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BULLETIN No. 40

Calcareous Deposits of Southwestern British Columbia

by
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DRAWINGS

Calcareous Deposits of Southwestern British Columbia

INTRODUCTION

This bulletin includes reports of surveys of most of the known commercial or potentially commercial, readily accessible calcareous deposits of southwestern British Columbia. It is essentially a revision of Bulletin No. 23, Calcareous Deposits of the Georgia Strait Area, by W. H. Mathews, that was published by the British Columbia Department of Mines in 1947. The reports cover the same area as Bulletin No. 23 except that material dealing with the State of Washington has been omitted. There has been no change in organization of material, and the four introductory chapters of Bulletin No. 23 have been retained with little alteration. Many of the reports on individual deposits have been used, with only minor changes made in the original text as written by Mathews. Some reports have required extensive revision to bring them up to date and descriptions of a few new deposits have been added—these are all marked by asterisks.

Field work upon which the revision is based was carried out in the 1956 field season by J. W. McCammon. During the course of the work all of the large deposits and most of the small ones were examined. The writer gratefully acknowledges the assistance given him by the operators of the various deposits and by R. H. Farquhar, who served as student assistant.

DEFINITIONS, CHEMICAL SYMBOLS AND ABBREVIATIONS

The classification of limestone used in this bulletin follows closely that used by Goudge (1944), and differs from Goudge principally in using " High-calcium Limestone " as a separate class rather than part of the " Calcium Limestone " class.

Limestone denotes a rock of sedimentary origin consisting mainly of calcium carbonate (calcite) or the double carbonate of calcium and magnesium (dolomite). A rock containing less than 50 per cent* combined calcite and dolomite is, therefore, not considered to be a limestone.

Limestone may be subdivided on the basis of chemical composition into four classes:—

(1) *High-calcium Limestone.*—Denoting a limestone containing at least 95 per cent* calcium carbonate ($CaCO_3$) and not more than 2 per cent magnesium carbonate ($MgCO_3$); these are equivalent to 53.3 per cent lime (CaO) and 0.96 per cent magnesia (MgO).

(2) *Calcium Limestone.*—Denoting a limestone whose calcium content greatly predominates, but which cannot be classed as high-calcium limestone. Calcium limestone may contain up to 4.79 per cent magnesia, equivalent to 10 per cent magnesium carbonate.

(3) *Magnesium Limestone.*—Denoting a limestone containing more than 4.79 per cent and less than 19.15 per cent magnesia.

(4) *Dolomitic Limestone.*—Denoting a limestone containing more than 19.15 per cent and less than 21.86 per cent magnesia, the theoretical magnesia content of the mineral dolomite.

The term " dolomite " is restricted to the pure mineral ($CaMg(CO_3)_2$). The term " marble " is used in this report in its geological sense as crystalline limestone, not in the popular sense as an ornamental limestone.

* All percentages are by weight.

In the chemical analyses quoted in this bulletin the components of limestone are given in terms of oxides and " ignition loss," the latter consists chiefly of carbon dioxide (CO_2). The essential oxides in limestone, lime (CaO), and magnesia (MgO) are reported in some publications as calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$). These oxides may be recalculated as the carbonates or vice versa using the following data:—

1 per cent CaO is equivalent to 1.78 per cent $CaCO_3$.
1 per cent MgO is equivalent to 2.09 per cent $MgCO_3$.
1 per cent $CaCO_3$ is equivalent to 0.560 per cent CaO.
1 per cent $MgCO_3$ is equivalent to 0.478 per cent MgO.

In order to save space, chemical formulæ and other abbreviations have been used in the tables of chemical analyses throughout this bulletin. The abbreviations used are explained below:—

Symbolic Formula	Full Chemical Name
Fe_2O_3	Iron oxide; contains 69.94 per cent iron by weight.
MnO	Manganese oxide; contains 77.44 per cent manganese by weight.
P_2O_5	*Phosphorus pentoxide; contains 43.65 per cent phosphorus by* weight.
TiO_2	Titanium dioxide; contains 59.95 per cent titanium by weight.
Al_2O_3	Aluminium oxide (alumina); contains 52.91 per cent aluminium by weight.
CaO	Calcium oxide (lime); contains 71.47 per cent calcium by weight.
MgO	Magnesium oxide (magnesia); contains 60.32 per cent magnesium by weight.
S	*Sulphur.*
Insol.	Acid insoluble matter; contains those minerals, chiefly silicates, which do not dissolve when heated with hydrochloric acid as described on page 30.
R_2O_3	Aluminium oxide, with those oxides of titanium, zirconium, beryllium, chromium, quinquavalent phosphorus, quinquavalent arsenic, and quinquavalent vanadium present in the limestone. Usually for limestones R_2O_3 is essentially aluminium oxide, the remaining substances listed being present *in* very low percentages if at all.
Ig. Loss	The percentage loss in weight when the limestone is ignited in a furnace. Such ignition decomposes the carbonates of calcium and magnesium, forming calcium and magnesium oxides and gaseous carbon dioxide. This carbon dioxide escapes and, together with the minor amounts of water and organic matter present, accounts for practically all the loss in weight on ignition.
H_2O 105°	Water which is released from the sample when it is heated at *105° C.*

CHAPTER I.—GEOLOGY

ORIGIN OF CALCAREOUS DEPOSITS

Carbonates of calcium and magnesium may be precipitated from aqueous solutions, usually sea-water, by several different agencies. The calcareous deposits thus formed may be subdivided into several more or less independent types based on their modes of origin:—

(1) Those consisting of the accumulated shells, or fragments of shells, precipitated by the larger organisms.
(2) Those precipitated by micro-organisms in which shells or shell fragments are not evident, at least to the unaided eye.
(3) Those precipitated by chemical means, such as a change in the temperature or in the CO_2 content of the solution.
(4) Those composed of any two or all of the above agencies.

Except where limestones have been extensively recrystallized, those formed by the accumulation of larger shells and shell fragments are easily recognizable. Where the limestone is fine-grained and devoid of visible shells or shell fragments, however, the origin may be doubtful. Such a limestone may have been precipitated originally as a fine-grained ooze, either by micro-organisms or by chemical action, or by a combination of the two. Where shells and shell fragments are found in a matrix of fine-grained limestone, larger organisms and also micro-organisms or chemical action, or both, were responsible for the original deposition. Such a case is found at one horizon in the limestone of Texada Island where, however, shell fragments are exceeding widely scattered. It is clear that this horizon and the adjacent unfossiliferous limestone originated almost entirely through microbiological or chemical action. The scarcity of shells in most of the limestone deposits, except in some of the Palæozoic crinoidal limestones of the area, suggests that larger organisms played but a minor part in the precipitation of the original material, but in several deposits the recrystallization of limestone has been sufficient to obliterate fossil remains and their origin must remain in doubt.

Submarine vulcanism, according to Kania (1929), may play an important part in the precipitation of limestone by heating the overlying sea-water, eliminating much of its content of carbon dioxide, and converting the dissolved calcium bicarbonate to insoluble calcium carbonate. The precipitated ooze, he believes, may be carried by submarine currents into hollows in the sea floor to give rise to thick but lenticular deposits of limestone.

Nearly all the limestones of the area studied were evidently deposited as limy ooze, marine shells, etc., on ancient sea floors. Under these circumstances uniform conditions apparently prevailed over many acres or even many square miles of sea floor for appreciable periods of time. During such a period several inches to several feet of calcareous material might be deposited and would retain fairly uniform physical and chemical characteristics throughout. At the same time greater or less amounts of mud and sand or volcanic ash might be deposited with the calcareous material, and thus contribute to the impurities present in the resulting limestone. For any one of several reasons, conditions might change and sedimentation cease, or sediment of a different character be laid down. In this way a deposit consisting of roughly horizontal layers of different compositions would be formed. A gradual change in conditions would lead to a progressive change in the physical characteristics and composition of the sediment being laid down. Similarly an abrupt change in conditions would produce a distinct discontinuity in the character of the sediment. At the present time such discontinuities between successive strata are in many cases marked by conspicuous joints, which may be termed " bedding fractures."

Not all the limestone deposits of the area were, however, laid down in marine waters or under the circumstances described above. Some limy oozes have been and are being deposited in fresh-water lakes as " marl." Organisms, notably the aquatic plant *Chara*, have been credited with assistance in the precipitation of this fresh-water marl. As in the case of marine deposits, marl may display more or less distinct stratification. The conditions suitable for precipitation of marl must be distinctly limited, for of all the lakes in the area studied only Cheam Lake, in the eastern part of the Fraser Valley is known to contain marl. Marl deposits are commonly found in the lakes of the Interior of British Columbia, where a drier climate prevails, and in many, but not all, cases in the vicinity of large outcroppings of limestone.

Calcareous waters issuing on to the land surface as springs, entering caves, or percolating through surface soils may deposit calcareous material known as "travertine." The compact but cellular form of travertine is commonly referred to as "tufa." Physico-chemical action, such as concentration of dissolved carbonates by evaporation loss of carbon dioxide, and change in temperature, is probably chiefly responsible for the deposition of travertine. Large deposits of travertine are rare in southwestern British Columbia, although two small deposits southeast of Rosedale have been worked to a limited extent.

Low-grade calcareous deposits may be reworked by various agencies and in some cases become concentrated. Clam shells and shell fragments scattered across the sea bottom may be transported by waves and currents, cast up on the shores, and washed to leave layers of high-grade shell sand. The native Indians, who for centuries collected clams and mussels for food, have left in places near the coast concentrations of their shells in kitchen middens. These two types of shell deposits have locally been sufficiently large and high grade to have been worked commercially. The mechanical erosion of limestone and subsequent deposition of undissolved detritus can take place, and a deposit at Departure Bay may possibly have originated in this way.

The original calcareous deposits as first laid down are believed to have been in general composed dominantly of calcium carbonate. Some marine shells, however, do contain considerable quantities of magnesia, and this constituent may be retained in the resulting deposit. Selective solution of calcium carbonate from these shells may lead to a concentration of magnesia in the residue. Such a process may be responsible for some deposits of magnesium limestone. It is considered, however, that most of the magnesia contained in limestone has been introduced by reaction between sea-water and part or all of the calcareous sediment during or shortly after its deposition and prior to its deep burial. Such a reaction gives rise to beds or fine laminæ of magnesian or dolomitic limestone interstratified with calcium-rich limestone. Such beds or laminæ are composed either of grains of dolomite disseminated through a calcite matrix or of nearly pure dolomite.

Silica (SiO_2) may be introduced, like dolomite, into the sediment during or shortly after its deposition as jelly-like layers or masses. Such a gel, subsequently converted into flint or chert, commonly takes the form either of nodules, of various sizes and shapes, arranged in groups parallel to the stratification, or of more or less continuous beds. Silica in the form of sand grains may also be incorporated with the calcareous sediment, but this form is rare.

Other impurities that may be introduced along with calcareous material in the original sediment include mud (rich in alumina and insoluble matter), volcanic ash (rich in insoluble matter), and carbonaceous matter from organisms.

The limestone beds themselves may be overlain and underlain by bedded material of a totally different composition, notably shales, argillites, and schists, cherts, and volcanic rocks.

MODIFICATIONS OF CALCAREOUS DEPOSITS

Most of the calcareous deposits, as originally formed, consisted of horizontal or nearly horizontal strata, each of which possessed more or less uniform physical and chemical characteristics. In at least the older deposits, however, the original structure has rarely been undisturbed. The formerly flat-lying strata have been tilted, warped, and in some cases complexly folded. Strata have been fractured and faulted into more or less isolated blocks of all sizes. Careful study is in many cases necessary to recognize the original stratification and to decipher the complex structures into which it has been deformed. Nor is the structure alone modified; the texture of the deposit, too, may be altered by the action of heat and pressure working over long periods of time, converting limy ooze to the solid rock known as limestone and recrystallizing limestone into marble.

FOLDING

One limestone deposit exhibiting a simple folded structure is that at Limekiln Bay, in the northern part of Texada Island (Fig. 1). Here on shore cliffs and in an old quarry is exposed the western part of a broad saucer-shaped structure. The strata dip, in general, toward the centre of this structure at angles of not more than 20 degrees. Some beds can be traced for the full length of the quarry face, some 400 feet; others exposed at opposite ends of the quarry lie below the level of the quarry floor in its central part.

The limestone at Open Bay, Quadra Island, on the other hand, exhibits intense and complicated folding (Fig. 16). Here beds or laminæ of argillaceous limestone in purer limestone show crenulations on the flanks of small dragfolds situated, in turn, on the flanks of still larger folds. In any one part of the deposit the axial planes of the crenulations, dragfolds, and larger folds have a rough parallelism. In some parts of the deposit, however, the folds may be upright, elsewhere overturned either to the east or west, and in one place the folds are recumbent. Lacking some readily recognizable stratigraphic horizon it would be exceedingly difficult to determine whether the regional dip of the deposit is to the east or west. Fortunately, however, several lava flows are interbedded with the limestone, and although these, too, exhibit larger-scale folding, it is clear that they and the limestone with them dip at moderate angles to the east.

Between these two extremes in intensity of folding all degrees may be found in the limestone deposits of southwestern British Columbia. No extensive flat-lying deposits of limestone exist, such as occur in the Palæozoic rocks of southern Ontario or of the mid-western States.

FAULTING

Some of the clearest examples of faulting occur in the quarry at Limekiln Bay (*see* Fig. 1) and on the adjacent shore cliffs. Here the saucer-shaped folded structure is complicated by two sets of eastward-trending, southward-dipping normal faults. The beds on the south sides of these faults are in each case dropped with respect to the corresponding beds on the north sides by amounts varying from a few inches to more than 10 feet. Here the reason for the present discontinuity in the strata or in rock of a given chemical composition is clearly evident. In this exposure it is also apparent that the dip of a single fault may change from bed to bed. Moreover, the displacement at different parts of the same fault shows distinct variations. One small fault at the north end of the quarry dies out up the dip, the displacement varying from about 2 inches at the quarry floor to zero a few feet higher. The sum of the displacements in the southern set of faults is at the quarry face almost 8¾ feet, and at the shore cliffs, 200 feet to the west, 11½ feet.

Similar features are found in faults elsewhere, although they are nowhere as well revealed as at Limekiln Bay. In some of the limestone deposits, faults are of considerable magnitude; one on Texada Island is estimated to have a displacement exceeding 1,000 feet. Where the fault movement has a horizontal component or where a fault cuts tilted beds, it can be detected by the displacement in plan view of beds, contacts, or other formerly continuous features. In many cases, faults can be recognized by the termination of a given stratum at a zone of crushing, but the direction and amount of the displacement cannot be determined. In most deposits the abrupt termination of a limestone bed along its length can be attributed to faulting.

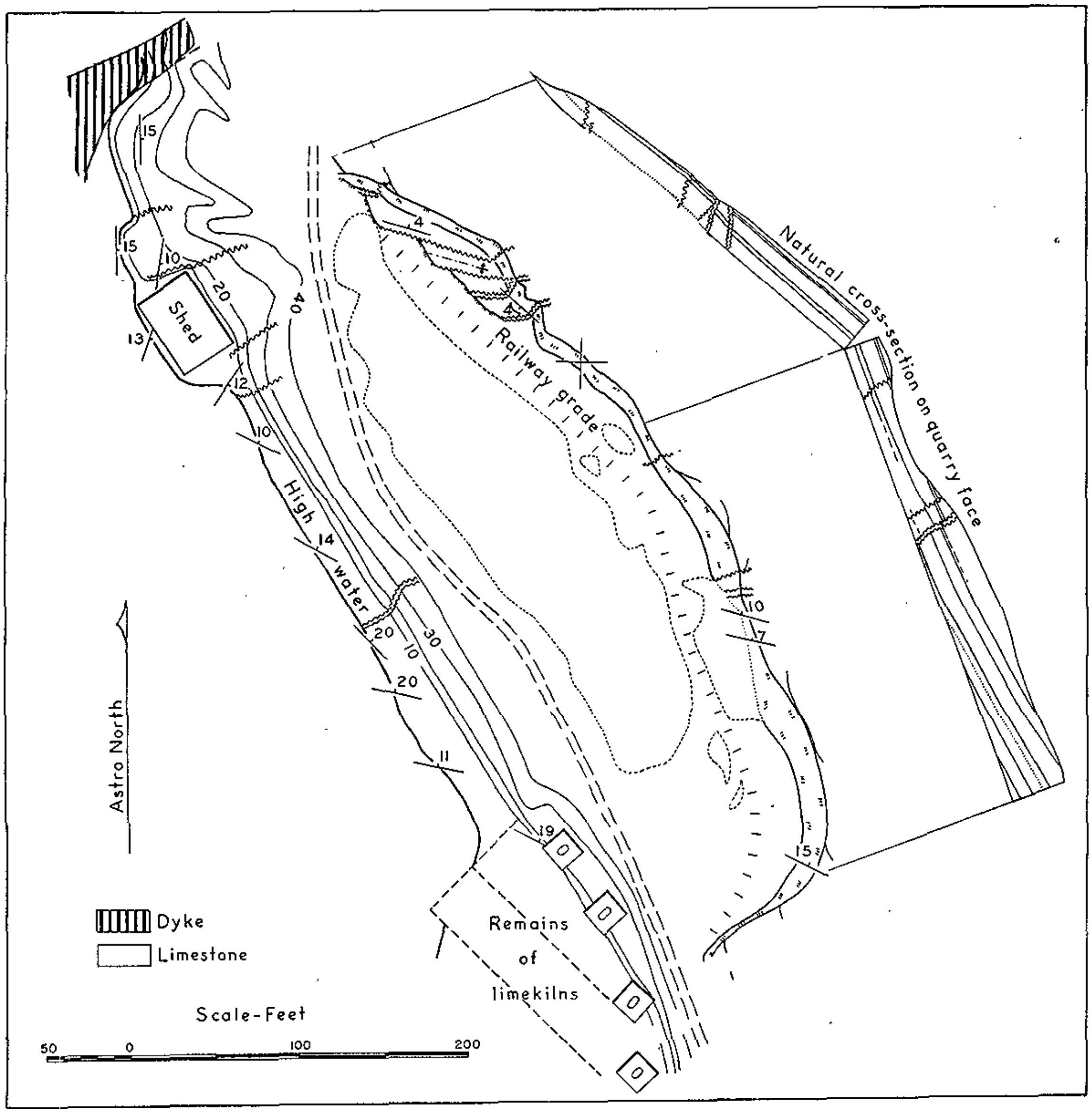

Figure 1. Limekiln Bay quarry.

TEXTURAL CHANGES

The calcareous sediment most nearly in its original condition is the fresh-water marl of Cheam Lake. The stratified jelly-like ooze at the bottom of this lake is so soft that it can be stirred into a pulp and pumped through a 3¾-inch pipe. The relatively undisturbed limestone of Limekiln Bay and of the southwestern part of Blubber Bay has become converted during millions of years from what was probably a similar ooze when first laid down on the sea floor into solid limestone, which, however, retains the former fine-grained texture and a dark colour contributed by finely disseminated carbon presumably inherited from former organisms.

Limestone has been converted into a coarse-grained marble in the vicinity of some intrusive igneous rocks, which for a time must have contributed considerable heat to the adjoining calcareous rocks. Such marble at the west end of No. 1 quarry, Beale

Quarries Limited, Vananda, contains calcite crystals from 1 to 1½ inches in diameter, and calcite crystals 4 inches across are reported by Swanson (1924, p. 115) from the limestone at the Texada Island iron mines. Rarely, however, does the grain size of marble reach such dimensions.

Limestone has developed a characteristic gneissic banding of dark carbon-rich and light carbon-poor bands, each usually a fraction of an inch thick in areas of tight folding, such as that extending along the east coast of Texada Island from Grilse Point to Eagle Bay. This gneissic structure is apparently related to shearing along bedding planes during folding. It is best defined along the flanks of folds and is ill-defined or missing at their axes. Gneissic banding is not necessarily parallel to the bedding; indeed there is probably a tendency for it to parallel the axial plane of folds irrespective of bedding. Shearing movements unrelated to folding may be responsible for belts of similar gneissic limestone in gently folded rocks. Such an occurrence was found at one place west of the Vananda Road in the Pacific Lime Company property at Blubber Bay, Texada Island. At one point on the north shore of Sturt Bay, Texada Island, two sets of intersecting gneissic bands were observed.

INTRODUCTION OF EXTRANEOUS MATERIAL INTO CALCAREOUS DEPOSITS AFTER DEPOSITION

INTRUSIVE ROCKS

In some of the limestone deposits extraneous material has been introduced in the form of dykes and sills, injected originally as molten rock along fractures in the limestone, either cutting across or parallel to the stratification. These dykes and sills vary markedly in colour, texture, and in chemical composition, although all are high in insoluble matter. In some areas, notably in the northern part of Texada Island, they are sufficiently abundant to add materially to the problems of extraction and treatment of limestone. Further details on these dykes and sills are given in the descriptions of the various deposits.

Some of the limestone deposits have been invaded by larger intrusive masses. In the northern part of Texada Island the limestones have been intruded by several gabbro to quartz diorite stocks, roughly elliptical in shape, from a few hundred feet to more than half a mile across. Rarely has any limestone been left within the area occupied by one of these stocks.

Very large areas in the Coast Mountains and considerable areas on Vancouver Island and in the Cascade Mountains have been invaded by granitic batholiths. In parts of the batholiths roof pendants or large inclusions of older rocks, a part or all of which may consist of limestone, do exist, hence these batholiths cannot be overlooked in prospecting for limestone deposits. Near Bold Point on Quadra Island, and a few miles northwest of Powell River, several such roof pendants or inclusions of limestone are known and are large enough to be of possible commercial interest.

VEINS AND REPLACEMENTS

Veins and replacements of a wide range of mineralogical character in the limestone deposits of the region have been formed, presumably by the precipitation of material from aqueous solutions percolating along fractures and through permeable zones. Some of these veins and replacements appear to have been produced by the redistribution of constituents already within the limestone of the vicinity, others were clearly derived from more distant sources.

In the first of these two classes may be included veinlets of dolomite, calcite, and serpentine, and grains and irregular masses of olivine, serpentine, etc. Fine veinlets of dolomite cutting across calcium-rich limestone are common features in many of the limestone deposits. Such veinlets are, however, most abundant within a foot or two of beds of dolomitic or magnesian limestone, and it is evident that these beds are the source of the magnesia in the veinlets. No large irregular masses of dolomite which might be formed by the introduction of large amounts of foreign magnesia are known. Veinlets of calcite similar to those of dolomite are common in beds of magnesian and dolomitic limestone, and though in some cases they extend many feet from the nearest calcium-rich bed, they, too, are presumably of local origin.

Grains of olivine and small veins and segregations of serpentine are apparently formed as a result of metamorphism by the recombination of magnesia and silica in magnesium-rich limestones, with or without the introduction of additional silica.

In the second of the two classes may be included vein-like to more or less irregular replacements, known as "skarn," consisting of lime silicates, chiefly garnet, diopside, wollastonite, etc., with varying amounts of pyrite, magnetite, chalcopyrite, bornite, etc. These skarn bodies occur in several of the limestone deposits but are most common on the northern part of Texada Island, where several have been mined for their copper-gold or their iron content, and similar bodies too small and too low grade to be mined for their metal content are large enough to interfere with limestone quarrying. The skarn bodies are younger than most of the intrusions commonly occurring along their contact, partly within the intrusives and partly within the intruded limestone. A few bodies lie many feet from the nearest intrusion, commonly either along a prominent fracture or along a fold axis. It is apparent that the former content of silica, iron, sulphur, etc., of the adjacent limestone was insufficient to provide for these skarn bodies by a process of segregation and, therefore, that these constituents must have been introduced from more distant sources. It is equally clear, however, that much of the material in the skarn was formerly present in the host rock. The calcium-magnesium ratio in the skarn, for instance, approximates that of the limestone within which it is found, hence it may be concluded that neither of these constituents was added. In some cases it is possible to trace intrusive contacts and stratification in the limestone across skarn bodies.

Some pyrite, etc., is found extending for many feet along thin and minutely contorted argillaceous beds in certain localities, as, for example, in the Little Billy quarry, Texada Island. Whether or not the pyrite has been introduced or is part of the original sediment is not known.

CLASTIC DYKES

Clastic dykes occur in many of the limestone deposits but are of minor importance except in the uppermost few feet of bedrock. These clastic dykes usually consist of fractures and solution fissures filled with cream-coloured sand and gravel washed from the overlying glacial drift. A few dykes in the northern part of Texada Island are filled with a characteristic green sand and gravel, clearly derived from the greenstone intrusions cutting the limestone in their vicinity. Since the latter dykes contain no material of glacial origin, it is possible that they are of pre-Glacial age.

WEATHERING OF CALCAREOUS DEPOSITS

In unglaciated areas, limestone is commonly covered by a layer of residual soil made up of insoluble matter from decayed limestone. All the limestone deposits of southwestern British Columbia have, however, been glaciated, and any such residual soil which may have been developed prior to the ice age has been stripped away. These deposits are either bare or covered by glacial and fluvioglacial debris transported from adjacent areas and usually containing only small amounts of calcium carbonate. Probably the surface layer of limestone affected by post-Glacial weathering and solution is no more than a few inches thick, except in the vicinity of running water, along wave-swept shores, and in fractured zones.

MINERALOGICAL COMPOSITION OF LIMESTONES AND THEIR COMMON IMPURITIES

Calcite and Dolomite.—As indicated earlier, calcite and dolomite are the two essential constituents of limestone. In all but the highest-grade calcium-rich limestones within the area studied the mineral dolomite has been recognized and is present in amounts approximately sufficient to account for the magnesia content indicated by chemical analysis. Calcite and dolomite are similar in many respects. Calcite has a hardness of 3, dolomite a hardness of 3.5. Calcite has a specific gravity of 2.71 to 2.72, dolomite a specific gravity of 2.8 to 2.9. Both minerals possess rhombohedral cleavage. Their optical properties are similar. In some respects, however, the minerals are markedly different. Calcite dissolves readily in cold dilute acid with vigorous effervescence; dolomite is relatively insoluble. The rate of reaction of dolomite with other reagents is likewise much slower than that of calcite. Calcite recrystallizes much more readily than dolomite, hence with an equivalent degree of metamorphism high-calcium limestone gives rise to a much coarser-grained rock than does dolomitic limestone. Dolomite tends to assume its typical crystal form, the rhombohedron, at the expense of calcite which, therefore, in magnesium limestone, occupies the interstices between dolomite grains.

Silica-bearing Minerals.—Silica may occur in limestone in the form of grains of quartz deposited with the original sediment and of nodules and streaks of flint or chert introduced during, or slightly after, deposition of the sediment. Within the limestones of the area no veins of hydrothermal quartz in contact with limestone are known. Any such hydrothermal silica presumably enters into combination with the limestone to produce lime silicates. Silica may also exist in limestone in combination with other substances, as, for example, in clay minerals and feldspar grains, etc., accumulated in the original sediment, formed subsequently by the reconstitution of these original impurities or introduced long after deposition. The distribution of silica-bearing minerals may, therefore, be concordant with the stratification or may be completely independent of stratification. Most of the silica-bearing minerals are insoluble in nitric, sulphuric, or hydrochloric acids, and these, together with the silica contents of the few partially soluble silicates and such non-silicate minerals as carbon, are reported in the analyses quoted in this bulletin as " insoluble matter."

Iron-bearing Minerals.—Iron may exist in limestone in the form of: carbonates—siderite, $FeCO_3$; and ankerite, $Ca(Mg, Fe)(CO_3)_2$: sulphides—pyrite, FeS_2, chalcopyrite, $CuFeS_2$; etc.: oxides—hematite, Fe_2O_3; limonite, $Fe_2O_3.nH_2O$; magnetite, Fe_3O_4: and silicates—olivine, $(Fe, Mg)_2SiO_4$; chlorite; garnet; etc. Some of these minerals were original, some were formed by recombination, and some were subsequently introduced. Iron-bearing impurity in limestone may, therefore, be distributed more or less concordantly with the stratification of the limestone or may be totally independent of it. In the chemical analyses given in this report, the Fe_2O_3 reported is the total iron in the sample, calculated to Fe_2O_3. The total iron may exist in acid-soluble minerals and in acid-insoluble minerals. If some of the iron is in acid-insoluble minerals, then it will also be included with the acid-insoluble matter, quoted in this report as " Insol."

Alumina-bearing Minerals.—Argillaceous limestones are rich in alumina, as are also some tuffaceous limestone. The alumina-bearing minerals present in limestone include clay minerals, micas, feldspars, garnets, etc., and being essentially a part of the original deposit tend to be distributed more or less uniformly in any bed. In the chemical analyses quoted, alumina, along with titania and manganese oxide, is included in " R_2O_3."

Sulphur.—Either as an original or an introduced constitutent of limestone, sulphur may occur in the form of metallic sulphides, notably pyrite, chalcopyrite, etc., as hydrogen sulphide occluded within the rock and, possibly, as sulphates.

Carbon.—The carbon, which was presumably derived from organic matter entombed during sedimentation, contributes to the limestone its dark colour. As little as 0.1 per cent elemental carbon is sufficient to give limestone a black colour. In some foliated limestone found on Texada Island, carbon tends to segregate into bands.

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CHAPTER II.—QUARRYING AND PROCESSING

GENERAL PROCEDURE

Most of the limestone in southwestern British Columbia is obtained from shelf quarries opened in hillsides. In these quarries there are no problems of drainage, hoisting, etc. Where, for various reasons, the horizontal extent of a quarry but not its depth is limited, the deposit may be worked by a pit quarry, as at Blubber Bay. Glory-holes, funnel-shaped pits from which broken limestone is drawn through chutes and loaded underground into cars and trammed to the surface, have been worked at Blubber Bay and Bamberton. In this method the need for power-shovels is eliminated but the problems arising when large blocks plug the loading-chutes offset this advantage. No glory-hole has been operated since about 1932. No attempt has been made in British Columbia at large-scale underground mining of limestone.

The limestone deposits in this area are worked, as a rule, in one or more benches each with a vertical or steeply sloping working-face. These faces may be from a few feet to 150 feet in height, and from a few tens of feet to about 1,000 feet long. Holes are drilled into the bench by drills generally set up on the quarry floor at the base of the working-face and on the level above this face. The drill-holes are generally arranged in a definite pattern, comprising horizontal "lifters" drilled at the level of the quarry floor, "breast-holes" started on the face a few feet above the quarry floor and commonly inclined at a low angle upwards, and "down holes" drilled vertically downwards from the top of the bench from a few feet to as much as 35 feet behind the quarry face. In some of the quarries no standard drilling round is adopted, but drills are set up on the floor, face, or top of the bench, wherever convenient, and a round is improvised to meet the local circumstances. The former method, being systematic, is simpler and more economical, but is less adaptable to irregularities in the ground surface, to variations in the character of the rock, etc. Percussion drills powered by compressed air are used in most of the smaller quarries; "wagon drills," large compressed-air drills on wheeled mountings, are used in most of the larger quarries; and well or churn drills are used only in the largest quarries and only for "down" holes. When the drilling of a round of holes is completed, they are loaded with dynamite, all the charges detonated simultaneously, or nearly so, and a few tons to several hundred thousand tons of limestone broken in a single "primary blast."

After the primary blasting, any loose rock is barred or blasted down from the face to prevent subsequent rock-falls which could be hazardous to workmen on the quarry floor. Larger blocks which have come to rest on the floor may be broken by sledging or by secondary blasting, the latter either by mudcapping (bulldozing) or plug-holing (block-holing), to facilitate handling. The broken limestone is then loaded into trucks by power-shovels.

Limestone is generally crushed and sized before shipment. In some cases large blocks, weighing approximately 100 pounds, are sorted out by hand and shipped directly as "man rock." Commonly, however, the broken rock is passed across a grizzly to eliminate fines. The oversize may then be broken by means of gyratory and jaw crushers. Ground limestone, generally handled in a dry state, except in cement manufacture, is commonly pulverized in a hammer mill, or, less often, in a ring-roll or in a ball mill. In many cases the grain size of the ground limestone is determined by the spacing of the mesh bars in a hammer mill, or in other cases it may be sized in a revolving or vibrating screen. The limestone may be distributed in bulk, as is generally the case with the coarser products, or in paper sacks, as is the case with the finer products.

INFLUENCE OF IMPURE BEDS AND IGNEOUS BODIES ON QUARRYING AND PROCESSING OF LIMESTONE

Where, because of the presence of impure beds or of igneous bodies, only a part of a limestone deposit is of a desired grade, some modification of the procedure of extraction and processing is necessary. In one method a segregation is made before quarrying and only the purer beds free from igneous bodies are quarried; in a second method pure limestone and impurities are quarried separately, the segregation being made during the course of quarrying; and in a third method the entire deposit is quarried and the impurities subsequently segregated.

If only beds of a desired grade are quarried, it may be necessary to open in the deposit one or more partly or completely isolated quarries whose size and economy of operation depend firstly on the thickness of beds which can be quarried as a unit to obtain the desired grade, secondly on the inclination of these beds, and thirdly on their freedom from igneous bodies. The width of strata on a horizontal bedrock surface—that is, the width in plan—depends upon the thickness of the strata and their inclination. In selective quarrying, this plan-width of the purer beds of limestone, or of that portion of the purer beds which can be exposed economically by removing overburden, limits the width of the quarry at the bedrock surface. Also, since a certain slope to the quarry walls must be maintained for the sake of safety, the width of the quarry tends to diminish at depth even if a footwall of impure rock is not encountered. The amount of limestone that can profitably be extracted by this method of quarrying may, therefore, be much less than the amount present in the deposit. Therefore, where the purer beds are relatively thin or igneous bodies are common, the size of the quarries might be so small that their cost of operation would be prohibitive.

In the second method, in which high-grade limestone and impurities are quarried separately, several alternative procedures are possible. Limestone, for example, may be quarried up to its contact with a steeply dipping dyke, the face then cleared, the dyke blasted down and removed to the waste dump, and the quarrying of limestone beyond the dyke resumed. Again, where beds are flat-lying, it may be possible to quarry impure beds in separate benches and in this way segregate high- and low-grade rock. By the first method, selective quarrying of a high-grade bed overlain by an impure bed or an igneous body is possible for only a short distance down the dip before the danger of collapse of the overhanging wall becomes imminent. In this case the second method of quarrying is adopted wherever the cost of removing the overhanging material is justified by the value of the additional high-grade rock made accessible. As a result of these and similar variations of the second method, larger quarries can be obtained than by the first method, but at the expense of handling a greater amount of waste rock.

In the third method high-grade limestone and impurities are quarried together and subsequently segregated. During the course of quarrying, a small amount of impure material, whether low-grade limestone or igneous rock, etc., tends to become mixed with a considerably greater amount of the higher-grade limestone. A steeply dipping dyke trending at right angles to the quarry face, for example, is distributed through and thus contaminates a volume of broken limestone out of all proportion to the size of the dyke. It may, nevertheless, be possible to segregate contaminating rock during loading and to discard it or to dispose of it as low-grade limestone. Where loading of broken limestone is carried on by hand, it is readily possible to sort out at least the larger blocks of dyke rock. Impure limestone can also be segregated during quarrying and loading, although less readily than the easily distinguishable igneous rocks. In a few places, notably in the Lehigh Valley of Pennsylvania, the grade of limestone after it has been ground is improved by a process of selective flotation, but no such method has been adopted in British Columbia.

INFLUENCE OF OVERBURDEN AND SURFACE LIMESTONE ON QUARRYING AND PROCESSING OF LIMESTONE

Overburden—gravel, sand, silt, clay, and glacial till—if mixed with broken limestone during quarrying contaminates it as do impure limestones and igneous rocks. It is customary to remove overburden by stripping prior to quarrying, much as, for example, a cover of impure limestone might be removed in an upper bench to expose underlying high-grade limestone, but whereas impure rock might have a sale value as low-grade limestone, overburden has generally no such value. The expense of removing and disposing of the overburden covering a given area is justified only if marketable limestone of sufficient value is exposed by the stripping.

Open solution cracks, common in the upper few feet of the limestone deposits, not only add difficulties to drilling and blasting but are apt to contain considerable amounts of unconsolidated material which contaminate the quarried product. This surface limestone must, nevertheless, be removed to make accessible the underlying more readily quarried and less contaminated rock.

The unconsolidated material, occurring as a thin mantle of drift, as a residue from stripping operations, or as the filling of solution cracks near the surface, can be segregated from the broken limestone either by grizzlies, screens, or hand-sorting.

INFLUENCE OF TOPOGRAPHY ON QUARRYING

Topography has a marked influence on both the type of quarry developed for the extraction of limestone and on the initial cost of development.

Where the limestone is exposed on a horizontal land surface, it can be extracted only by a pit quarry; where exposed on a sloping surface, it can be extracted by a shelf quarry in which problems of hoisting and drainage can be eliminated; where, however, the limestone is exposed on a steep or precipitous mountainside, this advantage is offset not only by the hazardous and inefficient height of quarryface that is obtained as the face is advanced only a short distance, but also by the danger of rock-falls from the slopes above the quarry.

As considerable expense may be involved in opening a quarry, a limestone deposit whose original surface approximates the form of the developed quarry is desired. In such a case a minimum volume of excavation or of filling is necessary to establish a flat floor on which mechanical equipment can be operated, and after a minimum of drilling and blasting, a face on which systematic quarrying can be conducted is developed. If, moreover, the surface in advance of the quarry face is flat, a constant height of face can be maintained and a uniform and systematic quarrying procedure carried on. A bluff or cliff, of the height of the proposed quarry face, rising from a flat base to a flat top, is therefore preferred, because it requires a minimum cost of development before a normal quarrying procedure can be established.

TRANSPORTATION

Limestone may be hauled from quarry to processing plant or shipping point by means of trucks, narrow- or full-gauge railways, or aerial tramways. In general such hauls are short and relatively inexpensive. From processing plant or shipping plant to the ultimate market, limestone and limestone products are transported by truck at relatively high costs per ton mile, by rail at considerably lower costs per ton mile, or by barge at somewhat less cost again. As many of the hauls by rail and barge, however, exceed 100 miles, costs of transportation may approach the costs of quarrying and processing, and add considerably to the final price of the limestone. This relatively high cost of transportation permits economical operation of smaller higher-cost quarries serving local markets, in competition with larger lower-cost but more remote quarries. Cement plants are generally established close to sources of limestone, and the cost of transportation to the ultimate market is borne by the higher-priced finished products. Sources of other raw materials, labour, and power, however, commonly determine the site of other lime- and limestone-consuming industries.

MARKETING

Sales of limestone and limestone products are generally arranged either by an agent or by direct negotiation between producer and consumer. Prices and specifications are established by individual contract. In view of the wide variations in specifications and in amounts of limestone, etc., purchased by various consumers the prices at shipping points vary markedly, and with the great variations in the distance and means of transportation prices at the point of consumption have still wider ranges.

Canada and the United States impose duties on imports of limestone in certain forms and on imports of some products derived from limestone.

USES AND SPECIFICATIONS FOR LIMESTONE

BUILDING INDUSTRY

Portland Cement

Large quantities of limestone are used annually in the production of Portland cement. In the manufacture of this product a wet-pulp or "slurry," consisting of about 75 per cent calcium carbonate, 10 to 17½ per cent silica, 2½ to 10 per cent combined ferric oxide and alumina, and not over 5 per cent combined magnesia and alkalis, is burned in a rotary kiln and the resulting clinker is ground in a dry condition. Specifications of cements used for different purposes vary markedly, hence the kiln feed may differ somewhat from that given above. The mix is made up of limestone, siliceous material (quartz, sand, siliceous limestone or acid igneous rocks), and aluminous material (clay, shale or argillaceous limestone), in proportions which give the desired composition of kiln feed. Calcium-rich limestone, or somewhat impure argillaceous or siliceous limestone may, therefore, all be used in the manufacture of cement, but magnesian and dolomitic limestones are not suitable.

One cement plant is operating in British Columbia at Bamberton on Vancouver Island and one is being built near Vancouver.

The British Columbia Cement Company Limited, of Victoria, operates a cement plant that produces 2¼ million barrels (350 pounds per barrel) of cement per year, at Bamberton, on Saanich Inlet. Limestone for the cement is obtained from a quarry adjacent to the plant and from company quarries at Cobble Hill and Blubber Bay on Texada Island. Greenstone, intimately associated with the limestone in the Bamberton quarry, is used to supply the necessary silica, iron, and alumina.

This company was founded in 1918 by the amalgamation of the Associated Cement Company (Canada) Limited, with its Bamberton plant, and the Vancouver Portland Cement Company, with a plant at Tod Inlet. The latter part is now largely dismantled.

Builders' Lime

Lime is widely used in plaster, mortar, and whitewash, for which purposes it must satisfy certain specifications, notably as to grain size, rate of settling, soundness, plasticity, and colour. Such properties in lime are determined in part by the chemical composition, in part by the physical character of the limestone from which it is made, and in part by the conditions in processing. Limestone containing more than about 1 per cent iron oxide (FeO) and about 0.03 per cent manganese oxide (MnO) produces a lime having an undesirable buff to brown colour. Limestone containing more than 1 per cent magnesia gives trouble in burning, and the resulting lime plaster tends to blister or "pop." Physical characters of the limestone not only determine the ease or difficulty of burning, but may also affect other properties. The conditions of processing determine or affect final grain size, rate of settling from a suspension, etc. It is not, in general, possible to determine merely from examination of a given limestone sample and from its chemical analysis whether it would be suitable for builders' lime. Burning tests, preferably in a model or full-scale kiln, and laboratory or field tests of the resulting lime are essential in indicating the value of a new limestone deposit for this product.

In British Columbia one company, Gypsum Lime and Alabastine, Canada, Limited (Pacific Lime Division), makes lime. The company has a quarry and processing plant at Blubber Bay, Texada Island, and a plant in Vancouver.

Building-stone

A very limited amount of limestone and marble has been quarried in the Georgia Strait area for use as a building and ornamental stone. The reddish crinoidal limestone of Anderson Bay was for a time quarried by the Continental Marble Company and by A. Henderson, of Nanaimo, but no activity is known to have taken place in this area since 1916. The first quarry on Texada Island, on the north shore of Sturt Bay, was operated for a test shipment of ornamental stone by Captain Sturt, prior to 1886. No further shipments are known to have been made from this quarry.

The excessive jointing of the limestone and marble deposits, together with the limited local demand for building and ornamental stone, is apparently responsible for the absence of this industry in British Columbia.

AGRICULTURE

In inadequately drained, water-logged soils, the presence of carbonic acid and of organic acids formed by the accumulation and decomposition of vegetable matter gives rise to " sour " land. Where the rate of removal of soluble lime salts from the soil by cropping, and especially by the leaching effect of rain-water in excessively drained land, exceeds the rate of replacement of these salts by the weathering of insoluble calcium minerals, deficiency of available calcium ultimately results and soil acidity is apt to follow. Acid soils of both these origins are found in southwestern British Columbia, and the low, poorly drained, fine-grained Recent alluvial sediment brought down by such rivers as the Fraser is particularly apt to become acid. On extremely acid soils but few plants, notably peat-moss and blueberry, find their optimum conditions; most plants grow but do not give their maximum yields, and some plants, notably the legumes, do not grow satisfactorily at all. The application of burned lime, hydrated lime, or ground limestone to the soil corrects acidity and may effect an increased production in many, but not all, crops.

It will be understood that the necessity and amount of liming of soils varies not only with the character of the soils themselves, but also with the nature of the crops to be grown on them. Liming of soils does not, in general, give rise to an enormous increase in crop yields, as may the use of certain fertilizers. In some cases an improvement in soil texture may be the only appreciable benefit. In still other cases the improvements, if any, may be so limited as to fail to justify the cost of liming. The soil scientists in southwestern British Columbia have not yet carried on sufficient experimentation to determine quantitatively how beneficial liming may be, and are, therefore, unable to voice a unanimous opinion on the merits of liming in certain of the common soil series. The need for lime or limestone in the lowland clay soils of the area, notably the Ladner series of the Fraser Delta, however, seems unquestioned.

Hydrated lime, ground limestone, and marl are all suitable for liming soils. Burned lime (quicklime), which is difficult to handle, is not used for this purpose. Hydrated lime has the advantage of having a greater lime content (up to 76 per cent) and of bringing about a quicker response in soils than ground limestone (lime content up to 56 per cent). Ground limestone, on the other hand, produces no detrimental effects in case of an excessive application, as does burned and hydrated lime, and its influence may be prolonged over a period of years as the larger particles of limestone slowly dissolve. Marl is comparable in its effects to ground limestone.

The active ingredient, lime, in agricultural limestone products varies from about 76 per cent in pure hydrate to less than 25 per cent in some air-dried marl. Ground high-calcium limestone may contain 56 per cent lime. Most impurities in the limestone —moisture, silica, iron, etc.—are inert; they neither contribute to its effects nor actively detract from them. They do, however, dilute the active ingredient and necessitate the use of a greater weight of product in obtaining a given effect on the soil. A few constituents, notably nitrogen and organic matter in marl and phosphorus in limestone, may be beneficial, but they are generally present in minor amounts. The price for lime, hydrate, ground limestone, and marl is, therefore, based on the lime content, plus cost of packaging, transportation, etc.

Since 1943 the Provincial Government has paid a subsidy to British Columbia farmers using lime or lime products for soil amendment purposes. Since October 1st, 1956, the basis for payment has been as follows:—

(*a*) Ground limestone and comparable products must be ground to a fineness that permits 100 per cent to pass through a screen with 10 meshes per linear inch, and at least 30 per cent through a screen with 100 meshes per linear inch.

(1) Ground limestone analysing 80 per cent or over calcium carbonate or its equivalent in neutralizing value shall be allowed a subsidy of $3 per ton.

(2) Ground limestone analysing 70 to 80 per cent calcium carbonate or its equivalent in neutralizing value shall be allowed a subsidy of $2.50 per ton.

(*b*) Hydrated lime having a minimum content of 85 per cent of calcium hydrate or its equivalent and of a fineness of texture comparable to the standard set in (*a*) above shall be entitled to a subsidy of $3 per ton.

(*c*) Dry marl having a minimum content of 75 per cent calcium carbonate or its equivalent and of a fineness acceptable to the British Columbia Lime Committee and having less than 20 per cent moisture will be entitled to a subsidy of $3 per ton.

(*d*) Marl analysing below 75 per cent calcium carbonate or its equivalent or wet marl (i.e., marl with 20 per cent or more moisture content) will be entitled to a subsidy payable at the discretion of the Committee and on the basis of samples submitted.

The maximum amount of subsidy payable to one purchaser in one year to be on 100 tons.

Some limestone products, notably hydrated lime, are used in the preparation of many plant sprays, insecticides, and fungicides. Hydrate free from grit, which might give rise to undue wear in the spray pumps, is desired for this purpose. Lime is also used as the base for certain chemical fertilizers.

Small amounts of limestone, shell, granite, and gravel, crushed to about 5 to 10 mesh, are used as poultry grit. Ground limestone is also used to a limited extent in supplying calcium requirements for poultry and other farm stock.

METALLURGY

Limestone and lime are used by metallurgical plants, chiefly as a flux in smelting. The Tacoma copper smelter and the basic open hearth at the Seattle plant of the Bethlehem Steel Company consume the largest amounts. Impurities normally occurring in limestone are not actively detrimental in flux but merely dilute the active ingredient. The value of the lime or limestone is, therefore, based on the lime content of the product.

Smaller amounts of lime are used in the cyanidation of gold ores and in concentrating ores by flotation.

PULP AND PAPER INDUSTRY

Limestone and lime are widely used in the pulp and paper industry in the preparation of cooking-liquors for the extraction of lignins from wood and also in the preparation of solutions for bleaching pulp.

Much of the pulp in the coastal area is produced by the acid-sulphite process in which limestone, or lime, is commonly used. Cooking-liquor for this process is made from limestone in two ways, by the tower method or by the milk-of-lime method. About 300 pounds of limestone is consumed for every ton of pulp produced by the sulphite process.

In the tower method for producing cooking-liquor, limestone, in lumps greater than 5 or 6 inches in diameter, is treated in towers with a falling current of water and a counter-current of sulphur dioxide gas. The product of the tower is a solution consisting of sulphurous acid, formed by the combination of water and sulphur dioxide, together with calcium bisulphite formed by the reaction of some of the sulphurous acid with the limestone. Insoluble residue from the limestone settles from the solution and is removed periodically, but carbon, mica, and pyrite are apt to float off with the liquor and contaminate the pulp. Magnesian limestone dissolves slowly, and if present in large amounts not only may reduce the output of the towers, but also may form a spongy residue which crumbles and tends to choke the flow of the sulphur dioxide. Operators, therefore, desire a limestone containing not more than about 4 per cent magnesia.

In the milk-of-lime process for producing cooking-liquors, sulphur dioxide is passed through an aqueous suspension of lime, of either the high-calcium or, preferably, the high-magnesium variety. Insoluble matter, carbon, mica, and pyrite are, as in the tower method, objectionable.

In the Kraft or sulphate process for the manufacture of pulp, wood is digested in an alkaline or " caustic " cooking-liquor. After digestion the cooking-liquor is separated from the pulp, evaporated, sodium sulphate is added, and the mixture burned to eliminate organic matter. The residue is leached with water, then causticized with lime, and after the sludge has been removed the alkaline cooking-liquor is left. In some places the sludge from the causticization stage has been burned to recover its lime content.

Bleaching solution for pulp is made from high-calcium lime and liquid chlorine. For this purpose the lime must have a low magnesia and iron content, and insoluble matter and unburned carbonate should be at a minimum. The lime, moreover, must be capable of both absorbing chlorine rapidly and of settling rapidly from a suspension.

MISCELLANEOUS

Other uses for limestone or lime in southwestern British Columbia are in refining of sugar, in tanning of hides, in the manufacture of bleaching powders and solutions for domestic use, and for stucco dash and terrazo chips, etc.

Dolomite is used as the source of magnesium metal (thermal ferrosilicon process), and dead-burned dolomite is used as a refractory, notably in basic open-hearth steel furnaces. Neither production of magnesium metal nor open-hearth steel-making is done in British Columbia at this date.

CHAPTER III.—EXAMINATION OF CALCAREOUS DEPOSITS

GENERAL

Three factors are considered to be of prime importance in the evaluation of a limestone deposit—size, grade, and accessibility to markets.

Although estimation of the total tonnage of a deposit may be possible in some cases, it may be impossible to determine the proportion of the deposit that is economically recoverable. Existing information may be inadequate, for example, to permit determination of the area from which overburden and impure rock can be removed economically to expose high-grade limestone. The scale and method of quarrying can, moreover, have a marked influence on the amount of material that may be recovered from a deposit; hence in the case of an undeveloped deposit the estimation of quantity of available limestone is doubly difficult. However, to aid in a preliminary assessment of the size of deposits described in Chapter V, the writers have noted, where possible, the outcrop length and the width or, if determined, the stratigraphic thickness and attitude, together with information on the presence of igneous rocks and on the thickness of overburden.

The grade of limestone that can be produced may be difficult to determine, especially in the case of undeveloped deposits. This is particularly true in the case of a large limestone body made up of interbedded high- and low-grade strata, where either the high-grade strata alone might be selectively quarried or the entire deposit quarried on a large scale to obtain a lower-grade product. A deposit might, moreover, be quarried by such a method that included igneous rocks could be eliminated from the final product or by such a method that these rocks would be left in the product.

In view of the significance of transportation in determining the cost to a consumer of a limestone product, accessibility of a deposit to its markets is of prime importance. Cost of transportation from a deposit to market is determined not only by the distance, means of transport, etc., but also by the volume of material handled, and is hence subject to considerable variation. Cost of transportation may be difficult to assess in the case of undeveloped deposits where the initial cost and cost of maintenance and depreciation of any transportation facilities that may have to be installed, and the amount of material to be handled, etc., are uncertain.

Other factors, in addition to the three given above, which may be of importance in the evaluation of a limestone deposit include availability to supplies of water, power, and fuel, accommodation for labour, topography, climate, etc.

The final evaluation of any deposit is beyond the scope of the survey on which this publication is based. The writers have, however, attempted to include in the descriptions of individual deposits what they regard as considerations of economic importance, but have avoided presenting estimates of tonnage and costs, both of which might subsequently prove to be misleading. Analyses of samples taken during the course of the survey are included, together with a note on the method of sampling followed in each case and whether igneous rocks, etc., had been excluded in sampling. It should be recognized that these analyses at best only approximate the grade of limestone that is being or can be produced from any deposit.

The principles of the field mapping of mineral deposits are widely known, but the recognition in the field of magnesian and calcium-rich limestone, and the principles of sampling, are less generally understood, in spite of their economic importance. The following notes which may be of assistance in future studies of limestone deposits are, therefore, included.

Moreover, as methods of chemical analyses may vary, notes by the Chief Assayer and Analyst of the British Columbia Department of Mines on the procedures used in the analyses quoted in this report have also been included.

FIELD RECOGNITION OF CALCIUM- AND MAGNESIUM-RICH-LIMESTONE

If it is possible in the field to recognize calcite and dolomite, the two essential minerals in limestone, and to determine the amounts of each, it becomes possible to estimate the chemical composition of the rock. Such estimates can be very useful, not only in prospecting for a limestone deposit of suitable grade, but also in making preliminary assessments of the size and attitude of such a deposit. After considerable experience with comparisons of specimens and analyses, it may be possible to make these determinations with the unaided eye. The minerals can, however, be made more conspicuous by chemical tests and the estimates made more reliable. A comparison of the physical characteristics of calcite and dolomite and a description of two of the most useful field tests are given below.

(1) *Acid Etch.*—A common test for calcite and calcium-rich limestone is the application of cold dilute acid, commonly 1:5 hydrochloric acid. Calcite and calcium-rich limestone effervesce vigorously in such acid, whereas dolomite reacts feebly. This test, however, is in itself unsatisfactory since a small amount of calcite disseminated through magnesian limestone can give rise to an effervescence but little less vigorous than that of high-calcium limestone. If, however, a specimen of the limestone to be tested is immersed in the cold dilute acid for a period of from one-half to one minute, then rinsed and dried, a characteristic texture is produced. Calcite and high-calcium limestone in this test develop a smooth glazed surface resembling that of vein-quartz or paraffin; insoluble minerals, including dolomite, which is almost unaffected by this treatment, retain the texture of the original surface and stand up in relief above the calcite (after Goudge, M. F., 1940, p. 484).

(2) *Ferric Chloride—Ammonium Polysulphide Etch.*—A cold saturated solution of ferric chloride in water reacts with calcite within one-half to one minute to produce a surface film of ferric carbonate. If calcite so treated is rinsed in water to remove excess ferric chloride and immersed in a solution of ammonium polysulphide, the reaction with the ferric carbonate film gives rise to a conspicuous black coating of ferric sulphide in the calcite. Dolomite remains almost unaffected, but longer immersion in ferric chloride permits the development of a weak ferric sulphide stain. Insoluble matter, silica, etc., do not respond to this test no matter how long they are immersed in ferric chloride. On drying, the ferric sulphide stain reverts to brown ferric carbonate (after Holmes, A., 1930, pp. 264, 265).

Other similar tests, most of them less applicable for field use, are given in standard texts on petrography (*see* Holmes, A., 1930, pp. 265–268). It should be emphasized that calcite, and the rarer calcium carbonate mineral aragonite, respond to the tests outlined above, but except with a prolonged etch, dolomite does not respond and cannot generally be distinguished from more completely insoluble minerals. Other characteristics, notably hardness, are necessary in determining the presence of dolomite.

Pure calcite consists of 56.1 per cent lime (CaO) (100 per cent $CaCO_3$), pure dolomite of 30.4 per cent lime (54.3 per cent $CaCO_3$) and 21.9 per cent magnesia (MgO) (45.7 per cent $MgCO_3$). A limestone composed, for example, of about 90 per cent calcite and 10 per cent dolomite, as indicated by tests and physical characteristics, would contain about 2.2 per cent magnesia (4.6 per cent $MgCO_3$); a limestone composed of about 10 per cent calcite and 90 per cent dolomite would contain about 19.7 per cent magnesia (41.2 per cent $MgCO_3$).

The character of the weathered surface also serves to distinguish calcium-rich and magnesium-rich limestone. The period of post-Glacial weathering has been sufficiently long in British Columbia to permit the development on limestone of an etched surface somewhat similar, though on a much larger scale, to that obtained by immersion in acid. The weathered surface of a calcium-rich limestone presents a smooth outline, although, in the case of marble, rapid weathering along crystal boundaries, cleavage, etc., may give a minutely roughened texture. Joints in calcium-rich limestone are generally widely gaping. Small caves and pot-holes, usually a few inches wide, are common. Dolomite grains and veinlets generally, but not invariably, stand up on the limestone surface in marked relief, as does silica and other insoluble material. Dolomitic limestone, on the other hand, is much more resistant to weathering and its surface commonly presents a more or less angular outline. Joints and solution cracks developed along calcite veinlets are deep and narrow, little if at all gaping. The outcrop, therefore, commonly presents a deeply but finely scored appearance brought about by numerous intersecting cracks. Silica and other insoluble material stand up above the dolomite surface, though with little relief.

On recrystallization high-calcium limestone becomes marble. Any silica present or introduced may combine with the calcite to form white needles and fibres of wollastonite or tremolite disseminated through the marble. Dolomitic limestone, on the other hand, is less susceptible to recrystallization but apparently more susceptible to brecciation. Any silica present or introduced may combine with dolomite and other impurities to form olivine, serpentine, chlorite, or diopside—all minerals tending to be yellow or green in colour. A yellow colour is also common but not diagnostic of dolomitic limestone which has not recrystallized. Dolomitic limestone likewise tends to be slightly harder and have a slightly higher specific gravity than calcium-rich limestone.

SAMPLING

If a limestone deposit were of uniform composition throughout, a single chip would be a representative sample of the entire deposit. Very rarely, however, is limestone of uniform composition across more than a few feet of beds. As described previously, a limestone deposit is composed of successive layers or strata of different composition. A sample may be representative only of a particular stratum. Studies, moreover, show that neither the thickness nor the composition of any stratum is constant over its entire extent, but both tend to change gradually from place to place (*see* Fig. 2, and table, p. 59). Thus a sample of one stratum is representative only of that part of the stratum which is close to the point sampled.

A sample consisting of a single chip taken at random is almost certain not to be representative of a succession of limestone beds. In the case of the Limekiln Bay quarry, for example, only two beds, one of argillite and an underlying bed of orange-weathering magnesian limestone, would have been readily distinguishable at the time of quarrying. Any single 6-inch piece taken at random from an apparently uniform succession above the argillite bed could contain from less than 0.58 to 13 per cent magnesia, depending on which bed was sampled. Since, however, only 7 feet out of the 28.2 feet exposed at the north end of the quarry and only 4 feet out of 29.7 feet exposed at the south end of the quarry are composed of magnesian limestone, the odds are against the selection of magnesium rock in a single grab sample and favour selection of a rock of somewhat higher grade than the average of the entire succession. In other cases, where impure beds predominate in the succession, the odds are in favour of a single grab sample containing more than the average content of impurities.

The size of a grab sample is significant. In the case of the Limekiln Bay quarry, a minute sample of the size of a single crystal in the limestone might consist either of a grain of dolomite containing more than 20 per cent magnesia or a grain of calcite containing almost no magnesia. A sample the thickness of a single dolomitic lamina might likewise be composed almost entirely of either dolomite or calcite. On the other hand, no sample consisting of, say, a 5-foot cube could contain more than 6.2 nor less

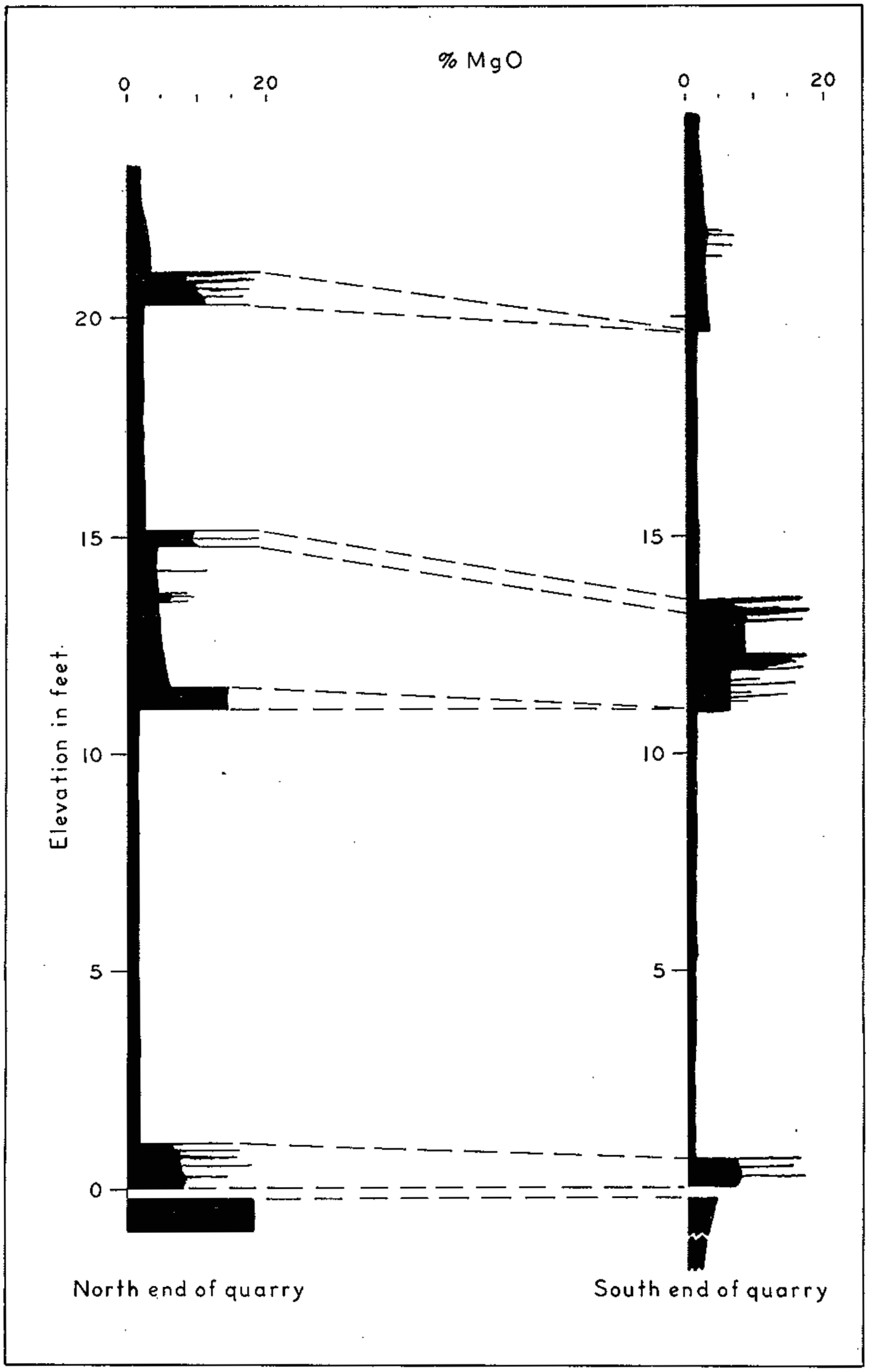

Figure 2. Distribution of magnesia in strata, Limekiln Bay quarry.

than about 0.58 per cent magnesia, and the odds are that it would contain much closer to the average amount, about 2.08 per cent magnesia, of the entire succession above the argillite bed.

A fully representative sample of a succession of strata can be obtained in two ways: (1) By sampling the individual beds and computing the average of the succession, weighting each analysis according to the thickness of limestone it represents, or (2) by collecting across the full width of beds to be sampled the limestone chips cut by hand *from a continuous channel of uniform depth and width, or the core from a diamond-drill* hole of uniform diameter, or the dust and cuttings from an air- or churn-drilled hole, likewise of uniform diameter. It may be advantageous but is by no means necessary that the sample should be cut along a line at right angles to the strata, and in some cases it may be necessary to sample along a line cutting obliquely across the stratification, in which case, however, the stratigraphic thickness of the beds sampled is not the length of the line sampled.

An approximate sample can be made up from a series of chips of uniform size taken at regular intervals across the succession. Such samples can be obtained much more cheaply and readily than can continuous channel or drill samples, especially in the case of surface sampling of partly drift-covered areas in undeveloped deposits. This method, on the other hand, suffers from some of the shortcomings of the grab-sample method inasmuch as the chance inclusion in the sample of one chip from a very thin impure bed could unduly contaminate the sample. In spite of this handicap this method was adopted in obtaining most of the samples analysed for this report.

Samples should be taken along one or more lines cutting directly or obliquely across the bedding. It should be readily apparent that if a series of chips or a channel were taken along a line parallel to the stratification they would be no more representative of a full succession of beds than would a single chip from one bed. In some cases, however, stratification is not apparent, and it is then necessary to assume that bedding is parallel to the length rather than the width of the deposit and then sample accordingly. In some cases the uncertainty of the attitude of the bedding raises doubts as to the amount of limestone represented by the sample and reduces the significance of the analysis.

THE CHEMICAL ANALYSIS OF LIMESTONE

BY G. C. B. CAVE*

Procedures for the technical analysis of limestone are generally available (Hillebrand, 1919, 1953; Mellor and Thompson, 1938; Scott, W. W., 1939). Therefore, in the present notes, procedures currently used in this laboratory, and hence used for the analyses in this bulletin, are only briefly described. The notes will consist chiefly of comments on these procedures, with some attention to sources of error. On request, this laboratory will be pleased to provide detailed procedures of analysis. Many of the analyses reported in this bulletin are "technical"; that is, they are routine analyses suitable for the economic evaluation of deposits. "Refined" analyses are more time-consuming, and are generally made only when the results are to be used for more theoretical studies.

Acid-insoluble Matter.—In this bulletin, acid-insoluble matter is designated as "Insol." This assay is to some extent empirical. The percentage of acid-insoluble matter usually depends on the following factors: Fineness of grinding of the sample, strength and kind of acid or acids used for solution of the sample, the temperature and length of time of digestion of acid and sample. The procedure adopted for results in this bulletin was: To a 0.5-gram sample, 25 ml. of water and 10 ml. of hydrochloric acid (s.g. 1.19) were added and the mixture was then evaporated to dryness on a hot-plate. Reproducible *results were obtained.*

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If the results are to be used for mineralogical studies, a determination of silica rather than of acid-insoluble matter may be required.

R_2O_3.—R_2O_3 in this bulletin* comprises the oxides (ignited), except iron oxide, that are precipitated when the filtrate (oxidized if necessary) from the assay for acid-insoluble matter is made alkaline to methyl red on the addition of ammonium hydroxide. Therefore, it may include oxides of aluminium, titanium, zirconium, beryllium, chromium, quinquavalent phosphorus, quinquavalent arsenic, and quinquavalent vanadium. Any silica left in solution from the assay for acid-insoluble matter would also be precipitated. If insufficient iron, aluminium, etc., is present to combine with the phosphate (or arsenate), the remainder of this anion will be precipitated as a calcium salt, thus introducing a negative error into the calcium assay.

It is important to precipitate R_2O_3 at the proper pH. This pH lies between 6.5 and 7.5 for the complete precipitation of aluminium. At a higher pH the hydrated aluminium oxide is in part dissolved because of its amphoteric nature. Further, sufficient ammonium chloride must be present prior to the precipitation of R_2O_3 by ammonia, especially if magnesium is present. Long-continued boiling of the solution containing the precipitated R_2O_3 and long-continued standing of this precipitate in the mother liquor are prejudicial to good results. A double precipitation of R_2O_3 is advisable if the analysis is to have any degree of refinement. Washing of the R_2O_3 precipitate should be done with a hot 2-per-cent solution of ammonium chloride or ammonium nitrate; pure hot water will peptize the precipitate. The ignition and desiccation of the R_2O_3 precipitate require attention. Ignition to constant weight at over 1,200° C. is required. Ignited alumina, particularly, absorbs water, and should be desiccated for a minimum period of time and then weighed in a covered crucible.

Finally, the ammonium hydroxide solution used to precipitate the R_2O_3 group should be free of carbonate. Otherwise, calcium carbonate would be precipitated along with the R_2O_3.

MnO (Total).—It is the total manganese, not merely the acid-soluble part, that is reported in the present bulletin; to conform with custom, the manganese is reported as the oxide.

To decompose a limestone sample completely, advantage may be taken of the fact that a sintered mass, completely soluble in acid, is obtained on igniting the sample for fifteen minutes at 1,100° C. in a covered platinum crucible. For this procedure the silica present should not exceed 15 per cent and the R_2O_3 plus iron oxide should not exceed 5 per cent. To make this procedure applicable to all cases, especially to siliceous limestones and calcareous marls, this laboratory mixes a 1-gram sample with 0.5 gram of sodium carbonate, and sinters the mixture for twenty minutes at 1,100° centigrade in a covered platinum crucible. The cooled sinter is then dissolved by treating it with 10 ml. of water and 10 ml. of nitric acid (s.g. 1.42). The manganese is then converted to permanganate by the well-known persulphate method. If much iron is present, phosphoric acid is added (it is also then added to the standard solutions). The depth of the permanganate colour is read in a photoelectric colorimeter and the readings converted to per cent manganese oxide by the use of a graph previously set up from prepared standard manganese solutions.

Alternatively (Sandell, 1950), the limestone may be decomposed with diluted sulphuric acid and 48 per cent hydrofluoric acid, in a platinum dish. After evaporating the mixture to fumes of sulphuric acid, the evaporation is repeated after adding a few drops of nitric acid and more diluted sulphuric acid. Soluble salts are then dissolved in water, and any insoluble material is filtered off and normally is discarded. Sulphuric and phosphoric acids are added to the filtrate, which is then divided exactly in half. One half is kept for use as a blank, after being diluted in the same proportion as the other half. This other half is treated with potassium periodate, then heated in a boiling-water bath for twenty minutes. After cooling the solution and suitably diluting it for measurement, its

* *See* page 7 for a further explanation of chemical symbols.

depth of colour is measured against the blank, in a photoelectric colorimeter or in a spectrophotometer at 525 millimicrons.

Persulphate was the oxidant used for all assays reported in Bulletin 23 (1947), and designated in the present revised bulletin as having been submitted by W. H. Mathews. Subsequently it was found that periodate is preferable to persulphate for oxidizing manganese. Consequently the periodate method was adopted for manganese assays, and was used for all samples designated in the present bulletin as having been submitted by J. W. McCammon.

Fe_2O_3 (Total).—It is the total iron, namely, that in both acid-soluble and acid-insoluble minerals, that is reported in this bulletin; to conform with custom, this iron is reported as the oxide. A 1-gram sample is mixed with 0.5 gram of sodium carbonate, and the mass is sintered as in the manganese assay. The sinter is dissolved in diluted hydrochloric acid, and the solution is evaporated to dryness. Soluble salts are then dissolved by adding exactly 1 ml. of hydrochloric acid (s.g. 1.19) and then 20 ml. of water, and heating the mixture. Any silica is filtered, and discarded if small in amount. The filtrate is assayed for iron by an original modification of the salicylate colorimetric method (Snell, 1936; Mehlig, 1938; Scott, R. O., 1941), and the depth of the purple colour is read on a photoelectric colorimeter. Good results have been obtained by this modified salicylate method.

Before applying the salicylate colorimetric method to other kinds of material, the analyst should be sure elements in detrimental amounts are absent; a fairly complete list of these elements is given in the literature (Mehlig, 1938; Scott, 1941). For example, the aluminium content of the final solution should not exceed 10 milligrams per 100 ml. of solution; larger amounts cause a negative error in the iron result. In the analyses for the present bulletin, spectrographic analyses were used to confirm that metals were not present in percentages that would cause interference.

CaO.—The percentages reported in this bulletin are of acid-soluble lime, determined on the filtrate from the R_2O_3 assay. The calcium is precipitated as oxalate from an alkaline solution, the washed precipitate is dissolved, and the oxalic acid is titrated with a standard solution of permanganate. As a voluminous literature exists on this method, comments will be brief. When the percentage of calcium need not be known very exactly, and where the magnesium in the sample is less than 5 per cent, one precipitation of calcium as oxalate will suffice; but the analyst should realize that the calcium oxalate will then be contaminated with alkalis, barium, strontium, magnesium, and manganese. Reprecipitation of the calcium as oxalate will remove the barium if in the low percentages usually found, the alkalis, and not quite all the manganese. Strontium will be quantitatively reprecipitated with the calcium as oxalate. It should be remembered also that calcium oxalate is somewhat soluble in hot water; 100 ml. of water at 95° C. dissolve 1.5 milligrams of calcium oxalate.

There have been objections to the filtration of calcium oxalate through paper, since in the subsequent titration the paper is usually added to the oxalic acid solution being titrated, whereupon the paper reduces a little of the permanganate. To avoid this possible source of error, the precipitated calcium oxalate may be filtered through a Gooch crucible with an asbestos pad, or through a sintered glass crucible.

It is to be noted that very rapid methods have recently become available for the volumetric determination of calcium and magnesium; ethylenediamine tetraacetic acid is the titrant, and Murexide and Eriochrome Black T are the currently used indicators.

MgO.—The percentages reported in this bulletin are of acid-soluble magnesia, determined on the filtrate from the lime assay. For most samples, the gravimetric 8-hydroxyquinoline method was used. However, in the case of a few of the samples, 8-hydroxyquinoline failed to precipitate the magnesium, for an undetermined reason. In such cases, the magnesium was readily precipitated from a new sample, as the phosphate. Instead of igniting and weighing the phosphate precipitate, it was dissolved and the magnesium in it was determined indirectly from the phosphate content, which was determined colorimetrically by the phosphovanadomolybdate method described below.

P_2O_5 (Total).—It is the total phosphorus, not merely the acid-soluble part, that is reported in the present bulletin; to conform with custom, the phosphorus is reported as the pentoxide.

For samples submitted by W. H. Mathews, and reported in Bulletin 23 (1947), the gravimetric phosphomolybdate method was used. For samples submitted by J. W. McCammon, a recently adopted colorimetric method which depends on the colour of phosphovanadomolybdate was used, and is preferred to the gravimetric method.

In the gravimetric phosphomolybdate method, a large sample is treated with nitric acid. The insoluble residue is fused with sodium carbonate, the melt is extracted with nitric acid, the solution is evaporated to dehydrate silica, and the soluble salts are dissolved in nitric acid. The two nitric acid solutions are then combined, ferric chloride is added, and the phosphorus is precipitated as iron phosphate. The iron phosphate is separated by filtration, then is dissolved in diluted nitric acid and the phosphorus is determined gravimetrically by the well-known phosphomolybdate method. Either the phosphomolybdate precipitate is dissolved, reprecipitated, and weighed or else the phosphate is finally precipitated as magnesium ammonium phosphate, ignited to magnesium pyrophosphate, and weighed.

In the gravimetric phosphomolybdate method, a standardized procedure is needed, because the composition of the yellow precipitate depends on such factors as the temperature of the solution when precipitation is made, period of digestion of the precipitate in the solution, concentration of reagents, and the composition of the phosphate-containing solution. The phosphorus must be present as orthophosphate. Substances which, if present in the solution, would contaminate the phosphomolybdate precipitate include quinquavalent vanadium, arsenic, titanium, zirconium, and silicon. Titanium and zirconium may be precipitated as phosphates early in the assay.

In the colorimetric phosphovanadomolybdate method (Brabson, 1944; Racicot, 1951) the sample is treated with diluted perchloric acid, the insoluble residue is fused with sodium carbonate, the melt is extracted with diluted perchloric acid, then the two solutions are combined and evaporated to fumes of perchloric acid in order to dehydrate silica. To the cooled solution, ammonium vanadate solution is added and the resulting solution is filtered. To the cooled filtrate, ammonium molybdate solution is added, the resulting solution is diluted with water to a pre-assigned volume, and let stand for thirty minutes. A sample plus reagent blank is carried through the entire procedure, with only the ammonium molybdate omitted. The depth of colour is measured against the blank, in a photoelectric colorimeter or in a spectrophotometer.

S (Total).—It is the total sulphur, not merely the acid-soluble part, that is reported in the present bulletin. The usual gravimetric method was used. Thus the sample is decomposed with aqua regia, and twice evaporated to dryness with hydrochloric acid. Soluble salts are dissolved in diluted hydrochloric acid and the mixture is filtered. The sulphur in the filtrate is precipitated, and finally weighed as barium sulphate. The acid-insoluble matter is fused with sodium carbonate, the melt is extracted with water, and the mixture is filtered. The filtrate is acidified with hydrochloric acid and evaporated to dryness to dehydrate silica. Soluble salts are dissolved in diluted hydrochloric acid, the silica is filtered off, and the sulphur is precipitated in the filtrate, and finally weighed as barium sulphate.

H_2O.—This symbol in the table of analyses refers to the loss in weight of a sample dried at 105° C.

CHAPTER IV.—STRATIGRAPHY OF SOUTHWESTERN BRITISH COLUMBIA

PALÆOZOIC ROCKS

Palæozoic rocks are widely distributed throughout the western part of the Cascade Range. These rocks are composed for the most part of sheared sediments, including chert, quartzite, schistose argillite, and limestone lenses, together with tuffs, agglomerates, flows, locally pillow lavas, and structureless greenstones. The so-called old metamorphic series is evidently made up of rocks of widely differing ages, for fossils ranging from Ordovician (Smith, W. S., 1916) to Pennsylvanian or Permian (Daly, 1912) have been found in various parts of the area. Because of the extreme complexity in the structure of these rocks and the apparent scarcity of readily recognizable horizons, no attempt has been made on any large scale to subdivide the series. It is evident, however, that Permo-Carboniferous rocks are widely represented, for fossils of this age have been found through the greater part of the Chilliwack group, more than 6,000 feet thick, outcropping along the 49th parallel (Daly, 1912), and other fossils of this age have been found in the area southeast of Granite Falls, Washington (Weaver, 1912). Crinoid stems, made up of stacks of calcite disks up to three-fourths of an inch in diameter, are common in the Chilliwack group and in the Cache Creek group of similar age in the Interior of British Columbia, where stems of this size are not known to occur in the Mesozoic rocks. These stems may, therefore, be considered as strongly suggestive, although not necessarily diagnostic of an Upper Palæozoic age. Such stems in Cascade limestone were reported as early as 1896 (Walcott, pp. 53–55) and have been found in several of the Washington deposits.

The occurrence of Palæozoic rocks on and adjacent to Vancouver Island was first indicated by Richardson, who, in 1872, collected fossils, identified as Permian or Carboniferous, from the limestones of Horne Lake and the Ballenas Islands (Richardson, 1873 and 1874). This identification was later questioned by Clapp (1912, p. 70), who favoured their inclusion in the Triassic. Gunning (1930, p. 59), however, later obtained a full collection of fossils, identified as Permian or Pennsylvanian, from the limestone of the Buttle Lake area. Upper Palæozoic forms were found by Sargent (1941, p. 19) in the area south of Buttle Lake and by Stevenson (1944, p. 144) in an area about 10 miles southeast of Alberni. In the locality southeast of Alberni the fossils were recovered from limestone bodies interbedded with or overlying a complex series including cherts, argillites, and limestone, tuffs, breccias, amygdaloids, pillow lavas, and structureless greenstones of either intrusive or extrusive origin, all more or less schistose, generally badly faulted and locally contorted. These rocks are lithologically similar to unfossiliferous schists, etc., first mapped and described in detail by Clapp (1912) as the Sicker series. This series is indicated by Clapp as extending with possibly some discontinuities from the vicinity of Alberni southeasterly to Mount Sicker, the type locality, and beyond to Saltspring and Moresby Islands (*see* Fig. 4), a total distance of 70 miles. Fyles (1955) found Permian fossils in a limestone band (previously mapped as Triassic Sutton formation) at the east end of Cowichan Lake. He included the limestone in the Sicker group and placed it as the top member of this group and immediately underlying greenstones of the Vancouver group.

The San Juan Islands of the State of Washington, which at the closest point lie 7 miles to the southeast of Moresby Island, are underlain by a thick series of similar schistose rocks in which fossils ranging from Upper Devonian to Upper Permian age have been found (McLellan, 1927).

The rocks of Anderson Bay (McConnell, 1914), at the southern end of Texada Island, are lithologically similar to these Palæozoic rocks; they contain large crinoid stems such as are described above and underlie, apparently with a slight angular unconformity, known Upper Triassic rocks. These Anderson Bay rocks are, therefore, also regarded as Upper Palæozoic in age.

TRIASSIC ROCKS

The Triassic rocks of Vancouver Island were first studied and described in detail by G. M. Dawson (1887). As a result of his investigations along the shores of the northern part of Vancouver Island and adjacent islands, he proposed a stratigraphic succession which to this day has not been superseded. His descriptions can, therefore, be quoted directly.

" By far the greater part of the area of the northern portion of Vancouver Island is occupied by rocks of volcanic origin, which at first sight, and as judged by Eastern American analogies, might often be supposed to represent formations occupying a very low stage in the geological scale. These volcanic rocks . . . have since been subjected to metamorphism more or less intense . . . and now form, for the most part, rocks which might be spoken of as ' traps ' and ' greenstones.' . . .

" The greater part of this old volcanic series appears to have been built up of basaltic and trachytic [andesitic(?), *Ed.*] lava flows, alternating with rough volcanic breccias and tuffs, largely composed of fragments derived from such flows. These rocks are now represented by hard amygdaloids and agglomerates of general dark greenish colours, though often greyish and sometimes purplish or reddish; by felsites, more or less porphyritic, and by hard, regularly stratified ash-beds. . . ."

Dawson noted the widespread presence of " ropy " structure on the surfaces of flows and may have been referring to the pillow structure, undescribed as such in his day, which is common in this series.

Dawson adds: " In association with these volcanic rocks, limestones, argillites, and quartzites occur, possibly at several different horizons, but one of these, which is of considerable thickness and great persistency and possesses very distinctive characters, has now been recognized at a number of places, from the northern part of Georgia Strait around the north end of the island and in Quatsino Sound. This intercalated zone is of considerable thickness, having been estimated at 2,500 (feet) at one place on the north coast of the island, where it appeared to be fully displayed. Massive limestones form its lower portion. The upper part of the limestone becomes interbedded with argillites in regular flaggy layers, and black, flaggy argillites, interbedded with quartzites, overlie these. Where the top of this argillite series is seen it often holds tuffaceous and fine agglomeritic beds, and is followed, in ascending order, by a great thickness of the altered volcanic rocks. In other localities the limestone is found to become interbedded with volcanic materials beneath, and though no complete section of the entire series can be offered, it is quite clear, from observations made in a great number of places, that these sedimentary materials form an intercalation in the great volcanic series. . . .

"As a convenient distinctive name for the whole, I shall employ the term *Vancouver series,* including for the present under this name not only the entire mass of volcanic materials which unconformably underly the Cretaceous, but also the interbedded limestones and flaggy argillites and quartzites. If this great mass of rocks should eventually prove separable into Triassic and Carboniferous portions, I would suggest the retention of the name Vancouver series for the former."

Subsequently geological studies in the area, notably by O. E. LeRoy (1908), J. A. Bancroft (1913), R. G. McConnell (1914), V. Dolmage (1918), C. H. Crickmay (1928), and H. C. Gunning (1931), etc., have led to subdivision of the Vancouver series and fuller descriptions of its parts.

The lower part, probably more than 10,000 feet thick, chiefly massive volcanic rocks, pillow lavas, and scattered limestone lenses, has been described under the names Texada group (LeRoy, 1908), Valdes group (Bancroft, 1913), Texada porphyrites (McConnell, 1914), and Karmutsen volcanics (Gunning, 1931). None of the known limestone lenses in typical occurrences of the Texada formation are thick enough to be commercially valuable. Some of the main occurrences of limestone up to 2,500 feet thick, described by Dawson, were for a time considered to be Palæozoic and some Triassic, but subsequent discoveries of fossils have indicated that all are Triassic, and, as indicated by Dawson, presumably all of a single horizon. This limestone has been described in reports as the Marble Bay formation (LeRoy, 1908; Bancroft, 1918; McConnell, 1914), the Quatsino Limestone (Dolmage, 1918; Gunning, 1931), and the Open Bay group (Bancroft, 1913). The latter differs from the typical Marble Bay formation in being distinctly argillaceous, but is apparently a more or less distinct facies of the same stratigraphic horizon.

The upper part of the Vancouver group, made up of argillites, impure limestones, calcareous sandstones, quartzites, and in places interbedded andesites, has been described by Bancroft (1913) and Crickmay (1928) as the Parsons Bay group and by Gunning (1931) as the Bonanza group.

Fossils are, in general, sparingly distributed throughout the series. Dawson reports finding no fossils in these rocks except those of Triassic age, but the stratigraphic location of these discoveries are, however, not known.

Fossils from the lower Texada formation found by Mathews in 1945 on the west shore of Texada Island, 1½ miles northwest of Davie Bay (*see* Fig. 14), have been identified by McLearn as *Paratropites* sp., *Hannaoceras* sp., *Cœnothyris* sp., *Pecten* sp., and crinoid stems of the Karnian stage of the Upper Triassic.

Fossils reported by McConnell as found in the Marble Bay formation of Texada Island include *Pentacrinus* cf. *asteriscus* Meek, *Terebratula* sp., *Pleuromya?* sp., *Pinna* sp. Those found by the writer on Texada Island include *Lima?* sp., *Pecten* n. sp.?, indeterminate gastropods, corals, and an indeterminate ammonite, *Clionites?*. From the latter fossils the age is inferred as "probably Triassic." These rocks, however, overlie the Texada formation in which the Karnian fossils, already described, were found. Fossils found by Gunning at Open Bay have been identified by McLearn as *Hannaoceras (Polycyclus), Trachisagenites, Tropites,* and probably *Discotropites* and *Arcestes*. They are described as an Upper Triassic fauna of probably later Karnian age, representing possibly the fauna of the *Trophites subbulatus* zone.

Fossils found in the upper Parsons Bay formation include *Pseudomonotis subcircularis* Gabb, two species of *Halobia, Monotes alaskana* Smith, a new species of Entolium, and several new ammonites. They have been described in considerable detail by Crickmay (1928), who considers the upper members as including some forms of Lower Jurassic age.

Rocks of the Vancouver group occur in the southern part of Vancouver Island, where they consist for the most part of altered andesitic and basaltic volcanics, now greenstones, with scattered limestone lenses. The rocks here are much more strongly folded and faulted than in the northern part of Vancouver Island and on Texada Island. Fossils have been found in one of the limestone lenses within the volcanics, on the south shore of Cowichan Lake (Clapp, 1912, p. 68), which were at first identified as Lower Jurassic but subsequently were referred (*see* McCann, 1922, p. 29) to the Lower Noric (i.e., Upper Triassic, above the *Tropites subbulatus* zone of the Marble Bay formation and below the *Monotis subcircularis* zone of the Parsons Bay formation). The thick succession of greenstones in this part of the area bears a distinct lithologic similarity to the Texada formation, but unless the fossils described above have a wider range than hitherto recognized, vulcanism must have persisted to a distinctly later stage of the Triassic in Southern Vancouver Island than in other parts of the Georgia Strait area. The Vancouver volcanics in the southern part of Vancouver Island differ from the Texada formation, however, in the degrees of folding and, locally, of metamorphism. The limestone deposits associated with these volcanics are, moreover, much thicker, more lenticular, and more complexly folded and faulted than those of the Texada formation, and hence for convenience are described in this report under the original name given them by Clapp (1912), the Sutton limestones.

Specimens of the Triassic fossil *Halobia* are reported from a series of angular, poorly sorted conglomerates or breccias, grits, shales, etc., known as the Haro formation, occurring at Davidson Head, the northernmost point of San Juan Island, Washington (McLellan, 1927). These rocks may be the equivalent of the Parsons Bay formation, and, if so, they represent the only occurrence so far established of the latter formation on or adjacent to the southern part of Vancouver Island.

The Cultus formation, a succession of argillites with associated sandstone, grit, and some conglomerate, outcrops in the eastern part of the Fraser Valley. One collection of fossils (Daly, 1912) has been discovered in this formation and has been identified as *Arniotites vancouverensis* Whiteaves and *Aulacoceras?* resembling *A. Carlottense* Whiteaves. Judging from these fossils and the lithology, the Cultus formation may also correspond to the Parsons Bay formation.

MIDDLE JURASSIC TO RECENT SEDIMENTS AND VOLCANICS

Stratified deposits, both sedimentary and volcanic, continental and marine, ranging in age from Middle Jurassic to Recent, cover parts of the Georgia Strait area, particularly in the vicinity of Georgia Strait itself, of Puget Sound, and of the Strait of Juan de Fuca. These Middle Jurassic to Recent deposits contain no large or high-grade calcareous deposits and effectively conceal from discovery and development any Palæozoic or Triassic limestone deposits that may underlie them. The weakly resistant Tertiary sediments of this group underlie a lowland or coastal plain on which much of the agricultural and industrial development of the region has taken place. Most of the markets for limestone and limestone products lie within this coastal plain and, therefore, at a greater or less distance from the better sources of raw material.

Rocks of Middle and Upper Jurassic age, chiefly argillites, tuffs, agglomerate, flows, and conglomerate, are found in the Harrison Lake area near the eastern end of the Fraser Valley (Crickmay, 1930, *a* and *b*) (Geol. Surv., Canada, Map 737A, 1943). At several places along the west shore of Cascade Peninsula, near the southeast end of Harrison Lake, thin beds of impure limestone occur with arenaceous beds. None appears to offer economic possibilities.

Sediments of Lower Cretaceous age, chiefly conglomerate, sandstone, shale, and pyroclastics are known to occur in the Harrison Lake area and in the northwestern part of the San Juan Archipelago (Crickmay, 1930, *a* and *b*) (Geol. Surv., Canada, Map 737A, 1943) (McLellan, 1927). No limestone deposits are known in these rocks.

A series of sediments of Upper Cretaceous age, chiefly shales, sandstones, conglomerates, in part of continental origin and coal-bearing, outcrop along the western shores of Georgia Strait as well as in the central part of Southern Vancouver Island. The basal conglomerates and sandstones of this series are locally calcareous (Richardson, 1878, pp. 168, 169) (Clapp, 1914, pp. 55, 56), but limestone deposits approaching commercial size or grade are not known in these rocks.

A group of flows and pyroclastics, the Metchosin volcanics, with minor associated sediments, containing marine fossils identified originally as Upper and, more recently, as Middle or Lower Eocene age, outcrop on Vancouver Island close to the shores of the Strait of Juan de Fuca, and on the Olympic Peninsula (Clapp, 1917; Weaver, 1937; Park, 1942; Green, 1945). In the latter area the series contains lenses of limestone, some large enough to justify quarrying if the grade were sufficiently high.

The Metchosin volcanics in the northern part of the Olympic Peninsula grade upward into a succession of tuffs and shales, also of Eocene age, known as the Crescent formation.

Sediments of Eocene age underlie large areas in the Fraser and Nooksack Valleys and to the east of Puget Sound, as well as local areas within the Cascade Mountains. These sediments, consisting of sandstones, shales, and conglomerates, are chiefly continental in origin and locally contain coal seams, but parts are of marine origin. An occurrence of an "impure marl-like material" in these sediments has been reported from a point about 8 miles northwest of Bellingham (Glover, 1935, p. 14), but no other calcareous deposits have been noted. Volcanic and hypabyssal igneous rocks are associated with the sediments in the vicinity of the Fraser Delta, and are Eocene or younger (Johnston, 1923).

A succession of marine sediments of Oligocene and Miocene age outcrop along the southern shores of Vancouver Island, on the western, northern, and eastern shores of the Olympic Peninsula, and in local areas in the vicinity of Puget Sound. These sediments are made up for the most part of sandstones, commonly cemented by abundant calcite conglomerate, thin beds of sandy shale, and marl (Clapp, 1917).

Quaternary volcanic rocks, devoid of calcareous deposits, occur on Mount Baker in Washington and in the Coast Mountains near Squamish, B.C.

Quaternary sediments, chiefly of glacial and alluvial origin, cover large areas, particularly in lowlands of the Fraser Valley region. The glacial deposits, till, and associated outwash are the products of two periods of glaciation. Separating these glacial deposits are interglacial sands, gravels, silts, and clays. In two localities glacial silts contain deposits of travertine that have been worked as a source of lime. Elsewhere these glacial and interglacial deposits are not known to contain accumulations of calcareous materials. Alluvial deposits are being laid down along the lower portions of the rivers and in the adjacent marine waters. Calcareous sandstone is reported from the mouth of the Fraser River (Johnston, 1921, p. 35). Post-Glacial lacustrine deposits are also known, of which one, at Cheam Lake (*see* p. 99), is composed of marl which has been recovered for agricultural purposes.

INTRUSIVE ROCKS

Very large areas of intrusive rocks, composed chiefly of granodiorite and quartz diorite, occur in the Coast Mountains of British Columbia, and similar large intrusives are found in the northern part of the Cascade Mountains of British Columbia and Washington and on Vancouver Island. Most of these intrusives are believed to be of Late Jurassic and Cretaceous age. They intrude rocks older than the Upper Jurassic and are unconformably overlain by Cretaceous sediments. A few smaller intrusives cut the Upper Cretaceous rocks of the east coast of Vancouver Island, others cut the Eocene rocks of the south coast of Vancouver Island, and at least one large intrusive cuts Miocene volcanics in the Central Cascades. Clearly, therefore, two or more periods of intrusion can be recognized.

Smaller masses of basic intrusive rocks are found. These include the ultrabasic intrusives of Northern Washington (Bennett, 1940; McLellan, 1927) and of Southern Vancouver Island (Clapp, 1917). Others are composed of diorite and gabbro and may be either basic borders to the granitic intrusives or independent stocks.

Basic dykes and sills are common in some of the older stratified rocks, as on Texada Island (*see* p. 56). In some cases these may be feeders to immediately overlying volcanics, but in many cases they cut granitic rocks which themselves intrude these older stratified rocks, and the dykes and sills can therefore be referred to a significantly later period. Dykes of granitic composition are found generally in the vicinity of larger granitic masses and can be considered as apophyses of these masses.

Not all the areas mapped as being underlain by the larger granitic intrusives are necessarily devoid of limestone deposits. As indicated on page 92, in some places roof pendants or large inclusions of any of the older rocks may be composed in part or entirely of limestone.

STRATIFIED ROCKS OF UNCERTAIN AGE

The age and correlation of several areas of unfossiliferous stratified rocks remain uncertain. Some of these rocks, such as those of the Nitinat, Leech River, and Malahat formations of Southern Vancouver Island (Clapp, 1912), were studied prior to the establishment on palæontological evidence of the stratigraphic succession in the Georgia Strait area. The existing information on these rocks is inadequate to permit correlation with the formations whose age has been established, if indeed they correspond to any of those formations. Other areas of rocks, particularly those in the isolated roof pendants of the Coast Mountains, have a lithology such that they can be correlated on the basis of existing information with more than one unit of the established succession. The degree of deformation and alteration within the roof pendants, moreover, adds to the problems of correlation. All the above-mentioned rocks should be mapped as of uncertain age until such time as they can be re-examined and can be reliably correlated on the basis of stratigraphic evidence with recognized formations, or dated on palæontological evidence.

Probably all the rocks indicated as of uncertain age are Mesozoic or older. With the exception of those in the central part of the Olympic Peninsula, all are cut by granitic intrusives. Some of the rocks contain limestone deposits and one unit, the Nitinat formation of Southern Vancouver Island, contains considerable limestone or its alteration products.

CHAPTER V.—DESCRIPTIONS OF DEPOSITS

INDEX MAPS

The following notes, descriptive of calcareous deposits, are grouped according to the geological age of the deposits; the notes are arranged geographically in each group. The locations of the deposits in southwestern British Columbia are indicated on Figure 3 (in pocket) and those on Texada Island are shown in more detail on Figure 6 (in pocket).

PALÆOZOIC LIMESTONES

GENERAL

Limestones are found at several, perhaps many, horizons within the Palæozoic section, and show distinct variations in thickness, chemical composition, and other characters. Many of the occurrences are less than 100 feet thick and perhaps not more than a few hundred feet long. Several of the smaller deposits which have been worked are composed of high-calcium limestone, a few contain magnesian beds, some contain siliceous beds and nodules, and some are argillaceous. The better of the smaller deposits have been quarried as a source of stone for pulp-mills, smelter flux, glass, agricultural stone, builders' and chemical lime, etc. Thicker deposits occur at Buttle Lake (Gunning, 1930), where the upper horizon varies from 100 to 500 feet in thickness; at Chilliwack River (Daly, 1912) they are about 600 feet thick; and at Horne Lake (p. 49) at least 1,200 feet thick. Probably all of these thicker deposits are Upper Palæozoic and many may belong to a single horizon. The deposits are in general somewhat siliceous, although smaller high-grade parts may be found within them.

The Palæozoic rocks have been subjected in most places to more or less intense deformation and, being composed in part of relatively incompetent thin-bedded argillaceous rocks and ribbon cherts, have been highly folded and faulted. Palæozoic rocks of central Vancouver Island and the Chilliwack River district, however, have escaped severe deformation.

Some of the larger deposits of limestone, for example those of Buttle Lake and Chilliwack River, can be traced continuously for miles. Many of the smaller deposits are, however, lenticular and are terminated by faults or squeezed to feather edges by folding.

Five of the Palæozoic deposits of British Columbia have been worked: two in the eastern part of the Fraser Valley for agricultural stone, one on Texada Island for ornamental stone, and two at Cobble Hill for cement rock and agricultural stone.

Palæozoic Limestone Deposits

Location	Product	Owner or Operator	Status, 1956
British Columbia Cascades			
Chilliwack River			Undeveloped.
Popkum	Ground limestone	T. Mairs	Operating.
Agassiz	Ground limestone	H. Cutler	Operating.
Bear Mountain			Undeveloped.
Vancouver and Gulf Islands			
Cobble Hill	Ground limestone	N. K. Bonner	Quarry idle.
Raymond	Cement rock, limestone	B.C. Cement Co.	Operating.
Cowichan Lake			Undeveloped.
Mount Brenton			Undeveloped.
Nanoose Bay			Undeveloped.
Schooner Cove			Undeveloped.
Ballenas Islands			Undeveloped.
Anderson Bay	Ornamental stone		Idle.
Horne Lake		B.C. Cement Co.	Undeveloped.
Buttle Lake			Undeveloped.

Chilliwack River*

(a) Section 29

Location and Accessibility.—Numerous limestone deposits occur in the Chilliwack River valley (Daly, 1912). The most accessible of these is on a steep-sided knoll that rises 700 feet above the water on the south side of the river immediately west of the mouth of Slesse Creek. This deposit is in the North Half of Section 29, Township 1, Range 28, west of the 6th meridian, 13 miles east of Vedder Crossing. A good logging-road passes by the north end of the knoll.

Geology.—The limestone forms a zone about 400 feet thick that is exposed for nearly half a mile along the precipitous northwest side of a northeast-trending elongated knoll. The zone is interbedded with greywacke, chert, and slaty argillite. Within the zone there appears to be an upper limestone member at least 200 feet thick and a lower limestone member at least 100 feet thick separated by a mixed band of cherty argillite and greywacke. Thin chert bands and lenses are present in both limestone members, more abundantly in the upper one. The limestone is grey and crystalline. No intrusive rocks are known.

The structure is complicated by folding and faulting, but the rocks have a general northeast strike with a variable dip usually to the southeast. There are some indications that the beds may be overturned.

Analyses of samples taken by Mathews follow:—

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
Upper limestone—										
Top 100 feet	15.1	0.47	0.42	0.05	2.50	43.6	0.03	0.06	37.8	0.06
Bottom 100 feet	22.5	2.12	0.91	0.63	0.82	40.1	0.07	0.03	33.2	0.07
Lower limestone	17.8	0.97	0.64	0.13	0.36	43.7	0.09	0.09	35.9	0.11

Development and Operation.—No development has been attempted on this deposit. Impurities in the limestone render it suitable only for agricultural use or cement rock. The distance from markets and difficulty of quarrying due to its topographic setting are drawbacks to exploitation of the deposit.

(b) Sections 32 and 33

Location and Accessibility.—A second easily accessible limestone deposit outcrops on the north side of the Chilliwack River 1 mile northeast of the mouth of Slesse Creek. This deposit is exposed at the river in the northwest part of Section 33, Township 1, Range 28, west of the 6th meridian, strikes across the corner of Section 32, and continues on into Section 5 of Township 2, Range 28, west of the 6th meridian. A branch of the main Chilliwack River logging-road passes around the southeast end of the deposit.

Geology.—The geological setting of this deposit is similar to that of the one in Section 29. An upper limestone member nearly 400 feet thick and a lower limestone member of undetermined thickness separated by a band of slaty argillite and greywacke are interbedded with greywacke, slaty argillite, and chert. The upper limestone member contains thin bands and lenses of black chert. The limestone is medium-grained grey crystalline rock with some irregular patches and veinlets of white calcite and quartz. No dykes were seen.

The bedding of the rocks strikes northwest and dips 20 to 50 degrees northeast. Minor folding is present.

The limestone is exposed in a 75- to 100-foot-high bluff at the road and forms the face of a cliff up the hill along strike.

* *See* Introduction, page 7.

Analysis of one sample taken across the top 200 feet of the upper limestone member along the road is as follows: Insol., 8.24; R_2O_3, 0.44; Fe_2O_3, 0.34; MnO, 0.005; MgO, 0.29; CaO, 50.3; P_2O_5, 0.022; S, 0.119; Ig. Loss, 40.1; H_2O, 0.12.

Development and Operation.—No development has been attempted on this deposit. Economic considerations are similar to those for the deposit on Section 29.

POPKUM*

Location and Accessibility.—Two parallel bands of limestone outcrop along the base of Mount Cheam on the south side of the Fraser Valley, 12 miles east of Chilliwack. The main exposures are in the South Half of Section 9, Township 3, Range 28, west of the 6th meridian. Other outcrops show in Section 4, immediately to the south. A quarry on the lowest outcropping is one-quarter mile south of the Cariboo Highway and about a mile and a half from Popkum Station on the Canadian National Railway.

Geology.—The limestone occurs as two bands, the lower at least 80 feet thick and the upper more than 250 feet thick, interbedded with siliceous argillite. The lower band outcrops at 150 feet elevation in the quarry near the base of the mountain. At the quarry, limestone is exposed for 350 feet along strike. The top of the limestone is marked by overlying argillite exposed in the northeast corner of the quarry; the bottom is concealed by drift. What is probably the same limestone band is exposed again at 450 feet elevation in a creek bed one-quarter mile south of the quarry.

The upper limestone band outcrops 1,000 feet east of the quarry in a bluff at 350 feet elevation near the base of the mountain. The same band is exposed to the south in a dry wash and at 1,000 feet elevation in the creek bed above the lower band. One or two other outcrops can be seen high up the mountainside south of the creek-bed exposures.

The limestone in both bands is dark grey, medium grained, and crystalline. Chert layers and lenses and some scattered veinlets and masses of white calcite and quartz are present.

No intrusive rocks were seen in any of the exposures.

The average strike of the rocks is north 30 degrees west and the average dip is 30 degrees northeastward.

Analyses of three samples follow. The first two were taken in the quarry by Mathews in 1945, the third is a random sample taken from the crusher feed-bin in 1956.

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
Top 50 feet	16.1	0.31	0.17	0.017	0.38	45.6	0.03	0.088	37.1	0.09
Lower 30 feet	14.7	0.03	0.10	0.013	1.18	46.0	0.03	0.090	38.0	0.05
Bin	4.6	0.22	0.09	0.002	0.54	52.4	0.03	0.035	41.9	0.06

Development and Operation.—This deposit was worked successively by Western Canada Lime Company, Chilliwack Lime and Fertilizer Company, Popkum Lime Products Company, and Adanac Lime Company. Fraser Valley Lime Supplies took over the operation in 1949 and has worked it continuously to date.

The present quarry is 210 feet long, 70 feet wide, and has a maximum face height of about 90 feet. An old quarry 60 feet in diameter is situated 100 feet south of and 50 feet above the south end of the working-face. The rock is drilled with a jackhammer, blasted from the face, hand-loaded into a truck, and hauled to a mill 500 feet northwest of the quarry. In the mill the rock is ground and is packaged in paper sacks for use as industrial and feed lime. During 1956 six men produced 4,700 tons of crushed limestone from this quarry.

References

Goudge, M. F. (1930): Preliminary report on the limestone of British Columbia, *Mines Br., Canada,* Inv. Min. Res., 1929, pp. 56–64.

Goudge, M. F. (1944): Limestones of Canada, Pt. V, *Mines Br., Canada,* Pub. No. 811, pp. 179, 181.

AGASSIZ*

Location and Accessibility.—The Agassiz limestone deposit is at the southeastern base of a hill that projects through Recent flood-plain sediments on the north bank of the Fraser River 2 miles southwest of Agassiz. It lies near the boundary between Sections 14 and 23, Township 3, Range 29, west of the 6th meridian. A good road extends to the deposit.

Geology.—The main exposures of limestone are in three quarries spaced along a distance of 350 feet in a northwest-trending row. Limestone is also exposed on the bank of the Fraser River 300 feet south of the west quarry and in a short adit about 200 feet east of the east quarry.

The limestone appears to be at the crest of a small westerly plunging anticline. Light grey-green siliceous tuff or impure quartzite that overlies the limestone is exposed along the north limits of the quarries. The contact between this rock and the limestone strikes north 75 degrees east and dips 45 degrees north. The contact between the limestone and tuff on the south limb is obscure and bedding is indistinct in the limestone, but planar structures that possibly represent bedding strike about east and dip between 20 and 40 degrees south. A small hump of greenstone exposed in the floor of the centre quarry may represent the rock that underlies the limestone.

The limestone is light-grey fine-grained rock. Dark streaks and scattered pyrite grains are present. Bedding is indistinct or lacking.

Several dykes are exposed in the quarries. A north-striking greenstone dyke that dips steeply eastward forms part of the west wall of the west quarry. In the central quarry a similar and parallel dyke forms the west wall, and another that strikes north 60 degrees west and dips 80 degrees southwest forms the present north face. A greenstone dyke, apparently a continuation of the last-mentioned one, cuts across the centre of the east quarry entrance. Another thin greenstone dyke and a thin crushed granitic dyke show in the present face of the east quarry.

Joints with variable spacing and attitudes are numerous in the limestone and several faults are present.

Analyses of six samples follow. The first three were taken by Mathews in 1945, presumably across the face of the central quarry as it stood then. The fourth sample was taken across the face of the west quarry, the fifth sample was taken across the face of the east quarry, and the sixth sample was finished mill product taken from the bagging-machine spout in 1956.

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
Top 20 feet	17.3	18.20	0.64	0.08	0.54	28.1	0.04	0.18	35.2	0.09
Middle 20 feet	18.2	2.56	0.76	0.07	0.62	43.6	0.04	0.28	33.8	0.06
Lower 30 feet	12.8	2.10	0.67	0.17	0.82	46.0	0.03	0.25	36.9	0.12
West quarry face	18.0	1.22	0.53	0.05	1.01	44.0	0.02	0.16	34.9	0.11
East quarry face	11.2	0.72	0.40	0.14	0.61	48.8	0.01	0.04	38.1	0.09
Mill product	23.9	1.68	1.32	0.26	1.91	41.1	0.03	0.15	30.9	0.14

Development and Operation.—The deposit was first worked under the name of Agassiz Lime Quarry, for about eight years by Mr. Tuitton of Agassiz, from 1945 to 1948 by Hiram Cutler and son, and since 1949 by the younger Hiram Cutler.

The original workings form the present centre quarry 120 feet northwest of the crushing plant. When the dyke was encountered in the face, this quarry was abandoned and a new quarry was opened 150 feet farther to the northwest. Recently the second quarry was abandoned and a new quarry was started 100 feet north of the plant. In August, 1956, the west quarry was about 70 feet in diameter with a 53-foot-high face,

* *See* Introduction, page 7.

the centre quarry was 100 feet long and 80 feet wide with a 55-foot-high face, and the new east quarry was 80 feet long by 30 feet wide with a 40-foot-high face.

The rock is drilled with a jackhammer, blasted, and transported by a ¼-cubic-yard loader to the crushing plant. The plant produces 16 to 20 tons per day of ground limestone that is bagged in paper sacks and sold for agricultural and barn lime. During 1956 three men produced 1,400 tons of crushed limestone at this quarry.

Reference

Goudge, M. F. (1944): Limestones of Canada, Pt. V, *Mines Br., Canada,* Pub. No. 811, pp. 177, 181.

BEAR MOUNTAIN*

Location and Accessibility.—A band of limestone outcrops along the upper part of the southwest face of Bear Mountain, a mountain at the southeast corner of Harrison Lake 4 miles northeast of Agassiz. A rough, steep road that branches off Chaplin road northeast of Agassiz has been built to a copper prospect near the bottom limit of the limestone at the south end of the mountain. A logging-road also reaches to within a short distance of the bottom limit of the limestone about a mile north of the copper showing.

Geology.—The limestone occurs as a band interbedded with siliceous argillite. The band is at least 250 feet thick and can be traced in steep cliff faces for over a mile northwestward along the mountainside. To the south the band is cut off at about 900 feet elevation by granodiorite. To the north it pinches out and does not extend as far as the shore of Harrison Lake. The lowest exposures of the limestone are at about 900 feet elevation, with the highest over 600 feet above.

The limestone is medium to coarse grained and varies in colour from white to grey and brown. On weathered surfaces the rock tends to crumble around individual grains to form a coarse sand. Bedding is indistinct in the limestone itself, but scattered argillaceous interbeds indicate the attitude of the series.

The rocks have a general northwest strike and a steep to vertical dip.

Analysis of one sample consisting of chips taken at 20-foot intervals across 260 feet of exposure at the south end of the deposit gave the following results: Insol., 10.1; R_2O_3, 0.42; Fe_2O_3, 0.19; MnO, 0.007; MgO, 0.16; CaO, 51.6; P_2O_5, 0.025; S, 0.003; Ig. Loss, 37.1; H_2O, 0.07.

Development and Operation.—No development has been done on this deposit to date.

VANCOUVER ISLAND AND VICINITY

COBBLE HILL*

Location and Accessibility.—Two small areas of limestone are exposed on the southeast side of Cobble Hill, on Lots 11 and 12, Range 5, Shawnigan Land District. The limestone on Lot 12 is one-quarter mile west of Cobble Hill Station. A road extends from the station up the hill to a small quarry at the southeast end of the deposit. The limestone on Lot 11 is one-half mile southwest of the station. It is on top of a low hump on a shoulder of the main hill and can be reached by a rough abandoned road.

Geology.—On Lot 12 the limestone overlies dark chert. Outcrops are few and the structure is not clear. On the east side of the quarry the chert strikes north 40 degrees west and dips steeply to the southwest. The limestone zone is more than 100 feet wide and can be traced for over 400 feet along strike. No dykes were seen.

The limestone is not uniform. Some is fine grained, greenish grey, hard, and dolomitic; some is coarse grained, dark, and fossiliferous with a high calcium content; and some is siliceous because of cherty inclusions. As noted by Mathews (1947, p. 54), the fossil content, association with chert, and lack of dykes suggests an Upper Palæozoic age for the rock.

* *See* Introduction, page 7.

The limestone on Lot 11 is similar to that on Lot 12. It is associated with chert, argillite, and tuff and contains numerous crinoids and shell fragments. The structure is obscure.

Analyses.—Samples 1 and 2 were taken by Mathews across the limestone exposure on Lot 12 before the quarry was started. Sample 3 was taken across the 40-foot-wide face of the quarry in September, 1956.

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
1. South 48 feet	11.7	0.50	0.57	0.12	1.18	47.5	0.07	0.04	38.4	......
2. North 48 feet	10.7	0.32	0.43	0.11	6.65	41.8	0.05	0.06	39.8	......
3. 40 feet	5.0	0.76	0.42	0.09	8.46	40.9	0.04	0.09	40.8	0.12

Development and Operation.—Norman K. Bonner, of Cobble Hill, opened a quarry on Lot 12 in 1946 and built a crushing-mill. The operation has been carried on to date and is operated under the name of Cobble Hill Lime Products. In 1956 the quarry was not being worked. It was 70 feet long, 40 feet wide, and had a face 70 feet high. Mr. Bonner was buying limestone from the B.C. Cement Company quarry at Raymond and grinding it at his own mill to produce powder for coal-mine dusting and agricultural lime.

Raymond*

Location and Accessibility.—The Raymond limestone deposit is in Lot 9, Range 3, Shawnigan Land District, at the southwest corner of Cobble Hill. It is reached by a 1.5-mile road that branches off the Cobble Hill–Shawnigan Lake Highway 1.6 miles south of Cobble Hill Station.

Geology.—The deposit consists of a large northeasterly trending limestone lens that forms the central part of a low knoll. To the north and west the limestone is overlain by volcanic flow rock and to the south and east is underlain by cherty argillite and tuffaceous sediments. The lens is at least 2,200 feet long and 700 feet wide at the widest point, which is adjacent to the quarry near the southwest end. At the southwest limit the limestone ends abruptly by the edge of a small creek in a gully, probably at a fault. Toward the northeast the limestone lenses out irregularly between the sedimentary rocks to the southeast and the volcanic rocks to the northwest. The apparent angle between the limestone-volcanic contact and the strike of the sedimentary rocks suggests an unconformable contact. No bedding was recognized within the limestone itself, but thin discontinuous chert beds present in the limestone at the north end of the quarry strike north 70 degrees east and dip 45 degrees to the northwest. Cherty and argillaceous beds that underlie the limestone strike north 60 degrees east and dip 35 degrees northwest. Diamond drilling has confirmed this attitude of the rocks. The indicated thickness of the limestone in the quarry area is therefore about 500 feet.

The limestone is medium to coarse grained, light grey, massive rock. Fossils, mainly crinoids, are present. In the central part of the limestone lens foreign inclusions and interbeds are negligible. Toward the upper surface, however, discontinuous light-coloured chert beds 1 to 4 inches wide and 6 inches to 3 feet apart are common. Similar chert beds, although much less abundant, occur near the lower contact. Crinoids are numerous in the chert. No dykes are visible. The rock is highly jointed.

Although to date no positive age determination has been made, the nature of the limestone, its geological setting, and apparent fossil content indicate that the rock is most likely Palæozoic and can be correlated with the Sicker group limestone (Fyles, 1955, p. 19) found at Cowichan Lake, a few miles to the northwest.

Analyses.—The main bulk of the limestone is high-calcium or close to high-calcium stone. The magnesia content is normally less than 1 per cent, although one irregular patch is known to run higher. Samples taken by Mathews in 1945 across the old quarry face had the following compositions:—

* *See* Introduction, page 7.

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
Southwest 40 feet	4.1	0.25	0.32	0.03	0.41	52.9	0.06	0.03	41.9	0.04
Middle 40 feet	3.6	0.15	0.13	0.02	0.28	53.5	0.02	0.02	42.2	0.04
Northeast 40 feet	2.2	0.24	0.11	0.02	0.37	54.1	0.04	0.02	43.0	0.04

Development and Operation.—Quarrying was originally carried out on this deposit at the northeast end of the lens. Raymond & Sons operated the quarry for about ten years beginning in 1886, and burned the stone for lime in a kiln that still stands. Agricultural lime is reported to have been quarried from the same spot in 1916 and 1918. The property is now owned by the British Columbia Cement Company Limited.

The company opened the present quarry at the southwest end of the limestone deposit in 1953. At the beginning of September, 1956, the quarry was 500 feet wide and had advanced into the knoll 300 feet. The maximum face height was 89 feet. A Bucyrus-Erie 27 churn drill is used to drill vertical holes behind the main face. On lower faces, air leg drills are used to drill flat blast-holes. Broken rock is loaded by a diesel-driven shovel into 15-ton trucks and transported nearly 13 miles to the cement plant at Bamberton. Loading and hauling of the rock is done by contract. The company is now building a private road from the quarry to Bamberton that will decrease the haulage distance to about 8 miles.

During 1956, 293,041 tons of limestone was mined at this quarry.

References

Clapp, C. H. (1917): Sooke and Duncan map-area, *Geol. Survey, Canada,* Mem. 96.

Goudge, M. F. (1944): Limestones of Canada, *Mines Br., Canada,* Pub. No. 811, p. 136.

COWICHAN LAKE*

Location and Accessibility.—Limestone outcrops in several places near Cowichan Lake. The most accessible deposit forms a southeasterly trending zone that cuts diagonally across the peninsula near the east end of the lake. What is apparently a continuation of the same zone appears again on the east side of Fairservice Creek, 1½ miles southeast of Lake Cowichan Post Office, and can be traced at least 3 miles southeastward along the south side of Cowichan Valley. The limestone zone on the peninsula is crossed at the southeast end by a side road half a mile from the highway between Youbou and Lake Cowichan village. Logging-roads extend from the village to the Fairservice Creek deposit.

Geology.—The limestone is associated with chert, tuffaceous sediments, and volcanic rocks. It is underlain by bedded chert, tuffs, and breccia of the Sicker group and overlain by diabase and basalt of the Vancouver group. Within the limestone zone, chert and cherty limestone are interbedded with relatively pure limestone. The purer limestone is light-grey to white, fine- to medium-grained granular rock in which bedding is generally obscure. The impure limestone is well bedded. Much of the rock is crinoidal. The limestone-chert zone is between 500 and 1,000 feet thick, strikes northwestward, and dips 30 to 70 degrees southwest.

Clapp (1912) mapped the limestone on the peninsula as part of the Sutton formation, which is of Triassic age (*see* p. 36), but Fyles (1955, p. 19) found it contained Lower Permian brachiopods, crinoids, and fusulinids.

A few dykes intrude the limestone.

Development and Operation.—No development work has been done on this limestone.

Two samples were taken of the limestone on the peninsula. Sample No. 1 consisted of chips taken at 3-foot intervals across 50 feet of outcrop at the end of the road to the forestry lookout on Bald Mountain. Sample No. 2 consisted of chips taken at 10-foot

* *See* Introduction, page 7.

intervals across 200 feet of beds just north of Marble Bay on the south side of the peninsula. Analyses of the samples follows:—

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
No. 1	3.48	0.44	0.22	0.02	0.64	53.3	0.04	0.003	42.4	0.11
No. 2	5.70	0.28	0.10	0.02	0.84	51.5	0.04	0.011	41.4	0.13

Mount Brenton Deposit

Clapp (1912, p. 67) reports " a very small limestone lens 25 feet long and 10 feet wide on Mount Brenton, which is apparently intercalated with tuffaceous volcanics of the Sicker series. This is the only limestone, as far as known, which occurs with rocks of the Sicker series." The small size of this deposit clearly precludes its commercial development.

Nanoose Bay

Impure limestone in beds as thick as 4 feet outcrop for 100 yards along the north shore of Nanoose Bay 0.4 mile west of Richard Point light. The limestone is interbedded with siliceous beds and all are highly contorted.

Schooner Cove Deposits

Limestone is reported by Richardson (1874, p. 97) from Schooner Bay [Schooner Cove, *Ed.*], on the northeast shore of Vancouver Island, where it " occurs in beds from 3 to 5 feet thick, which are largely intermixed with masses of beautifully crystalline tremolite."

Ballenas Islands Deposits

Limestone was reported to occur on the Ballenas Islands, off the east shore of Vancouver Island and 15 miles northwest of Nanaimo, by Richardson (1874, p. 98). He notes 50 feet of " reddish very pure limestone in beds of from 2 to 18 inches thick, holding well-defined fossil stems of encrinites, corals, and brachiopods," on the southeastern part of the larger island. No such thickness of pure limestone was found by the writer. The underlying rock, described by Richardson as " 150 to 200 feet of grey limestone, in some parts interstratified with fine-grained black slate . . ." is predominantly argillaceous. No deposit of commercial size was found on either island.

Anderson Bay, Texada Island

Location and Accessibility.—The Anderson Bay limestone deposit is near the southern end of Texada Island from a quarter to five-eighths of a mile west of Anderson Bay (Fig. 4). What is presumably the same limestone outcrops on the west coast of Texada Island 1½ miles southwest of Anderson Bay. The limestone lies in Lots 26, 339, 345, and 340. Anderson Bay provides good shelter from most winds for tugs, barges, and small craft.

Geology.—The Anderson Bay limestone deposit, about 200 feet thick, is interbedded with more or less schistose sediments, volcanics, and pyroclastics of the Anderson Bay formation (McConnell, 1914). It strikes northward to northeastward and dips westward at angles of from 30 to 60 degrees. It rests on a sheared greenstone breccia or squeezed volcanic conglomerate. At its northern end it is overlain by several hundred feet of mottled greenish and purplish flow breccias and amygdaloids, above which rise steep bluffs of massive and ellipsoidal green volcanics, presumably those of the Texada formation. On the west coast of the island the limestone outcrops along the base of the bluffs and is overlain directly by similar massive and ellipsoidal green volcanics. It is possible, therefore, that the latter rest unconformably on the breccias, amygdaloids, and limestones of the Anderson Bay formation. In the central part of the island the limestone is apparently missing. At its northern end the limestone is apparently truncated by a fault trending northwestward along Anderson Bay and the valley draining into it. Limestone has been reported to occur near a small promontory on the east coast of the island between 1 and 2 miles north of Anderson Bay, and may be the faulted continuation of the limestone deposit.

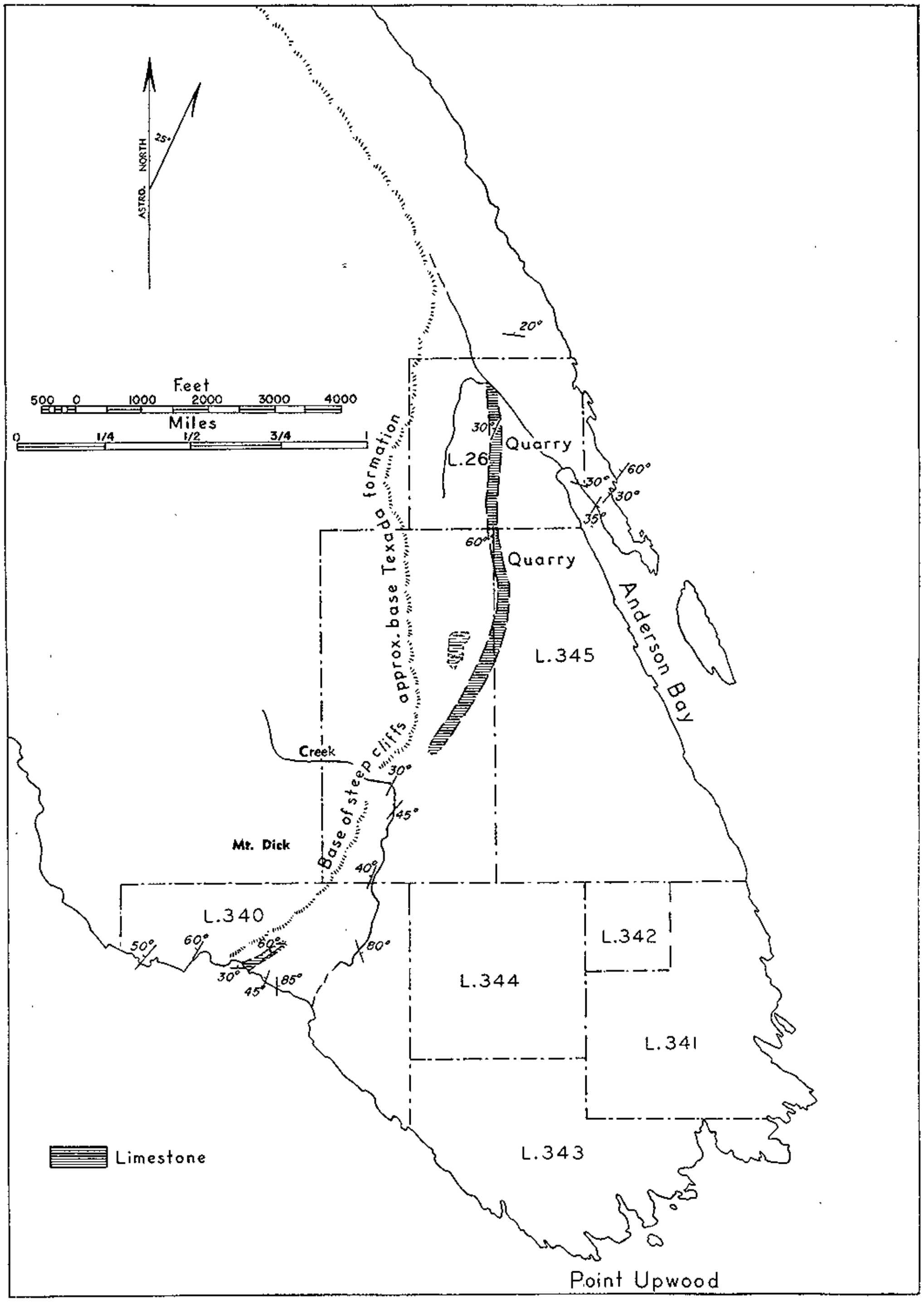

Figure 4. Anderson Bay area, Texada Island.

The lowermost 40 to 50 feet of the deposit consists of white to pink crinoidal limestone, grading upwards into a banded pink to red crinoidal limestone from 30 to 50 feet in thickness. In some places this red limestone contains lenses of jasper. It is overlain by red to green argillaceous and tuffaceous limestone. The upper half of the deposit is, in general, poorly exposed, but it evidently contains a considerable proportion of magnesian beds, together with white calcium limestone.

Imperfect fossils obtained from the limestone exposure on the west coast of the island have been identified as "*Spiriferina?*, a coral, crinoid stems, bryozoan" but are not diagnostic. In view of the apparent unconformable relationship of the Anderson Bay formation beneath the Upper Triassic Texada formation, the lithological similarity with Palæozoic rocks elsewhere in the Georgia Strait area, and the presence of the large fossil crinoid stems, the Anderson Bay formation is tentatively included in the Upper Palæozoic.

Analyses.—Analyses of the limestone follow:—

From Base	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
134–175 feet	2.82	0.52	0.42	0.12	1.22	52.1	0.20	0.001	42.6	0.12
72– 87 feet	4.52	2.87	2.47	0.04	8.48	38.4	0.26	0.003	42.8	0.12
40– 70 feet	2.56	0.19	0.35	0.04	0.50	53.1	0.04	0.007	42.9	0.09
0– 40 feet	1.80	3.15	0.43	0.06	1.14	49.9	0.02	0.005	43.4	0.12

Development and Operation.—Two small quarries have been opened on this deposit for the recovery of ornamental stone. These are described by Parks, who also discusses in some detail the character of the stone. At that time Lot 339 was held by the Malaspina Marble Quarries Company, Limited, of Vancouver, and had been worked under royalty by the Continental Marble Company, also of Vancouver. Lot 26 was held by the Nootka Quarries, Limited, of Victoria, and Lot 340 by William Astley, of Vancouver. So far as is known there has been no activity in this area since 1917, and all holdings of the above lots have lapsed.

References

Dawson, G. M. (1887): Report on a geological examination of the northern part of Vancouver Island and adjacent coasts, *Geol. Surv., Canada,* Ann. Rept., New Ser., Vol. 2, pp. 1B–107B.

McConnell, R. G. (1914): Texada Island, B.C., *Geol. Surv., Canada,* Mem. 58, pp. 14–17.

Parks, W. A. (1917): Report on the building and ornamental stones of Canada, Vol. V, Province of B.C., *Dept. of Mines, Canada,* Rept. No. 452, p. 150.

Horne Lake*

Location and Accessibility.—Limestone is exposed for 6 miles in an arc round the north and west sides of Horne Lake. Most of the outcrops are in Lots 250, 251, and 272 of Alberni Land District. The east end of the limestone deposit is 6 miles by road from the Island Highway and 5½ miles from Dunsmuir Station on the Esquimalt and Nanaimo Railway. A public road and a logging-road extend to the east end of the lake from the highway. The logging-road continues west and south along the north shore and up the sidehill southwest of the lake.

Geology.—The limestone forms a band of variable thickness that is overlain by massive greenstone and pillow lava and underlain by banded greenstone tuffs and breccia. The thickest part of the limestone band, more than 1,200 feet of strata, is exposed in the cliffs that form the southeast face of Mount Mark. Here the lowest part of the limestone, lying directly upon thin-bedded green tuffs, is coarse grained and medium grey, is full of crinoids, and contains minor scattered discontinuous chert beds. Toward the middle of the section, argillite and tuff lenses and beds occur interstratified with

* *See* Introduction, page 7.

limestone. Higher still in the section, several gabbro sills are visible. Above the sills, zones of thin-bedded chert are interlayered with the limestone. Pillow lava rests upon the top of the chert-limestone sequence. Nowhere else in the immediate area is this entire section exposed. Toward the east end of the lake the total section is much thinner, the cherty top section and sills are absent, and the overlying lava rests upon coarse-grained crinoidal limestone. Similarly, to the west the section thins to less than 400 feet above the northwest corner of the lake, the chert and sill sections are absent, and the pillow lava rests on crinoidal limestone. These relationships appear to indicate an unconformable contact between the limestone and overlying lava.

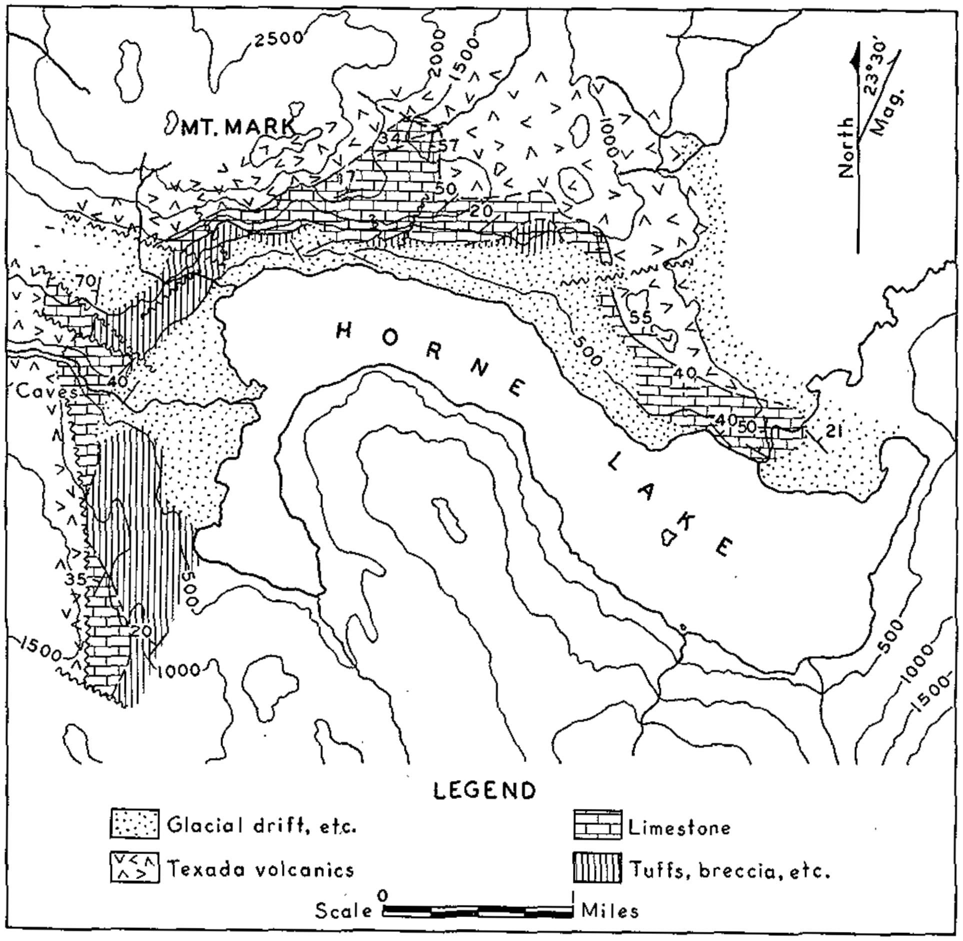

Figure 5. Horne Lake area, Vancouver Island.

At its eastern end the limestone body passes southeastward under the waters of Horne Lake. Limestone has been reported in Cameron Draw, south of the east end of the lake, but it does not extend to the shores of either Horne Lake on the north or Cameron Lake on the south. At the other extremity, the limestone body is exposed more or less continuously around the west end of the lake to a fault nearly 2 miles south of Qualicum (Big Horn) River. No limestone was found south of and immediately adjacent to the fault, although other deposits, undoubtedly parts of the same main body, occur within a mile in that direction.

Crinoid stems, cup corals, and other fossils collected from the limestone and chert beds by Richardson (1873, p. 54) were determined as being "either Permian or Carboniferous, most probably the latter."

Apart from the gabbro sills, no other intrusive rocks were seen in association with the limestone.

The rocks are folded into a broad northerly plunging anticline complicated by subordinate folds and numerous faults.

Development and Operation.—No attempt has been made to exploit this limestone. British Columbia Cement Company, present owner of most of the deposit, has carried out a limited mapping and sampling programme in the area.

Southwest of Horne Lake

Richardson (1873, p. 55) describes a series of slates, limestone, etc., in the area southwest of Horne Lake. These were not examined. They are at present too inaccessible to be of commercial interest.

Buttle Lake

Descriptions of the geology of the Buttle Lake limestone deposits are given by Gunning (1930, pp. 55–78) and Sargent (1941, pp. 17–21, 73), but no information is available on the chemical composition. The deposits, though large, are too remote to be of commercial interest at the present time.

TRIASSIC LIMESTONE DEPOSITS

GENERAL

The principal Triassic limestone deposits are those of the Marble Bay formation,* well exposed and extensively quarried, on the northern part of Texada Island. The same formation is exposed in several other parts of the Georgia Strait area, but has not yet been worked in any of these localities. Smaller deposits, the so-called Sutton limestones, within the undifferentiated Vancouver series of Southern Vancouver Island have proved commercial. Limestone lenses are known in the Texada formation of the northwestern part of the Georgia Strait area and calcareous sediments are reported from the Parsons Bay formation, but as far as is known none is of sufficient size and grade to have justified quarrying.

The Triassic limestone deposits, unlike those of the Palæozoic, are rarely associated with or contain beds of chert. Argillaceous impurities are likewise rare except in the Marble Bay formation at Open Bay on Quadra Island, and in the Parsons Bay formation. The deposits are generally associated with volcanic rocks, and ill-defined or irregular bodies of greenstone—either flows, sills, or tuff beds—are present in many of the limestones. Fine-grained greenstone dykes and other intrusives are likewise common. Most of the deposits are composed of calcium or high-calcium limestone; locally, however, as in the upper part of the Marble Bay formation, magnesian and dolomitic beds are present, but no dolomitic beds thick enough to provide a source of high-grade dolomite without sorting or beneficiation are known.

Except on Southern Vancouver Island the Triassic rocks have not, in general, been intensely folded. The thick accumulation of massive flows in the Texada formation presumably formed a rigid mass which for the most part yielded to stress by large-scale block-faulting and by tilting rather than by tight folding. On Southern Vancouver Island, however, the Triassic volcanics and the interbedded Sutton limestones dip steeply or are cut by a myriad of closely spaced faults. Close folding is also found in the eastern part of the limestone belt of Quadra and Texada Islands in the upper part of the Marble Bay formation nearest the granitic intrusions of the Coast Mountains.

The Triassic deposits can be divided into (1) small deposits commanding only a local market and (2) larger deposits which lend themselves to cheaper large-scale development and which command correspondingly wider markets. In the former category

* *See* page 35, Triassic rocks.

may be included most of the Sutton deposits in the southeastern part of Vancouver Island, and in the latter can be included those of the Marble Bay formation of Texada Island.

Triassic Limestone Deposits

Location	Product	Owner or Operator	Status, 1956
Texada Island			
Limekiln Bay	Lime	Pacific Lime Div., G.L.A. Co.	Idle.
Blubber Bay	Lime, limestone	Pacific Lime Div., G.L.A. Co.	Operating.
Blubber Bay	Crushed limestone	Industrial Lime Products	Idle.
Blubber Bay	Cement rock	B.C. Cement Co.	Operating.
Eagle Bay		McMillan Lime & Mining Co.	Undeveloped.
Marble Bay	Pulp stone, etc.	W. S. Beale	Operating.
Vananda	Pulp stone, etc.	La Farge Cement Co.	Operating.
Centre of island	Pulp stone, etc.	W. S. Beale and K. Johnson	Idle.
Centre of island	White Rock	D. McKay	Operating.
Paxton Lake	Limestone	Texada Mines	Undeveloped.
Davie Bay		B.C. Cement Co.	Undeveloped.
Quadra Island			
Open Bay			Undeveloped.
Vancouver Island			
Campbell River			Undeveloped.
Malahat	White Rock	R. Stebbins	Idle.
Wrigglesworth Lake		H. M. Jones	Undeveloped.
Bamberton	Cement rock	B.C. Cement Co.	Operating.
Tod Inlet	Cement rock	B.C. Cement Co.	Abandoned.
Millstream	Lime, etc.		Abandoned.
Atkins Road	Sand-lime brick	Silica Brick & Lime Co.	Abandoned.
Parsons Bridge	Lime, flux	Victoria Lime and Tyee Copper Cos.	Abandoned.
Rosebank	Lime	Raymond & Sons and Rosebank Lime Co.	Abandoned.

GEOLOGY AND LIMESTONE DEPOSITS OF NORTHERN PART OF TEXADA ISLAND

Texada Formation

The Texada formation is made up of altered volcanic rocks, chiefly massive and amygdaloidal flows, pillow lavas, and possibly some agglomerate, greenstone masses of uncertain origin, and lenses of limestone. Dykes are common, and although many dykes of similar character cut the overying Marble Bay formation, some, at least, may be feeders for the extrusive members of the Texada formation. The presence of limestone interbedded with the volcanics indicates that at least part of the formation was laid down under submarine conditions.

Rocks of the Texada formation outcrop on the west coast of Texada Island from Crescent Bay to the iron mines and inland as far as Priest and Emily Lakes. Flow contacts, pillows, and limestone beds in this area dip moderately, averaging 20 degrees to the northeast. Similar rocks outcrop in the area east of a line from Paxton and Myrtle Lakes north to a point on the northeast shore of the island about one-quarter mile east of Beale Quarries plant. Near this line the volcanics dip westward at angles of from 30 to 50 degrees.

Lenses, strings of lenses, inclusions, and beds of limestone are described by McConnell (1914, pp. 18, 20, 25, 68, 69, 71) as occurring within the Texada formation. Few of these are more than a few feet across and none are known to be of interest as a source of commercial limestone.

Marble Bay Formation

Stratigraphy

The Marble Bay formation is made up almost exclusively of calcareous rocks, ranging from high-calcium to dolomitic limestone. The formation can be subdivided on the basis of chemical composition into three members, each several hundred feet in thickness, the first and lowermost being composed almost exclusively of high-calcium limestone, the second made up predominantly of calcium limestone but including some magnesian and some high-calcium limestone, and the third and uppermost made up predominantly of magnesian limestone. Although it is doubtful that the contacts between these members, as mapped, lie at precisely the same stratigraphic horizon throughout the northern part of the island, the members themselves nevertheless represent definite stratigraphic units.

The base of the Marble Bay formation is well exposed on the steep shore cliffs on the northeastern shore of Texada Island 1¼ miles east of Vananda. Here a layer of limestone 2 feet thick, striking north 10 degrees west and dipping 30 degrees westward, rests on a succession of amygdaloidal flows and pillow lavas having the same attitude. Above this layer of limestone there is a flow or sill 6 feet thick followed by the main limestone succession. Talus about 50 feet west of this contact and apparently derived from a horizon higher in the limestone succession includes some pillow lava, and although no flows occur in place at the shoreline, an isolated block of greenstone is embedded in the limestone a few feet west of the talus.

The contact of the Marble Bay and Texada formations is also exposed on the west side of the island one-quarter to three-quarters of a mile northwest of the iron mines (*see* Fig. 6). In this locality the strike of the bedding in the limestone and volcanics is variable, but the dips, except at one point, are between 10 and 30 degrees northeastward.

The contact of the two formations was seen at one other point, about 500 feet northeast of the Commodore mine and close to the northeastern boundary of Lot 513. Limestone rests, at this place, on an irregular chilled upper surface of a porphyritic greenstone body. No weathering is recognizable in the greenstone, nor is any basal conglomerate present. The limestone itself is unaltered and relatively pure. At one point a tongue or clastic dyke of limestone extends for about 1 foot downward into the greenstone.

The Marble Bay formation, therefore, appears to rest conformably on the Texada formation. There is no suggestion of an erosional interval between the two formations, and it would seem that the change from a period of submarine vulcanism to one of submarine deposition of limestone was abrupt. Only east of Vananda and north of Priest Lake (*see* Fig. 6) is there any apparent interbedding of limestone and volcanics near the contact of the two formations.

The first member of the Marble Bay formation is best exposed on the precipitous shore cliffs between the Beale Quarries Limited wharf, 1 mile east of Vananda, and the top of the Texada formation, one-quarter mile farther east. Gypsum Lime and Alabastine No. 1 quarry penetrated the upper 300 feet of the member but did not reach its base. Partially exposed sections of the member occur in the southern portion of the limestone belt near the iron mines. Each of these sections is composed almost exclusively of high-calcium limestone (*see* tables of analyses, pp. 65, 76). Several magnesian beds a few inches to a few feet thick occur in the upper part of the first member in the Nos. 1 and 2 quarries, Beale Quarries Limited, but these make up a very small proportion of the total section exposed there.

The base of the second member is marked at Blubber Bay by an abrupt change from the underlying high-calcium beds to a zone of calcium limestone, locally siliceous and magnesian, up to 25 feet thick, followed by beds of calcium and high-calcium limestone containing scattered magnesian beds. The base of the member is not exposed on the shore cliffs east of Vananda where a quartz-diorite stock separates the outcrops of the first and second members.

A shell-bearing horizon occurs in the lower part of the second member on the old iron mines road 400 feet northeast of Stanley Beale's original black-rock quarry, and not more than 100 feet above the top of the first member. The shells have been identified by F. H. McLearn, of the Geological Survey of Canada, as:—

" *Lima?* sp.
gastropods
Pecten n. sp.?
Age: Triassic? "

A similar shell-bearing limestone, also in the lower part of the second member, and possibly the same horizon as the last, outcrops on the west coast of the island at the south end of Limekiln Bay. The fossils from this locality have been identified by McLearn as:—

" indeterminate gastropods
coral
indeterminate ammonite, *Clionites?*
Lima? sp.
Age: Probably Triassic."

Only fragmentary sections of the lowermost few hundred feet of the second member are found, the best being to the west of Blubber Bay between the Gypsum Lime and Alabastine quarries and the government wharf (*see* Fig. 7, in pocket). Elsewhere this part of the formation is either partly concealed by drift in inland areas or in its possible exposures south of Grilse Point is complicated by faulting and folding.

Higher parts of the section are, however, well exposed on the shore of Limekiln Bay. The section at the Limekiln Bay quarry bears a distinct similarity to that near the government wharf at Blubber Bay and is hence assumed to be several hundred feet above the base of the second member. From this quarry to the top of the second member near Cohoe Point the section is continuously exposed. The stratigraphic thickness of beds between the quarry and the top of this member, neglecting possible repetition or elimination of beds by faulting, is about 1,250 feet. The thickness of the second member is, therefore, estimated to be between 1,500 and 2,000 feet.

Another section of the second member is found along the eastern part of the island from the Little Billie mine to the head of Sturt Bay. The structure here is, however, complicated by cross-folding adjacent to some gabbro-diorite stocks, and no continuous section has been measured. The Marble Bay mine, started in the middle or upper part of the second member, penetrated to a depth of 1,570 feet below sea-level through limestone of the second and possibly also of the first member. As the mine was flooded in 1944 and 1956, the section here could not be examined.

The second member of the Marble Bay formation is made up predominantly of calcium limestone. The lower part of the member is made up, in general, of calcium limestone with thin, widely spaced beds of magnesian or dolomitic limestone, and with a few thick beds of high-calcium limestone. In the higher parts of the member, magnesia-rich beds are thicker and more numerous, but calcium limestone nevertheless predominates and locally high-calcium beds may be present, though nowhere are they known to exceed 20 feet in thickness.

The second member grades upward in the section from Limekiln Bay to Cohoe Point into a part of the succession in which magnesian beds predominate. This latter part of the succession is designated the third member. Rocks of similar composition and likewise above the second member outcrop north of Sturt Bay in a belt extending northward along the eastern shore of the island as far as Grilse Point. A third and smaller area of similar magnesia-rich limestones, which may also be referred to the third member, occurs east and southeast of Blubber Bay in the western part of the B.C. Cement property (Lot 12) and the eastern part of the Fogh property (Lot 9).

The section of the third member south of Cohoe Point consists of more than 500 feet of magnesian limestone interbedded with some calcium limestone, and possibly some dolomitic limestone. The lower limit of the member, where it is in contact with the calcium-rich limestones of the second member, is not clearly defined, and the uppermost part of the member is concealed beneath the sea. Since elsewhere on the northern part of the island the third member is highly folded and possibly faulted, no other section can be satisfactorily measured.

A closely folded belt of calcium and high-calcium limestones extending from Grilse Point to the head of Sturt Bay and bounded on either side by rocks of the third member is believed to represent the second and first members of the Marble Bay formation repeated in a major anticlinal structure, but could conceivably represent horizons above the third member exposed in a sharp synclinal structure. A further description of these rocks is given on page 68.

Structure

The principal geological structure on the northern part of Texada Island is a northerly to northwesterly plunging syncline. The Marble Bay formation is exposed in the central part of this syncline in a belt 8 miles long and up to 2 miles wide. North and northwest of Vananda the eastern limb of the fold is concealed beneath the waters of Georgia Strait. On either side of the limestone belt the volcanics of the Texada formation dip beneath the Marble Bay formation at angles of from 20 to 50 degrees, and the limestones in the immediate vicinity of the contact have similar attitudes.

Although the principal structure of the Marble Bay formation is simple, smaller structures within the formation show wide variations in complexity. In parts of the syncline, for example near Limekiln Bay and in the area between the iron mines and Emily Lake, the beds are warped into gentle folds whose limbs in few places dip more steeply than 30 degrees. In the southwestern part of Blubber Bay the first member of the Marble Bay formation has been exposed at the crest of a broad dome or northeasterly plunging anticline. The Limekiln Bay quarry lies on the western part of a shallow basin-shaped structure. On the other hand, the structure in a belt extending from Grilse Point to Sturt Bay is exceedingly complex (*see* pp. 67–71). Here close folds a few tens of feet across, many of them overturned, are common, and at least one major fold involving many hundreds of feet of strata and likewise overturned is present. The relationship between this belt of highly folded limestones and the gently folded strata west and south of Blubber Bay is, unfortunately, partly concealed. Nevertheless, a transition from gently folded beds on the west to more closely folded beds on the east is indicated. The reason for the localization of intense folding to the belt south of Grilse Point is not certain.

Faulting has complicated the geological structure of the northern part of Texada Island. Many normal faults, but only a few small reverse faults, have been recognized. In many cases the displacement of the normal faults is small, ranging from a few inches to a few feet, but in a few cases the faults are of much greater magnitude. Since, however, there are no recognizable horizons within either the Marble Bay or Texada formations, these major faults can be detected, in general, only where they cross and displace the Marble Bay–Texada contact. This contact normally trends northward or northwestward, parallel to the strike of individual beds, but in several places it follows a northeasterly or easterly course for as much as several hundred feet. Where such a northeasterly or easterly trending contact is exposed, in pits and mine workings, as at the Commodore mine (Lot 513), the Sentinel mine (Lot 423), and an unnamed working in the Rose Mineral Claim (Lot 196), steeply dipping shear zones with limestone hangingwall and greenstone footwalls are exposed. In the deep, narrow open-cut northeast of the Lake iron mine (Southwest Quarter of Lot 3) the immediate contact is now concealed, but the steep dip and the presence of copper mineralization suggest that here too the Marble Bay and Texada formations are in faulted relationship. It seems probable too that at most of the places where the contact follows a northeasterly or easterly trend it marks the site of a normal fault.

Intrusive Rocks

Diorite-gabbro Stocks

Diorite-gabbro stocks, many less than 200 feet across, a few larger, and one almost 1,000 feet wide and 3,000 feet long, occur in the vicinity of Vananda and Blubber Bay, intruding the Marble Bay and Texada formations (McConnell, 1914, pp. 28–30). They vary markedly in texture and composition. The limestone in the vicinity of the stocks is severely crumpled. It is probable that this crumpling has been brought about by the intrusion of the stocks, but it is also possible that, during subsequent folding, crumpling has been concentrated in the relatively plastic limestone near its contact with the relatively rigid diorite-gabbro.

Quartz-diorite Stocks

Two quartz-diorite stocks, each at least several thousand feet long, half a mile east of Vananda (Stevenson, 1944) and one in the vicinity of the iron mines, 4 miles south of Vananda (Swanson, 1924), cut the Marble Bay and Texada formations. In the vicinity of the Vananda stock the limestone is crumpled and recrystallized; in the vicinity of the iron mines stock the limestone is distinctly recrystallized, but as no stratification is visible no information is available on possible folding.

Dykes

Basic dykes are common in both the Texada and Marble Bay formations but have been studied in detail only in the latter formation. The majority of the dykes are not more than a few feet in thickness and may be conveniently described as "greenstone." The only original feature observed in these intrusives is, in some cases, porphyritic texture. Larger dykes reach 20 to 40 feet in thickness and some of these, for example the dyke between Gypsum Lime and Alabastine No. 1 and No. 2 quarries, are sufficiently coarse in texture to be described as diorite.

A line of outcrops of quartz porphyry, apparently a single belt of *en échelon* dykes, none more than 40 feet across, extends from Limekiln Bay east to the northeast shore of the island, a total distance of 4,300 feet.

In most cases the dykes have been more resistant to erosion than the adjacent limestone, and as they commonly project from a few inches to several feet above their surroundings, they are generally conspicuous. Along the shores these dykes give rise to long, narrow, steep-sided reefs projecting out toward the deep water. On the other hand, some of the smaller and more closely fractured dykes, where subject to wave action, are readily eroded and form the loci for small chasms. In the immediate vicinity of Beale Quarries, Vananda, the basic dykes have been severely crushed, eroded, and subsequently buried under a rubble fallen from the more resistant limestone walls. In this area the dykes are apparent only along the shores and in excavations.

The frequency of dykes varies from place to place in the limestone belt. In some parts, especially in the Blubber Bay area, the interval between dykes rarely exceeds 100 feet. A marked concentration of dykes was encountered in Gypsum Lime and Alabastine No. 3 quarry (*see* Fig. 8) and contributed to its abandonment. Elsewhere, on the other hand, dykes may be found only at intervals of several hundred feet.

Many of the dykes occupy small normal faults cutting the limestone, and in a few places dykes have been crushed and sheared, indicating that locally fault movements have continued after the intrusion of the dykes. In many cases, however, no faulting along the fracture occupied by the dyke can be detected. A few dykes, such as one at the eastern end of Gypsum Lime and Alabastine No. 2 quarry, occupy fractures which follow the axial plane of a minor bend in the strata.

In many places dykes narrow abruptly and terminate. One such dyke southwest of Gypsum Lime and Alabastine No. 3 quarry (*see* Fig. 8) pinches out from a thickness of 8 feet within a distance of 40 feet. Commonly the ends of such dykes are bowed or hooked, and in many cases a second dyke starts close to the point where one terminates. Thus a string of *en échelon* dykes is found, apparently occupying a system of tension fractures.

Dyke patterns are apparent in many places, and bear a distinct relationship to the attitude of the bedded rocks of the Marble Bay formation. Where the strata are only

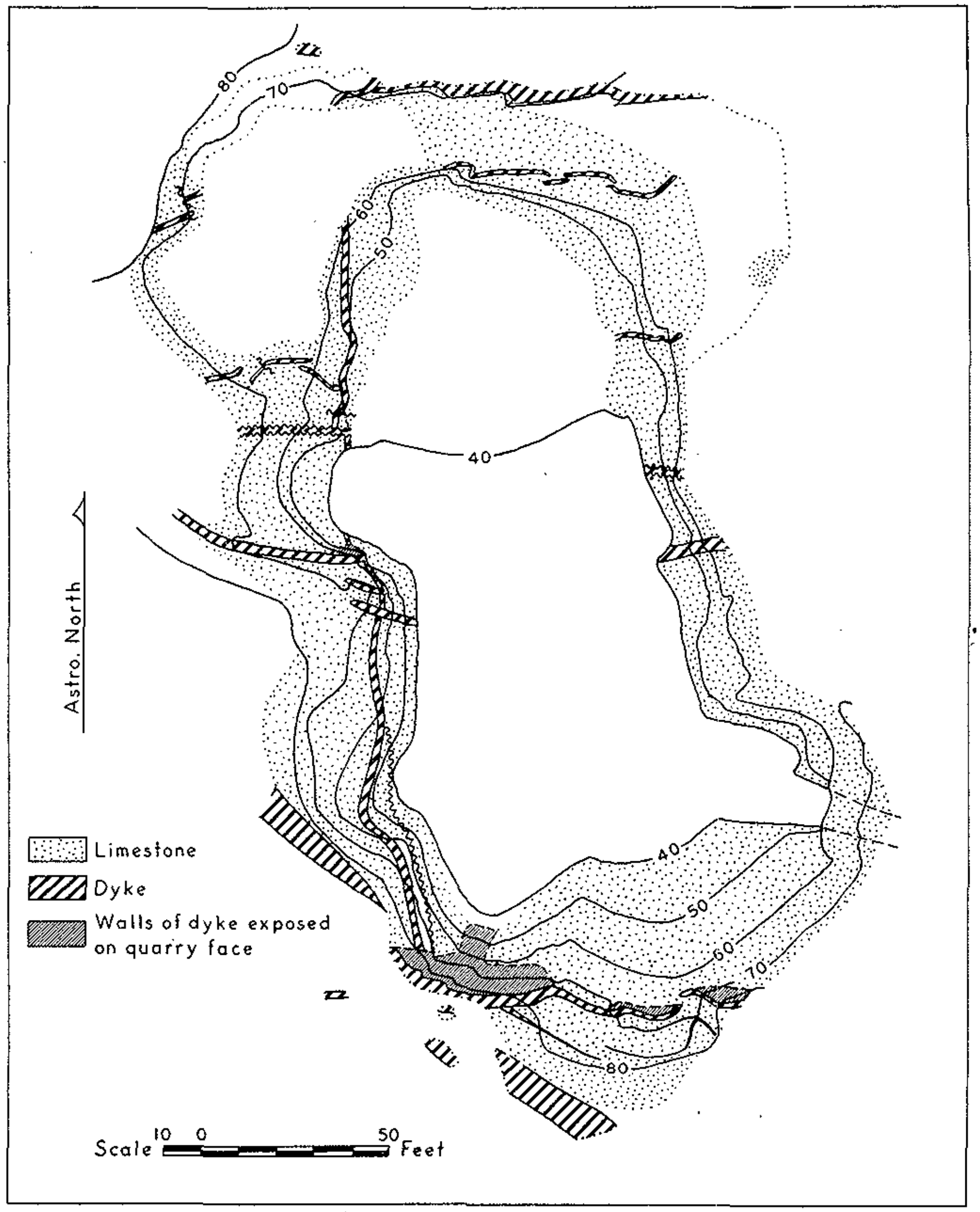

Figure 8. Dykes in No. 3 quarry, Gypsum Lime and Alabastine property.

gently folded, as near Limekiln Bay and near the southwestern part of Blubber Bay, the majority of the dykes trend south 70 to 80 degrees east and dip at high angles, generally to the south. Other dykes have an average strike of north 70 degrees east and south 45 degrees east. A few dykes, notably the diorite dykes in Gypsum Lime and Alabastine quarries, alternate between two or three of the trends given above. On the other hand, at Cohoe Point, where the limestone beds dip 50 to 70 degrees northward or northwestward, many of the greenstone dykes tend to follow the bedding planes, and a few strike about south 50 degrees east and dip steeply either northeastward or southwestward. In the vicinity of the British Columbia Cement Company Grilse Point quarry several of the greenstone intrusives strike northward, parallel to the foliation in the limestone, but elsewhere on the British Columbia Cement Company's property the intrusives generally cut obliquely across bedding or foliation, and several easterly trending transverse dykes are known.

The *en échelon* arrangement of many dykes, especially those trending south 80 degrees east, in the Blubber Bay area suggests that they follow fractures produced by tension in a north–south direction. The presence of many dykes along the easterly trending normal faults, as well as the scarcity of dykes having a northerly trend are in accord with this orientation of stress. Clearly, however, stresses were influenced by planes of weakness, either bedding planes or planes of foliation already in existence within the folded limestones, and so produced a variety of fracture patterns which were followed by the dykes.

The age of the dykes is uncertain. Stevenson (1944, p. 166) reports that one group of greenstone dykes cuts only the limestone adjacent to the quartz-diorite stock east of Vananda, and a younger group also cuts the quartz diorite. Some easterly trending dykes cut the diorite-gabbro stocks and some in the vicinity of the stocks are badly crushed (*see* p. 75); possibly the crushing accompanied the intrusion of the stocks. The dykes as well as the stocks postdate the Upper Triassic Marble Bay formation, and they are not known to intrude the Upper Cretaceous sediments 2 miles southeast of the iron mines.

Upper Cretaceous Sediments

Upper Cretaceous shales, sandstones, and conglomerates are exposed near Gillies Bay and Mouat (Lower Gillies) Bay, 3 and 6 miles respectively southeast of the iron mines (McConnell, 1914, pp. 31–39). They rest unconformably on the Texada formation and are themselves slightly folded. These sediments are not known to be cut by any of the diorite-gabbro, greenstone, or quartz-diorite intrusives common in the area farther north.

Quaternary Sediments

Glacial till is widespread in the northern part of the island but is nowhere known to be deep, and in many localities is absent. The till contains blocks of greenstone and less limestone, both presumably of local origin; boulders of sandstone and conglomerate, similar to the Upper Cretaceous sediments of the eastern part of Vancouver Island; and granitic rocks. Glacial striæ indicate that the ice moved southeastward across the island.

Interglacial deposits and an older glacial till are present in a few localities, notably east of Crescent Bay and southeast of the iron mines (McConnell, 1914, pp. 39–41). Here they have accumulated to depths locally exceeding 150 to 250 feet and effectively prevent the examination and development of any underlying deposits of limestone. Beds of sand interstratified with silt in the Crescent Bay area, however, prove to be valuable aquifers and provide most of the water needed for industrial and domestic purposes in the Gypsum Lime and Alabastine plant and adjacent townsite.

Late Glacial raised beaches and post-Glacial alluvium are present on the island but are of limited extent.

Limekiln Bay Quarry

Location and Accessibility.—The Limekiln Bay quarry is on Lot 23 on the shore of Limekiln Bay, and is accessible by road from Blubber Bay one-half mile to the north-east. At the time the quarry was operated, loading facilities for boats were available on the shore of Limekiln Bay, but the bay is open and no adequate shelter could be provided in the case of westerly gales. The bay is, moreover, shallow, and with the facilities then existing only shallow-draught boats and barges could land.

Geology.—The Limekiln Bay quarry lies in the lower part of the second or middle member of the Marble Bay formation. The base of this member is not exposed in the vicinity of Limekiln Bay, hence the exact stratigraphic position of the deposit with respect to that horizon is not known. The limestones, however, bear a marked resemblance to those which are exposed on the west shore of Blubber Bay near the government wharf, and are a few hundred feet stratigraphically above the base of the second member.

The limestone deposit at Limekiln Bay is made up of alternating beds of calcium or high-calcium limestone, several feet thick, interbedded with magnesian beds generally a foot or less thick. The latter are, as a rule, themselves made up of fine but continuous laminæ of dolomite interbedded with calcium or magnesian limestone. One argillaceous bed, up to 3 inches thick, occurs in the lower part of the section. It overlies at the northern end of the quarry face a conspicuous orange-weathering massive, rather than laminated, magnesian bed about 2 feet thick. An irregular lower surface of this bed suggests it originated by replacement, although at what stage of the history of the deposit is not evident. This bed does not appear 350 feet to the southeast at the opposite end of the quarry.

The beds have been warped into a broad saucer-shaped structure (*see* Fig 1, p. 12). Along the shore the beds dip northward or eastward at angles of from 10 to 20 degrees; inland at the quarry face the beds dip northward at angles of not more than 15 degrees and become horizontal at the northern end of the quarry.

Several eastward-trending southward-dipping normal faults interrupt the continuity of the strata on both the quarry face and the shore cliffs. The displacement on these faults varies from a fraction of an inch to about 10 feet (*see* p. 11).

No intrusions cut the limestone in the quarry, but a large dyke outcrops immediately north of the northern end of the face.

Overburden is lacking or is rarely more than a foot in thickness adjacent to the quarry, but it deepens appreciably a few tens of feet east of the quarry.

The limestone, like that of Blubber Bay, is, in general, black and fine grained. The weathering which has taken place since the quarry was abandoned, about 1912, has been sufficient to differentiate the calcite and dolomite in the limestone. The latter mineral stands up in relief as fine white laminæ, or less commonly as disseminated grains and short fine veinlets.

Analyses.—Channel samples were taken of individual beds throughout the complete stratigraphic section exposed at both the northern and southern ends of the quarry. In the following table analyses of the same beds at both the northern and southern ends of the quarry are listed together, the one from the southern end being in italics. The magnesia content of the beds is represented diagrammatically in Figure 2, page 29.

Thickness	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O at 105° C.
Top of section—										
3.0 feet[1]	*0.48*	*0.58*	*0.14*	*0.012*	*1.73*	*52.87*	*0.013*	*0.03*	*43.92*	0.01
6.0 feet	*0.20*	*0.14*	*0.05*	*0.005*	*2.17*	*53.68*	*0.011*	*0.02*	*43.47*	0.02
1.0 feet	0.60	0.63	0.35	0.019	7.88	46.20	0.021	0.09	44.18	0.05
0.0 feet (missing)	------	------	------	------	------	------	------	------	------	------
6.2 feet	0.50	1.10	0.07	0.008	2.06	54.79	0.012	0.03	41.83	0.04
7.5 feet	*0.36*	*0.15*	*0.03*	*0.005*	*1.09*	*54.69*	*0.015*	*0.04*	*43.48*	*Nil*
0.5 feet	0.50	1.15	0.13	0.009	7.24	46.91	0.020	0.02	43.83	0.02
0.5 feet	*0.50*	*0.20*	*0.08*	*0.009*	*5.92*	*49.34*	*0.013*	*0.04*	*43.90*	*0.03*
4.0 feet	0.50	0.60	0.14	0.009	5.25	49.64	0.014	0.04	43.56	0.05
2.7 feet	*0.36*	*0.07*	*0.12*	*0.008*	*7.85*	*47.42*	*0.014*	*0.06*	*43.92*	*Nil*
0.5 feet	0.30	0.49	0.43	0.019	13.00	41.06	0.016	0.13	45.00	0.02
0.0 feet (missing)	------	------	------	------	------	------	------	------	------	------
12.0 feet	0.20	0.23	0.06	0.009	0.58	55.69	0.008	0.03	42.98	*Nil*
12.2 feet	*0.20*	*0.15*	*0.04*	*0.005*	*0.77*	*55.29*	*0.011*	*0.04*	*43.10*	*0.03*
1.0 feet	*0.70*	*1.18*	*0.30*	*0.026*	*7.50*	*47.72*	*0.018*	*0.07*	*43.07*	0.04
0.8 feet	*1.30*	*1.65*	*0.34*	*0.016*	*7.42*	*46.51*	*0.014*	*0.07*	*43.25*	*Nil*
0.3 feet	32.00	37.16	6.44	0.021	9.59	2.02	([2])	([2])	12.52	0.01
0.2 feet	*35.92*	*37.59*	*5.01*	*0.041*	*4.09*	*3.94*	([2])	([2])	*9.81*	*0.60*
0.8 feet[1]	0.70	1.04	0.54	0.027	16.69	36.53	0.020	0.08	44.55	*Nil*
17.5 feet	*0.20*	*0.24*	*0.05*	*0.008*	*2.17*	*54.18*	*0.008*	*0.02*	*43.50*	*Nil*
Base of section in quarry.										

[1] Section at north end of quarry incomplete. [2] Not determined.

Development and Operation.—Quarrying was commenced on this site in the late eighties of the last century, but was active at that time for only a short period. The Marble Bay Company, after encountering rock of an unsatisfactory grade for the production of lime in their Marble Bay quarry, acquired Lot 23 in 1902, erected a kiln, and recommenced quarrying there. This operation was later extended with the construction of three additional kilns, and continued under the management of the Marble Bay Company and of the Tacoma Steel Company until about 1912. There is no record of production since that time. Lot 23 and the surrounding lots are now controlled by Gypsum Lime and Alabastine, Canada, Limited.

The quarry face is about 600 feet long, up to 35 feet high, and has been advanced a maximum of 100 to 150 feet from its initial position. Broken rock was apparently sorted by hand, and a large amount of waste remains stacked on the quarry floor. Usable rock was trammed on a narrow-gauge railway from the face to the four kilns situated on the shore at the south end of the quarry. Burned lump lime in barrels was apparently loaded into boats from a shed on the steep shore cliff near the north end of the quarry.

References

Goudge, M. F. (1944): Limestones of Canada, *Mines Br., Canada,* Pub. No. 811, p. 150.
McConnell, R. G. (1914): Texada Island, B.C., *Geol. Surv., Canada,* Mem. 58, p. 97.

Gypsum Lime and Alabastine, Canada, Limited (Pacific Lime Division)

Location and Accessibility.—Gypsum Lime and Alabastine company bought the former Pacific Lime Company in 1955. The property thus acquired includes Lot 13, containing the abandoned Nos. 1, 2, and 3 quarries formerly operated by Pacific Lime Company, and Lot 305 containing No. 4 quarry, from which all production was coming in 1956. No. 4 quarry is 2 miles by paved highway from Blubber Bay, which has good harbour facilities.

Geology.—The four quarries on this property lie within the upper part of the first member and the lower part of the second member of the Marble Bay formation. Quarry No. 1 appears to have been started on the outcrop of the first member, and was subsequently worked to a depth of almost 300 feet below the original surface or 238 feet below sea-level before being abandoned in 1942. Quarry No. 2, adjacent to No. 1, lies within the upper part of the first member and the lowermost few tens of feet of the second member. Quarry No. 3 is entirely within the second member at an undetermined distance above its base. Quarry No. 4 appears to lie within the first member.

The first member of the Marble Bay formation here, as at Beale Quarries and elsewhere, apparently is composed entirely of high-calcium limestone. The rock obtained from No. 1 quarry is reported to have been uniformly high in grade from top to bottom. The same strata exposed in No. 2 quarry are composed of high-calcium limestone, and analyses of drill cores obtained by the company show that high-calcium rock persists here to a depth of at least 240 feet below the floor of No. 2 quarry. As might be expected in rock having such a limited range in composition, stratification is not readily apparent. A few gently dipping continuous fractures paralleling the bedding in the overlying second member may perhaps mark discontinuities between successive strata. No other evidences of stratification could, however, be found. In many places the rock is broken by sets of fairly uniformly spaced plane fractures which generally meet the stratification of the overlying beds at a high angle. The extreme regularity of this fracturing is further testimony of the marked uniformity in the characteristics of the limestone of this first member.

The base of the Marble Bay formation is exposed nowhere in the vicinity of Blubber Bay, hence the total thickness of high-calcium beds here is not known. It must, however, exceed the 300-foot thickness exposed in No. 1 quarry, and may be comparable to that of the first member at Beale Quarries, 5 miles to the southeast, where it approximates 500 feet.

The second member of the Marble Bay formation, exposed in Nos. 2 and 3 quarries, is neither as high grade chemically nor as uniform as the first member. In neither quarry has weathering proceeded to a stage in which variations in mineralogical composition are evident, as is the case at the Limekiln Bay quarry (*see* p. 58). Stratification is made apparent only through the variations in physical characteristics of the rock. The gently dipping "bedding fractures" are more conspicuous and more closely spaced than in the upper part of the first member. That these are parallel to stratification can be confirmed by chemical analyses. Some strata are harder and tougher than others; some possess a conchoidal fracture, others do not. Some strata, moreover, are closely and irregularly fractured; adjacent strata may be blocky-jointed. Nowhere, however, is there uniform fracturing, similar to that of the first member, extending across a thickness of more than a few feet of beds.

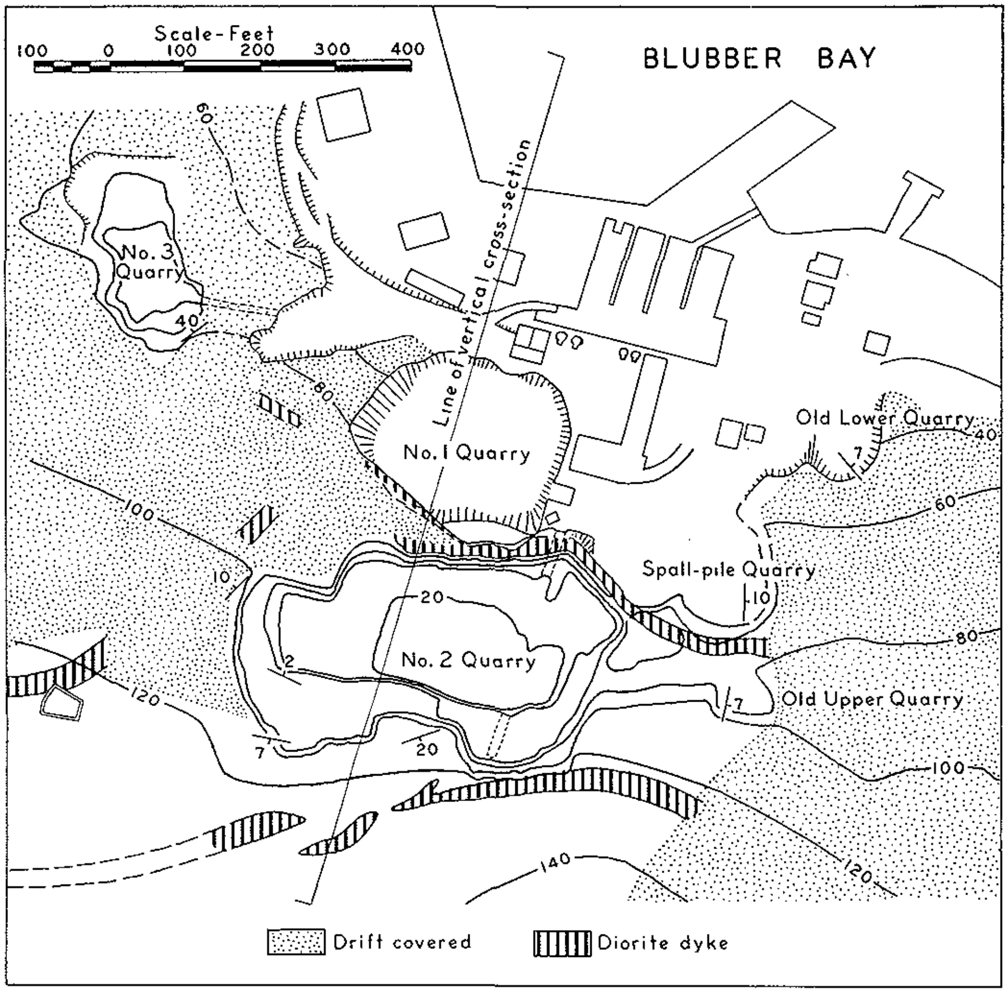

Figure 9. Gypsum Lime and Alabastine abandoned quarries.

The stratification of the second member might easily be deciphered in this area were it not for marked changes in characters along bedding planes. Variations of the chemical composition of the corresponding succession of beds in different places, as between opposite ends of the No. 2 quarry, are distinct (*see* analyses, p. 65). Whether these are brought about by progressive changes in most or all of the succession, or by the lenticular nature of a relatively minor thickness of impure beds, has not been determined. Changes

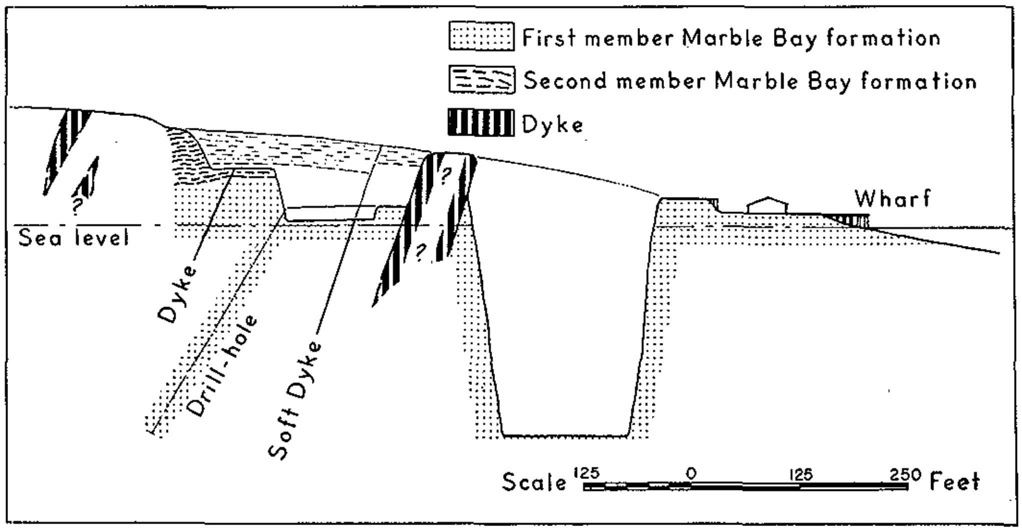

Figure 10. Cross-section of Gypsum Lime and Alabastine quarries.

in physical characteristics of the beds along strike are likewise noted. A bed susceptible to fracturing at one end of a quarry may be much less so at the other. The spacing of the bedding fractures varies to some extent, and some of these fractures appear or die out along the quarry walls. It is not possible, therefore, to establish a single standard stratigraphic section, based either on chemical or physical characteristics, which is applicable over more than a single quarry or a part of a quarry. The contact between the high-grade and uniform rock of the first member and the less pure and variable rock of the second member is, however, distinct, and since as far as can be determined it lies at a single stratigraphic horizon throughout the quarries, it is one plane to which all sections are generally referred.

The major structure in the vicinity of the Nos. 1, 2, and 3 quarries is interpreted as a broad dome complicated by faulting. Only the northeastern flank of this dome is well exposed in the quarries; the northwestern and southern flanks are partly exposed, and the southwestern flank not at all. Dips of the strata exposed in the quarry radiate, in general, from a point near the southwestern corner of No. 2 quarry. A few local divergences from this radia pattern occur, one in the southeastern corner of No. 2 quarry adjacent to a major dyke and others in No. 3 quarry.

Near the centre of the dome the dips rarely exceed 5 to 10 degrees, except in the disturbed zone near the major dyke, mentioned above, in No. 2 quarry. In No. 3 quarry, however, about 500 feet from the centre of the dome, the dips locally reach 40 degrees.

The top of the first member in the southern half of No. 2 quarry is followed closely by the floor of the upper bench, rising from an elevation of about 45 feet above sea-level at the eastern wall of the quarry to about 73 feet near the centre of the dome at the southwestern corner of the quarry. Near the western end the continuity of this horizon is interrupted by an irregular network of at least four steeply dipping faults whose displacement varies from a few inches to possibly 10 feet. An eastward-trending southward-dipping normal fault crosses the northern part of No. 2 quarry and is marked by a crushed dyke. North of this fault the top of the first member is from 10 to 20 feet higher than at corresponding points immediately south of the fault.

Large diorite dykes and smaller greenstone dykes are common in the vicinity of the quarries. One of the diorite dykes separates Nos. 1 and 2 quarries, a second lies immediately south of No. 2 quarry. Smaller dykes are widespread. One concentration of dykes was met in No. 3 quarry (Fig. 8, p. 57), but only one dyke is reported from No. 1 quarry and only two, with branches, occur in No. 2 quarry. With but one exception the dykes in the quarry area are steep dipping, and easterly trends predominate. Most of the dykes follow joint-planes but one or two follow fault planes.

Overburden varies from zero to at least several feet in thickness. In many places the limestone is effectively concealed, whereas the dykes, being more resistant to erosion, project above the overburden.

The rock from the quarries is, in general, black and fine grained. Impurities in the beds of the second member consist for the most part of dolomite and quartz, either disseminated as grains so fine that nearly all pass a 40-mesh screen or locally as minute veinlets. The mineralogical character of the few impurities in the rock of the first member has not been recognized.

Vein-like and irregular masses of white limestone are found within typical black limestone in various parts of the quarries. The vein-like masses, which may be a fraction of an inch wide and several feet long, usually cut across the bedding. They occur in swarms, which in many cases are confined to a single stratum. Careful sampling of the white-rock shows that it is almost identical in chemical composition with the adjacent black-rock, apparently differing significantly only in the content of free carbon. The white-rock here has evidently been formed by the bleaching of black limestone adjacent to fine fractures by solutions or vapours which have migrated along them. No obvious fracture now exists along most of the white-rock veins. Many apparently irregular bodies of white-rock, notably adjacent to the dyke on the north wall of No. 2 quarry, are actually composed of a coalescing network of broad vein-like masses. The bleaching of black limestone is accompanied by certain physical changes.

In the No. 4 quarry no stratification is visible and analyses fail to indicate any readily apparent zoning or bedding. The limestone throughout most of the quarry is uniform looking, fine-grained black rock. At the west end a mottled light- and dark-grey streakiness occurs, and on the wall northwest of the sump two 15- to 20-foot-wide irregular zones of interbanded black and white rock are visible. These latter zones are nearly vertical and strike about north 15 degrees west.

Four large and several small dykes and some irregular patches of igneous rock intrude the limestone in the No. 4 quarry area. The large dykes are 10 to 20 feet wide and each can be traced for several hundreds of feet. One of these has a steep south dip and strikes east all the way across the centre of the quarry. The other three strike slightly west of north and are nearly vertical or have steep east dips. Some of these igneous masses are fine-grained greenstone and others are porphyries. In many cases the dyke walls are sheared and several of the dykes themselves are highly sheared.

Two strong sets of joints are visible in various parts of No. 4 quarry. Both sets extend fairly uniformly from the surface to the quarry floor. One set strikes approximately north 60 degrees east and has a vertical to steep south dip, while the other set strikes about east and west and has a steep dip to the north. Some faults are present, and a shatter zone 35 to 50 feet wide with a northwest strike is exposed in the quarry wall at the corner just southeast of the sump.

Analyses.—Samples were collected by Mathews in 1945 from strata exposed in No. 2 quarry. All but two of the analyses quoted are of samples obtained from the southeastern part of No. 2 quarry, but, to show the variations along strike of the bedding, two additional analyses of the same strata exposed at the western end of the quarry are also given. The first of these, 20.6 feet in thickness, is from beds corresponding to the 19.5-foot section from the southeastern end of the quarry; the second, also 20.6 feet in thickness, is, however, from beds corresponding only to the upper 20 feet of the 27.3-foot section from the southeastern corner. Samples Nos. 1 to 9 from No. 4 quarry were taken as indicated on Figure 11 by McCammon in 1956.

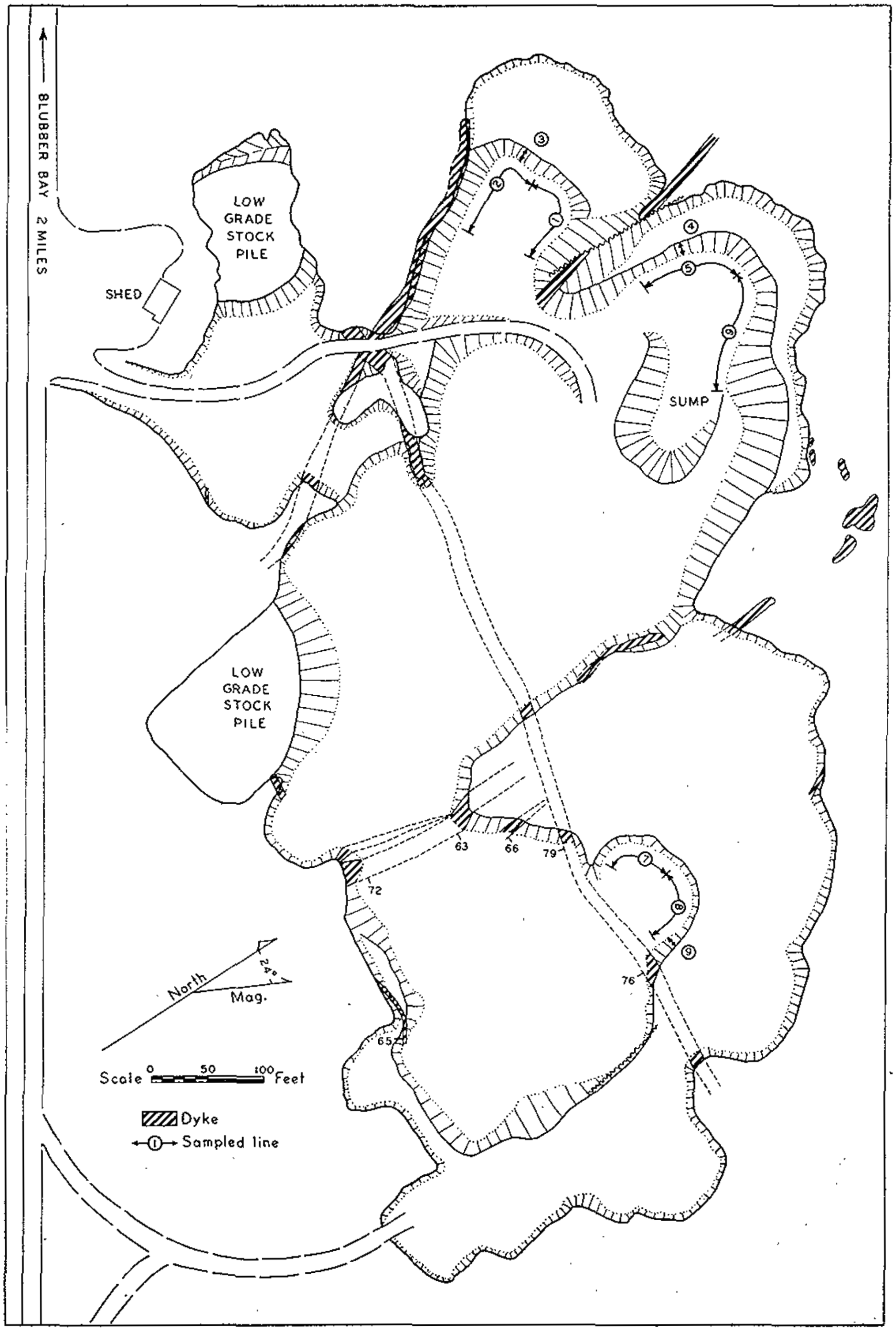

Figure 11. Gypsum Lime and Alabastine No. 4 quarry.

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
No. 2 Quarry										
Quarry rim—										
17.5 feet	0.74	0.04	0.08	0.010	3.73	51.55	0.007	0.03	44.09	0.08
26.8 feet	0.64	0.03	0.09	0.020	2.62	52.59	0.010	0.04	43.96	0.07
19.5 feet	0.48	0.04	0.11	0.024	2.10	53.78	0.007	0.03	43.79	*Nil*
20.6 feet[1]	*0.68*	*0.01*	*0.10*	*0.016*	*1.99*	*53.71*	*0.008*	*0.07*	*43.78*	*0.05*
27.3 feet	3.24	0.08	0.43	0.075	6.81	46.23	0.007	0.05	43.19	0.01
20.6 feet[1]	*0.73*	*0.01*	*0.11*	*0.016*	*2.06*	*52.17*	*0.017*	*0.05*	*44.05*	*0.04*
Top of first member—										
19.8 feet	0.23	0.01	0.04	0.015	0.47	55.35	0.012	0.01	43.74	0.01
20.0 feet	0.17	Tr.	0.04	0.006	0.46	55.33	0.021	0.02	44.03	*Nil*
Quarry floor.										
No. 4 Quarry										
Sample No. 1	0.92	0.16	0.05	0.001	0.19	54.40	0.013	0.02	43.60	0.06
Sample No. 2	0.78	0.14	0.10	0.004	0.04	54.50	0.023	0.04	43.50	0.07
Sample No. 3	0.96	0.22	0.05	0.001	0.09	54.20	0.013	0.02	43.50	0.08
Sample No. 4	0.98	0.06	0.05	0.001	0.20	54.80	0.009	0.03	43.60	0.05
Sample No. 5	0.92	0.08	0.09	0.001	0.03	55.00	0.008	0.04	43.50	0.07
Sample No. 6	0.46	0.04	0.04	0.006	0.02	55.30	0.013	0.03	43.70	0.07
Sample No. 7	15.80	3.32	1.53	0.019	0.04	44.50	0.133	0.22	35.20	0.24
Sample No. 8	0.92	0.04	0.06	0.002	0.03	54.80	0.008	0.02	43.50	0.09
Sample No. 9	3.38	0.06	0.09	0.003	0.03	53.50	0.008	0.03	42.30	0.08

[1] Alternative samples, *see* Analyses, page 63.

Development and Operation.—At some time between 1890 and 1900 Lot 13, along with Lot 12 on the opposite shore of Blubber Bay, was held by Carter Cotton, who attempted, unsuccessfully, to start a lime-burning industry on the bay. Lot 13 was subsequently acquired by H. W. Treat, of the Van Anda Copper and Gold Company. Treat, in turn, sold the property to W. S. Planta, of the Blubber Bay Lime Syndicate, who began quarrying and burning limestone on Lot 13 and continued operations for a year and a half. This syndicate's holdings were then sold in 1910 to the original Pacific Lime Company Limited which operated quarries and kilns until 1916. At that date a new company, bearing the same name, took over the operations and continued production almost continuously until 1955. On April 30th, 1955, Pacific Lime Company Limited was purchased by Gypsum Lime and Alabastine, Canada, Limited, and the operation has since been known as the Pacific Lime Division of the latter company.

History.—Initial developments of the deposit prior to 1911 consisted of two small quarries, one at the eastern edge and the other at the southeastern corner of the quarry area (Fig. 9). Between 1911 and 1928 No. 1 quarry, together with the "Spallpile quarry," covering in all an area up to 600 feet long and from 200 to 300 feet wide, were worked from the surface down to a level 20 feet above the sea. During this time an adit was driven through the dyke on the south wall of No. 1 quarry, and a glory-hole and pit developed in what is now No. 2 quarry. From 1928 to 1942 most of the production was obtained by excavating No. 1 quarry, about 250 feet in diameter, to a final depth of 238 feet below sea-level. The operation of this quarry was discontinued in 1942. No. 3 quarry, 100 by 250 feet in plan, was worked to a comparatively shallow depth between 1936 and 1938. Development and production after 1942 was confined to No. 2 quarry, which in the summer of 1945 had reached a length of 500 feet with an average width of 250 feet. The floor of the lowest bench in this quarry was then about 5 feet above sea-level.

Quarrying ceased in No. 2 quarry in 1948 after No. 4 quarry had been opened. It is now partly filled with water. Since 1948 all production has been from No. 4 quarry.

In August, 1956, No. 4 quarry was roughly 1,100 feet long, 500 feet wide, and 50 feet deep. Quarrying was being carried out only in the northeast corner of the quarry.

The top 10 to 20 feet of rock is badly fractured and is contaminated with overburden. This rock is blasted off and removed to waste. The solid rock below is then removed as a single bench. Wagon drills and Gardner-Denver rotary drills are used to drill horizontal and vertical blast-holes. Broken rock is loaded by diesel-driven shovels on to 18-cubic-yard-capacity trucks and hauled to the Blubber Bay plant. There the limestone is crushed, sized, and stockpiled or loaded directly into scows. Part of the limestone is burned in a vertical stack kiln at Blubber Bay (other vertical kilns and a rotary kiln are idle), and part is shipped to a burning and processing plant operated by the company in Vancouver. Limestone not required for burning is shipped to pulp-mills, cement plants, and smelters. In conjunction with the kiln at Blubber Bay the company also operates a lime processing and hydrating plant that produces all types of quicklime and hydrated lime for building, industrial, chemical, and agricultural purposes.

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Fogh Property

Location and Accessibility.—Several small quarries and test-pits in the northern part of Lot 9, on the south side of Blubber Bay, are at distances of from a few hundred to 2,000 feet from an old wharf at the northwestern corner of the property, and approximately 1 mile by road from the government wharf on the west side of Blubber Bay.

Geology.—The western half of the property is undertain by limestone of intermediate grades, the continuation of the second member of the Marble Bay formation of the Gypsum Lime and Alabastine property to the west (*see* p. 61), and of the first or westernmost belt of the British Columbia Cement property to the north (*see* p. 67). East of this is the belt of magnesian limestone extending south from the British Columbia Cement property, and east of this again is limestone of intermediate grades, with some foliated, possibly high-calcium, limestone.

At the western edge of the property the strata are gently folded, but eastward the folding becomes more intense and complex. The structure of the eastern part of the property is similar to that of the British Columbia Cement property.

Dykes, generally having an easterly trend, are common, and several small diorite-gabbro stocks outcrop in the north-central part of the property adjacent to the Paris mine.

An area of drift about a quarter of a mile in diameter occurs in the northern part of the property adjacent to the southeastern corner of Blubber Bay. Elsewhere overburden is relatively thin or missing.

The rocks of the western part of the property are fine grained and black. The magnesian limestone in the central part of Lot 9 is fine to medium grained and cream or light brown in colour. The limestone in the eastern part is fine grained to granular, generally grey, and massive or foliated.

Analyses.—The belt of magnesian limestone extending into the property from the north was sampled along an old logging-road northeast of the Paris mine and southeast and south of the abandoned white-rock quarry. Each sample was made up of chips taken at 10-foot intervals for a distance of 100 feet. Dyke rock was excluded from the samples. The analyses follow:—

Distance from—	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O 105° C.
East edge of belt—										
0–100 feet	1.14	0.55	0.86	0.138	14.32	37.86	0.014	0.14	45.33	0.06
100–200 feet	0.70	0.63	0.40	0.121	16.81	36.82	0.011	0.03	44.80	0.04
200–300 feet	0.40	0.78	0.24	0.067	6.59	48.22	0.015	0.03	43.89	0.05
West edge of belt—										
300–400 feet	0.30	0.28	0.19	0.058	2.06	53.75	0.011	0.02	43.40	0.05

No other samples were taken on this property.

Development and Operation.—Lot 9 was held at some time prior to 1908 by Harry Trim, chiefly for the base-metal rights to the Paris mine. The property was subsequently acquired by Messrs. Fogh, Cox, and Johnson. Fogh interested Swedish capital in the possibilities of lime production from the property and had a concrete lime kiln erected for this purpose. Apparently because of failure to locate lime of suitable quality the operation was not a success. In 1929 the Western Lime Products Company, Incorporated, of Seattle, was producing chicken grit and agricultural limestone on the property. In 1931 the property was held by the Petrie Lime Company and leased from that company by Coast Quarries Limited, of Vancouver, who for several months quarried white-rock from a point northeast of the Paris mine. No production has been recorded since 1931. In 1956 the property was held by Industrial Lime Products Limited, of Vancouver.

The largest of the quarries is in the northeastern part of the property. This quarry, approximately 100 by 150 feet in plan, was worked by Coast Quarries Limited for white-rock. In the northwestern part of the property there are two quarries up to 50 feet long and about 30 feet wide and small test-pits are numerous.

Reference

McConnell, R. G. (1914): Texada Island, B.C., *Geol. Surv., Canada,* Mem. 58, p. 66.

British Columbia Cement Company Limited

Location and Accessibility.—The British Columbia Cement Company quarries are situated on Lot 12, east of Blubber Bay. This property is about 1¼ miles by road from the government wharf on the west side of Blubber Bay. The company wharf is situated on the east side of the bay, close to the crushing plant, and is sheltered from all but northwesterly winds.

Several quarries have been opened on this property, two adjacent to the crushing plant, a third on the shore of Blubber Bay one-quarter mile north of the plant, and a fourth near Grilse Point one-half mile northeast of the plant.

Geology.—The limestone beds of Lot 12, unlike those of the opposite shore of Blubber Bay, are squeezed into tight minor folds a few tens of feet across and are faulted. It would prove exceedingly difficult to decipher the general stratigraphy and structure on this property were it not for the systematic programme of sampling and analysis of limestones carried out by the company to delimit areas of high-grade rock. With the aid of the assay plan, however, it has been possible to recognize six more or less well-defined belts of limestone of different grades, each several hundred feet wide, crossing the property from north to south. From west to east these belts are: (1) Limestone of intermediate grades, including both calcium and magnesian limestone, exposed along the shore of Blubber Bay, (2) magnesia-rich limestone which continues southward into Lot 9 (*see* Analyses, above), (3) limestone of intermediate grades, (4) high-calcium and calcium limestone, (5) limestone of intermediate grades, and (6) magnesia-rich limestone, exposed on the east shore of the island.

The fourth belt, composed of high-grade rock, terminates southward with an irregular contact against rock of intermediate grades near the southern edge of the property. The third and fifth belts are thus linked to form a crude horseshoe-shaped area of limestone of intermediate grades. This horseshoe is flanked, in turn, by the areas of magnesia-rich limestone. The distribution of the rocks of the five eastern belts indicates, therefore, the presence of a major plunging fold in which are but three stratigraphic units: (1) A succession of high-calcium and calcium limestones, (2) limestones of intermediate grades, and (3) magnesia-rich limestones.

Diamond-drill cores have been obtained from several places in and adjacent to the surface exposures of high-grade limestone to determine whether the major fold is anticlinal, in which case the high-grade rock would be expected to underlie an area greater than its surface extent, or synclinal, in which case the high-grade rock would be of more limited extent at depth. Of six vertical holes, 100 to 160 feet deep, drilled near the southern contact of the belt of high-grade limestone, two remained in rock of intermediate grades throughout their length, two collared in rock of intermediate grades passed downward into high-grade rock, and two were drilled in high-grade rock throughout their length. The information obtained from these holes thus favours the anticlinal hypothesis. Three holes drilled along the western edge of the same belt indicate that its contact with lower-grade rock dips steeply westward. A gentle westerly dip of the stratification at one point on the surface along the contact suggests that the beds are here not overturned, and again the anticlinal hypothesis is favoured. Four holes drilled along the eastern edge of the belt indicate, however, that the contact here dips steeply westward. Dragfolds overturned to the east occur along the eastern shore of the island, and it is possible that the eastern contact of the high-grade limestone is overturned. No faulting has been detected at either contact. The stratigraphic section appears, therefore, to be made up of high-grade limestone at the base, overlain by limestone of intermediate grades, overlain, in turn, by magnesia-rich limestone, all being exposed in a major southerly plunging anticline. Because of the presence of minor folds and possibly of faults, it is not possible to compute the true stratigraphic thickness of these units, but, judging from the widths of the belts, the thickness of each is probably several hundred feet.

The general similarity of the stratigraphic succession here to that more firmly established elsewhere on the island is marked. Moreover, the eastern belt of magnesia-rich limestone has been traced southeastward to Sturt Bay where it clearly lies at a horizon above the second member of the Marble Bay formation, and can, therefore, be termed the third member. It may also be correlated with the magnesia-rich beds exposed at Cohoe Point. The limestones of intermediate grades exposed in the horseshoe-shaped area apparently underlie the third member, and may, therefore, be referred to the second member; the high-grade limestone at the core of the fold may similarly be referred to the first member. Thinning of the strata at the flanks of the fold may account for the reduction from the 1,500- or 2,000-foot thickness of the second member indicated in the Limekiln Bay and Marble Bay sections to only several hundred feet here. Comparable thickening of the first member at the crest of the fold might be anticipated.

The western belt of magnesia-rich limestone, bounded on either side by limestones of intermediate grades, is believed to mark the site of a closely folded syncline. A geological section across the full width of the property thus indicates an incomplete W-shaped structure, the easternmost limb of which lies beneath the waters of Malaspina Strait.

The limestones are intruded by a diorite-gabbro stock in the northwestern part of the property, and in its vicinity the structure is still further complicated. High-calcium limestone bounds the stock on the southwest and southeast, truncating the western belts of intermediate and magnesia-rich limestones described above. Faulting and possible cross-folding occur in this vicinity. The stock outcrops along the shore of Blubber Bay for a distance of 1,000 feet and extends inland for 200 to 300 feet. Several smaller diorite-gabbro intrusions outcrop in the southeastern part of the property.

Greenstone and diorite dykes are common, especially near the diorite-gabbro stock. The dykes generally trend within a few degrees of east, or north, or northeastward. About half of them are vertical and the rest, with one or two exceptions, dip steeply to the south or east. The dykes are usually resistant to erosion and form conspicuous ribs that extend out beyond the shores as reefs. At the Grilse Point quarry, however, many of the dykes are crushed and sheared and tend to weather down more quickly than the surrounding limestone, thus leaving hollows that fill with surface debris. In the quarry it is not unusual to find that the dykes pinch and swell abruptly both vertically and laterally or split into two or more smaller dykes (*see* Fig. 12).

Overburden is shallow over most of the area except near the southeastern corner of Blubber Bay.

In the southwestern part of the property, where the limestone is less closely folded than elsewhere, it is fine grained and generally black. Magnesia-rich limestone beds, however, tend to be cream-coloured throughout. The high-grade limestone of the core of the major fold is generally granular, foliated, and grey in colour.

The foliation of this high-grade limestone is apparently related to the folding; it tends, in general, to be parallel to the axial planes of the minor folds, and is better developed on the flanks of the folds than on their crests. In the northern part of the property the foliation dips steeply to the east, in the southern part it dips, in general, steeply to the west. Where, as at the Grilse Point quarry, the foliation dips into, rather than out of, a quarry face, it leads to difficulties in the clean and efficient breaking of the limestone in primary blasting.

White-rock is developed locally, and although in many places it parallels foliation, in other places it crosscuts any foliation and is clearly related to fractures.

Analyses.—Samples, each made up of chips taken at 10-foot intervals across a width of 100 feet, were obtained in the central part of the property across the full width of the belt of high-grade limestone. Dyke rock where encountered was omitted in sampling, but some white to cream-coloured feldspathic material, of uncertain origin, is included, and leads to an increase in the amounts of insoluble matter and R_2O_3.

West to East	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
0–100 feet	0.16	0.33	0.12	0.013	0.34	54.98	0.012	0.04	43.98	0.08
100–200 feet	5.02	0.87	0.35	0.025	0.90	51.27	0.059	0.07	41.41	0.12
200–300 feet	0.16	0.45	0.11	0.009	0.28	55.17	0.023	0.03	43.87	0.07
300–400 feet	8.64	2.13	0.33	0.019	0.80	48.80	0.052	0.02	38.99	0.12
400–500 feet	0,20	0.12	0.06	0.026	0.32	55.14	0.023	0.03	44.10	0.08
500–600 feet	0.60	0.24	0.14	0.026	1.84	52.75	0.018	0.03	44.23	0.07

Development and Operation.—At some time in the nineties of the last century a pot-kiln was erected on the east shore of Blubber Bay for Carter Cotton, then owner of Lots 12 and 13, but because of the inferior grade of limestone quarried near by and of the limited market for lime the operation was abandoned. Lot 12 was later acquired by the British Columbia Cement Company, which in 1930 commenced quarrying limestone to augment the production from its Bamberton quarry for the Bamberton cement plant. The quarrying was begun in two openings close to the crushing plant and wharf, but it soon encountered, as did Cotton's operation, inferior grades of limestone. A narrow-gauge railway was then laid northward along the shore of Blubber Bay for a distance of 1,000 feet and a new quarry opened on the belt of high-grade limestone at the southern contact of the diorite-gabbro stock. Quarrying was continued here until most of the readily available high-grade limestone above the track grade was extracted. The railway was then extended for an additional 1,250 feet along the shore, past the diorite-gabbro stock, to the exposures of the main belt of high-grade limestone, where a new quarry, still in operation, was opened. In 1953 the railway was replaced by a truck-road.

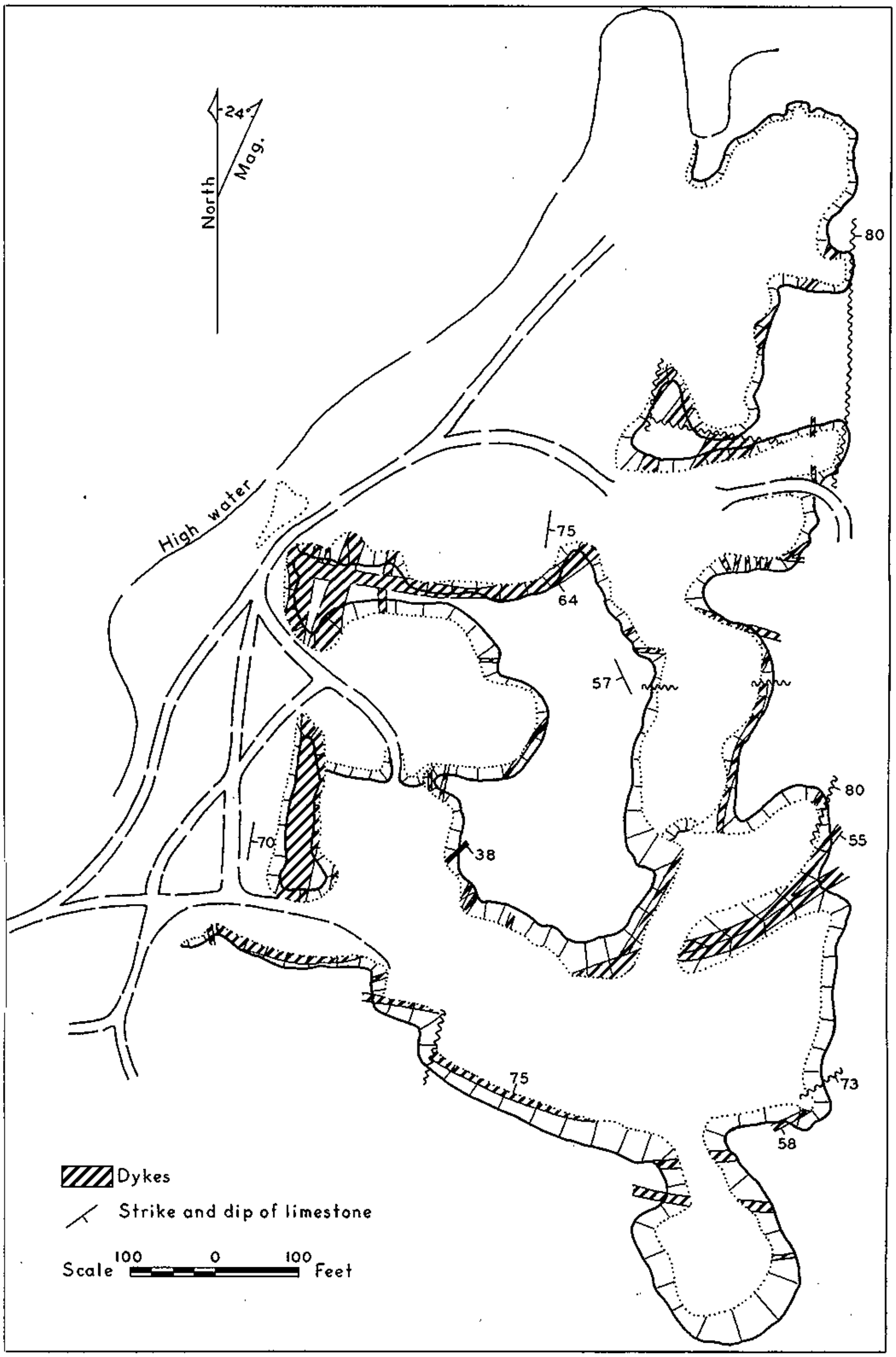

Figure 12. British Columbia Cement quarry, Grilse Point.

In August, 1956, all production was coming from the large Grilse Point quarry. This quarry had an irregular face about 1,500 feet long from north to south and from 10 to 110 feet high, which had been worked inland for distances of from 300 to 1,000 feet from the shore (*see* Fig. 12). Dykes are numerous in the quarry, and in the course of quarrying as much dyke-contaminated rock as possible is left in place. As a result the plan of the quarry is very irregular. In order to obtain the highest possible quarry face, at the north end of the quarry the floor has been worked down to a level less than 10 feet above high tide, with the result that when an exceptionally high tide is accompanied by a strong west wind this part of the quarry is inundated.

A Bucyrus-Erie churn drill is used to drill vertical blast-holes. These holes are spaced at 20-foot centres with 25 feet of burden, and are drilled 9 feet below the grade line of the quarry floor. Broken rock is loaded by diesel-driven shovels into 15-ton-capacity Euclid trucks and transported to the crushing plant at the company wharf. At the crushing plant a 36- by 48-inch Dominion jaw crusher discharges a 5-inch product that an overhead conveyor moves to a stockpile. An underground conveyor beneath this stockpile moves material to scows for shipment as required. In 1956, 186,300 tons of limestone was produced from this quarry.

McMillin Lime & Mining Company

Location and Accessibility.—The limestone deposit held by the McMillin Lime & Mining Company is situated in the North Half of Lot 3, adjacent to Eagle Bay on the east coast of the island 1½ miles northwest of Vananda Cove. Eagle Bay itself is small, but is large enough to accommodate a tug and scow and affords good protection from storms. A wharf on the east side of the bay near its head is now unusable. The bay is about 3 miles from Vananda by way of the Blubber Bay road and a branch road across the property.

Geology.—Three southeasterly trending belts of limestone of different grades, each several hundred feet wide, cross the property. The belt on the southwest consists essentially of high-calcium limestone, the middle belt of mixed calcium and high-calcium limestone, and the belt on the northeast of magnesia-rich limestone. The latter is exposed along the east shore of the island from Grilse Point on the north to Sturt Bay, southeast of this property, and is included in the third member of the Marble Bay formation. The southwestern and middle belts evidently correspond respectively to the fourth and fifth belts of limestone of the eastern part of the British Columbia Cement Company property 2½ miles to the northwest and, presumably, to the first and second members of the Marble Bay formation. The magnesia-rich limestone underlies about one-half of the area of the property and the high-calcium limestone about one-sixth.

The strata exposed in Eagle Bay and on adjacent shores has been warped into a series of minor open folds, usually a few tens of feet across, and in most cases plunging gently northwestward. Dips rarely exceed 40 degrees. A few minor faults have been observed.

Stratification is not apparent inland, however, and only on the basis of the correlation of belts between this and the British Columbia Cement Company property is the structure assumed to consist of a major anticline which exposes underlying high-calcium limestone at its core.

Greenstone dykes are present in the property but are by no means as common as in the Blubber Bay area.

Overburden is thin or missing over much of the property. Two large swamps, each several hundred feet wide and more than 1,000 feet long, occupy a part of the property, and overburden may be deep in linear depressions or strike-valleys cutting across the property.

Analyses.—A series of samples of limestone have been obtained from the property, each composed of chips at 20-foot intervals across a width of 200 feet measured at right angles to the trend of the belts. The sampled section starts at a point about 500 feet south 10 degrees west of the head of Eagle Bay, and extends south 40 degrees west to the end of the good exposures, a point about 600 feet south 80 degrees east of the southwest corner of the property. Dyke rock was not included in the samples.

Distance from Northeast End of Section	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
Belt of mixed calcium and high-calcium limestone—										
0–200 feet	0.50	0.14	0.16	0.028	0.43	55.80	0.014	0.05	43.15	*Nil*
200–400 feet	0.40	0.14	0.12	0.016	1.30	53.98	0.015	0.03	43.76	0.04
400–600 feet	2.00	0.50	0.39	0.023	2.28	52.97	0.016	0.11	41.78	0.02
600–800 feet	1.00	0.38	0.30	0.065	5.91	49.14	0.020	0.05	43.48	0.03
Belt of high-calcium limestone—										
800–1,000 feet	0.50	0.16	0.12	0.023	0.90	54.59	0.022	0.08	43.75	0.04
1,000–1,200 feet	0.50	0.15	0.08	0.023	0.25	55.19	0.019	0.03	43.76	0.05
1,200–1,400 feet	0.30	0.09	0.07	0.028	0.36	55.19	0.035	0.03	43.72	0.02
1,400–1,600 feet	0.40	0.23	0.15	0.048	0.40	55.59	0.017	0.04	42.97	0.04
West end of sampled section—area of drift cover, including scattered outcrops of limestone of intermediate grades.										

Development and Operation.—The deposit was acquired from W. S. Planta in 1944 by the McMillin Lime & Mining Company, headed by P. V. McMillin, of the Roche Harbor Lime & Cement Company, Roche Harbor, Wash. During the winter of 1944–45 the company completed an examination of the property and constructed a wharf at Eagle Bay and a road leading to this point from the system of roads already existent on the island. No further development had been done to the end of 1956, and the wharf was then in a state of disrepair.

Marble Bay Quarry*

Location and Accessibility.—Limestone is quarried on Lot 1 near the west shore of Marble Bay, the south arm of Sturt Bay. A wharf and good shelter for shipping are available adjacent to the quarries. The property is less than 1 mile by road from Vananda.

One of the original quarries is about 175 feet west of the old lime kiln on the west side of Marble Bay. Two quarries, formerly worked separately but now joined and operated as one, form a working face that extends from 300 to 1,000 feet southwest of the kiln. Two small test-quarries are on the flat above and behind the main quarry, one 200 feet to the south and the other 200 feet to the west.

Geology.—The quarries are in the upper part of the second member of the Marble Bay formation and are probably 2,000 feet or more above the base of the limestone succession. The more than 200 feet of strata exposed in the quarries are made up of calcium and magnesian limestone with some high-calcium beds; calcium limestone is generally predominant.

The rocks in the quarry face are moderately folded and are faulted. A gentle anticline in the east half of the quarry grades into a southwesterly dipping monocline toward the west. Both folds plunge to the southeast at low angles. Vertical movement along the faults appears to have been small, and the amount of horizontal movement is unknown. One fault at the east end of the quarry strikes northwest and dips steeply northeast, two near the centre of the quarry strike north and dip steeply east, and one in the southwest corner of the quarry strikes slightly north of west and dips steeply south.

A small diorite-gabbro stock is exposed along the shore adjacent to the lime kiln for about 250 feet and extends inland for an unknown distance. A 10-foot wide north-

* *See* Introduction, page 7.

easterly striking vertical diorite dyke projects out from the face near the west end of the quarry. Four other dykes—three near the centre of the face and one at the east end—consist of sheared greenstone and have a northerly trend.

Overburden is rarely more than a few feet deep.

The colour of the rock ranges from black to light grey. Magnesian varieties are pale brown or, where serpentine and other magnesian silicates have developed, greenish. Most of the rock is moderately fine grained.

Analyses.—In 1945 Mathews took samples from the old quarry west of the lime kiln and from what would now be the west and east ends, respectively, of the main quarry. These samples consisted of chips taken at 2-foot intervals across 20 feet of beds with dyke rock excluded. Samples A and B were taken in 1956 by McCammon from the two small quarries behind the main face. Sample A consisted of chips taken across 15 feet of beds in the west quarry, and sample B consisted of chips taken across 20 feet of beds in the south quarry.

	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
Old quarry, west of lime kiln—										
Top	0.72	0.27	0.26	0.081	2.87	54.08	0.009	0.04	42.03	0.03
Bottom	0.68	0.09	0.14	0.023	3.89	53.50	0.012	0.06	42.08	0.04
Main quarry, west end—										
Top	1.44	0.18	0.20	0.040	4.05	52.47	0.013	0.05	42.00	0.06
Bottom	2.60	1.42	0.62	0.098	5.71	48.74	0.013	0.06	41.19	0.07
Middle section—										
Top	0.52	0.25	0.23	0.035	1.70	53.78	0.015	0.08	43.22	0.03
Middle	0.30	0.11	0.22	0.026	2.72	54.49	0.015	0.07	42.36	0.05
Bottom	0.44	0.12	0.27	0.030	3.69	52.87	0.015	0.06	42.87	0.06
East end—										
Top	0.68	0.34	0.14	0.014	4.00	51.26	0.013	0.04	43.52	0.04
	2.26	0.81	0.35	0.028	11.90	43.10	0.017	0.09	41.63	0.01
	0.90	0.13	0.12	0.016	0.75	55.86	0.007	0.04	42.35	0.07
Bottom	0.90	0.19	0.10	0.025	1.11	54.81	0.010	0.04	42.53	0.06
Southeast quarry—										
Top	2.40	1.94	0.62	0.023	5.35	48.84	0.033	0.20	41.10	0.07
Middle	2.10	1.50	0.58	0.032	17.05	37.03	0.024	0.15	42.03	0.02
Bottom	1.30	0.58	0.30	0.058	5.72	49.14	0.016	0.10	42.94	0.04
A	2.62	0.28	0.22	0.006	5.18	48.50	0.012	0.08	43.20	0.15
B	2.24	0.64	0.27	0.041	4.61	49.20	0.009	0.03	43.30	0.12

Development and Operation.—In 1898 or 1899 William Christie and J. J. Palmer, of the Marble Bay Company, built the lime kiln on the west shore of Marble Bay and operated quarries and the lime plant for several years. As the quality of lime produced from this property was not high, the Marble Bay Company acquired Lot 23 on Limekiln Bay and transferred its operations to that area. During or after World War I the Marble Bay quarries were reopened by the Tacoma Steel Company, who shipped limestone to Powell River for use in the pulp-mill. In 1922 the Powell River Company acquired Parcel A of Lot 1, which includes the present quarry, and operated it until 1933. At this time the Powell River Company was able to get a more satisfactory limestone from a quarry newly opened east of Vananda by F. J. Beale, and the Marble Bay quarry was abandoned. In December, 1945, the Marble Bay quarry was reopened by the Powell River Company under the supervision of Stanley Beale, son of F. J. Beale. Stanley Beale operated the quarry under the name Marble Bay quarry until 1951, when the name was changed to W. S. Beale Limited quarry. This name was changed in 1955 to W. S. Beale (1955) Ltd.

The westernmost quarry is about 50 feet in diameter with walls 15 feet high. The main quarry has an over-all length of nearly 1,000 feet with a maximum face height of 90 feet. The two small quarries south and west of the main one are about 50 feet in diameter with 10-foot-high faces.

All production now comes from the main quarry. The quarry is worked with one face the full 90 feet high. Air leg drills are used to drill horizontal blast-holes parallel to the face. Broken rock is loaded by diesel shovel into trucks that transport the rock to a ramp and dump it on to a screen which separates pulp rock from the finer " spalls." Pulp rock, 5 to 18 inches in diameter, is shipped to pulp-mills, chiefly at Powell River, and spalls go to the Tacoma smelter. In 1956 seven men produced 38,282 tons of limestone at this quarry.

References

Carmichael, H. (1899): *Minister of Mines, B.C.,* Ann. Rept. 1899, p. 804.
McConnell, R. G. (1914): Texada Island, B.C., *Geol. Surv., Canada,* Mem. 58, p. 96.

BEALE QUARRIES LIMITED

Location and Accessibility.—The workings of Beale Quarries Limited are on and near the northeastern shore of Texada Island, from half a mile to a mile east of Vananda, on Lots 7 and 499, and are accessible by road from Vananda. Barges may be loaded directly from a wharf on the unsheltered shore at the site of No. 1 quarry. Protection for shipping is found at Vananda Cove, 1 mile to the west, which is of limited size and exposed to northerly and northwesterly winds, and in Sturt Bay, 1¼ miles to the west, which is larger and more sheltered.

Six quarries have been opened by the company, Nos. 1 and 2, adjacent to one another, on the exposed shore cliffs about 1 mile east of Vananda, and Nos. 3, 4, and 5 quarries about 1,800 feet southwest, 2,000 feet west, and 2,000 feet southeast, respectively, of Nos. 1 and 2 quarries. A white-rock quarry is situated 1,500 feet south of No. 5 quarry.

Geology.—The quarries are in the lower part of the Marble Bay formation. Quarry No. 5 lies approximately 400 feet stratigraphically above the base of the Marble Bay formation and in the upper part of the first member. Quarry No. 2 may include beds both above and below the horizon of quarry No. 5. Quarry No. 1 is in badly folded and faulted beds at or above the horizons of quarry No. 2. Quarries Nos. 3 and 4, both at about the same horizon, lie within the second member probably several hundred feet above its base. The first member of the Marble Bay formation is here made up almost entirely of high-calcium limestone. As would be expected with its limited range in composition, physical characteristics are likewise relatively uniform and stratification is not readily apparent.

Several magnesian beds a few inches to a few feet thick outcropping in the Nos. 1 and 2 quarries are in the upper part of the first member. They make up a small fraction of the section, only four beds being recognized on the cliff and quarry faces across an exposed width of almost 1,000 feet.

Higher parts of the section in the second member, exposed in Nos. 3 and 4 quarries, are made up of alternating beds of calcium and magnesian limestone, the former generally predominating, cut by a network of calcite and dolomite veinlets. Stratification can as a rule be distinguished in these rocks.

In the eastern part of the limestone belt, from No. 2 quarry to the base of the formation, the strata dip westward at an angle of about 40 degrees. In No. 2 quarry, however, the westward dip steepens, and in the western part of this quarry and in No. 1 quarry the strata are apparently highly folded and faulted. This folding and faulting may be related to the intrusion of the quartz-diorite stock which adjoins No. 1 quarry on the west. Southwest of the stock, as at quarries Nos. 3 and 4, moderate southwesterly dips of the strata prevail.

Faults are not apparent in the eastern part of the property but are abundant in quarries Nos. 1 and 2. The pattern of faulting here has not been deciphered. The quartz diorite is cut by faults trending approximately south 70 degrees east and dipping steeply southward near both the west end of No. 1 quarry and the Little Billie mine (Stevenson, 1944).

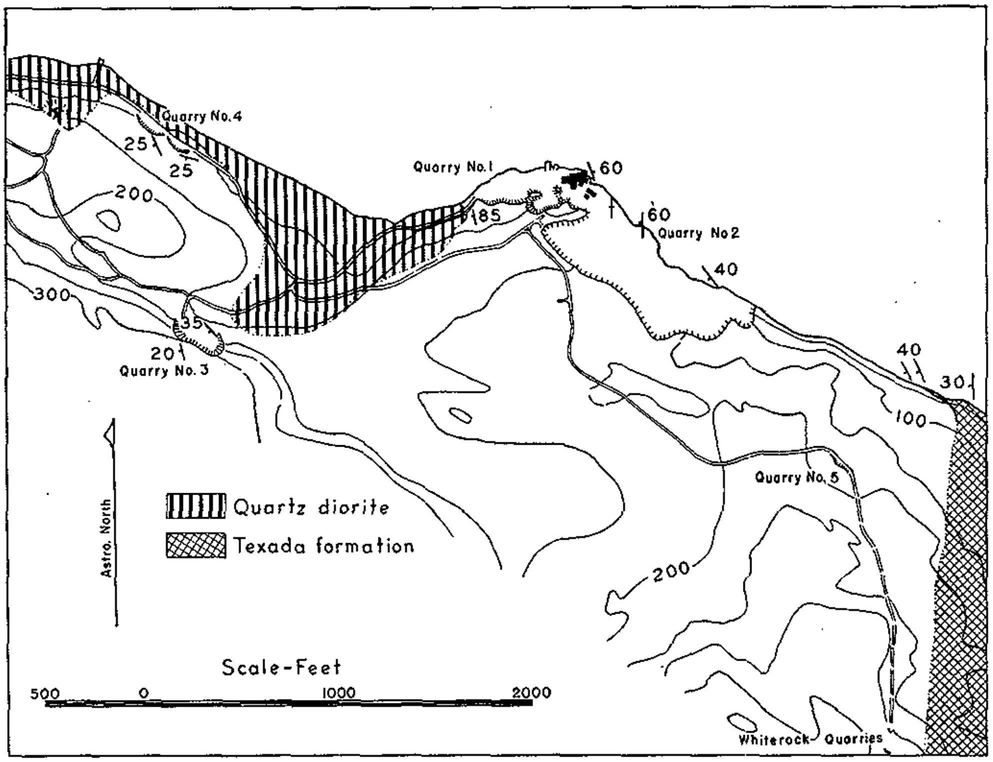

Figure 13. Beale Quarries, Vananda.

Greenstone dykes are present here, as elsewhere on the northern part of Texada Island, but they are not, in general, as common as in the Blubber Bay area. Nearly all the dykes cutting the volcanics underlying the limestone in this vicinity trend eastward, but no one trend prevails in those cutting the limestone itself. They range in width from a few inches up to about 20 feet, and some irregular masses are still larger. Most of the dykes in quarries Nos. 1 and 2, unlike those elsewhere on the island, are crushed, and, being more susceptible to erosion than the adjoining limestone, are marked by shallow ravines which are partly filled with limestone blocks fallen from their walls. The dykes do not outcrop, therefore, except on the quarry walls and on the sea cliffs. Some, at least, of these dykes may have been intruded prior to the quartz diorite, and it is possible, therefore, that the crushing, like the folding and faulting in the limestone, accompanied the intrusion of the stock. One easterly trending greenstone dyke cuts both quartz diorite and limestone west of No. 1 quarry.

The quartz diorite outcrops along the shore west of No. 1 quarry for a distance of more than 2,500 feet, and extends inland for a maximum distance of about 750 feet. It is clearly responsible for the recrystallization of the limestone around its borders and may be responsible for much of the folding and faulting in the same area.

Overburden is thin or missing over much of the area, except in the ravines and hollows on the sites of crushed greenstone bodies.

The limestone is fine grained and black in No. 5 quarry, more than 2,000 feet from the nearest outcrop of quartz diorite, but along the shore and in the other quarries the limestone is grey and medium to coarse grained. The grain size of the limestone becomes, in general, progressively greater toward the quartz-diorite stock until within a few feet of this intrusive individual crystals of calcite reach 1½ inches in diameter. Magnesian beds have, however, resisted this recrystallization and even adjacent to the quartz diorite are relatively fine grained.

Fine-grained white-rock, similar to that occurring in the Gypsum Lime and Alabastine quarries, has been recovered from a local occurrence 1,500 feet south of No. 5 quarry.

Analyses.—Samples were taken of uniform chips at the following intervals across specified distances. In Nos. 2 and 5 quarries and in the shore cliffs east of No. 2 quarry the stratification was not sufficiently apparent for sampling to be related to the stratigraphic section. For this reason, a continuous succession of samples was taken along the shore cliffs and quarry faces which, in general, trend northwestward, cutting across stratification at an oblique angle. Therefore, the distances across which these samples were taken probably are considerably greater than the stratigraphic thickness of beds represented in them. In quarries Nos. 3 and 4, where stratification was apparent, the samples were taken across the beds, and the distances measured are the stratigraphic thickness of beds represented.

Length	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
No. 4 Quarry[1]										
Top of section at west end of quarry—										
30 feet	0.24	0.65	0.02	0.008	1.93	52.66	0.013	0.03	44.55	0.04
30 feet	0.48	0.97	0.11	0.009	2.79	52.16	0.017	0.07	43.34	0.06
30 feet	0.44	3.13	0.06	0.008	5.24	50.15	0.008	0.03	41.31	0.05
30 feet	0.44	1.08	0.06	0.007	4.47	52.98	0.013	0.04	41.18	0.01
Base of section at east end of quarry.										
No. 3 Quarry[1]										
Top of section—										
30 feet	0.50	0.74	0.11	0.059	2.11	52.67	0.013	0.04	43.56	0.05
30 feet	0.38	0.61	0.07	0.023	2.68	52.26	0.013	0.05	43.64	0.04
30 feet	0.44	1.19	0.10	0.008	4.23	51.76	0.017	0.05	42.08	0.05
Fault.										
30 feet	0.30	0.49	0.19	0.012	2.83	53.68	0.020	0.08	42.25	0.06
30 feet	0.64	0.14	0.28	0.018	0.83	53.47	0.017	0.09	44.32	0.04
30 feet	1.68	1.03	0.15	0.020	9.05	47.12	0.011	0.04	41.09	0.06
30 feet	0.50	0.66	0.19	0.014	1.92	53.58	0.015	0.08	43.00	0.05
Base of section.										
No. 2 Quarry[2]										
West end of sampled section—between No. 2 and No. 1 quarries opposite the compressor-house—										
100 feet	0.48	0.17	0.11	0.041	1.77	54.31	0.008	0.03	43.48	0.03
Dyke at west end of No. 2 quarry—										
20 feet	0.20	0.11	0.18	0.026	2.82	54.08	0.017	0.04	42.61	0.07
50 feet	0.20	0.13	0.05	0.006	0.60	55.86	0.019	0.01	43.00	0.06
15 feet	0.20	0.15	0.06	0.007	0.50	55.75	0.008	0.03	43.30	0.04
50 feet	0.10	0.16	0.03	0.007	0.56	55.54	0.008	0.03	43.70	0.07
50 feet	0.50	0.34	0.05	0.010	0.68	55.43	0.006	0.01	42.61	0.07
50 feet	0.34	0.14	0.05	0.009	0.53	55.75	0.006	0.02	43.06	0.06
50 feet	0.18	0.14	0.05	0.012	0.68	55.43	0.006	0.02	43.40	0.04
50 feet	0.36	0.23	0.04	0.005	0.50	55.54	0.005	0.03	43.25	0.08
40 feet	0.50	0.35	0.05	0.008	0.29	55.54	0.004	0.01	43.04	0.07
50 feet	0.50	0.32	0.08	0.012	1.30	54.39	0.005	0.04	43.40	0.06
45 feet	0.40	0.20	0.05	0.013	0.65	55.54	0.006	0.01	43.00	0.08
East end of No. 2 quarry, July, 1944.										
Shore Cliffs East of No. 2 Quarry[3]										
100 feet	0.30	0.28	0.03	0.006	0.56	55.65	0.007	......	42.96	0.05
100 feet	0.30	0.17	0.03	0.004	0.40	55.75	0.007	......	43.20	0.04
100 feet	0.34	0.15	0.04	0.003	0.36	55.98	0.007	0.03	43.22	0.09
40 feet	0.34	......	0.02	0.003	0.33	56.00	......	0.02	43.42	0.08
East end of sampled section.										
No. 5 Quarry[2]										
70 feet	0.36	0.44	0.09	0.014	1.30	55.23	0.007	0.03	42.33	0.04

[1] Samples consist of chips taken at intervals of 3 feet.
[2] Samples consist of chips taken at intervals of 5 feet.
[3] Samples consist of chips taken at intervals of 10 feet.

Development and Operation.—Quarrying in this area was begun in 1933 by F. J. Beale, who had previously operated the Powell River Company quarry at Marble Bay. Subsequently Beale sold the property to Beale Quarries Limited, who continued to operate it under the management of Balfour Guthrie & Company (Canada), Limited. In early 1956 the Lafarge Cement Company bought the Beale Quarries property and leased some adjoining ground.

In August, 1956, only No. 2 quarry was being worked. It was 1,100 feet long, had a maximum face height of 110 feet, and had been advanced inland as much as 500 feet from the shoreline. The greater part of the quarry was being worked in two benches, each with 50-foot faces. In the southwest corner, however, a small secondary bench was worked between the main benches and a second small bench was being started halfway up the face of the upper bench.

Quarry No. 1 was abandoned because of the excessive amount of greenstone encountered in it. Quarries Nos. 3 and 4 were abandoned because of inferior grade of limestone. Quarry No. 5 was abandoned because of its distance from loading facilities.

In the quarrying procedure wagon drills are used to drill blast-holes. Broken rock is loaded by diesel shovels and transported by truck to a crushing plant. Rock larger than 5 inches in diameter is shipped to pulp-mills and the undersize is milled to be sold as crushed or pulverized limestone. A conveyor system is used to load scows. When weather is suitable, a scow may be brought to the dock and loaded. During stormy weather scows are kept at Sturt Bay. A tug is maintained by the company to tow scows from the quarry wharf to Sturt Bay at any time during the day if a storm develops, or in the routine operation to tow the scow to shelter in the evening and to return it to the quarry next day or when weather permits. In this way it is possible to load scows on an exposed shoreline and at the same time provide adequate shelter for the scows. Rarely, even during winter, are loading operations held up for more than a few days by a continuous period of stormy weather.

In 1956 about 129,000 tons of limestone was produced, and thirty-four men were employed in the crushing plant and quarry.

Johnson Quarries*

Location and Accessibility.—Two small adjoining quarries are situated near the boundary of Lots 69 and 492 about 1,000 feet south 15 degress west of the outlet of Priest Lake. They are about 2 miles by road from the Sturt Bay and Vananda wharfs.

Geology.—The quarries are in the second member of the Marble Bay formation at an undetermined distance above its base. The succession exposed in the quarries is made up of calcium limestone interbedded with minor amounts of magnesian limestone. The beds are slightly arched. In the northwest corner of the west quarry they dip westward at about 20 degrees, and in the southeast corner of the same quarry they dip southward at less than 10 degrees. The rock is mostly fine grained and dark grey to black with some light-grey bands.

Two northeastward-striking vertical dykes of badly fractured and pyritized porphyry are exposed in the west quarry. One dyke is exposed for 60 feet along the southeast face and the other is exposed for 50 feet along the top of the northwest face.

The rock in both quarries is highly jointed. On a knoll 50 feet east of the east quarry the limestone consists of recemented breccia.

Analyses.—Samples 1 and 2 were taken by Mathews in 1945, presumably from the west quarry. No. 1 was taken across the upper 12 feet and No. 2 across the lower 15 feet of the face at that date. Samples 3 and 4 were taken by McCammon in 1956. No. 3 was taken across 38 feet of beds in the southwest face of the west quarry, and No. 4 was taken across 25 feet of beds in the face of the east quarry.

* *See* Introduction, page 7.

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
No. 1	1.00	0.24	0.13	0.037	3.54	50.87	0.014	0.04	44.19	0.01
No. 2	1.92	0.20	0.20	0.019	1.62	52.16	0.017	0.04	43.57	*Nil*
No. 3	1.86	0.10	0.16	0.005	1.68	52.70	0.017	0.06	43.30	0.14
No. 4	2.46	0.62	0.42	0.009	4.78	48.40	0.008	0.05	43.40	0.15

Development and Operation.—The original quarry on this site was opened and operated for a short time in 1945 by Stanley Beale, of Vananda, to supply pulp rock for the Powell River Company. Later the quarry was reopened and enlarged and a second small quarry was started east of and adjoining the original one. Both quarries were soon abandoned. In 1956 the Ideal Cement Company, of Denver, is reported to have bought the property.

In August, 1956, the west quarry was 140 feet long and 100 feet wide with a 38-foot-high face. The east quarry was 50 feet in diameter with a maximum face height of 25 feet.

S. Beale Black-rock Quarries*

Location and Accessibility.—Three small " black-rock " quarries have been worked on Lot 25. On the old road to the iron mines, now used as a logging-road, there is a north-south and east-west road junction near the centre of Lot 25. One quarry is a quarter of a mile north of the cross-roads, one is a quarter of a mile south of the cross-roads, and the third is about the same distance west of the cross-roads. The quarries are approximately 1½ miles from the iron mines wharf and 3½ miles from the Vananda and Sturt Bay wharfs.

Geology.—The quarries are in the upper part of the first member of the Marble Bay formation a few hundred feet above the base of the limestone succession.

In the north quarry the limestone is uniform fine-grained black rock that weathers light grey. On fresh surfaces no stratification is visible, but on the weathered surfaces of prominent vertical joint-planes in the quarry face a lineation, apparently bedding, strikes north 25 degress east and dips 29 degrees west. What appears to be cross-bedding indicates that the tops of the beds are to the west. Some small indistinct inclusions on the weathered face near the quarry floor may be fossils. No dykes are exposed in the quarry.

Mathews states that the rock in the west quarry is fine grained and black, closely resembling the black limestone at Blubber Bay. Several joints dip about 10 degrees to the north similar to the bedding fractures in the Gypsum Lime and Alabastine quarries at Blubber Bay. No other indications of stratification are evident. One dyke of undetermined thickness, that strikes south 20 degrees east and dips 80 degrees west, forms the east wall of the quarry.

The rock in the south quarry is similar to that in the other quarries. No stratification is visible and no dykes are exposed in the quarry. Joints are numerous and closely spaced.

Analyses.—In 1945 Mathews took three samples from the west quarry. No. 1 was taken across the top 9 feet of strata bounded by " bedding fractures." No. 2 was taken across the middle 6 feet, and No. 3 across the lowest 4.2 feet of strata. In 1956 McCammon took sample No. 4 across 31 feet of strata exposed in the face of the north quarry and sample No. 5 across 23 feet from the floor to the top of the face of the south quarry.

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
No. 1	0.20	0.15	0.03	0.010	0.43	55.39	0.022	0.03	43.66	0.01
No. 2	0.44	0.17	0.02	0.005	0.40	55.39	0.010	0.04	43.36	0.01
No. 3	0.50	0.14	0.05	0.007	0.43	55.29	0.009	0.04	43.27	0.02
No. 4	0.78	0.22	0.07	0.003	0.24	54.3	0.004	0.01	43.7	0.14
No. 5	0.76	0.26	0.04	Trace	0.15	54.5	0.005	Trace	43.7	0.10

* *See* Introduction, page 7.

Development and Operation.—Stanley Beale, of Vananda, opened up and worked these quarries for short periods. In 1956 it was reported that the Ideal Cement Company, of Denver, acquired Lot 25. In July, 1945, the west quarry face was 35 feet across, 15 feet high, and had been advanced 40 feet from its initial position. In August, 1956, the north quarry was 80 feet in diameter with a maximum face height of 31 feet, and the south quarry was 100 feet in diameter with maximum face height of 35 feet.

WHITE-ROCK DEPOSITS

The mode of occurrence of white-rock has already been mentioned (p. 63). It apparently consists, for the most part at least, of dark limestone bleached by solutions which have permeated along fractures and soaked into adjacent rock. Most of these fractures are no longer open, hence the bleaching is evidently not related to the existing solution channels or to the present land surface. Workable deposits exist at any place in which extensive fracturing has been accompanied by sufficient bleaching to create a body of white-rock large enough and free enough from residual masses of darker limestone to permit economic quarrying and marketing. Impurities, other than iron, which might stain the rock, and dark minerals, are not detrimental.

The price per ton of clean white-rock is considerably higher than that of ordinary limestone. Therefore, deposits of white-rock smaller and more remote than any commercial deposit of ordinary limestone may be worked profitably. No very extensive bodies of clean white-rock are known on the island, but many smaller masses have been worked. White-rock was produced by the Pacific Lime Company from the western part of Lot 13; by Coast Quarries Limited from Lot 9; by B.C. Cement Company from a body on Lot 12 at the southwest contact of the gabbro-diorite stock on the shore of Blubber Bay; by Beale Quarries Limited from a body south of quarry No. 5; by S. Beale from Lot 423; and by various individuals from numerous points up to 1½ miles south and southeast of Vananda. Present production comes from the McKay quarry.

MCKAY QUARRY*

Location and Accessibility.—The McKay quarry is near the centre of Lot 500, a short distance northeast of the road from Vananda to Raven Bay. It is 2 miles by road southeast of Vananda.

Geology.—This quarry is in the lower part of the Marble Bay formation, probably near the top of the first member. The exposures in the quarry consist of irregular masses of white-rock in black-rock. No regular zoning pattern is apparent. Contacts between the two colours are sometimes sharp and sometimes gradational. No bedding is discernible, although thin dark vertical streaks that strike west of north are present in some of the white-rock. All of the rock is fine grained.

Several faults are visible in the quarry faces. All strike within a few degrees of east and are either vertical or have steep southerly dips. A fault contact between the Marble Bay formation and Texada volcanics is within a few hundred yards to the southeast.

No dykes are exposed in the quarry. Overburden is shallow.

Analyses.—Two samples were taken for analysis. Sample No. 1 consisted of chips of white-rock taken at random throughout the quarry. Sample No. 2 consisted of random chips of black-rock.

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
No. 1	0.78	0.06	0.04	0.003	0.47	54.7	0.018	0.01	43.6	0.12
No. 2	0.68	0.06	0.11	0.002	0.36	54.9	0.010	0.02	43.7	0.12

* *See* Introduction, page 7.

Development and Operation.—Don McKay, of Vananda, has operated this quarry for several years. The quarry is worked selectively to remove the white-rock and leave as much as possible of the black-rock standing. For this reason the shape is very irregular. In August, 1956, the workings consisted of a bottom section 150 feet long and 50 feet wide; 12 feet above the bottom floor was a second level 50 feet long and 30 feet wide; and 22 feet higher still was a top level developed as two separate adjacent openings, each about 100 feet long and 60 feet wide. The face of the top level had a maximum height of 70 feet.

The white-rock is trucked to a crushing plant at the Vananda dock, where it is crushed for stucco dash and ground for whiting. Dark rock is sold for pulp rock. In 1956 about 3,000 tons of white limestone and 4,500 tons of dark limestone were quarried.

Texada Mines Property*

Location and Accessibility.—The Texada Mines Ltd. property is on the west coast of Texada Island 3 miles northwest of Gillies Bay. There is a good road from the property to Gillies Bay and from Gillies Bay to Vananda. The company maintains a wharf at the property to load iron ore into deep-sea ships.

Geology.—The company mines iron by the open-pit method from deposits associated with a quartz-diorite intrusion that is near the contact between the Marble Bay limestone formation and the Texada volcanics. The northern part of the property is largely underlain by Marble Bay limestone which is cut by scattered dykes.

At the Lake pit limestone formed a capping over the orebody. In preparing to mine the iron ore the limestone was stripped off and dumped separate from the other waste materials. The dump contains at least 100,000 tons of fairly clean limestone in pieces ranging in diameter from 1 inch to 3 feet. The rock is medium to fine grained and is mostly black with some white.

Analyses.—The mining company has drilled several 200-foot-deep diamond-drill holes at various places to test the limestone. Analyses of the drill cores show the rock to be a very uniform high-calcium limestone averaging greater than 54 per cent calcium oxide, less than 1 per cent magnesium oxide, and very low in manganese.

The analysis of a sample consisting of equal-sized chips taken at random from the surface of the limestone dump follows: Insol., 2.30; R_2O_3, 0.22; Fe_2O_3, 0.09; MnO, 0.005; MgO, 0.02; CaO, 53.4; P_2O_5, 0.008; S, 0.03; Ig. Loss, 42.8; H_2O, 0.08.

DAVIE BAY LIMESTONE BELT

Location and Accessibility.—A northwestward-trending belt of limestone, 4 miles long and as much as 1 mile wide, exists near the west coast of Texada Island in the vicinity of Mouat (Lower Gillies) and Davie Bays. It lies 10 to 15 miles southeast of Vananda, the nearest regular port of call for coastal steamers. Davie Bay can be reached by road from Vananda.

Mouat Bay has an exposed and shelving shore, and although the hulk of the old Canadian Pacific steamer "Princess Beatrice" has been beached there to serve as a breakwater for booming operations, no suitable shelter exists for tugs and scows. Davie Bay is well sheltered and though of limited size is suitable for tugs and scows if not for larger vessels.

Geology.—As stratification has been found nowhere in the limestone belt, direct evidence of its relationship to the surrounding volcanic rocks of the Texada formation could not be determined. In view of similarity of this limestone in appearance and composition to the limestone on the northern part of Texada Island, it may, with little doubt, be referred to the Marble Bay formation overlying the Texada formation. The volcanic rocks exposed along the shore to the southeast of the limestone belt strike eastward at a marked angle to the concealed limestone-volcanics contact. The limestone in this part appears, therefore, to be in faulted relationship with the Texada formation to the west.

* *See* Introduction, page 7.

Along the northeastern edge and at the northern end of the limestone belt, however, the main limestone body appears to be in conformable relationship with the volcanics, for at several places a bed of limestone a few feet across has been found in the Texada formation paralleling the contact with the main limestone body (*see* Fig. 14). The limestone body appears, therefore, to be a southwestward-dipping block of the Marble Bay formation bounded on the west by a fault. A possible southward-plunging fold is indicated at the north end of the belt by the form of the contact. The high-grade limestone of the lower part of the Marble Bay formation should, therefore, occur along the eastern edge of the belt and, as is shown by sampling, does so, at least near the southeastern end. The angle of the dip and the thickness of limestone in the belt have not been determined, but calcium limestone similar to that in the second member of the Marble Bay formation farther north occupies the southwestern half of the belt, hence possibly 1,000 feet of limestone may be present in some parts.

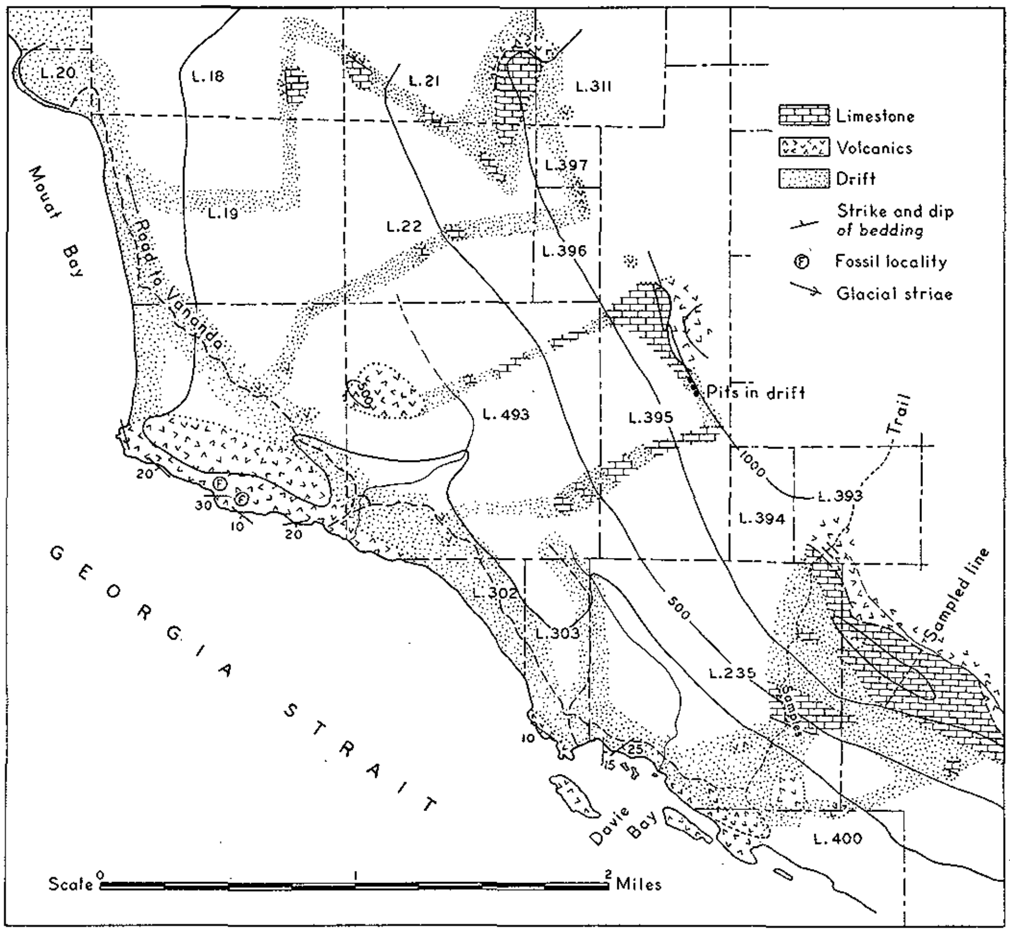

Figure 14. Davie Bay area.

No dykes have been observed in the limestone and very few in the volcanics exposed along the shore between Mouat and Davie Bays.

Overburden is extensive in the western part of the limestone belt and its depth along the eastern shore of Mouat Bay may exceed 150 feet. In most parts of the higher and more steeply sloping eastern half of the limestone belt, overburden is thin or missing. The projection of the eastern contact of the limestone belt under a local cover of drift in the central part of Lot 395 is marked by a series of conical pits as much as 100 feet wide and 40 feet deep where the unconsolidated debris has apparently fallen through a central aperture into an underlying chamber, presumably in the limestone or along the limestone-volcanics contact. It is reported that prospectors once found one of these chambers accessible and descended into it in an unsuccessful search for ore, but so far as is known none of the chambers can now be reached.

Analyses.—Samples, each composed of chips taken at 25-foot intervals along a line 250 feet long, obtained from the southern end of the limestone belt (*see* Fig 14), have the following analyses:—

Distance from—	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
Southwestern edge of exposure—										
0–250 feet	0.40	0.20	0.25	0.009	3.52	51.08	0.017	0.04	44.42	0.13
250–500 feet	0.20	0.01	0.13	0.004	3.66	51.38	0.093	0.03	44.54	0.08
500–650 feet	0.24	0.11	0.16	0.006	3.14	51.59	0.046	0.03	44.56	0.10
Drift-covered area about 500 feet wide.										
Northeastern edge of exposure—										
1,250–1,000 feet	0.24	0.42	0.11	0.006	1.70	53.38	0.011	0.06	43.96	0.07
1,000– 750 feet	0.18	0.40	0.07	0.004	1.00	54.45	0.010	0.03	43.93	0.07
750– 500 feet	0.30	0.19	0.06	0.003	1.22	54.45	0.013	0.04	43.88	0.05
500– 250 feet	0.30	0.06	0.07	0.006	2.98	52.31	0.028	0.03	44.32	0.13
250– 0 feet	0.42	0.12	0.10	0.006	0.74	54.35	0.014	0.03	43.91	0.04
Contact with Texada *formation.*										

Development.—No attempt has been made to quarry limestone in this area. Most of the ground is now controlled by the British Columbia Cement Company. This company carried out an extensive exploration and drilling programme during 1955 and 1956.

Reference

McConnell, R. G. (1914): Texada Island, B.C., *Geol. Surv., Canada,* Mem. 58, pp. 90, 99.

OPEN BAY DEPOSITS†

Location and Accessibility.—Limestone interbedded with volcanics occurs in a belt averaging three-quarters of a mile wide extending northwestward from Open Bay on Quadra Island. Open Bay can be reached by boat from Heriot Bay, 2½ miles to the south.

Open Bay is shallow and has a low irregular shoreline. No adequate shelter exists for tugs and scows from southeasterly gales, but a few small islets offshore provide a measure of protection. Good shelter for shipping can be obtained at Heriot Bay and Drew Harbour, 2½ and 3 miles respectively to the south.

Geology.—The Open Bay deposits consist chiefly of argillaceous limestone interstratified with and overlying ellipsoidal and amygdaloidal lavas of the Texada formation. The lowest limestone member is poorly exposed at the west end of Open Bay but well exposed about 1 mile inland where it exceeds 100 feet in thickness. At the shore it dips about 30 degrees eastward and is overlain by about 350 feet of ellipsoidal and massive lava exposed on the first promontory from the west end of the bay. This is overlain by 50 feet or less of limestone which in turn is overlain by about 200 feet of lava exposed on the second promontory from the west end of the bay. Possibly as much as 500 feet of steeply dipping limestone and at least one greenstone body are incompletely exposed in the next bay to the east. East of this bay intensely folded argillaceous limestones and pillow lava are exposed in a belt about 2,000 feet wide bounded on the east by intrusive granitic rocks.

† Maps and information collected by Dr. H. C. Gunning and undergraduate students in geology at the University of British Columbia were of assistance to the writer in the examinations of these deposits.

The prevailing dip of the bedded rocks is northeasterly throughout Open Bay. The extreme folding of the sediments in the eastern half of the bay, however, obscures the general structure, but the pillow lava interbedded with the argillaceous limestones, though folded itself, clearly conforms to this general northeasterly dip.

Dykes a few feet wide are present in parts of the area and lenticular sills a few inches to a few feet wide are common. The contact with the granitic rocks at the northeastern edge of the belt is irregular in detail but follows in general a relatively straight line northwestward across the island, truncating the limestone belt at an acute angle. For this reason the limestone belt does not extend as far as Granite Bay (Bancroft, 1913; Cairnes, 1913, p. 58), on the opposite shore of Quadra Island, 8 miles northwest of Open Bay.

Overburden is scarce or absent on the low ridges extending inland from the bay, but is extensive and of undetermined depth in the valleys.

The limestone is in general black and granular and emits a distinct odour of hydrogen sulphide when broken. Fine laminæ of argillaceous impurities are distributed throughout the rock. Fossils found by Dr. Gunning and students from the University of British Columbia near the west edge of the intensely folded belt are reported to be of Karnian (Upper Triassic) age (*see* p. 36).

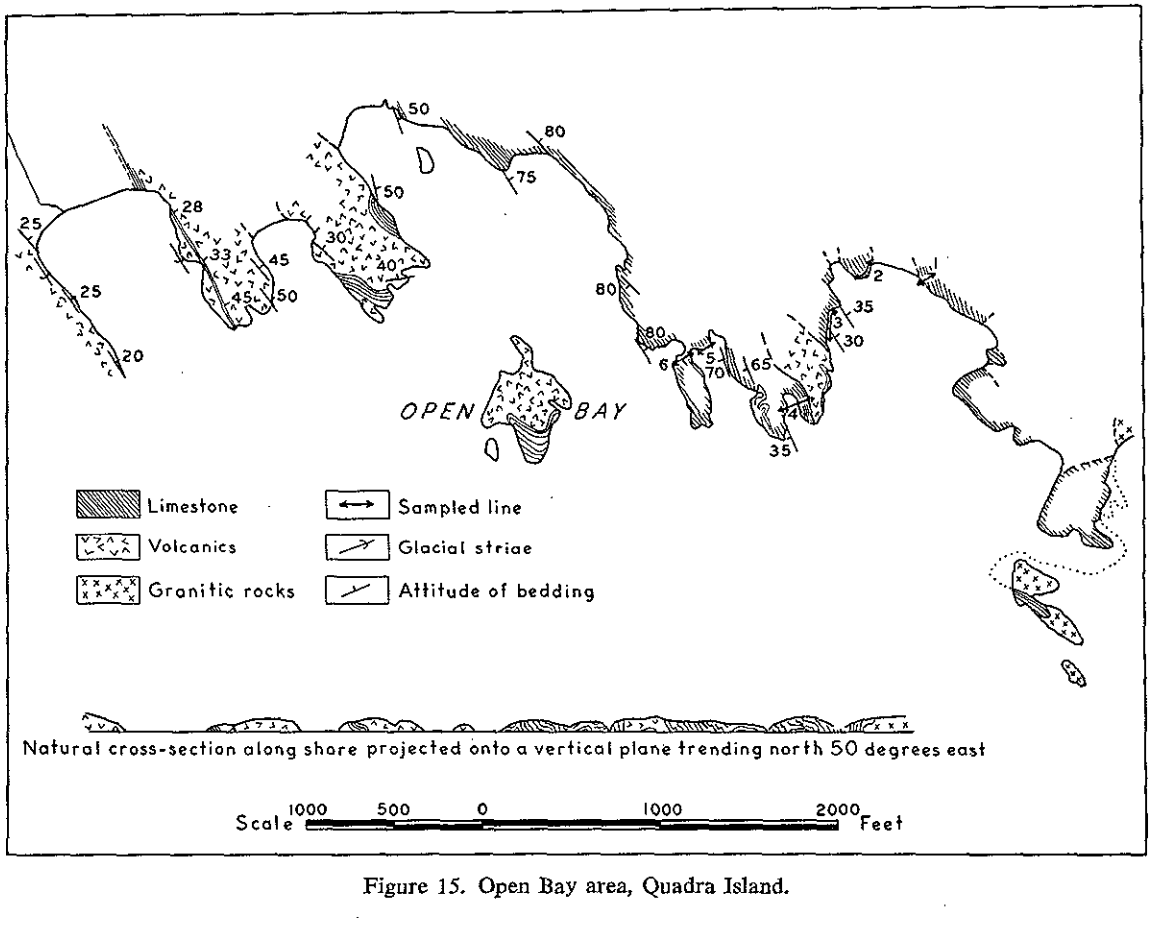

Figure 15. Open Bay area, Quadra Island.

Analyses.—Samples, each composed of up to ten chips at 10-foot intervals measured across the strike of the limestone, were obtained from the lowest and westernmost limestone member, about 1 mile from Open Bay, and across the northeastern folded belt along the shore of Open Bay (Fig. 15).

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
No. 1	12.44	0.78	0.05	0.006	0.32	47.29	0.090	0.24	38.54	0.06
No. 2	11.20	2.25	0.56	0.024	0.22	47.86	0.112	0.22	38.52	0.08
No. 3	13.28	1.70	1.03	0.023	0.06	46.18	0.131	0.45	37.00	0.11
No. 4	5.08	0.50	0.29	0.025	0.64	51.69	0.095	0.13	41.39	0.06
No. 5	15.72	1.08	0.70	0.008	0.40	44.94	0.119	0.25	36.54	0.32
No. 6	10.14	1.04	1.04	0.014	0.48	47.70	0.078	0.62	38.95	0.10
West edge of intensely folded belt.										
No. 7	1.66	0.16	0.14	0.018	0.32	54.04	0.041	0.06	43.27	0.01

Development and Operation.—Two test-pits were found in the steeply dipping limestones near the western edge of the folded belt on the shore of Open Bay, and a kiln exists near by. Operations were evidently abandoned before more than a few tens of tons had been quarried.

The limestone in the upper part of the section is high enough in insoluble matter to be unsuited for anything except, perhaps, the manufacture of cement. There is no adequate shelter for shipping and the comparatively low elevation of the ground would prohibit the development of a high quarry face above water-level anywhere adjacent to the shore.

The lowest belt of limestone is of better grade, but where well exposed is fully 1 mile from tidewater.

LIMESTONE IN THE CAMPBELL RIVER AREA

Limestone occurs at several places from 16 to 20 miles west and southwest of Campbell River on Vancouver Island. According to Gunning (1930, p. 62), "limestone outcrops on the north-central shore of Upper Campbell Lake and continues north beyond the 50th parallel, outcropping in Greenstone Creek about 3 miles above its mouth. A few remnants of the same bed are found capping knolls along the west contact of the Quinsam granodiorite, south of Upper Campbell Lake, and what is presumably the same horizon is in part replaced by magnetite ore on the Iron Hill claim just south of Upper Quinsam Lake. What may be a continuation of this horizon to the south-east was encountered on the west fork of Oyster River 16 miles south of the 50th parallel." These deposits, which overlie a thick succession of volcanics of the Vancouver series, and which apparently underlie a succession of highly folded impure limestones, argillites, quartzites, and volcanic rocks of Upper Triassic age, are believed to correspond to the Marble Bay formation of Texada Island. Although logging roads and railways have been built to many of these localities mentioned above, their remoteness from the coast probably precludes early development of these deposits.

"SUTTON" LIMESTONE DEPOSITS OF THE SAANICH PENINSULA AND MALAHAT DISTRICTS

General

The limestone deposits of the Saanich Peninsula and the Malahat and Cowichan Lake districts can be readily distinguished from those occurring elsewhere in the Georgia Strait area. These so-called Sutton limestones have been mapped as part of the Vancouver series by Clapp (1912, 1913, 1917). The age of the Sutton limestone is now placed as Upper Triassic, on the basis of fossils found in a limestone body at Cowichan Lake (McCann, 1922; Martin, 1916). The limestone deposits of the Saanich and Malahat districts have yielded no fossils and are clearly distinct in structure, though perhaps not in age, from the Triassic deposits elsewhere in the area.

The limestone deposits occur in an area underlain predominantly by greenstones, which are dense, fine grained, in places porphyritic, and generally devoid of megascopic structures such as stratification. In a few places the greenstone has a fine-banded structure and such rocks may have been derived from tuffs. None of the banded greenstones have, however, been found in close association with the limestone.

The limestone bodies occur as irregularly elongated masses, generally of small extent, although one exceeds 1 mile in length and one-quarter mile in width. Wherever the margins of the limestone bodies are exposed, they are found to be steeply dipping.

Many tabular to lenticular bodies of greenstone are found within the limestone deposits. These bodies are in general parallel to one another, to banding and possible stratification in the limestone, and the strike and dip of the deposits themselves. The margins of the greenstone bodies are either faulted or are irregular in detail; unlike those of dykes and sills which occupy clear-cut fractures, some of the bodies pinch out or terminate in bulbous ends within the limestone. No conclusive evidence of the origin of these greentsone masses has been found, but the existing data favour their interpretation as flows. Clearly defined greenstone dykes cutting across the prevailing trend of a deposit are rare. In a large part of the Saanich and Malahat districts, however, the limestones and greenstones are intruded by a complex system of dykes and irregular masses ranging in composition from diorite to granodiorite, and including possibly gabbroic phases.

Sections measured across the full width of the limestone deposits show very marked variations from place to place. Some parts of a deposit are free from magnesian impurities, others may be made up predominantly of magnesian limestone. Similarly, some parts are almost free from sill or flow-like bodies of greenstone, which may predominate in other parts only a few hundred feet away and along strike. An original lenticular character of limestone deposits incorporated in a succession of lavas may account for most of these variations, although strike faulting and transverse faulting presumably complicate the sections.

In a few cases, notably at Tod Inlet, a series of limestone bodies, *en échelon* in a single belt, may represent a single limestone horizon repeatedly offset by transverse faulting. In other cases the limestone horizon may be terminated against intrusive bodies, or interrupted by tight folds. Where the drift cover is fairly extensive, discontinuities may be more apparent than real.

Bamberton Deposit

Location and Accessibility. — The Bamberton limestone deposits of the British Columbia Cement Company Limited are on the west side of Saanich Inlet in Lots 73 and 95. They are less than 1 mile by road from the Island Highway and about 25 miles by road from Victoria. Wharfs and loading facilities are within a few hundred feet of the quarry.

Geology. — The Bamberton limestone deposits consist of one or more limestone members intimately associated with tabular bodies of greenstone of uncertain origin. Stratification has not been recognized in the deposit except near the northwestern corner of the upper part of the main quarry, where alternating magnesium-rich and calcium-rich beds strike north 60 degrees west and dip 70 degrees northeastward. At places throughout the main quarry, however, a faint banding in the limestone has a similar strike and dip, as have a conspicuous joint pattern, many faults, and most of the tabular greenstone bodies. The aggregate thickness of limestone exceeds 500 feet in the section across and to the northeast of the face of the lower bench in the main quarry. In this section the rock consists dominantly of high-calcium limestone in the lower or southwestern part, and of magnesian limestone in the upper or northeastern part beyond the limit of the quarry (*see* analyses). Greenstone bodies occupy a considerable proportion of the section across the limestone belt 300 feet to the southeast of this face, and an aggregate thickness of only about 250 feet of limestone is known to be present, most of which, however, is high-grade limestone. A decrease in the thickness of at least the high-calcium limestone of the southwestern part of the belt also takes place between the face of the lower bench and that of the upper bench to the northwest. The explanation of these changes in thickness is not evident. To the northwest of the main quarry, two small quarries show the limestone continues at least 1,000 feet.

An exposure of limestone and intercalated greenstone occurs on the shore of Saanich Inlet about one-quarter mile north of the main quarry. Here banding in the limestone, conspicuous joints, and tabular bodies of greenstone strike about north 50 degrees west and dip 50 degrees southwest. A total thickness of about 350 to 400 feet, measured at right angles to the prevailing attitude, is present in this exposure, of which possibly not more than one-half is limestone.

The greenstone bodies within the limestone at both the above-mentioned localities range from a few inches to at least 50 feet in thickness. Most are lenticular, and are bounded on one or both sides by faults. The greenstone is dense, fine grained, and devoid of megascopic features, which might provide a clue to its origin. Swanson* reports finding in a thin section of one specimen of porphyritic greenstone from the quarry a vague spherulitic texture in the altered fine- to very fine-grained matrix. He interprets this rock as being " in part a devitrified glass," and suggests that it may have been a glassy flow or possibly a tuff. The general parallelism of the greenstone bodies to one another and to the banding as well as to the one case of stratification within the limestone also suggests that they may be sills, flows, or beds. The opposing dips of the greenstone bodies in the main quarry and in the exposures on the shore one-quarter mile to the north suggest that they have been folded at some time following their emplacement. Greenstone dykes, cutting across the prevailing trend of the rocks at marked angles, are known but are small and few in number.

At least one body of light green to white rhyolite occurs at the mouth of the lower level of the main quarry, and another at the northwestern end of the upper level.

The igneous rocks mentioned are utilized as a source of silica, alumina, and iron for the cement plant. These rocks, therefore, do not have to be segregated from the limestone, and discarded. In view of their economic importance, a suite of specimens of the various igneous rocks was collected by the company and submitted to commercial analysts for chemical analysis; petrographic study was carried out by Swanson. Two main groups of igneous rocks can, on the basis of their analyses, be clearly distinguished, one characterized by a low silica content of 35 to 50 per cent, the other by a high silica content of 70 to 74 per cent. In the former group belong the greenstones, consisting of laths of plagioclase feldspar now partly altered to sericite, carbonate, and kaolin, in a fine-grained matrix of chlorite, carbonate, sericite, and a small amount of quartz; epidote is present locally. These rocks have chemical compositions approximating those of altered basalts from other localities. In the high-silica group belong the rhyolites, consisting of phenocrysts of feldspar, and locally of quartz, in a fine-grained groundmass of quartz and alkali feldspar, now partly altered to sericite. Carbonate and iron oxides along fine veinlets as well as chlorite and epidote are present locally. The composition of the high-silica group approximates that of an average rhyolite.

Faults are common in the quarries, and generally trend northwestward and dip steeply to the northeast or southwest. A few transverse faults are also known, one, dipping steeply southeast along the western face of the upper part of the main quarry, truncating the main belt of high-grade limestone. A second transverse fault at the mouth of the lower level of the main quarry is inferred from the presence of one or more rhyolite bodies (*see* above) and by an abrupt change in the trend of the greenstone bodies.

Overburden, consisting of stratified sands and gravels, silt, and glacial till, some of which contains very large boulders, covers most of the area adjacent to the quarries, except on steep rocky bluffs which rise to the west and southwest of the main quarry. Many exposures of drift exceed 10 feet in depth, and an average thickness of at least several feet can be expected.

* Swanson, C. O. (former Professor of Mineralogy and Petrography, University of British Columbia): Unpublished report.

The limestone from the deposit is generally dark blue and fine grained. It is only locally banded. White-rock is present but is not common.

Analyses.—Eight samples, each composed of chips taken at 6-foot intervals, were taken across the limestone belt at the head of the lower quarry. The first two samples were beyond the confines of the quarry, the others from the top of the lower quarry face as it existed in April, 1946. Greenstone was excluded from the samples but a pale green rhyolite(?), distinguishable only with difficulty from the limestone, was included in Sample 5.

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
No. 1	1.4	Trace	0.420	0.072	11.80	42.2	0.009	0.033	44.9	......
No. 2	3.8	1.16	0.520	0.080	8.92	42.2	0.016	0.053	43.0	......
No. 3 (not accessible)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
No. 4	2.0	0.18	0.160	0.041	1.93	52.8	0.022	0.024	43.1	0.02
No. 5	52.5	1.00	0.760	0.022	0.39	24.9	0.030	0.069	20.3	0.03
No. 6	4.8	0.29	1.150	0.023	0.87	51.8	0.031	0.027	40.9	......
No. 7	1.1	0.08	0.057	0.016	0.40	54.8	0.021	0.024	43.3	......
No. 8	0.6	Trace	0.056	0.014	0.55	55.3	0.019	0.040	43.6	......
No. 9	1.1	0.28	0.370	0.030	0.55	54.7	0.024	0.140	43.0	0.07

Development and Operation. — The Bamberton deposits, formerly known as the Elford deposits, were worked at least as early as 1907 when limestone was quarried and burned by Elford & Company, but these operations had been abandoned by 1911. The Associated Cement Company then acquired the property, erected the present cement plant, and produced Portland cement from 1913 to 1917. In 1919 the Associated Cement Company and the Vancouver Portland Cement Company were amalgamated to form the present British Columbia Cement Company Limited, which recommenced operations at the Bamberton quarry and cement plant in 1921. The quarry and plant have been in continuous production since that time. In recent years additional limestone needed in the cement production has been obtained from the company's quarries on Texada Island and at Cobble Hill.

The limestone from the Bamberton deposit is obtained from a main quarry adjacent to and west of the plant and from two smaller quarries above and in line northwest of the main quarry. Some limestone was obtained in the past from two small quarries near the south end of the plant and from the shore deposit one-quarter mile north of the plant.

The main quarry floor is about 90 feet above sea-level. The floor of an upper level in the face is 150 feet higher. The highest point on the quarry rim is nearly 300 feet above the main floor. One small quarry is 400 feet northwest of the main quarry and has a floor elevation 323 feet above sea-level. A second small quarry, 100 feet beyond the first, is 100 feet still higher.

In the quarrying procedure, vertical and horizontal blast-holes are drilled with wagon drills. Broken rock is loaded by electric shovels and transported by trucks to the crushing plant. During 1956, 212,585 tons of limestone was mined at the quarry.

The cement plant uses the wet process to produce 2¼ million barrels of cement yearly. At present four kilns are in use and a fifth is being installed. The operating kilns include two that are 150 feet long and 9 feet in diameter, one that is 200 feet long and 10 feet in diameter, and one that is 350 feet long and 11½ feet in diameter. The new kiln will be similar to the largest of these. The kilns are fired with powdered coal.

References

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Brewer, W. M. (1926): *Minister of Mines, B.C.,* Ann. Rept. 1926, pp. 334–337.

Tod Inlet Deposits

Location and Accessibility.—Several limestone bodies occur on and near Tod Inlet, on the east side of Saanich Inlet, in Lot 15, Range 1 west, and Lots 14 and 15, Range 2 west, South Saanich Land District, and in Lot 23, Highland Land District. Tod Inlet is accessible by road from Victoria, 13 miles to the south, or by water for both small and large shipping.

Geology.—The deposits which reach 250 feet in width and 500 feet in length occur as a series of southeastward-trending *en échelon* bodies in greenstone. Stratification observed in the body west of Tod Inlet strikes south 30 degrees east and dips 30 to 35 degrees southwestward; the attitude of stratification in the other bodies has not been determined.

Greenstone dykes are present.

Overburden is in some cases light, but the deposit at Butchart Gardens is buried at its north end under a drift cover many feet deep, and the deposit west of Tod Inlet is largely concealed by drift.

The limestone is blue, grey, or almost white, and is fine grained.

Development and Operation.—Limestone was quarried and burned at Tod Inlet prior to 1904. In that year the limestone deposits were acquired by the newly formed Vancouver Portland Cement Company, who erected a cement plant of 100,000-barrels-a-year capacity. This plant was, by 1907, expanded to a capacity of about 300,000 barrels a year. The Vancouver Portland Cement Company and Associated Cement Company, owning the cement plant at Bamberton on the west side of Saanich Inlet, were amalgamated in 1918 to form the British Columbia Cement Company. This company in 1921 transferred the cement production to the Bamberton plant and the Tod Inlet plant and quarries were closed.

Since the abandonment of these operations the buildings of the Tod Inlet plant have been used to house a small cement-tile industry operated by the British Columbia Cement Company. One of the abandoned quarries was planted with ornamental flowers and has become a part of the now famous "Butchart Gardens." A second quarry is now used as a reservoir. A third quarry, adjacent to the Tod Inlet plant, is flooded. The limestone deposit west of Tod Inlet was never developed.

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Clapp, C. H. (1912): Southern Vancouver Island, *Geol. Surv., Canada,* Mem. 13, p. 197.
——— (1913): Geology of Victoria and Saanich map-areas, *Geol. Surv., Canada,* Mem. 36, pp. 134, 135.

Malahat Deposit*

Location and Accessibility.—The Malahat limestone deposit is at the northwest corner of a small unnamed lake near the centre of Block 201, 2½ miles by road southwest of Malahat, an Esquimalt and Nanaimo Railway station 20 miles north of Victoria. It is about 20 miles by road from Victoria.

Another deposit of limestone is exposed between the unnamed lake and Devereux Lake, half a mile to the southeast.

Geology.—The first deposit is exposed for 1,000 feet from the edge of the lake along the top of a low northwest-trending ridge. The exposed width ranges from 60 feet at the southeast end to 250 feet at the northwest end. To the south the limestone plunges under the lake and to the north it ends abruptly in 20-foot-high bluffs at the

* *See* Introduction, page 7.

edge of a swampy depression. Along the southwest the limestone is in contact with gneiss and to the northeast is covered with overburden.

The limestone is medium- to fine-grained dark-grey to white rock. Planes that appear to represent bedding strike between 35 and 50 degrees west of north and dip about 65 degrees northeast. The rock contains several sets of closely spaced joints.

Lenses and dykes of greenstone are present. Overburden is shallow.

The second deposit can be traced from a point 200 feet west of the west end of Devereux Lake for 1,200 feet northwestward toward the first deposit. The average exposed width is 150 feet. At the northwest end this band doubles back and appears to form a small anticlinal nose that plunges steeply to the northwest. The enclosing rock is gneiss. The limestone in this deposit has the same appearance as that in the first deposit.

Analyses.—Samples from the first deposit have been analysed. Samples Nos. 1, 2, and 3 were taken by J. M. Cummings prior to 1946. Sample No. 1 was taken across 150 feet near the northwest end of the deposit, sample No. 2 was a composite one taken across 50 feet near the middle of the deposit, and sample No. 3 was taken across the quarry face of that time. Sample No. 4 was taken by McCammon across the quarry face as it was in June, 1956.

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
No. 1	1.8	0.29		......	2.24	51.9	......	......	......	......
No. 2	2.2	0.32		......	0.80	53.3	......	......	......	......
No. 3	2.2	0.47		......	0.44	53.3	......	......	......	......
No. 4	2.3	0.10	0.10	0.002	0.24	54.1	0.019	0.03	42.8	0.12

Development and Operation.—Only the first limestone deposit has been worked. It is on land owned by Robert Stebbins. During 1944 the deposit was quarried under lease by F. Jefford, of Victoria, as a source of white-rock. Later the quarry was operated under lease by Marble and Associated Products of 507 Ellice Street, Victoria, to supply white-rock for the manufacture of stucco dash, putty flour, and other crushed products. There was no activity on the property in 1955 or 1956. In June, 1956, the quarry opening was 170 feet long and 50 feet wide at the widest point. The maximum face height was about 25 feet. The ruins of an old lime-burning kiln stand adjacent to the quarry.

WRIGGLESWORTH LAKE*

Location and Accessibility.—A limestone band outcrops near the west edge of Lot 8 along the west side of Wrigglesworth Lake, three-quarters of a mile southwest of Silvene Station on the Esquimalt and Nanaimo Railway 17 miles north of Victoria. A good logging-road 1.3 miles long extends from the lake to the railway and the Trans-Canada Highway at a point one-quarter mile south of Malahat Post Office.

Geology.—The limestone forms a low ridge that extends for 1,300 feet northwestward from the southwest corner of the lake. The limestone belt is about 250 feet wide at the southeast end and 350 feet wide at the northwest end. At the southern extremity it ends at a narrow gully in fault contact with interbedded ribbon cherts, slates, and tuffs which underlie the area to the south and east. At the northern end the limestone ends in bluffs that slope down to a small creek that flows into Wrigglesworth Lake. More limestone outcrops on the opposite side of the creek about 300 yards to the northwest. Along the southwest side the limestone is in contact with gneissic greenstone.

The limestone is white to dark grey and medium to fine grained. No bedding is apparent, although there is some streakiness. Scattered small lenses of chert and some greenstone dykes occur in the limestone.

Overburden is shallow.

* *See* Introduction, page 7.

Analyses.—Two samples from the deposit were analysed. Sample No. 1 consisted of chips taken across 350 feet near the northwest end of the limestone and sample No. 2 consisted of chips taken across 240 feet near the southeast end. Dyke rock and chert were excluded.

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
No. 1	1.50	0.16	0.07	0.006	0.44	54.5	0.009	0.01	43.3	0.11
No. 2	1.84	0.22	0.13	0.010	0.47	54.1	0.011	0.04	43.1	0.13

Development and Operation.—It is reported (*Minister of Mines, B.C.*, Ann. Rept., 1911, p. 207) that J. Wrigglesworth prospected this limestone deposit with test-pits about 1891. Apparently nothing other than some desultory sampling has been done since. The land upon which the limestone lies is now owned by H. M. Jones, of Malahat Post Office.

Millstream Deposit

Location and Accessibility.—A limestone deposit occurs on Millstream Road in the Highland District, 2.5 to 2.9 miles north of Langford Station on the Esquimalt and Nanaimo Railway 8 miles west of Victoria.

Geology.—The deposit is reported to be 1,000 feet wide and 3,000 feet long (Clapp, 1917, p. 106) and is surrounded by greenstone and intrusive bodies. Part of the limestone is fine grained, part recrystallized. The recrystallized limestone shows textural variations apparently related to stratification. This banding at one point near the southwest end of the deposit dips 40 degrees northwest, at another point in the southern of two old quarries the banding dips about 20 degrees southeast. Overburden is lacking on knolls but is deep in the intervening hollows.

Analyses.—The analyses of two samples, free of dyke rock, each composed of a series of chips taken at 5-foot intervals across 50 feet in the northern quarry, follow:—

	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
North sample	3.3	0.27	0.089	0.017	1.97	52.7	0.010	0.002	41.4	0.32
South sample	0.5	0.04	0.200	0.004	3.08	52.1	0.013	0.025	43.8	0.14

Development and Operation.—Limestone is reported to have been quarried in the Highland District, probably from this deposit, prior to 1908. Two quarries, both abandoned, have been opened in this deposit, 2.9 and 2.7 miles respectively north of Langford Station. Each quarry has a curved face 60 to 100 feet long and up to 20 feet high. The remains of an old kiln can be found near the northern quarry.

Atkins Road Deposit

Location and Accessibility.—Limestone outcrops on Atkins Road adjacent to the Esquimalt and Nanaimo Railway 0.9 mile east of Langford Station and 7 miles west of Victoria, in Lots 105 and 1, Esquimalt Land District.

Geology.—Limestone is exposed over an area several hundred feet long and possibly 200 feet wide. It consists of fine-grained blue limestone containing light-coloured bands dipping steeply westward. Greenstone bodies of uncertain origin are closely associated with the limestone. The deposit is partly covered by a thick deposit of fluvioglacial sand and fine gravel.

Analyses.—Three samples were taken, one consisting of chips taken at 6-foot intervals across 60 feet of the north and east face of a shallow pit, partly flooded; a second taken at 4-foot intervals for 60 feet east of this pit; and a third consisting of chips from scattered outcrops near the roadside a few hundred feet south of the pit. Dyke rock was excluded in sampling. The analyses of these samples follow:—

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
North and west face	0.6	0.08	0.087	0.010	0.11	55.2	0.014	0.017	43.6	0.14
East of face	1.9	0.10	0.110	0.012	0.16	54.6	0.029	0.016	42.9	0.14
Roadside	1.3	0.06	0.081	0.006	0.94	54.0	0.010	0.009	43.3	0.10

Development and Operation.—The deposit was worked for a few years following the erection of a sand-lime brick plant in 1907 by the Silica Brick & Lime Company (Robertson, 1907); three small quarries north of the railway and one larger quarry and two sand-pits south of the railway were opened. The quarries were idle in 1956.

References

Robertson, W. F. (1907): *Minister of Mines, B.C.*, Ann. Rept., 1907, pp. 155–157.

Clapp, C. H. (1913): Geology of Victoria and Saanich map-areas, *Geol. Surv., Canada*, Mem. 36, p. 134.

Parsons Bridge Deposit

Location and Accessibility.—A limestone deposit occurs on the northwestern slope of a knoll 0.2 mile southwest of Parsons Bridge at the head of Esquimalt Harbour. It is 6 miles by road from Victoria.

Geology.—The deposit is at least 100 feet wide and 200 feet long. The limestone shows a distinct banding, probably related to stratification, with marked variations in attitude. Greenstone bodies are present within the limestone. A granitic intrusive limits the deposit on the southeast and east. Overburden is lacking on the upper part of the knoll but mantles the lower slopes where it covers the limestone deposit to the west and north.

Analyses.—Two samples, free of dyke rock, each composed of chips taken at 6-foot intervals, were taken across the face of the lower quarry and the adjacent slope to the south. The analyses follow:—

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
Northern 60 feet	2.6	0.45	0.37	0.013	1.28	53.2	0.015	0.082	42.2	0.02
Southern 60 feet	1.9	0.38	0.28	0.017	0.90	53.7	0.009	0.057	42.6	0.14

Development and Operation.—The limestone was originally quarried for flux by the Tyee Copper Company and later quarried and burned by the Victoria Lime Company for agricultural lime. The ruins of an old kiln stand beside the quarry.

Reference

Clapp, C. H. (1913): Geology of Victoria and Saanich map-areas, *Geol. Surv., Canada*, Mem. 36, p. 135.

Rosebank Deposit

Location and Accessibility.—The Rosebank limestone deposit is west of Esquimalt Harbour on Lots 96 and 1, Esquimalt Land District. The main quarries are about 2,000 and 3,000 feet respectively west of the shore of Esquimalt Harbour and were formerly reached from it by means of a narrow-gauge railway. The deposit is 7 miles by road from Victoria.

Geology.—The limestone occurs in a belt at least 1¼ miles long and about one-quarter mile wide. The belt is bounded on both northeast and southwest by greenstone.

The limestone is grey and fine grained; banding is present in many places and, together with a distinct fracture cleavage, strikes northwestward and dips at angles of 70 degrees or more, generally to the northeast. In one place two sets of fracture cleavage intersect to give rise to vertical splinters of limestone. Bodies of greenstone of uncertain origin are present in the limestone in addition to well-defined dykes.

The limestone has been quarried on a series of small knolls. The intervening hollows are covered with 5 feet or more of overburden.

Development and Operation.—The quarries are from 100 to several hundred feet in diameter and have been worked to a maximum depth of about 50 feet. These operations, carried on originally by Raymond & Sons and later by the Rosebank Lime Company, were started prior to 1907 and continued until about 1932. At one stage three lime kilns were being operated. Since 1932 the property has been acquired by the Department of National Defence.

Reference

Clapp, C. H. 1913): Geology of Victoria and Saanich map-areas, *Geol. Surv., Canada,* Mem. 36, p. 134.

LIMESTONE IN THE PARSONS BAY FORMATION

No workable deposits of limestone are known in the Upper Triassic Parsons Bay formation, but the presence of calcareous material has been noted by Dawson, Bancroft, and McLellan.

Hernando Island

Bancroft (1913, p. 76) describes the rocks of the Parsons Bay formation at Hidalgo Point on Hernando Island, in the northern part of the Strait of Georgia, as follows:—

"In this locality the stratified series, which comprises cherty argillites, quartzites, numerous intercalated sheets of intrusive(?) greenstones, and a layer of blue limestone which is four inches in thickness, are intersected by numerous dark dikes. They occupy a very small area, being intruded by granodiorite and olivine-gabbro which cuts them off on every side except the northern."

Twin Islands

Bancroft (1913, p. 76) reports that: "On Iron Point, on Twin Islands, about two miles (N. 50° W.) from Hidalgo point, a small patch of stratified rocks occurs in which thin limestone layers are numerous, alternating with argillites and quartzites. They frequently contain garnet, pyrite, and occasionally a little magnetite, the presence of the last two minerals causing them to weather in brilliant red and in black colours. Their dip is 25° toward the northeast, while their strike is N. 54° W. Some of the limestone beds contain geodes lined with calcite, the formation of which may have been due to the presence of shells. A very imperfect cast of a pelecypod was found in a layer of impure limestone, which, from its convex shape and the character of its ribs and ear, is believed to be the right valve of distorted *Pseudomonotis subcircularis.*"

LIMESTONE DEPOSITS OF UNCERTAIN AGE ENCLOSED IN GRANITIC ROCKS

GENERAL

Medium-sized to small deposits of limestone completely surrounded by areas of granitic rock occur on and near the northeastern shores of Georgia Strait. Some of the deposits, such as those at Bold Point and Dinner Rock, may be inclusions or roof pendants of the Marble Bay formation and others may be part of the Palæozoic succession, but, in general, too little is known of these deposits to permit correlation with other deposits in the Georgia Strait area.

Only three of the deposits are known to have been worked for their limestone content—these have been examined either by the writers or by J. M. Cummings, formerly with the British Columbia Department of Mines. Information on the others has been obtained entirely from the published reports of G. M. Dawson, J. A. Bancroft, O. E. LeRoy, and E. M. J. Burwash.

DESCRIPTION OF OCCURRENCES

Pryce Channel Deposit

"Upon the mainland, almost directly opposite (the Redonda Island deposits), it is reported that marble is exposed in the bed of a stream which enters Pryce channel about three-quarters of a mile west of Elizabeth island." (Bancroft, 1913, pp. 66–67.)

Redonda Island Deposits†

Location and Accessibility.—Limestone occurs on the precipitous northern shore of West Redonda Island about 1½ miles west of George Point and a few hundred feet west of the northwest corner of Lot 3439. The deposit can be reached only by boat. According to Brewer (1919) "there are no beaches, sheltered coves, or anchorages where vessels could lie safely in the neighbourhood, except on the opposite or north side of Pryce Channel."

Geology.—Limestone on Redonda Island occurs apparently as inclusions in the prevailing granitic rocks. Two deposits are exposed on the shore, each about 100 feet across. One extends southward up the steep hillside for a minimum of 200 feet and is cut by several dykes. Other smaller bodies are reported on the Elsie and Eagle Mineral Claims, one-half mile northwest and one-quarter mile west respectively. Goudge (1944, p. 161) refers to the presence of brucite and of dolomite in the limestone at the quarry. He found the average brucite content to be low, but his sample across a width of 20 feet, in which a concentration of brucite occurs, was found to contain 20.5 per cent magnesium oxide.

Analyses.—The analyses of three samples taken in the quarry by Mr. Cummings follow:—

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
No. 1	1.8	0.23	0.17	0.014	2.60	52.5	0.012	0.080	42.9	......
No. 2	1.7	0.40	0.25	0.019	6.24	48.4	0.015	0.090	42.9	0.06
No. 3	6.6	0.72	0.24	0.035	4.28	48.3	0.012	0.030	39.8	......

Development and Operation.—The easterly of the two limestone bodies exposed on the shore was quarried in 1920 by the Nickson Construction Company, who shipped 8,450 tons of limestone to the Whalen Pulp & Paper Company. This deposit was also worked in 1926, but there is no record of any work having been done on it since that time. In 1938 the quarry was about 200 feet long from north to south, about 100 feet high, and the face reached an elevation of more than 100 feet above the water.

Bold Point Deposits

Two or more limestone bodies within granitic rocks occur in a northeasterly trending belt 1,000 feet long and 200 feet wide in Lot 4, 1 mile north 20 degrees west of the wharf at Bold Point on the east shore of Quadra Island. The deposits are accessible by a short road and abandoned logging-roads from this wharf. An analysis of a composite sample made up of six chips from various parts of the limestone belt follows: Insol., 4.60;

† Report compiled from published information and from data supplied by J. M. Cummings.

R_2O_3, 0.59; Fe_2O_3, 0.10; MnO, 0.01; MgO, 0.72; CaO, 53.35; P_2O_5, 0.03; S, 0.02; Ig. Loss, 40.23; H_2O, 0.07.

A few tons of limestone are reported to have been shipped from this area prior to 1925, but no development has taken place since that time. The limited area of the deposits does not favour large-scale quarrying and no local market exists for a small operation.

Reference

Bancroft, J. A. (1913): Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B.C., *Geol. Surv., Canada,* Mem. 23, p. 79.

Theodosia Arm Deposit

"In Theodosia Arm . . . between Martin and Ellen Points on the north side (just west of the entrance to Theodosia Arm), a small mass of stratified rocks appears, surrounded on all sides by those of granitoid character. These consist of a grey and white spotted marble, in which kernels and veinlets of pale green serpentine have been developed, with some blackish, hard argillites with rusty joints. The dip and strike are very irregular, but the former appeared to average (strike south 82 degrees east, dip 70 degrees north). These rocks occupy the shore for about 200 feet only." (Dawson, 1887, p. 27B.)

Dinner Rock Deposits

Location and Accessibility.—The Dinner Rock limestone deposits occur on and near the shore of the mainland 8 miles northwest of Powell River and a few hundred feet southeast of a reef known as Dinner Rock. One of the bodies of limestone outcrops on the shore cliffs a few feet west of the northwest corner of Lot 5347. Two others lie within a few hundred feet north and northwest of this body in Lot 2362. A logging-road about 1 mile long extends from the beach, 100 yards north of the limestone outcrops, to the Powell River–Lund Highway at a point 9.6 miles northwest of the bridge over Powell River. A low rocky reef extending out from the shore 100 yards south of the limestone might provide a measure of protection for tug and barge from southeasterly winds, but no shelter exists from westerly winds. The nearest harbour is at Lund, 3 miles to the north.

Geology.—The deposits consist of inclusions or roof pendants, made up entirely of structureless limestone, within granitic and dioritic rocks which are in places distinctly epidotized. The body exposed on the shore cliffs is only 150 feet long and a maximum of 50 feet wide. A second body 300 feet to the northeast is about 300 feet long and 200 feet wide, and a third, one-quarter mile to the northwest, is at least 300 feet long in a northwesterly direction and of undetermined width.

No argillite such as has been reported by Bancroft was found in this vicinity.

Analyses.—Samples were taken from the limestone body exposed at the shore and from the second body. No sample was obtained from the third mass. The shore body samples consisted of chips taken at 5-foot intervals across the stated distances and the other samples consisted of chips taken at 10-foot intervals across 100 feet. The analyses follow:—

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
Shore exposure—										
Northwest end, 68 feet	2.22	0.22	0.25	0.040	2.38	51.64	0.028	0.03	43.08	0.03
Southeast end, 80 feet	4.84	0.44	0.67	0.041	2.82	49.23	0.051	0.17	41.66	0.08
Northeastern body—										
Northwest 100 feet	0.40	0.82	0.25	0.036	3.70	50.87	0.030	0.05	43.96	0.14
Middle 100 feet	1.20	0.15	0.14	0.048	3.32	51.69	0.025	0.03	43.26	0.16
Southeast 100 feet	0.10	0.22	0.21	0.021	6.18	48.62	0.035	0.02	44.54	0.10

Development and Operation.—No development has been carried out. The grade and size of the known deposits, moreover, do not justify development unless other near-by limestone bodies are found. Though no readily available harbour exists to facilitate transportation of limestone from this locality by water, its accessibility by road to one possible market, Powell River, justifies further search for limestone deposits in this vicinity.

Reference

Bancroft, J. A. (1913): Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B.C., *Geol. Surv., Canada,* Mem. 23, p. 66.

Hardy Island Deposit

"On Hardy island, Jervis inlet, the limestone occurs as a narrow band with a visible width of a little over fifty feet. This band strikes across the island and runs inland on Nelson island for a short distance [*see* below]. In part the rock is flat lying and in part highly contorted. It is a fine-grained, impure crystalline limestone, with a pitted or fluted weathered surface. It holds long areas of siliceous material filled with pyrite, which coincide with the bedding planes and represent subsequent mineralization."

". . . the limestone is closely associated with finely banded siliceous schists." (LeRoy, 1908, pp. 14–15.)

Nelson Island Deposit

Location and Accessibility.—Limestone occurs in the northwestern part of Nelson Island near the head of Blind Bay. It outcrops on the shore on Lot 5377 and is reported to extend inland up the steep slopes of Nelson Island for at least one-half mile across Lots 5377 and 5570. The property can be reached from Pender Harbour, between 13 and 14 miles by boat to the south. Blind Bay is large and provides excellent shelter for shipping. Rock from a quarry on the property has been dumped at the shore to form a jetty extending to low-tide mark, hence adequate facilities for loading ships could readily be constructed.

Geology.—The limestone outcrops in a belt at least 200 and possibly as much as 400 feet wide, striking south 30 degrees east. At the shore the limestone is bounded on the north by a slightly gneissic grey porphyry, possibly an altered lava. About 400 feet farther north this porphyry is intruded by a grey granitic rock. On the south the limestone is bounded by a series of green distinctly banded tuffs which outcrop southerly along the shore for about 1,400 feet as far as a second granitic body. The tuffs strike from south 10 degrees to south 30 degrees east and dip from 60 to 90 degrees westward. Similar attitudes exist in the limestone where, however, some isoclinal folding is evident.

A few discontinuous dykes cut the limestone.

Overburden is relatively light.

The rock is white to cream in colour and relatively fine grained. It is distinctly and finely bedded.

Analyses.—Four samples, each made up of chips, taken at 4-foot intervals measured at right angles to the strike of the limestone belt, and representing widths of from 16 to 40 feet, were taken in the quarry in the central part of the belt about 300 feet from shore. Dyke rock was excluded in sampling. The analyses of these samples follow:—

Distance from North End	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S	Ig. Loss	H_2O
0– 16 feet	1.82	0.24	0.21	0.081	0.76	53.94	0.012	0.02	42.94	0.04
16– 44 feet	1.58	0.32	0.43	0.157	1.56	52.87	0.012	0.06	43.18	0.18
44– 84 feet	1.64	0.26	0.12	0.054	0.38	54.15	0.016	0.01	43.33	0.12
84–108 feet	4.16	0.26	0.31	0.111	0.42	52.61	0.012	0.01	42.12	0.21

Development ond Operation.—The property was developed by International Lime Corporation Limited, and has not been worked since about 1937. The registered owner of the property is Andrew J. Jorgenson, of Tacoma, Wash.

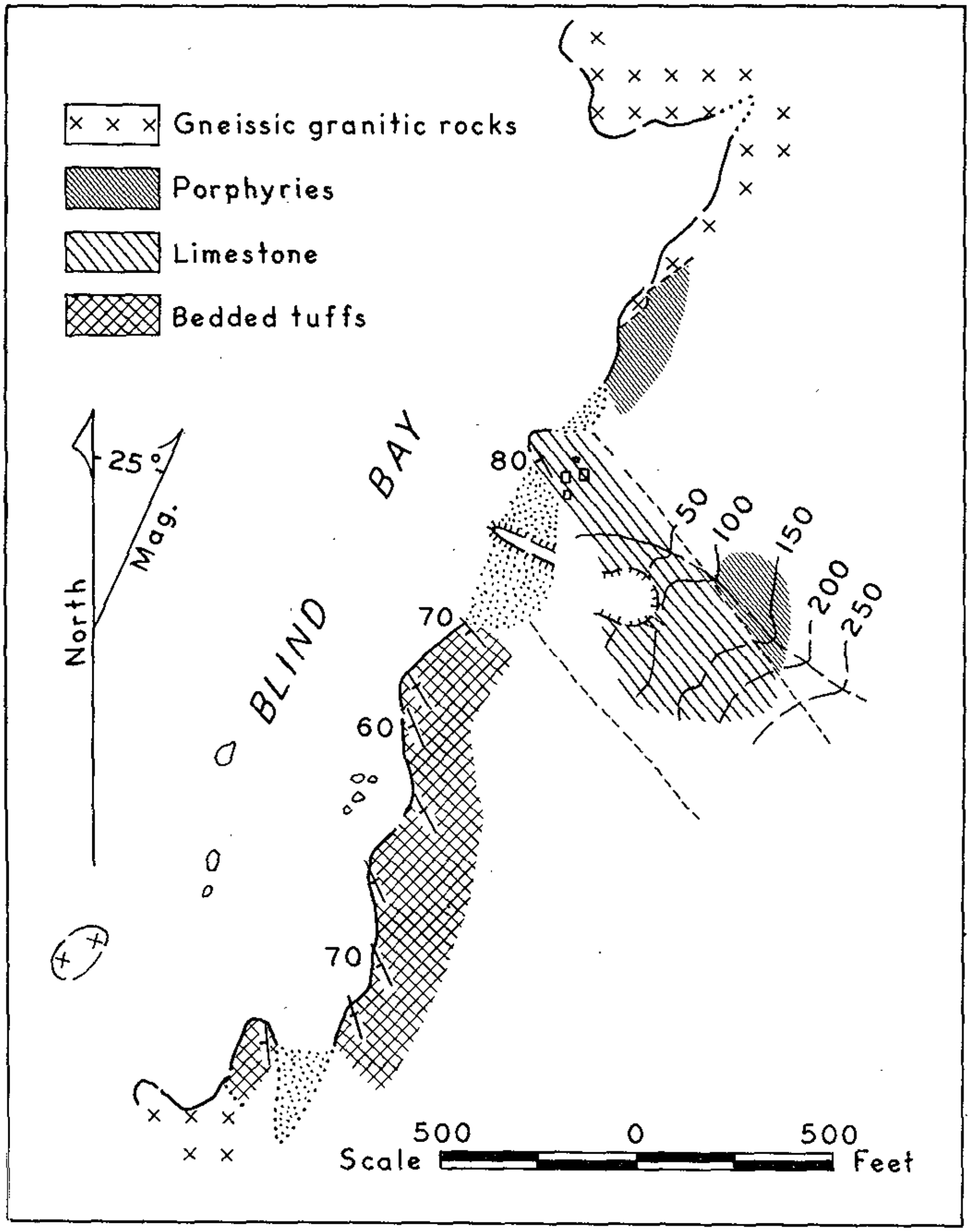

Figure 16. Blind Bay area, Nelson Island.

A quarry about 100 feet in diameter and with a face up to 60 feet high has been opened in the central part of the limestone belt on a knoll near the base of the steep mountainside of Nelson Island. An adit has been driven for 75 feet into the face of the quarry, and several trenches have been dug to expose the limestone at the surface 200 feet beyond the face. The jetty mentioned above was constructed from rock obtained from the quarry. A kiln is reported to exist on the property. The quarry and jetty are now overgrown with young alder.

The quarry could be extended as far as the trenches, 200 feet from the present face and 150 feet above the present floor, without encountering any major physical problems, but beyond this point the steep slope of the land surface would require quarrying in benches at successively higher levels.

Reference

LeRoy, O. E. (1908): Preliminary report on a portion of the main coast of British Columbia and adjacent islands included in the New Westminster and Nanaimo districts, *Geol. Surv., Canada,* Rept. No. 996.

CAMBRIAN CHIEFTAIN*

Location and Accessibility.—A large lens of dolomitic limestone is described by W. R. Bacon (1950, p. 171) on the Cambrian Chieftain mineral claim. This claim is 3½ miles north 24 degrees east from the head of Pender Harbour. A road to the property, 5.6 miles long, branches eastward off the Gibsons–Pender Harbour Highway at the settlement of Kleindale.

Geology.—The dolomitic limestone is an obscurely bedded body which has an average width of 100 feet and a minimum indicated length of 1,020 feet. It is associated with thin-bedded limestone and chert in a predominantly volcanic roof pendant surrounded by granitic rock.

Analyses.—Nine grab samples taken from the dolomitic limestone body averaged 19,8 per cent magnesia (MgO). Analyses of six of the grab samples follow:—

Sample	SiO_2	R_2O_3	Fe_2O_3	MgO	CaO	Ig. Loss	H_2O
No. 1	3.3	0.5	0.6	19.3	32.3	44.0	0.1
No. 2	5.1	0.9	0.6	20.0	31.5	41.9	0.1
No. 3	3.4	0.6	0.4	18.8	33.1	43.5	0.1
No. 4	3.4	0.6	0.4	20.1	31.7	43.6	0.1
No. 5	2.1	0.4	0.4	21.1	30.6	45.1	0.2
No. 6	2.9	0.8	0.5	20.7	30.9	44.2	0.1

Development and Operation.—The dolomitic limestone is associated with rocks containing copper mineralization. Some development has been done on the copper showings but none on the dolomitic limestone.

MIDDLE POINT DEPOSIT

"Crystalline limestones occur at Middle Point, also called McNaughton Point, (5 miles south-east of Pender Harbour), on the main coast, in a few small contorted and faulted beds, which are lenticular and pinch out along strike.

". . . the limestone is closely associated with finely banded siliceous schists." (LeRoy, 1908, p. 15.)

SALMON INLET (ARM) DEPOSIT

A large body of white crystalline limestone is reported to occur about 1½ miles up Thornhill Creek, which flows into Salmon Inlet (a branch of Jervis Inlet) from the south, 8 miles east of the mouth of the arm.

LYNN CREEK DEPOSIT

Burwash (1918) reports the presence of limestone with associated zinc mineralization near the head of Lynn Creek, north of Vancouver.

NITINAT LAKE*

Location and Accessibility.—A band of limestone more than a mile wide is exposed on the shores near the south end of Nitinat Lake. Nitinat Lake is a tidal lake on the west coast of Vancouver Island approximately 70 miles northwest of Victoria. The

* *See* Introduction, page 7.

limestone is 2½ miles up the lake from its outlet into the ocean. On the north shore the main showings are on Lots 63, 565, and an unnumbered lot between them. On the south shore, limestone is exposed on Lots 746, 743, and T.L. 8062P.

Boats as large as fish-packers enter the lake from the ocean, but can do so only during the short period of slack water. The entrance, less than 200 feet wide at places, is crooked and has a current reported to run as fast as 7 or 8 knots. An added hazard is the presence of a bar across the mouth of the outlet.

The nearest settlement is the Indian village of Clo-oose, on the coast 1 mile south of the lake outlet.

Geology.—The limestone, some siliceous and dolomitic beds, and highly altered zones together form a band that is bounded on both sides by granitic rock, chiefly granodiorite and diorite. The general strike of the rocks is northwestward, and the dip is moderate to steep to the northeast, although in one or two places the strike is nearly west or slightly south of west. A few dark dykes cut the limestone.

The limestone varies from coarse-grained white marble to fine-grained grey thin-bedded siliceous material. The best-looking rock is on the north shore on the unnumbered lot east of Lot 63. From the east side of Lot 63 white marble bluffs nearly 100 feet high extend for more than 700 feet northeast along the edge of the lake. Most of the limestone seen on the south shore of the lake is dark and impure.

Clapp (1912) included this limestone in the Nitinat formation, which he thought was probably Triassic or Jurassic but might possibly be of Palæozoic age. In 1956 a search for fossils was unsuccessful.

Clapp (1912) indicated a second belt of Nitinat formation crossing the lake near the upper end. However, a careful search was made along both shores, and no limestone was found other than that already described near the outlet of the lake. Most of the rock along the northeast half of the lake consists of interbedded cherty crystal tuffs.

Analyses.—One sample was taken for analysis. This consisted of chips taken at 10-foot intervals at water-level starting at the east boundary of Lot 63 and continuing along the marble bluffs for 750 feet northeastward. The analysis follows: Insol., 3.38; R_2O_3, 0.34; Fe_2O_3, 0.17; MnO, 0.006; MgO, 0.39; CaO, 53.3; P_2O_5, 0.008; S, 0.06; Ig. Loss, 42.3; H_2O, 0.16.

Development and Operation. — No development has been done on this deposit. Although the deposit is large and parts are pure, the isolated location and difficulty of access make it unattractive under present conditions.

CALCAREOUS DEPOSITS IN THE MIDDLE JURASSIC TO RECENT SUCCESSION

GENERAL

Upper Jurassic to Recent sediments and volcanics in southwestern British Columbia generally do not contain valuable calcareous deposits. However, an occurrence of limestone in Upper Jurassic rocks near Harrison Lake is known (p. 37). Calcareous sandstones are known from a few localities at the base of the Upper Cretaceous succession on the shores of Georgia Strait, from the marine Oligocene or Miocene sediments on Southern Vancouver Island, and in the Recent delta of the Fraser River. Marls are reported from the Oligocene or Miocene sediments on Southern Vancouver Island, and are now accumulating in Cheam Lake at the eastern end of the Fraser Valley. One small deposit of travertine was once worked southeast of Rosedale, and a second in the same area was being worked in 1956. Shell mounds accumulated in recent times on the sites of Indian villages are common, and at least one has proved sufficiently large and high grade to justify mining. Shell sands of very limited extent are produced by wave and current action during storms and have been worked by individuals during periods of unemployment.

DESCRIPTION OF OCCURRENCES

CALCAREOUS DEPOSITS AT DEPARTURE BAY

Location and Accessibility.—A calcareous deposit, referred to by Clapp (1913, pp. 55, 56, 123, 124) as an impure calcarenite, occurs at two places on the north shore of Departure Bay, at and one-half mile east of the Dominion Biological Station respectively. Similar rocks are mapped in three small areas about 2½ miles northwest of the Biological Station. The deposits are accessible by road from Nanaimo, 4 miles south of Departure Bay.

Geology.—The deposits consist of a green sandstone in which occurs a greater or less amount of calcium carbonate, generally as equidimensional spherical to angular grains 1 to 2 mm. in diameter, and in the finer-grained cementing material. Some of the calcium carbonate grains are composed of shell fragments, and some may be oolites of chemical origin. All the deposits lie at the base of the Upper Cretaceous succession and rest with or without basal conglomerate unconformably on the Vancouver series, here composed of greenstone, which clearly provided most of the detrital material in the sandstone. In the section exposed on the shore near the Biological Station a total thickness of about 50 feet of sandstone and basal conglomerate, dipping about 20 degrees southward into Departure Bay, is present. A few layers are relatively rich in calcium carbonate, and one such layer, about 2 inches in thickness, has the following analysis: Insol., 20.40; $R_2O_3+Fe_2O_3$, 5.96; MgO, 1.88; CaO, 39.5; Ig. Loss, 32.2.

An analysis given by Clapp (1914, p. 124) of a similar calcareous sandstone is as follows: Insol. mineral matter, 15.42; ferric oxide and alumina, 5.40; lime, 42.41; magnesia, 0.94.

A succession similar in character and comparable in thickness to that at the Biological Station is exposed on the shore one-half mile east of the station where, however, the beds dip steeply eastward and southeastward. The deposits 2½ miles northwest of the station have not been examined by the writers.

Development and Operation.—Clapp in 1914 reported that a test-quarry had been opened on the deposit at Departure Bay, but no subsequent development has evidently taken place. The extremely limited quantity of sandstone rich in calcareous matter, and the unsatisfactory grade of it eliminates the possibility of commercial operation.

CHEAM LAKE MARL

Location and Accessibility.—Cheam Lake is 9 miles east of Chilliwack, in the Northwest Quarter of Section 5, the Northeast Quarter of Section 6, the Southwest Quarter of Section 8 in Township 3, Range 28, west of the 6th meridian, and on the Cheam No. 1 Indian Reserve. It is less than one-half mile from the Cariboo Highway, and about 1 mile by road from Popkum Station on the Canadian National Railway.

Geology.—The deposit consists of a layer of brownish to white jelly-like marl containing scattered snail and pelecypod shells, accumulated on the floor of the shallow lake in post-Glacial time. The marl is reported to be from 4 to 12 feet thick and to lie on 2 feet of blue clay and this, in turn, to lie on sand. The chief impurities consist of mud brought in by a stream from the south, and concentrated near its mouth, and of wind-blown dust. Organic matter, nitrogen, and sulphur are present in greater amounts than in most of the older limestone deposits, but the magnesia content is very low (*see* analyses).

In addition to the marl within the lake, a second deposit originally underlay to a depth of as much as 13 feet an area of low land about 4 acres in extent, apparently a former arm of Cheam Lake, in the Southwest Quarter of Section 8.

Development and Operation.—Marl has been dug from the Cheam Lake deposit along the east shore and at the northeast corner of the lake. At present Popkum Marl Products Limited, managed by W. A. Munro, mines marl on the east shore. This property was originally operated by Fraser Valley Chemicals and later by Marlime Limited.

The marl and overlying humus are dug by dragline and loaded on to trucks. Some of the material is dried in an oil-fired rotary kiln. Wet, semi-dry, and dry humus and marl are produced.

Cheam Marl Products Limited, with A. M. Davidson as manager, digs marl at the northeast corner of the lake. The company has dug a large drainage ditch to lower the lake level. Several acres, probably occupied formerly by an arm of the lake, have been stripped of marl. Draglines are used to dig on-shore material and a bucket scraper is used to retrieve material from the lake bed. The marl is sold wet or semi-dry or it can be dried in a rotary kiln.

The amount of marl available in Cheam Lake is very difficult to estimate in view of the indefinite moisture content of the jelly-like material. The following analyses have been made of three samples of material pumped from the lake after it had been partly dried in bins and are quoted both on a moisture-free basis and as received. The calcium carbonate content of the three samples "as received"—that is, of partly dried marl—ranged from 35.4 to 37.9 per cent.

Sample	Insol.	R_2O_3	Fe_2O_3	MnO	MgO	CaO	P_2O_5	S[1]	Ig. Loss	N[1]	Organic[1,2]	H_2O at 105° C.
No. 1—												
Moisture-free	13.10	0.81	1.06	0.046	0.08	40.26	0.049	0.67	44.43	0.51	5.10	0.0
As received	....	....	....	....	....	*19.9*[3]	....	....	....	....	....	50.6
No. 2—												
Moisture-free	8.70	0.67	0.77	0.032	0.10	44.00	0.040	0.55	45.07	0.43	3.90	0.0
As received	....	....	....	....	....	*21.3*[3]	....	....	....	....	....	51.7
No. 3—												
Moisture-free	5.45	0.35	0.72	0.029	0.20	46.40	0.031	0.59	45.97	0.51	3.00	0.0
As received	....	....	....	....	....	*20.1*[3]	....	....	....	....	....	55.0

[1] Included in ignition loss.
[2] Includes carbon.
[3] Calculated from CaO content of moisture-free sample.

Travertine

*Rosedale Marl Lime Products Ltd.**

Location and Accessibility.—A small travertine deposit was worked for a short time near the centre of Section 35, Township 2, Range 29, west of the 6th meridian. The quarry is 2 miles by road or 1½ miles in a straight line southeast of Rosedale.

Geology.—The deposit consists of a fan-shaped mound of travertine about 100 feet long, 75 feet wide, and 25 feet thick. A few inches of soil covers the travertine. The mound lies against the base of a low ridge that slopes up to the main Skagit Mountains. A small creek issues from a spring in the bank above the mound and flows around its north end. No travertine is being deposited at present by this water.

Analysis.—The analysis of a sample of the travertine taken across the quarry face follows: Insol., 10.2; R_2O_3, 0.96; Fe_2O_3, 0.69; MnO, 0.007; MgO, 0.42; CaO, 47.9; P_2O_5, 0.032; S, 0.08; Ig. loss, 39.7; H_2O, 0.40.

Development and Operation.—C. C. Shaver quarried travertine at this deposit during 1954. The rock was blasted down, crushed, dried in an oil-fired kiln, ground in a ball mill, and elevated to storage bins. The product was sold for agricultural purposes. The operation proved uneconomic and has been closed since 1954. The plant was still in fair condition in 1956.

*Marble Hill Travertine Deposit**

Location and Accessibility.—A deposit of travertine underlies the bottom of a small gully near the northwest corner of Fractional Section 16, Township 2, Range 29, west of the 6th meridian. The quarry and processing plant at the deposit are 4.9 miles by road south and west of Rosedale.

* *See* Introduction, page 7.

Geology.—The travertine forms a layer beneath 2 to 5 feet of earthy overburden in the bottom of a gully that is about 100 feet wide and 400 feet long. It is reported that auger holes indicate that travertine underlies the entire gully bottom. The thickness of the travertine is not known, but it is more than 10 feet in the quarry. No bedrock is exposed in the immediate vicinity of the quarry.

Analysis.—The analysis of one sample taken across the quarry face follows: Insol., 8.1; R_2O_3, 0.94; Fe_2O_3, 0.57; MnO, 0.004; MgO, 0.26; CaO, 48.9; P_2O_5, 0.025; S, 0.20; Ig. Loss, 40.7; H_2O, 0.30.

Development and Operation.—The travertine is on land owned by W. J. Duperron and is leased from him by Marble Hill Lime Products, of Chilliwack. Lime is reported to have been produced from this deposit as long ago as 1930. The present operators have only recently taken over the deposit. The travertine is blasted and bulldozed loose from a quarry face 50 feet wide and 10 feet high. The loosened material is carried 100 feet by a front-end loader to the plant. Wet rock is dried by being spread over a wood-fired boiler. The dried travertine is crushed and bagged and sold to feed companies.

Shell Mounds

Kuper Island†

Location and Accessibility.—The Kuper Island shell deposit is situated on Clam Bay at the north end of Kuper Island, 20 miles southeast of Nanaimo.

Geology.—The shell mound consists of an old Indian midden, accumulated probably over a period of centuries. Most of the deposit is made up of clam shells, bones, ashes, assorted debris, and rare human artifacts. Mounds composed largely of mussel shells are found in a few places at the base of the deposit. The relative freedom from sand is considered to be evidence of the absence of wave and current action during the formation of the mound. The deposit is reported to have covered an area of about 12 acres to a depth of as much as 15 feet.

Development and Operation.—The deposit was worked in recent years by West Coast Shell Company, of New Westminster, and has now been exhausted. During the period of operation the shell was hauled by dragline to a central bunker, washed and jigged to remove most of the impurities, flumed to a dock, drained, then loaded by dragline on to a scow to be hauled to the New Westminster plant.

Other Shell Deposits

Another shell deposit exists at the northern end of Denman Island, 5 miles east of Courtenay. This deposit, like the one at Kuper Island, is made up of the shells of clams and mussels together with broken utensils, bones, ashes, etc. Over a considerable area near the shore the shells are reported to be cupped, one inside the other, as if rolled into a common orientation by wave action. The deposit is about 10 acres in extent and up to about 9 feet deep. Much of the shell has, however, been rendered friable, perhaps by age or fire, and it has not proved possible to recover a sufficient quantity of poultry grit to make the deposit commercial.‡

Many other similar shell mounds‡ are known in the Georgia Strait area, but because of the small size, or deficiencies in grade and character of the shell, have not proved commercial.

Shell Sands

In localities such as at False Creek in Vancouver, shell sands may accumulate entirely as a result of wave and current action along the shore. These deposits, a fraction

† From information provided by A. E. Pickford, of the Provincial Museum, Victoria, and J. A. Robinson, of the West Coast Shell Company, New Westminster.

‡ Smith, Harlan I. (1903): Shell heaps of the Lower Fraser River, *Am. Mus. Nat. Hist.*, Jesup North Pacific Expedition.

‡ *Idem* (1907): Archæology of the Gulf of Georgia and Puget Sound, *Am. Mus. Nat. Hist.*, Jesup North Pacific Expedition.

of an inch in depth, form after violent storms as a result of transportation of clam shells to the shore and washing by the waves. Such layers of shell and shell fragments can be collected by means of a basket-like scoop, screened, and sold as poultry grit. The recovery of shell sand by individuals was carried on during times of unemployment close to such populated centres as Vancouver, but the extremely limited character of the deposits discourages their operation during periods of high wages.

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a mobile loader. The products are sold for agricultural use and as an industrial filler. A crew of seven men produced 6,584 tons of limestone. A total of 6,604 tons of limestone products was sold in 1962.

Beale Quarries Division (Lafarge Cement of North America Ltd.).*— Vananda (49° 124° N.W.). Head office, 1051 Main Street, Vancouver 4; quarry office, Vananda. W. D. Webster, quarry superintendent. The quarry, crushing plant, and loading-dock are on the east coast of Texada Island, 1 mile south of Vananda. Open-pit benching was used to produce 502,279 tons of limerock, of which 435,000 tons was crushed and 401,000 tons was shipped. A crew of twenty-three men was employed.

Ideal Cement Company Ltd.*

Vananda (49° 124° N.W.). British Columbia office, 1155 West Georgia Street, Vancouver 5; quarry office, Vananda. W. S. Beale, manager, Rock Products Division; J. K. Johnson, superintendent. Rock quarries were operated on Lot 25, 2 miles south of Vananda and adjacent to the crushing plant and loading-dock at Marble Bay. Open-pit bench-quarrying methods were used to produce 125,000 tons of limerock, of which 103,000 tons was crushed and shipped. The materials shipped included rip-rap rock, pulp rock, cement rock, metallurgical limerock, and limerock for the production of calcium carbide. A crew of twelve men was employed.

Imperial Limestone Company Limited*

Vananda (49° 124° N.W.). Office, 7309½ East Marginal Way, Seattle 8, Wash.; plant and quarry office, Vananda. J. A. Jack, president; E. Jack, superintendent. The quarry and primary crushing plant are on Lot 500, near the summit of a small hill 1 mile west of Spratt Bay on the east coast of Texada Island. At the quarry plant the limerock is sorted into white and grey fractions. The select white limestone is trucked to the plant at Vananda for further crushing to produce stucco dash and whiting. The run-of-pit and sorted grey rock was trucked to the main crushing plant at Spratt Bay.

A crew of fourteen men mined, crushed, and shipped 44,483 tons of limerock.

Gypsum, Lime Division (Domtar Chemicals Limited)*

Blubber Bay (49° 124° N.W.) British Columbia office, 1105 West Pender Street, Vancouver 1; quarry office, Blubber Bay; lime plants, Blubber Bay and Vancouver. A. M. Stewart, west coast manager; J. M. Greenaway, Blubber Bay plant manager. The limestone quarry is approximately 2 miles south of Blubber Bay at the north end of Texada Island. The crushing, storage, and loading facilities were expanded by the addition of a 42- by 48-inch Telsmith jaw crusher, a 50-foot extension to the reclaiming tunnel, and a new shuttle conveyor for loading barges up to 10,000 tons capacity. A new haulage road was constructed from the pit to the plant in order to avoid the payment of highway overload penalties.

A crew of fifteen men was employed at the quarry and crushing plant, and forty-five men in the lime plant. Open-pit bench-mining methods were used to produce 388,000 tons of limestone, of which 345,000 tons was shipped.

* By J. E. Merrett.

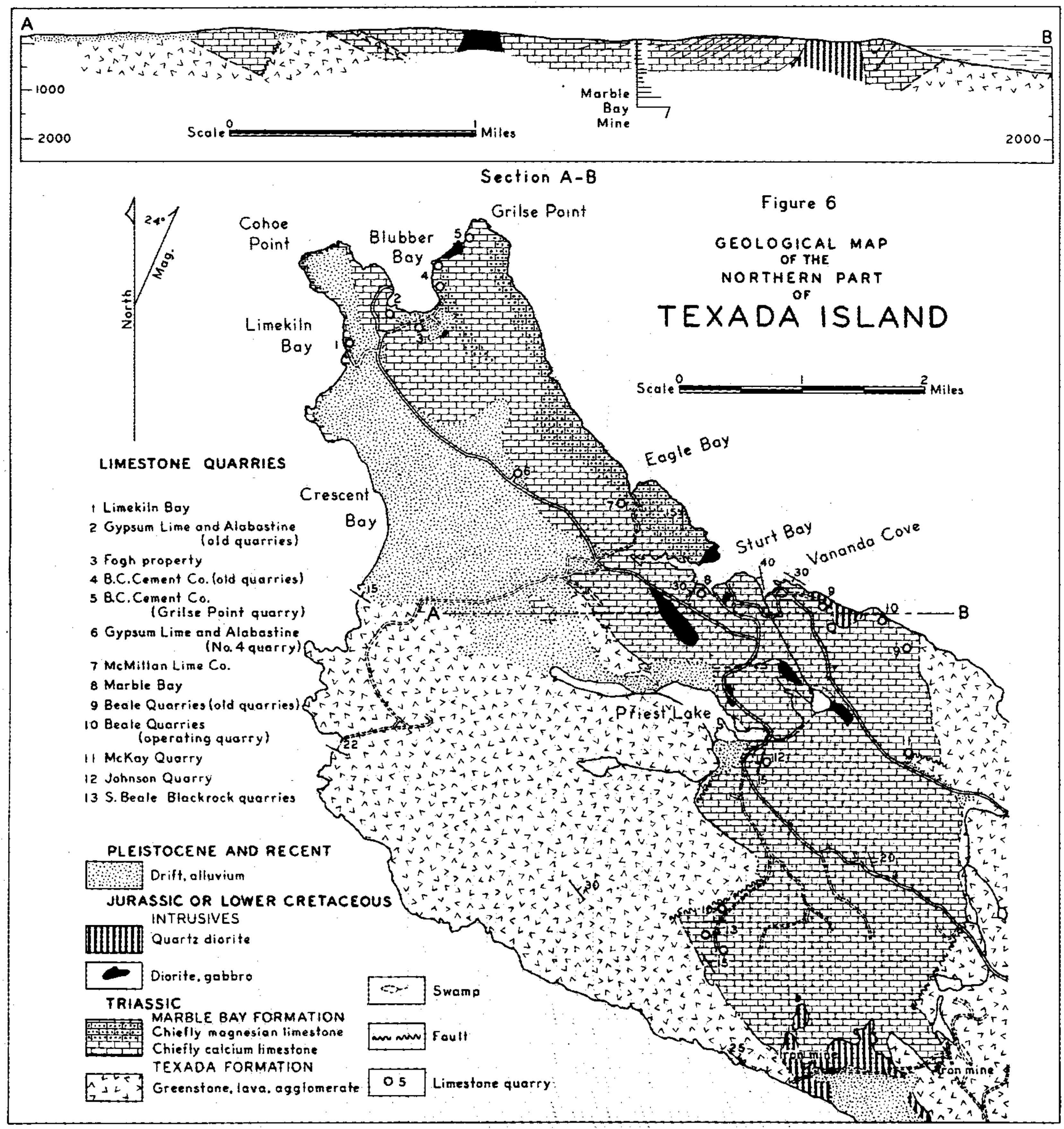
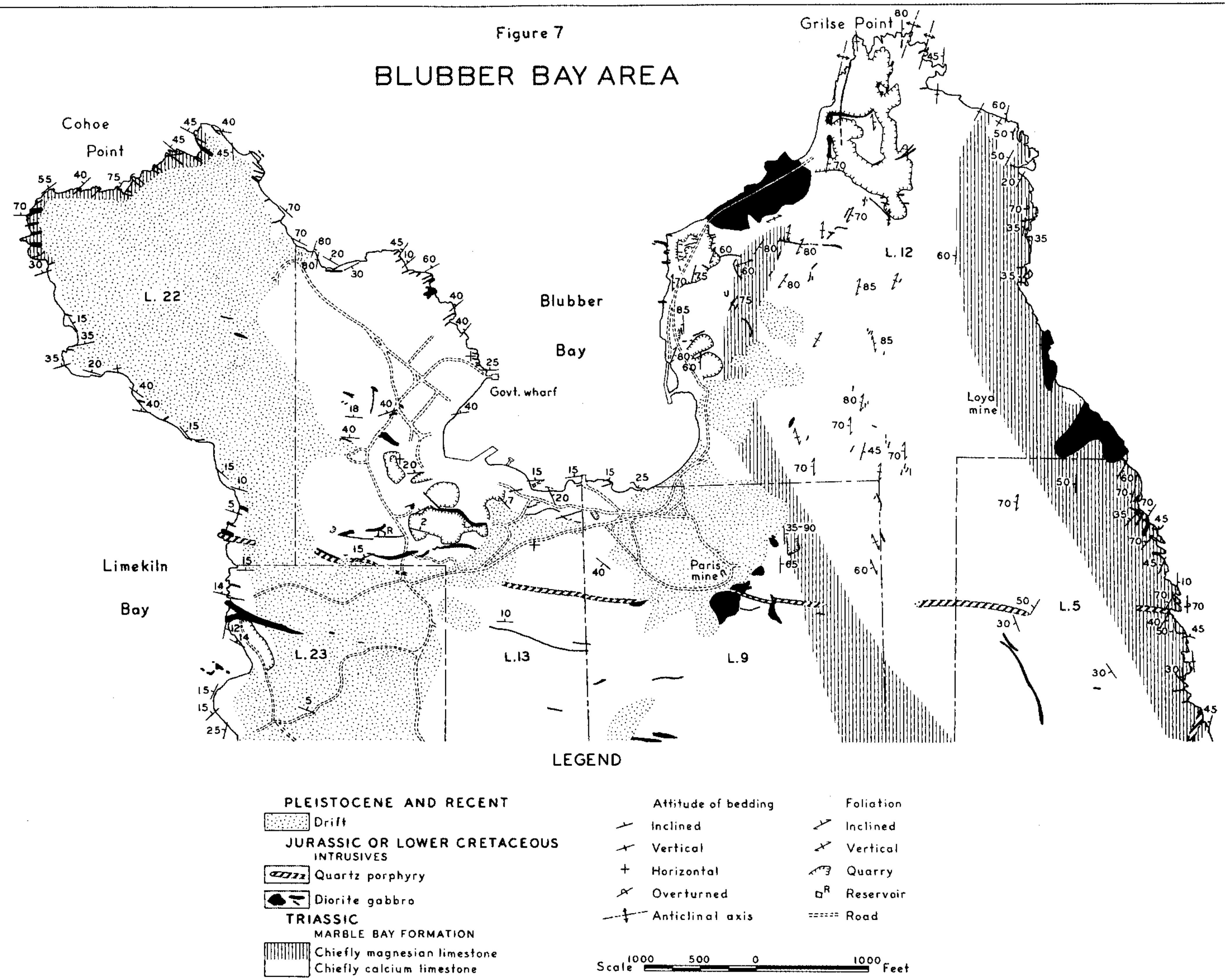
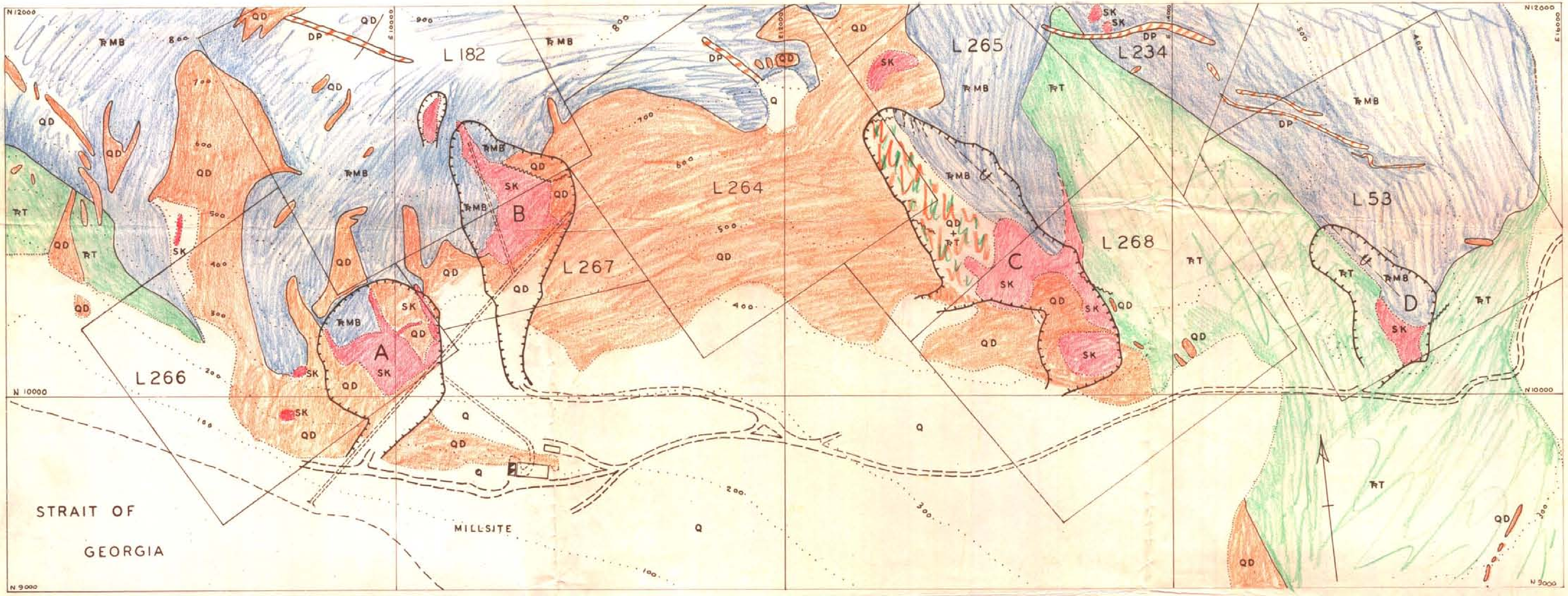

A
B
1000
2000
2000
Marble
Bay
Mine
Scale 0 1 Miles
Section A-B
Figure 6
GEOLOGICAL MAP
OF THE
NORTHERN PART
OF
TEXADA ISLAND
Scale 0 1 2 Miles
North
Mag.
24°
Cohoe Point
Blubber Bay
Grilse Point
Limekiln Bay
Crescent Bay
Eagle Bay
Sturt Bay
Vananda Cove
Priest Lake
Iron mine
LIMESTONE QUARRIES
1 Limekiln Bay
2 Gypsum Lime and Alabastine (old quarries)
3 Fogh property
4 B.C.Cement Co. (old quarries)
5 B.C.Cement Co. (Grilse Point quarry)
6 Gypsum Lime and Alabastine (No. 4 quarry)
7 McMillan Lime Co.
8 Marble Bay
9 Beale Quarries (old quarries)
10 Beale Quarries (operating quarry)
11 McKay Quarry
12 Johnson Quarry
13 S. Beale Blackrock quarries
PLEISTOCENE AND RECENT
Drift, alluvium
JURASSIC OR LOWER CRETACEOUS
INTRUSIVES
Quartz diorite
Diorite, gabbro
TRIASSIC
MARBLE BAY FORMATION
Chiefly magnesian limestone
Chiefly calcium limestone
TEXADA FORMATION
Greenstone, lava, agglomerate
Swamp
Fault
O 5 Limestone quarry

Figure 7

BLUBBER BAY AREA





Q	OVERBURDEN
D	LATE DYKES
SK	SKARN & MAGNETITE
QD	QUARTZ DIORITE
DP	DIORITE PORPHRY
TrMB	MARBLE BAY LIMESTONE
TrT	TEXADA VOLCANIC FM.

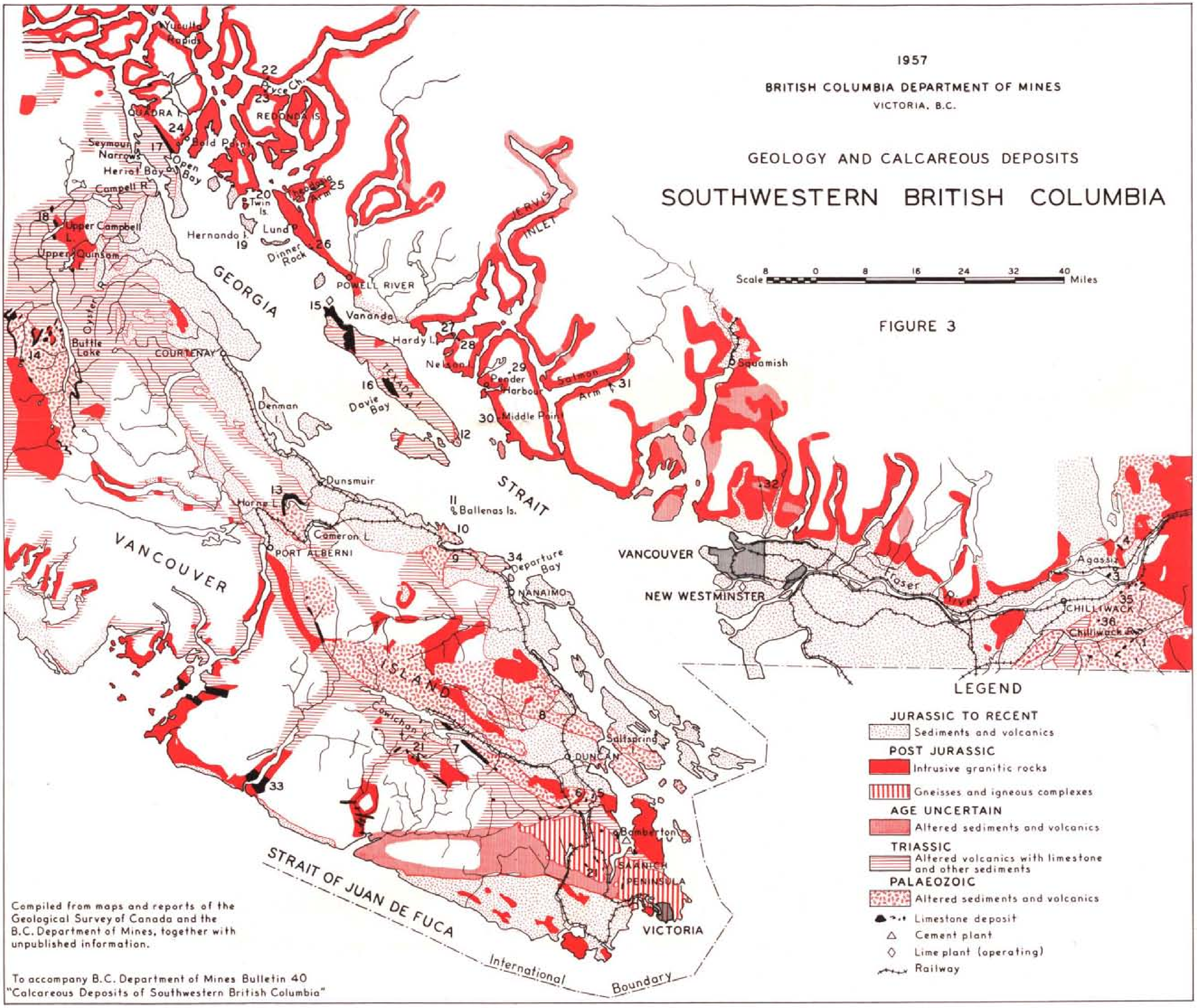
TEXADA MINES

SCALE 0 400 800 FEET

A PRESCOTT PIT
B YELLOW KID PIT
C PAXTON PIT
D LAKE PIT

#40 1

DRAWN BY A&B JULY'63



LIMESTONE DEPOSITS

PALAEOZOIC

CASCADE MOUNTAINS

1. Chilliwack River
2. Popkum
3. Agassiz
4. Bear Mountain

VANCOUVER ISLAND AND VICINITY

5. Cobble Hill
6. Raymond
7. Cowichan Lake
8. Mt. Brenton
9. Nanoose Bay
10. Schooner Bay
11. Ballenas Islands
12. Anderson Bay
13. Horne Lake
14. Buttle Lake

TRIASSIC

15. Northern Texada Island
16. Davie Bay
17. Open Bay
18. Campbell River Area
19. Hernando Island
20. Twin Islands
21. Sutton Deposits

AGE UNCERTAIN

22. Pryce Channel
23. Redonda Island
24. Bold Point
25. Theodosia Arm
26. Dinner Rock
27. Hardy Island
28. Nelson Island
29. Cambrian Chieftain
30. Middle Point
31. Thornhill Creek
32. Lynn Valley
33. Nitinat Lake

JURASSIC TO RECENT

34. Departure Bay
35. Cheam Lake
36. Marble Hill

#40 (2)