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HIGH-CALCIUM LIMESTONES OF EASTERN WASHINGTON

By

JOSEPH W. MILLS

With a section on
LIMESTONE IN THE BOUNDARY, LEADPOINT, SPIRIT, AND
DEEP LAKE QUADRANGLES OF NORTHERN STEVENS COUNTY

By R. G. YATES,

U. S. GEOLOGICAL SURVEY



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FOREWORD

Since the early days of Washington's statehood, limestone has been recognized as one of the important mineral resources of the State. The second annual report of the Washington Geological Survey, published in 1903, gave details on the State's limestone deposits, and in later years four other reports published by the Survey and its successor agencies have given additional information on this resource. Still other reports by Federal and private agencies have been published in response to demands for data on limestone here. Although some of the earlier reports included analyses to show the purity of the rocks, very few of the samples for analysis were taken systematically in a way that would fairly represent the deposits sampled.

Prior to 1900 limestone was produced for use as building stone here, and another important use was for the production of burned lime. Portland cement plants soon became leading consumers of limestone, and they continue as such to the present time. Limestone is used in large quantities in the pulp industry in the Northwest, but in 1962 there were no commercial lime-burning plants in the State.

Recognizing the potential for industrial development in Washington based on more intensive use of our mineral resources, and recognizing the need to up-date the State's knowledge of raw material resources in order to channel those resources into the State's growing economy, the Industrial Raw Materials Advisory Committee of the Department of Commerce and Economic Development in 1958 recommended that a comprehensive survey be made of the limestone resources of Washington. It was suggested that the investigation should determine the amount and quality of stone available in the largest and most accessible deposits in both the eastern and western parts of the State.

With the interest and support of the Industrial Raw Materials Advisory Committee, a limestone market survey was completed by the Department of Commerce and Economic Development and a survey of the limestone deposits was commenced in 1959 by the Division of Mines and Geology of the Department of Conservation. The Division of Industrial Research at Washington State University was engaged to analyze some 750 limestone samples. We were fortunate to obtain the services of Dr. Joseph W. Mills, Chairman of the Department of Geology at Washington State University, to make the survey of limestone in eastern Washington, which is reported here as Bulletin 48 of the Division of Mines and Geology.

Marshall T. Huntting, Supervisor
Division of Mines and Geology

May 15, 1962

CONTENTS

	<u>Page</u>
Foreword	
Abstract	1
Acknowledgments	2
Definitions	2
Mineralogical composition of limestones and common impurities	3
Origin	4
Post-depositional changes	5
Field characteristics and identification	6
Sampling	10
Analyses	12
Sample preparation	13
Analytical chemical procedures	13
Spectrochemical procedure	14
Spectrochemical analyses	15
Mining and processing	18
Evaluation of deposits	19
Production and consumption	19
Uses and specifications	23
Physical uses	26
Chemical uses	26
Portland cement	26
Agricultural limestone	27
Fluxing stone	28
High-calcium lime	28
Alkali manufacture	29
Glass manufacture	29
Sugar refining	30
Calcium carbide	30
Pulp and paper	30
Limestone whitening	31
Selected references	33
Deposits	35
Distribution of carbonate rocks in eastern Washington	35

CONTENTS

	<u>Page</u>
Deposits—continued	
Pend Oreille County	37
Metaline district	37
Limestone of the lower units of the Metaline Limestone.....	39
Lehigh Portland Cement Company property, Metaline Falls	39
Lime Lake area	41
Three Mile Creek area	41
Slate Creek area	42
Getchell-Dehuff property	44
Limestone of the upper unit of the Metaline Limestone	47
Black Heart claims	47
Beatty Lake area	48
Hoage Lake area	49
Russian Creek area	51
Z Canyon area	53
Other occurrences of Metaline Limestone	54
lone area	54
lone quarry	56
Green quarry	58
Thackston property	59
Parker Lake district	60
Hauck property	60
Stevens County	61
LIMESTONE IN THE BOUNDARY, LEADPOINT, SPIRIT, AND DEEP LAKE QUAD-	
RANGLES OF NORTHERN STEVENS COUNTY, By R. G. Yates	61
Introduction	61
General geologic relations	61
Descriptions of the more important limestone units	65
Reeves limestone zone.....	65
Metaline Formation	66
Deep Creek district	67
Cedar Lake deposit	68
Aladdin deposit	70
Northport district	73
Janni quarry area	74
Janni Northeast area	78

CONTENTS

	<u>Page</u>
Deposits—Continued	
Stevens County—Continued	
Northport district—Continued	
Onion Creek deposit	81
Northport Smelter quarry	83
John Sherve property	85
Ester Sherve property	88
Rainey property	89
Broderius deposit	92
Makynen property	93
Ideal Cement Company Northport quarries	96
Other areas of Northport district	102
China Bend district	102
China Bend area	102
Columbia Rock Company quarry area	105
Bossburg district	107
Bossburg East area	108
Bossburg North area	113
Bossburg vicinity	116
Evans district	117
U.S. Gypsum Co. upper quarry	117
U.S. Gypsum Co. lower quarry	121
Ideal Cement Co. quarry area	123
Brooks property	126
Orient-Kelly Hill district	129
Barstow area	133
Kettle Falls North district	134
Pingston Creek area	138
Hanson property	142
Kettle Falls South district	143
Mingo Mountain area	143
Heidegger Hill district	145
The Splitoff deposit	147
Heidegger Hill deposit	149
Thorpe Road area	152

CONTENTS

	<u>Page</u>
Deposits—Continued	
Stevens County—Continued	
Hunters Creek district	152
Hunters Creek road area	153
Hunters Creek road north area	153
Adams Mountain area	154
Locke road area	154
Harvey Creek North Fork area	155
Springdale-Valley district	155
Carbonate rocks of the fault block	155
Rocks east of the fault block	156
Rocks west of the fault block	156
Springdale area	157
Jumpoff Joe Lake Southwest deposit	157
Jumpoff Joe Lake West deposit	160
Valley district	162
Valley to Chewelah district	163
Addy district	164
Colville district	164
Colville Mountain area	166
South end Old Douglas Mountain area	166
Truman Wood Creek and Prouty Creek areas	167
Pinkney City area	167
Jones Ridge area	168
Churchill Ridge area	169
Joe Creek area	169
Binger Canyon area	169
Jumpoff Joe Bluff area	169
North Fork Mill Creek area	170
Clugston Creek area	170
Keystone Marble Company deposit	171
Jefferson Marble, Mining and Milling Company deposit	171
Rattlesnake Mountain area	173
Echo Peak area	173
Hoeft property	173
Spokane Indian Reservation	176
Cayuse Mountain area	176

CONTENTS

	<u>Page</u>
Deposits—Continued	
Northeastern Ferry County	177
Orient district	177
Barstow area	178
Lake Ellen district	179
Southern Ferry County	179
East half Colville Indian Reservation	179
Covada area	183
Keller area	183
Northwestern Ferry County	184
Curlew Northeast district	186
Shasket Creek area	186
Little Goosmus Creek area	188
Vandiver property	189
Limestone in the SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 6, T. 39 N., R. 34 E.	189
Helphrey property	190
Republic Northeast district	190
Lambert Creek area	191
Republic North district	195
Curlew Lake area	195
Mires Creek area	198
Herron Creek area	198
Copper Lakes district	198
Doblasue property	200
Union Lime quarry area	200
Empire Creek district	203
Iron Mountain district	204
Other occurrences of limestone of Permian age in northwestern Ferry County ...	204
Curlew Northwest district	205
North Fork St. Peter Creek district	205
Wauconda Southwest district	205
Swan Lake Road area	208
Sheep Mountain area	209
Okanogan County	210
Buckhorn Mountain—Havillah district	210
Buckhorn Mountain area	211

CONTENTS

	<u>Page</u>
Deposits—Continued	
Okanogan County—Continued	
Buckhorn-Havillah district—Continued	
Chewsaw to Muskrat Lake area	214
Bunch-Wildermuth property	215
Havillah area	216
Wauconda district	218
Toroda Creek road area	218
Toroda Creek North area	220
Sinlahekin district	221
Wannacut Lake area	221
Cayuse Mountain area	224
Other areas of limestone in northern Okanogan County	227
Blue Lake area	227
Whisky Mountain area	227
Aeneas Creek area	227
Kruger Mountain area	227
Jackass Butte area	228
West half Colville Indian Reservation	229
Nespelem area	230
Riverside district	230
Dunn Mountain area	232
Frye Lake area	236
Johnson Creek road area	238
Asotin County	238
Lime Hill area	238
Appendix A—Chemical analyses of eastern Washington limestones	244
Appendix B—Spectrochemical analyses of eastern Washington limestones	252
References cited	265

CONTENTS

ILLUSTRATIONS

Plate	1. Generalized geologic map of northeastern Washington	In pocket
	2. Geologic map of the Metaline mining district	In pocket
	3. Map showing distribution of Cambrian limestone and dolomite in Deep Creek district	In pocket
	4. Map and cross section of Ideal Cement Company Northport quarries	In pocket
	5. Geologic map of Heidegger Hill district	In pocket
	6. Geologic map of Colville district	In pocket
	7. Map of Wannacut Lake area	In pocket
		<u>Page</u>
Figure	1. Thin-bedded fractured limestone, Bossburg East area (photograph)	6
	2. Pitted weathered surface of high-calcium limestone (photograph)	7
	3. Elephant-hide texture on weathered surface of dolomite (photograph)	8
	4. Weathered limestone and dolomite (photograph)	9
	5. Pie diagram showing the relative volumes of limestone sold or used for different purposes in the United States in 1958	25
	6. Map of Slate Creek area	43
	7. Map of Getchell-Dehuff property and Black Heart claims	45
	8. Map of Hoage Lake area	50
	9. Map of Russian Creek area	52
	10. Map of lone area	55
	11. Map of lone quarry	57
	12. Map of Cedar Lake deposit	69
	13. Map of Aladdin deposit	71
	14. Janni quarry, Northport (photograph)	75
	15. Map of Janni quarry area	76
	16. Map of Janni Northeast area	80
	17. Map of Onion Creek deposit	82
	18. Map of Northport smelter quarry	84
	19. Map of John and Ester Sherve properties	86
	20. Map of Rainey and Broderius deposits	90
	21. Map of Makynen deposit	94
	22. Ideal Cement Company Northport quarries (photograph)	97
	23. Map of China Bend area	103
	24. Map of Columbia Rock Company quarry area	106

CONTENTS

	<u>Page</u>
Figure 25. Large hill of limestone, sec. 33, T. 38 N., R. 38 E., Bossburg (photograph)	108
26. Small hill of limestone, sec. 33, T. 38 N., R. 38 E., Bossburg (photograph)	109
27. Map of Bossburg East area	110
28. Map of Bossburg North area	114
29. Map of U.S. Gypsum Company upper quarry, Evans	118
30. U.S. Gypsum Company upper quarry, Evans (photograph)	119
31. Map of U.S. Gypsum Company lower quarry, Evans	122
32. Ideal Cement Company quarries, Evans (photograph)	124
33. Map of Ideal Cement Company quarry area, Evans	125
34. Map of Brooks property	127
35. Geologic Map of part of Kelly Hill district	130
36. Map of Kettle Falls North district	135
37. Steep west side of Pingston Creek North reef (photograph)	137
38. Map of Pingston Creek South and middle reefs	140
39. Map of Pingston Creek North reef	141
40. Map of Mingo Mountain area	144
41. Map of The Splitoff deposit	148
42. Map of Heidegger Hill deposit	151
43. Map of Jumpoff Joe Lake area	158
44. Map of Jumpoff Joe Lake Southwest deposit	159
45. Map of Jumpoff Joe Lake West deposit	161
46. Map of Hoeft property	175
47. Geologic map of east half of Colville Indian Reservation	180
48. Geologic map of Curlew Northeast district	187
49. Geologic map of Republic Northeast district	192
50. Map of Lambert Creek area	193
51. Geologic map of Republic North district	196
52. Map of Curlew Lake area	197
53. Geologic map of Copper Lakes district	199
54. Map of Union Lime quarry area	202
55. Geologic map of Curlew Northwest district	206
56. Geologic map of Wauconda Southwest district	207
57. Map of Buckhorn Mountain area	212
58. Map of Bunch-Wildermuth property	217
59. Map of Toroda Creek road area	219

CONTENTS

	<u>Page</u>
Figure 60. Map of Cayuse Mountain area	225
61. Map of Dunn Mountain area	233
62. Map of Frye Lake area	237
63. Geologic map of Lime Hill area	239
64. Lime Hill (photograph)	240

TABLES

Table 1. Amount and value of limestone (crushed and broken stone) sold or used by producers in the United States in 1958	20
2. Limestone (crushed and broken stone) sold or used by producers in the United States in 1957 and 1958	20
3. Limestone consumption by major consuming industries in Washington in 1959	21
4. High-calcium limestone consumption in Washington in 1958	22
5. Limestone consumption in the United States in 1958, by uses	24
6. Chemical specifications for high-calcium limestone for use in industry	31
7. High-calcium limestone deposits of eastern Washington, potential uses, and reserves	32
8. Chemical analyses of samples of limestone from Lime Hill	241

HIGH-CALCIUM LIMESTONES OF EASTERN WASHINGTON

By Joseph W. Mills

ABSTRACT

Limestone occurrences in Pend Oreille, Stevens, Ferry, Okanogan, and Asotin Counties of eastern Washington were studied during the summers of 1959 and 1960 for the purpose of determining the size, grade, and geologic setting of deposits containing in excess of 95 percent CaCO_3 . Special attention was given to the deposits that are close to transportation routes and potential marketing centers.

The general geologic setting of the limestone occurrences in districts and the details of occurrence in 117 areas are described in the text and illustrated in 59 geologic maps. Of the limestone occurrences in the 117 areas, 59 are considered to be of early Paleozoic (Cambrian) age, 45 of late Paleozoic age (principally Permian, some Mississippian and Pennsylvanian), 4 of Triassic age, and 9 of unknown age.

Three hundred and sixty-three limestone chip samples were taken and chemically analyzed for CaO , MgO , SiO_2 , R_2O_3 , and P_2O_5 . Selected groups of these samples were analyzed for TiO_2 , S , Na_2O , and K_2O .

All samples were analyzed spectrochemically also. All contain SrO (0.01 to 0.04 percent), MnO (0.01 to 0.10 percent), and CuO (0.0006 to 0.0030 percent). Chromium is found in all samples from Asotin, Ferry, and Okanogan Counties, and in many from Stevens County. Limestones that are shown by field observation and chemical analysis to be the most siliceous and argillaceous contain the greatest number and largest amounts of V, Cr, Cu, Ni, Zr, Ti, Sr, and Mn. Barium is found in only 3 samples, silver in 15, and lead in 18. No element or group of elements is characteristic of any distinctive limestone unit or formation.

Twenty-nine deposits, totaling in excess of 250 million tons, are composed of high-calcium limestone. Of these, 14 are in Stevens County, 7 in Pend Oreille County, 6 in Okanogan County, and 2 in Ferry County. All of them are chemically suitable for use as mineral filler, 23 for use in the pulp and paper industry, 24 for the manufacture of finishing lime, 16 for whiting, 11 for use in sugar purification, as metallurgical lime, and as chemical lime, 6 for the manufacture of calcium carbide, and 1 for use as glass flux. All the high-calcium limestone deposits and many lower grade deposits described in the report are suitable for the manufacture of portland cement and for other limestone uses for which the chemical specifications are less stringent.

The nature, origin, identification, sampling, analysis, mining, processing, evaluation, production, consumption, uses, and specifications (7 tables) of limestone are discussed also.

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The value of the report has been greatly enhanced by the contributions of R. G. Yates, of the U.S. Geological Survey, and W. A. G. Bennett, of the Washington State Division of Mines and Geology. Dr. Yates provided the text and geologic map dealing with the geology of the Deep Creek district. Dr. Bennett prepared the geologic map and helped materially in the preparation of the text on the geology of the Colville district. J. A. Wolfe and S. S. Comstock, of the Ideal Cement Company, supplied survey and analytical information on limestone deposits at Lime Hill, Northport, Evans, and Bossburg. R. E. Sorenson generously provided analytical data obtained by the Hecla Mining Company from limestone deposits in the Northport and Metaline districts. J. E. Hayes, of the Utah-Idaho Sugar Company, and F. C. Appleyard, of the U.S. Gypsum Company, supplied analytical data obtained by their companies from several deposits in northeastern Washington.

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DEFINITIONS

Limestone is rock of sedimentary origin made up of 50 percent or more of the minerals calcite (calcium carbonate) and dolomite (double carbonate of calcium and magnesium). Pure limestone, which is rare, contains 100 percent CaCO_3 . The term high-calcium limestone is used in this report for limestone that contains 95 percent or more of calcium carbonate.

Dolomite is sedimentary rock containing more than 50 percent of the minerals calcite and dolomite, in which the mineral dolomite is more abundant than calcite. The term marble is used commonly to refer to a coarse-grained crystalline limestone or dolomite, generally the product of the metamorphism of limestone and dolomite; it is so used in this report. Commercially, the term marble has long been applied to any stone, other than those known in the trade as granite, that has a pleasing appearance and will take a polish. Bates (1960, p. 69) proposes that the term be applied to metamorphic carbonate rocks used for polished stone.

MINERALOGICAL COMPOSITION OF LIMESTONES
AND COMMON IMPURITIES

Calcite, aragonite, and dolomite.—Limestone is composed essentially of calcite or calcite and dolomite. Calcite is calcium carbonate (CaCO_3) crystallized in the rhombohedral system. It has a hardness of 3 and a specific gravity of 2.71 to 2.72. Because of the similarity of the effective ionic radii of magnesium and calcium ions, a limited amount (4 percent) of magnesium can substitute for calcium in the calcite crystal lattice. Aragonite is calcium carbonate crystallized in the orthorhombic system. The stability relations of calcite and aragonite were studied by Johnston, Merwin, and Williamson (1916), and at all temperatures and pressures likely to be encountered in sedimentary environments, calcite is the stable form. Sea shells are secreted wholly, or in a few cases partly, as the mineral aragonite by the living organisms. With time the aragonite recrystallizes entirely to calcite, so that most calcareous fossils are composed of calcite, not aragonite. Dolomite, the double carbonate of calcium and magnesium ($\text{CaCO}_3 \cdot \text{MgCO}_3$) crystallizes in the rhombohedral system. It has a hardness of 3.5 and a specific gravity of 2.8 to 2.9. It can be distinguished from calcite by the very faint reaction or, very commonly, the entire lack of effervescence when cold dilute acid is applied to a fragment of the mineral. If the cold acid is applied to the powdered mineral, however, or if hot acid is applied to a fragment, brisk effervescence will result. 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.

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. Such chert impurities stand in relief on the weathered surface of the limestone. Silica may be present in limestone in the form of hydrothermal quartz stringers, veins, and masses. Some of the silica in the limestone from the Dunn Mountain area, Okanogan County, may be of this origin. Silica may also exist in limestone in combination with other elements, as, for example, in clay minerals and feldspar grains, etc., accumulated in the original sediment. Silica may also exist in combination with other elements in minerals (especially mica, amphibole, garnet, and epidote) formed by reconstitution of the sedimentary minerals or introduced during metamorphism and alteration of the strata by hydrothermal waters subsequent to deposition.

Alumina-bearing minerals.—The alumina-bearing minerals present in limestone include clay minerals, mica, feldspars, garnets, and other silicate minerals. The clay minerals were deposited at the same time as the calcium carbonate, in the form of disseminations or distinct thin films and beds of shale. Most of the other alumina-bearing minerals are the products of metamorphism.

Iron-bearing minerals.—Iron may exist in limestone in the form of carbonates (siderite, ankerite), sulfides (pyrite, marcasite), oxides (limonite, hematite, magnetite), and silicates (garnet, chlorite, olivine, etc.). Normally, iron minerals are present only in small amounts. Some of these minerals were

original, some were formed by recombination, and some were subsequently introduced. In the spectrographic analyses given in this report, the Fe_2O_3 reported is the total iron in the sample, calculated to Fe_2O_3 . In the chemical analyses given in this report, the R_2O_3 is the total iron, calculated to Fe_2O_3 , and alumina (Al_2O_3) combined.

Sulfur.—Sulfur occurs in limestone in combination with iron as pyrite or marcasite, as sulfates, and as hydrogen sulfide occluded within the rock. In places, notably in mining districts, limestones contain sulfur in combination with base metals.

Carbon.—The carbon, which was presumably derived from organic matter entombed during sedimentation, contributes the gray color to the limestone. The dark-gray color of many limestones has little or no bearing on the value of the limestone for most uses. During the calcining of limestone the carbon is driven off.

Phosphorus.—Phosphorus in very small quantities is present in all samples taken during this study. The combination in which it occurs has not been determined. It is reported in the analyses given in this report as percent P_2O_5 .

Alkalies.—Soda (Na_2O) and potash (K_2O) are found in very small quantities in some of the limestone sampled during this study. In some samples the potash and soda, especially the former, are contained within muscovite mica and feldspar disseminated through the limestone. In other samples the combination in which soda and potash occur is unknown.

ORIGIN

All limestones were formed under water by the action of organic, chemical, or physical agencies, or some combination of these, on dissolved calcareous matter. Calcareous waters issuing onto the land surface as springs, entering caves, or percolating through surface soils may deposit calcareous material known as "travertine" or "tufa." Some limy oozes have been and are being deposited in fresh-water lakes as "marl." Deposits of travertine and marl are found in eastern Washington (Valentine, 1960, p. 58, 59), but they are too impure to qualify as high-calcium limestone and they are not included in this study. By far the greatest proportion of limestones, including all those reported in this study, were deposited under marine conditions, in depths of water as much as several hundred feet. Sea waters are for the most part nearly saturated to supersaturated with calcium carbonate. Precipitation of calcium carbonate is favored by (1) shallow water, (2) a decrease in the CO_2 content of water, (3) high surface temperature, (4) higher than normal marine salinity, (5) alkalinity, or relatively high pH, and (6) oxidizing conditions. Of the several factors inducing limestone deposition, the loss of CO_2 is of first importance. The loss of CO_2 is favored by shallow water (aeration and agitation) conditions, a rise in temperature, and removal of CO_2 by plants, especially by marine algae. The relative importance of purely chemical precipitation as compared with the action or influence of organisms in producing limestone has not been well established, but organisms appear to play the predominant role.

The calcium carbonate removed from the sea water may take the form of a fine-grained ooze on the sea bottom, an incrustation about plant parts, or it may be incorporated in the shells and tests of marine invertebrate animals. Many of the marine plants and animals that secrete calcium carbonate for protective and supporting parts are colonial or at least gregarious in habit. Their limy remains may accumulate and be preserved in large concentrations. Compaction, consolidation, and lithification of soft oozes, after burial under succeeding strata, generally involve widespread resolution, cementation, dehydration, and crystallization. Limestone detritus, formed by subaerial or subaqueous mechanical breakdown of limestone, shells, and other forms of calcium carbonate, may be redeposited to form clastic limestones. Such accumulations are controlled by the same physical laws that govern the processes of destruction, sorting, transportation, and deposition of noncalcareous sands and muds.

Dolomite forms by chemical replacement of limestone (1) on the ocean floor during the accumulation of the sediment, or (2) by magnesia-bearing waters long after consolidation, lithification, and elevation of the sediment above sea level have taken place.

It follows from what has been said about the origin of limestones that they may be classified, on the basis of their origin, as organic, inorganic, or clastic, or as some combination of these. Organic limestones are those resulting from the vitalizing processes of organisms. They include limestones made up of the shells of organisms and those resulting from the precipitation of calcium carbonate by algae and bacteria. Inorganic limestones were precipitated by purely chemical or physiochemical means without direct precipitation by organisms. Clastic limestones are those detrital limestones that have resulted from the deposition of eroded, broken, or ground up fragments or particles of limestone of any origin. Most of the limestones examined during this study were deposited originally as oozes on the sea bottom and are either inorganic or organic in origin. Most of the limestones of Permian age in eastern Washington are not markedly stratiform like the older limestones; their form and fossil content show that they are of organic origin. Some of the limestones of Permian age in the Kettle Falls and Kelly Hill districts contain fragmented fossil parts and angular quartz grains indicating a clastic origin for these rocks.

POST-DEPOSITIONAL CHANGES

The limestones of northeastern Washington, with the exception of some of the deposits of late Paleozoic age, were originally formed as horizontal or nearly horizontal strata. They have since been lifted above the sea, tilted, warped, and complexly folded. The strata have been faulted and fractured on a scale ranging from the great fault blocks of the Metaline district, Pend Oreille County (pl. 2), and the Republic district, Ferry County, to the intimate small fractures in the limestone at Bossburg (fig. 1). Dynamic metamorphism and thermal metamorphism have resulted in a coarsening of the grain size of the limestone and in the formation of new minerals by recombining the chemical ingredients of impurities. Hot circulating (hydrothermal) waters have altered parts of the limestone to dolomite and have added silica and other mineral impurities. In the Metaline and Northport districts, dolomites and dolomitized limestones are the hosts for the accumulations of valuable ores of lead and zinc.



FIGURE 1.—Typical very thin bedded crumpled and fractured limestone in NE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 33, T. 38 N., R. 38 E., Bossburg East area.

FIELD CHARACTERISTICS AND IDENTIFICATION

During the present study it was necessary to be able to distinguish readily between relatively pure limestone and impure limestone, dolomitic limestone, and dolomite. Inability to make these distinctions in the field would require resorting to expensive chemical analyses and the loss of much time spent examining, sampling, and mapping carbonate rocks unsuitable for most limestone uses. The presence of appreciable quantities of chert, argillaceous material, and most other impurities can usually be recognized by examination of the weathered outcrop and by careful examination of specimens with the aid of a hand lens. The distinction between limestone and dolomite or dolomitic limestone is difficult for the untrained

but easy for the practiced observer. Limestone can be distinguished from dolomite, on freshly broken surfaces, by the application of cold dilute acid; 1:15 hydrochloric acid was used in this study. Calcite and calcium-rich limestone effervesce vigorously in such acid, whereas dolomite reacts very feebly or not at all. However, this test is not entirely satisfactory, because a limestone specimen containing both calcite and dolomite will effervesce, though the effervescence will be less vigorous than for a high-calcium limestone. A more effective test, but one not used in this study, is reported by Mathews and McCammon (1957, p. 27) as follows:

If . . . a specimen of the limestone to be tested is immersed in the cold dilute (1:5 hydrochloric) 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.



FIGURE 2.—Typical pitted weathered surface of high-calcium limestone.

Another test that may be used on fresh rock surfaces, but which was not used in this study, is the ferric chloride-ammonium polysulphide etch test, described by Mathews and McCammon (1957, p. 27) as follows:

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.

A distinction between limestone and dolomite can be made fairly well after some practice, on the basis of the difference in hardness of calcite and dolomite. Limestone can be scratched more easily than dolomite by drawing the point of a geology pick lightly across the surface of the carbonate rock. The difference in hardness, as indicated by the depth of the scratch, is determined more easily on a weathered than on a fresh surface.



FIGURE 3.—Typical elephant-hide texture on weathered surface of dolomite.

One of the most reliable criteria, at least in climatic regions like eastern Washington, is the character of the weathered surface of the outcrop. The weathered surface of a calcium-rich limestone presents a smooth outline and a pitted surface (fig. 2); each pit or small hemispherical depression is smooth. On some surfaces the crowded depressions are small ($1/16$ to $1/4$ inch), on others they are broader ($1/2$ to 4 inches) and flatter. The rock surface has a sugary texture. Small caves, gaping joints, and pot-holes are common. Impurities stand up in relief on the limestone surface. The weathered surfaces of dolomite present a more angular outline and exhibit far fewer and shallower solution pits. The pits are commonly developed in crisscrossing linear patterns controlled by joints, giving the surface of the dolomite a wrinkled and lined appearance, sometimes referred to as elephant-hide textures (fig. 3). Silica and other insoluble materials stand up above the dolomite surfaces, though with little relief. The color of the weathered surface of the carbonate rock may be helpful in distinguishing between dolomite and limestone. Dolomite most commonly, though by no means invariably, weathers light brown, pale buff, or cream, whereas limestone weathers light gray to dark gray, and rarely brown, buff, or cream.

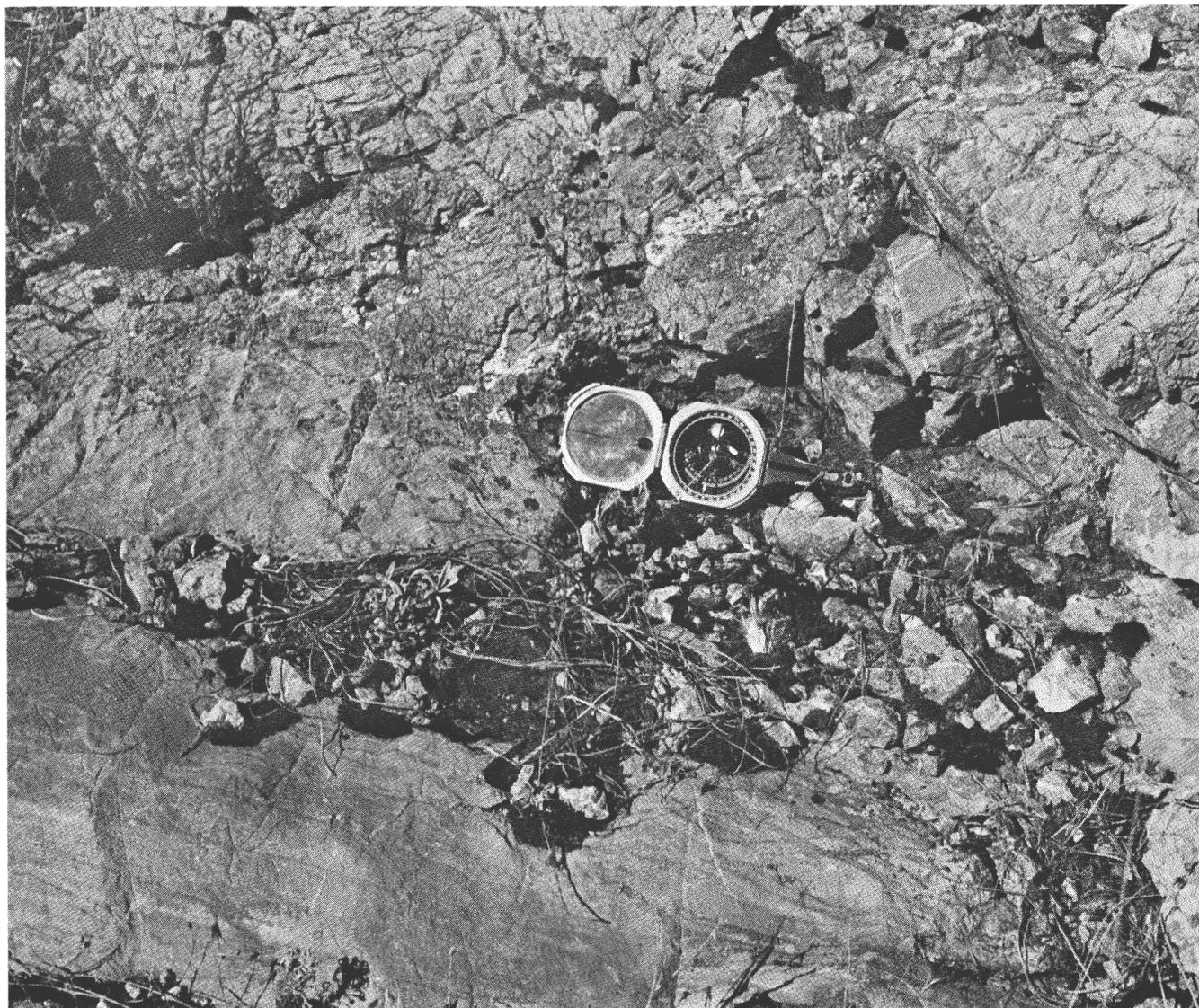


FIGURE 4.—Weathered limestone (foreground) and dolomite (background).

Pure dolomite in great thicknesses is found in some areas of eastern Washington. For example, the middle unit of the Metaline Limestone in the Metaline district (pl. 2), Pend Oreille County, and the lower part of the succession of carbonate beds in the Riverside district, Okanogan County, are composed principally of dolomite. In other areas, dolomite strata are found interbedded with limestones or dolomitic limestones. A third way in which dolomite occurs is as numerous grains, blebs, stringers, and small masses scattered through limestone strata. The differences in color, amount of relief, and the texture of the weathered surface between the calcitic and dolomitic parts of the dolomitic limestones (fig. 4) provide a ready means of identifying the dolomitic limestones. The dolomite bodies may transect the bedding of the limestone in a random manner, or they may show a more pronounced development along the bedding planes. In either case, the inclusion of the dolomite results in a rock (dolomitic limestone) that is too rich in magnesia for most limestone uses and too low in magnesia for most dolomite uses. Large areas on both sides of the Columbia River between Northport and Bossburg are underlain by dolomite, interbedded dolomite and limestone, and by dolomitic limestone.

SAMPLING

Sampling procedures used to determine the composition or quality of a limestone deposit vary widely according to the geology of the deposit, the use to which the limestone may be put, the time and cost involved, and many other factors. In this study we were concerned with obtaining samples representative of limestone occurrences that were determined, on the basis of preliminary examination and geologic mapping, to be sufficiently large and free of impurities to be potential sources of high-calcium limestone. Limestones that were obviously very impure usually were not sampled. In some instances, however, very large and easily accessible deposits of impure limestone were sampled (e. g., Heidegger Hill), especially if these had been reported by others to be of high purity. Factors other than the purity, accessibility, and size of the limestone deposits, that governed the number and kind of samples taken, were the time and cost involved in the sampling.

Each limestone occurrence was examined carefully prior to sampling. If it was found to be of sufficient purity and size to justify sampling the geology was mapped (time permitting), paying particular attention to the attitude and continuity of the limestone. Samples were then taken in a direction as nearly at right angles to the strike of the bedding in the limestone as good exposures permitted. The sample consisted of unweathered chips, ranging from sand size to pieces approximately 1 inch in diameter, taken at 10-foot intervals along the sample direction. The total bulk of a single sample ranged from approximately 7 to 11 pounds (bag limit), depending upon the length of the sample. Where the sample length approximated the true thickness of the limestone or where the lithology was quite uniform, the length was commonly 50 feet, and the sample weight approximately 9 pounds. The location, bearing, and slope of the sample line was recorded along with a brief description of the structure and lithology of

the limestone. Twelve samples were taken in Asotin County, 27 in Pend Oreille County, 38 in Ferry County, 75 in Okanogan County, and 211 in Stevens County.

In order to test the reliability of the sampling, within the limits of accuracy of the analytical method, two sets of duplicate samples (S-98 to S-102 and S-104 to S-106) were taken on the small hill in the Bossburg East area, Stevens County. The second set was taken within a few feet of the first set taken a month earlier. The results of the analyses of the two sets of duplicate samples are as follows:

Sample no.	CaO		MgO		SiO ₂		R ₂ O ₃		P ₂ O ₅	
	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
S-98	55.02	54.68	0.39	0.56	0.70	0.47	0.10	0.13	0.010	0.028
S-99	54.10	54.53	0.87	0.77	1.41	0.54	0.12	0.15	0.017	0.026
S-100	53.81	55.13	1.12	0.52	0.87	0.83	0.12	0.33	0.020	0.027
S-101	53.89	54.38	0.72	0.63	1.83	1.37	0.18	0.16	0.020	0.031
S-102	54.83	55.28	0.33	0.22	0.96	0.42	0.16	0.15	0.017	0.010
S-104	55.08	54.98	0.30	0.31	0.58	0.37	0.14	0.21	0.017	0.018
S-105	55.16	54.78	0.34	0.58	0.72	1.18	0.19	0.12	0.031	0.056
S-106	55.02	54.98	0.34	0.49	0.42	0.35	0.12	0.12	0.041	0.007
Average	54.66	54.90	0.62	0.46	0.95	0.63	0.14	0.17	0.021	0.025
Set 1 Set 2 × 100	99.7		135		150		82		84	

The degree to which the analyses of the two sets of samples are not in agreement is partly due to the sampling method and partly due to the analytical method. Some measure of the reliability of the analytical procedures may be obtained from the duplicate analyses (reruns of the same sample) recorded below.

Sample no.	CaO	MgO	SiO ₂	R ₂ O ₃	P ₂ O ₅
S-20	52.26	2.40	0.96	0.27	0.035
S-20	52.34	2.48	----	----	0.032
S-20	52.19	2.42	----	----	0.037
S-20	52.34	2.45	0.96	0.35	0.032
S-20	52.19	2.52	0.90	0.31	0.037
S-20	52.57	2.56	0.83	0.36	0.036
S-20	-----	2.51	0.86	0.29	-----
S-45	-----	0.28	----	----	0.035
S-45	-----	0.28	----	----	0.033
S-45	-----	-----	----	----	0.035
S-45	54.25	0.28	1.67	0.46	0.032
S-45	53.61	0.28	1.51	0.48	-----
S-23	53.39	1.13	1.58	0.81	0.007
S-23	-----	1.26	----	----	-----
S-23	-----	1.18	----	1.09	0.003
S-23	-----	0.95	----	0.94	0.007
S-33	-----	----	2.60	----	-----
S-33	53.64	----	2.57	0.31	-----
S-33	53.53	----	2.52	0.40	-----
S-33	53.59	0.69	2.56	0.36	0.039

A comparison of the differences between duplicate samples and duplicate analyses of the same sample shows that the differences in the content of CaO , R_2O_3 , and P_2O_5 for duplicate samples are no greater than the differences in the content of CaO , R_2O_3 , and P_2O_5 reported for reruns of a single sample. The differences in the content of MgO and SiO_2 between duplicate samples in some instances are larger than the differences between duplicate analyses of the same sample. A comparison of the average composition of a number of samples and the average composition of their duplicate samples shows that, with the exception of silica, the averages are within the limits of analytical error. The silica is an exception; it probably is more difficult to duplicate in resampling because it is distributed in a less uniform way than are the other impurities in the limestone.

ANALYSES

Chemical and spectrographic analyses were made on 363 chip samples from eastern Washington deposits of high-calcium limestone. The analyses were made by the Chemistry-Spectroscopy Laboratories of the Division of Industrial Research, Institute of Technology, Washington State University, under the supervision of Mark Adams. The principal analysts were Clarence Homi and Robert Keough. C. E. Harvey was responsible for the spectrochemical analyses.

All samples were chemically analyzed for CaO , MgO , SiO_2 , R_2O_3 , and P_2O_5 and were analyzed spectrochemically for all elements detectable.

Seven single samples and 20 composite samples (combinations of from 3 to 6 contiguous samples) were analyzed for Na_2O , K_2O , TiO_2 , and S. The samples were chosen at random, except that most were limestones that contained in excess of 54 percent CaO .

The range in the content of these constituents is Na_2O , 125 to 270 ppm; K_2O , 300 to 840 ppm; TiO_2 , $\sqrt{-30}$ to 315 ppm; and S, 14 to 470 ppm. No correlation was found between the content of Na_2O , K_2O , TiO_2 , or S and the content of CaO , MgO , SiO_2 , or R_2O_3 . None of the single or composite samples of limestones from different counties or of different ages had a content of Na_2O , K_2O , TiO_2 , or S that was sufficiently characteristic of the limestone to serve as a means of identifying either the location or the age of the rock.

The results of the chemical analyses are reported under the heading "Quality and quantity of limestone" in the descriptions of the individual deposits and are shown in the appendix on pages 244 to 251. A table of spectrographic analyses is given in the appendix on pages 256 to 264.

The chemical analytical procedures followed by the chemists of the Washington State University Chemistry-Spectroscopy Laboratories are reported by them (1961, written communication) as follows:

$\sqrt{-30}$ means that the sample contains less than 30 ppm, the detectable lower limit.

SAMPLE PREPARATION

The sample was crushed to 1/4 inch, cut in half, and ground to a fine powder. About 1/2 pound of the powder was dried at 110° to 112°C for several hours and used for the chemical analysis.

ANALYTICAL CHEMICAL PROCEDURES

Loss on ignition procedure.—A 1.0000 g sample was weighed into a freshly ignited and weighed crucible and placed in the muffle at no more than 300° to 400°C. The temperature was increased to 1,000° to 1,100°C and held there for at least 1 hour. The crucible was transferred to a desiccator containing fresh CaO and quickly weighed as soon as cool. (Note: Samples placed in a hot furnace tend to splatter. Crucibles heated above 1,100°C may stick to sample.)

Silica procedure.—The sample from the ignition was put in an evaporating dish and moistened with alcohol. Water, then diluted HCl, was added to dissolve the sample. The crucible was rinsed into the dish with HCl. Alcohol was expelled by heating, then 5 ml of HClO_4 was added and the solution evaporated at below boiling. HCl was added and the hot solution filtered through No. 30 Whatman filter paper. After thorough washing with hot 1:10 HCl, the sample was ignited at 1,000° to 1,100°C and weighed. (Note: Alcohol is necessary to slow exothermic hydration of CaO. The alcohol must be removed before adding HClO_4 to avoid possible explosive reaction.)

R_2O_3 procedure.—The filtrate from silica was heated to near boiling in a 400 ml beaker, and 5 ml of saturated NH_4Cl was added. 1:1 NH_4OH was added until a faint odor of NH_3 persisted. (Methyl red can be used to help detect the proper pH.) After heating for 5 to 15 minutes the solution was filtered through a No. 31 Whatman paper into a 250 ml volumetric flask followed by washing with 1 percent NH_4NO_3 solution at pH 6.5 to 8.0. The precipitate was ignited at 1,000°C. (Note: The NH_4OH should be of a good quality, free from silica and carbonates.)

Ca and Mg procedures.—The filtrate from R_2O_3 was diluted to 250.0 ml, and 10 ml was pipetted into a wide mouth flask, buffered with 3 ml of $\text{NH}_4\text{Cl} - \text{NH}_4\text{OH}$ buffer and titrated to a pure blue with Uni-Ver indicator. Standard CaCO_3 and the same pipet were used to check the titer of the EDTA titrant before each group of samples was titrated. Ca was found by difference by subtracting the equivalents of Mg from the equivalents of combined Ca and Mg as determined by this EDTA titration.

Mg procedure.—Seven to 9 ml of 20 percent Na_2SO_4 were added to 100 ml of the filtrate from R_2O_3 and left to stand cold for 10 minutes. It was then warmed to 90°C for about half an hour and filtered through very fast paper. Two ml of saturated $(\text{NH}_4)_2\text{C}_2\text{O}_4$ were added. It was then heated at 70° to 80°C for 2 to 3 hours, while being kept slightly basic followed by filtration through a No. 32 Whatman paper, cooled, and titrated with EDTA.

Phosphorus procedure.—0.284 g of sample was dissolved in a minimum amount of 1:1 HCl in a 100 ml volumetric flask. To this solution, diluted to 50 to 70 ml, 5.0 ml of 2.5 percent ammonium

molybdate in $10\text{NH}_2\text{SO}_4$ was added and stirred well. After stirring, 2.0 ml of 0.15 percent hydrazine sulfate was added and the mixture shaken. The flask was placed in boiling water for 10 to 11 minutes, then removed and placed in a cold water bath until cool. The solution was diluted to volume and the absorbance was read on a DU Spectrophotometer at 830 μ with a 0.04-mm slit.

SPECTROCHEMICAL PROCEDURE

The choice of spectrochemical procedures to be applied to a problem is largely determined by the concentration range sought, and two or more techniques may have to be applied to determine separately major constituents, minor constituents, and extremely low trace elements. The latter may frequently involve a preliminary separation and concentration technique.

In the limestone problem, a single technique was applied because major constituents were determined chemically and extremely low levels down to parts-per-billion range were not sought. The procedure used would detect most elements in the samples in a range of 10 to 50 ppm. This was a simple direct-current arc technique, using standard pre-form electrodes with 10 mg of sample and 10 mg of graphite containing a constant amount of two elements whose presence in the samples was highly improbable. These elements, platinum and germanium, served as reference or so-called internal standard elements, the choice of one or the other being determined by the burning characteristics of the particular elements involved. For elements in the low to medium boiling point range, germanium was used as internal standard. High boiling point elements required platinum as internal standard.

The achievement of best quantitative results required a large number of standards since there was considerable variation in the CaO/SiO_2 ratio in the samples submitted. This variation produces a matrix effect in changing sensitivity of detection for various elements. Consequently, a series of matrices were prepared, containing varying amounts of CaO , SiO_2 , Al_2O_3 , and MgO . To these in turn were added portions of standard mixes referred to as "addition mixes." These contain various elements at known levels of concentration and permitted the introduction of various minor elements in a range of 0.0001 to 1.0 percent. While the entire group of 15 addition mixes would be necessary to cover every element in the periodic system normally detectable by spectrographic methods, a group of four mixes covered the elements found in the limestones submitted. Each of these was introduced at seven levels of concentration into each matrix type and intensities studied to determine possible variations due to changes in the CaO/SiO_2 ratio.

Thus, the procedure applied to both standards and samples consisted of weighing 10 mg of sample and 10 mg of graphite containing internal standards into a pre-formed cup-type electrode, burning to completion in a direct current arc and photographing the resulting spectrum on 35 mm film. After processing the film, various spectrum lines were measured for various elements, with the choice of line being determined by the range of concentration of the element involved. The intensity ratio of sought-for element and internal standard was then determined and a curve established to define the change of

intensity with the change of concentration. The percentage of various elements in the sample was then determined from these so-called working curves.

SPECTROCHEMICAL ANALYSES

Spectrochemical analyses were made of every limestone sample for the determination of all elements detectable. The following elements, expressed as oxides, were detected and reported as percentages on a dry weight basis:

	<u>Detection limit</u>		<u>Detection limit</u>
Al ₂ O ₃ (1)	0.0010	V ₂ O ₅	0.0030
Fe ₂ O ₃ (1)	0.0005	NiO	0.0010
SrO	0.0001	ZrO ₂	0.0020
MnO	0.0005	Ag ₂ O	0.0002
CuO	0.0002	PbO	0.0020
Cr ₂ O ₃	0.0005	BaO	0.1500
TiO ₂	0.0020	CoO (2).....	0.0010

- (1) Al₂O₃ and Fe₂O₃, combined, were reported in regular standard chemical analyses as R₂O₃.
 (2) CoO was sought but not found in any sample.

Strontium (SrO).—All samples contain SrO. For the most part, the content of SrO ranges from 0.0100 to 0.0400 percent. No average content was calculated but it probably is less than 0.0200 percent. Unusually large amounts of SrO are to be found in the following samples:

<u>Sample nos.</u>	<u>Area</u>	<u>Percent, average</u>
F-24 to F-30	Sheep Mountain	0.040
Ok-50 to Ok-69	Riverside	0.115
Ok-37 to Ok-43	Cayuse Mountain	0.140
A-1 to A-12	Lime Hill	0.055

Manganese (MnO).—All samples contain MnO, the content ranging widely but generally within the range 0.010 to 0.100 percent. Considerably larger than average amounts of MnO are found in the following samples:

<u>Sample nos.</u>	<u>Area</u>	<u>Percent, average</u>
S-68, S-69, S-143 to S-145	Glasgo Lakes	0.208
S-1 to S-4	Hanson property	0.285
S-76 to S-78, S-71, S-121 to S-123	The Splitoff	0.208
S-168	Chewelah (dolomite)	0.230
S-115 to S-120	Pinkney City	0.460
Ok-70 to Ok-74	Riverside	0.174

Copper (CuO).—All samples contain copper in amounts that range from approximately 0.0006 to 0.0030 percent. In general, the samples from Pend Oreille County contain less copper than average and those from Ferry County and the gray limestones of the Riverside district, Okanogan County, contain more copper than average. Samples that contain appreciably more CuO than the average are:

<u>Sample nos.</u>	<u>Area</u>	<u>Percent, average</u>
S-124 to S-129	Heidegger Hill	0.0047
S-114	Jones Ridge	0.0095
S-115 to S-120	Pinkney City	0.0053
F-24 to F-30	Sheep Mountain	0.0101
Ok-53 to Ok-58	Riverside	0.0081
Ok-70 to Ok-74	Riverside	0.0158

Chromium (Cr₂O₃).—Chromium is found in all samples from Asotin, Ferry, and Okanogan Counties, and in many from Stevens County. It is not present in the samples from Pend Oreille County, except from the samples taken in the lone Quarry. Chromium seems to be characteristic of the white limestone of the Broderius-Janni Northeast-Janni quarry-Makynen areas, Northport district, Stevens County (0.0007 to 0.0019 percent). Also, it seems to be present in larger than average amounts in the limestones of the Evans-Kettle Falls areas (Ideal, 0.0011 percent; Brooks, 0.0010 percent; Pingston Creek, 0.0012 percent; Hanson, 0.0014 percent). Higher than average concentrations are found also in the following samples:

<u>Sample nos.</u>	<u>Area</u>	<u>Percent, average</u>
S-70, S-72 to S-75, S-112, S-113	Hoeft property	0.0031
S-115 to S-120	Pinkney City	0.0030
S-114	Jones Ridge	0.0067
Ok-1, Ok-2, Ok-70 to Ok-74	Riverside	0.0040

Titanium (TiO₂).—TiO₂ is present in most samples, in amounts less than 0.050 percent. It is present in higher than average amounts in the following samples:

<u>Sample nos.</u>	<u>Area</u>	<u>Percent, average</u>
S-76 to S-78, S-71, S-121 to S-127	The Splitoff	0.102
Ok-70 to Ok-74	Riverside	0.095
F-24 to F-30	Sheep Mountain	0.074
S-115 to S-120	Pinkney City	0.230

Vanadium (V_2O_5).— V_2O_5 is absent from all samples except the following:

<u>Sample nos.</u>	<u>Area</u>	<u>Percent, average</u>
S-115 to S-120	Pinkney City	0.005
Ok-1 and Ok-2	Riverside	0.041
Ok-5	Riverside	0.011
Ok-53 to Ok-58	Riverside	0.019
Ok-70 to Ok-74	Riverside	0.007
F-24 to F-30	Sheep Mountain	0.024
A-1, A-2, A-4 to A-6	Lime Hill	0.010

Nickel (NiO).—The only samples that have NiO in significant amounts are the following:

<u>Sample nos.</u>	<u>Area</u>	<u>Percent, average</u>
S-115 to S-120	Pinkney City	0.003
Ok-53 to Ok-58	Riverside	0.003
Ok-70 to Ok-74	Riverside	0.004
F-24 to F-30	Sheep Mountain	0.003

Zirconium (ZrO_2).— ZrO_2 is absent from all samples, except the following:

<u>Sample nos.</u>	<u>Area</u>	<u>Percent, average</u>
S-115 to S-120	Pinkney City	0.008
S-168	Chewelah (dolomite)	0.014
S-184, S-185, S-188	Janni	0.009
S-190	Makynen	0.002
S-212	Cayuse Mountain	0.014
F-22	Swan Lake	0.003
F-24 to F-27	Sheep Mountain	0.003
PO-5	Ione Quarry	0.002
Ok-1 to Ok-4	Riverside	0.004
Ok-53 to Ok-57	Riverside	0.007
Ok-70 to Ok-74	Riverside	0.023

Silver (Ag_2O).—Silver is present in the following samples:

<u>Sample nos.</u>	<u>Area</u>	<u>Percent, average</u>
S-6	China Bend	0.0012
S-14	Makynen	0.0004
S-16	Rainey	0.0029
S-124	Heidegger	0.0009
S-212	Cayuse Mountain	0.0005
Ok-1 to Ok-5	Riverside	0.0004
Ok-8	Wauconda	0.0004
Ok-72	Riverside	0.0015
F-1	Doblasue	0.0005
F-25	Sheep Mountain	0.0011
PO-15	Getchell	0.0007

In four contiguous samples, S-208 to S-211, on the big hill at Bossburg, Stevens County, the average content of Ag_2O is 0.0006 percent. The samples were taken only a few hundred feet to the east of the abandoned silver-producing Young America mine.

Lead (PbO).—Lead is found only in the following samples:

<u>Sample nos.</u>	<u>Area</u>	<u>Percent, average</u>
S-6	China Bend	0.018
S-10, S-11	Columbia Rock Co.	0.004
S-45, S-46, S-47	Pingston Creek	0.006
S-143, S-144	Glasgo Lakes	0.005
S-183	Janni	0.002
S-184	Janni Northeast	0.005
Ok-20	Buckhorn Mountain	0.003
Ok-28	Wannacutt	0.009
F-12	Lambert Creek	0.045
F-15	Vandiver	0.300
F-17, F-18	Little Goosmus Creek	0.006
PO-26, PO-27	Hauck	0.003

Barium (BaO).—Barium was found only in samples F-24, F-25, and F-29, Sheep Mountain, Ferry County.

Remarks on spectrochemical analyses.—

- (1) All samples contain CuO, SrO, and MnO.
- (2) No element or group of elements seems to be characteristic of any distinctive limestone unit or formation.
- (3) Limestone samples from Pend Oreille County are entirely lacking in vanadium, barium, lead, nickel, chromium (except lone quarry), zirconium (except lone quarry), and silver (except sample PO-15).
- (4) Samples taken during this study that were determined by field observation and chemical analysis to be the most siliceous and argillaceous, such as the limestones of Sheep Mountain, Ferry County, Pinkney City, Stevens County, and the gray limestones of the Riverside district, Okanogan County, contain the largest amounts and the greatest number of the elements vanadium, chromium, copper, nickel, zirconium, titanium, strontium, and manganese.

MINING AND PROCESSING

Both underground mining (room-and-pillar, shrinkage stope, and block caving) and quarrying are accepted methods for mining limestone. The limestone deposits of eastern Washington are in hilly terrain, so that the cheapest mining methods are possible, that is, bench-quarrying. The active limestone quarries of the Ideal Cement Company, at Northport, and the Lehigh Portland Cement Company, at Metaline Falls, are bench-quarry operations; so were the abandoned quarries at Evans and lone. More details on the individual active operations are given in the discussion of the respective properties.

Processing of most limestone simply involves crushing and sizing. Crushing and grinding is done by means of jaw, rotary, or gyratory crushers, ball mills, rod mills, and tube mills. Sizing may be

accomplished by various combinations of rotating screens, vibrating screens, wet classification devices, air separators, and the like.

Lime is made (Bowen, 1957, p. 301, 302) by heating ("burning") the limestone in vertical or rotary kilns at a temperature of approximately 1,200°C. The calcite is converted to the metallic oxide CaO (quicklime, lime), and carbon dioxide gas is driven off. The major evolution of gas from high-calcium limestone is between 900°C and 1,000°C. The product, quicklime, is caustic and unstable when exposed to air, making it difficult to handle. Consequently, most lime is sold in the hydrated form (calcium hydroxide), in which it is more stable and does not require special processing and handling equipment. Quicklime is commonly hydrated, after crushing to minus 1-inch size and screening out of impurities, in shallow closed pans by introduction of water. Water is added, the pan is rotated, and the bottom is continuously scraped until evolution of steam ceases and the contents become light and dry.

EVALUATION OF DEPOSITS

Three factors are considered to be of prime importance in the evaluation of a limestone deposit—size, grade, and accessibility to markets. Other factors of importance include availability to supplies of water, power, fuel, and labor; climatic conditions; and topographic relief.

During this study an estimate was made of the minimum tonnage of limestone available in each of the high-calcium limestone deposits. The estimates that are made are based upon the size, shape, and the geology of the deposit, and the analyses of the samples. This information is incorporated in table 7, page 32. Information on the kinds of markets and prices for limestone in Washington are to be found in the following section, Production and Consumption. More information can be gained from the papers and monographs listed in the general reference list on pages 33 to 35.

PRODUCTION AND CONSUMPTION

An idea of the important role carbonate rocks play in our mineral economy is provided by the following statement by Gillson (1960, p. 145, 148).

The tonnage of the carbonate rocks produced exceeds the tonnage of every other crude mineral product (excluding sand and gravel and fuels) and in 1957, (the last year for which complete figures are available) the value of the carbonate rock produced, and excluding the lime and cement made from them, represented 9.5 pct of the value of the entire mineral production of the United States, excluding fuels.

According to the U.S. Bureau of Mines Minerals Yearbooks, the United States production of crushed and broken limestone and dolomite in 1956, 1957, and 1958 was:

Year	Short tons	Value
1956	401,800,000	\$563,435,000
1957	405,459,000	585,937,000
1958	413,571,000	596,714,000

The amount and value of limestone (crushed and broken stone) sold or used by producers in the United States in 1958, by uses, according to Gillson (1960, p. 188) is shown in table 1.

TABLE 1.—Amount and value of limestone (crushed and broken stone) sold or used by producers in the United States in 1958. (after Gillson, 1960)

Use	Short tons	Value	Unit value
Railroad ballast	4,306,883	\$ 5,289,611	\$1.24
Riprap	4,762,986	5,131,492	1.08
Concrete and roadstone	226,693,011	298,956,285	1.27
Agricultural stone	19,922,185	33,901,456	1.70
Fluxing stone	25,615,617	36,536,964	1.42
Miscellaneous	109,167,451	146,948,763	1.38

Gillson (1960, p. 189) breaks down the figures for "miscellaneous uses" in the form of a table showing the limestone (crushed and broken stone) sold or used by producers in the United States (including Hawaii and Puerto Rico) in 1957 and 1958. His table is reproduced, in part in modified form, in table 2 below.

TABLE 2.—Limestone (crushed and broken stone) sold or used by producers in the United States in 1957 and 1958

Use	1957			1958		
	Quantity thousand short tons	Value (thousand dollars)	Unit value	Quantity thousand short tons	Value (thousand dollars)	Unit value
Cement, portland and natural ..	72,103	\$ 75,677	\$1.48	73,976	\$ 78,240	\$1.57
Lime and dead-burned dolomite	17,146	25,764	1.50	14,508	22,093	1.52
Alkali works	4,899	4,551	0.93	5,420	7,811	1.44
Filler (not whiting substitute) ..	2,940	8,223	2.80	3,141	7,157	2.28
Limestone sand	2,311	3,054	1.32	1,431	2,272	1.59
Glass	1,204	3,589	2.98	964	2,864	2.98
Calcium carbide	857	839	0.98	742	727	0.98
Limestone whiting ^{1/}	809	6,019	7.45	712	6,379	8.96
Sugar refining	780	1,866	2.39	850	2,004	2.35
Coal-mine dusting	565	2,231	3.95	479	1,921	4.01
Paper	504	1,356	2.69	417	1,210	2.90
Mineral food	453	2,657	5.86	623	3,551	5.70
Other ^{2/}	5,352	9,567	1.79	5,904	10,721	1.85
Total	109,923	\$145,393		109,167	\$146,950	

^{1/} Includes stone for filler for calcimine, caulking compounds, ceramics, chewing gum, explosives, floor coverings, laundry compounds, glue, grease, insecticides, leather goods, paint, paper, phonograph records, plastics, pottery, putty, roofing, rubber, toothpaste, wire coating, and unspecified uses.

^{2/} Includes stone for acid neutralization, carbon dioxide, chemicals, concrete blocks and pipes, dyes, electric products, fill, letter and barn snow, oil-well drilling, patching plaster, rayons, rice milling, roofing granules, silicones, spalls, stucco, terrazzo, artificial stone, target sheets, and water treatment.

Table 3, prepared by the Business and Economic Research Division of the Department of Commerce and Economic Development, State of Washington, shows the consumption of limestone by the major consuming industries in the State of Washington in 1959. The table also shows the proportion of the limestone produced within the State to that consumed within the State.

TABLE 3.—Limestone consumption by major consuming industries in Washington in 1959

Industry	Total consumption (tons)	Produced within Washington (percent)	Produced outside Washington (percent)
Portland cement	1,356,000	89	11
Pulp and paper	159,374	16	84
Steel-alloy and chemical	42,257	1	99
Agriculture	20,138	40	60
Other (concrete, riprap, ballast, etc.)	308,115	49	51
Total	1,885,884		

In addition to the 159,374 tons of limestone, the pulp and paper industry in 1959 used 54,722 tons of lime, none of which was produced in Washington. The figures in table 3 illustrate to what extent the limestone-consuming industries of the State, except the cement industry, are dependent upon sources of limestone outside the State. Sixty-five percent of all the limestone used in the State, excluding that used in portland cement, is mined outside the State. The situation is even more critical when we look at the figures for high-calcium limestone, such as is used by the pulp and paper, steel, and chemical industries. Only an average of 12 percent of the limestone used by these industries is produced within the State. When we consider the additional limestone required to make the lime for use in the pulp and paper industry, the State's production contribution to the needs of the high-calcium (and lime) consumers in the State is only 9 percent.

Table 4 lists the principal consumers, but not all consumers, of high-calcium limestone in the State of Washington, and the approximate number of tons of high-calcium limestone used by each consumer per month. The table does not include manufacturers of portland cement, because ordinarily they would not use a high-calcium limestone.

TABLE 4 —High-calcium limestone consumption in Washington in 1958^{1/}

Industry	Company	Consumption, tons per month	Minimum acceptable percent CaCO ₃
Sugar	Utah-Idaho Sugar Company, Toppenish	12,660	97
Pulp and paper	Scott Paper Co., Everett	2,100	97
	Crown Zellerbach Corp., Port Angeles	2,170	90
	Weyerhaeuser Timber Co., Everett	1,710	96
	Inland Empire Paper Co., Millwood	150	98
	Columbia River Paper Mills, Vancouver, Washington	70	--
Metallurgy	American Smelting and Refining Co., Tacoma	1,800	--
Other	Pacific Carbide and Alloys Co., Portland ^{2/}	2,000	97
	Pacific Northwest Alloys, Inc., Spokane	1,350	94
	Northwestern Glass Co., Seattle	400	99
	Reichhold Chemicals Inc., Tacoma	150	97

^{1/} Table is incomplete. It does not include the consumption of portland cement plants and possibly other important consumers.

^{2/} Not a Washington consumer.

The following list of Washington manufacturers using limestone is taken in part from the report of Klemgard (1958, p. 6-8).

(1) Cement manufacturers

Ideal Cement Co.
Denver National Bldg.
821 - 17th St.
Denver 2, Colo.

Lehigh Portland Cement Co.
Metaline Falls, Wash.

Lone Star Cement Corp.
Superior Division
120 Sixth Ave. N.
Seattle 9, Wash.

Manufacturers Mineral Co.
1107 W. Idaho St.
Seattle 14, Wash.

The Olympic Portland Cement Co.
Division of Permanente Cement Co.
P. O. Box 17
Bellingham, Wash.

(2) Fertilizer manufacturers

Agriform Co. of Washington
Bldg. 63, Navy Base
Pasco, Wash.

American By-Products Co., Inc.
East B Street
Yakima, Wash.

The Chas. H. Lilly Co.
1900 Alaska Way
Seattle, Wash.

Northwest Processing Co.
1953 South C Street
Tacoma, Wash.

Oregon-Washington Fertilizer Co.
2218 Airport Way
Seattle 14, Wash.

Seattle Chemurgic Industries
Seattle, Wash.

Stauffer Chemical Co.
Tacoma, Wash.

(3) Smelters

American Smelting and Refining Co.
Tacoma, Wash.

(4) Paper and pulp mills

Columbia River Paper Mills
Vancouver, Wash.

Crown Zellerbach Corp.
Camas, Wash.

Crown Zellerbach Corp.
Port Townsend, Wash.

Everett Pulp and Paper Co.
Lowell, Wash.

Fibreboard Products, Inc.
Port Angeles, Wash.

Inland Empire Paper Co.
Millwood, Wash.

Longview Fibre Co.
Longview, Wash.

Portco Corp.
Paper Products Div.
Vancouver, Wash.

Potlatch Forests, Inc.
Lewiston, Idaho

Puget Sound Pulp and Timber Co.
Bellingham, Wash.

Rayonier, Inc.
Hoquiam, Wash.

Scott Paper Co.
Everett, Wash.

St. Regis Paper Co.
Tacoma, Wash.

Weyerhaeuser Timber Co.
Everett, Wash.

(5) Sugar (beet)

Utah-Idaho Sugar Co.
Toppenish, Wash.

Utah-Idaho Sugar Co.
Moses Lake, Wash.

(6) Limestone (crushed, ground, or powdered)

Ideal Cement Co.
Denver National Bldg.
821 - 17th St.
Denver 2, Colo.

Manufacturers Mineral Co.
1107 W. Idaho St.
Seattle 14, Wash.

The Olympic Portland Cement Co.
Division of Permanente Cement Co.
P. O. Box 17
Bellingham, Wash.

(7) Chemicals and alloys

Pacific Northwest Alloys, Inc.
Spokane, Wash.

Reichhold Chemicals Inc.
Tacoma, Wash.

(8) Glass

Northwestern Glass Co.
Seattle, Wash.

USES AND SPECIFICATIONS

Limestone has many uses (Hodge, 1938; Lamar and Willman, 1938; Bowen, 1957; Gillson, 1960). For convenience, they are classified roughly as "physical uses" and "chemical uses," even though there is often a relationship between the physical and chemical characteristics of limestones. The physical

properties of the carbonate rocks are discussed in detail by Gillson (1960, p. 136-142). The chemical composition is discussed briefly by Gillson (1960, p. 142-145).

Lamar (1959, p. 13) defines "physical uses" and "chemical uses" as follows:

Physical uses include those for which the physical properties of a limestone are of primary importance and for which specifications for the physical properties of the limestone commonly exist. Weather resistance, color, hardness, wear resistance, soundness, water absorption, and weight per cubic foot are the properties generally involved, singly or in combination.

Chemical uses are those in which the chemical composition of a limestone is of primary importance and limestone used for chemical purposes must pass certain specifications relating to the percentage of calcium carbonate, magnesium carbonate, iron oxide, silica, or other compounds present.

The specifications for some uses involve both the physical character and chemical composition of limestone. Uses of this sort are treated under the heading of chemical uses because the physical property most commonly involved is the size of the pieces of stone. Size is not commonly a characteristic of natural stone but rather is controllable during crushing.

Table 5 has been prepared from tables 1 and 2, with the addition of tonnage figures for dimension stone, in order to compare the annual (1958) production of limestone for physical uses and limestone for chemical uses. In addition, table 5 differentiates between limestone and high-calcium limestone for chemical uses.

TABLE 5.—Limestone consumption in the United States in 1958, by uses

Consuming industry	Thousands short tons
Concrete and roadstone	226,693
Riprap	4,763
Railroad ballast	4,307
Filler (not limestone whiting)	3,141
Limestone sand	1,431
Dimension stone	979
Coal-mine dusting	479
Total consumption for PHYSICAL USES	241,793
Cement	73,976
Agriculture	19,922
Consumption limestone for chemical uses	93,898
Fluxing stone	25,616
Lime and dead-burned dolomite	14,508
Alkali manufacture	5,420
Glass	964
Sugar refining	850
Calcium carbide	742
Limestone whiting	712
Mineral food	623
Paper	417
Other	5,904
Consumption high-calcium limestone for chemical uses .	55,756
Total consumption for CHEMICAL USES	149,654
Total consumption	391,447

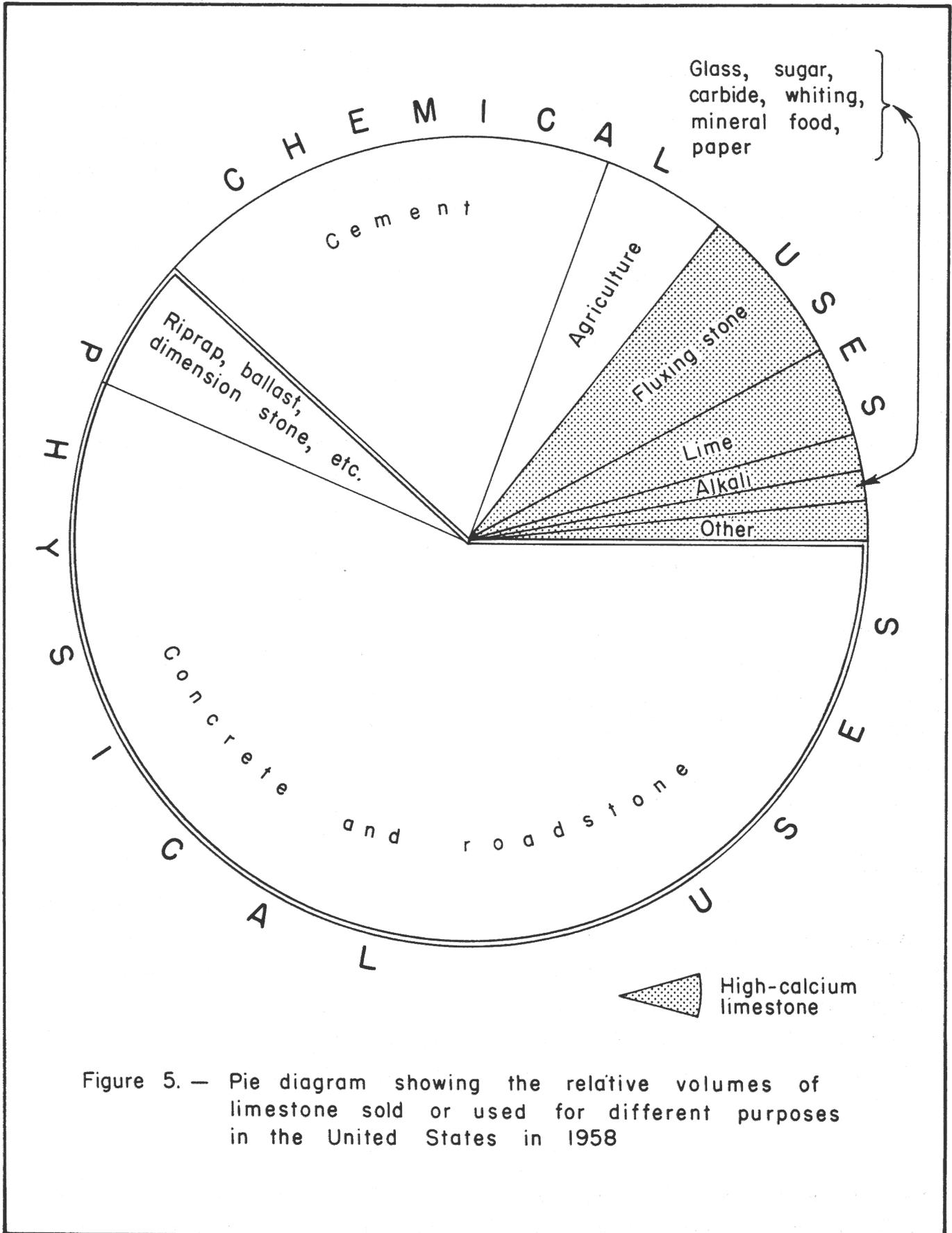


Figure 5. — Pie diagram showing the relative volumes of limestone sold or used for different purposes in the United States in 1958

PHYSICAL USES

The physical uses listed in table 5 account for 62 percent of the limestone sold or used in the United States in 1958. Concrete aggregate and roadstone account for 58 percent of all limestone sold or used. Limestone for concrete aggregate, railroad ballast, chips for blacktop roads, chips for stucco, roofing granules, terrazzo and artificial stone, roadstone, limestone sand, and roadbase should be sound, hard stone. Stone for some of these uses must pass a wear-resistance test and other tests. A uniform and desirable color, such as white, brown, pink, or black is often demanded in limestone chips used for stucco, terrazzo, and artificial stone. Hardness, durability, ability to take a good polish, and low liquid absorption also are desirable in terrazzo chips. Stone for filter beds for sewage disposal plants must pass 20 cycles of a sodium sulfate soundness test, or an equivalent test. Riprap is used to protect embankments and the shores of rivers and lakes from destruction and consists of large pieces of stone, all or some of whose dimensions commonly are measured in feet. Building stone and other types of cut stone should have a pleasing color and good weather resistance. Fill material may be waste limestone from various sources and is used to make road fills and the like. Roofing granules, used for coating roofs, should be hard and have good weather resistance.

CHEMICAL USES

Chemical uses consumed 38 percent of all the limestone sold or used in the United States in 1958. The lower quality limestones (less than 95 percent CaCO_3) accounted for 24 percent of the total limestone sold for chemical uses, most of which went into the manufacture of portland and natural cement, making this use second only to concrete aggregate and roadstone in tonnage consumed. High-calcium limestones (95 percent or more CaCO_3) accounted for 14 percent of national production; the largest tonnages of high-calcium limestone are used as a flux in metallurgy and for the manufacture of lime.

Limestone suitable for the manufacture of cement or for agricultural use is very seldom high-calcium limestone. The first concern of this report is with high-calcium limestones, and for this reason portland cement use and agricultural use will be treated only briefly. Most of the following discussion deals with the use of high-calcium limestone. For more details on cement use, the reader is referred to the excellent paper by Clausen (1960) and the monograph by Bogue (1955); valuable information on agricultural uses can be found in the paper by Gault and Ames (1960a). A summary of the high-calcium limestone specifications for use in the principal consuming industries is given in table 6 on page 31. Table 7, p. 32, lists the deposits in eastern Washington that meet these specifications.

Portland Cement

Portland cement is a material which, when mixed with water and allowed to hydrate, is a ceramic binding material used to cement aggregates (crushed stone, gravel, and sand) together in concrete,

the most universally used building material of today. Its principal uses are in highways, buildings, military construction, public utilities, and sewer and water works.

Cement raw materials may be divided into those essentially supplying the lime component ("calcareous"), the silica component ("siliceous"), the alumina component ("argillaceous"), and the iron component ("ferriferous"). Some limestones, called cement rock, contain the proper proportions of CaCO_3 and argillaceous, siliceous, and ferriferous impurities for the manufacture of cement without previous modification. Most cement, however, is made from a mixture of limestone (less often marl, alkali waste, sea shells, or chalk) and clay or shale (less often slag, sand, quartzite, or iron ore). The ratio of limestone to clay or shale in the raw mix varies according to the chemical composition of each, but when comparatively pure limestone is used the mix consists roughly of 4 parts by weight of limestone to 1 part of clay or shale. The CaO content of the limestone used in the raw feed may be as low as 75 percent. Commonly a CaO content of 85 to 90 percent is preferred. The most important factor controlling the suitability of a limestone for the manufacture of portland cement is its magnesium oxide content. The limestone should contain less than 3 percent MgO. Next to magnesia, silica and alumina are the most influential impurities. If they occur in too high a percentage, their presence must be balanced by the introduction of high-calcium limestone.

The processing of the raw materials into finished cement embraces four stages (Clausen, 1960, p.213):

- (1) Size reduction (blasting, crushing, grinding) to obtain the fineness and surface which will permit the chemical reactions to take place between the components, and formation of the cement compounds during the subsequent pyro-processing.
- (2) Blending, correction and homogenization of the raw mix to obtain the exact desired composition and uniformity.
- (3) Liberation of carbon dioxide (calcination) and pyro-processing (burning) to form new compounds.
- (4) Fine pulverization of kiln product ("clinker"), with addition of gypsum.

Agricultural Limestone

Calcium and magnesium are necessary for general soil fertility and plant nutrition. Agricultural limestone and dolomite function not only to replenish the calcium and magnesium cropped and leached from soils but also to correct soil acidity, to improve physical and microbiological conditions in the soil, and to increase the efficiency of other fertilizers. Carbonate rock can also have desirable effects on the solubility, availability, and reduction of toxicity of other elements that are essential plant nutrients. Small amounts of limestone and dolomite are used in mixed fertilizers to condition the mixtures, to reduce chemical attack on bag materials, and to correct any tendency of the fertilizer to increase soil acidity.

Limestones may contain small quantities of many of the trace elements, such as manganese, copper, zinc, boron, cobalt, and molybdenum, essential to plant growth.

There is no one standard set of specifications for agricultural limestone. The CaCO_3 content of agricultural limestone may be as low as 75 percent, but 90 percent or more is preferred.

Fluxing Stone

Limestone, as well as dolomite and lime, is used in the smelting of iron and other metals to supply basic CaO (and MgO) which can combine with the undesirable acid constituents in the ores and fuels to form a slag separable from the molten metal. Chemically, the ideal flux stone is low in acid constituents such as silica, alumina, sulfur, and phosphorus and certain other deleterious elements, and is easily calcined in the furnace. Physically, the desirable stone is fine grained and is strong enough to withstand abrasion in handling and shipping, blast furnace stack pressures, and the burden of ore and coke. The steel industry uses the greatest tonnage of flux and furnace stone. Limestone acceptable for blast furnaces should contain less than 5 percent and preferably less than 3 percent SiO₂. The MgO content of the high-calcium limestone is not critical. The composition of the flux stone used in open hearth furnaces is more critical. Silica must be less than 2 percent, and less than 1 percent is preferred. The upper limit of magnesia is 5 percent. Both blast furnace and open hearth furnace fluxing stone should have a low content of phosphorus and sulfur. The maximum amounts permissible are approximately 0.01 percent P₂O₅ and 0.50 percent S.

Limestone flux is used in copper and lead smelting when the ores are more acidic than basic, and high-calcium limestone with low silica is desired.

High-Calcium Lime

Lime is the second largest in tonnage of all chemicals produced in the United States. Crushed high-calcium limestone yields carbon dioxide gas when heated to the dissociation temperature of approximately 1,400° to 1,700°F, and highly basic calcium oxide, or quicklime, remains. Quicklime is known also as lime, burnt lime, caustic lime, and live lime. Dolomitic limestones and dolomites calcine to calcium oxide and calcium-magnesium oxide (dolomitic lime). When treated with water, quicklime slakes, giving off heat and increasing in volume to form calcium hydroxide or hydrated lime. Hydrated lime is more stable than quicklime and can be stored and handled more safely. For many of its uses it is interchangeable with quicklime.

Patterson (1960, p. 463) reports that there are about 7,000 uses for lime. Boynton and Gutschick (1960, p. 509) tabulate 50 of the principal uses for lime.

Approximately 3 percent of all the lime produced in the United States is classed as agricultural lime and is used to neutralize acid soils, improve soil tilth, and supply the essential plant nutrients calcium and magnesium.

Approximately 16 percent of the lime manufactured is used in the construction industry as finishing lime, mason's lime, and for soil stabilization. Most of the lime used in the construction industry goes into mortar, plaster, and stucco. Some of these limes are made from dolomite or dolomitic limestones and some are made from high-calcium limestones. Limestones for production of high-calcium lime

must contain not more than 1 percent MgO nor more than 1 percent iron oxide. The lime made from the high-calcium limestone must also satisfy certain physical specifications.

Approximately 81 percent of the lime produced in the United States is classed as "chemical lime," which in the lime industry is defined as lime consumed by the metallurgical and chemical process industries. In most instances it enters a specific chemical reaction; however, in others it simply serves as a raw material. It is broadly employed as an acid neutralizing agent, a flocculant, flux (purifier), causticizing agent, lubricant, dessicant, bonding agent, solvent, for hydrolyzation, and for absorption (Boynton and Gutschick, 1960, p. 510). Generally, high-calcium limes are preferred over dolomitic. By far the largest consumer of chemical lime is the steel industry, which uses the lime as a flux in open hearth and electric furnaces. Limestone suitable for the making of lime for metallurgical use should contain at least 97 percent CaCO_3 , and not more than 2 percent SiO_2 , 2 percent Al_2O_3 , 0.01 percent P_2O_5 , or 0.50 percent S. The second largest tonnage of chemical lime is used to make calcium carbide and cyanamide. Lime and charcoal are calcined together in electric furnaces to produce calcium carbide. Limestone for making lime suitable for this purpose must contain at least 97 percent CaCO_3 , and less than 1.0 percent MgO, 1.2 percent SiO_2 , 0.5 percent R_2O_3 , 0.01 percent P_2O_5 , and no more than a trace of sulfur. The third largest tonnage of chemical lime is consumed by the chemical industry in the manufacture of alkalis (soda ash, caustic soda, bicarbonate of soda, ammonium and potassium compounds). For alkali chemical lime the limestone should contain at least 97 percent CaCO_3 , and not more than 2.0 percent SiO_2 , 1.0 percent Al_2O_3 , or approximately 0.01 and 0.50 percent P_2O_5 and S. The fourth largest consumer of high-calcium lime is the pulp and paper industry. Although limestone is the preferred base for preparation of bisulfite cooking liquor in the sulfite pulp process, a few plants use quicklime for this purpose. In all paper processes, lime is used with chlorine to prepare calcium hypochlorite solutions for bleaching paper pulp. Other important uses for high-calcium chemical lime are for municipal and industrial water softening and purification, sewage and industrial wastes treatment, glass manufacture (flux), the concentration of ores, and numerous other applications. Limestone suitable for making lime for these uses must contain at least 95 percent CaCO_3 , and for most uses it must contain at least 97 percent CaCO_3 .

Alkali Manufacture

The raw materials for the manufacture of soda ash by the ammonia soda process are common salt and high-calcium limestone. Most users insist on limestone with a silica content under 1 percent.

Glass Manufacture

High-calcium limestone is used in making bottle and window glass. The limestone should contain not more than 0.3 percent iron oxide. According to Hodge (1938, p. 523, 524) limestones suitable for glass manufacture contain from 97.6 to 99.56 percent CaCO_3 , 0.10 percent to 1.05 percent MgO,

0.2 percent to 0.4 percent R_2O_3 , and 0.2 percent to 1.7 percent SiO_2 . The Northwestern Glass Company, Seattle, specifies a limestone containing in excess of 98.7 percent $CaCO_3$ and less than 0.05 percent Fe_2O_3 .

Sugar Refining

Lime is used in the manufacture of cane and beet sugar to precipitate impurities from the syrup or to precipitate the sugar from the impure solutions. Cane sugar companies buy burnt lime. Beet sugar companies, like those in Washington, burn high-calcium limestone to make lime, and both the lime and the carbon dioxide gas are used. Limestone for this purpose must contain not less than 97 percent $CaCO_3$, and not more than about 2.5 percent MgO , nor more than 1.0 percent SiO_2 . It must also be free of impurities that would impart a taste. The effectiveness of any given limestone for sugar-refinery use can be determined only by use-tests.

Calcium Carbide

The two major outlets for calcium carbide are the generation of acetylene and the production of cyanamide, each of which has important uses of its own while also serving as a source of numerous other products. Calcium carbide is made by heating a mixture of lime and coke in an electric arc furnace. Limestone specifications vary with the different users. However, a combination of data from several sources suggests that the limestone should contain not less than 97 percent $CaCO_3$, and not more than 0.50 percent to 1.0 percent MgO , 1.2 percent SiO_2 , 0.5 percent R_2O_3 , 0.01 percent P_2O_5 , and a trace of sulfur. The Pacific Carbide and Alloys Company, Portland, Oregon, requires that limestone for their use contain not more than 1 percent MgO , 1 percent SiO_2 , 0.5 percent Fe_2O_3 , and 0.007 percent P_2O_5 .

Pulp and Paper

Both lime and limestone are used in the paper industry in the preparation of cooking-liquors. By digesting the wood at high temperature and pressure with an acid cooking-liquor, all the constituents of the wood chips except cellulose are dissolved and removed. The two common methods for preparing the bisulfite liquors for the digestion of the wood pulp are (1) the milk-of-lime process, in which previously calcined and hydrated limestone is exposed in a thin fluid to the action of sulfur dioxide and (2) the tower system, in which coarsely broken raw limestone, packed in towers, is traversed by a rising current of sulfur dioxide while water percolates downward. The "acid" produced by either method is a solution of calcium or magnesium bisulfite, or both, which also contains dissolved sulfur dioxide. The milk-of-lime process is best served by a high-magnesia lime; the tower process, by a high-calcium limestone. In both processes the limestone (or lime) must have a very low content of insoluble matter, carbon, mica, and pyrite.

In the Kraft, or sulfate, process for the manufacture of pulp, a high-calcium lime containing less than 2 percent MgO is desired.

The specifications placed on limestone for paper manufacture by companies in Washington vary to some extent. Limestone of the following composition probably would suit the requirements of most paper companies: CaCO₃ not less than 95 percent, MgO less than 3.0 percent, SiO₂ less than 1.5 percent, and R₂O₃ less than 0.5 percent.

Limestone Whiting

Limestone whiting is very finely ground high-purity limestone. Ground whiting may also be prepared by fine grinding of chalk or marble. Precipitated whiting is a finely divided calcium carbonate product obtained by chemical precipitation from a solution or suspension containing lime. Approximately three-fourths of all whiting produced is used in making paint, rubber, and putty, in the order named. The rest is used for many diversified purposes, including calcimine, pottery, paper, crayons, dyes, fabrics, plastics, phonograph records, dentifrices, chewing gum, baking powder, tanning, abrasives, shoe dressing, explosives, medicine, foundry compounds, white ink, wire coating, chemicals, glue, grease, animal nutrients, flooring, caulking compounds, and insecticides. The desirable characteristics of a high-grade whiting are: good white color, fine particle size, freedom from grit, and chemical purity. Color is of utmost importance for virtually all applications. Although purity is particularly important in the chemical and ceramic industries, the chemical composition is less important in determining the suitability of whiting for most uses. Limestone suitable for the manufacture of ceramic whiting is limited to a minimum of 96 percent CaCO₃, a maximum of 1 percent MgCO₃ (0.5 percent MgO), 2 percent SiO₂, 0.25 percent Fe₂O₃, and 0.1 percent SO₃.

TABLE 6.—Chemical specifications for high-calcium limestone for use in industry

Industry	Minimum		Maximum						
	CaCO ₃	CaO	MgO	SiO ₂	Al ₂ O ₃	R ₂ O ₃	Fe ₂ O ₃	P ₂ O ₅	S
Glass	98	55.0	1.0		0.10				
Calcium carbide and cyanamide	97	54.5	1.0	1.2		0.5	0.05	0.01	trace
Chemical	97	54.5		2.0	1.0			0.02 ^{1/}	0.05 ^{1/}
Metallurgical	97	54.5		2.0	2.0			0.01	0.50
Sugar	97	54.5	2.5	1.0					
Whiting (ceramic)	96	54.0	0.5	2.0			0.25		
Pulp and paper	95	53.3	3.0	1.5		0.5			
Construction (finishing lime)	95	53.3	1.0				1.0		
Filler	95 ^{2/}	53.3							
Cement	75 ^{2/}	42.0	3.0	20.0		5.0		0.5	low

^{1/} Maximum allowable percentage of P₂O₅ and S in lime.
^{2/} Not a high-calcium limestone.

TABLE 7.—High-calcium limestone deposits of eastern Washington, potential uses, and reserves

Deposit	Glass	Calcium carbide	Chemical lime	Metallurgical lime	Sugar	Whiting (ceramic)	Finishing lime	Pulp and paper	Filler	Reserves (millions of tons)
Aladdin							X	X	X	1.5
Black Heart					X		X	X	X	1.0
Bossburg East (small hill)						X	X	X	X	13.7
Brooks						X	X	X	X	4.5
Buckhorn Mountain			X	X		X	X	X	X	0.6
Buckhorn Mountain						X	X	X	X	15.0
Bunch							X	X	X	5.0
Cedar Lake					X		X	X	X	25.0
Columbia Rock Company			X	X			X	X	X	1.3
Copper Lakes			X	X	?	?	X	X	X	0.7
Getchell-Dehuff		X	X	X	X	X	X	X	X	20.0
Hoage Lake							X	X	X	10+
Ideal, Northport							?	?	X	60.0
Janni Quarry							X	X	X	1.0
Janni, Northeast							X	X	X	6.0
Lambert Creek									X	?
Onion Creek			X	X	X		X	X	X	0.8
Pingston Creek			X	X	X		X	X	X	7.6
Rainey		X	X	X	X	X	X	X	X	3.5
Russian Creek		?	?	?	X	X	X	X	X	13.0
E. Sherve		X	X	X	X	X	X	X	X	5.7
J. Sherve		X	X	X	X	X	X	X	X	11.0
Slate Creek		X	X	X	X	X	X	X	X	40.0
Thackston						X	X	X	X	?
Three Mile Creek					X	X	X	X	X	0.4
Toroda Creek North			X	X		X	X	X	X	Small
Toroda Creek Road					X		X	X	X	Small
U.S. Gypsum, Evans						X	X	X	X	4.0
Wannacut Lake					X	X	X	X	X	Several million

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DEPOSITS

DISTRIBUTION OF CARBONATE ROCKS IN EASTERN WASHINGTON

The area of northeastern Washington extending from the Cascade Mountains east to Idaho and from the Columbia and Spokane Rivers north into Canada is known as the Okanogan Highlands. Incised into this highland are five major north-trending valleys occupied, from west to east, by the Okanogan, Sanpoil, Kettle-Columbia, Colville, and Pend Oreille Rivers (pl. 1). Most of the sedimentary rocks of northeastern Washington are found within or bordering these river valleys. Parts of the major river valleys, especially the Sanpoil, are underlain by volcanic and sedimentary rocks of Tertiary age. The mountain ranges between the valleys are composed principally of granitic intrusive rocks of Mesozoic and Tertiary age, including the Colville batholith of Okanogan County, the granitic rocks of the northern Kettle Range in Ferry County, and the Loon Lake and Kaniksu batholiths of Stevens and Pend Oreille Counties. Notable exceptions to the generalization that the ranges are composed of granitic rocks are the southern Kettle Range and part of the northern Kettle Range in Ferry County and the Huckleberry Mountains in Stevens County, which are composed of Paleozoic and Precambrian sedimentary and metamorphic rocks. The distribution of the areas underlain by sedimentary rocks is shown in plate 1. Some of these areas are composed predominantly of non-carbonate sedimentary rocks and others are composed predominantly or entirely of carbonate rocks. Carbonate rocks, both limestones and dolomites, are found in rocks of Precambrian, Paleozoic, and Triassic age. All of the high-calcium limestone deposits found during this study are Paleozoic in age, and most are early Paleozoic (Cambrian).

In southeastern Washington, limestone occurs in the Lime Hill area of northeastern Asotin County.

The distribution of the areas of northeastern Washington underlain by sedimentary and a lesser amount of volcanic rocks of Precambrian age is shown in plate 1. These areas are: northeastern Pend Oreille County, southern Pend Oreille County (Bead Lake region), and southwestern Stevens County. The rocks are almost entirely clastic sedimentary rocks or their metamorphosed equivalents (argillite, phyllite, slate, sandstone, quartzite). A very little impure limestone and dolomite is found interbedded with the clastic rocks in Pend Oreille County (e. g., Parker Lake district, p.60). A great thickness of dolomite (Stensgar Dolomite), but no limestone, is interbedded with clastic and volcanic rocks in southwestern Stevens County. Further discussion of these rocks is given under the heading "Valley district," on page 162.

Areas underlain principally by clastic rocks (sandstone, quartzite, argillite, and phyllite) of early to middle Paleozoic (Cambrian, Ordovician, Silurian, and Devonian) age are distributed (pl. 1) over a broad area extending southwest from northeastern Pend Oreille County to southwestern Stevens County, and between Springdale and Chewelah in southeastern Stevens County. Thin, generally argillaceous, limestones are interbedded with the clastic rocks.

Areas underlain principally or exclusively by limestone and dolomite of early Paleozoic (Cambrian) age are numerous and extensive in Stevens County and northern Pend Oreille County. All the areas of this rock shown on plate 1, except the area between Springdale and Chewelah, are composed of limestones and dolomites of Cambrian age. The limestone and dolomite between Springdale and Chewelah is Carboniferous in age. The greatest number of areas and greatest tonnages of high-calcium limestone found during this study are of Cambrian age. Districts or areas containing limestones of Cambrian age discussed in this report are: Deep Creek (p. 67), Northport (p. 73), China Bend (p. 102), Columbia Rock Company (p. 105), Bossburg (p. 107), Evans (p. 117), Barstow (p. 133), Kettle Falls South (p. 143), Hunters Creek (p. 152), Addy (p. 164), Colville (p. 164), Metaline (p. 37), and lone (p. 54). Districts containing limestone of Carboniferous age, the Springdale-Valley district and the Valley-to-Chewelah district, are discussed on pages 155 and 163 of this report.

Areas underlain by clastic sedimentary rocks, greenstones, and limestones of late Paleozoic (principally Carboniferous and Permian) and Triassic age (pl. 1) are in northern and western Stevens County, southeastern and western Ferry County, and central and southeastern Okanogan County. Districts and areas of limestone of late Paleozoic age discussed in this report are: Evans (p. 117), Orient-Kelly Hill (p. 129), Kettle Falls North (p. 134), Heidegger Hill (p. 145), Hunters Creek (p. 152), Covada (p. 183), Keller (p. 183), Curlew Northeast (p. 186), Republic Northeast (p. 190), Republic North (p. 195), Copper Lakes (p. 198), Empire Creek (p. 203), Iron Mountain (p. 204), North Fork St. Peter Creek (p. 205), and Wauconda Southwest (p. 205). Districts or areas containing limestone of Triassic (?) age are: Lime Hill (p. 238), Curlew Northeast (p. 186), and Riverside (p. 230).

Areas underlain by pre-Tertiary metamorphic rocks (schist, gneiss, quartzite, amphibolite greenstone, graywacke, volcanic rocks, and intrusive rocks) containing some limestone marble and dolomite marble are (pl. 1) in western Spokane and Lincoln Counties, northern and eastern Ferry County, and northern Okanogan County. Districts or areas in this category that were examined during this study are: Cayuse Mountain (p. 176), Buckhorn Mountain-Havillah (p. 210), Wauconda (p. 218), Wannacut Lake (p. 221), West Half Colville Indian Reservation (p. 229), Jackass Butte (p. 228), and other areas in northern Okanogan County (p. 227).

PEND OREILLE COUNTY

Metaline District

The Metaline district is considered to be that part of the northwest corner of Pend Oreille County that extends south from the International Boundary for a distance of 20 miles to the town of Lone on State Highway 6. The district is confined to T. 40 N., R. 44 E.; Tps. 38, 39, and 40 N., R. 43 E.; and the east side of T. 38 N., R. 43 E. (pl. 2).

The district is served by a branch line of the Chicago, Milwaukee, St. Paul and Pacific Railroad and by State Highway 6. Both routes follow the Pend Oreille River, which flows north through the central part of the district. Good graveled roads, especially the Z Canyon and Slate Creek roads, permit access to the margins and extremities of the district. Lone, Metaline, and Metaline Falls are the principal towns.

The Metaline quadrangle, of which the Metaline district is the northwest quarter, has been mapped geologically by Park and Cannon (1943). They show the principal bedrocks of the district to be lower Paleozoic metasedimentary rocks to which they assign the formation names, from oldest to youngest: Gypsy Quartzite (Lower Cambrian—5,300 to 8,500 feet thick), Maitlen Phyllite (Lower Cambrian—5,000 feet thick), Metaline Limestone (Middle Cambrian—3,000 feet thick), and Ledbetter Slate (Ordovician—2,500 feet thick).

Plate 2 shows that most of the Metaline Limestone and all of the Ledbetter Slate are confined to a great down-faulted block or graben that Park and Cannon call the Valley Block. Bordering the block are topographically higher areas that are composed of the older Maitlen Phyllite and Gypsy Quartzite. The Valley Block is complexly faulted and folded. Park and Cannon (1943, p. 30) suggested that the complexity of the structure may have resulted in part from the dropping of a down-pointed wedge (Valley Block) between two downward-converging major faults, the Flume Creek fault on the west and the Slate Creek fault on the east. Lesser fault zones of both normal and reverse type are numerous and complicate the fold picture. The principal fold structure, according to Jenkins (1924, p. 32), is a depressed anticline along the central portion of the Valley Block bounded on both the east and the west by normal faults. The evidence of this anticline, which plunges southward, is shown best near the International Boundary in the northeastern part of the district (pl. 2). Here the older Maitlen Phyllite is exposed along the axis of the fold, and the younger Metaline Limestone is exposed along the limbs to the east and west and around the nose of the fold to the south.

Although beds of carbonate rocks are found interbedded with the argillaceous rocks of the Maitlen Phyllite and the Ledbetter Slate, they are not very thick or extensive; further, they are quite often phyllitic or argillaceous and hence too impure to be of any value. In our study of the limestone resources of the district, our attention was confined to the thick carbonate units of the Metaline Limestone.

The Metaline Limestone is divided by Park and Cannon (1943, p. 18) into four members, as follows:

Section east of Metaline Falls

<u>Top</u>	<u>Feet</u>
Mottled dense gray limestone; few chert nodules	150
Mottled dense gray limestone; many chert nodules	450
Fine-grained cream-colored dolomite, particularly in upper part. Alternating layers of black and white dolomite	1,200
Interbedded limestones and limy shales, locally dolomitic. Grades conformably into Maitlen Phyllite	1,200

Dings and others (1956) divide the Metaline Limestone into two units. They consider the dolomite and silicified dolomite of the district to be the product of alteration of the Metaline Limestone. Following are their descriptions of the two units of the Metaline Limestone and the altered rocks, taken from the explanation on their map of the Metaline mining district.

Metaline Limestone

Upper unit is gray, very fine-grained, massive limestone, locally shaly beds and partings in uppermost portion. Metamorphosed to layered marble near Russian Creek. Lower unit is chiefly thin- to medium-bedded, dark-gray to gray limestone and limy shale. Fossils rare, locally abundant on Quarry Hill. Upper and lower units everywhere separated, and locally cut by dolomite.

Silicified dolomite

Medium to strongly, and irregularly, silicified (jasperoid) dolomite and/or limestone. Rock medium to dark gray, commonly irregularly brecciated, and consists of variable quantities of crystalline (recrystallized) dolomite, coarse calcite, some limestone, and locally sphalerite and/or galena. Locally grades irregularly into non-silicified dolomite and limestone. Many small bodies not shown on map.

Dolomite

Chiefly light- to medium-gray, crystalline (recrystallized), dolomite. Contains some beds, lenses and pods of black dolomite, and black dolomite with conspicuous spots and streaks of white dolomite that generally occur sparingly in a thick zone stratigraphically midway in the main dolomite body. Dolomite grains range greatly in size, at many places within short distances. Coarse-grained rock, obliteration of bedding planes, and local sulfides characterize upper stratigraphic position. Grades into limestone and silicified dolomite.

Plate 2 is a geologic map of the Metaline mining district slightly modified after the map of Dings and others (1956). The lower limestone unit is found outside of the Valley Block immediately east of the Slate Creek fault. It is also well exposed within the Valley Block in the northeastern part of the district, where it is involved in the south-plunging anticline mentioned earlier. The upper unit of the Metaline Limestone is found only within the Valley Block toward its west side. Most of the altered rocks lie above the lower unit and below the upper unit, although some dolomitized areas are found within both the lower and upper units.

During the course of this study attention was devoted only to the more accessible occurrences of the lower and upper limestone units of the Metaline Limestone. Some samples and analyses referred to in the following section of the report have the prefix WGB. These are samples taken by W. A. G. Bennett in 1928. The descriptions of these samples and sample locations are taken from Bennett's original notes, which he kindly made available to the author.

Limestone of the Lower Unit of the Metaline Limestone

Lehigh Portland Cement Company Property, Metaline Falls

NE $\frac{1}{4}$ sec 27, T. 39 N., R. 43 E.

Location, accessibility, and ownership.—The Lehigh Portland Cement Company (Head Office—718 Hamilton Street, Allentown, Pa.) operates a limestone quarry in the NE $\frac{1}{4}$ sec. 27, T. 39 N., R. 43 E., about 1 mile east of their cement manufacturing plant at Metaline Falls. The town of Metaline Falls is on State Highway 6, about 15 miles south of the International Boundary. It is the northern terminus of a branch of the Chicago, Milwaukee, St. Paul and Pacific Railroad.

Geology.—Limestone beds of the lower unit of the Metaline Limestone crop out over a length of 1 mile along the top of a north-trending ridge, about 1 mile east of Metaline Falls, between altitudes of 2,800 and 3,400 feet above sea level. The limestone is a fine-grained dark-gray rock with a few crystals of clear calcite. Part of the rock is mottled and contains irregular small patches and a few seams of white calcite. The bedding strikes about N. 10° E. and dips from 35° to 45° W. Park and Cannon (1943, p. 19) determined the rocks in the quarry to be Middle Cambrian in age on the basis of fossil evidence.

According to A. B. Clayton (1961, written communication) the quarry operation was begun at the northern end of the ridge and continued to the south within a bed of limestone that contains a high percentage of calcium carbonate, very little magnesium carbonate, and very minor amounts of sodium and potassium. Stratigraphically above and below this bed are blue to gray limestones containing small percentages of magnesium carbonate and varying amounts of alumina and silica. These limestones are blended with the purer limestone for the manufacture of cement. The total usable stratigraphic thickness of limestone beds in the quarry area averages about 600 feet.

Mining operations.—The quarry pits and benches extend southward from the north end of the ridge for a length of about three quarters of a mile, with access roads to each pit. The quarry is worked in benches or levels as much as 65 feet in vertical height. A row of vertical blast holes 20 feet on center are drilled 20 feet back from the face and deep enough to penetrate 5 feet below the quarry floor of the next lower bench. These holes are drilled by one man with a truck-mounted Joy rotary drill using a 7 3/8-inch steel rotary bit. When more stone is required, a row of these holes is charged with 60 percent strength dynamite cartridges and detonated with primacord and millisecond delay blasting caps.

Drill cuttings are used as powder tamping. In new faces and corners where the Joy drill is not applicable, an air-operated Gardner-Denver "Air Trac" drill is used to drill holes as much as 40 feet in length at any desired angle. The "Air Trac" drill has a long carriage that permits use of long drill rods; four-point tungsten carbide 2 3/4-inch detachable bits allow many holes to be drilled without change of bits or drill rods. A portable compressor is used near the "Air Trac" drill to reduce length of air supply lines. Holes are usually drilled on 6-foot centers and loaded with cartridges of 60 percent strength dynamite.

After the primary blast, the quarry floor below the blasted face is cleared of "fly" rock with a bulldozer; a Caterpillar tread-mounted Bucyrus B54 electric shovel is moved into the pit for loading of two 10-ton Mack trucks. Rock pieces larger than 18 inches in diameter are laid aside by the power shovel when loading trucks. These large rocks are drilled with a jackhammer and blasted with 40 percent dynamite, or they are broken by use of a 2-ton drop ball, operated by a Caterpillar Model D-8 bulldozer with a 30-foot boom and winch attachment.

The crushing plant, at the north end of the quarry, has an approach ramp so that trucks can back in and dump into the top of an Allis-Chalmers 9-K Gates gyratory crusher that takes pieces up to 18 inches in diameter. Below the crusher the rock flows by gravity to a Syntron vibrating grizzly, and the oversize is divided equally between two 5K Gates gyratory crushers. The minus 3 -inch product goes by belt conveyor to the tram loading bins.

A day shift operation of the shovel and trucks is usually sufficient to supply the day shift tramway operation and to fill the bins for an afternoon tram shift operation, delivering a total of 1,000 to 1,200 tons of limestone per day to the plant.

Cement plant.—Tram buckets empty the quarry rock into bins at the plant site in Metaline Falls. This rock has a CaO content that ranges from 65 to 95 percent. It is crushed, sampled, and blended so as to provide a kiln feed that contains about 76 percent CaO. The remaining 24 percent is chiefly alumina and silica from the argillaceous impurities in the limestone and the SiO₂ added to the kiln feed (5 pounds of quartzite for each 95 pounds of limestone) in the form of crushed quartzite. The mixture is roasted in a rotary kiln 350 feet long and 10 feet in diameter at a clinkering temperature of 2,700°F. The resulting cement clinker, mixed with 5 percent gypsum, is crushed and ground dry in ball and rod mills, stored in bulk in silos, or bagged for shipment. The plant is rated at 1 1/2 million barrels of cement per year. It has a maximum capacity of 4,500 barrels of cement per day.

Quality and quantity of limestone.—No samples were taken, but it is quite unlikely that any appreciable amount of the limestone quarried contains more than 95 percent CaO. The entire production is, and will continue to be, for cement manufacture. No limestone tonnage reserve figures were determined. Such figures probably would be of the order of several tens of millions of tons of limestone suitable for cement making.

Lime Lake Area
SW $\frac{1}{4}$ SW $\frac{1}{4}$ T. 39 N., R. 43 E.

Location and accessibility.—According to Bennett (Bennett, W. A. G., 1960, written communication) limestone crops out on a ridge northwest of Lime Lake, about 2 miles northeast of Metaline Falls. The area is within a quarter of a mile of State Highway 6 and is easily accessible by means of the Lime Lake graveled road.

Geology.—Gray limestone, similar to the gray limestone of the lower unit of the Metaline Limestone in the Lehigh Portland Cement quarry, crops out on the crest and west side of the ridge northwest of Lime Lake. The bedding strikes northeastward and dips moderately to the northwest. The limestone is underlain by dolomite and phyllite.

Quality and quantity of limestone.—Bennett sampled the entire thickness (75 feet) of the limestone; the location of the sample is shown on figure 7, on p. 45. The analysis of his sample (WGB-8) is as follows:

Sample no.	Length (feet)	CaCO ₃	MgCO ₃	Loss on Ignition	CaO	MgO	SiO ₂	R ₂ O ₃
WGB-8	75	96.71	0.44	42.76	54.33	0.21	2.24	trace

Bennett estimated the tonnage of rock of this purity in the immediate vicinity of the sample site to be 50,000 tons.

Three Mile Creek Area
SE $\frac{1}{4}$ sec. 11, T. 39 N., R. 43 E.

Location and accessibility.—Limestone of the lower unit of the Metaline Limestone crops out in many places along a series of low ridges roughly paralleling State Highway 6 for at least 2 miles northeast from the Lime Lake outcrops. The ridges lie from 300 to 700 feet east of the highway. These outcrops were examined, and one sample (PO-25) was taken across one of the larger outcrops 3.7 miles north of Metaline Falls and 300 feet east of State Highway 6 (pl. 2) in the SE $\frac{1}{4}$ sec. 11, T. 39 N., R. 43 E.

Geology.—The limestone on this low ridge is part of the lower limestone unit of the Metaline Limestone. According to Dings and others (1953), the outcrop is about 200 feet west of the upper contact of the Maitlen Phyllite. The limestone is gray, fine grained, and slightly argillaceous. Beds strike N. 13° E. and are overturned toward the west so that they dip 70° eastward beneath the older Maitlen Phyllite.

Quality and quantity of limestone.—Sample PO-25 was taken in an east-west direction across the full width of the outcrop (55 feet), representing a stratigraphic thickness of 52 feet of limestone. The analysis of this sample follows:

Sample no.	Length (feet)	CaCO ₃	MgCO ₃	Loss on Ignition	CaO	MgO	SiO ₂	R ₂ O ₃	P ₂ O ₅
PO-25	55	97.28	0.88	42.90	54.65	0.42	0.57	0.95	0.032

The analysis shows the rock to be a high-calcium limestone of exceptional purity, chemically suitable for sugar refining and the manufacture of pulp and paper, whiting, filler, and finishing lime. The area is heavily wooded and outcrops are small and moss covered, so that it is very difficult to determine how much rock of this quality is available. The low ridge on which the sampled outcrop was found is shown on Dings' map (Dings and others, 1953) to be about 800 feet long. The limestone in the ridge amounts to approximately 4,000 tons per vertical foot, or 400,000 tons to a depth of 100 feet. Though the tonnage is not large, the deposit is particularly valuable because of its high purity and because it is only 300 feet from State Highway 6 and 3.7 miles from the railroad terminus at Metaline Falls.

Slate Creek Area

SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 20, T. 40 N., R. 44 E.

Location, accessibility, and ownership.—The area examined and sampled is reached by driving north from Metaline Falls on State Highway 6 to the Slate Creek road, then northeast along that road for a distance of 3.4 miles. From this point it is necessary to walk 800 feet northwest to the edge of the outcrop area (fig. 6). According to county records the area is U.S. Government land.

Geology.—The area was chosen for examination because it possesses the largest relatively accessible area of outcrop of the lower unit of the Metaline Limestone in the northeastern part of the Metaline district. The largest limestone outcrop lies about 1,000 feet northwest of the Slate Creek road. This outcrop, half a mile long and from 100 to 400 feet wide, parallels the Slate Creek road between 3,250 and 3,500 feet above sea level (fig. 6). The outcrop is composed of light-gray to gray, fine- to medium-grained, massive limestone. Bedding strikes northeastward and dips from 23° to 35° NW. Two samples, PO-11 and PO-12, were taken of this limestone. A much smaller outcrop of limestone, farther upslope and 1,500 feet northwest of the Slate Creek road, is composed of light-gray fine-grained thin-bedded limestone. This rock contains up to 0.5 percent of fine-grained muscovite, best displayed on parting surfaces. Bedding strikes N. 20° W. and dips 35° SW. Two samples, PO-9 and PO-10, were taken of this limestone.

Quality and quantity of limestone.—Samples PO-9 and PO-10 were taken, over lengths of 100 feet and 120 feet respectively, of the light-gray fine-grained limestone. Samples PO-11 and PO-12 were taken down a steep rock face across the east end of the large outcrop of massive limestone. The horizontal lengths of these two samples were determined to be 100 feet and 130 feet, respectively. The stratigraphic thicknesses of the limestone strata represented by the combined pair of samples PO-9 and PO-10 and the pair of samples PO-11 and PO-12 are estimated to be 150 feet and 230 feet,

respectively. The analyses of these samples are as follows:

Sample no.	Length (feet)	CaCO ₃	MgCO ₃	Loss on Ignition	CaO	MgO	SiO ₂	R ₂ O ₃	P ₂ O ₅
PO-9	100	97.88	0.75	43.29	54.99	0.36	0.65	0.32	0.003
PO-10	120	97.47	1.19	43.53	54.76	0.57	0.43	0.39	0.003
PO-11	100	96.65	1.00	43.06	54.30	0.48	1.10	0.62	0.004
PO-12	130	97.15	0.90	43.25	54.58	0.43	1.15	0.41	0.004

All four sample analyses show the limestone to be a high-calcium type, with an average CaCO₃ content of about 97.5 percent. The limestone of the smaller outcrop (PO-9 and PO-10) is of exceptional purity. The outcrop, however, is too small for the calculation of any significant tonnage of limestone. The amount of high-calcium limestone available to a depth of 350 feet beneath the larger outcrop is estimated to be 40 million tons. It should be kept in mind that only two samples were taken across this larger outcrop and these may not be representative of the entire outcrop or of the limestone at depth. Insofar as the samples are representative of the limestone, the rock is suitable for use in the manufacture of calcium carbide, chemical lime, metallurgical lime, finishing lime, ceramic whiting, pulp and paper, and filler. Features of this deposit that tend to detract from its value, notwithstanding the large tonnage, are the attitude of the beds, the steepness of the hillside, and the remoteness of the area. In spite of these handicaps, the potential value of high-calcium limestone may make further exploration profitable.

Getchell-Dehuff Property
W $\frac{1}{2}$ sec. 6, T. 40 N., R. 44 E.

Location, accessibility, and ownership.—The Getchell-Dehuff property is located in the W $\frac{1}{2}$ sec. 6, T. 40 N., R. 44 E., Pend Oreille County. The northern boundary of the property is the International Boundary. State Highway 6 crosses the western part of the property. The nearest rail point is Metaline Falls, 15 miles to the south. Ownership is claimed by Roy Getchell and Art Dehuff of Metaline Falls.

Geology.—The ground east of State Highway 6, extending for three-fourths of a mile south from the International Boundary, rises rapidly to a summit 1,000 feet above and half a mile east of the highway (fig. 9). Rock outcrops on this mountain are numerous; the two most extensive ones are shown on figure 7. According to recent geologic work (Dings and others, 1956), most of the bedrock in this area is the lower unit of the Metaline Limestone—"chiefly thin- to medium-bedded, dark-gray to gray limestone and limy shale." The average strike of these rocks is approximately north and the dip is moderate toward the west. The bedrock is cut by numerous northeast-striking faults, two of which are shown in figure 7, one on each side of the two major outcrops on the property. The outcrops are part of an upthrown fault block or horst.

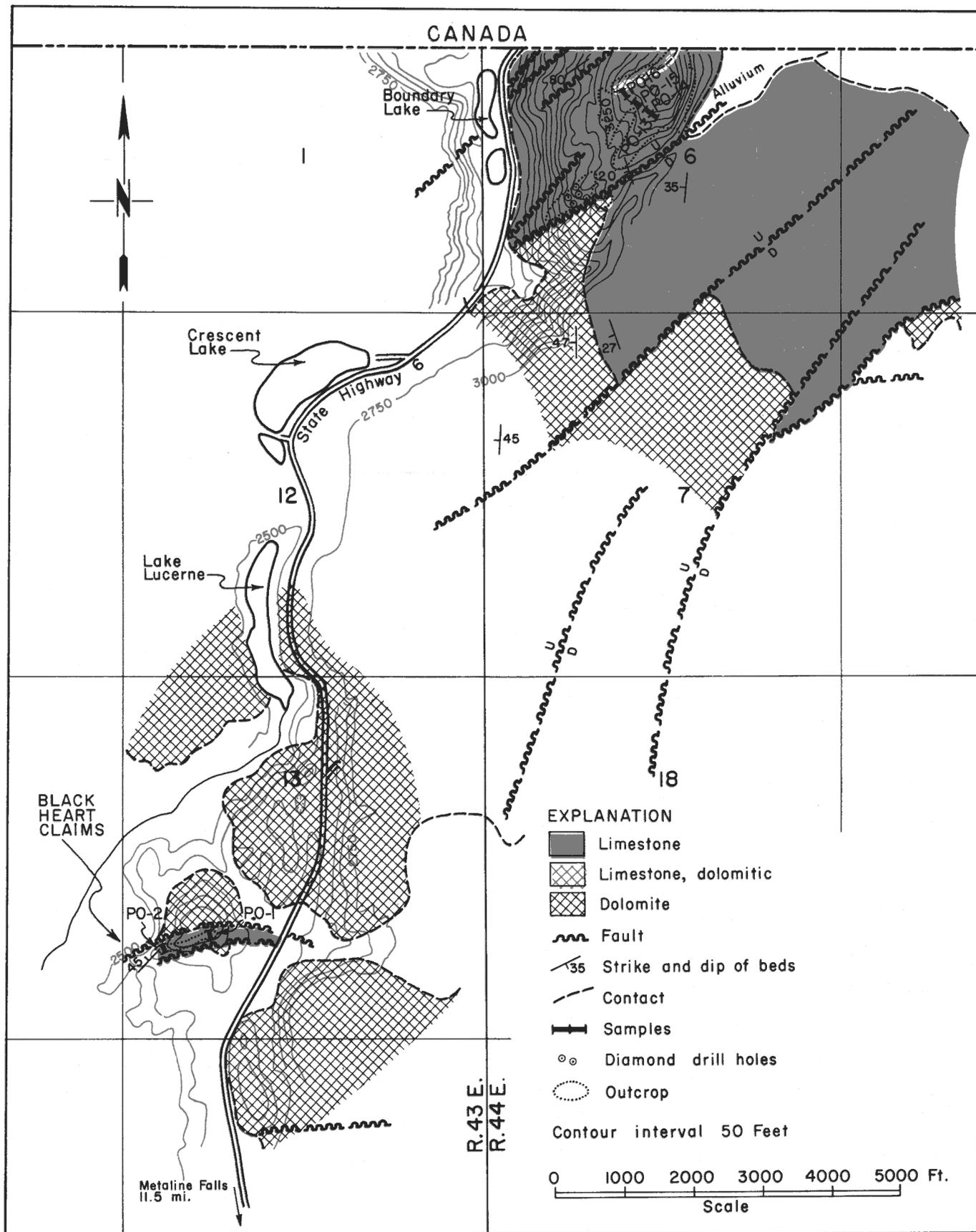


FIGURE 7.—Getchell-Dehuff property and Black Heart claims. Secs. 1, 12, 13, and 24, T. 40 N., R. 43 E. and secs. 5, 6, and 7, T. 40 N., R. 44 E. Map modified from U.S. Geological open-file map by M. G. Dings and others, 1956.

In the course of this study, the two principal outcrop areas were mapped on aerial photo enlargements; the resulting map was reduced to the scale of the U.S. Geological Survey Open File Report (Dings and others, 1956) and reproduced on figure 7. The limestones are light gray to gray in color, fine to medium grained, and massive. No bedding was recognized, although numerous joint surfaces that may be parallel to the bedding have trends that range from N. 45° E. to N. 80° E. and dips that range from 20° to 30° SE. According to a report loaned to the writer by the Hecla Mining Company, bedding in the southwestern part of the property strikes north and dips 27° W.

The limestone in the southwestern outcrop, approximately 1,000 feet long and 300 feet wide, appears to be quite pure. The Hecla Mining Company drilled five diamond drill holes on this outcrop, as shown on figure 7, for a total core length of 410 feet. Logs of the holes indicate that the color of the rock varies from light greenish gray to dark gray and black. The texture varies from dense to medium grained, but more often it is "finely crystalline." The much larger outcrop to the northeast, extending to the International Boundary, is composed of the same kind of limestone as the smaller outcrop. However, toward both the southeast and northwest sides of the outcrop the rock becomes less pure. Toward the southeast it contains 1 or 2 percent of very fine grained silver-white mica, and the rock has a pronounced parting. The limestone along the northwest side and at the northern end of the outcrop contains numerous scattered blebs and lenticles of dolomite.

Quality and quantity of limestone.—No samples were taken on the southwestern outcrop because the Hecla Mining Company had already drilled there. The CaCO_3 and MgCO_3 content, as indicated by weighted core analyses, for each of the five holes drilled by Hecla are as follows:

Diamond drill hole no.	Weighted average percent		Total core length (feet)
	CaCO_3	MgCO_3	
1	96.2	0.8	58.1
2	95.7	0.4	49.1
3	96.7	0.7	118.2
4	94.1	0.9	103.3
5	93.7	0.7	76.5

The weighted core analyses indicate that the CaCO_3 content of the limestone of the southwestern outcrop is slightly in excess of 95 percent. Mapping by the Hecla Mining Company indicates that the dips of the bordering major faults are away from each other, so they would present no problem to mining the block between them. It is conservatively estimated that the block bounded approximately by the outcrop borders and altitudes 2,850 and 3,150 feet contains 4 million tons of limestone. Sampling of the larger outcrop to the northeast was confined to the better exposures of high-grade limestone. The four samples, (PO-13 to PO-16) are considered to be representative of an outcrop width of 650 feet. The analyses of these four samples are as follows:

Sample no.	Length (feet)	CaCO ₃	MgCO ₃	Loss on Ignition	CaO	MgO	SiO ₂	R ₂ O ₃	P ₂ O ₅
PO-13	100	97.15	0.96	42.88	54.58	0.46	1.42	0.76	0.005
PO-14	100	97.22	1.00	43.28	54.62	0.48	0.76	0.39	0.003
PO-15	65	97.15	1.00	42.99	54.58	0.48	0.89	0.80	0.005
PO-16	100	95.68	1.50	42.82	53.75	0.72	1.44	0.89	0.004

On the basis of these sample analyses it appears that the limestone of the larger outcrop contains, on the average, about 97 percent CaCO₃. Hence it qualifies as a high-calcium limestone. It is remarkably free of magnesia. The silica content is less than 1.5 percent and may be as low as 1 percent on the average. The limestone is chemically suited to the manufacture of chemical lime, metallurgical lime, finishing lime, pulp and paper, and mineral filler. The analyses show that the silica content is slightly in excess of that generally permitted for sugar refining and the R₂O₃ content is a little too high for the manufacture of limestone whiting. More sampling may indicate that the limestone is suitable for these uses. The amount of high-calcium limestone estimated to be present to a depth (altitude 2,825 feet) of 400 feet below the summit is 20 million tons.

Limestone of the Upper Unit of the Metaline Limestone

Black Heart Claims

SW $\frac{1}{4}$ sec. 13, T. 40 N., R. 43 E.

Location, accessibility, and ownership.—The Black Heart property is located about 3 miles south of the International Boundary and 1,000 feet west of State Highway 6, in the SW $\frac{1}{4}$ sec. 13, T. 40 N., R. 43 E. The nearest railroad connection is the terminus of the branch of the Chicago, Milwaukee, St. Paul and Pacific Railroad at Metaline Falls, 12 miles to the south. The property comprises two claims, the Black Heart Lime Placer Group and the Black Heart Lime Placer Group No. 2. According to statements stored at the discovery posts, the claims are held by D. H. Getchell, Art Dehuff, R. H. Getchell, Nellie Getchell, E. C. Houss, and Janette Houss, all of Metaline Falls.

Geology.—The outcrop area (fig. 7), approximately 1,000 feet long and 80 feet wide, is on the steep south-facing slope of a wooded hill 1,000 feet west of State Highway 6. There is a difference in elevation of about 50 feet between the north and south sides of the outcrop. Geologic mapping by the U.S. Geological Survey (Dings and others, 1956) indicates that this outcrop is part of a tabular body of upper Metaline Limestone less than 200 feet thick, bounded by subparallel faults. The limestone is white to light gray and fine to very fine grained. The beds strike northeastward and dip 45° NW.

Quality and quantity of limestone.—Two samples (PO-1 and PO-2) were taken at opposite ends of the outcrop and across the full width of the outcrop. Sample PO-1 was taken on a bearing S. 25° E. for a horizontal distance of 75 feet; sample PO-2 was taken on a bearing S. 35° E. for a horizontal length of 70 feet. The analyses of these samples are as follows:

Sample no.	Length (feet)	CaCO ₃	MgCO ₃	Loss on ignition	CaO	MgO	SiO ₂	R ₂ O ₃	P ₂ O ₅
PO-1	75	96.12	2.01	43.54	54.00	0.96	0.54	0.54	0.012
PO-2	70	96.71	1.90	43.29	54.33	0.91	0.77	0.35	0.004

The analyses show the rock to be a high-calcium limestone containing, on the average, 96.4 percent CaCO₃. The limestone is suitable for such high-calcium limestone uses as the manufacture of finishing lime, pulp and paper, and mineral filler, as well as cement. The outcrop is ideally situated for quarrying. However, it is impossible to determine, without further testing, how much rock of this quality is available. It is not known to what depth the limestone is likely to extend, because the position of the bottom of the limestone formation is not known and the attitude of the bounding faults is unknown. If it is assumed that the bottom of the limestone formation is at least 120 feet below the outcrop and that the faults are vertical then the maximum amount of limestone present above the altitude of State Highway 6 is 1 million tons.

Beatty Lake Area

NE $\frac{1}{4}$ sec. 27, T. 40 N., R. 43 E.

Location and accessibility.—Limestone crops out prominently in the NE $\frac{1}{4}$ sec. 27, T. 40 N., R. 43 E., about $\frac{1}{4}$ mile east of the Metaline-Gardner Caves road at Beatty Lake. Beatty Lake is approximately 8 $\frac{1}{2}$ miles north of the town of Metaline Falls which is on a branch of the Chicago, Milwaukee, St. Paul and Pacific Railroad. The area was not examined during the present study. The following information was obtained from W. A. G. Bennett (written communication) and by reference to the U.S. Geological Survey Open File Report Preliminary Map (Dings and others, 1956).

Geology.—The limestone east of Beatty Lake is shown on figure 7 to be part of a band of gray, very fine grained upper Metaline Limestone, approximately 1,800 feet wide, extending north from Beatty Lake for a distance of 2 miles. Bedding in the limestone strikes due north; dips range from 30° to 35° W.

Quality of limestone.—Bennett sampled the limestone (WGB-12) from east to west for a length of 600 feet, or a stratigraphic thickness of approximately 300 feet. He reports (written communication, 1960) that the limestone "is quite uniform except for minor portions which are spotted with dolomite. The dolomite appears to form rounded globular and veinlike masses in the limestone." The one analysis of this rock is as follows:

Sample no.	Length (feet)	CaCO ₃	MgCO ₃	Loss on Ignition	CaO	MgO	SiO ₂	Al ₂ O ₃
WGB-12	600	89.32	7.02	43.65	50.18	3.36	0.44	0.46

The presence of dolomite referred to by Bennett is verified by the chemical analysis (MgO, 3.36 percent). The limestone contains too little CaCO₃ (89.0 percent) and too much magnesia to be classed as a high-calcium limestone or to be suitable for the making of portland cement.

Hoage Lake Area

SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 22, T. 40 N., R. 43 E.

Location and accessibility.—The Hoage Lake area is in the SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 22, T. 40 N., R. 43 E., about 1 mile north of the Beatty Lake area. Limestone is exposed on a prominent hill $\frac{1}{2}$ mile northeast of Hoage Lake, $\frac{1}{4}$ mile east of the Metaline-Gardner Caves road, and $9\frac{1}{2}$ miles north of the town of Metaline Falls. Metaline Falls is on State Highway 6 and on a branch of the Chicago, Milwaukee, St. Paul and Pacific Railroad.

Geology.—The limestone of the Hoage Lake area is the northern extension of the upper unit of the Metaline Limestone of the Beatty Lake area just described. The general location is shown on plate 2; the local geology and sample locations are shown on figure 8. The limestone is light gray to gray, fine grained, and well bedded. Bedding strikes N. 20° E. and dips approximately 33° W. Faulting has disturbed the limestone in a few places, and solutions following the fault planes and zones have caused some silicification of the limestone adjacent to the faults. Such areas were not sampled. One such area (fig. 8) separates the almost continuous line of samples PO-17 to PO-23 from sample PO-24. All samples were taken in a due east direction. The first seven samples (PO-17 to PO-23) represent a combined horizontal length of 700 feet, including a covered interval 40 feet long.

Quality and quantity of limestone.—The chemical analyses of samples PO-17 to PO-24 are as follows:

Sample no.	Length (feet)	CaCO ₃	MgCO ₃	Loss on Ignition	CaO	MgO	SiO ₂	R ₂ O ₃	P ₂ O ₅
PO-17	100	98.51	0.61	43.72	55.34	0.29	0.16	0.15	0.004
PO-18	60	98.77	0.73	43.75	55.49	0.35	0.07	0.18	0.002
PO-19	100	97.63	0.75	43.76	54.85	0.36	0.23	0.16	0.004
PO-20	100	98.01	0.54	43.32	55.06	0.26	0.86	0.14	0.003
PO-21	100	98.26	0.75	43.70	55.20	0.36	0.11	0.32	0.011
PO-22	100	98.38	0.54	43.73	55.27	0.26	0.16	0.18	0.004
PO-23	100	97.42	1.17	43.53	54.73	0.56	0.72	0.25	0.014
PO-24	100	98.13	0.96	43.66	55.13	0.46	0.41	0.12	0.005

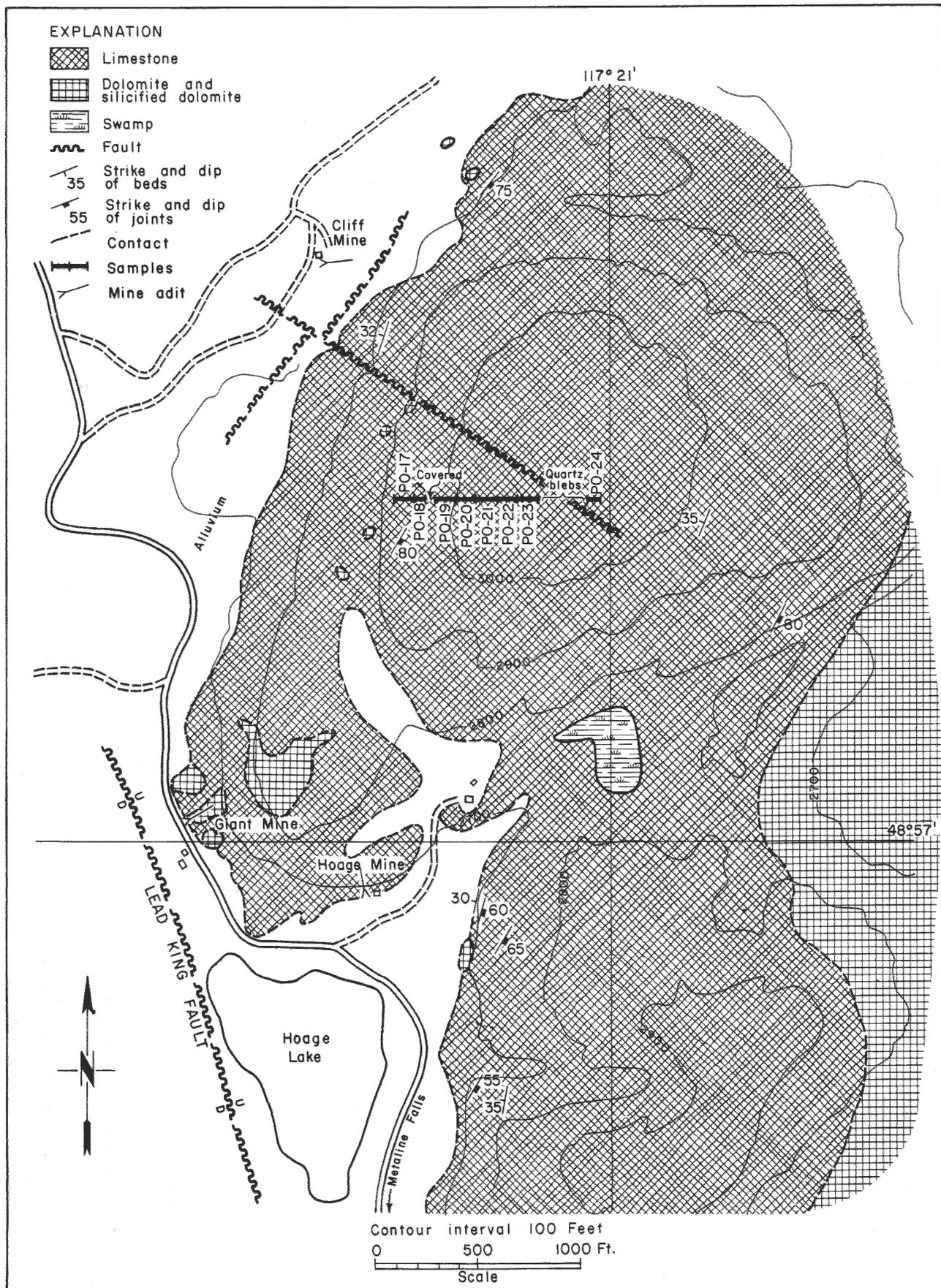


FIGURE 8.—Hoage Lake area. Topography and geology from U.S. Geological Survey open-file map by M. G. Dings and others, 1956.

The rock that was sampled is a high-calcium limestone of exceptional purity, suitable for all high-calcium limestone and lime uses, probably including glass manufacture. The average content of CaO is 55.1 percent and of CaCO_3 is 98.2 percent. Limestone within a radius of several hundred feet of the sampled area appears to be of comparable quality. It is estimated that there is at least 10 million tons of high-calcium limestone in the sampled area above the altitude of the Metaline-Gardner Caves road. The amount of limestone in the entire hill extending for two-thirds of a mile northeast of Hoage Lake, above the altitude of the road, is estimated to be 175 million tons. There is no assurance that the entire hill is composed of limestone of as high purity as that sampled, but there is no doubt that the area has one of the largest potential reserves of high-calcium limestone in Pend Oreille County. The hill provides an excellent site for quarrying; it has practically no overburden and is easily accessible.

Russian Creek Area

$E\frac{1}{2}$ sec. 4, T. 40 N., R. 43 E.

Location, accessibility, and ownership.—The Russian Creek area is in the $E\frac{1}{2}$ sec. 4, T. 40 N., R. 43 E., adjacent to the International Boundary. A good graveled road from Metaline, 12 miles to the south, to Gardner Caves State Park ($NE\frac{1}{4}SE\frac{1}{4}$ sec. 4, T. 40 N., R. 43 E.) provides ready access to the limestone occurrences of the area. According to county records, all of sec. 4 is U.S. land except for Gardner Caves State Park and the $SE\frac{1}{4}NE\frac{1}{4}$ sec. 4, which is owned by Day Mines, Inc. The general location of the area is shown on plate 2.

Geology.—According to the work of Dings and others (1956), the limestone cropping out within sec. 4 (pl. 2) is part of the upper limestone unit of the Metaline Limestone. Of the two large outcrops in the Russian Creek area (one on each side of the road), only the northern one was examined. The limestone here is white to light gray, medium to coarse grained, and massive. Except for the presence of a very few thin (less than 1 inch) muscovite schist layers, it appears to be a very pure calcite marble. No bedding was recognized, but the rock exhibits some layering, which Dings interprets as due to differentiation by shear.

Bennett examined the same outcrop in 1928 and sampled it approximately at the places shown on figure 9. He reports as follows (written communication, 1960):

Sample No. 5 . . . was taken across the bedding from south to north over a distance of approximately 900 feet and near a small sink in the limestone along the trail which leads to a cave on the top of this ridge. This rock is marble (crystalline limestone) of remarkable purity, white with shades of gray. The bedding is uniform in color, and no magnesium was encountered. The dip is toward the south at 35° to 40° . . .

Sample No. 6 . . . was collected about . . . 100 feet east of the cave. This was taken from north to south and across the bedding. The marble is the same here as in No. 5.

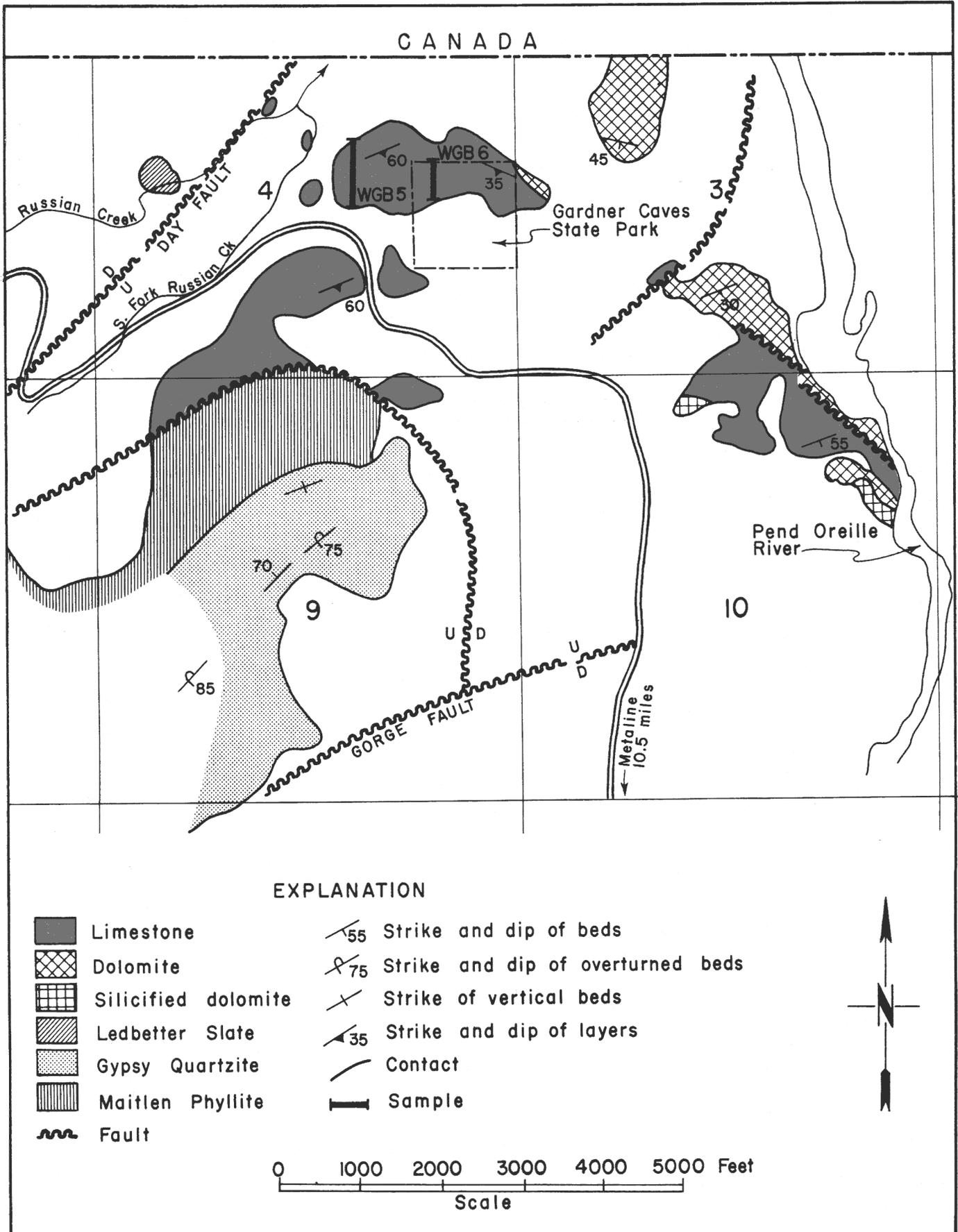


FIGURE 9.—Russian Creek area. Secs. 3, 4, 9, and 10, T. 40 N., R. 43 E. Geology from U.S. Geological Survey open-file map by M. G. Dings and others, 1956.

Quality and quantity of limestone.—The chemical analyses of the samples taken by Bennett are as follows:

Sample no.	Length (feet)	CaCO ₃	MgCO ₃	Loss on Ignition	CaO	MgO	SiO ₂	Al ₂ O ₃
WGB-5	900	96.97	1.05	43.29	54.48	0.50	0.76	0.08
WGB-6	500	97.24	1.61	43.64	54.63	0.77	0.51	trace

The analyses substantiate the field observations that the rock is a high-calcium limestone of remarkable purity. The average content of CaCO₃ is 97.2 percent. It is estimated that the outcrop sampled by Bennett contains 13 million tons of limestone above the altitude of the road. Other outcrops of the upper limestone unit of the Metaline Limestone in sec. 4, if included in the estimate, probably would bring the total limestone tonnage available in the area to several times that amount. The rock is suitable for the manufacture of finishing lime, sugar, pulp and paper, and mineral filler; it may also be suitable for the manufacture of calcium carbide, chemical lime, and metallurgical lime.

Other limestone.—Limestone is reported, by D. L. Sauer of Sandpoint, Idaho, to crop out on claims (Apex group) staked by him, on both sides of Russian Creek in the central parts of secs. 7 and 8, T. 40 N., R. 43 E. The limestone is probably the westward extension of the upper unit of the Metaline Limestone cropping out in sec. 4, T. 40 N., R. 43 E. A sample submitted by the owner to the Inland Analytical Laboratories, Inc., was found to contain 55.38 percent CaO, 98.83 percent CaCO₃, 0.84 percent MgCO₃, 0.18 percent Fe₂O₃, and 0.15 percent SiO₂. The rock is a high-calcium limestone of a quality comparable to the limestone in the Russian Creek area sampled by Bennett. It is not known how representative this sample is of the limestone that, according to Mr. Sauer, crops out over a width of from 200 to 400 feet and a length of 1½ miles. The Apex claims were not examined during this study because they were not brought to our attention until all the field work had been completed.

Z Canyon Area

NE¼NE¼ sec. 15 and NW¼NW¼ sec. 14, T. 40 N., R. 43 E.

Location and accessibility.—Z Canyon is a spectacular gorge on the Pend Oreille River at the corner common to secs. 10, 11, 14, and 15, T. 40 N., R. 43 E., approximately 8 miles north of Metaline Falls. The Metaline-Gardner Caves graveled road is about 1 mile to the west of the canyon.

Geology.—The vertical walls of the gorge of the Pend Oreille River a quarter of a mile south of Z Canyon expose a 500-foot vertical thickness of limestone belonging to the upper limestone unit of the Metaline Limestone. Several hundred feet of additional thickness of limestone is exposed on the steep hills bordering the gorge. The average strike of the limestone beds is N. 10° W., and the dip ranges from 25° to 35° W.

Quality and quantity of limestone.—No samples were taken by the writer. However, Bennett (written communication, 1960) took two samples (WGB-10 and WGB-13), one on the east side of the gorge and one on the west. The exact locations of these samples are not known, but they were taken approximately where shown on plate 2. Sample WGB-10 was taken "on the east side . . . about $\frac{1}{4}$ mile back from the river and between 400 and 500 feet above the river." Sample WGB-13 was taken "along the slope down to the bluff at Z Canyon on the west side . . . a short distance north of the cable which extends across the river." (Bennett, written communication, 1960.) The analyses of these samples are as follows:

Sample no.	CaCO ₃	MgCO ₃	Loss on Ignition	CaO	MgO	SiO ₂	Al ₂ O ₃
WGB-10	95.83	3.30	43.12	53.84	1.58	1.28	trace
WGB-13	85.56	9.15	42.98	48.07	4.38	3.48	0.19

The limestone on the east side of the river (WGB-10) is a high-calcium limestone with sufficient magnesia and silica to prohibit its use for most purposes, with the possible exception of cement manufacture. The limestone on the west side of the river (WGB-13) is much too impure to be of any value. It should be kept in mind that the lengths and even the exact locations of samples WGB-10 and WGB-13 are not known; there is no assurance that these samples are really representative of the tremendous amount of limestone in the Z Canyon area.

Other Occurrences of Metaline Limestone

Ione Area

Location and accessibility.—Carbonate rocks lie immediately west and north of the town of Ione, in sec. 31, T. 38 N., R. 43 E., sec. 36, T. 38 N., R. 42 E., and sec. 1, T. 37 N., R. 42 E. State Highway 6 and the Chicago, Milwaukee, St. Paul and Pacific Railroad pass through Ione within 1 mile of the limestone outcrops.

Geology.—Two hills west and north of Ione rise to elevations 500 feet and 800 feet above the surrounding alluvium. Outcrops of limestone and dolomite are especially numerous in prominent cliffs along the southeast sides of these hills (fig. 10). The limestone north of Ione is considered to be part of the lower limestone unit of the Metaline Limestone on the basis of the presence of fossil algae (?) and the general similarity of its lithology to the Metaline Limestone. The limestone west of Ione lies above the dolomite and may be part of the upper unit of the Metaline Limestone. The dolomite is the middle unit of the Metaline Limestone. The dolomite is a yellow-white fine-grained crystalline dolomite or dolomite breccia that weathers to a pale-yellow or yellow-brown color and exhibits very little bedding. Most of the limestone in the area is gray to dark gray, fine grained, well bedded, slightly dolomitic and

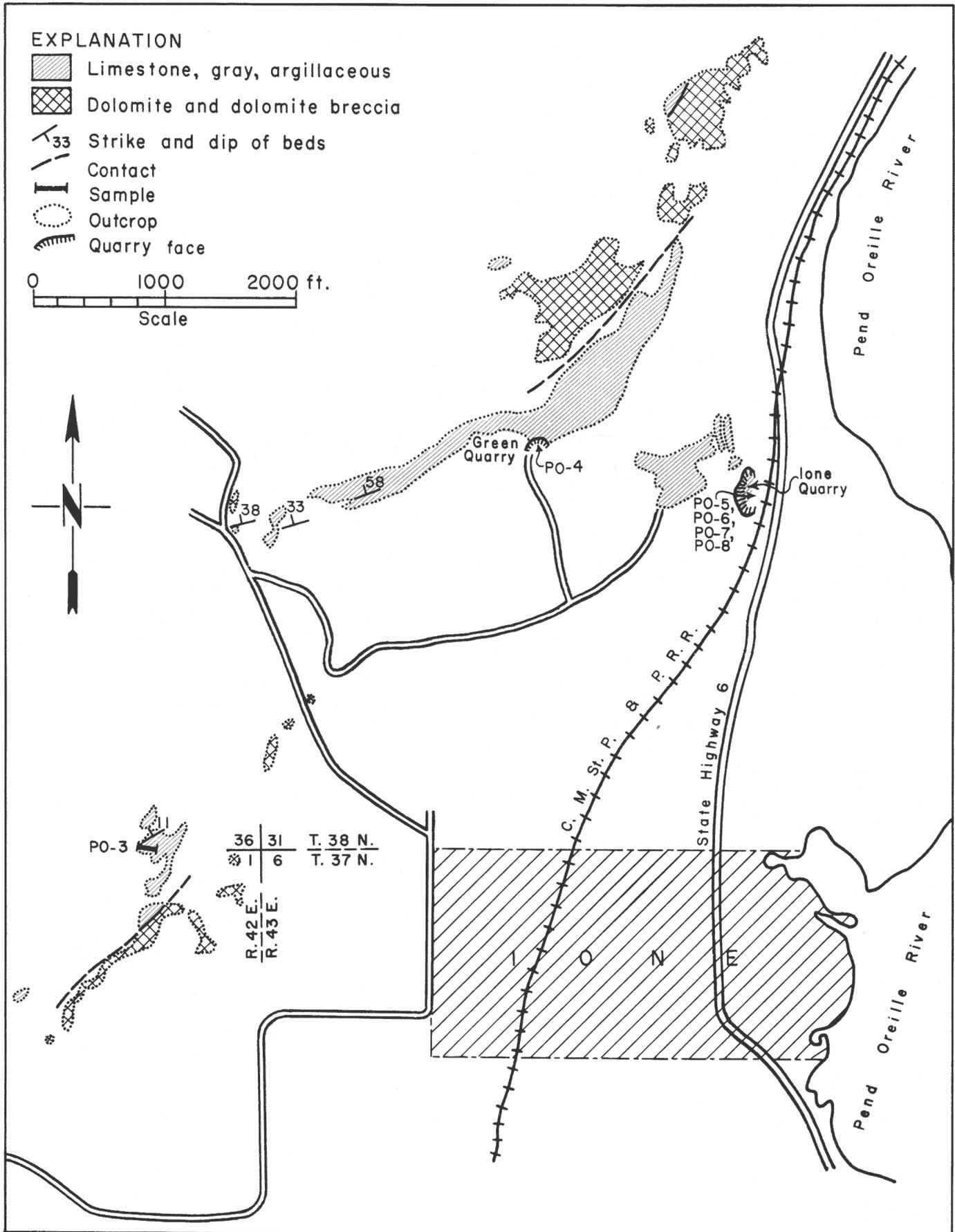


FIGURE 10.—Lone area. Sec. 1, T. 37N., R. 42 E., sec. 36, T. 38 N., R. 42 E., and sec. 31, T. 38 N., R. 43 E. Geology by J. W. Mills. Base map from aerial photo enlargement.

argillaceous. In many places it exhibits banding on the weathered surface, owing to the presence of numerous red-brown weathering streaks and blebs elongated parallel to the bedding. Most of these are discontinuous argillaceous and dolomitic interbeds. The limestone north of lone contains abundant round to elliptical, concentrically banded structures, probably algae, as much as $\frac{1}{3}$ inch in diameter and 1 inch long. They are most obvious on the rock surface where they weather in relief. Bedding in the carbonate rocks generally strikes to the northeast and dips moderately to the northwest.

lone Quarry

SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 31, T. 38 N., R. 43 E.

Location, accessibility, and ownership.—A small abandoned quarry, known in the past as the Jordan quarry and as the Allen quarry, is in the SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 31, T. 38 N., R. 43 E., immediately west of the Chicago, Milwaukee, St. Paul and Pacific Railroad and State Highway 6, one mile north of lone (fig. 10). It was originally located in 1901 by F. G. Jordan. A little natural hydraulic cement was manufactured at this place in 1904 (Shedd, 1913, p. 181). According to county records at Newport, the property lies within the patented claim "Pole Star," owned by Otto C. Frei of Atlanta, Georgia. Hodge (1938, p. 128) reports that approximately 150,000 tons of rock has been taken from the quarry and that the greater part was used for flux by the Bunker Hill and Sullivan Company, which operated the quarry at one time.

Geology.—The bulk of the rock exposed in the quarry is the gray, slightly dolomitic and argillaceous limestone referred to earlier. No bedding was recognized, and it is assumed that bedding attitudes are much the same as they are elsewhere in the lone area. The rock in the upper part of the quarry has a distinctly greenish cast, which is due to the presence of finely disseminated talc. A fault breccia zone separating the gray limestone from yellow-white crystalline dolomite is exposed in the southern corner of the quarry (fig. 11).

Quality and quantity of limestone.—A number of limestone analyses of samples taken in the vicinity of lone have been reported (Shedd, 1913, p. 183-185), but their precise locations are not stated. These analyses indicate that the oxide content ranges as follows: CaO, 40.47 to 51.12 percent; MgO, trace to 3.91 percent; R₂O₃, 1.06 to 10.08 percent; and SiO₂, 3.10 to 17.04 percent. The purest limestone reported by Shedd contained 51.12 percent CaO, 0.96 percent MgO, 1.68 percent R₂O₃, and 3.10 percent SiO₂.

Twelve samples of the limestone from the lone quarry were taken in 1954 by officers of the Utah-Idaho Sugar Company. The analyses of these samples were made available through the courtesy of John E. Hayes, Chief Chemist, Utah-Idaho Sugar Company. The analyses are as follows:

Sample no.	CaCO ₃	MgCO ₃	Insol.	R ₂ O ₃
1	86.74	2.66	8.50	1.56
2	88.99	2.78	7.38	1.42
3	85.52	3.06	9.62	1.30
4	82.42	4.24	11.55	1.98
5	87.91	2.26	9.38	0.90
6	85.49	3.34	10.06	1.40
7	85.45	1.94	11.23	1.64
8	91.59	2.26	6.20	0.92
9	89.73	2.78	6.92	1.04
10	92.51	1.96	4.67	0.85
11	91.59	1.44	5.79	0.94
12	89.02	1.94	7.55	1.16

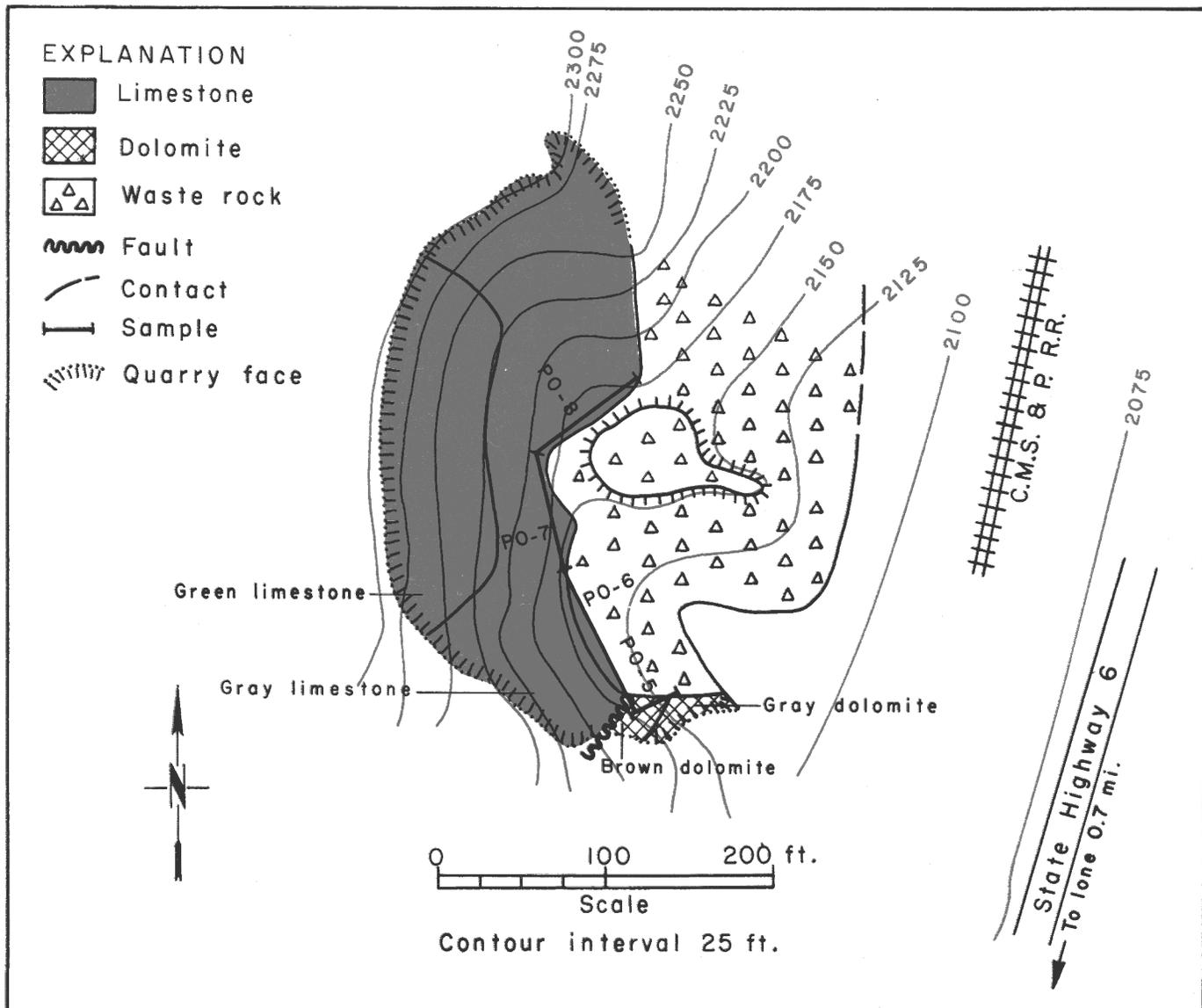


FIGURE 11.—lone quarry. Sec. 31, T. 38 N., R. 43 E. Geology by C. E. Stearns and R. D. Boettcher. Base and topography by plane table and alidade survey.

The locations of four samples taken during this study are shown on figure 11. Sample PO-5 was taken over a horizontal length of 23 feet, starting at the dolomite contact and extending across the fault breccia zone between the dolomite and the gray limestone. Samples PO-6, PO-7, and PO-8 were taken along horizontal lengths of 94 feet, 80 feet, and 75 feet, respectively, at the base of the quarry face. They consisted of dark-gray fine-grained slightly dolomitic and argillaceous limestone, with numerous brown streaks and patches that are characteristic of the weathered surface of this limestone where it is exposed northwest and west of the quarry. The analyses of these samples are as follows:

Sample no.	Length (feet)	CaCO ₃	MgCO ₃	Loss on Ignition	CaO	MgO	SiO ₂	R ₂ O ₃	P ₂ O ₅
PO-5	23	52.74	40.57	44.41	29.63	19.41	3.45	2.93	0.008
PO-6	94	85.10	4.08	39.95	47.81	1.95	6.39	3.50	0.016
PO-7	80	83.38	4.49	38.64	46.84	2.15	7.60	4.22	0.019
PO-8	75	91.12	1.82	41.51	51.19	0.87	3.72	2.27	0.011

It is quite clear, from the analyses, that the rock is much too impure to be classed as a high-calcium limestone and that it contains too much MgO for the manufacture of portland cement.

Green Quarry

SE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 31, T. 38 N., R. 43 E.

Location, accessibility, and ownership.—The abandoned Green quarry is located in the SE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 31, T. 38 N., R. 43 E., on the south side of a prominent and precipitous rock outcrop (fig. 10). A good graveled road connects the quarry site with lone, 1 $\frac{1}{2}$ miles distant. County records indicate that the quarry is on U.S. land. The Green Company, N. 119 Post Street, Spokane, operated the quarry in 1956 and mined an estimated 10,000 tons of rock, reportedly for sale to sugar manufacturers. Most of this rock is stockpiled at the quarry; presumably the product was found to be unsuitable for sugar manufacture and was never shipped.

Geology.—The rock exposed in the quarry is a gray argillaceous limestone, probably the lower limestone unit of the Metaline Limestone. It is similar to, but apparently less pure than, that exposed in the lone quarry. Many boulders in the Green quarry are brecciated, serpentinized, and dolomitized. Weakly developed bedding in the limestone bedrock strikes N. 20° W. and dips 38° N.

Quality of limestone.—An attempt was made to take representative chip samples of the quarry walls, but the precipitous and overhanging nature of these and the adjacent outcrops, together with the great amount of loose rock presented too great a hazard for sampling. Sample PO-4 was obtained by taking approximately 10 pounds of chips from the fresh surfaces of 66 rock blocks removed by quarrying. It is recognized that all of these are not necessarily what the operators may have considered to be shipping rock; but the sample probably is fairly representative of the total rock broken. The analysis of PO-4 is as follows:

Sample no.	CaCO_3	MgCO_3	Loss on Ignition	CaO	MgO	SiO_2	R_2O_3	P_2O_5
PO-4	84.60	6.33	40.68	47.53	3.03	5.34	2.86	0.009

The analysis indicates that the rock is unsuitable for cement making or for any use requiring a high-calcium limestone.

Thackston Property
NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 1, T. 37 N., R. 42 E.

Location, accessibility, and ownership.—Of all the limestone exposed in the lone area, that which appeared upon examination to be the purest is exposed in the SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 36, T. 38 N., R. 42 E., on State land; and its extension into the NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 1, T. 37 N., R. 42 E., on the property of Josephine Thackston of Los Angeles. The nearest road is the Cedar Creek road a quarter of a mile to the northeast (fig. 10).

Geology.—The rock crops out on the summit of a ridge about 500 feet above the farmland at the base of the hill. Overburden is less than 2 feet in depth over an area of 300 by 300 feet at the hill summit. The rock is a gray, gray-weathering, fine-grained, relatively pure limestone. Bedding strikes range from N. 54° E. to N. 70° E., and dips range from 10° to 20° NW. The limestone, where sampled (PO-3), is underlain by dolomite breccia at a depth of less than 150 feet.

Quality of limestone.—One sample, PO-3, was taken across an essentially continuous outcrop for a horizontal length of 90 feet. It is estimated to represent a true thickness of approximately 20 feet of limestone. The analysis is as follows:

Sample no.	Length (feet)	CaCO_3	MgCO_3	Loss on Ignition	CaO	MgO	SiO_2	R_2O_3	P_2O_5
PO-3	90	96.78	0.98	43.36	54.37	0.47	0.91	0.56	0.004

The analysis shows that the rock is a high-calcium limestone; the CaCO_3 content is calculated as 96.8 percent. Despite the high purity shown by analysis, the rock can not be assumed to have much potential value until it can be demonstrated that there is a large tonnage of limestone of similar grade. The area of exposure is small, and the true thickness of the sampled section is only 20 feet. Stripping and further sampling could be done easily, because the overburden is not deep. The chemical analyses show that the high-calcium limestone is suitable for the manufacture of ceramic whiting, finishing lime, mineral filler, pulp and paper, and cement.

Parker Lake District

Hauck Property

NE $\frac{1}{4}$ sec. 28, T. 35 N., R. 43 E.

Location, accessibility, and ownership.—The Hauck property lies $1\frac{1}{2}$ miles north of Parker Lake in the NE $\frac{1}{4}$ sec. 28, T. 35 N., R. 43 E. The property can be reached by driving north from Cusick on State Highway 6 for 8 miles to the Cusick Creek road, thence up the Cusick Creek road a distance of 4 miles to Parker Lake, and $5\frac{1}{2}$ miles to the property of E. F. Hauck of Kennewick, Washington.

Geology.—The property is underlain by rocks of the Priest River Group of Precambrian age, including phyllite, quartzite, greenstone, and limestone (Park and Cannon, 1943). The region is heavily wooded, and outcrops are scarce. Carbonate rocks crop out and show in bulldozer cuts in the NE $\frac{1}{4}$ sec. 28. These outcrops and workings expose light-gray, medium- to coarse-grained, friable dolomite. No limestone was found. Two samples were taken of two of the carbonate rock outcrops. Samples PO-26 and PO-27 were taken by Stearns and Boettcher over a length of 80 feet each. The analyses of these samples are as follows:

Sample no.	Length (feet)	CaCO ₃	MgCO ₃	Loss on Ignition	CaO	MgO	SiO ₂	R ₂ O ₃	P ₂ O ₅
PO-26	80	46.21	37.95	36.29	25.96	18.16	19.29	0.52	0.060
PO-27	80	55.91	44.52	46.37	31.41	21.30	0.26	0.26	0.003

The analyses show that the rock sampled is dolomite and silicified dolomite, not limestone.

STEVENS COUNTY

LIMESTONE IN THE BOUNDARY, LEADPOINT, SPIRIT, AND DEEP LAKE

QUADRANGLES OF NORTHERN STEVENS COUNTY^{1/}

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I n t r o d u c t i o n

The geology of the Boundary, Leadpoint (Yates and Robertson, 1958), Spirit, and Deep Lake (Yates and Ford, 1960) quadrangles in northern Stevens County were recently mapped by the writer assisted by J. F. Robertson, A. B. Ford, H. F. Albee, and P. M. Blacet. Much of this area is underlain by Paleozoic marine sedimentary rocks that include substantial thicknesses of carbonate rocks, including both limestone and dolomite, some of which may be of commercial value. No sampling or detailed examination of the limestone unit was undertaken, mainly because the primary objective of the mapping was an understanding of the lead-zinc deposits that occur throughout the area. The limestone units were mapped (pl. 3), however, and a semiquantitative appraisal was made of their compositions. Although this does not lead to definitive judgments on the commercial possibilities, it does delimit areas where prospecting for limestone might be fruitful.

All the sedimentary rocks, which range from Precambrian to probably Carboniferous in age, are mildly to strongly metamorphosed, intensely folded and faulted, and intruded by granitic rocks of Cretaceous age and mafic and felsic dikes of probable Tertiary age. This history of strong deformation, igneous intrusion, and metamorphism introduced factors that influence the commercial usability of the limestone, and accordingly must be considered in any description of the limestone resources of the area.

G e n e r a l G e o l o g i c R e l a t i o n s

The area is divided into two parts by the east-west trending granodioritic mass of the Spirit pluton, an offshoot of the Kaniksu batholith. Most of the limestone and dolomite is in the larger area of sedimentary rocks north of the pluton; the relatively small fringe of sedimentary rocks south of the pluton and within the map area contains much less limestone. Some carbonate units shown along the south border of the map extend for several miles southwestward toward Colville. North of the pluton, the sedimentary rock assemblages are separated into two groups by the northeastward-trending Leadpoint fault. The rocks southeast of the fault record the

^{1/} Publication authorized by the Director, U.S. Geological Survey

same major periods of carbonate deposition as those to the northwest, but equivalent units differ in both composition and thickness and accordingly must be considered separately.

The major episodes of carbonate deposition occurred during the Cambrian, but minor periods occurred both before and after the Cambrian. Carbonate units younger than Cambrian occur only in the area northwest of the Leadpoint fault. These younger units consist of widely spaced, thin, or discontinuous limestones in a stratigraphic sequence in which fossils have not been found. The best evidence indicates that they are younger than Devonian and older than Permian. Carbonate rocks believed to be older than Cambrian occur only south of the batholith in the Deep Lake quadrangle and are not commercially significant. Neither the Precambrian nor post-Cambrian rocks are shown on plate 3.

The sedimentary history of the early Paleozoic rocks of northeastern Washington was outlined by C. F. Park, Jr., and R. S. Cannon, Jr. (1943, p. 11-22), who described in chronologic sequence the rocks of the Metaline quadrangle, which lies immediately east of the map area. They considered Cambrian sedimentation as probably beginning with the deposition of a shale, the Monk Formation of Daly (1912, p. 146-147). This formation, the uppermost part of which is locally limestone, grades upward into the Gypsy Quartzite (Park and Cannon, 1943, p. 13-15), which in turn grades through a transitional limestone unit into the Maitlen Phyllite (Park and Cannon, p. 15-17). The Maitlen Phyllite grades into a thick limestone-dolomite assemblage, the Metaline Formation (Park and Cannon, p. 17-19), which is the last representative of Cambrian sedimentation, as this formation is conformably overlain by the Ledbetter Slate of Ordovician age (Park and Cannon, p. 19-22).

All the above Paleozoic formations, with the possible exception of the Monk, are present in the map area (pl. 3). The oldest positively identified rock unit in the map area is the Gypsy Quartzite, the base of which is not exposed. This quartzite is shaly in its upper part and grades upward into the Maitlen Phyllite, the metamorphic equivalent of a shale that has a thickness of about one mile. The limestone that occurs within the transition zone between quartzite and phyllite is tentatively correlated with the Reeves Member of the Laib Formation (equivalent to the Maitlen Phyllite) (Fyles and Hewlett, 1959, p. 25; and Green, 1954, p. 12) of southern British Columbia. This limestone, following local usage, is called informally the Reeves limestone zone. It consists of a single unit southeast of the Leadpoint fault and three limestone units separated by schistose phyllite northwest of the Leadpoint fault. The Maitlen Phyllite contains a few thin interbedded limestones that are rarely more than 10 feet thick on the southeast side of the Leadpoint fault. On the northwest side of the fault, the Maitlen also contains several limestones, which are as much as 100 feet thick. These limestone units within the Maitlen Phyllite are not shown on plate 3 because they are relatively impure, thin, or remote from roads.

The Maitlen Phyllite grades upward into the thick limestone-dolomite section of the Metaline Formation. The typical section of the Metaline Formation in the Metaline, Boundary, and Spirit quadrangles consists of a lower limestone unit, a middle dolomite unit, and an upper limestone unit. The upper limestone is succeeded sharply by the black slates of the Ledbetter Slate. The change from the deposition of carbonate rocks to black shale, as

well as the lithology of the Metaline Formation, however, is not the same in the Leadpoint quadrangle (southeast of the Leadpoint fault) as it is to the east and west. In the Leadpoint quadrangle, the Metaline section consists of the same lower limestone unit and the same middle dolomite unit; but this middle unit, instead of being followed by limestone, grades upward into an intraformational dolomite breccia that in turn is followed by limy shales, impure limestone, and more dolomite breccia. The uppermost rock, a dolomite, grades rapidly by cyclic change into the Ledbetter Slate of Ordovician age.

These black slates of the Ordovician age appear to have been overlain by a thick assemblage of rocks that are predominantly fine-grained clastics, black to gray in color. Near the base of this assemblage are a few lenses of limestone of possible Devonian age, and near what appears to be the upper part of the assemblage are a few thin limestone and greenstone units that conceivably could be equivalent to Permian rocks found farther west in Ferry County and to the northwest in British Columbia. Such tenuous evidence as this suggests that these rocks are Carboniferous, a conclusion that as yet has no fossil support. The structural relations between rock units in this assemblage are so complex that no sequential arrangement is possible now. The overall unity of lithology, however, indicates that they belong to the same general period of sedimentation and are quite closely related. The assemblage does contain a few limestone units, which are not described here because they either are of doubtful purity or are thin or discontinuous, and for the most part are difficult of access.

The Paleozoic sedimentary rocks were folded and faulted before intrusion of the Spirit pluton. The general structural trends resulting from this deformation are northeasterly. Many faults, however, trend in other directions; some northward, others northwestward, and a few eastward. The fault pattern, consequently, is complex, but because the major faults are fairly widely spaced, fault terminations of potentially commercial limestones would not seriously restrict their exploitation. However, minor faults, with displacements of 100 feet or less, are abundant and might complicate quarry operations.

Other common structural features are joints across the bedding and shears near the plane of bedding. These vary greatly in distribution, continuity, and spacing. In general, the limestones and dolomites are too well bedded to yield large blocks for building stones, although the possibility of finding material suitable for such use should not be ruled out.

Another structural feature important to the exploitation of a limestone is attitude of the bedding and its relation to topography. Bedding attitudes of the limestone are steep, in general ranging from 30° to vertical and averaging about 60° . Any particular limestone unit commonly is exposed along its strike through a range in elevation largely determined by the local relief, which is commonly between 1,000 and 2,000 feet. This favorable exposure is the result of the steep dip, steep topographic slopes, and the discordance between topographic and bedding trends.

Thermal metamorphism and hydrothermal alteration locally caused changes in mineral composition and texture of the carbonate rocks. The metamorphism is related to the Spirit pluton, which is surrounded by an aureole of metamorphosed rocks. North of the pluton, carbonate rocks are metamorphosed

through a distance of about one mile; to the south, the metamorphic aureole extends for an unknown distance beyond the map border. Hydrothermal alterations produced areas of dolomitized and silicified limestone, which are irregularly distributed and not particularly abundant.

As a result of the thermal metamorphism, the limestone and dolomite were recrystallized to rocks of larger grain size and interlocking textures. Locally, marbles were developed. The principal compositional changes resulting from the metamorphism are the formation of calcium and magnesian silicates—mainly diopside, tremolite, and forsterite, and, less commonly, wollastonite. Iron minerals are uncommon and rarely occur more than 100 feet from the pluton. The development of the silicates is highly irregular, apparently depending upon the original silica content of the carbonate rocks, the local introduction of silica from the magma, and possibly upon the migration and reconcentration of original silica in the carbonate rocks. At many places within the metamorphic aureole, both limestone and dolomite show no effects of metamorphism other than recrystallization. Apparently these rocks are essentially free of original quartz and were not enriched by silica from outside sources either before or during metamorphism.

Some silica was introduced into the carbonate rocks by hydrothermal solutions genetically related to the lead-zinc deposits. This silica may be related in time of emplacement and origin to that introduced into rocks of the metamorphic aureole, although it occurs far from any known exposures of granitic rocks. It is not restricted to the metallized areas but is most abundant there, where it occurs as quartz in veinlets along joints and other openings and as irregular replacements of the carbonate rock.

Dolomitization was the only other alteration process that made any significant changes in original compositions of the limestones.^{2/} Although dolomite is abundant in the area, dolomites formed by hydrothermal alteration are relatively rare, certainly not nearly as common as they are in the neighboring Metaline quadrangle. The dolomite shown on plate 3 is believed to be primary, that is, a product of the environment of deposition and not the product of post-orogenic hydrothermal alteration. Hydrothermal dolomite, which is not shown on plate 3, has a spotty and highly irregular distribution and rarely extends for more than a few score feet in any direction. Although it may be related to the lead-zinc deposits, it is not always associated with them; as much hydrothermal dolomite occurs away from the deposits as near them. Veinlets of dolomite cutting the carbonate rocks are rare; veinlets of calcite cutting both limestone and dolomite are very common.

However, it cannot be said with assurance that large areas of limestone have completely escaped dolomitization by hydrothermal solutions. Conceivably, minor enrichments in magnesia could have escaped detection by the field methods used to distinguish between calcite and dolomite; however, laboratory checks on collected specimens confirm the field determinations and

^{2/} During the field work, the carbonate rocks were constantly tested with dilute hydrochloric acid. Admittedly, this test is crude, giving only a rough approximation of the calcite content of a limestone; nevertheless, it adequately indicates those rocks that have a high magnesia content. As a check on the field determinations, all specimens of carbonate rock that were collected were treated with copper nitrate, which selectively stains the calcite a bright blue.

support the conclusion that most rocks mapped as limestone contain, on the average, probably less than 5 percent magnesia. Exceptions to this generalization will be pointed out in the descriptions of individual units. It must be emphasized that the commercial value of rocks described as limestone can be determined only by careful sampling and chemical analysis, work that was beyond the scope of the project from which this information is drawn.

D e s c r i p t i o n s o f t h e
M o r e I m p o r t a n t L i m e s t o n e U n i t s

Reeves Limestone Zone

In the area southeast of the Leadpoint fault, the Reeves limestone zone occurs on both flanks of an anticline whose axis trends arcuately southwestward from the southeast corner of the Leadpoint quadrangle to the Spirit pluton. Both flanks of the anticline are compressed into minor synclines segmented by faults. Despite the folding and faulting, the Reeves is a fairly continuous unit. Where unfaulted, its thickness ranges from 300 to 400 feet. Its contact with the underlying interlayered phyllite and quartzite is sharp; its contact with the overlying phyllite is cyclic, thin layers of limestone alternating with phyllite through a stratigraphic interval of more than 100 feet.

The limestone is a creamy white, medium- to coarse-grained rock that has fair to poor bedding and a pronounced shear cleavage. Locally, it is banded white and gray, but the banding persists for only short distances along the strike. In places it is faintly mottled with pinkish-buff mottles in a white background. The mottles consist of light-tan dolomite crystals set in a calcite matrix. Quartz in both rounded grains and clusters of irregularly shaped grains is the other common impurity. Although no analyses are available, the silica content appears to range from less than 1 percent to about 10 percent. White mica, which ranges from a trace to about 1 percent, is present along some shear planes.

In the area northwest of the Leadpoint fault, the Reeves limestone zone occurs in three discrete units. The two lower units range in thickness from 50 to 200 feet. The upper unit is nowhere present in its entirety, but a thickness of about 1,000 feet can be measured along the county road 1 mile south of Cedar Lake. The variations in thickness may be partly depositional, but most likely they are principally structural. Bedding is somewhat better preserved than in the Reeves limestone zone southeast of the Leadpoint fault.

Impurities are the same as those in the Reeves limestone zone southeast of the Leadpoint fault; however, dolomite appears to be less abundant and white mica more abundant. Analyses of five grab samples taken from the units on Red Top Mountain show a considerable range in composition. They do not necessarily even approximate the average composition of the unit sampled. Silica ranges from 1.2 to 9.2 percent; total iron as Fe_2O_3 , from 0.02 to 0.92 percent; combined Na_2O and K_2O , from 0.09 to 0.34 percent; MgO , from 0.72 to 8.8 percent; and CaO , from 43.8 to 54.2 percent (as determined by Rapid Rock Analysis, U.S. Geological Survey, Washington, D.C.).

Metaline Formation

Lower member.—The lower member of the Metaline Formation is the thickest limestone unit in the area; nevertheless, it is not particularly promising as a source of high-quality limestone, but it is the same stratigraphic member of the Metaline from which limestone is quarried for the cement plant at Metaline Falls. It should not be overlooked in prospecting, for careful sampling might show that parts of it meet commercial specifications.

Large areas on both sides of the Leadpoint fault are underlain by the lower member of the Metaline Formation. Nowhere on the southeast side is there a complete unfaulted section of this member; however, the stratigraphic relations with overlying and underlying rocks can be observed. Its thickness is between 5,000 and 10,000 feet but may be exaggerated by unrecognized structural duplication. Northwest of the Leadpoint fault the thickness is much less, probably nowhere more than 1,200 feet. On both sides of the fault the limestone grades into the underlying Maitlen Phyllite and has a fairly sharp contact with the overlying dolomite member of the Metaline Formation.

On both sides of the Leadpoint fault the lower member is typically a fine-grained dark-gray limestone, indistinctly and discontinuously bedded with buff dolomitic limestone. The overall appearance is that of a mottled rock, with the amount of buff mottles highly variable but commonly much less than the background of dark-gray limestone. The relative purity of any area of limestone appears to be largely a function of the abundance of the mottles, which contain, besides predominant calcite, variable amounts of quartz, dolomite, white mica, and limonite. The mica may make the rock unfit for uses which require limestone with a low alkali content.

The above-described rock constitutes the lower member of the Metaline Formation in most areas where this member was mapped, but the area northeast of Leadpoint contains, in addition to this rock, varieties that were not found elsewhere. Most of this area is underlain by typical mottled limestone, but intercalated with it are at least one and possibly two units of black dolomite from 100 to 300 feet thick and several subunits of thin-bedded limy shale.

Upper member.—An upper limestone member of the Metaline Formation is found only northwest of the Leadpoint fault. This member is confined to a belt that extends from the Deep Creek valley southwestward to the Spirit pluton at Stoddard Mountain. The structure of the belt is that of an overturned limb of a fold dipping steeply to the southeast.

The upper member is a light-gray to white, medium- to coarse-grained limestone that has a maximum thickness of about 2,000 feet. Its contact with the black slates of the Ordovician is sharp; its contact with the middle dolomite member of the Metaline is also sharp. Bedding is apparent through color variations; in many places it was destroyed during recrystallization and resulting migration of the pigmentsing material.

Impurities are dolomite, quartz, and white mica. The dolomite occurs as irregular and discontinuous replacements near the base and top of the unit and as 1- to 3-inch lenses erratically distributed through the limestone. Quartz occurs as angular grains singly and in clusters, as veinlets,

and as small nodules, which are probably recrystallized chert. Mica occurs as thin flakes along bedding and cleavage planes, and where abundant, gives a sheen to these planes. Although no analyses of this rock are available to the writer, field inspections show evidence that much of it is not of commercial quality. The impurities, however, vary considerably in amount, so it is very possible that the unit may contain commercial limestone deposits.

On the southeast side of the fault, the rocks above the lower limestone member are predominantly dolomite. The dolomite section contains a small amount of limestone, which is not thick enough to separate as a member and is too inferior in quality to describe as a potential source of commercial limestone.

Limestones of uncertain stratigraphic position.—In the southern part of the map area (pl. 3), on the west side of the South Fork of Deep Creek above the Goldfield mill, are several closely associated limestone units that have not yet been satisfactorily placed in the stratigraphic succession. The best evidence suggests that they belong to the Monk Formation (Park and Cannon, 1943, p. 11-13), which in the Metaline quadrangle grades into the overlying Gypsy Quartzite. The possibility that they are stratigraphically equivalent to the Reeves limestone zone has not been eliminated, however.

The limestone units, which range from 50 to about 700 feet in thickness, are separated by units of quartzitic schist of comparable thicknesses. All these limestone units are white to gray, thin- to medium-bedded rocks with a coarse granular texture, having been recrystallized by heat from the Spirit pluton. The mineral assemblages in the associated schist indicate that the temperature of metamorphism was high enough to form silicates in the limestone, such as forsterite, diopside, and possibly wollastonite, provided quartz was present. These minerals are not conspicuously present, however, so it can be inferred that the limestone is low in magnesia and low in silica unless, of course, temperatures were too low to form wollastonite. Because of an easily accessible location, these limestones deserve prospecting.

(End of report by Yates)

Deep Creek District

The carbonate rocks of the Deep Creek district, Stevens County, have been mapped (Yates and Robertson, 1958; Yates and Ford, 1960), and their distribution is illustrated in plate 3 of this report. Hodge (1938, p. 122) has the following to say about the Deep Lake area:

A large area of limestone extends from Deep Lake (Stevens County) northward to the international boundary, a distance of 10 miles, and has about the following composition:

SiO ₂	1.76	MgO	Trace
Al ₂ O ₃ , Fe ₂ O ₃	Trace	CaCO ₃	98.85
CaO.....	55.37		

Hodge does not tell of the kind, number, or locations of samples that led him to make this statement. In the light of recent work, it is quite certain that the quantity of high-quality limestone is much

smaller than might be inferred from Hodge's report. The area referred to by Hodge, some 50 square miles, is shown by Yates (pl. 3) to contain at least four mappable carbonate rock units. The composition varies widely between units and within individual units. An idea of the potential value of these carbonate rocks as sources of high-calcium limestone can be obtained from Yates' discussion of them (p. 61-67) and by reference to the "Explanation of Rock Units" of the quadrangle geologic maps by Yates and Robertson, and Yates and Ford.

The time and effort devoted to estimating the possible worth of these rocks was determined by:

- (1) the limited time available;
- (2) the probability of there being limestone of high quality, as determined by reference to the geologic maps and by conversations with R. G. Yates;
- (3) the relative inaccessibility of most of the carbonate rock outcrops; and
- (4) to a minor degree, the author's familiarity with carbonate-bearing terrain in the Spirit quadrangle.

With these limitations in mind, examinations were confined to the lower member of the Metaline Formation in sec. 5, T. 39 N., R. 42 E., and in secs. 10 and 11, T. 39 N., R. 41 E.; the Reeves limestone zone 1 mile south of Cedar Lake; and the middle member of the Metaline Formation near Aladdin 1 mile south of the Goldfield mill (pl. 3).

The outcrops of the lower limestone member of the Metaline Formation were found to be composed of dark-gray fine-grained medium-bedded impure limestone. The impurities are numerous streaks, lenses, and thin beds of brown-weathering dolomitic limestone, argillaceous limestone, and phyllite. The rocks appear to be very similar to those cropping out for several miles northeast of Colville. Sampling in the Colville area (e. g., Pinkney City, p. 167) has established that these rocks are much too impure to be of any value for most uses. The impure limestone of sec. 5, T. 39 N., R. 42 E., and secs. 10 and 11, T. 39 N., R. 41 E., was not sampled.

The purest limestones found in the Boundary-Leadpoint-Spirit-Deep Lake quadrangles area are close to good roads and are discussed in detail below.

Cedar Lake Deposit

Sec. 35, T. 40 N., R. 41 E.

Location, accessibility, and ownership.—Limestone crops out along the Deep Lake-Boundary road about halfway between Leadpoint and Cedar Lake (fig. 12) in the $SE\frac{1}{4}$ sec. 35, T. 40 N., R. 41 E. The limestone is exposed in small road cuts and for a quarter of a mile to the east and up to altitudes of 350 feet above the road. Most of the limestone is in the $N\frac{1}{2}SE\frac{1}{4}$ sec. 5, on property owned by Herman E. Cusic, of Colville. It extends for a short distance into the $SE\frac{1}{4}SE\frac{1}{4}$ sec. 5, on property owned by Vallie L. Van Sickle, of Colville. The closest railroad facilities are at Northport.

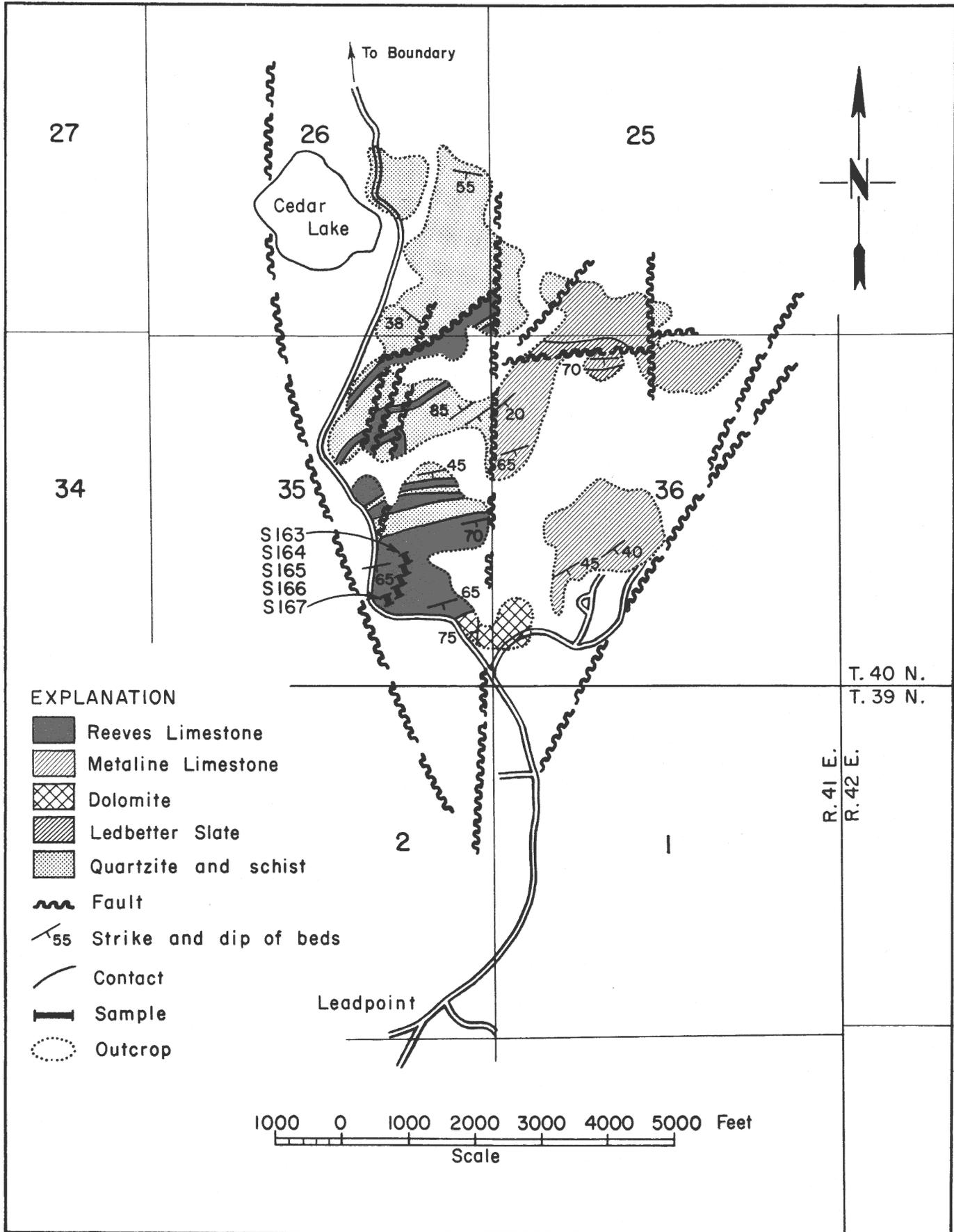


FIGURE 12.—Cedar Lake deposit. Secs. 25 and 35, T. 40 N., R. 41 E. Map modified from U.S. Geological Survey preliminary geologic map of the Leadpoint quadrangle, Stevens County, by R. G. Yates and J. F. Robertson, 1958.

Geology.—The limestone is part of the Reeves limestone zone mapped by Yates (fig. 14) and described by him as "a creamy white, medium- to coarse-grained rock that has fair to poor bedding and a pronounced shear cleavage . . . white mica, which ranges from a trace to about 1 percent, is present along some shear planes." Bedding strikes range from N. 75° E. to N. 80° E., and dips range from 55° to 80° S. The limestone outcrop is bounded on the east, south, and west by alluvium and major faults beneath the alluvium. On the north the limestone is in contact with chlorite-sericite schist (fig. 12). The true thickness of limestone exposed is approximately 1,000 feet.

Quality and quantity of limestone.—Five samples (S-163 to S-167, inclusive) were taken across the strike of the bedding for a combined horizontal sample length of 488 feet (fig. 12). They are believed to be representative of a true thickness of approximately 450 feet, or almost one-half of the total thickness of limestone exposed. The rock sampled is a white to cream white, medium- to coarse-grained, well-bedded limestone. It contains a few muscovite phyllite and moscovite schist laminae as much as one-eighth of an inch thick, but usually much thinner. The analyses of these samples are as follows:

Sample no.	Length (feet)	CaCO ₃	MgCO ₃	Loss on Ignition	CaO	MgO	SiO ₂	R ₂ O ₃	P ₂ O ₅	Na ₂ O (ppm)	K ₂ O (ppm)	TiO ₂ (ppm)	S (ppm)
S-163	100	96.92	1.69	43.48	54.45	0.81	0.37	0.36	0.007				
S-164	100	95.03	3.80	43.71	53.39	1.82	0.43	0.43	0.004				
S-165	88	95.84	2.88	43.74	53.84	1.38	0.34	0.37	0.004	135	490	-30	63
S-166	100	94.29	3.80	43.84	52.97	1.82	0.53	0.50	0.005				
S-167	100	97.03	1.82	43.67	54.51	0.87	0.46	0.40	0.004				

The samples and analyses show that the rock is a high-calcium limestone containing, on the average, 53.83 percent CaO, 1.34 percent MgO, 0.43 percent SiO₂, 0.51 percent R₂O₃, and 0.005 percent P₂O₅. The limestone is pure enough for use in the manufacture of pulp and paper, and as a mineral filler. It is also suitable for the manufacture of portland cement. There is estimated to be 25 million tons of high-calcium limestone above the level of the road in the SE $\frac{1}{4}$ sec. 35, T. 40 N., R. 41 E.

Aladdin Deposit

Sec. 29, T. 38 N., R. 41 E.

Location, accessibility, and ownership.—A hill of limestone 1 mile long and $\frac{1}{4}$ mile wide lies in the valley of the South Fork of Deep Creek, 2 miles north of Aladdin, in secs. 29 and 32, T. 38 N., R. 41 E. The summit of the hill (altitude 2,633 feet above sea level) is $\frac{1}{4}$ mile west of the Aladdin road, 22 $\frac{1}{2}$ miles northeast of Colville. Access is gained easily from Colville or from Spirit, at the junction of the Aladdin road and the Northport-Deep Lake road, 5 miles to the north. Limestone of high purity crops out in the SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 29, T. 38 N., R. 41 E., on property listed in county records as U.S. land. The closest railroad facilities are at Northport and Colville.

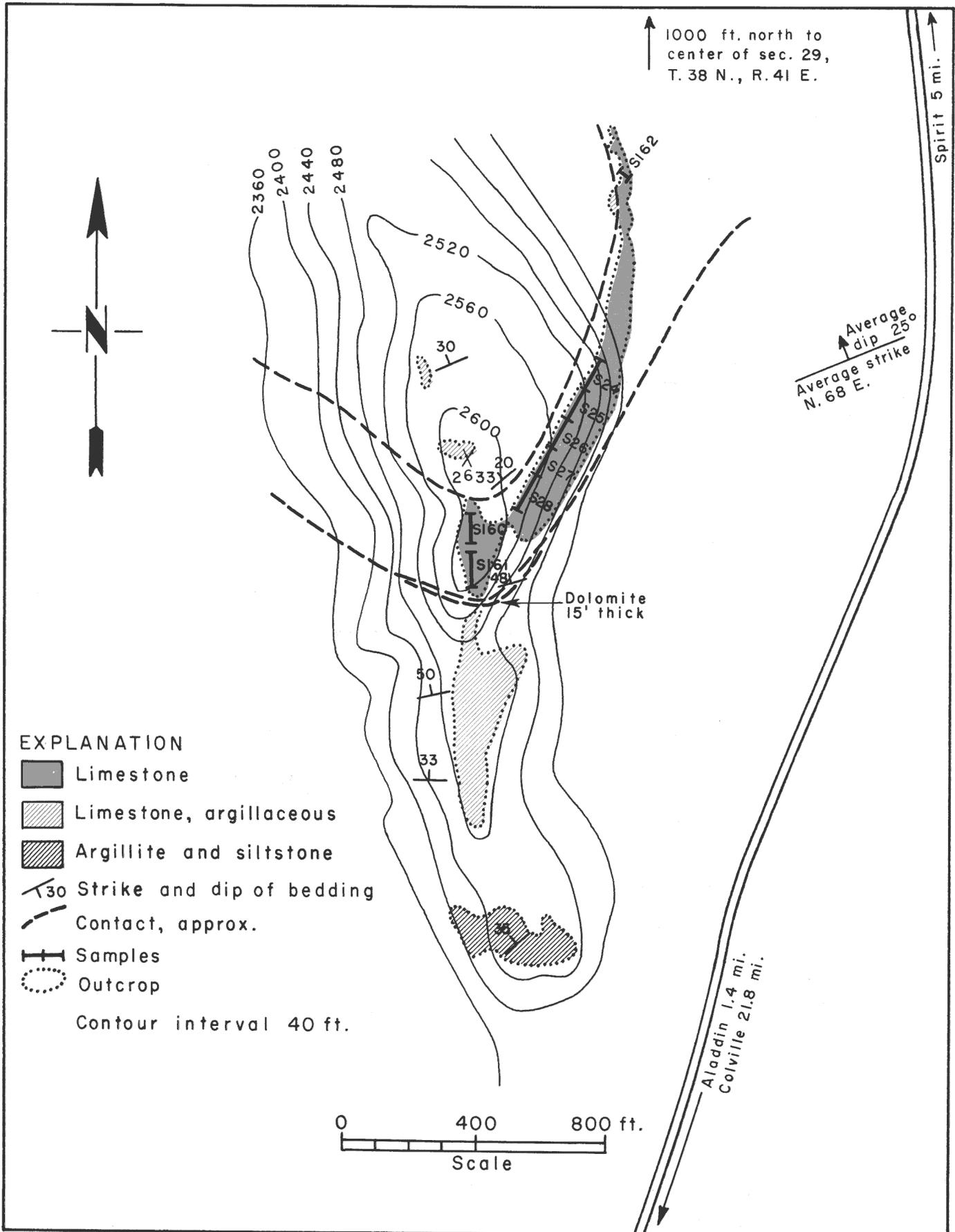


FIGURE 13.—Aladdin deposit. Secs. 29 and 32, T. 38 N., R. 41 E. Geology by J. W. Mills, C. E. Stearns, and R. D. Boettcher. Base from aerial photo enlargement. Topography from U.S. Geological Survey Spirit quadrangle map.

Geology.—Most of the hill is heavily wooded and has no outcrops. The best bedrock exposures are along the crest of the ridge for a quarter of a mile south from the summit and in a vertical rock face, as much as 80 feet high and a quarter of a mile long, along the east side of the hill facing the Aladdin road (fig. 13). Weaver (1920) mapped this as Old Dominion Limestone (Paleozoic). Yates shows (pl. 3, this report) the rocks to be part of the lower limestone member of the Metaline Formation and hence Middle Cambrian in age. In the legend of their map of the Leadpoint quadrangle, (Yates and Robertson, 1958) the lower member of the Metaline Limestone is described, in part, as follows:

Medium- to dark-gray, fine-grained, thick-bedded limestone, and finely mottled gray- and buff-weathering limestone . . . with intercalated thin beds of gray, limy to argillaceous phyllite and minor amounts of mica schist . . . Bedding indistinct and discontinuous.

The sedimentary rocks of the Aladdin hill have strikes that range from east to northeast and dips that range from 20° to 50° N. The average strike is N. 68° E., and the average dip is 25° N. The strike of the bedding is almost directly across the direction of elongation of the hill, so that the rocks composing the southern outcrops are older and lower in the sedimentary section than those composing the northern outcrops. The oldest rocks, exposed along the hill crest south of the summit, are dark- and light-gray thin-bedded argillites and siltstones, somewhat hornfelsed. They are overlain by dark-gray fine-grained thin-bedded limestone and siliceous limestone interbedded with lesser amounts of dark-gray argillite and siltstone. Above this impure dark-gray limestone, and separated from it by a bed of white fine-grained dolomite 15 feet thick, is a section of relatively pure light-gray coarse-grained limestone 160 feet thick. It is this limestone that is of potential value. Overlying it is an unknown thickness of dark-gray fine-grained argillaceous limestone, too impure to be of any interest in this study.

Quality and quantity of limestone.—The limestone of interest is the 160-foot-thick section between the older and younger argillaceous limestone units. It is a light-gray, medium- to coarse-grained, massive limestone. The slightly weathered rock in place and in large blocks on the talus slope on the east side of the hill is not very coherent. Most specimens can be broken easily by a hammer blow into a calcite "sand" composed of crystals of white and light-gray calcite up to an eighth of an inch in diameter. The more weathered specimens, though appearing quite firm, can be easily crushed in the hand to a calcite "sand." Many specimens, when freshly broken, have a fetid odor. Freshly broken unweathered surfaces display numerous sparkling calcite crystal and cleavage surfaces.

Representative samples are not obtained easily, because of the thin soil cover at the ridge crest, where samples S-160 and S-161 were taken, and the very steep nature of the outcrop along the east side of the hill. Samples S-160 and S-161 were taken for horizontal lengths of 100 feet and 115 feet, respectively. It was difficult to break sample pieces from the smooth outcrop here. Furthermore, the thin soil cover prevented the selection of sample pieces at regular intervals and may be responsible for some contamination by soil particles. Nevertheless, these two samples are believed to be reasonably representative of the entire thickness of limestone. Samples S-24 to S-28 were taken continuously over a combined length of 500 feet along the top of the limestone cliff. They were taken nearly parallel to

the upper contact of the limestone (fig. 13), so that they are representative of probably no more than 30 feet of true thickness. Terrain roughness and thick brush prevented sampling at the base of the cliff, and the cliff face is much too steep to sample. Examination of small parts of the south end and the base of the cliff revealed the rock to be identical in appearance with that sampled from S-24 to S-28. One sample, S-162, was taken down the cliff face, near its northern end where it is much less steep, for a length of 50 feet. This sample is representative of a true thickness of 45 feet of the upper part of the limestone unit.

Shedd (1913, p. 160) reports one analysis of white coarse-grained limestone from sec. 29, T. 39 N., R. 41 E. The sample analyses are as follows:

Sample no.	Length (feet)	CaCO ₃	MgCO ₃	Loss on Ignition	CaO	MgO	SiO ₂	R ₂ O ₃	P ₂ O ₅	Na ₂ O (ppm)	K ₂ O (ppm)	TiO ₂ (ppm)	S (ppm)
Shedd	—	—	—	42.50	55.37	trace	1.76	trace	—				
S-24	100	95.14	1.57	42.72	53.45	0.75	1.67	0.70	0.006				
S-25	100	96.40	1.88	43.18	54.16	0.90	0.53	0.32	0.005				
S-26	100	97.10	1.71	43.18	54.55	0.82	0.63	0.29	0.005	235	660	-30	30
S-27	100	95.51	2.03	42.89	53.66	0.97	1.59	0.52	0.005				
S-28	100	98.47	1.09	42.79	55.32	0.52	0.81	0.35	0.004				
S-160	100	92.28	2.99	42.24	51.84	1.43	2.69	1.28	0.014				
S-161	115	94.00	1.92	42.16	52.81	0.92	2.62	1.02	0.004				
S-162	50	95.64	3.28	43.78	53.73	1.57	0.55	0.34	0.003				

Unweighted averages of the sample analyses, excluding Shedd's sample, show the composition to be 53.63 percent CaO (95.46 percent CaCO₃), 0.98 percent MgO, 1.38 percent SiO₂, 0.60 percent R₂O₃, and 0.006 percent P₂O₅. This permits classification of the rock as a high-calcium limestone. In view of what has been said earlier about the possible soil and weathered rock contamination of samples S-160 and S-161, which analyses show to be the least pure, it is believed that the bulk of the limestone contains at least 54 percent CaO, less than 1 percent MgO, less than 1 percent SiO₂, and less than 0.5 percent R₂O₃. The rock meets the chemical specifications for use in the manufacture of builders' lime, pulp and paper, mineral filler, and portland cement.

A sample made up of a composite of samples S-24 through S-28 contained 235 ppm Na₂O, 660 ppm K₂O, less than 30 ppm TiO₂, and 30 ppm S. Sample S-26 analyzed by itself showed 260 ppm Na₂O, 580 ppm K₂O, less than 30 ppm TiO₂, and 30 ppm S.

It is estimated that 1½ million tons of high-calcium limestone is available over the entire length of the cliff face and for a distance of 75 feet northwest of the cliff face. Assuming that the limestone underlying the hilltop continues in thickness and purity, it is conceivable that 11 million tons would be available above the altitude of the Aladdin road. Quarrying operations could be begun easily and advantageously at the north end of the outcrop, 900 feet east of the Aladdin road.

Northport District

In this report the Northport district is defined as the area of northeastern Stevens County that extends for 6 miles downstream and 2 miles upstream from the town of Northport, and for 2 miles on

either side of the Columbia River. Northport is 26 miles in a direction N. 12° E. from Colville and is 6 miles south of the International Boundary. The area is serviced by road (State Highway 22), rail (Great Northern Railway), and water (Columbia River).

Most of the bedrock is of two kinds, argillaceous rocks and carbonate rocks. The argillaceous rocks, which include argillites, phyllites, quartz-mica schists, and argillaceous quartzites, are grouped by Weaver (1920, p. 72) under the name Mission Argillite. The carbonate rocks, called the Northport Limestone (Weaver, 1920, p. 75), include dolomite, dolomitic limestone, and limestone. They vary widely in color from white, to gray, to dark gray, and buff; in texture from fine grained to coarsely crystalline; and in structure from strongly layered and thin bedded to massive and thick bedded. Campbell (1947, p. 600) correlates the Mission Argillite and the Northport Limestone of the Northport region with the Maitlen Phyllite (Lower or Middle Cambrian) and the Metaline Limestone (Middle Cambrian) of the Metaline district.

The argillaceous rocks and the carbonate rocks have been subjected to one or more major periods of folding, so that they strike northeast and dip to the southeast or northwest. Two miles southwest of Northport the folds are so tightly compressed that both fold limbs dip south to the same degree (fig. 16). That is, the folds are isoclinal and overturned toward the northwest. The rocks have been further disrupted by faulting and by igneous intrusion. Three miles south of Northport the metamorphosed sedimentary rocks have been intruded by the Loon Lake Granite batholith (Weaver, 1920), a westward extension of the Kaniksu batholith of Cretaceous age (Park and Cannon, 1943, p. 26). Dikes and sills of andesite porphyry, diabase, and lamprophyre, intruding the metasedimentary rocks and the granite, are believed to be Tertiary in age.

Carbonate rocks (Northport Limestone) are widespread in this and adjoining areas along the Columbia River, but they are all highly dolomitic except in the areas discussed in the following sections of the report.

Janni Quarry Area

Sec. 13, T. 39 N., R. 39 E.

Location, accessibility, and ownership.—The area lies along the southeast side of State Highway 22, from 2½ to 3 miles southwest of Northport. The Janni quarry and mill (fig. 14) are at the edge of the highway, in sec. 13, T. 39 N., R. 39 E., and on a spur of the Great Northern Railway. According to county records, the quarry and the surrounding area (fig. 15) are owned by Peter Janni and Joseph Janni of Northport.

Operation.—The Janni quarry has been in operation since 1900, and over 2 million tons of rock has been mined. Present annual production is approximately 40,000 tons. All rock is hand sorted. The coarser sizes (greater than 8 inches in diameter) are sold to paper mills. Rock ground to smaller chips and to flour is sold for roofing, terrazzo flooring, stucco, plaster, agricultural stone, and as a food additive.

The quarry is approximately 1,200 feet long and is 400 feet wide at its widest point. The lower floor is at an altitude of 1,345 feet above mean sea level, or 33 feet above the Columbia River. The upper quarry floor has an altitude of 1,430 feet. The highest point on the quarry walls is 1,610 feet above mean sea level, or 265 feet above the lower quarry floor. During 1959 the upper quarry was leased to W. Hemphill of Seattle, who shipped 400 tons of crushed limestone per day to the Trail smelter of the Consolidated Mining and Smelting Company of Canada for smelter flux. The flux rock was shipped in 25-ton trucks, although most of the Janni limestone is customarily transported by the Great Northern Railway.

Geology.—The area is one of tightly folded argillaceous and carbonate rocks intruded by narrow dikes and sills of andesite porphyry and diabase, and offset by faults (fig. 15). The fold axes bear



FIGURE 14.—Janni quarry, Northport. View looking east.

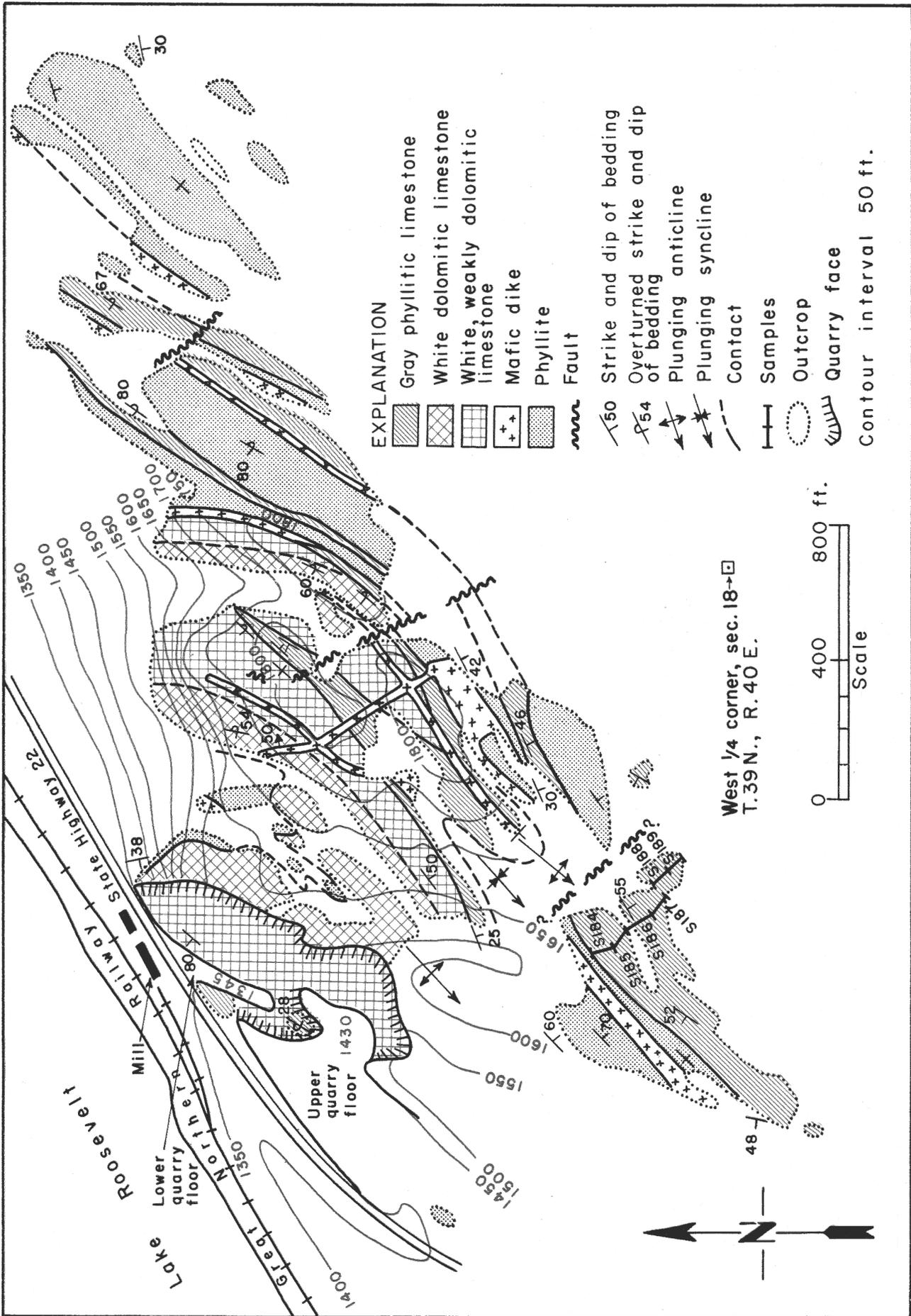


FIGURE 15.—Janni quarry area. Sec. 13, T. 39 N., R. 39 E. Geology by J. W. Mills, C. E. Stearns, R. D. Boettcher, and C. D. Rau. Base from aerial photo enlargement. Topography by plane table and alidade survey.

southwestward and plunge moderately in the same direction. In many places the folds are overturned toward the southeast. The metasedimentary rocks are, from oldest to youngest, sericite phyllite, white limestone, gray limestone, and interbedded phyllite and quartzite with a few gray limestone beds. Bedding and cleavage are well displayed in the argillaceous rocks and facilitate an understanding of the structural complexities.

The gray limestone ranges from fine to medium grained; it is thin bedded and distinctly layered; and it contains as much as 10 percent white mica (muscovite), which imparts a slight sheen to the fresh and gray weathered surface. In a few places the gray limestone beds display excellent drag folds that, like the cleavage in the phyllite, contribute to the unraveling of structural details.

The white limestone has a snow-white to pale yellow-white color on fresh and weathered surfaces; on a fresh surface the fine-grained rock has a pronounced sparkle that is due to light reflecting from the lustrous calcite crystals and cleavage surfaces and from small muscovite flakes that are invariably present in amounts up to 3 percent. The rock is quite massive, and bedding is difficult to recognize. Dolomitization of the white limestone has been partial or complete over large areas (fig. 15). The partially dolomitized rock (dolomitic limestone) can be identified on weathered surfaces by the weather-resistant lenticles and "knots" of pure dolomite. The highly or completely dolomitized limestone does not effervesce in 1:15 HCl, and its weathered surface displays the typical lined and jointed "elephant-hide" texture.

The rock quarried is a white to pale yellow-white, fine- to medium-grained, massive, slightly dolomitic limestone. A few dark-colored igneous rock dikes, as much as 18 inches thick, intrude the limestone. Poorly preserved bedding strikes northeast and dips northwest at approximately 80°. Sericite phyllite crops out beneath the limestone 400 feet northeast of the quarry. The quarry is on the northwest limb of an anticline plunging moderately (20°?) to the southwest. The axis of the anticline is 400 feet southeast of the quarry. For 100 feet on each side of this axis the limestone has a considerably higher content of dolomite than has the quarry rock.

Quality and quantity of limestone.—No samples of the Janni white limestone were taken during this study, because analyses of samples taken by former workers are available. Shedd (1913, p. 155) reports the following analysis of a sample from this quarry: 93.3 percent CaCO_3 , 52.25 percent CaO , 2.92 percent MgO , 1.98 percent SiO_2 , and 0.40 percent R_2O_3 . Rock taken from the quarry in 1938 was reported (Hodge, 1938, p. 117) by the operators to contain 96.0 percent CaCO_3 , 2.0 percent MgO (average), and from 0.5 to 1.5 percent SiO_2 . The results of sampling done by the Hecla Mining Company in 1956 were made available to the writer through the courtesy of company officers and Peter Janni. Two samples along the east face of the lower quarry, 225 feet long and 140 feet long, were found to contain, respectively, 94.1 percent and 90.0 percent CaCO_3 , and 2.49 percent and 6.04 percent MgO . Hecla also reports (1959, written communication) that rock sampled over a length of 320 feet along the southeast face of the upper quarry contains 84.6 percent CaCO_3 and 10.5 percent MgO . Further sampling (Hecla) on the west limb of the anticline on which the quarry is located, across

the nose of the fold, and on its east limb showed the rock to contain from 71.8 to 87.7 percent CaCO_3 and from 8.15 to 22.1 percent MgO . Similarly, sampling carried out 1,100 feet southeast of Janni's mill, across 240 feet of white limestone, indicates a CaCO_3 content of 91.0 percent and an MgO content of 5.62 percent.

All the white limestone within a quarter of a mile of the Janni quarry is the same rock unit, repeated by folding. Because of this and because of the magnesian character of those parts that have been sampled and analysed, it is reasonable to conclude that there is no very large volume of high-calcium white limestone here. There remains, in the quarry walls, about 1 million tons of limestone of a grade equal to that quarried until the present time (1960). With careful hand sorting, the quarry can be expected to continue to supply its markets for many years to come. No large-scale operation will ever be possible, because it is impossible to avoid inclusion of dolomitic rock in amounts great enough to make the product unmarketable for uses requiring high-calcium limestone.

Despite the fact that the gray limestone is clearly less pure than the white limestone, sampling the gray limestone was done in order to obtain first-hand knowledge as to its composition. Six samples (S-184 to S-189) were taken across the strike of the bedding on an outcrop approximately 1,000 feet south of the Janni quarry. The analyses of these are as follows:

Sample no.	Length (feet)	CaCO_3	MgCO_3	Loss on Ignition	CaO	MgO	SiO_2	R_2O_3	P_2O_5
S-184	65	85.07	3.80	39.27	47.79	1.82	9.11	2.07	0.030
S-185	75	89.85	4.10	41.56	50.48	1.96	4.59	1.33	0.014
S-186	75	92.67	2.53	42.22	52.06	1.21	3.13	1.18	0.014
S-187	75	91.19	4.08	42.32	51.23	1.95	3.12	1.42	0.018
S-188	80	87.18	5.43	41.46	48.98	2.60	5.11	1.52	0.009
S-189	65	88.25	6.06	41.61	49.58	2.90	4.08	1.40	0.018

The unweighted average composition is 50.02 percent CaO , 2.07 percent MgO , 4.86 percent SiO_2 , 1.49 percent R_2O_3 , and 0.016 percent P_2O_5 .

These analyses show that the rock is unsuitable for cement manufacture or for any use requiring a high-calcium limestone.

Janni Northeast Area
Sec. 7, T. 39 N., R. 40 E.

Location, accessibility, and ownership.—Section 7 is a block of ground of irregular shape owing to the fact that its northern and western limits are outlined by the Columbia River. The section has an area of approximately $\frac{1}{2}$ square mile and it lies about 2 miles southwest of Northport. Its northern edge is crossed by State Highway 22 and the Great Northern Railway. According to county records, the land on which most of the limestone is found is owned by Peter Janni, of Northport.