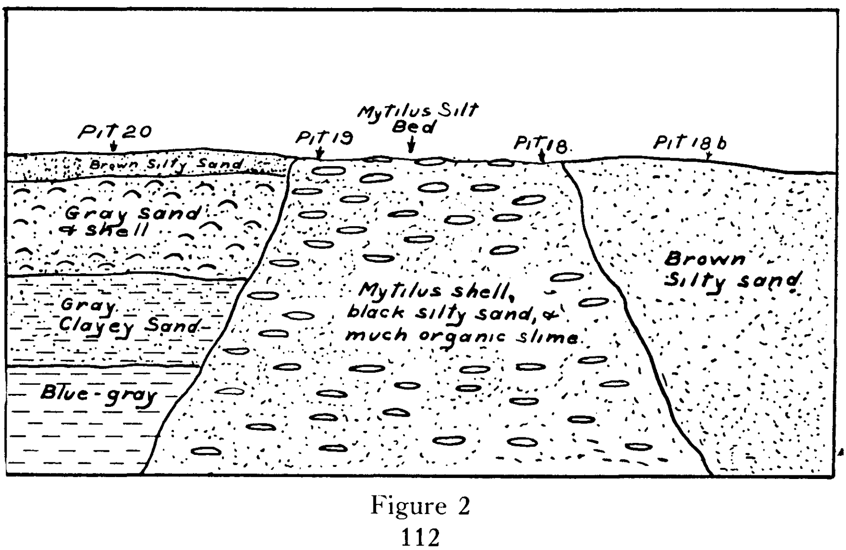


Figure 2

From Fig. 2, it can be seen that the *Mytilus* bed is funnel shaped with the apex upward. Black silty-sand, rich in organic slime and H_2S, and with an acid pH, occupies the interstices. Permeability is small and the porosity is high. This is thus a trap for the accumulation of the products of organic decomposition.

2. A marine blue clay sediment unit is found in the vicinity of pit #24. (See accompanying map). This clay is exposed at the surface and rests directly on bedrock at a depth of seven feet. The marine blue clay is probably in large part an original marine deposit of the Pleistocene; however, it possibly consists in part of slump material derived from the marine blue clay banks. Actually this marine blue clay unit is at the head end of a littoral zone basin less than one foot in depression over an area approximating the enclosure of lines drawn from pits 11, 15, 25, and 28 (see Map). The basin is apparently controlled by the bedrock outcrop in the vicinity of pit #28; the silt bed controlled by boulder and *Mytilus* traps in vicinity of pits 16, 18, 19 and 29; and the coarser debris of the littoral sediments in vicinity of pits 10, 13, 14, and 15. It is in this basin the marine blue clay dominates as the sediment type—either as uniform marine blue clay or as part of a sediment mixture as for example clayey-silty-sand. The slow surface drainage, (lag of the tidal drainage due to the depression) and poor permeability of the sediment makes for an acid pH condition which is detrimental to *Mya* growth and survival.

The entire cove area, exclusive of the boulder pavement, shows poor sorting regardless of sediment type. This indicates that the majority of the sediment has a source area close by, i. e., the banks and local bedrock erosion. Although some of the sediment may have been transported into the cove from more distant sources, the bulk of the material is locally derived. Rock type, fragment shape, and sediment unit distribution enter into this conclusion.

Bank Sediments

The bank sediments of the Medomak Cove area show a facies change. Texture, color, and lithology distinguish the facies.

The bank sediments of the southwest shore are marine blue clay. The particle size is less than 2mm. The bank sediment of the northeast shore, on the other hand, is a glacial till, tan in color with a particle size range from clay to large boulders. A comparison of the sorting coefficients supports this differentiation.

Division of the Area into Three Main Categories

The Medomak Cove area may be split into three main categories of sediment, based on sediment type of the basal profile zone and the bank sediment type.

Area I: This area lies southwest of the stream channel which bisects the cove.

The bank sediment is marine blue clay showing no particle size greater than 2mm, with the exception of a few lone pebbles. However, glacial till is in evidence further up the slope of the bank (approximately $\frac{1}{2}$ mile). The picture then, is that the marine clay is deposited, up slope, on the flanks of glacial till. On the other hand, the marine blue clay along the shoreline and on the littoral zone rests on bedrock (data by augering.) Thus, in the geologic past, glacial till probably formed the bank sediment of the cove area, then as marine action began to dominate the scene it swept a portion of the bedrock clear of till and deposited marine clay. This is not true of the bank sediments of the northeast shore (discussed elsewhere in this report). We hypothesize, therefore, that the wave and current action at the time of marine clay deposition was dominantly in a northwest direction sweeping the bedrock clear of glacial till; subsequently quiet water conditions ensued with deposition of the marine clay on the shoreline bedrock and encroaching up the flanks of the remaining upslope till. That the till once formed the bank sediments of the entire cove area is evidenced by the huge boulders remaining in the vicinity of pits #15, 16, 17, and 20. This boulder accumulation along with the boulders found in the vicinity of pit #50 may well mark a former shoreline by a curved line connection from pit #50 to #17. These boulders are resting on bedrock. It may be recalled that similar relations were found in the Stover Cove area at Harpswell, Maine (see Report of State Geologist 1947-48). It may also be mentioned that augering of the bank sediments of Area I shows less than one foot of top soil lying directly on top of the marine clay.

The littoral surface sediment of Area I has already been mentioned. This area we find to have marine clay forming the basal profile zone at varying depths. The marine clay rests directly on bedrock. At certain locations the marine clay appears at the surface of the littoral zone, and is one of the dominant surface sediment units of Area I (see map).

Area I is an area of active bank slump, the sediments of which are contributing to the present day deposits of the littoral zone.

The test pits of Area I show that the sediment profile is composed of 2 or 3 profile zones, to a depth of 24″. The profile zones are of a poorly sorted sediment ranging from clay size particles to pebbles, and some cobbles. The dominant color for the area is dark gray to light gray.

Area II: This area flanks the permanent stream channel at the head end of the cove and is characterized by a black to a black-gray silty-sand containing much organic slime. Here the sediment profile consists of one or two profile zones. Where two profile zones are present, the differences in color and texture are slight. The sediment forms a relatively thin veneer covering the bedrock of the area (gneiss and schist). Average depth of bedrock at the head end of the cove is approximately 1.5 feet, permeability is low, porosity is high, much organic decomposition is going on, and the *Mya* growth is relatively poor.

Area III: This area lies northeast of the stream channel. The bank sediment of this area is glacial till. The sorting is poor with a range in particle size from clay to boulders and with pebbles, cobbles and boulders foreign to the bedrock of the area. It is hoped that final comparative studies of the heavy mineral suites from both bank areas and the littoral sediments will yield conclusive information as to agent of deposition and source area of the material.

Color comparisons of the bank sediments of Areas I and III show that those of Area III are more highly oxidized than those of Area I.

The basal profile zone of the *littoral sediments* of Area III is derived from the bank sediment. This conclusion is based on color and textural similarities of grains from pebble to clay size. Bank slump is not in evidence. Surface sediments of the littoral zone are comparable to those of Area I, with the exception of the marine clay units of Area I.

Comparison of the Chief Characteristics of Areas I and III

Area I. Bank Sediments:

1. Marine blue clay (mbc).
2. Very moist and highly plastic.
3. Sorting coefficient (Trask) lower than that of the bank seds of Area III.

4. Contains no boulders or cobbles.
5. Contains "pipe-stem" concretions throughout the entire exposure of the bank sediments. These "pipe-stem" concretion structures of oxidized bank sediment surround roots of vegetation.

Area I, Littoral Sediments:

1. Basal profile zone same as bank sediment, marine blue clay.
2. Sediment profile usually composed of two or three profile zones.
3. Coloration of sediment ranges from dark gray or black at the top to light gray at the bottom of the profile.
4. Surface sediment, except for the basin area of marine clay unit (pits 11-24 vicinity), is similar, lithologically, to Area III surface sediments.
5. Permeability of the littoral sediments of Area I is less than those of Area III, hence, yield an acid pH.
6. Dominant growth rates of *Mya arenaria* range from poor to fair. The higher the clay and silt percentage of profile zone 2 and 3 the more acid the environment, the poorer the *Mya* growth. These findings are similar to those of the Stover Cove, Harpswell Area.

Area III, Bank Sediments:

1. Composed of glacial till.
2. Sediment is dry and relatively permeable.
3. Sorting coefficient higher than that of Area I bank sediments.
4. Many pebbles, cobbles and boulders.
5. No concretions found.

Littoral Sediments of Area III:

1. Sediment of basal profile zone is tan colored (profile zones 3 and 4). Much weathered biotite can be seen. Profile zone 4 has a higher clay content than profile zone 3.
2. Sediment profile usually made up of four profile zones.
3. Color of the sediment ranges from dark gray or black at the top to light tan at the bottom of the profile.
4. Surface sediments similar to those of Area I.
5. Permeability of littoral sediments greater than that of Area I. Hence, good subsurface drainage yields a pH more alkaline than the sediment of poor permeability in Area I.
6. Dominant growth rates of *Mya arenaria* ranges from fair to good.

Conclusions and Discussion of Areas I, II, and III

In general, the surface sediments can be mapped as continuous units around the entire cove area, i. e., silty-sand, scattered and mixed pebbles, cobbles and boulders, boulder concentration juxtaposed against the wave-cut bank, heavy cover mixed pebbles and cobbles.

The northeast shoreline littoral sediments appear to be more influenced by longshore currents than the comparable sediments found on the southwest shoreline. This is significant in that there is a greater abundance of material within the pebble to cobble size range on the northeast shore than is found on the southwest shore. This material in the vicinity of pits 42-46 inclusive has been worked into a lens of gradationally distributed pebbles, large to small, in the direction of the head end of the cove. The large pebbles are in the vicinity of pit 45 and the gradation follows the marsh grass at pit 42.

This permits two inferences:

1. Due to the configuration of the northeast shoreline stronger longshore currents are generated than on the southwest shoreline.

2. There is abundant coarse material (pebbles and cobbles) to form heavy cover sediment units of this material. The above inferences raise the question of source area of the coarse material. Since a heavy cover of this material is not common to the entire cove area it may be suggested:

a) The coarse material of the northeast shoreline is not being supplied by incoming, marine transported, debris. Such debris would be common to both shorelines, and this is not true. Therefore, since the bank sediments of the northeast shore have a large percentage of debris of pebble and cobble size, these may be the source area for the accumulated littoral debris of comparable size. It is also noteworthy that the pebbles on the northeast shore are more angular than those of the southwest shore. The configuration of the northeast shore sets up stronger longshore currents.

b) An alternative is that the coarse debris in question is marine transported into the cove, and that the distribution of the pebbles indicates merely that there is a strong incoming tide or wave current that is developed into a dominant transporting current that follows the northeast shore and distributes its load there.

Since coarse debris transportation originating outside of the cove area would have to be common, to some degree, to the entire cove area we would expect to find some type of heavy cover of coarse debris somewhere on the southwest shore. There is only one such place on the southwest shore, in the vicinity of sample area 36S. Here is a concentration of small and medium pebbles with some wave worn "pipe-stems." This indicates that the material is from the southwest shore banks, leaving behind a moderately coarse fraction of particles after the fine material has been washed away by marine action. The significance of sample 36S is that it appears to be an accumulation of coarse material from marine blue clay. It is accumulated here because of a natural trap due to the dock in this vicinity.

The writer concludes that the heavy cover of pebble size material in the Medomak cove area is bank derived.

There is a definite zone of scattered large boulders at the low tide level. These boulders possibly mark the one time bank-line of the cove area. Glacially dumped debris probably represented the original unconsolidated material of the cove area (Pleistocene time). Wave action, since that time, has carried away the material finer than boulder size or brought about a redistribution leaving a fringe of boulders as remnants of the old shoreline.

TABLE I

SEDIMENT PROFILES OF THE MEDOMAK COVE AREA

Pit	*Profile Zone*	*Thickness*	*Color*	*H_2S*	*pH*	*Sediment Texture and Remarks*
1	1	½″	Brown	—	6.7	Sandy-silt
	2	3″	Brown	Sl	6.8	Silty-sand
	3	19″	Dark Gray	-	6.7	Silty-sand with shell and pebbles.
	4	pit bottomed				Dirty marine blue clay
2	1	½″	Brown	-	6.9	Silty-sand with pebbles
	2	3.5″	Dark Gray	Sl	7.2	Sand with pebbles and shell
	3	17″	Blue Gray	-	-	Marine blue clay, dirty, with shell
	4	pit bottomed				Marine blue clay
3	1	¼″	Brown	-	6.0	Sand (less than 2mm) with scattered pebbles
	2	4.5″	Dark Gray	-	5.5	and sand; mixed
	3	16″	Blue Gray	-	5.7	Sandy marine blue clay with pebbles
	4	pit bottomed				Marine blue clay
4	1	¼″	Brown	-	-	No pH determination too gravelly
	2	2″	Dark Gray	-	7.2	Sand with pebbles and shell
	3	12″	Blue Gray	-	3.1	Sandy marine blue clay with much pebbles
	4	pit bottomed				Cobbles and large pebbles
5	1	⅜″	Brown	-	6.8	Silty sand with scattered pebbles and shell
	2	7″	Gray	-	3.2	Sand and pebbles with shell
	3	12″	Blue Gray	-	-	Marine blue clay with sand and pebbles
	4	pit bottomed				Cobbles and pebbles
6	1	½″	Brown	-	5.9	Silty-sand with pebbles
	2	3″	Dark Gray	Sl	5.7	Sand and pebbles
	3	8.5″	Blue Gray	-	5.3	Sandy-marine blue clay with mixed pebbles
	4	pit bottomed				Cobbles and pebbles
7	1	½″	Brown	-	6.9	Sand and scattered mixed pebbles
	2	2.5″	Dark Gray	-	6.2	Sand with mixed pebbles
	3	7″	Blue Gray	-	5.8	Sandy-marine blue clay with pebbles
	4	pit bottomed				Cobbles and pebbles
8	1	⅜″	Brown	-	3.9	Sand with scattered pebbles
	2	5″	Dark Gray	Y	-	No pH determination too gravelly, Sand and mixed pebbles
	3	pit bottomed	Blue Gray	-	-	Marine blue clay with sand and pebbles
9	1	0.5″	Brown	-	3.8	Sandy-silt
	2	4″	Brown Gray	-	6.0	Silty-sand
	3	7″	Dark Gray	-	6.8	Sand with pebbles and shell
	4	pit bottomed				Marine blue clay
10	1	2″	Brown	-	6.8	Mixed sand
	2	4″	Blue	-	7.2	Marine blue clay and veg. roots
	3	pit bottomed	Blue	-	-	Marine blue clay-clean
		General Remarks:	This pit is located on top of what appears to be an active slump mass migrating over the littoral zone toward the L.T. line. This mass supports marsh grass growth.			
11	1	½″	Brown	-	6.6	Sand with scattered pebbles
	2	2.5″	Dk.-M-Brown	Y	6.8	Sand with pebbles, also roots
	3	4″	Blue	-	6.4	Clean marine blue clay
	4	9″	Blue	-	-	Sandy-pebbly marine blue clay. This layer shows a noticeable difference in texture from that of profile zone 3 both in feel and appearance.
		Remarks:	This profile appears to be a direct reflection of bank slumping of the area profiled by Pits 10, 11, and 24, i. e., clean marine blue clay overlying coarser material. In other words this clean marine blue clay is not the basal profile member as recorded by augering in most of the other pits of the southwest shore.			
12	1	2″	Brown	-	6.9	Silty-clayey sand
	2	¾″	Dark Gray	-	6.4	Sand, shell
	3	9″	Blue	-	6.1	Marine blue clay (by section)
	4	pit bottomed				Marine blue clay to bedrock by augering

TABLE I (Continued)

Pit	Profile Zone	Thickness	Color	H_2S	pH	Sediment Texture and Remarks
13	1	3/8″	Brown	–	7.0	Silty-sand
	2	4.5″	Bk-M-Brown	S1	6.8	Sand with pebbles and shell
	3	pit bottomed	Blue	–	6.4	Clean marine blue clay
14	1	1/2″	Brown	–	5.4	Silty-sand
	2	4.5″	Bk-M-Brown	Y	3.7	Coarse sand with pebbles and shell The pH may be in error because of the coarseness of the sediment
	3	6.5″	Bk-M-Gray	Y	5.5	Silty-sand with pebbles and shell
	4	pit bottomed	Blue	–	4.6	Clean marine blue clay
15	1	1/4″	Brown	–	6.8	Silty-sand with pebbles
	2	8″	Bk-M-Gray	Y	5.7	Silty-sand with pebbles and shell (shell chiefly Mytilus)
	3	pit bottomed	Blue	–	7.0	Pebbly-sandy-clay
16	1	1/4″	Brown	–	6.7	Sandy-silt
	2	11.5″	Black	Y	6.9	Silt, rich in organic slime. Contains Mytilus shells
	3	pit bottomed at 12″				Boulders and Bedrock
17	1	1/4″	Bk-M-Gray	–	6.7	Sandy-silt with some pebbles and shell
	2	10″	Black	Y	6.9	Silt with shell debris
	3	pit bottomed	Black	Y	–	Silt with boulders, shell, and bedrock
18	1	1/2″	Brown	–	6.7	Sand with crushed shell debris and pebbles
	2	8″	Black	Y	6.9	Silty sand with pebbles and shell
	3	pit bottomed			–	Silty sand with pebbles, cobbles, boulders and bedrock
18A	1	1/2″	Brown	–	–	Silty-sand with pebbles
	2	7″	Black	Y	7.2	Silty-sand with pebbles and shell debris
	3	pit bottomed				Sand
19	1	3/8″	Brown	–	6.3	Sandy-silt
	2	1.5″	Black	Y	7.0	Silt with much organic slime
	3	9″	Black	Y	6.6	Silt with much shell debris and organic slime
	4	pit bottomed	Black			Silty sand with cobbles and boulders. Not certain of bedrock
20	1	1/4″	Brown	–	7.0	Sandy-silt with shell and pebbles
	2	5.5″	Black Gray	S1	6.8	Sand and shell
	3	3.5″	Dark Gray	S1	6.4	Silty-sand and shell
	4	pit bottomed	Black			Marine blue clay
21	1	1/4″	Brown	–	7.0	Silty-sand
	2	4.5″	Dark Gray	–	6.8	Sand with shell and pebbles
	3	pit bottomed	Black		6.6	Marine blue clay
22	1	1/8″	Brown	–	7.0	Silty-sand with pebbles
	2	2.5″	Dark Gray	S1	7.0	Clayey-sand with shell and pebbles
	3	pit bottomed	Black		6.6	Marine blue clay
23	1	1/8″	Brown	–	6.7	Sandy-clayey-silt
	2	2″	Dark Gray	S1	6.9	Clayey-sand with shell
	3	pit bottomed	Black			Marine blue clay
24	1	2.5″	Brown	–	6.9	Sand and pebbles
	2	6.0″	Black	–	6.7	Clean marine blue clay
	3	pit bottomed	Black	–	7.0	Sandy-pebbley-marine blue clay
25	1	1/2″	Brown	–	5.4	Sand with pebbles
	2	4″	Black-M-Gray	S1	6.0	Sand with pebbles
	3	pit bottomed	Black			Marine blue clay
26	1	2″	Brown	–	6.6	Silty-sand
	2	3″	Dark Gray	S1	6.5	Fine sand-uniform
	3	pit bottomed	Black			Marine blue clay
27	1	2″	Brown	–	6.4	Silty-sand
	2	2.5″	Dark Gray	S1	6.8	Silty-sand with pebbles and shell
	3	pit bottomed	Black			Marine blue clay

TABLE I (Continued)

Pit	Profile Zone	Thickness	Color	H_2S	pH	Sediment Texture and Remarks
28	1	4″	Black Gray	Y	7.2	Silty-clayey-sand with pebbles and shell debris
	2	6″	Light Gray	–	4.8	Fine sand
	3	pit bottomed	Black	–		Marine blue clay
29	1	8″	Black	Y	3.3	Sandy-clayey-silt
	2	pit bottomed	Black-M-Gray	Y	–	Sandy-silt with pebbles, cobbles, and boulders, bedrock
30	1	4.5″	Black-M-Gray	–	6.2	Sandy-silt with shell debris
	2	pit bottomed at 11″	Black	Y	6.6	Sandy-silt with pebbles, bedrock
31	1	2.5″	Brown	–	5.8	Silty-sand with pebbles and shell
	2	pit bottomed 9″	Black	Y	6.2	Silty-clayey-sand with pebbles and bedrock
32	1	1″	Brown	–	6.6	Silty-sand
	2	6″	Black-M-Gray	Y	6.8	Sand with pebbles and shell
	3	pit bottomed	Black	–		Marine blue clay
33	1	3″	Black-M-Brown	–	6.5	Sand and pebbles
	2	4″	Brown	–	7.1	Sand and pebbles
	3	3″	Brown-M-Gray	–	6.2	Clay with sand lens
	4	pit bottomed	Brown			Sand and pebbles
34	1	3″	Brown-M-Gray	–	–	Pebbles and sand no pH
	2	8″	Black	–	6.3	Marine blue clay
	3	pit bottomed (22″)	Brown-Gray	–	7.2	Sandy-clay
35	1	½″	Brown	–	6.2	Fine sand
	2	4″	Black-M-Gray	Y	7.3	Mixed sand and pebbles
	3	7″	Light Brown	–	7.3	Sand with mixed pebbles
	4	pit bottomed	Light Brown	–	6.7	Clayey sand with pebbles
36	1	¾″	Light Brown	–	6.5	Silty-sand with scattered pebbles
	2	5″	Black-M-Gray	Sl	6.7	Sand, few pebbles
	3	9″	Light Brown	–	6.9	Sand with pebbles (chiefly large)
	4	pit bottomed	Brown-M-Gray	–	6.5	Clayey sand, pebbles and weathered biotite
37	1	3″	Brown	–	6.5	Silty sand
	2	3.5″	Black	–	6.6	Fine sand
	3	4.5″	Gray	–	6.4	Sand
	4	pit bottomed	Black			Marine blue clay
38	1	¼″	Brown	–	6.5	Sand with mixed pebbles. Medium cover
	2	6″	Black-M-Gray	Sl	5.8	Sand mixed pebbles
	3	pit bottomed (9″)	Gray	–	5.7	Hardpan, bedrock
39	1	2.5″	Brown	–	6.5	Silty sand
	2	8.5″	Black	Sl	6.7	Silty sand and pebbles
	3	pit bottomed	Dark Gray			Pebbles and bedrock
40	1	¼″	Brown	–	6.7	Sandy silt
	2	6″	Black	Y	6.8	Sandy silt with pebbles
	3	pit bottomed	Dark Gray	Sl	7.2	Sand
41	1	1″	Brown	–	5.4	Sandy silt
	2	5″	Black-M-Gray	Y	5.6	Sandy silt with pebbles
	3	pit bottomed	Gray	–	6.2	Fine sand
42	1	7″	Brown	Sl	6.8	Sand and pebbles uniformly mixed with much root material from marsh grass.
	2	pit bottomed	Dark Gray	–	6.8	Sand with pebbles
43	1	2.5″	Brown	–	7.0	Sandy-silt with pebbles
	2	7.5″	Black-M-Gray	Sl	7.5	Pebbly-clayey-sand
	3	pit bottomed	Gray	–	7.4	Fine sand, bedrock

TABLE I (Concluded)

Pit	Profile Zone	Thickness	Color	H_2S	pH	Sediment Texture and Remarks
44	1	4″	Brown	–	–	Heavy cover med. pebbles and sand
	2	7″	Black-M-Gray	Y	6.5	Silty-sand and pebbles
	3	pit bottomed (24″)	Dark Gray	–	7.4	Sand and pebbles
45	1	½″	Brown	–	7.3	Heavy cover pebbles with sand
	2	3″	Black-M-Gray	Y	5.9	Pebbles and sand
	3	pit bottomed	Gray	–	6.9	Pebbles and sand
46	1	2.5″	Brown	–	7.2	Sand and pebbles
	2	3″	Black-M-Gray	Sl	7.2	Sand with pebbles and shell
	3	5″	Tan	–	6.7	Sand with weathered biotite
	4	pit bottomed	Tan	–	5.4	Clayey sand
47	1	½″	Brown	–	–	Sandy silt
	2	3″	Black	Y	6.7	Sandy silt
	3	pit bottomed	Black-M-Gray	Y	–	Silty sand
48	1	¼″	Brown	–	6.3	Silty-sand
	2	7.5″	Black-M-Gray	Y	6.6	Sand with pebbles
	3	pit bottomed	Tan	–	6.3	Sand (dry)
49	1	2″	Brown	–	6.3	Sand and pebbles
	2	3″	Black-M-Gray	Sl	7.3	Sand and pebbles
	3	5″	Light Tan	–	6.5	Sand and pebbles
	4	pit bottomed	Light Tan	–	–	Clayey sand
50	1	2.5″	Brown	–	6.5	Silty sand and pebbles
	2	4.5″	Black-M-Gray	Y	6.9	Silty sand with pebbles
	3	pit bottomed	Brown			Sand, pebbles, cobbles, and boulders.
51	1	2.5″	Brown	–	6.9	Fine sand and pebbles
	2	4.5″	Dark Gray	–	7.2	Sand with pebbles and shell cobbles and pebbles
	3	pit bottomed				
52	1	2.5″	Brown	–	7.2	Sand with pebbles
	2	7″	Black	Y	7.0	Silty sand with pebbles
	3	pit bottomed	Gray	–	7.1	Sand with granules, uniform

END PITS

Note: Treuting has reported H_2S in certain pits where it was most likely putrifaction, i. e., he reports recent deaths in the pit. Also, his profiles, in some cases are off.

FIELD AND LABORATORY STUDY OF SHORE SEDIMENT OF SULLIVAN, MAINE

By Philip W. Stackpole

Preface

A coöperative investigation has been undertaken by the Maine Geological Survey and the Maine Department of Sea and Shore Fisheries, in an attempt to obtain information concerning the environmental factors that may be influencing the growth of the soft shelled clam, *Mya arenaria*.

This report presents the field and laboratory results of one of the initial investigations, made at Sullivan Flats, Sullivan, Maine. The field work was done in the summer of 1949. The procedure in the field consisted of mapping the relief and the surface sediments of Sullivan Flats, collecting sediment samples and data concerning them, and collecting biological specimens and data. The laboratory investigation consisted of a more detailed analysis of the information, 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.

Location of the Area

Sullivan Flats is located in the town of Sullivan, Hancock County, Maine, at the head of Sullivan Harbor which is between Hancock peninsula and Sorrento peninsula. Map X.

Outline of the Geology

The bedrock underlying the town of Sullivan and exposed in the Sullivan Flats area is the Ellsworth schist, and younger eruptive rocks. According to Smith, Bastin, and Brown,[1] the Ellsworth schist (Fig. 1) is the oldest formation in the region, is of sedimentary origin, and is presumably Cambrian or older in age. A dense volcanic rock is obviously younger than the Ellsworth schist. The manner in which the volcanics have cut across the schistosity of the schist and their lack of

[1]Smith, G. O., Bastin, E. S., and Brown, C. W., Description of the Penobscot Bay Quadrangle, Penobscot Bay Folio, Geologic Atlas of the United States, Folio 149, Washington, D. C., U. S. Geol. Survey, 1907.

metamorphism clearly shows their relative ages. Glacial erratics, striated bed rock, and the glacial till in the adjacent banks which rise steeply from the high tide level show the area was glaciated.

Topographic Relief

The littoral zone[1] exhibits a relatively smooth slope of high tide level to low tide level, of approximately one percent to one-third percent grade. Just above the high tide level, banks rise steeply to a height of twenty-five to forty-five feet above tide, and at that elevation level off to a rolling surface.

Drainage

No permanent fresh water streams drain into the area which was mapped. However, there are several localities near the base of the till bank where water was observed to seep up through the shoreline sediments. This drainage is intermittent, and with the exception of one locality which is plotted on the topographic base map (see Map X), was thought to be insignificant.

Drainage from and into the basin which separates the township of Hancock from the township of Sullivan (see index map included with Map I) exerts a complex effect on the currents infringing on Sullivan Flats. The flow of the current in the Taunton River, which connects this tidal basin with Sullivan Harbor, is influenced by tidal falls located due west of the Sullivan Flats area on the town line between Hancock and Sullivan. The direction of flow in the river is reversed with each changing tide.

Field Investigation

Mapping the Area

A topographic map, with a contour interval of one foot and a scale of 1:600 (1 inch equals 50 feet) was made with telescopic alidade and plane table. An assumed datum plane was used. This contour map served as a base on which:

A. The surface sediments were mapped. Map XI
B. The systematic distribution of test pits from which sediment samples, *Mya arenaria* counts, and other biological data were taken, is shown.
C. An isopleth map of clam density was plotted. Map XII
D. An isopleth map of clam growth was plotted. Map XIII

[1]Littoral zone refers to the area between high and low tide levels.

Location of Test Pits

Base stakes for section lines across the tidal zone were established along the traverse line used in making the topographic map. The traverse line roughly parallels the shoreline at nearly high tide level. The base stakes were lettered alphabetically. The first base stake, that for section "A," was driven 50 feet from the bench mark on bed rock near Dunbar's Coal Wharf on line with traverse station "1." The rest of the base stakes were located by measuring along the traverse line as listed below:

B — 100′ from A
C — 100′ from B
D — 100′ from C
E — 50′ from D (because of sharp curvature of shore)
F — 50′ from E (because of sharp curvature of shore)
G — 100′ from F
H — 100′ from G
I — 100′ from H
J — 100′ from I
K — 100′ from J
L — 100′ from K
M — 90′ from L (to avoid large glacial erratic)
N — 100′ from M
O — 100′ from N
P — 200′ from O (because of curvature of shore)
Q — 100′ from P
R — 100′ from Q
S — 200′ from R (because of curvature of shore)
T — 100′ from S
U — 100′ from T
V — 100′ from U

From each of these base stakes a section line was established approximately normal to the low water shoreline. Test pits were established on these section lines at 25 foot intervals as shown on Map I. The lowest pit in each section was numbered "1," and successively higher pits were numbered consecutively. This method of locating test pits facilitates reference to any one test pit. For example, "A-1" refers to the test pit nearest low tide level on section "A," and "M-9" refers to the test pit near high tide level on section "M." Obviously, the wider the tidal zone at any one section the larger the number of test pits on that section.

Field Classification of Sediments

The field classification of sediments was based on estimated size of particles greater than 4 mm. in diameter, and on feel and tectural appearance of particles finer than 4 mm. in diameter.

TABLE I[1]

Size Classification of Sediments Larger than Granules

Name	*Diameter*
Boulders	256 mm. and larger
Cobbles	64 mm. to 256 mm.
Pebbles	4 mm. to 64 mm.

Using this field classification, the surface sediments have been classified into ten general groups. Each group was mapped as a unit in the field.

The groups are as follows:

1. Bed rock and undisturbed bank.
2. Sand with some mixed pebble cover, and some cobbles.
3. Silty sand with very few pebbles and cobbles, some silt covered.
4. Sand with few pebbles.
5. Sandy clay with few pebbles and cobbles.
6. Boulders and cobbles.
7. Silty sand with pebbles and some small boulders.
8. Sandy silt, some silt covered.
9. Cobbles and large pebbles, as cover over coarse sand.
10. Large pebbles, some cobbles, and occasional boulders, as cover over sand.

An accurate classification of the sediments could only be determined by detailed laboratory analysis, consisting of sieving and hydrometer analysis. The results and methods used for these analyses will be found in a later section of the thesis.

Sediment Profiles

The terms for describing vertical sections through the shore sediments adopted by the Maine Geological Survey are:

Sediment Profile: A vertical section through an unconsolidated sediment, exhibiting successive layers of varying thickness.

[1]Adapted from Wentworth, C. K., A Scale of Grade and Class Terms for Clastic Sediments, Jour. of Geology, vol. 30, pp. 377-392, 1922.

Profile Zone: One of the several layers 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." Thus a profile zone may correspond to a sedimentary stratum, or it may refer to an oxidized, stained, or otherwise particularized portion of the profile column.

Profile Zones

The color and texture of the sediments are factors used to distinguish the several profile zones. In certain sediment profiles there may be little difference in the grain size distributions in the several profile zones. In these profiles the color of the sediments differentiates the several zones present. The field data on four sets of sediment profiles are recorded (Table II) and data on sediment texture may be found on the particle size distribution curves, which are included with the mechanical analysis data sheets. The four sets of sediment profiles represent vertical sections across the littoral zone along section lines A, H, M, and S.

Variations in Sediment Texture

Sediment texture refers to the grain size distribution of a given profile zone. In Table II, this is represented as "classification," and was determined either as a result of laboratory analysis, or by direct observation in the field.

In any one sediment profile, some zones show marked differences in texture as compared with adjacent zones. In others, very slight differences in texture are noted. An examination of the particle size distribution curves suggests the following generalities in the difference of sediment texture for the several profile zones:

1. Along section A, in test pits 1 and 2, profile zone "1" differs from profile zone "2," in that zone "1" shows a sediment of finer texture than the sediment in zone "2." In test pits 3 and 4, this situation is reversed, and zone "1" shows a sediment of coarser texture than the sediment in zone "2." Zone "3," where noted, shows very little change in texture from zone "2."

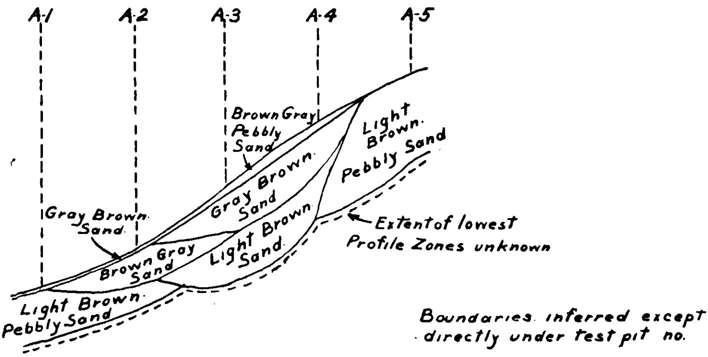


Figure I Sediment Profile Section A.

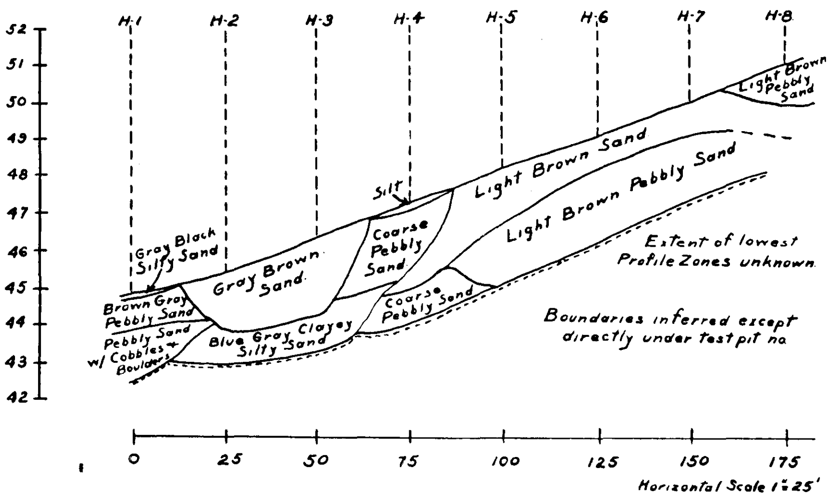


Figure 2 : Sediment Profile Section H

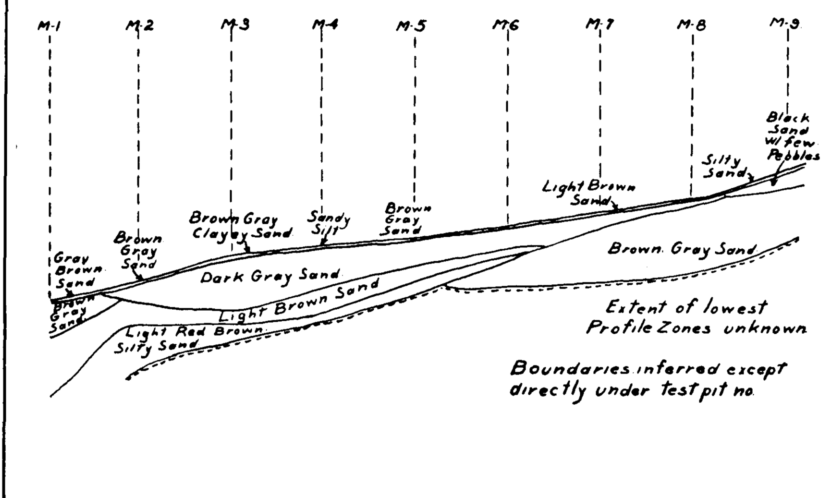


Figure 3. Sediment Profile. Section M

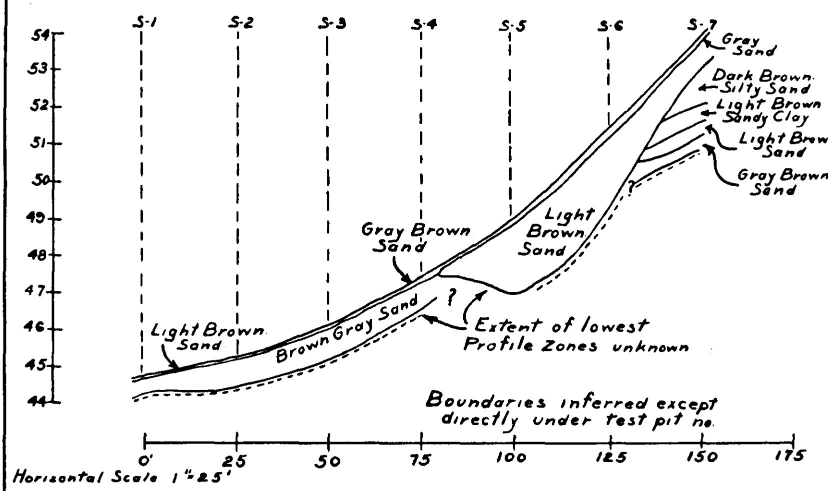


Figure 4 Sediment Profile - Section S.

2. Along section H, at test pits 1, 4, 5, and 7, the sediments in zone "1" show a texture finer than that in zone "2." At test pits 2, 3, and 8, the sediments in zone "1" show a texture coarser than that in zone "2."

3. Along section M, most all of the zones are composed of sediments classified as sand, yet variations in texture among the zones exists. At test pits 1, 2, 3, 4, 5, 6, 7, 8, and 9, zone "2" is coarser than zone "1" and zone "3" is finer than zone "1." The zones in section M exhibit a greater lateral development than in the other sections.

4. Along section S, the zones have a good continuity from test pit 1 through test pit 4. The sediments in zone "1" are noticeably finer than those in zone "2." However from test pit 5 to test pit 7, although a good continuity in the several zones exists, the sediments in zone "1" are noticeably coarser than in zone "2."

These variations suggest either changes in the grain size of the sediment as it is derived from its source, or changes due to varying degrees of effectiveness of the agency transporting or depositing them.

TABLE II

SEDIMENT PROFILE DATA FOR EACH PROFILE ZONE IN SECTIONS "A", "H", "M", AND "S"

Test Pit	Profile Zone	Sample No. (if taken)	Depth of Zone (inches) from	to	Color*	Classification**
A-1	1	A-1-1	S	½	gray-brown	sand
A-1	2	A-1-2	½	15	light brown	sand, pebbly
A-1	3	—	15	?	—	cobbles and boulders
A-2	1	A-2-1	S	½	gray-brown	sand
A-2	2	A-2-2	½	23	brown-gray	sand
A-3	1	A-3-1	S	¼	brown-gray	sand, pebbly
A-3	2	A-3-2	¼	15	gray-brown	sand
A-3	3	A-3-3	15	26	light brown	sand
A-4	1	A-4-1	S	½	brown-gray	pebbly sand
A-4	2	A-4-2	½	15	gray-brown	sand
A-4	3	A-4-3	15	25	light brown	sand
A-5	1	A-5-1	S	1	light brown	sand
	(note:	only one pro	file zone	noted in	test pit A-5)	
A-5	1	A-5-2	22	24	light brown	pebbly sand
H-1	1	—	S	1	grey-black	silty sand
H-1	2	H-1-1	1	12	brown gray	pebbly sand
H-1	3	H-1-2	12	?	gray-brown	pebbly sand, with cobbles and boulders
H-2	1	H-2-1	S	20	gray-brown	sand, with very thin silty cover
H-2	2	H-2-2	20	26?	blue-gray	clayey silty sand
H-3	1	—	S	25	gray-brown	same as H-2-1
H-3	2	—	25	?	blue-gray	same as H-2-2
H-4	1	—	S	O-2	—	silty cover
H-4	3	H-4-1	24	27	light brown	sand
H-4	4	—	27	38	—	coarse pebbly sand
H-5	1	H-5-1	S	15	light brown	sand
H-5	2	H-5-2	15	28?	light brown	pebbly sand
H-6	1	—	S	12	light brown	same as H-5-1
H-6	2	—	12	32?	light brown	same as H-5-2
H-7	1	—	S	10	light brown	same as H-5-1
H-7	2	—	10	32?	light brown	same as H-5-2

TABLE II (Continued)

Test Pit	Profile Zone	Sample No. (if taken)	Depth of Zone (inches) from	to	Color*	Classification**
H-8	1	—	S	14	light brown	same as H-5-2
H-8	2	H-8-1	14	20?	light brown	sand
M-1	1	M-1-1	S—	¼	gray-brown	sand
M-1	2	M-1-2	¼	12	brown-gray	sand
M-1	3	M-1-3	12	24?	light brown	sand
M-2	1	M-2-1	S	¼	brown-gray	sand
M-2	2	M-2-2	¼	7	dark gray	sand
M-2	3	M-2-3	7	14	light brown	sand
M-2	4	M-2-4	14	?	light red-brown	silty and sand
M-3	1	M-3-1	S	2	brown-gray	clayey sand
M-3	2	—	2	18	dark gray	same as M-2-2
M-3	3	—	18	23	light brown	same as M-2-3
M-3	4	—	23	?	light red-brown	same as M-2-4
M-4	1	—	S	1	—	sandy silt
M-4	2	—	1	13	dark gray	same as M-2-2
M-4	3	—	13	22	light brown	same as M-2-3
M-4	4	—	22	25?	light red-brown	same as M-2-4
M-5	1	—	S	¼	brown-gray	same as M-2-1
M-5	2	—	¼	10	dark gray	same as M-2-2
M-5	3	—	10	14	light brown	same as M-2-3
M-5	4	—	14	18?	light red-brown	same as M-2-4
M-6	1	—	S	½	light brown	same as M-7-1
M-6	2	—	½	7½	gray-brown	same as M-7-2
M-6	3	—	7½	10	light brown	same as M-2-3
M-6	4	—	10	11	light red-brown	same as M-2-4
M-6	5	—	11	20?	brown-gray	same as M-7-3
M-7	1	M-7-2	S	1	light brown	sand
M-7	2	M-7-2	1	5	gray-brown	sand
M-7	3	M-7-3	5	24?	brown-gray	sand
M-8	1	—	S	1	light brown	same as M-7-1
M-8	2	—	1	3	gray-brown	same as M-7-2
M-8	3	—	3	24?	brown-gray	same as M-7-3
M-9	1	—	S	½	—	silty sand
M-9	2	—	½	4½	black	sand with few small pebbles
M-9	3	M-9-1	4½	20?	brown-gray	sand
S-1	1	S-1-1	S	1	light brown	sand
S-1	2	S-1-2	1	6?	light gray	clayey sand
S-2	1	—	S	½	gray-brown	same as S-4-1
S-2	2	—	½	10?	brown-gray	same as S-4-2

TABLE II (Concluded)

Test Pit	Profile Zone	Sample No. (if taken)	Depth of Zone (inches) from	to	Color*	Classification**
S-3	1	—	S	$\frac{1}{2}$	gray-brown	same as S-4-1
S-3	2	—	$\frac{1}{2}$	10?	brown-gray	same as S-4-2
S-4	1	S-4-1	S	$\frac{1}{2}$	gray-brown	sand
S-4	2	S-4-2	$\frac{1}{2}$	10?	brown-gray	sand
S-5	1	S-5-1	S	3	gray-brown	sand
S-5	1	S-5-2	20	25?	light brown	sand
	(note:	only one pr	ofile zone	noted in	test pit S-5)	
S-6	1	S-6-1	S	2	gray-brown	sand
S-6	1	S-6-2	20	25?	light brown	sand
	(note:	only one pr	ofile zone	noted in	test pit S-6)	
S-7	1	S-7-1	S	2	gray	sand
S-7	2	S-7-2	2	10	light brown	sand
S-7	3	—	10	22$\frac{1}{2}$	dark brown	silty sand
S-7	4	—	22$\frac{1}{2}$	26$\frac{1}{2}$	light brown	sandy clay
S-7	5	S-7-3	26$\frac{1}{2}$	30	light brown	sand
S-7	6	S-7-4	30	40?	gray-brown	sand

*Color is for dry sediment if sample number is given or referred to; otherwise, field color is shown.

**Classification is the result of laboratory analysis if sample number is given or referred to; otherwise, field classification is shown.

S = surface ? = extent unknown

Transportation of Beach Sediment

Suspension

Suspension transportation floats particles and except for those of colloidal dimension, transportation depends upon velocity and turbulence.[1] Suspension transportation is aided by irregularities of the bottom, as these produce turbulence, which maintains particles in suspension. Owing to the fact that particles readily change from traction to suspension transportation on increase of velocity, and from suspension to traction transportation on decrease of velocity, it is not easy to consider these two methods of transportation separately as far as noncolloidal matter is concerned.

[1]Twenhofel, W. H., *Op. cit.* p. 191.

Flotation

According to McKelvey,[1] the requirements for the flotation of particles include surface tension, and adsorbed air film, which prevents wetting of the individual particles, and careful launching of the particles. Surface tension is mainly responsible for flotation, and using this fact, the maximum size of floatable particles has been derived in the following manner:[2]

If a = cube edge (cm.),
d = diameter of sphere (cm.),
Δ = specific gravity of the fluid,
δ = specific gravity of the particle,
T = surface tension of the fluid (for water at 20°C, T = 72.75 dynes/cm., but this value varies with temperature, and type and amount of dissolved material present),
and g = acceleration due to gravity,

then

$$a = \sqrt{\frac{4\,T}{(\Delta - \delta)g}}$$

and

$$d = \sqrt{\frac{6\,T}{(\Delta - \delta)g}}$$

For quartz grains with a specific gravity of 2.65, these expressions give the following results:

a = 4.243 mm. (cube edge).
Volume = 0.0762 cubic centimeters.
Weight = 0.202 grams.

d = 5.138 mm. (sphere diameter).
Volume = 0.07000 cubic centimeters.
Weight = 0.186 grams.

Although the sphere is larger in diameter than the cube, it represents a lesser volume and a lesser weight than the cube. It is concluded that an irregular boundary permits flotation of larger particles in terms of weight and volume, than is possible with a particle having a regular perimeter. The shape of the grains is not important except for large grains.

[1]McKelvey, V. E., The Flotation of Sand in Nature, p. 594, Amer. Jour. of Science, vol. 239, no. 8, 1941.
[2]McKelvey, V. E., *Op. cit.* p. 599.

The writer observed floating particles at Sullivan Flats. The particles were floated by the incoming tide, at times when the water was very quiet, carried shoreward, and deposited as the water ebbed. On the next advance of the water, other particles, or perhaps the same ones, were refloated and again deposited shoreward. This phenomenon as observed at Sullivan Flats appeared to be of little quantitative significance during the field season of 1949, but perhaps this may be an important factor contributing to the silt cover in certain areas of the flats.

McKelvey[1] found that clean sand floats more readily than dusty sand, and that gentle launching is important. Flotation can occur only if there are no breaking waves, or other disturbances of great enough magnitude to interfere. Thus the phenomenon of floating particles of sediments seems to have geological significance, and may be more common than realized.

Transportation by Kelp

In addition to the methods of transportation already mentioned, debris may be carried by kelp holdfasts, and dropped into deep water sediments, after the floating kelp has been eaten or become decayed. According to Emery and Tschudy,[2] many shallow water organisms may be deposited in foreign environments in this manner.

Emery and Tschudy[3] state that

> Numerous pebbles and cobbles still attached to kelp have been picked up on beaches, and in several instances pebbles with remnants of holdfasts have been found in relatively deep dredgings of the ocean floor. Although large kelps with floats are limited essentially to the Pacific and Antarctic regions, smaller algae from other coasts are also known to raft pebbles long distances.

Evidence of transportation of sediments by kelp was not seen in the Sullivan Flats area.

[1]McKelvey, V. E., *Op. cit.*, p. 606.
[2]Emery, K. O., and Tschudy, R. H., Transportation of Rock by Kelp, Geol. Soc. of Amer. Bull., vol. 52, 1941., p. 860.
[3]Emery, K. O., and Tschudy, R. H., *Op. cit.*, p. 855.

Wave Action

Johnson[1] has described the processes relating to beaches, and shows according to Martens,[2] that the action of waves is by far the most important factor in connection with the formation, modification, and destruction of beaches. The intensity of wave action varies with the width of open water, direction of the wind, and depth of water offshore. Martens[3] states that wave erosion of shore cliffs or of loose materials on the shallow sea bottom supplies most of the beach sediments. According to Johnson[4] waves and hydraulic currents caused by wind are the main factors in beach drifting and longshore drifting, and that it is possible for coarse material to be carried in one direction by beach drifting, and fine materials in the opposite direction by currents. Johnson[5] states that

> It appears that a great variety of wave currents operate in a most complicated and irregular manner, sorting and transporting debris in shallow water and on the beach in different ways depending on differences in outline of shore, angle of offshore slope, angle of wave approach, size of waves, kinds of waves, and other factors.

Undoubtedly the currents caused by the Taunton River at Sullivan Flats, already mentioned,[6] serve to further complicate the effect produced on the Sullivan Flats area as a result of wave and current action.

Field evidence shows that these processes are at work in the area. The scouring away of sediments at the bases of glacial erratics suggests current action at work modifying the sediment distribution (see Plate IIIa). The flotation of particles by advancing tides redistributes the finer surface sediments.

Significance of Sediment Color

The sediments at Sullivan Flats exhibit a variety of colors in the field. They range from very light brown to red-brown to black. Blue-gray sediments also were noted. The matter of color as a criterion for

[1]Johnson, D. W., Shore Processes and Shoreline Development, N. Y., John Wiley and Sons, Inc., 1919.

[2]Trask, P. D., Recent Marine Sediments, pp. 212-213, Tulsa, Amer. Assoc. of Petroleum Geologists, 1939.

[3]Trask, P. D., *Op. cit.* p. 213.

[4]Johnson, D. W., *Op. cit.*, pp. 87-148

[5]Johnson, D. W., *Op. cit.*, p. 148.

[6]See page 13, this thesis.

differentiating profile zones in the field is comparatively simple. When the sediments are thoroughly dried in the laboratory, the variety of colors which could easily be seen in the field are no longer easily distinguishable. Milner[1] states that dried laboratory samples (of sediments) are not as easily distinguished as field samples, and therefore the latter should be used as a basis of investigation. However, Twenhofel[2] discusses sediment colors on the basis of dry samples, and this procedure was followed in instances where laboratory samples were taken. Complete data as to sediment color were not obtained in the field. The writer believes that the field colors would have been more satisfactory in determining the significance of sediment color at Sullivan Flats. In sections "A," "H," and "M," the sediments classified in the laboratory as predominantly gray are host to good clam density, while those sediments classified as predominantly brown or light brown show poor clam density. In section "S," light brown sediments show good clam density at test pit S-5 only. From observation in the field, however, it can be stated with some degree of certainty, that the processes involved in sediment coloration are not factors affecting the growth of the soft shelled clam, but rather the presence of the clam affects sediment coloration in this area because these sediments contain more or less H_2S, for which a high content of organic matter is probably responsible.[3] Also other forms of life may contribute to sediment coloration.

Collection and Storage of Sediment Samples

The sample pits varied in depth from six inches to forty inches. The factor limiting the depth of excavation was the entrance of subsurface water, which destroyed the walls of the pit, and did not permit removal of representative samples from lower profile zones.

Upon removal from the test pits, each sample was immediately placed in a clean quart jar, and sealed to prevent contamination. Each jar was labeled with a sample number which could easily be used in referring to the location from which the sample was taken. For example: sample number "A-1-1" indicates that the sample is from sec-

[1]Milner, H. B., Sedimentary Petrography, Third Edition, p. 532, N. Y., Nordeman, Inc., 1940.

[2]Twenhofel, W. H., Principles of Sedimentation, pp. 578-586, N. Y., McGraw-Hill, Inc., 1939.

[3]Trask, P. D., Recent Marine Sediments, p. 170, Tulsa, The American Association of Petroleum Geologists, 1939.

tion "A," test pit "A-1," and from the first, or uppermost profile zone sampled at that pit; sample number "M-7-2" indicates that the sample is from section "M," test pit "M-7," and from profile zone "2," or the second zone sampled at that pit. The jars remained sealed until the samples were dried for laboratory analysis.

Horizontal Distribution of Surface Sediments

The horizontal distribution of surface sediments is indicated on Map I, this thesis. In general, the distribution is from very coarse sediments to fine sediments, proceeding from the high water shoreline toward the low water shoreline. This distribution is most clearly shown between sections "A" and "E," and between sections "Q" and "V." The area between sections "E" and "Q" also exhibit the same distribution, although not in as striking a manner, due to the fact the three sediments mapped as "sandy silt," "silty sand," and "sand with few pebbles" show an irregular distribution in this area.

Vertical Distribution of Sediments

The four sets of sediment profiles shown in Figures 1, 2, 3, and 4, represent vertical section across the littoral zone along section lines "A," "H," "M," and "S," respectively.

TABLE III

Pebble Count Data, with Location for Counts Made; Numbers Represent the Number of Rock Type at Each Location

Rock Type	Location		
	Midpoint of Littoral Zone on Section "D"	Till Bank above Section "D"	Excavation Approximately 500 feet north of Pit "S-6"
Gneiss (schist)	33	39	30
Granite	20	26	19
Syenite	—	—	2
Rhyolite	6	5	5
Quartz, milky	2	5	5
Coarse textured sandstone	9	—	—
Medium textured sandstone	8	7	15
Fine textured sandstone	12	11	19
Shale	10	7	4
Quartzite	—	—	1
	100	100	100

Origin of Sediments

The writer believes that at least a large portion of the sediments in the littoral zone at Sullivan Flats are derived from the banks of glacial till adjoining the area. In an effort to discover the origin of the beach sediments, three samples of the till bank sediments were obtained for laboratory analysis, and pebble counts of the till and beach sediments were made. The pebble counts were made of particles approximately one inch to one and one-half inches in diameter. One hundred pebbles were identified as to rock type in each count. (Table III).

Mechanical analyses of the bank sediments show a remarkable similarity to similar analyses of various samples of littoral sediments in the area. At various times during the field season, the writer observed the slumping of material from the till banks on to the littoral zone.

These three factors, then, indicate that the littoral sediments are largely derived from the till banks:

1. Marked similarity of rock type distribution from widely separated areas.
2. Marked similarity of grain size distribution of sediments in the littoral zone with those in the till banks.
3. Direct observation of till slumping on to the littoral zone.

Use of Biological Data

Introduction

The biological data collected at Sullivan Flats, Sullivan, Maine, during the field season of 1949, have been plotted according to clam density (Map II) and clam growth (Map III). The biological data, as reported by Mr. J. P. Barlow and edited by Mr. D. E. Wallace, are included as an Appendix I. It is thought by the writer that the most significant of the data are those concerning clam density and growth. Eventually a statistical study of biological-geological data should be made, in an attempt to correlate conditions in various areas. However, a statistical approach would not be of much significance until detailed data are collected from several areas.

Interpretation of Clam Density Isopleth Map

Comparison of the clam density isopleth map (Map II) with the surface sediments map (Map I) shows that a close correlation of the surface sediments with good clam density is not notable. Wallace[1] has defined good clam density, at Sullivan Flats, as that of three or more clams per square foot, and poor density as that of less than three clams per square foot. Poor density areas coincide closely, in general, with the areas mapped as "sandy silt, some silt covered." It may be noted that the centers of high density areas coincide with the sediments mapped as "silty sand with very few pebbles and cobbles, some silt covered"; specifically, these centers occur at test pits O-11, N-5, I-5, E-2, C-3, and B-4. The sediments mapped as "sand with few pebbles" contain three centers of good clam density; they are located at test pits V-5, S-5, and P-9. Except at test pits M-5 and M-9, the areas mapped as "sandy silt, some silt covered" do not favor good clam density. The other sediment types show little or no correlation with good clam density. Dow and Wallace[2] state that clams grow best in the lower portions of the flat, apparently because of the better circulation of water and longer feeding period. At Sullivan Flats, good density in the lower portion of the area can be noted at pit J-3 only. The middle portions of the flats exhibit good density at test pits A-4, B-4, C-4, D-4, E-4, H-3, I-5, J-7, M-5, N-5, O-11, and P-9. The middle portions of Sullivan Flats are host to better clam density than either the upper or lower portions of the flats.

Interpretation of Clam Growth Isopleth Map

Comparison of the clam growth isopleth map (Map III) with the surface sediments map (Map I) shows, as in the case of the clam density map, a lack of close correlation of the surface sediments with good clam growth. Wallace[3] has defined good clam growth at Sullivan Flats as that of 7 mm. or more average increase in size per year, and poor clam growth as that of less than 7 mm. average increase in size per year. Poor growth areas coincide closely, in general, with the areas mapped as "sandy silt, some silt covered." It may be noted that the centers of high growth areas coincide consistently with the sediments mapped as "silty sand with very few pebbles and cobbles, some silt covered"; specifically, these centers occur at test pits P-5, N-3, L-7, K-9, and C-2. The sediments mapped as "sand with few pebbles" contain three centers of good clam growth; they are located at test

[1]Wallace, D. E., verbal report, April, 1950.

[2]Dow, R. L., and Wallace, D. E., The Story of the Maine Clam, Bull., Maine Department of Sea and Shore Fisheries, p. 10, 1950.

[3]Wallace, D. E., verbal report, April, 1950.

pits P-9, N-1 and H-3. Except at test pits M-3 and B-1, the areas mapped as "sand silt, some silt covered" do not favor good clam growth. The other sediment types show little or no correlation with good clam growth. Good clam growth can be noted in the lower portions of Sullivan Flats at test pits N-1, N-3, M-3, and B-1; in the middle portions of the flats at test pits P-9, P-5, H-3, and C-2; and in the upper portions of the flats at test pits L-7 and K-9. In general, the middle and lower portions of Sullivan Flats are more favorable for good clam growth than the upper portions of the area. As previously stated, this is probably because of the better circulation of water and the longer feeding period in the middle and lower portions of the area.

Laboratory Investigation

Introduction

Krumbein and Pettijohn[1] state that:

> Whatever the point of view applied to sedimentary investigations, laboratory studies will become an increasingly important source of data. Not alone do laboratory analyses supplement and refine field observations, but often they afford data which cannot be gleaned by field methods alone.

The Sullivan Flats study has been primarily an attempt to correlate the sedimentary environment with the density and growth of *Mya arenaria*, and the time spent in the laboratory investigation has been largely concerned with the mechanical analysis of the sediment samples. Forty-seven sediment samples were collected for laboratory analysis. The number of samples was kept at a minimum by eliminating, as far as possible by comparison in the field, any obvious duplication of samples to be analyzed.

Laboratory Classification of the Sediments

In order to provide uniformity with the previous work of a similar nature, the size scale shown in Table IV was used.

[1]Krumbein, W. C., and Pettijohn, F. J., Manual of Sedimentary Petrography, pp. 3-4, N. Y., Appleton-Century Co., 1938.

TABLE IV

Laboratory Size Classification of Sediments

Name	Size Limits, Diameter, mm.		
Boulders	256	and	larger
Cobbles	64	to	256
Large pebbles	38	to	64
Medium pebbles	22	to	38
Small pebbles	4	to	22
Granules	2	to	4
Coarse sand	0.50	to	2
Medium sand	0.25	to	0.50
Fine sand	0.05	to	0.25
Silt	0.005	to	0.05
Clay	0.005	and	smaller

Trefethen's[1] classification triangle of combined sediments having a particle diameter less than two millimeters was used. This classification was used for naming all sediment samples.

Mechanical Analysis of Sediment Samples

All sediment samples were subjected to a mechanical analysis, which included a sieve analysis for the separation of particles larger than 0.074 mm. and a hydrometer analysis for particles smaller than 0.074 mm., provided at least 2% of the sample was smaller than 0.074 mm. In most of the analyses the entire sample as collected in the field was used. The sample was oven dried at not more than 100°C and, if necessary, separated into individual particles using a pestle and mortar. Care was taken that individual particles were not broken.

Sieve Analysis

Tyler Standard Screen Sieves were used for the sieve analysis of each sample. The sieves were shaken in a motor-driven, automatically timed shaking machine. The writer found that the average sample could be separated into the various sieves on an average of fifteen minutes shaking. Several samples required further pestle and mortaring and resieving, as some fractions of the sample contained aggregates after the initial pestle and mortaring.

[1]Trefethen, J. M., Classification of Sediments, Am. Jour. of Science, pp. 55-62, vol. 248, 1950.

Hydrometer Analysis

The fraction of the sieved sample which passed the 200 mesh to the inch sieve (less than 0.074 mm. in diameter) was separated into size grades by measurement of free fall of particles in a liquid medium. The medium used was water, with the addition of a few cubic centimeters of defloculating agent. The method of hydrometer analysis used was adapted from A. S. T. M. Specification D 422-39, A,[1] which is for sandy soils which have been dried and sieved prior to testing.

Presentation of Mechanical Analysis Data

The data obtained as a result of mechanical analysis of the sediment samples have been recorded on a data sheet designed specifically for this investigation. All weights recorded are in grams. The grain size distribution of the samples is presented as a series of curves plotted on semi-logarithmic paper.

Realizing that a statistical approach furnishes a means of summarizing a large amount of information in a convenient manner, such that comparisons are greatly simplified, the writer presents a measure of the degree of sorting of the grain sizes in each sediment sample, using a statistical method suggested by Krumbein and Pettijohn.[2]

Krumbein and Pettijohn[3] state that:

> Quartile measures are perhaps as widely used as any other device for describing and comparing sediments. . . . The great advantage of quartile measures is the ease with which they are determined from the analytical data. Three values usually suffice for the computation of the measures. These are the median and the first and third quartiles, each read directly from the cumulative curve. . . . The quartiles lie on either side of the median and are the diameters which correspond to frequencies (or per cent finer, by weight) of 25 and 75 per cent. By convention, the smaller diameter value is taken as the first quartile, Q_1. It is that diameter which has 25 per cent of the distribution smaller than itself and 75 per cent larger than itself. It is found from the cumulative curve by read-

[1]This method adapted by the University of Maine Soils Lab., from 1946 Book of A. S. T. M. Standards, Part II, Nometallic Materials—Constructional, Specification D-422-39 (A), pp. 653-655, Philadelphia, Amer. Soc. for Testing Materials, 1946.

[2]Krumbein, W. C., Pettijohn, F. J., *op. cit.* pp. 228-267.

[3]Krumbein, W. C., and Pettijohn, F. J., *op. cit.*, pp. 229-230.

ing the diameter value which corresponds to the point where the 25 per cent line intersects the cumulative curve. The third quartile, Q_3, is that diameter which has 75 per cent of the distribution smaller than itself, and 25 per cent larger than itself. It is found by determining the diameter value corresponding to the intersection of the 75 per cent line and the cumulative curve.

The simplest form of quartile deviation is the arithmetic quartile deviation, which is a measure of half the spread between two quartiles: $(Q_3 - Q_1) / 2$. The second possibility is a geometric quartile deviation, which is based on the ratio between the quartiles, instead of on their differences. It is the square root of the ratio of the two quartiles, so chosen that the value is always greater than unity: $\sqrt{Q_3 / Q_1}$. The geometric quartile deviation is called the "sorting coefficient."[1]

Because the arithmetic quartile deviation measures the difference between the quartiles, its value depends both on the size of particles involved and on the units of measurement used. Thus the arithmetic quartile deviation does not directly compare the relative spread of the curves, because the size factor colors the results. The geometric quar-

TABLE V

Sorting Coefficients for Sediment Samples

Sample Number	Sorting Coefficient (So)	Sample Number	Sorting Coefficient (So)
A-1-1	1.87	M-1-2	2.55
A-1-2	2.51	M-1-3	1.52
A-2-1	1.76	M-2-1	2.59
A-2-2	2.14	M-2-2	3.16
A-3-1	2.86	M-2-3	1.76
A-3-2	2.96	M-2-4	3.00
A-3-3	2.86	M-3-1	1.92
A-4-1	3.32	M-7-1	1.70
A-4-2	2.92	M-7-2	2.45
A-4-3	2.45	M-7-3	1.38
A-5-1	2.85	M-9-1	1.79
A-5-2	2.63	S-1-1	1.87
H-1-1	1.90	S-1-2	3.24
H-1-2	4.08	S-4-1	1.10
H-2-1	2.32	S-4-2	2.63
H-2-2	6.08	S-5-1	5.79
H-4-1	2.22	S-5-2	2.19
H-5-1	1.82	S-6-1	5.55
H-5-2	2.30	S-6-2	1.95
H-8-1	1.55	S-7-1	3.56
H-Bank	1.58	S-7-2	1.34
#1-1	1.61	S-7-3	2.22
#2-2	1.34	S-7-4	2.00
M-1-1	1.38		

[1]Idem., p. 230.

tile deviation, or sorting coefficient, "So," is a convenient measure to use for describing the spread of the curves, because, being a ratio between the quartiles, the size factor and the units of measurement are eliminated.[1] For this reason the values of "So" for the sediment samples has been obtained (Table V) in the manner already described, and as shown in Figure 5.

Krumbein and Pettijohn[2] state that:

> A value of So less than 2.5 indicates a well sorted sediment, a value of 3.0 a normally sorted sediment, and a value greater than 4.5 a poorly sorted sediment.

On this basis, all the sediment samples, with the exception of sample number H-2-2, are either well sorted sediments or normally sorted sediments. The value of the sorting coefficient for sample H-2-2 falls outside the limits for a normally sorted sediment, as So equals 6.08.

Of the 47 sediment samples, 1 is poorly sorted, 19 are normally sorted, and 28 are well sorted.

A comparison of the sorting in the various profile zones shows that in section "A," profile zone 1 is better sorted than profile zone 2, at test pits A-1, A-2, and A-3. At pits A-4 and A-5, profile zone 2 is better sorted than profile zone 1. In section "H," the sediments in zone 1 are better sorted than those in zone 2, at all test pits in the section. Again, in section "M," the sediments in zone 1 are better sorted than those in zone 2. In section "S," at test pits S-1 to S-4, zone 1 shows better sorting than zone 2. At test pits S-5, S-6, and S-7, the sediments in zone 2 are better sorted than those in zone 1.

Correlation of Sorting Coefficients with Clam Density and Growth

A comparison of the sorting coefficients with clam density shows that the sediments at test pits A-4 and S-5, which are host to good clam density (10-15 clams per square foot), are better sorted in profile zone 2 than in profile zone 1. This comparison also shows that the sediments at test pits H-3, M-5, M-7, and M-9, which are host to good clam density (10-25 clams per square foot), are better sorted in profile zone 1 than in profile zone 2. Only the test pits noted above are hosts to good clam density (as previously defined) in sections A, H, M, and

[1]Krumbein, W. C., and Pettijohn, F. J., *op. cit.*, p. 332.
[2]Krumbein, W. C., and Pettijohn, F. J., *op. cit.*, p. 232.

S. This evidence is not conclusive, but indicates that when better sorted sediments occur in profile zone 1, better clam density results.

A comparison of the sorting coefficients with clam growth shows that the sediments at test pits H-1, H-3, and M-3, which are areas of good clam growth (9-11 mm. average increase in size per clam per year), are better sorted in profile zone 1 than in profile zone 2. The areas at test pits A-4 and S-5 in which the sediments are better sorted in profile zone 2 than in profile zone 1, are not areas of good clam growth (as already defined). Again, this evidence is not conclusive, but indicates that when better sorted sediments occur in profile zone 1, better clam growth results.

In conclusion, it appears that there is a positive correlation between good clam density and growth with areas in which the sediments are better sorted in profile zone 1 than in profile zone 2.

Comparison of Sorting in Bank and Beach Sediments

The three sediment samples from the till bank are well sorted. This suggests that the generally well sorted sediments in the beach zone, assuming that they have been largely derived from the till bank, have not been subjected to agencies which have changed the sorting coefficients more than a very small amount.

A comparison of the sorting coefficients of the sediments at various beach levels, shows that at section A, H, M, and S, the surface sediments are better sorted in the upper and lower portions of the beach than in the middle portions of the beach. In profile zone 2, at sections A, H, and M, the sediments are better sorted in the upper and lower portions of the beach than in the middle portion of the beach. At section S, the sediments in profile zone 2 show progressively better sorting from the lower portion of the beach to the higher portion of the beach. In general, then, the beach sediments, with the exception of those in profile zone 2 at section S, show better sorting in the upper and lower portions of the beach than in the middle portion of the beach. It seems improbable that a redistribution and resorting of the sediments in the beach zone could produce sorting coefficients so similar to those of the sediments in the bank, if the beach sediments were not derived from the till bank.

Summary

The results of this investigation indicate that:

1. The silty sediments of Sullivan Flats do not favor good clam density; other sediment types show little or no correlation with good clam density.

2. The silty sediments of Sullivan Flats do not favor good clam growth; other sediment types show little or no correlation with good clam growth.

3. The middle portions of Sullivan Flats are host to better clam density than either the upper or lower portions of the flats.

4. The middle and lower portions of Sullivan Flats are more favorable for good clam growth than the upper portion of the area; this is possibly because of the better circulation of water and the longer feeding period in the middle and lower portions of the area.

5. In sections A, H, M, and S, the sediments classified in the laboratory as predominantly gray are host to good clam density, while those sediments classified as predominantly brown or light brown, show poor clam density. Probably the processes involved in sediment coloration of the gray to black sediments are not factors affecting the growth of the clam, but rather the presence of the clam affects sediment coloration, because these gray to black sediments contain more or less H_2S, for which a high content of organic matter is probably responsible. Other forms of life may also contribute to the coloration of the gray to black sediments.

6. A comparison of the sorting coefficient with good clam density shows that when better sorted sediments occur in profile zone 1, than in profile zone 2, better clam density results.

7. A comparison of the sorting coefficient with good clam growth, shows that when better sorted sediments occur in profile zone 1 than in profile zone 2, better clam growth results.

8. Those sediments which favor good clam density also favor good clam growth; and those which do not favor good clam density similarly do not favor good clam growth.

9. The sediments of Sullivan Flats are largely of local origin because of four factors: (1) a marked similarity of rock type distribution from

widely separated areas in the beach zone and in the till bank adjoining the area; (2) a marked similarity of grain size distribution of sediments in the beach zone with those in the till bank; (3) direct observation of till slumping from the banks on to the beach zone; and (4) a marked similarity of the sorting coefficients of the beach sediments and the sorting coefficients of the till bank sediments.

10. The reversing flow of the so-called Taunton River adjoining the Sullivan Flats area undoubtedly exerts a complex effect on the currents infringing on that area.

Procedure followed in making biological survey at Sullivan, Maine, August 1949[1]

Location of Sections:

Base stakes for sections were laid out on lines established by Philip Stackpole. These sections were lettered A-V. Section A's base stake was driven 50 feet from the bench mark at the coal wharf. The rest of the sections were located on Stackpole's line (which runs roughly parallel to the shoreline) as listed below:

B — 100′ from A
C — 100′ from B
D — 100′ from C
E — 50′ from D (because of sharp curvature of shore)
F — 50′ from E (because of sharp curvature of shore)
G — 100′ from F
H — 100′ from G
I — 100′ from H
J — 100′ from I
K — 100′ from J
L — 100′ from K
M — 90′ from L (less than 100′ to avoid large erratic on beach)
N — 100′ from M
O — 100′ from N
P — 200′ from O (because of curvature of shore)
Q — 100′ from P
R — 100′ from Q
S — 200′ from R (because of curvature of shore)
T — 100′ from S
U — 100′ from T
V — 100′ from U

From each of these base stakes the section was laid out approximately normal to the low water shoreline. Stations were established on these sections. The lowest station was at mean low water plus one

[1]These biological data were prepared by the Maine Dept. of Sea and Shore Fisheries from information supplied by John Barlow of the U. S. Fish and Wild Life Service.

foot (vertical distance). Mean low water was estimated from the morning low tide of August 15 (occurring at 10:10 A.M. EDST, and a plus 1 foot 3 inch tide). This lowest pit was always numbered "1" at each section. From Station 1, the other stations of each section were laid out. These were measured along the surface of the flat from station 1 toward the high water line. On sections A - F, stations were occupied every 25′ from station 1 to about the upper limit of the clam distribution (not to high water line). In the remaining sections, stations were set out at 50′ intervals. In all the sections every 25′ interval from station 1 on up the shore was assigned a number. Therefore sections A - F have samples taken from stations 1, 2, 3, 4, 5, etc., while most of the sections from G on have had only stations 1, 3, 5, 7, etc., occupied, and samples actually taken from them. In some instances stations have been interpolated on these sections. When possible these have been put on one of the regular 25′ intervals, and assigned a regular number. For example, half way between M-5 and M-7 a supplementary sample was taken. This station was thus given the designation M-6. In other cases where these regular 25′ intervals were unsatisfactory the station was located in the section by reference up or down the shore from the nearest established station. For example, G-5 plus 15 would be 15′ up the shore from G-5, and G-5 minus 15 would be 15′ down the shore from G-5.

The stations were displaced in a few instances a short distance to the right or left of the section line to avoid large rocks.

Procedure at Stations

At stations where adult clams were collected, pits were dug just to the right of the section line. These pits were 1′ x 2′, with the long axis parallel to the section line. They were dug from 8″ to 12″ deep, depending on the distribution of the adult clams, and all live clams encountered were saved for measurement.

From five or more of the live adult clams, anterior-posterior measurements of each of the growth rings or winter check lines were taken. All recordings are in millimeters.

I would like to note here that I had the usual difficulty in determining which of the numerous check lines were true annuli, especially the first one or two. Fortunately Dr. Belding was here when I first started aging the shells and I think I have done them fairly accurately under his tutelage.

Up to and including section L, all *Mya* shells from the surface of the pit, and in the pit were collected. To enable an estimate of the numbers of pairs of shells only left shells were counted. These were counted and are listed on the data sheets as "empty" or "dead" shells.

In section A-M at each station where pits were dug and at some supplementary stations (as noted on the data sheets), a sample of the surface sediment was sieved for spat. This was done by shaking the first inch of $\frac{1}{2}$ to 1 square foot of the surface sediment through a 2 mm. meshed tea strainer unless otherwise indicated. These spat samples were from just over the pit, or just to the right of the pit. Where a pit was not dug they were taken just to the right of the section line. The spat which I considered to have been set this year are listed under "O" yr.

DATA TABULATED BY PLOTS

Plot	No. of Year Classes Represented	Density per Square Foot Older Clams	Density per Square Foot "O" yr.	Aver. Growth Increment per Year Older Clams	Aver. Growth Increment per Year "O" yr.
A-1	…	…	None	…	…
A-2	2	.5	1	6	4
A-3	3	2.5	–	5.2	–
A-4	6	14	8	4.9	7
A-5	…	…	None	…	…
B-1	1	.5	–	8.4	–
B-2	1	.5	–	7.5	–
B-3	7	4.5	48	6	8
B-4	6	22.5	–	9.1	–
B-4 (9′ below)	1	–	18	–	9
B-5	…	…	None	…	…
C-1	…	…	None	…	…
C-2	2	3	–	11.8	–
C-3	5	45	–	5.6	–
C-4	…	…	None	…	…
C-4 (9′ below)	1	–	4	–	6
D-1	…	…	None	…	…
D-2	7	11	12	6.2	7
E-1	…	…	None	…	…
E-2	5	25	–	5.1	–
F-1	…	…	None	…	…
F-2	…	…	None	…	…
F-3	1	.5	–	6.4	–
G-1	…	…	None	…	…
G-3	5	8	54	5.7	6
G-5	3	6.5	–	6.9	–
G-5 (15′ above)	1	–	12	–	7
G-5 (25′ from)	1	–	6	–	6
G-7	1	.5	–	7.1	–
H-1	2	1	–	9	–
H-2	…	…	None	…	…
H-3	6	16.5	52	10.7	5
H-4	…	…	None	…	…
H-5	3	1.5	21	7	6
H-6	2	.5	17	7	8
H-7	…	…	None	…	…
I-1	3	2	–	14.8	–
I-3	4	2.5	–	8.9	–
I-5	5	26.5	18	8.6	6
I-7	…	…	None	…	…
I-7 (37′ from)	1	–	8	–	6
J-1	1	.5	–	7.7	–
J-3	9	36	148	6.7	7
J-5	6	9	–	5.3	–
J-7	8	18.5	104	7.1	6
J-9	3	1.5	12	7.1	7
K-1	6	4.5	–	9.7	–
K-3	1	–	46	–	8
K-5	1	–	20	–	7
K-7	3	3.5	–	6.1	–
K-9	2	3	6	12	5
L-1	…	…	None	…	…
L-3	…	…	None	…	…

Plot	No. of Year Classes Represented	Density per Square Foot Older Clams	Density per Square Foot "O" yr.	Aver. Growth Increment per Year Older Clams	Aver. Growth Increment per Year "O" yr.
L-5	7	15.5	76	7.6	7
M-1	4	2.5	1	6.8	4
M-2	1	–	2	–	5
M-3	2	1	7	11	6
M-4	2	6	67	5	7
M-5	8	28.5	218	6.3	7
M-6	2	6	272	4.5	6
M-7	6	13.5	258	5	5
M-8	2	7	194	5	7
M-9	5	10	76	5.4	7
N-1	6	8.5	4	10.8	6
N-3	4	2.5	–	10.2	–
N-5	5	26	–	6.5	–
N-7	5	9	–	5.4	–
N-9			None		
N-11	3	5.5	–	5.5	–
O-1	3	2.5	2	8.3	4
O-3	2	1	–	8.6	–
O-5	5	6	–	9.4	–
O-7	1	.5	–	5.8	–
O-9	5	6.5	–	6.5	–
O-11	6	10	–	6.1	–
O-13			None		
P-1	4	3	4	6.6	6
P-3	4	3.5	–	7.2	–
P-5	5	6	–	10.8	–
P-7	5	4 5	–	7.3	–
P-9	4	14.5	–	10.1	–
P-11	1	1	–	6	–
P-13			None		
P-15			None		
Q-1			None		
Q-3			None		
Q-5			None		
Q-7			None		
Q-9			None		
R-1	1	–	2	–	4
R-3			None		
R-5			None		
R-7			None		
S-1			None		
S-2			None		
S-3			None		
S-4			None		
S-5	7	13	65	6.2	7
S-6			None		
T-1			None		
T-3			None		
T-5			None		
T-7			None		
U-1			None		
U-3			None		
U-5	4	3	–	6.7	–
U-7			None		
V-3			None		
V-5	5	18.5	–	6.5	–
V-7			None		

LITTORAL SEDIMENTS AND ECOLOGY AT GREAT BAR JONESPORT, MAINE*

By William Fairley

Introduction

To attempt a correlation between the soft shelled clam, *Mya arenaria*, and its geological environment, portions of the field seasons of 1949 and 1950 were spent studying the beach materials of Great Bar.

A topographic base map with a one foot contour interval on a horizontal scale of fifty feet to the inch was made (Map XIV). On this base map the sediment boundaries were mapped in 1949, and again in 1950. The purpose of the remapping was to determine sediment distribution changes and the resultant effect on *Mya* colonies.

More than two hundred samples of the surface and subsurface sediments were collected. Mechanical size and statistical analyses of these samples is in progress and will be followed by particle shape analyses and by heavy mineral work.

Upon completion of biological work by the State Department of Sea and Shore Fisheries, clam density and rate of growth maps will be compared with the sediment maps to investigate possible correlations of the biological and physical factors.

This report discusses the geology of the Bar.

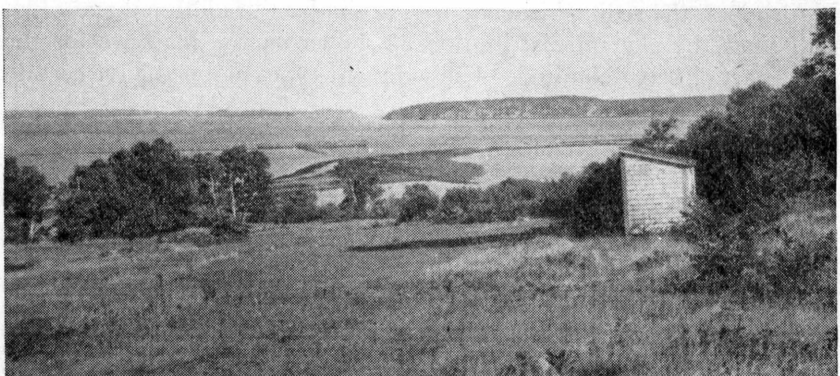


Fig. 1 General View of Great Bar, Jonesport, Maine

*This is a preliminary report. A more detailed consideration is presented as partial fulfilment of requirements for M. S. degree at the U. of Me. The thesis is on file at the U. of Me. Library, Orono, Me.

Great Bar (Map XIV) projects from the mainland between Chandler Bay and Englishman Bay (see also Fig. 1). Its area is about half a square mile, and it is completely covered by high tide. Bedrock probably controls its position. The highest portion of the Bar, here referred to as the ridge, is hook shaped. The curvature of the ridge to the south, seems to be due in part to drainage currents from Mason Bay and Chandler River to the north.

Sediment Classification[1]

As shown on (Map XIV) the following sedimentary types have been established:

1. A mixed pebble and cobble pavement, a pebble pavement, and a cobble pavement.
2. Lenses of sand. Some with pebbles and cobbles. Mechanical analyses of these lenses often show two maxima in the frequency distribution curve.[2]
3. A silt lens.
4. A conglomeration of sizes ranging from silt to medium boulders. Coarse sand, pebbles, or less commonly cobbles, predominate. Many of the sorting coefficients computed exceed Trask's figure of 4.5 for poorly sorted sediments.

Sediment Types

Although the sediment boundaries are in part gradational and often indistinct the general distribution as shown on the map are for the most part closely delimited. The sediment types mapped have certain distinguishing and characteristic features. (Map XIV).

The Pebble-Cobble Lens. This lens is near and parallel to the high tide shoreline and has been built up in part by pebbles and cobbles

[1]Trefethen's classification of sediments and unconsolidated mixtures has been adopted (Trefethen, 1950).

[2]This illustrates a shortcoming in the method of mechanical analysis for attempting a correlation between sediment grain size and *Mya* productivity. For example, one sample may contain a few pebbles or even only a single large pebble in a medium to coarse sand. Since the single pebble may account for as much as fifteen to twenty percent of the weight of the sample, a gravelly character may be ascribed to this sand when the results of the analysis are plotted on a triangular diagram. Furthermore, mechanical analyses give only weight percentages of the particles present, and indicate nothing as to bulk density or permeability, both of which are probably important in studying *Mya* productivity.

dragged landward by seaweed hold-fasts (Fig. 2). (This method of transport is further discussed in the section on transportation.) The lens extends from the projection of bedrock shown on the southern part of Map XIV northwestward until it meets the Pleistocene till bank. Northward it passes under a sand lens. Pits dug in and behind this pavement indicate that it has a rounded summit and slopes both toward the land and toward the water. This pebble-cobble pavement resembles a crescent shaped bay-mouth bar in its shape and in the position it occupies between the bedrock foreland and the till bank. The depression or "lagoon" behind the pavement has been almost entirely filled in by rain wash, decaying vegetation, and by material washed in from the sea by unusually high water.

Fig. 2 Seaweed attached to cobbles--a factor in cobble transportation

Because the pebbles and cobbles extend slightly above the mean high tide line, and because the depression behind them is being filled, a terrace-like feature is forming between the pavement and the higher mainland. This terrace, lying a few feet above the high tide line, might be mistaken as evidence for a slightly higher sea level or for coastal warp.

The Pebble Lens. This extends from near the mainland out along the ridge of the Bar and merges with the conglomerate lens near the change of trend of the Bar from east-west to north-south. Fishermen and clam diggers drive over this lens on the Bar, so the absence of cobbles and boulders is in part due to clearing the traffic lane.

The Sand Lenses. The eastern end of the ridge of the Bar has several sand lenses (Map XIV). The northern ones are ephemeral and variable in extent. Some days they are absent or nearly absent. Other days, a large amount of sand may be present. The sand in these lenses is migrating from the northeast to the southwest. As shown by the sand lens on the southeast tip of the Bar, the direction of migration changes from time to time. This lens has the form of a single, large current ripple. The relative positions of its stoss and less slopes have been observed to reverse themselves, indicating that currents from the southwest and currents from the northeast alternately control its form.

The sand lens near the high tide line also has the shape of a large current ripple and is moving landward. From 1949 to 1950 the measured movement of this lens was about ten feet in an easterly direction.

The most aberrant of the sand lenses is the "shoe string" lens on the western end of the ridge of the Bar. Its shape and extent vary greatly and it is often entirely absent. Its formation could be observed as the tide receded from the Bar. Currents from the north and south met on the ridge. Their mutual interference reduced competency with the consequent deposition of the lens.

Current ripples occasionally appear on these sand areas. A few measurements of ripples were taken on each lens. The ripple indices computed ranged from five to ten.

The Silt Lens. A dense population of mussels (*Mytilus edulis*) characterizes the silt lens. Both the silt and the mussels are new additions to the Bar within the last five or ten years. Before that time, the area as reported by residents and also as indicated by test pits dug through the silt, was similar to the adjacent sand and pebble lens.

The Conglomerate Lens. This lens covers the eastern end of the Bar and extends shoreward along the south side of the ridge until it gradually merges into the cobble pavement.

The Distribution Pattern. The reasons for the sediment distribution are related to the history of the Bar and to the geologic processes now at work on it.

The till bank probably once extended across the entire Bar. It is composed of material ranging from silt size to boulders. As the bank was eroded back, the coarser material was deposited. Subsequent wave action has sorted some of the heterogeneous bank material and has added new material from nearby bays.

Transportation of the Sediments

Most of the material moving across the Bar is transported by wave action. Transportation by current traction, saltation and suspension is evident. Transportation by seaweed hold-fasts is very common. Some material is carried by drifting ice; and floating sand has been seen.

Transportation by Seaweed Hold-fasts. This method of transportation has been found capable of a surprising amount of work. Its effectiveness has been known for a long time, but it has often been described as due only to flotation of the particle caused by the buoyancy of kelp and seaweed. Flotation probably plays a significant part in moving the particles. Also, the seaweed gives a wide surface area over which the tractional force of the waves is effective, and in shallow water may cause the particle to be dragged across the beach. One such cobble was observed to have dragged about fifty feet across the

Fig. 3 Path of a cobble dragged across the beach

pebble pavement. It plowed a shallow trough and left a low ridge on each side of the trough (see Fig. 3). Elongated particles (some as much as three inches long) were aligned in the marginal ridges with their long axes parallel to the trend of the trough.

To make quantitative measurements of the distances and rates at which rocks were being transported, numbers were painted on cobbles and their locations were marked with stakes. Some cobbles marked were never found again, while others moved a measurable amount in a definite direction across the beach. Others moved one direction one day, and another direction the next, depending on the wind direction. Cobbles without seaweed showed no movement during the observation period.

The greatest displacement rate recorded was forty feet in two days.

In large measure, the pebble-cobble pavement is believed to be due to pebbles to cobbles dragged landward (Fig. 2).

Pebbles dragging across fine sands and silts leave markings that resemble the trails in the paleontological record which have been attributed to worms, gastropods, and other invertebrates.

The hold-fasts on the rocks may soon decay so that the process by which they were moved is not obvious.

Ice Rafting. Sediment-laden ice blocks which become grounded and melt add much material to the Bar. The ice comes from the mouths of nearby streams and is made of relatively fresh water. Ice action apparently causes little or no erosion on the Bar. The winters have been less severe in this area the last few years, and floating ice is reported to have been much less abundant. Depriving the Bar of this source of sediment over a period of years could greatly effect its form and size.

Floating Sand. Only a very small amount of floating sand was observed. The flotation took place in the large sand lens enclosed by the hook of the Bar. The place of observation was to the south of the mapped area. Launching of the particles was effected by the incoming tide, and transportation was to the north, toward the ridge of the Bar.

The method and especially the amount of transportation probably has an important effect on *Mya* growth and survival. Rapidly shifting sands and gravels may crush the young clams and cover the siphon holes of the mature clams causing them to suffocate. Material in suspension is drawn through the siphon of the clam. How much such material can pass through the clam without disrupting his metabolism is not known.

REFERENCES

Trefethen, J. M., 1950. Classification of Sediments. Am. Jour. Sci., Vol. 248, pp. 55-62.

REPORT ON MANGANESE

By Joseph M. Trefethen

With increasing international tensions, mineral deficiencies within the United States are again a subject of grave consideration and concern. Investigation of Maine manganese deposits consequently has been continued by the Maine Geological Survey, U. S. Geological Survey and Bureau of Mines. Drilling and magnetic prospecting together with surface exploration in the Hovey and Maple Mountain area, Aroostook County, have been carried out. Specific results of the program have not been released. It may be reasonably assumed, however, that tonnages previously known through work by the M. A. Hanna Company, the U. S. Geological Survey, and Maine Geological Survey have been multiplied. *The problem of utilization, that is extraction of the manganese from these vast repositories is the challenge that must be met if these deposits are to be useful to the nation.* There is locked up in these Aroostook County deposits enough manganese to alleviate any temporary shortage that might develop in this country. As has been repeatedly emphasized by this survey, if a process can be developed to liberate the manganese from its imprisonment the strategic position of the United States will be incalculably enhanced.

The critical temperature of international relations and strategic significance of manganese in our industrial life warrant every effort to develop a process that can successfully handle large tonnages. This is true even though such a process requires substantial subsidy.

Research on an extractive process is in progress at the University of Maine, Melon Institute, U. S. Bureau of Mines, and several industrial laboratories. We urge intensification of this research.

The following data are of interest because they indicate that a simple acid leach removes a substantial percentage of the manganese in the ore (50% to 60%), and in this connection it might be well to point out that sulfuric acid can be made cheaply and in bulk from the largest iron sulfide deposit in the northeast, that at Katahdin Iron Works.

Extraction of Manganese Ore with Acid

Analysis of Ore (dry basis) Fe — 22.7%
Mn — 17.1%

Extraction Procedure: A 10 gram sample of the ore was stirred for the indicated length of time with 200 ml. of acid of a given concentration. The suspension was then filtered and manganese was determined in the filtrate by the bismuthate method.

Iron was also determined in all extractions except the last, but only a negligible quantity dissolved. In the SO_2 extraction a qualitative test showed only a small amount in the extract.

Sulfuric Acid

Stirred for 1 hour and then filtered.

Fineness of Ore	Manganese Extracted			
	3 N H_2SO_4		6 N H_2SO_4	
	% Ore	% Mn in Ore	% Ore	% Mn in Ore
Retained 100 mesh	8.9	52*	–	–
Passed 100 mesh	10.3	60	9.9	58

*100 (8.9/17.1)

Hydrochloric Acid

Stirred for 1 hour. Samples then stood from 1½ to 2 hours before filtration.

Fineness of Ore	Manganese Extracted			
	3 N HCl		6 N HCl	
	% Ore	% Mn in Ore	% Ore	% Mn in Ore
Retained 100 mesh	8.6	50	10.0	59
Passed 100 mesh	10.5	61	11.2	66

Sulfurous Acid

Stirred for ¾ hour with 200 ml. water into which SO_2 gas was continuously passed and then filtered. Sample used passed 100 mesh.

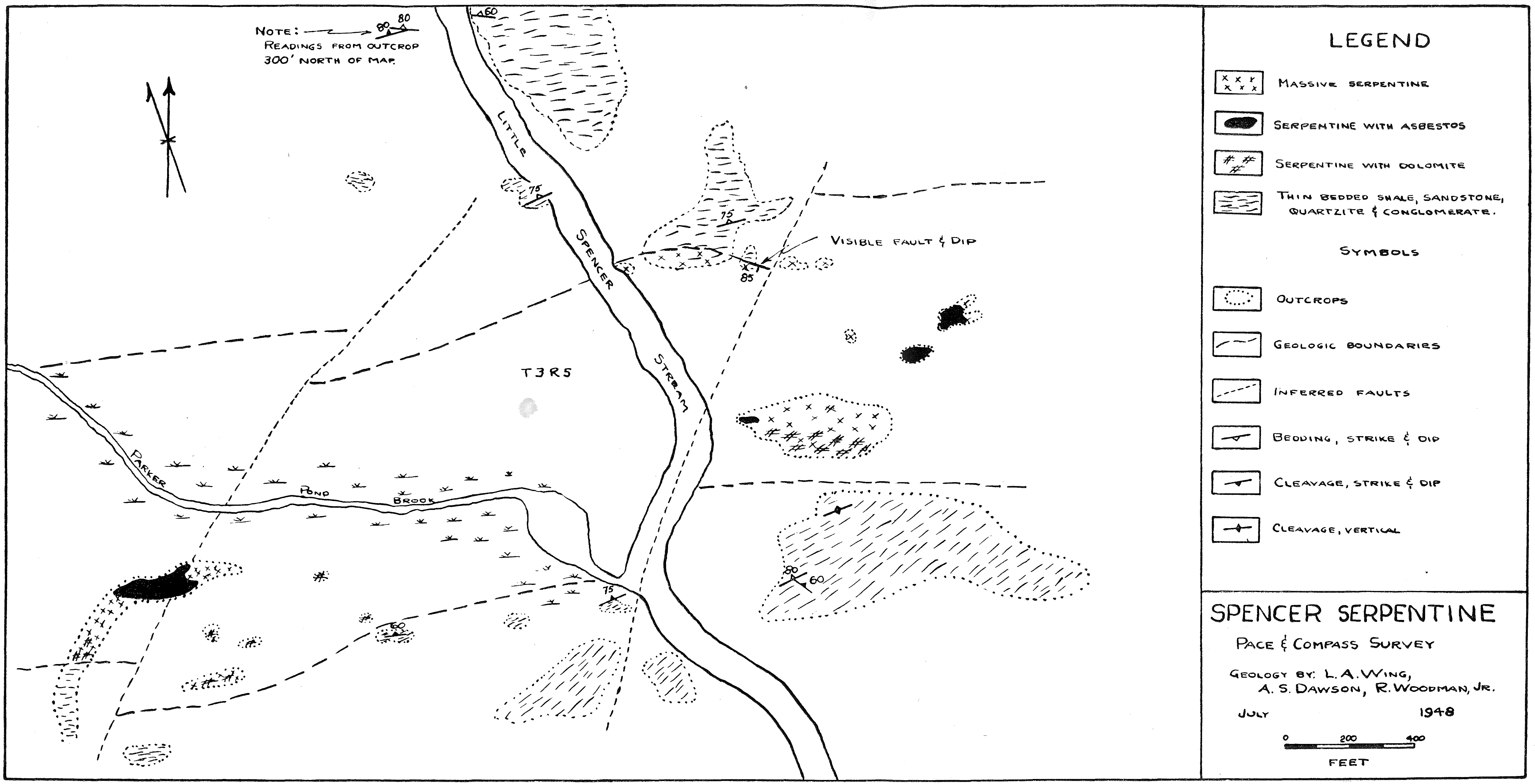
Manganese extracted: 5.4% ore, 32% Mn content.

Note 1: A distinct odor of chlorine was noted in the 6 N HCl extract indicating presence of manganese in some high oxidation state such as MnO_2.

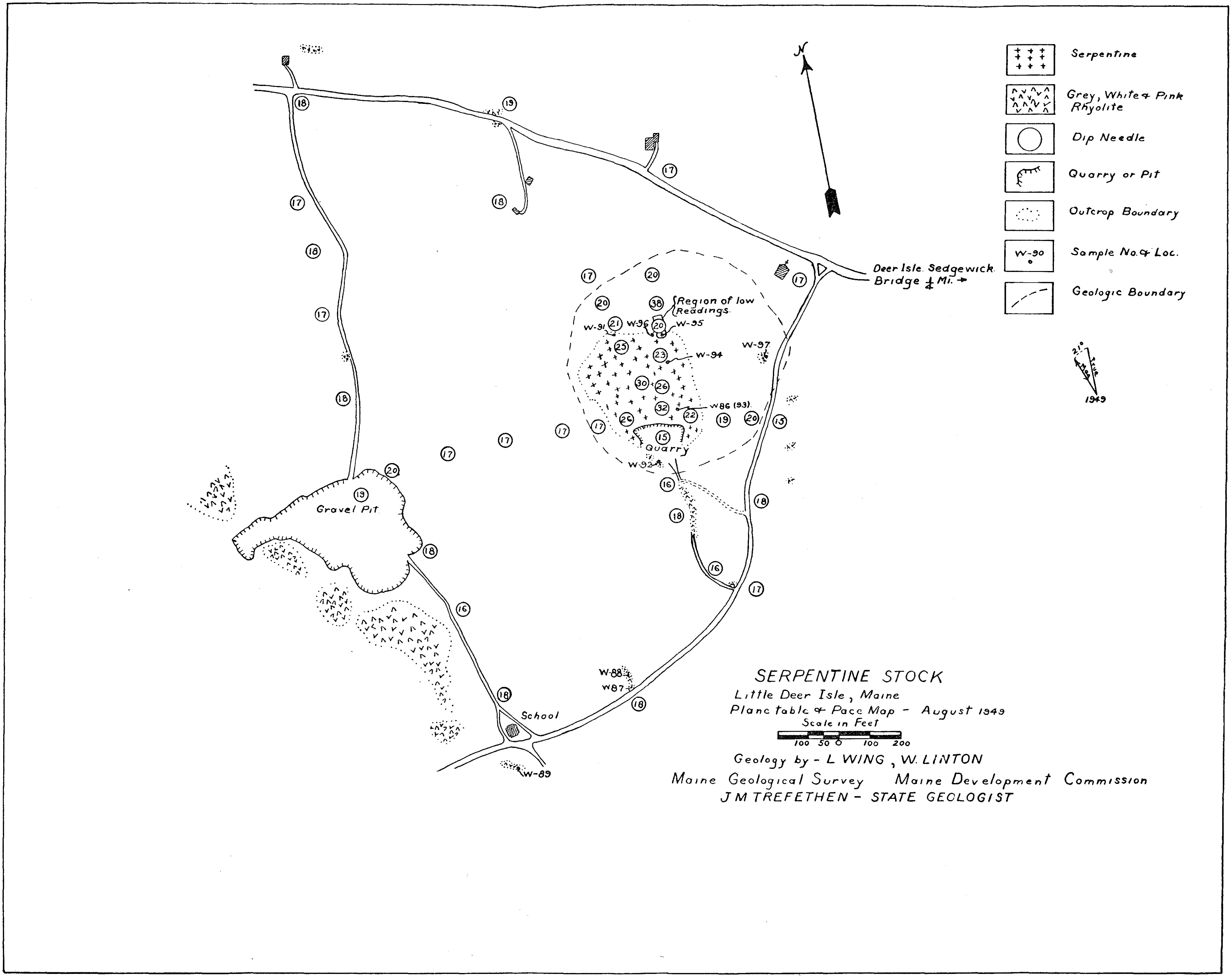
Note 2: All samples effervesced when acid was added indicating presence of carbonates.

Note 3: Perhaps H_2SO_4 saturated with SO_2 would work better than SO_2 alone. In any case, it might pay to try other concentrations for longer lengths of time. Perhaps a moderate amount of heat might also be applied.

These results of the acid leaching experiments are not presented as a solution to the problem of extracting the manganese from the Aroostook County manganese bearing beds, but rather as an indication of one approach to the separation of the manganese from its compounds in these rocks.

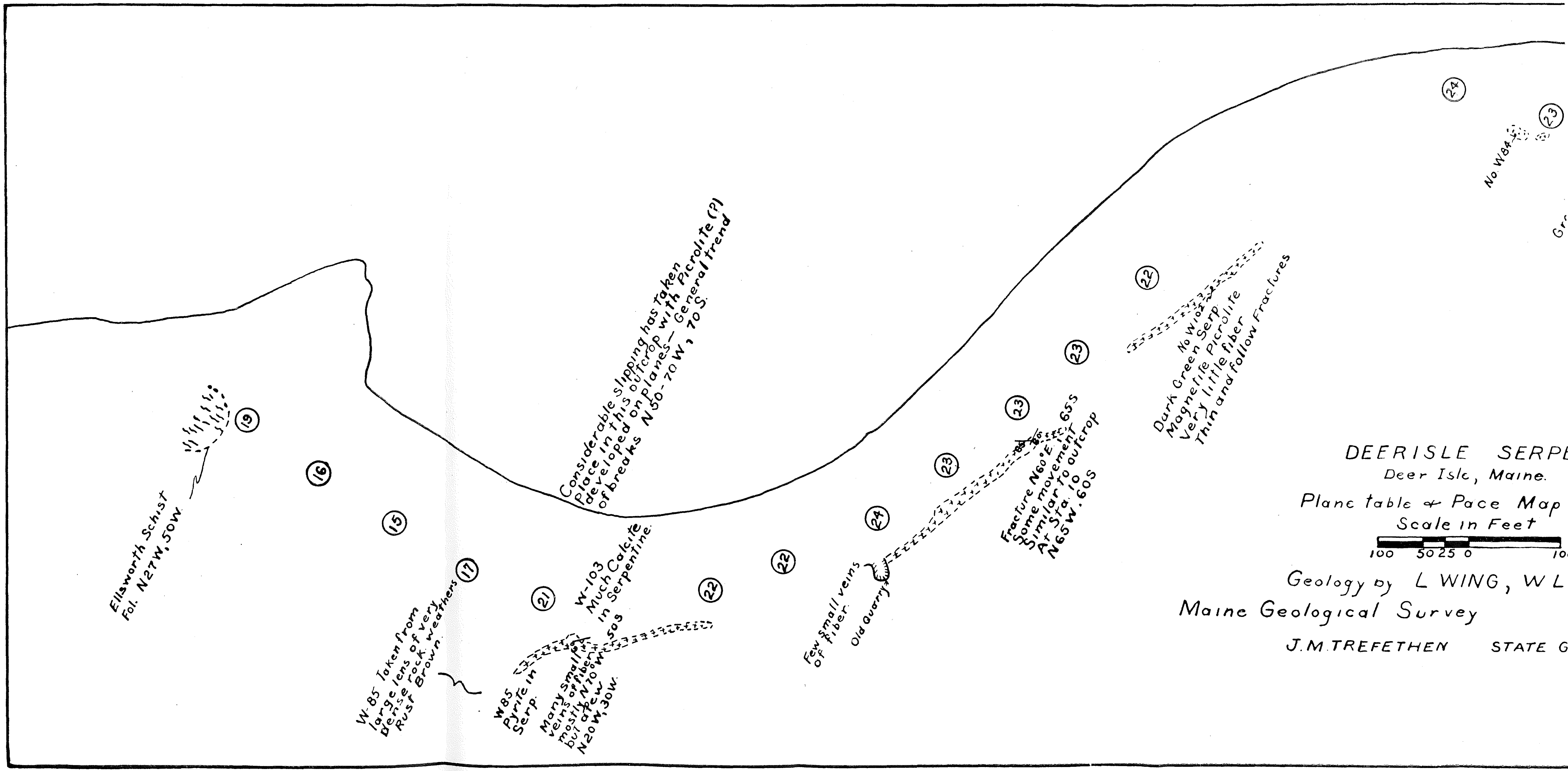

Note: Readings from outcrop 300' north of map.
80
80
Little Spencer Stream
Parker Pond Brook
T3R5
Visible fault & dip
75
75
85
60
75
60
80
60
LEGEND
Massive serpentine
Serpentine with asbestos
Serpentine with dolomite
Thin bedded shale, sandstone, quartzite & conglomerate.
SYMBOLS
Outcrops
Geologic boundaries
Inferred faults
Bedding, strike & dip
Cleavage, strike & dip
Cleavage, vertical
SPENCER SERPENTINE
Pace & Compass Survey
Geology by: L. A. Wing, A. S. Dawson, R. Woodman, Jr.
July 1948
0 200 400
FEET

MAP I



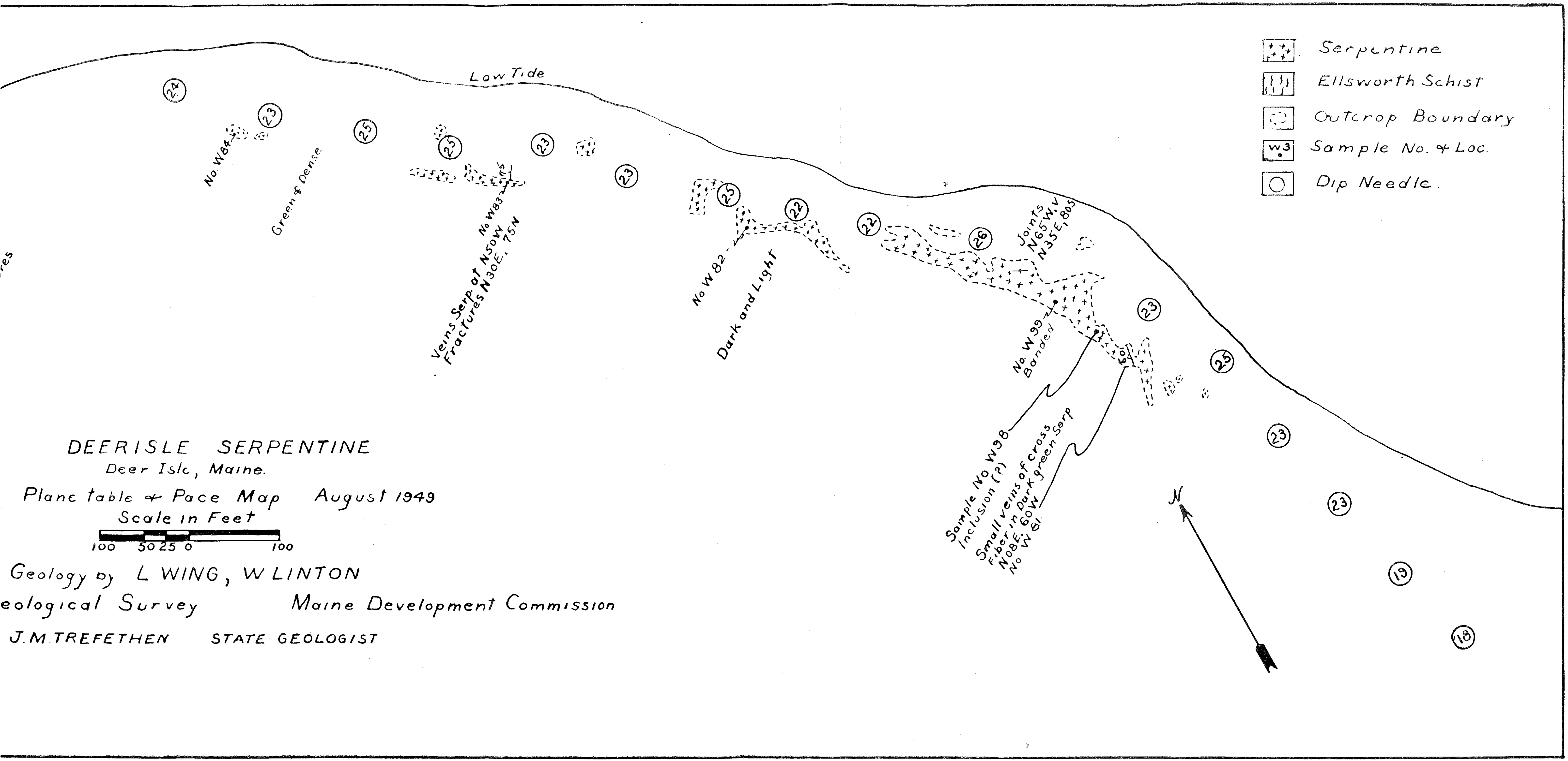
Serpentine
Grey, White & Pink Rhyolite
Dip Needle
Quarry or Pit
Outcrop Boundary
W-90
Sample No. & Loc.
Geologic Boundary
N
Deer Isle. Sedgewick Bridge 1/4 Mi.
Region of low Readings
Quarry
Gravel Pit
School
SERPENTINE STOCK
Little Deer Isle, Maine
Plane table & Pace Map - August 1949
Scale in Feet
100 50 0 100 200
Geology by - L WING, W. LINTON
Maine Geological Survey Maine Development Commission
J M TREFETHEN - STATE GEOLOGIST

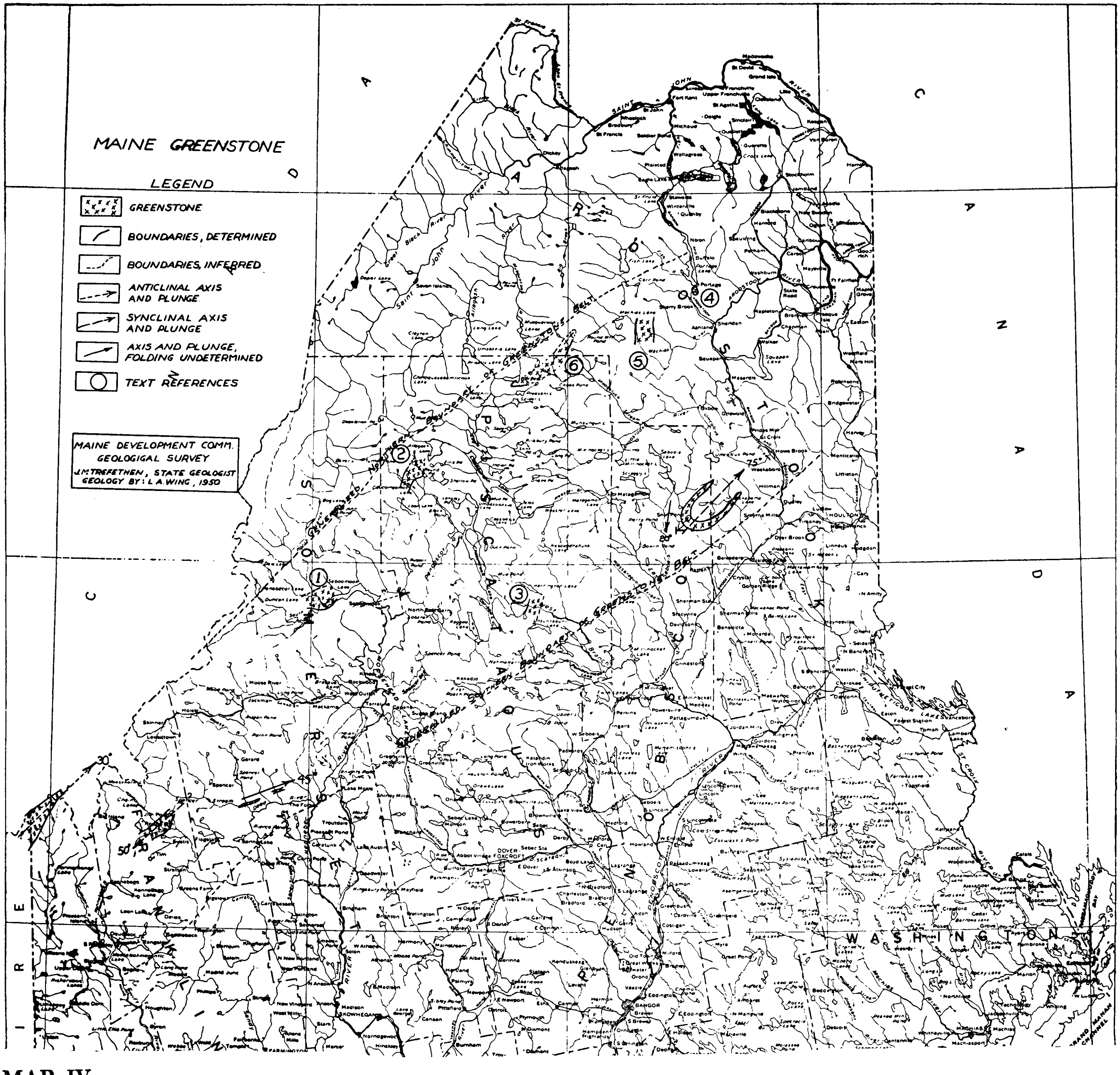
MAP II



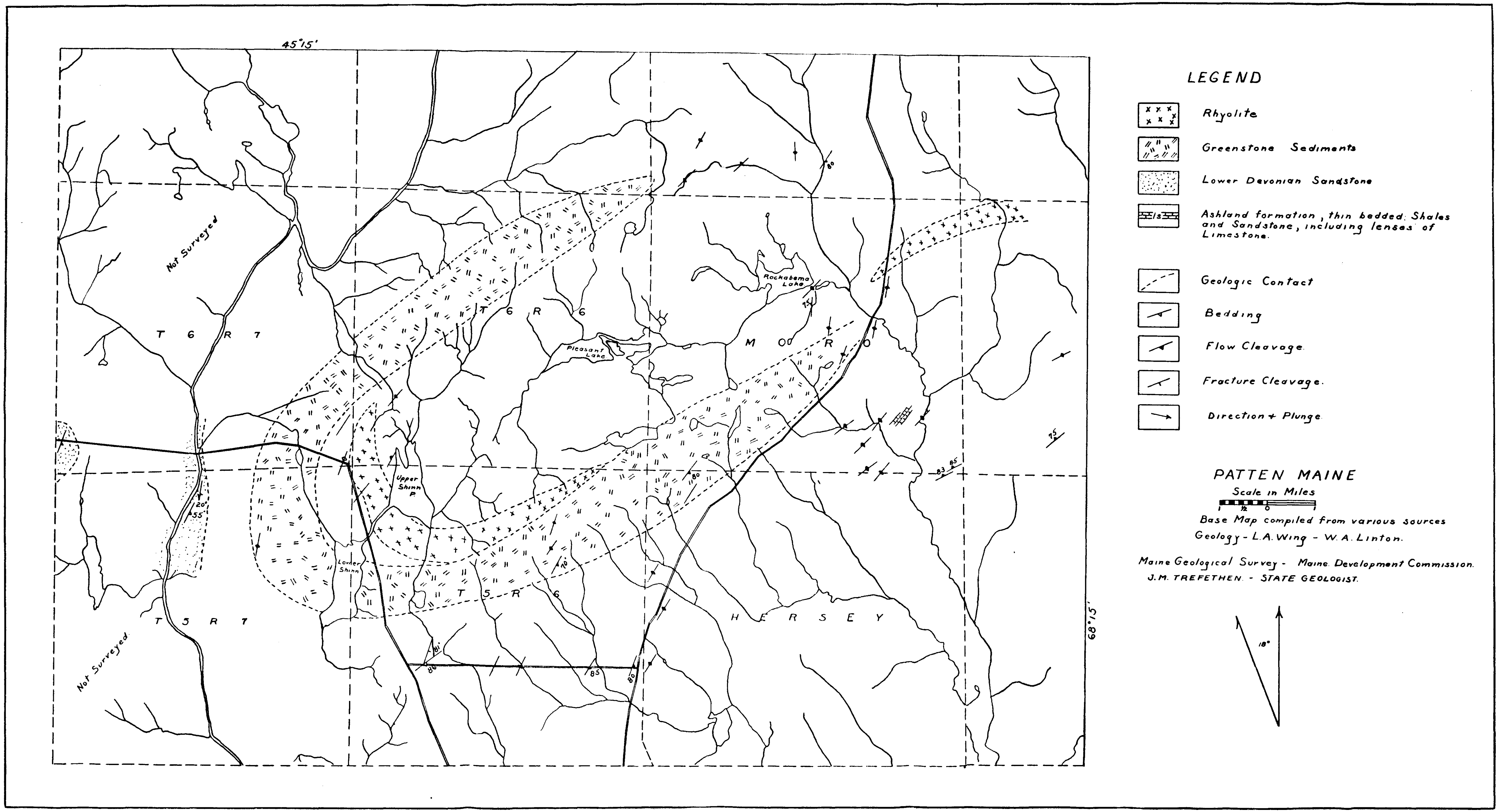
Ellsworth Schist
Fol. N27W, 50W
19
16
15
17
W-85 Taken from large lens of very dense rock weathers Rust Brown.
21
W85 Pyrite in Serp.
Many small veins of fiber mostly N70W, 50S but a few N20W, 30W.
W-103 Much Calcite in Serpentine.
Considerable slipping has taken place in this outcrop with Picrolite (P) developed on planes — General trend of breaks N50-70W, 70S.
22
22
Few small veins of fiber.
Old Quarry
24
23
Fracture N60°E, 65S
Some movement
Similar to outcrop At Sta. 10
N65W, 60S
23
23
22
No W107
Dark Green Serp.
Magnetite Picrolite
Very little fiber
Thin and follow Fractures
24
23
No W84
DEERISLE SERPE
Deer Isle, Maine.
Plane table & Pace Map
Scale in Feet
100 50 25 0 10
Geology by L WING, W L
Maine Geological Survey
J. M. TREFETHEN STATE G

MAP III

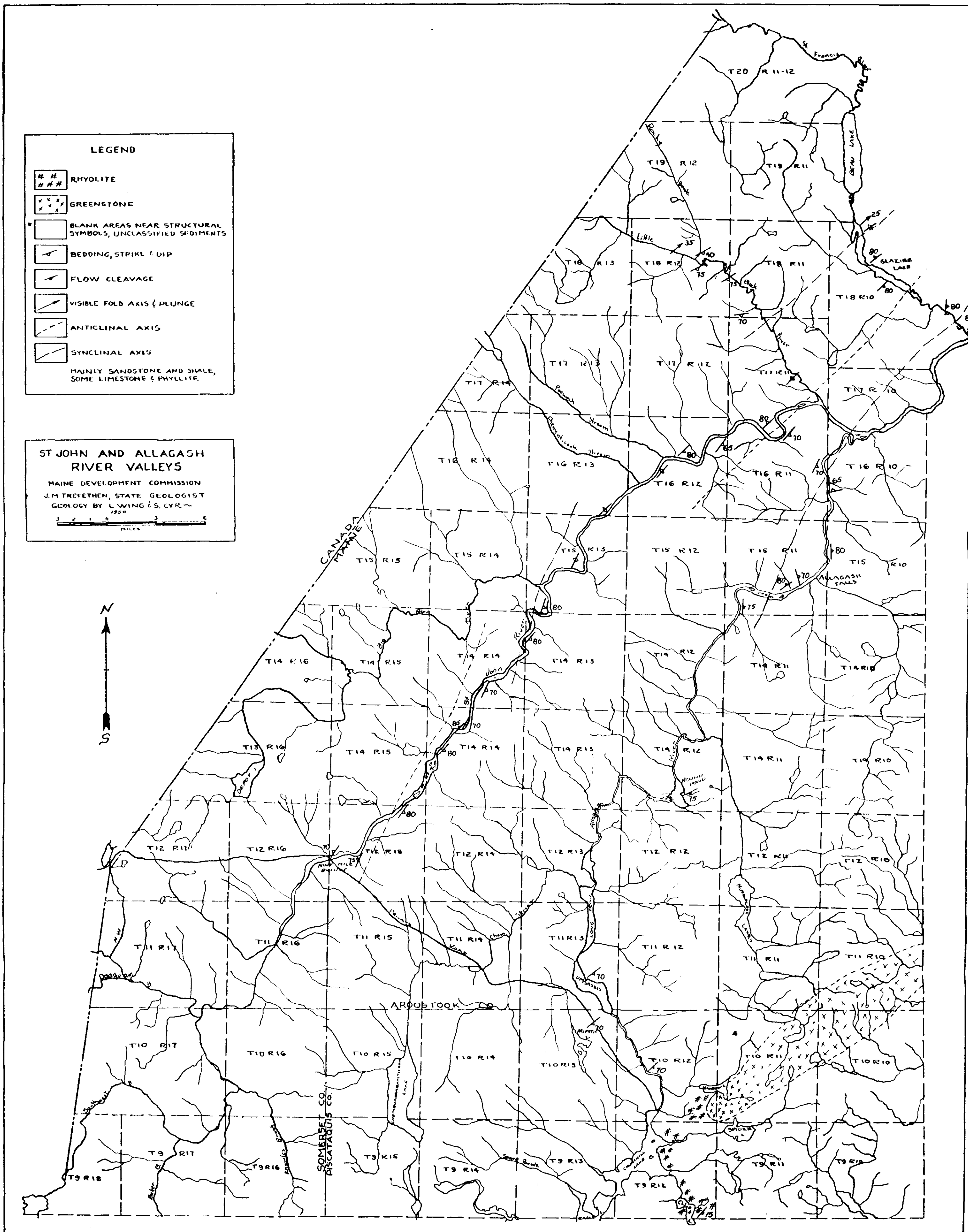

Serpentine
Ellsworth Schist
Outcrop Boundary
Sample No. & Loc.
Dip Needle
Low Tide
No W84
Green & Dense
No W83
Veins Serp at N50W
Fractures N30E, 75N
No W82
Dark and Light
Joints N65W, V
N35E, 80S
No W99
Banded
Sample No W98
Inclusion (?)
Small veins of cross fiber in Dark green Serp
N08E, 60W
No W81
N
DEERISLE SERPENTINE
Deer Isle, Maine.
Plane table & Pace Map August 1949
Scale in Feet
100 50 25 0 100
Geology by L WING, W LINTON
eological Survey Maine Development Commission
J.M.TREFETHEN STATE GEOLOGIST


MAINE GREENSTONE
LEGEND
GREENSTONE
BOUNDARIES, DETERMINED
BOUNDARIES, INFERRED
ANTICLINAL AXIS AND PLUNGE
SYNCLINAL AXIS AND PLUNGE
AXIS AND PLUNGE, FOLDING UNDETERMINED
TEXT REFERENCES
MAINE DEVELOPMENT COMM.
GEOLOGICAL SURVEY
J.M.TREFETHEN, STATE GEOLOGIST
GEOLOGY BY: L.A.WING, 1950
WASHINGTON
BANGOR
HOULTON

MAP IV


45°15'
68°15'
LEGEND
Rhyolite
Greenstone Sediments
Lower Devonian Sandstone
Ashland formation, thin bedded: Shales and Sandstone, including lenses of Limestone.
Geologic Contact
Bedding
Flow Cleavage
Fracture Cleavage
Direction + Plunge
PATTEN MAINE
Scale in Miles
Base Map compiled from various sources
Geology - L.A. Wing - W.A. Linton.
Maine Geological Survey - Maine Development Commission.
J.M. TREFETHEN. - STATE GEOLOGIST.
18°
Not Surveyed
T 6 R 7
T 6 R 6
T 5 R 7
T 5 R 6
MORO
HERSEY
Pleasant Lake
Rockabema Lake
Upper Shinn P.
Lower Shinn

MAP V


LEGEND
RHYOLITE
GREENSTONE
BLANK AREAS NEAR STRUCTURAL SYMBOLS, UNCLASSIFIED SEDIMENTS
BEDDING, STRIKE & DIP
FLOW CLEAVAGE
VISIBLE FOLD AXIS & PLUNGE
ANTICLINAL AXIS
SYNCLINAL AXIS
MAINLY SANDSTONE AND SHALE, SOME LIMESTONE & PHYLLITE
ST JOHN AND ALLAGASH RIVER VALLEYS
MAINE DEVELOPMENT COMMISSION
J.M TREFETHEN, STATE GEOLOGIST
GEOLOGY BY L. WING & S. CYR
1950
MILES
CANADA
MAINE
AROOSTOOK CO
SOMERSET CO
PISCATAQUIS CO
ALLAGASH FALLS
NINE MILE BRIDGE
GLAZIER LAKE
BEAU LAKE
T20 R 11-12
T19 R12
T19 R11
T18 R13
T18 R12
T18 R11
T18 R10
T17 R14
T17 R13
T17 R12
T17 R11
T17 R10
T16 R14
T16 R13
T16 R12
T16 R11
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T10 R15
T10 R14
T10 R13
T10 R12
T10 R11
T10 R10
T9 R18
T9 R17
T9 R16
T9 R15
T9 R14
T9 R13
T9 R12
T9 R11
T9 R10
N
S

MAP VI

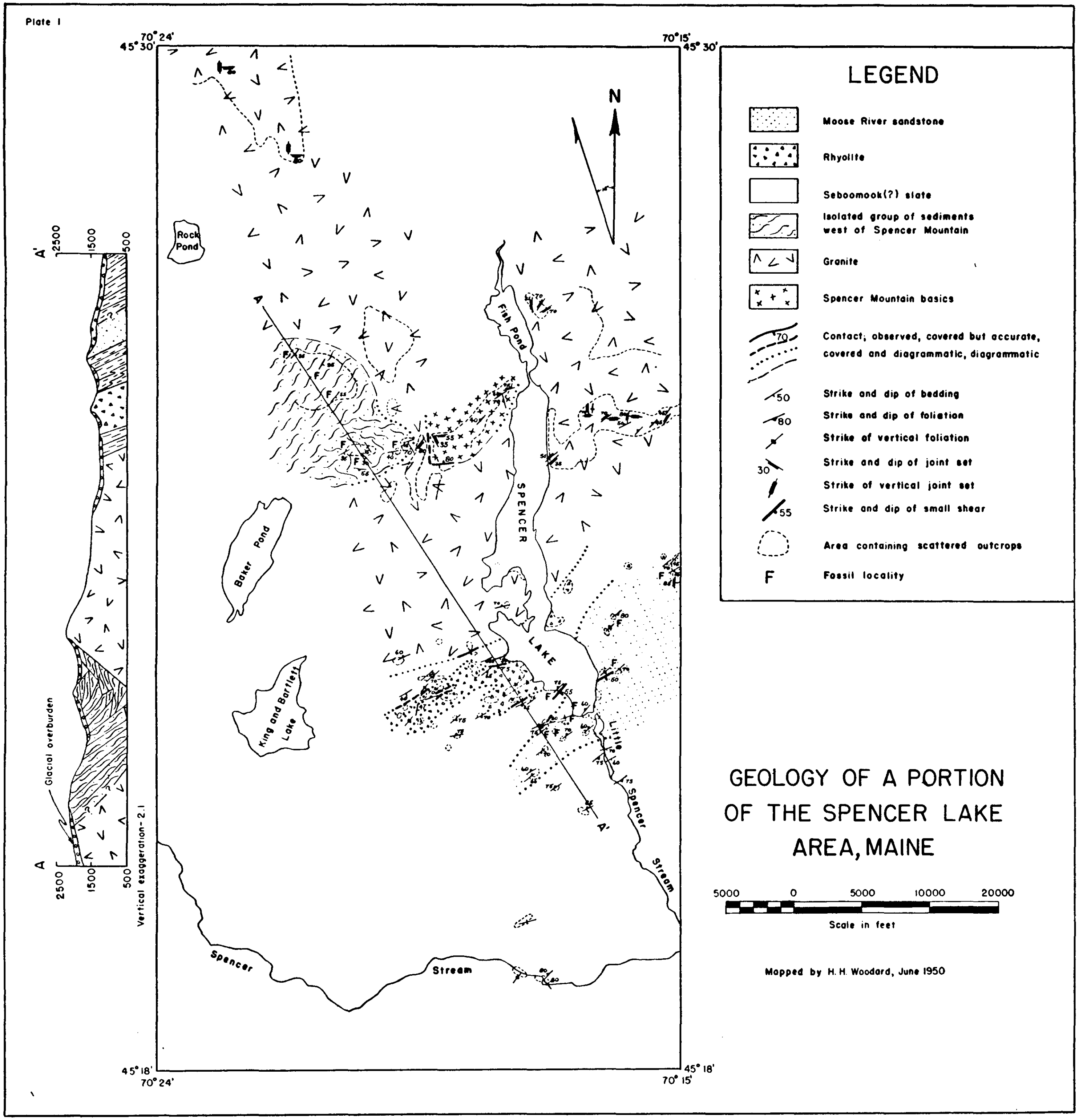
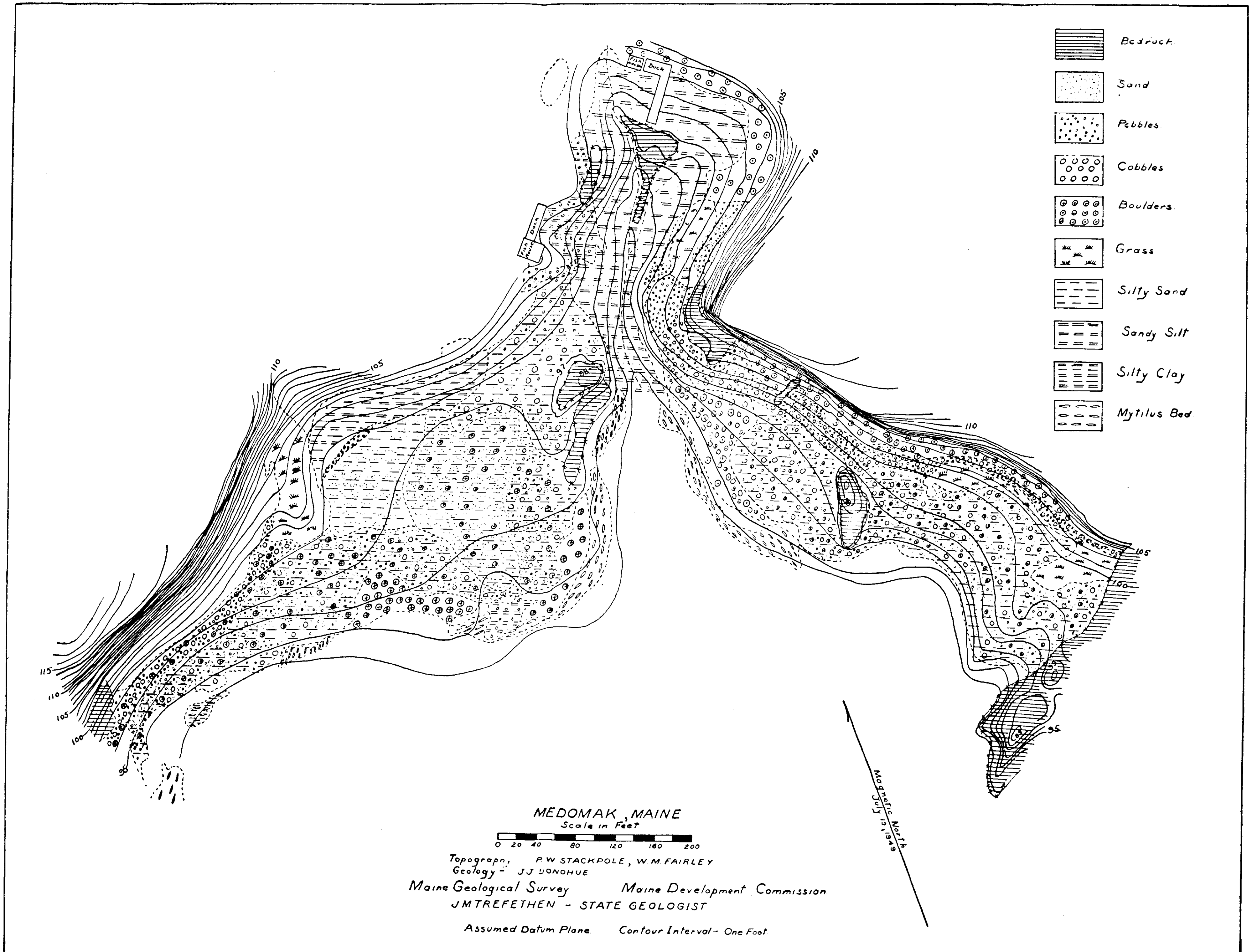


Plate I
GEOLOGY OF A PORTION OF THE SPENCER LAKE AREA, MAINE
LEGEND
Moose River sandstone
Rhyolite
Seboomook(?) slate
Isolated group of sediments west of Spencer Mountain
Granite
Spencer Mountain basics
Contact; observed, covered but accurate, covered and diagrammatic, diagrammatic
Strike and dip of bedding
Strike and dip of foliation
Strike of vertical foliation
Strike and dip of joint set
Strike of vertical joint set
Strike and dip of small shear
Area containing scattered outcrops
F Fossil locality
Scale in feet
5000 0 5000 10000 20000
Mapped by H. H. Woodard, June 1950
70° 24'
45° 30'
70° 15'
45° 30'
45° 18'
70° 24'
45° 18'
70° 15'
N
Rock Pond
Baker Pond
King and Bartlett Lake
Fish Pond
SPENCER LAKE
Little Spencer Stream
Spencer Stream
A
A'
2500
1500
500
Glacial overburden
Vertical exaggeration - 2.1

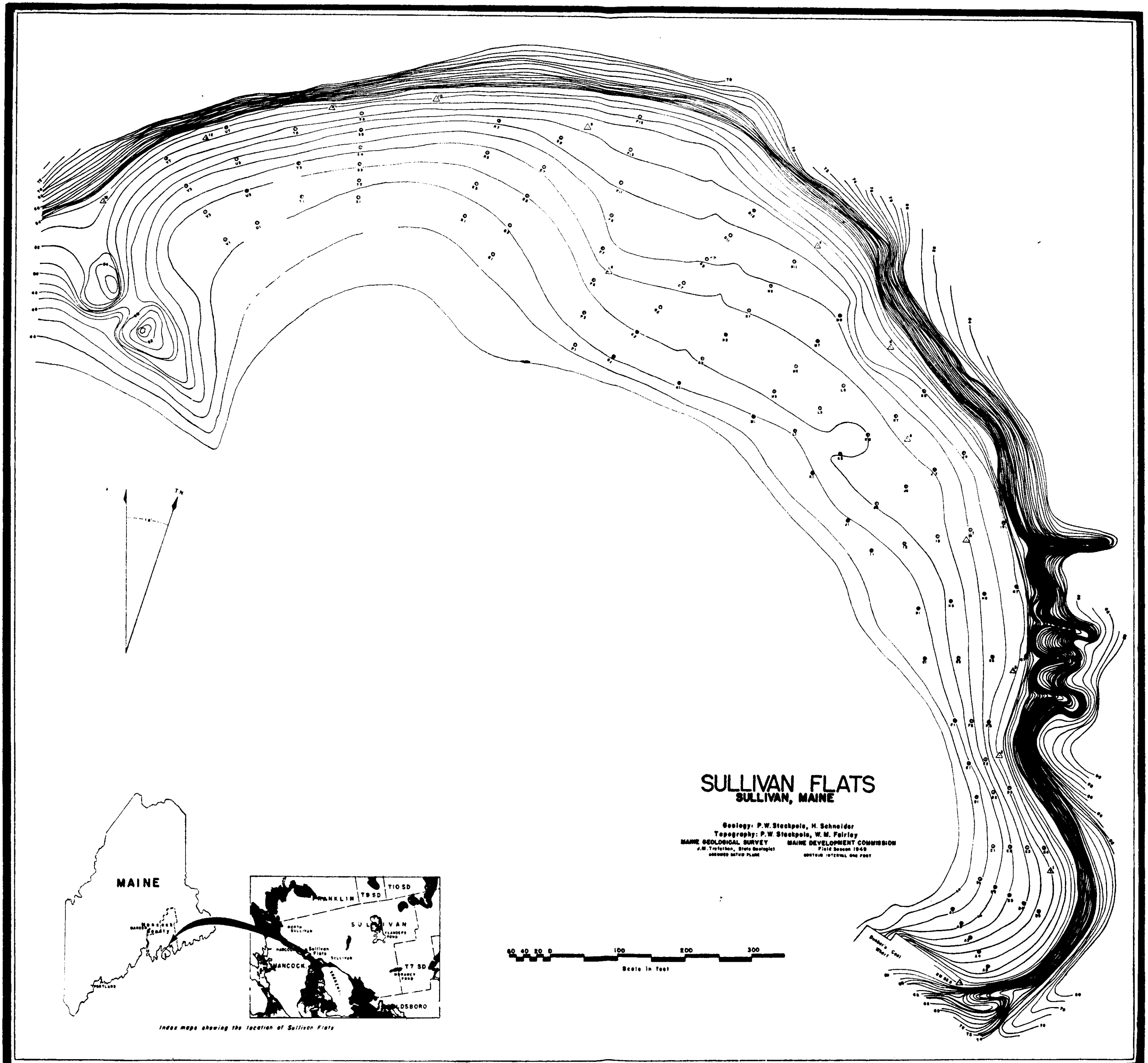
MAP VII


Bedrock
Sand
Pebbles
Cobbles
Boulders
Grass
Silty Sand
Sandy Silt
Silty Clay
Mytilus Bed
Dock
MEDOMAK, MAINE
Scale in Feet
0 20 40 80 120 160 200
Topograph, P. W. STACKPOLE, W. M. FAIRLEY
Geology - J J DONOHUE
Maine Geological Survey
Maine Development Commission
J M TREFETHEN - STATE GEOLOGIST
Assumed Datum Plane.
Contour Interval - One Foot
Magnetic North
July 13, 1949

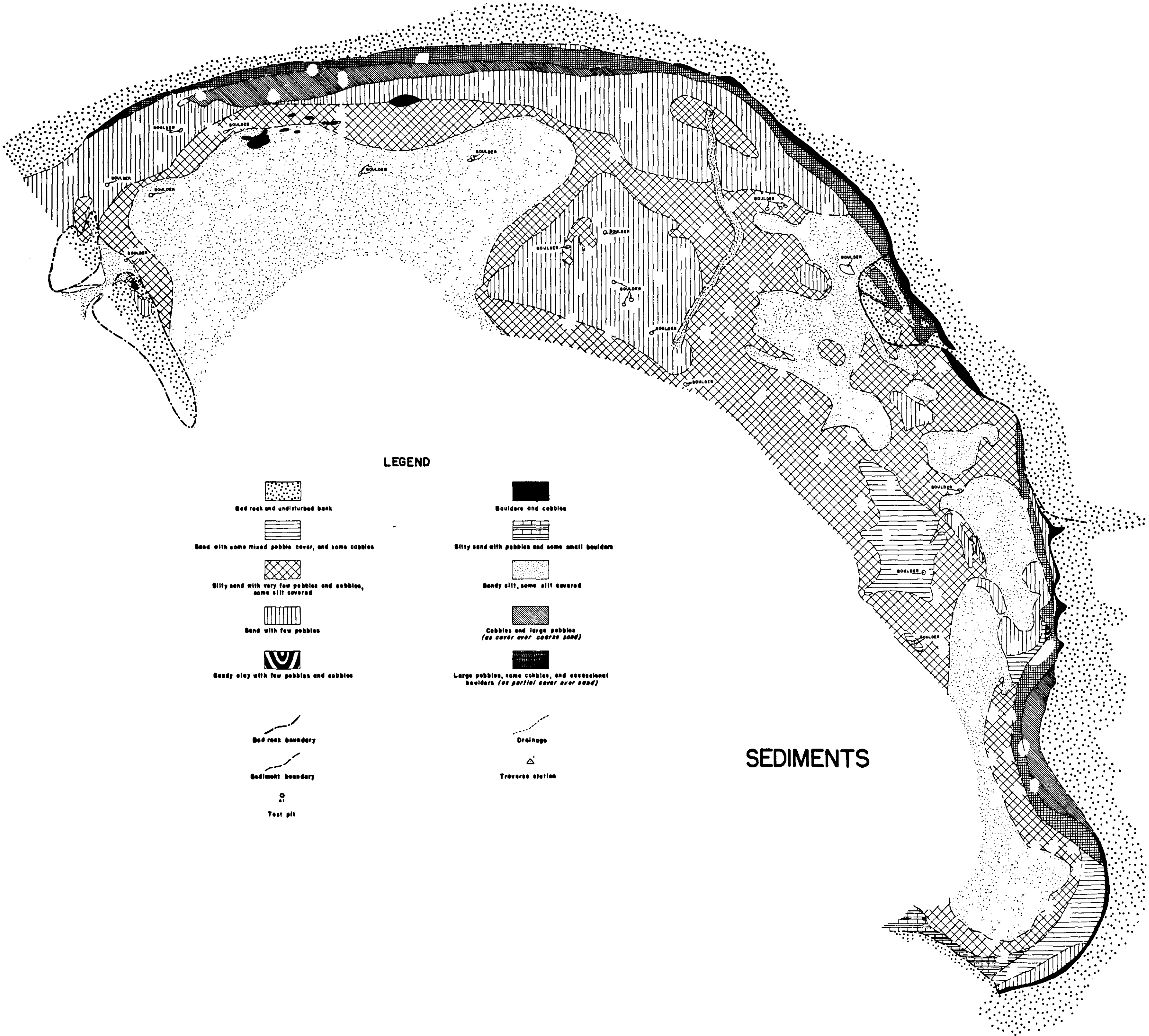
MAP VIII


Good Growth (70 MM - 85 MM)
Fair Growth (60 MM - 69 MM)
Poor Growth (0.0 MM - 59 MM)
Mytilus Edulis Beds
CLAM GROWTH
Medomak Maine
Scale in Feet
0 20 40 80 120 160 200
115
110
105
100
95
98
99

MAP IX

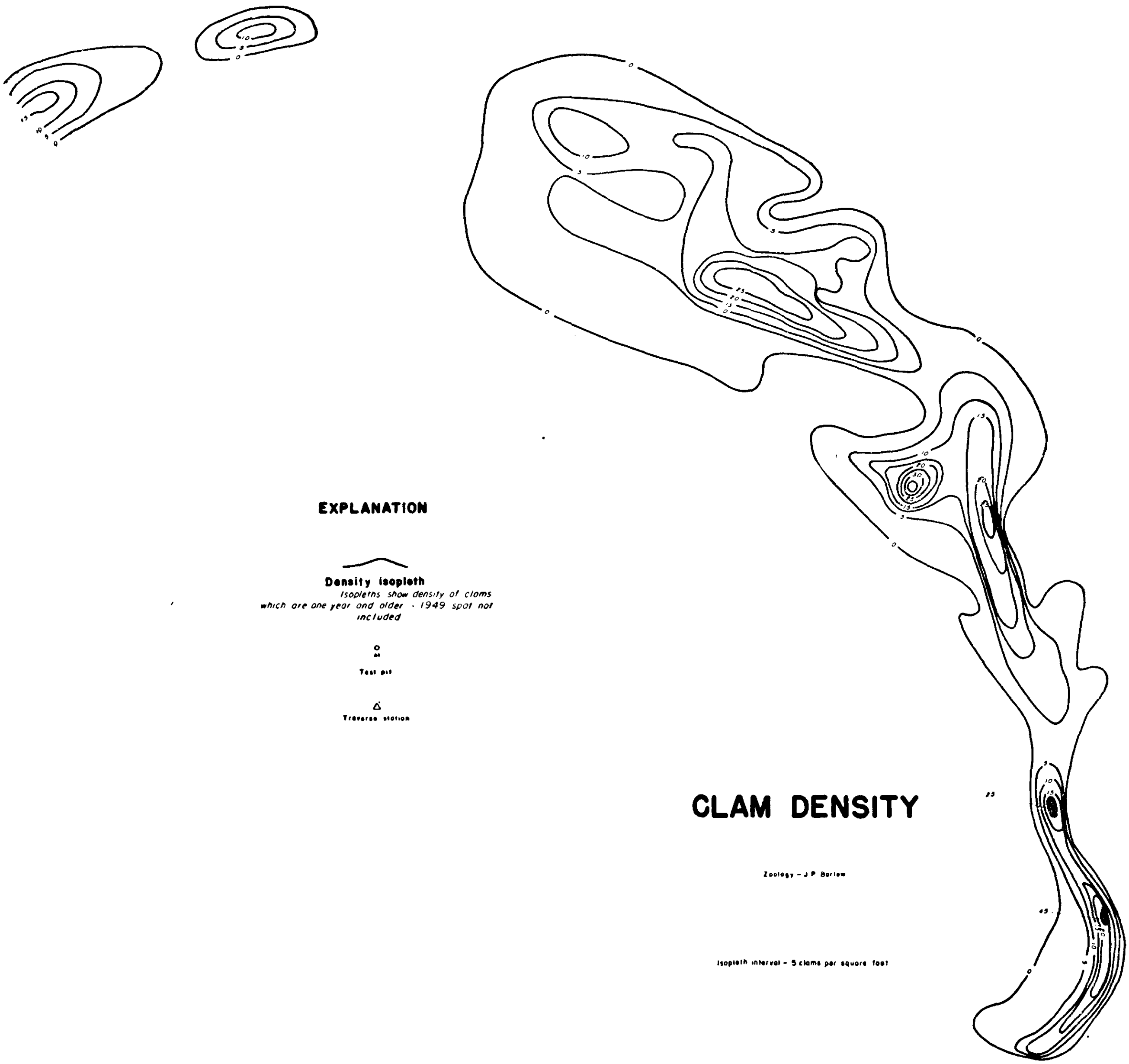

SULLIVAN FLATS
SULLIVAN, MAINE
Geology: P.W. Stackpole, H. Schneider
Topography: P.W. Stackpole, W.M. Fairley
MAINE GEOLOGICAL SURVEY
MAINE DEVELOPMENT COMMISSION
Field Season 1949
MAINE
TIO SD
T9 SD
SULLIVAN
NORTH SULLIVAN
Sullivan Flats
HANCOCK
T7 SD
Index maps showing the location of Sullivan Flats
60 40 20 0 100 200 300
Scale in feet

MAP X

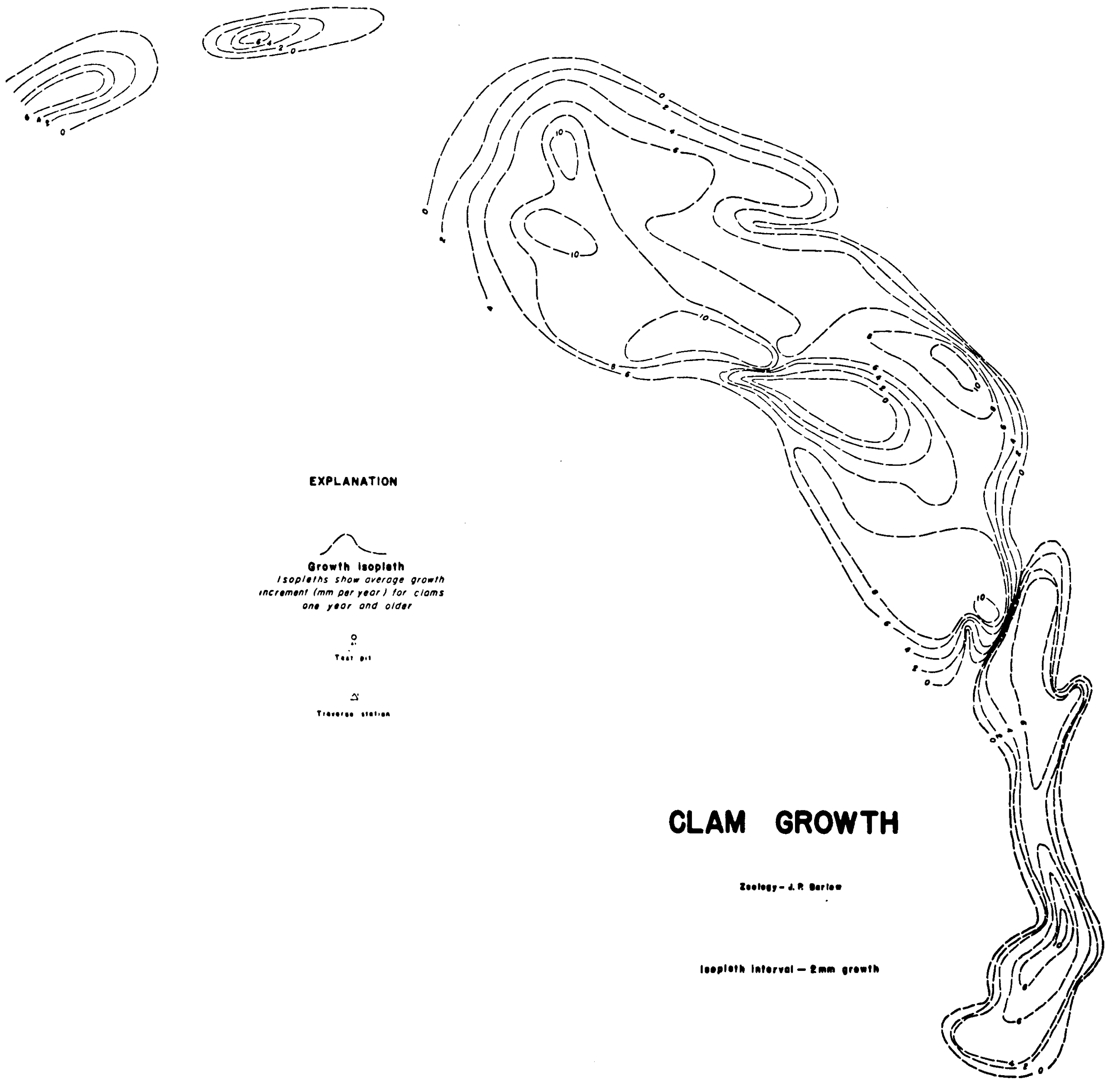


LEGEND
Bed rock and undisturbed bank
Boulders and cobbles
Sand with some mixed pebble cover, and some cobbles
Silty sand with pebbles and some small boulders
Silty sand with very few pebbles and cobbles, some silt covered
Sandy silt, some silt covered
Sand with few pebbles
Cobbles and large pebbles (as cover over coarse sand)
Sandy clay with few pebbles and cobbles
Large pebbles, some cobbles, and occasional boulders (as partial cover over sand)
Bed rock boundary
Drainage
Sediment boundary
Traverse station
Test pit
BOULDER
SEDIMENTS

MAP XI

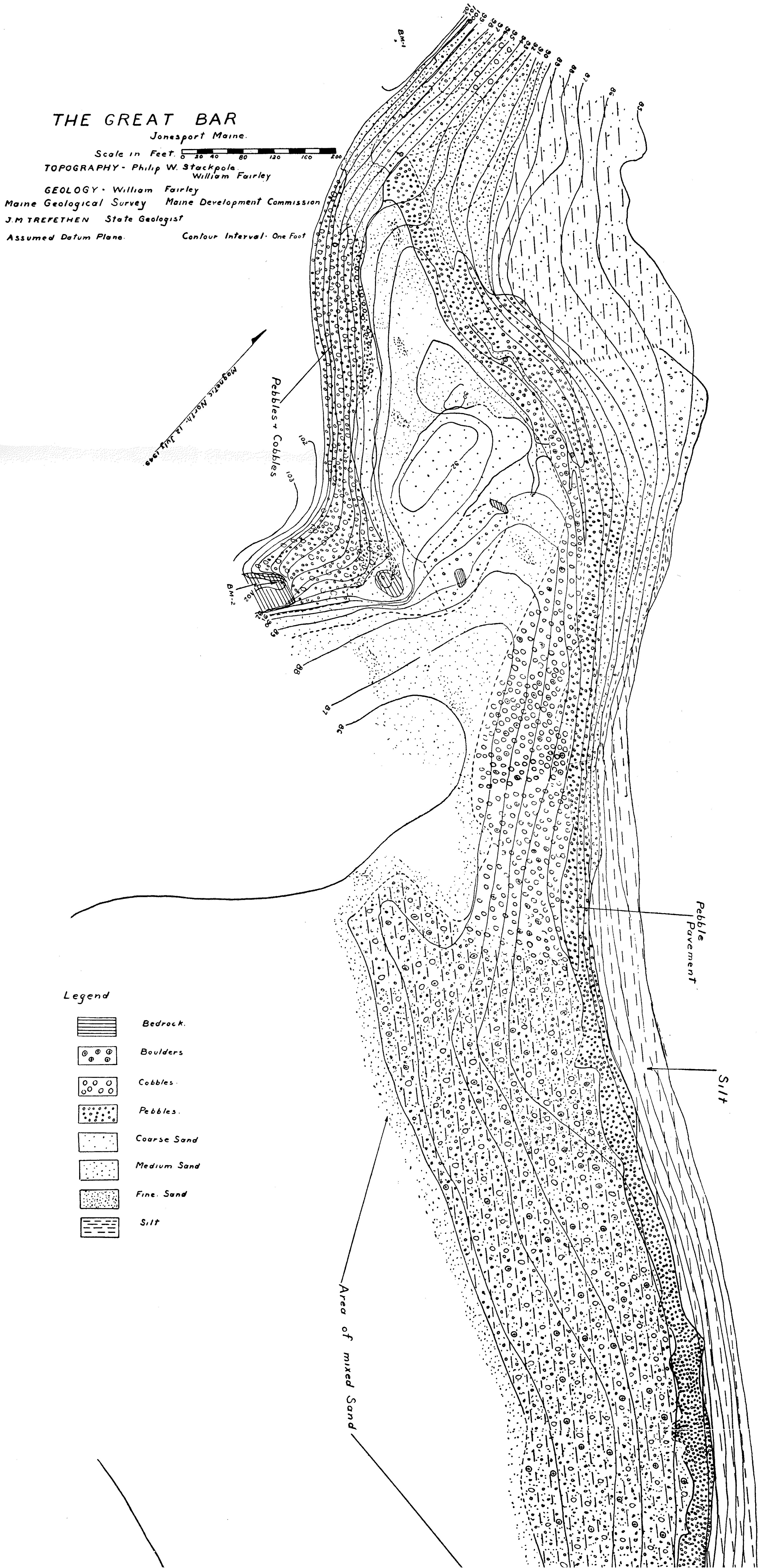

EXPLANATION
Density isopleth
Isopleths show density of clams which are one year and older - 1949 spat not included
Test pit
Traverse station
CLAM DENSITY
Zoology - J P Barlow
Isopleth interval - 5 clams per square foot

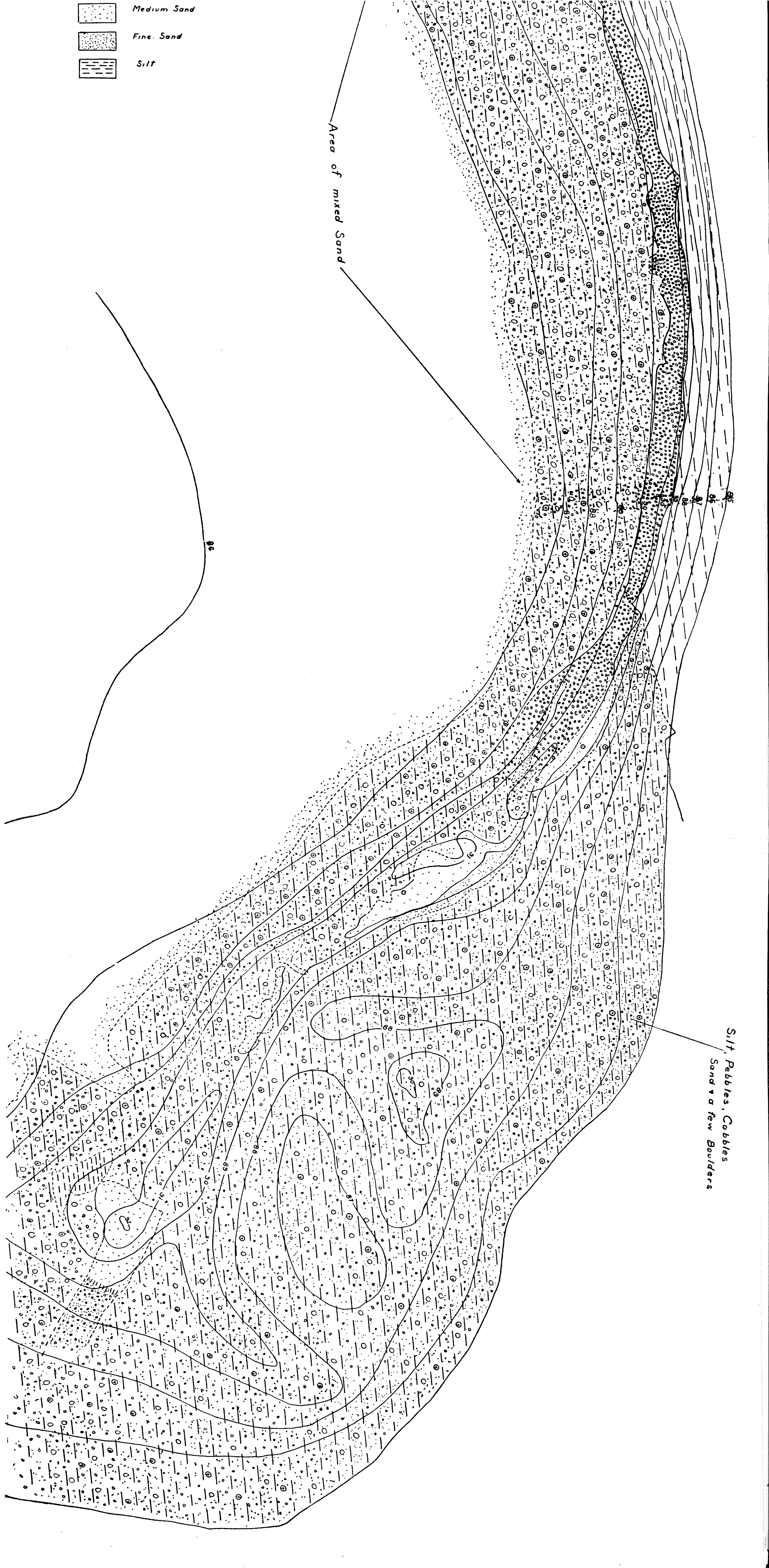
MAP XII


EXPLANATION
Growth isopleth
Isopleths show average growth increment (mm per year) for clams one year and older
Test pit
Traverse station
CLAM GROWTH
Zoology – J. R. Barlow
Isopleth interval — 2mm growth

MAP XIII

MAP XIV


THE GREAT BAR
Jonesport Maine.
Scale in Feet.
0 20 40 80 120 160 200
TOPOGRAPHY - Philip W. Stackpole
William Fairley
GEOLOGY - William Fairley
Maine Geological Survey
Maine Development Commission
J. M. TREFETHEN State Geologist
Assumed Datum Plane.
Contour Interval - One Foot
Magnetic North - 12 July 1949
Pebbles + Cobbles
BM-1
BM-2
Pebble Pavement
Silt
Area of mixed Sand
Legend
Bedrock.
Boulders
Cobbles.
Pebbles.
Coarse Sand
Medium Sand
Fine. Sand
Silt


Medium Sand
Fine Sand
Silt
Area of mixed Sand
Silt, Pebbles, Cobbles
Sand & a few Boulders

MAINE GEOLOGICAL SURVEY PUBLICATIONS

Reports

"First Annual Report on the Geology of the State of Maine"
by Lucius H. Merrill and Edward H. Perkins, 1930. *(Out of stock)*

"State Geologist's Report on the Geology of Maine 1930-32"
by Joseph C. Twinem and Edward H. Perkins. *(Out of stock)*

"Preliminary Geological Map of Maine"
By Arthur Keith and Edward H. Perkins, 1933.

"Report of the State Geologist, 1942-43"
by Joseph M. Trefethen

"Report of the State Geologist, 1943-44"
by Joseph M. Trefethen

"Report of the State Geologist, 1945-46"
by Joseph M. Trefethen

"Report of the State Geologist, 1947-48"
by Joseph M. Trefethen

"Report of the State Geologist, 1949-50"
by Joseph M. Trefethen

Bulletins

"Domestic Fuel Possibilities of Maine Peat"
by Joseph M. Trefethen and Robert B. Bradford, 1944.

"Geology of the Katahdin Pyrrhotite Deposit and Vicinity, Piscataquis County, Maine"
by Ralph L. Miller.

"Petrology of the Columbia Falls Quadrangle, Maine"
by Ruth D. Terzaghi.

"Geology of the Aroostook County, Maine, Manganese Deposits"
by Ralph L. Miller.

"Economic Geology of Some Pegmatites in Topsham, Maine"
by Vincent E. Shainin.

"Water in the Ground"
by Joseph M. Trefethen (in preparation)

Copies obtainable on request to the Maine Development Commission, Augusta, Maine.