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PRELIMINARY RESULTS OF A SURVEY FOR THICK HIGH-CALCIUM LIMESTONE DEPOSITS IN THE UNITED STATES

By R. E. Davis, W. P. Williams, R. B. Johnson, and W. L. Emerick

With a section on

POSSIBLE ALASKAN SITES FOR NUCLEAR REACTION EXPERIMENT IN LIMESTONE

By G. Donald Eberlein

Trace Elements Investigations Report 780

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This report is preliminary and has not been edited for conformity with Geological Survey format and nomenclature.

*Prepared on behalf of the U.S. Atomic Energy Commission.

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By G. Donald Eberlein

SUMMARY

Of the many areas that have received preliminary appraisal as potential sites for an underground nuclear explosion in a thick sequence of high-calcium limestone, 10 im the continental United States and 6 in Alaska appear to offer possibilities of meeting the primary criteria of purity and thickness. Field examination of these areas can be undertaken to determine whether they are suitable, but an approximation of the time involved suggests that 6 man-weeks of fieldwork would be required for each field appraisal. Further work would be required to locate sites in any of the areas that proved promising.

INTRODUCTION

The U.S. Geological Survey made a preliminary study of limestone deposits in the United States and Alaska for the purpose of selecting those deposits of sufficient size, relief, and purity in which to conduct an underground nuclear test. The results of this survey, prepared at request of the Lawrence Radiation Laboratory, Livermore, Calif., are presented in this report.

Information on the occurrence, location, geology, and topography of limestone deposits was obtained through search of the literature, including U.S. Geological Survey Bulletin 1019-I, "Annotated bibliography of high calcium limestone deposits in the United States," and from many U.S. Geological Survey geologists whose detailed geologic knowledge of many areas in the United States, as contained in the appendix, aided greatly in completion of the report. Information concerning limestone deposits in Alaska was furnished by G. D. Eberlein of the U.S. Geological Survey.

SITE SELECTION AND EVALUATION CRITERIA

The selection of areas containing possible underground test sites was made using specifications furnished by the Lawrence Radiation Laboratory. These requirements are listed below in general order of significance with comments on the possibilities of their fulfillment.

Requirement 1. Material to be greater than 95 percent $CaCO_3$ (preferably 99 percent).

It is possible to find such pure limestone in thicknesses of several tens of feet at many localities, and, less commonly, a few hundred feet can occur. Great thicknesses of limestone generally include small to large amounts of chert, dolomite, shale, sandstone, and insoluble impurities. A thick limestone composed of more than 95 percent $CaCO_3$ is uncommon.

Requirement 2. Calcite is the preferred medium, although a mixture of calcite and aragonite is acceptable if pure calcite cannot be located. Dolomite will not be considered as a suitable medium.

Requirement 3. Material should have no less than a 2,000-foot interval.

Requirement 4. Depth of burial between 1,000 and 2,000 feet with at least 500 feet of material between zero point and boundary of the limestone.

Requirements 3 and 4 are interpreted to mean that ideal conditions would include 2,000 feet of limestone with 95 percent or greater purity overlain by at least 1,000 feet of material that is not necessarily 95 percent pure limestone. If, however, depth of burial were at the minimum stated (1,000 feet) and the minimum amount of limestone stated (500 feet) surrounded the zero point, it would seem that 500 feet of any material overlying 1,000 feet of limestone would be acceptable.

Requirement 5. The formation shall be compact, massive, and structurally homogeneous.

"Compact" eliminates any limestone that might be cavernous or contain open solution-dissolved joints; "massive" has not been taken literally, as it would rule out thin-bedded deposits; "structurally homogeneous" precludes faulted areas but not areas that contain joints within the effects zone.

Requirement 6. Water content to be less than 10 percent but no active waterflow.

Requirement 7. If possible, tunnel access to the zero site is preferable as it allows the addition of neutron experiments with the least amount of completion.

Requirement 8. The site should be located in terrain which will allow drilling from the surface for the emplacement of instruments.

Topography above the general area should not be too extreme; preferably fairly flat for some distance around zero point.

In general the requirements for such a test site in limestone are highly restrictive. The requirements concerning purity and thickness (requirements 1 through 4) were considered of primary importance, whereas those for water content, structural homogeneity, tunnel accessibility, and terrain (requirements 5 through 8) were considered of secondary importance in that attempts to fulfill them would depend upon local conditions. Such factors as population density, power and other facilities, and land ownership were for the most part disregarded. The selection of an actual test site would require extensive detailed geologic, geophysical, and hydrologic study supplemented by physical exploration.

A primary difficulty encountered in the selection of test areas was the inadequacy of description, specifically, the absences or sparseness of chemical analyses of the limestones. In a broad sense, rocks classified as a limestone must contain greater than 50 percent carbonate minerals and greater than 50 percent of the carbonate fraction must be calcite; thus a very wide range of rocks can be and are properly described simply as limestones, but a limestone that contains more than 95 percent calcite generally forms only a small part of a carbonate rock sequence. Undoubtedly some areas tentatively selected as suitable for underground tests will upon detailed field evaluation prove unsatisfactory. On the other hand, areas deemed unsuited, from the literature search, might contain excellent test sites.

The regions considered in this study are Southeastern United States, Western United States (principally the States west of Colorado), and Alaska. The greatest effort was devoted to study of the limestone deposits in Western United States and Alaska because of low population density, greater areas of bedrock exposure, high relief, and relative low average rainfall. Summarized in table 1 are those areas that, based on the available geologic data, offer the best possibilities for test sites that fulfill most of the requirements set forth on pages 5-7.

Eastern United States

The Northeastern States were not considered because the rocks are structurally complex, the bedrock exposures are poor, and in most areas that contain limestone beds of sufficient purity, the relief is low. In addition, these states have high population density and relatively high average rainfall.

None of the limestone deposits in the Southeastern States meet the specification for 1,000 feet minimum thickness. Most of the uniformly high grade limestone deposits in these States are less than 500 feet thick (B. Gildersleeve, written communication, 1960), and noncontorted high-grade limestone deposits more than 100 feet thick are rare. Part of the Bangor limestone in northwest Georgia is as much as 500 feet thick, at least in part contains 95 to 99 percent $CaCO_3$, and is thick bedded. The Ste. Genevieve limestone is high grade in most places, but it is

Table 1.--Summary of data on high-calcium limestone areas for possible underground test sites in the Western United States

Map number (fig. 1)	Formation (age)	Location	Thickness available (feet)	$CaCO_3$ (percent)
1	Devils Gate limestone (Devonian)	Pequop Range between U. S. Routes 40 and 50 in northeast Nevada	Nearly 2,000	N.A. 1/
2	Highland Peak and Mendha limestones (Cambrian)	East-central Nevada	>4,185	N.A.
3	Bailey Springs limestone (Mississippian, Pennsylvanian, and Permian)	East-central Nevada	2,200-2,300	N.A.
4	Escabrosa and Horquilla limestones (Mississippian and Pennsylvanian)	Southeastern Arizona	Up to 1,500	98 but locally upper part silty and dolomitic.
5	Unnamed (Middle and Upper Devonian) 1/	Central Nevada	6,000±	N.A.
6	Unnamed (Devonian) 1/	Central Nevada	2,000±	A few analyses indicate 95±.

Table 1.--Summary of data on high-calcium limestone areas for possible underground test sites in the Western United States--Continued

Map number (fig. 1)	Formation (age)	Location	Thickness available (feet)	$CaCO_3$ (percent)
7	Madison, Deseret, Humbug, and Great limestone (Mississippian)	Northeast Utah	>4,550	N.A.
8	Great Blue and Humbug limestone (Mississippian)	Bannock Range, Idaho	>1,100	A few analyses indicate >95.
9	Redwall limestone (Mississippian)	Lake Mead-Grand Canyon, Arizona	<1,000	Do.
10	Pole Canyon limestone (Cambrian)	East-central Nevada	±2,000	N.A.

1/ N.A. - no analyses available.

generally less than 1,000 feet thick. Locally in southwest Virginia it is 1,500 feet thick but contains sandstone, shale, and argillaceous limestone.

Western United States

The information obtained from evaluation of 18 areas in Nevada, Montana, Idaho, Texas, Arkansas, Utah, Colorado, Arizona, and New Mexico that are underlain by limestone deposits are contained in the appendix. Of the 18 areas, only 10 (table 1) are considered as warranting further detailed study. In addition to these 16 deposits, information not included in the appendix was obtained on the Devils Gate formation in the Roberts Mountains, the "Great Blue" limestone in the Oquirrh Mountains in Utah, and the Mississippian limestones in the Gold Hill district in Utah. The descriptions of these formations in the literature, however, indicate that excessive amounts of chert, dolomite, silt, sand, and shale are included in the sections. Few or no chemical analyses of these beds are available.

The most favorable areas from the standpoint of high-$CaCO_3$ limestone in required thicknesses are in central and east-central Nevada, northeastern Utah, southeastern Arizona, southwestern New Mexico, and Idaho (table 1 and p. 16-33).

Northeastern Nevada

The Devils Gate limestone (table 1, fig. 1) of Devonian age, between U.S. Highways 40 and 50 in the Pequop Range, is nearly 2,000 feet thick, and in the upper part is massive to thick bedded. No information is available concerning the chemical composition of the

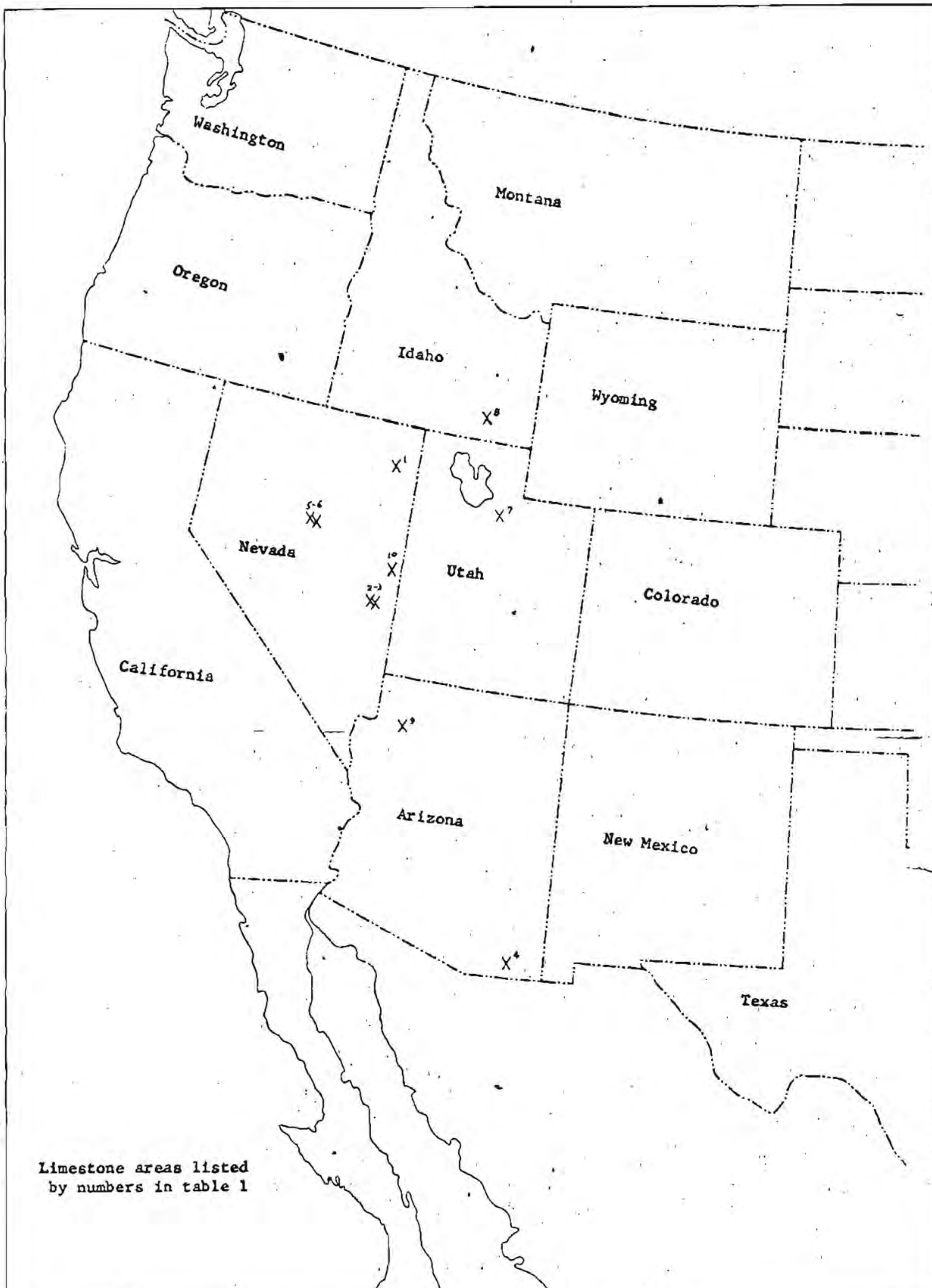

FIGURE 1.--LOCATIONS (X) OF TEN POSSIBLE HIGH-CALCIUM THICK LIMESTONE DEPOSITS IN THE WESTERN UNITED STATES

limestone in this area. The Pequop Range has a steep western front and, consequently, is an area in which minimum tunnel length may provide a maximum vertical cover. The geologic structure of the area is apparently simple; the rocks dip 10° to 15° eastward and are relatively unfaulted.

East-central Nevada

The Highland Peak limestone and Mendha limestone, both of Cambrian age, aggregate a thickness of more than 4,185 feet in east-central Nevada. Modern chemical studies of the formations have not been made for Ca/Mg. From published descriptions the formations appear to be nearly free of silt, clay, and chert; and field and laboratory study may locate a suitable site.

The Bailey Springs limestone of Mississippian, Pennsylvanian, and Permian age averages 2,200 to 2,300 feet thick in the same general area. Published descriptions do not mention dolomite or dolomitic limestone in the section, but note that chert is uncommon. Field and laboratory study may also determine a suitable site.

Southeastern Arizona and southwestern New Mexico

The Escabrosa limestone of Mississippian age is the thickest section of nearly pure limestone about which much is known. A few Ca/Mg ratios suggest that the formation averages 98 percent pure $CaCO_3$. The impure fraction is in the form of lenses of dolomite. Locally, the formation contains no dolomite, but may have as much as 5 percent chert. The Escabrosa averages 650 feet thick. Overlying the Escabrosa limestone is the Horquilla limestone that ranges from

600 feet to perhaps 1,500 feet in thickness. The Horquilla is composed of limestone and silty limestone; locally, the silt may be more than 5 percent of the rock. Generally, the Escabrosa becomes more dolomitic to the west and the Horquilla becomes thicker and siltier to the north and east. It may be possible to find a section where there is no dolomite in the Escabrosa and less than 5 percent silt in the Horquilla, but it would be optimistic to expect more than 1,500 feet of nearly pure limestone in this area. Fieldwork consisting of stratigraphic measurements, mapping, lithologic description, and sampling for Ca/Mg determination would be necessary to locate a site that would meet the specifications.

Nevada Test Site and vicinity

Particular attention was devoted to evaluation of limestone deposits in the Nevada Test Site. From our present knowledge of the general geology of the Test Site, there are no limestone deposits containing a minimum of 95 percent $CaCO_3$ and a minimum of 1,000 feet thick.

Possible limestone areas north and east of the Test Site in the Las Vegas Bombing and Gunnery Range could be explored if thicknesses on the order of 500 feet would be acceptable. The lithology of the carbonate units changes regionally; consequently the limestone section, which is not satisfactory at the Nevada Test Site, may prove satisfactory several miles outside of the Test Site boundary.

There are two localities within and adjoining the Nevada Test Site that contain 500 to 675 feet of nearly pure limestone which should be investigated if the experiment can be scaled down. These are at Banded Mountain and Jangle Ridge.

The southern part of Banded Mountain, on the east side of Yucca Flat, is one of the least faulted localities exposed on the Nevada Test Site. Here, the C and D units of the Yucca Flat formation are 675 feet thick and dip about 40° SW. Unit A of the Yucca Flat formation crops out on Jangle Ridge, 2 miles east of Banded Mountain. This unit is 570 feet thick and dips also southwest, probably about 35° to 40°.

Areas investigated in Western United States for underground site in limestone

Area 1

Central Nevada

Location: Secs. 7, 8, 17, 18, and 19 (unsurveyed), T. 25 N., R. 50 E., Eureka County, Nev.; Horse Creek Valley quad., 15-minute series.

Land ownership: Public Domain and private.

Geologic formation: Unnamed; correlates with Nevada and Devils Gate limestone; Middle and Upper Devonian age.

Analysis: Samples taken by Harold Masursky, U.S. Geological Survey, but no results to date (October 27, 1960).

Water content: Dry.

Interval: ±6,000 feet.

Depth burial: 150 feet of basalt cover.

Structure: Thick-bedded limestone; few scattered faults; average dip 30° E.; locally thin bedded, argillaceous, and dolomitic; 5 square miles of limestone.

Zero site access: Excellent; 650 feet of relief.

Surface drilling: Good.

Other notes: 1:24,000-scale topography available.

Remarks: No additional information at this time.

Source: Harold Masursky (oral communication).

Area 2

Central Nevada

Location: Cortez quad., sec. 16, T. 26 N., R. 48 E., Hill 8220.

Land ownership: Unknown, probably Public Domain.

Geologic formation: Devonian limestone undifferentiated; correlates with Rabbit Hill and Nevada formations.

Analysis: Probably greater than 95 percent $CaCO_3$ in thick-bedded part; less in thin beds.

Water content: Low, nearly dry.

Interval: ±2,000 feet thick; overlies 1,000 feet of thin-bedded Silurian limestone.

Depth burial: Thin colluvium only.

Structure: Two-thirds thick bedded, one-third thin bedded, alternating; scattered faults; average dip 25° SE.

Zero site access: No existing adit; excellent terrain for driving adit.

Surface drilling: Good possibilities.

Remarks: No additional information at this time.

Source: Harold Masursky (oral communication, 1960).

Area 3

Ely, Nevada

Location: Ely No. 3 quad.; Treasure Hill quad.; Hamilton mining district.

Land ownership: Unknown, probably part Public Domain.

Geologic formation: Guilmette limestone; Upper Devonian age.

Analysis: Probably greater than 95 percent $CaCO_3$, but only locally.

Water content: Low; probably nearly dry.

Interval: ±3,000 feet.

Depth burial: None, all Guilmette limestone.

Structure: Three-fifths thick bedded, two-fifths thin bedded, alternating; some faulting.

Zero site access: Excellent; Eberhard tunnel ±1 mile long in Hamilton district.

Surface drilling: Good.

Remarks: Overall purity probably not satisfactory; contains varied amounts of dolomite and chert.

Source: D. R. Shawe (oral communication, 1960); A. L. Brokaw (oral communication, 1960).

Area 4

Northeastern Nevada

Location: Pequop Mountains; off U.S. Route 40 and east of U.S. Route 93, Elko County, Nev.

Land ownership: Unknown.

Geologic formation: Devils Gate limestone; Devonian age.

Analysis: None available..

Interval: Devils Gate may approach 2,000 feet in this area.

Depth burial: Unknown.

Structure: Simple; 10° to 15° eastward; upper part of formation is thick bedded.

Zero site access: Unknown.

Surface drilling: The steep west front of the mountains may have suitable relief.

Remarks: Suitability not known; the limestone would have to be sampled to determine composition; no other information available.

Source: R. J. Roberts (oral communication, 1960).

Area 5

East-central Nevada

Location: Snake Range; Wheeler Peak quad.; about 50 miles southeast of Ely.

Land ownership: Nevada National Forest.

Geologic formation: Pole Canyon limestone; Middle Cambrian age.

Analysis: None available; probably greater than 95 percent $CaCO_3$, at least locally.

Water content: Probably very low.

Interval: About 2,000 feet.

Depth of burial: None.

Structure: Massive; 10° to 15° southwesterly dip.

Zero site access: Good; adit about 8,000 feet in length exists below base of the limestone.

Surface drilling: Perhaps satisfactory; jeep road to top of mountain.

Remarks: X-ray of one specimen shows 2 to 5 percent dolomite and 1 to 2 percent quartz.

Source: Geol. Soc. America Bull., v. 69, p. 221-240, 1958; Harold Drewes (oral communication, 1961).

Area 6

Northeastern Utah

Location: Sec. 27, T. 2 S., R. 3 E., Rock Canyon, Utah County, Utah.

Land ownership: Unknown.

Geologic formation: Madison, Deseret, Humbug, and Great Blue limestones; Mississippian age.

Analysis: None available.

Water content: Unknown; probably dry.

Interval:

Great Blue limestone	- possible	2,800 feet
Humbug limestone	- possible	500 feet
Deseret limestone	- possible	250 feet
Madison limestone	- possible	1,000 feet
Possible total interval		4,550 feet

Depth burial: +1,000 feet Manning Canyon shale; Mississippian and Pennsylvanian age.

Structure: Thick- and thin-bedded limestone; local thin beds of black shale; local cherty limestone.

Zero site access: Good; high relief.

Surface drilling: Unknown; probably feasible.

Other notes: Above location is near Provo, Utah; but other good sites farther away are probably available.

Remarks: No additional information has been found for this locality.

Source: A. A. Baker, 1947, Stratigraphy of the Wasatch Mountains in the vicinity of Provo, Utah, U.S. Geol. Survey Oil and Gas Prelim. Chart 30.

Area 7

Bannock Range, Idaho

Location: 1½ miles southeast of southeast corner of Rockland quad., T. 11 S., R. 34 E., 3½ miles southeast of Pauline, Idaho.

Land ownership: Public Domain.

Geologic formation: Great Blue and Humbug limestones; Mississippian age.

Analysis: 95 percent, or better, $CaCO_3$.

Water content: Probably low.

Interval: 1,100 feet aggregate; Humbug overlain by lower half Great Blue; overlain by 150 feet of shale, overlain by 500 feet cherty limestone.

Depth of burial: ±2,000 feet Manning Canyon, shale and limestone.

Structure: Alternating massive and thick to thin bedded; 40° to 45° easterly dip.

Zero site access: Excellent, adit present.

Surface drilling: Difficult, but probably not impossible; precipitous slopes.

Other notes: Army Map Service NK 12-4, series V5402.

Remarks: Looks good, but no additional information available.

Source: D. E. Trimble (oral communication, 1960).

Area 8

South Lemhi Range, Central Idaho

Location: T. 7 N., Rs. 29 and 30 E., Butte County, Idaho; 25 miles northeast of Arco.

Land ownership: Challis and Targhee National Forests.

Geologic formation: Brazer limestone; probably of Mississippian age.

Analysis: 96.13 percent $CaCO_3$.

Water content: Probably low.

Interval: Up to 10,000 feet.

Depth burial: Local cover of Wood River formation; calcareous quartzite.

Structure: Locally contorted; folds, some thrusts; basal 300 to 500 feet is thin bedded and siliceous; upper Brazer in beds 1 to several feet thick; scattered existing mines.

Surface drilling: May be locally difficult; precipitous slopes.

Other notes: AMS Idaho Falls, NK 12-1; AMS Dubois, Idaho, Montana, NL 12-10; Geol. Soc. America Bull., v. 58, no. 12, pt. 1; check northeast side of Saddle Mountain for less deformed rocks.

Remarks: Probably not satisfactory; contains dolomite, shaly and silty beds, etc.

Source: C. P. Ross (oral communication, 1960).

Area 9

West-central Montana

Location: ±28 miles southwest of Butte; secs. 5, 17, and 18, T. 2 S., R. 10 W.; Ore Camp Hill, Beaverhead County, Mont.

Land ownership: Beaverhead National Forest.

Geologic formation: Madison group; Mississippian age.

Analysis: 94.05 percent $CaCO_3$; (only locally).

Water content: Low.

Interval: 1,270 feet; 500 to 600 feet exposed.

Depth burial: Variable, depending on location; not great.

Structure: Steep dips; folding and thrusting; possible shattering.

Zero site access: Good terrain for adit; existing mines in vicinity.

Surface drilling: Good access.

Other notes: Army Map Service, Dillon, Mont.-Idaho, NL 12-7; Divide 3, Montana quad. 1:48,000; photographic coverage.

Remarks: Not satisfactory; dolomitic.

Source: W. B. Myers and A. E. Roberts (oral communication, 1960).

Area 10

Stanford-Hobson area, Little Belt Mountains, Central Montana

Location: Blacktail Hills Dome; secs. 13, 14, 23, and 24, T. 15 N., R. 10 E., Judith Basin County, Mont.

Land ownership: Unknown.

Geologic formation: Madison group, Mississippian age.

Analysis: Probably high $CaCO_3$.

Water content: Probably low.

Interval: +1,000 feet.

Depth burial: Unknown; probably shallow.

Structure: Low dome.

Zero site access: Fair; 500 to 600 feet of relief, for adit or incline.

Surface drilling: Good.

Remarks: Not satisfactory; dolomitic.

Sources: U.S. Geol. Survey Bull. 1027-J, G. D. Robinson and E. T. Ruppel (oral communications, 1960).

Area 11

Townsend Valley, Montana

Location: Secs. 4 and 8, T. 6 N., R. 1 E.; Limestone Hills, Broadwater County, Mont.

Land ownership: Unknown

Geologic formation: Madison group, Mission Canyon and Lodgepole limestones; Mississippian age.

Analysis: Unknown; probably high $CaCO_3$.

Water content: Probably low.

Interval: ±1,750 feet; 650 feet Lodgepole limestone overlain by 1,100 feet Mission Canyon limestone.

Depth burial: Unknown; probably shallow cover.

Structure: Broad folds, scattered faults.

Zero site access: Good; 700 feet relief for adit access.

Surface drilling: Probably not difficult.

Remarks: Not satisfactory; dolomitic.

Sources: U.S. Geol. Survey Bull. 1042N, A. E. Roberts (oral communication, 1960); E. T. Ruppel (oral communication, 1960).

Area 12

Southwest Montana

Location: Limestone Hills, secs. 13 and 14, T. 3 N., R. 2 W.; Jefferson County, Mont.; Devil's Fence quad.

Land ownership: Unknown; probably Public Domain and private.

Geologic formation: Lodgepole and Mission Canyon limestones of Madison group; Mississippian age.

Water content: Probably low.

Interval: 2,000 feet of total interval possible.

Depth burial: Shallow; probably colluvium only.

Structure: Thick-bedded Mission Canyon limestone, 1,200 feet thick; thin-beded Lodgepole limestone, 700 feet thick; broad folds, scattered faults.

Zero site access: Excellent, terrain for adit; ±850 feet of relief.

Surface drilling: Good possibilities.

Remarks: Questionable; some chert all the way through the section; Lodgepole quite silty locally; gently rolling topography.

Sources: U.S. Geol. Survey Prof. Paper 292. A. E. Roberts (oral communication, 1960); E. T. Ruppel (oral communication, 1960).

Area 13

Southwest Texas

Location: Brewster and Presidio Counties, Big Bend area, Texas.

Land ownership: Private, State, and Federal.

Geologic formation: Devils River limestone.

Analysis: 97.5 percent $CaCO_3$, 0.06 percent MgO, 1.08 percent SiO_2.

Water content: Water table: 800 to 1,200 feet depth.

Interval: +1,500 feet on Mesa de Anguila; (not completely measured).

Depth of burial: Up to 3,000 feet; cover includes limestones, clays, and shales.

Structure: Uniform sequence; medium to thick bedded, fine grained; forms spectacular cliffs and gorges.

Zero site access: Adit possibilities excellent; inoperative mercury mines present.

Surface drilling: Excellent opportunities.

Other notes: U.S. Geol. Survey Prof. Paper 312; Val Freeman (oral communication, 1960).

Remarks: Looks very good; locally cavernous; on U.S.-Mexico International Boundary; only one chemical analysis available.

Area 14

West Texas, Southern Guadalupe Mountains

Location: Northwest Culberson County: Guadalupe Peak, Tex.

Land ownership: unknown.

Geologic formation: Capitan limestone; Goat Seep limestone, Bone Spring limestone; Devonian age.

Analysis: Upper 500 feet is calcitic; lower 1,500 feet is dolomitic and calcitic; impurities in upper 500 feet may be less than 5 percent, but total unit has more.

Water content: Probably low.

Interval: 2,000 feet plus.

Depth burial: 1,000 feet plus.

Structure: Thick-bedded calcitic limestone; locally pure; uncontorted.

Zero site access: Excellent terrain for adit.

Surface drilling: Good.

Other notes: Guadalupe Peak quad., U.S. Geol. Survey Prof. Paper 215; P. T. Hayes (oral communication, 1960).

Remarks: Not satisfactory: Lower 1,500 feet is dolomitic.

Area 15

Southeast New Mexico, Central Guadalupe Mountains

Location: Sec. 30, T. 26 S., R. 20 E.; Otero County, N. Mex.

Land ownership: Unknown.

Geologic formation: Victorio Peak limestone facies of Bone Spring formation; Permian age.

Analysis: Unknown; local areas of high $CaCO_3$.

Water content: Probably low.

Interval: ±1,000 feet.

Depth burial: ±1,000 feet.

Structure: Thick bedded; has tendency toward abrupt lateral facies change.

Zero site access: Good; 500 feet of exposures in fault scarp.

Surface drilling: Good.

Remarks: Not satisfactory: lower 1,500 feet is dolomitic.

Sources: N. Mex. Institute of Mines and Mineral Resources, Bull. 49, Central Guadalupe Mountains, Socorro, N. Mex. P. T. Hayes (oral communication, 1960).

Area 16

Lake Mead-Grand Canyon, Arizona

Location: Pierce's Ferry, Iceberg Canyon (south); Quartermaster Canyon (north); Grand Gulch mine; 18.5 miles north of latitude 36°; 13.0 miles west of longitude 114.

Land ownership: Unknown, part Public Domain.

Geologic formation: Escabrosa-Redwall limestone.

Analysis: 95 percent, or better, $CaCO_3$.

Water content: Low.

Interval: 800 to 1,000 feet maximum.

Depth of burial: 800 feet Supai limestones and red beds overlie Redwall limestone; in turn overlain by heavy cover depending on location.

Structure: Flat-lying to 45° dip.

Zero site access: Excellent; existing adits in vicinity; Grand Gulch mine.

Surface drilling: Good, from bench-forming strata.

Other notes: U.S. Geol. Survey Bull. 798. McNair, AAPG Bull., v. 35, no. 3, p. 527. E. D. McKee and Curt Teichert (oral communication, 1960).

Remarks: Looks fair; too much cover, too close to National Park; recreation area, reservoir dam site. Not as thick as the Escabrosa farther south.

Area 17

Gunnison County, Colo.

Location: Secs. 11, 12, T. 46 N., R. 2 W., Gunnison County, Colo.; Iron Hill.

Land ownership: Private; controlled by Dupont Co.; much Dupont drilling in area as exploration for niobium.

Geologic formation: Carbonatite. Late Precambrian(?) age.

Analysis: 40 to 50 spectrographic analyses and X-ray diffraction all show various amounts of MgO.

Water content: Probably low.

Interval: Unknown for calcite section.

Depth burial: Shallow cover.

Structure: ±1 by 2 miles carbonatite intrusive; depth unknown; U.S.B.M. drilling to 800 feet.

Zero site access: Good; site is circular, dome-shaped hill with ±800 to 1,000 feet relief.

Surface drilling: Excellent; roads to summit.

Other notes: U.S. Geol. Survey Prof. Paper 197-A. J. C. Olsen and D. C. Hedlund (oral communication, 1960).

Remarks: Not satisfactory; composed mainly of dolomite; pyrite abundant locally; siliceous; contains veins of apatite, iron oxides, and inclusions of pyroxenites.

Area 18

Central Arkansas

Location: Magnet Cove, Malvern quad., secs. 18 and 19, T. 3 S., R. 17 W., Hot Spring County, Ark.

Land ownership: Private.

Geologic formation: Carbonatite; Cretaceous(?) age.

Analysis: 92.7 percent $CaCO_3$; (poor sample).

Water content: Probably large; shallow water table.

Interval: 600 by 1,000 feet by depth unknown.

Depth burial: Few feet of residual deposits.

Structure: Intrusive mass; much medium- to coarse-grained calcite; homogeneous.

Zero site access: Carbonatite forms low hills with 60 to 100 feet of relief.

Surface drilling: Excellent.

Other notes: U.S. Geol. Survey MF Map 53; U.S. Geol. Survey Bull. 1015-B; R. L. Erickson (oral communication, 1960).

Remarks: Not satisfactory; impurity content too high.

POSSIBLE ALASKAN SITES FOR NUCLEAR REACTION EXPERIMENT IN LIMESTONE

By G. Donald Eberlein

Introduction

This statement is intended to provide preliminary information regarding possible sites in Alaska for a proposed nuclear reaction experiment in limestone.

The determination of possible sites in Alaska is made difficult by the paucity of detailed geologic information available for site evaluation in terms of the specific criteria indicated. This is especially true with respect to chemical analyses and structural homogeneity. Much of Alaska receives moderate to heavy rainfall. It therefore is not a simple matter to locate a site with no active waterflow because of the development of karst topography. In that regard, the possible locations north of the 32°F isotherm would appear to be initially the most attractive because they are normally underlain by permafrost (perennially frozen ground).

The discussion that follows is focused upon those areas that may qualify on one or more counts, based on existing information both published and unpublished. Needless to say, before any site is seriously considered it should be field evaluated by a competent geologist. Summarized in table 2 are areas that, based on the available geologic data, offer the best possibilities for test sites.

Table 2.--Summary of data on high-calcium limestone areas for possible underground test sites in Alaska

Map number (fig. 2)	Formation	Location	Thickness available (feet)	$CaCO_3$ (percent)
1	Port Clarence limestone	Lost River area	500-1,000	N.A. 1/
2	Mount Distin limestone	Nome area	At least several hundred	N.A.
3	Tolovana limestone	Minto Flats-Dugan Hills area and White Mountains	1,500-3,000	X-rays indicate 99± at least locally.
4	- - -	Glacier Bay area	1,000±	A few analyses indicate 96-99.
5	(Silurian)	Heceta and Tuxecan Islands area	1,000-3,400	Probably greater than 95.
6	do.	Dall and Long Islands area	1,000+	Perhaps greater than 95.

1/ N.A. - no analyses available.

Possible localities

Seward Peninsula

Lost River area.--The Lost River area appears to offer good opportunity for evaluating the suitability of the Port Clarence limestone as a potential host rock for the proposed nuclear test (fig. 2). Geologic information about the Port Clarence limestone is fragmentary. The information that follows is based upon scanty published data and personal observations.

No chemical data are available concerning the purity of the Port Clarence limestone. Knopf (1908) states that the black phase of the limestone is "pure carbonate rock." Several thick sequences of black limestone that may aggregate 500 to 1,000 feet of section are exposed east of Lost River where thickness measurements would be easily obtainable.

The Port Clarence limestone is of early Paleozoic age and therefore probably contains little aragonite. The dolomite content cannot be evaluated without additional sampling, but some of the limestone is known to be nondolomitic.

The Port Clarence as a whole is several thousand feet thick and suitable spots could be found where 2,000 feet of limestone overlies the shot point. Depth of burial could reach 2,000 feet and still retain 500 feet above the base of the formation.

The Port Clarence limestone contains interbedded argillaceous limestone and thin-bedded limestone. In the Lost River area the

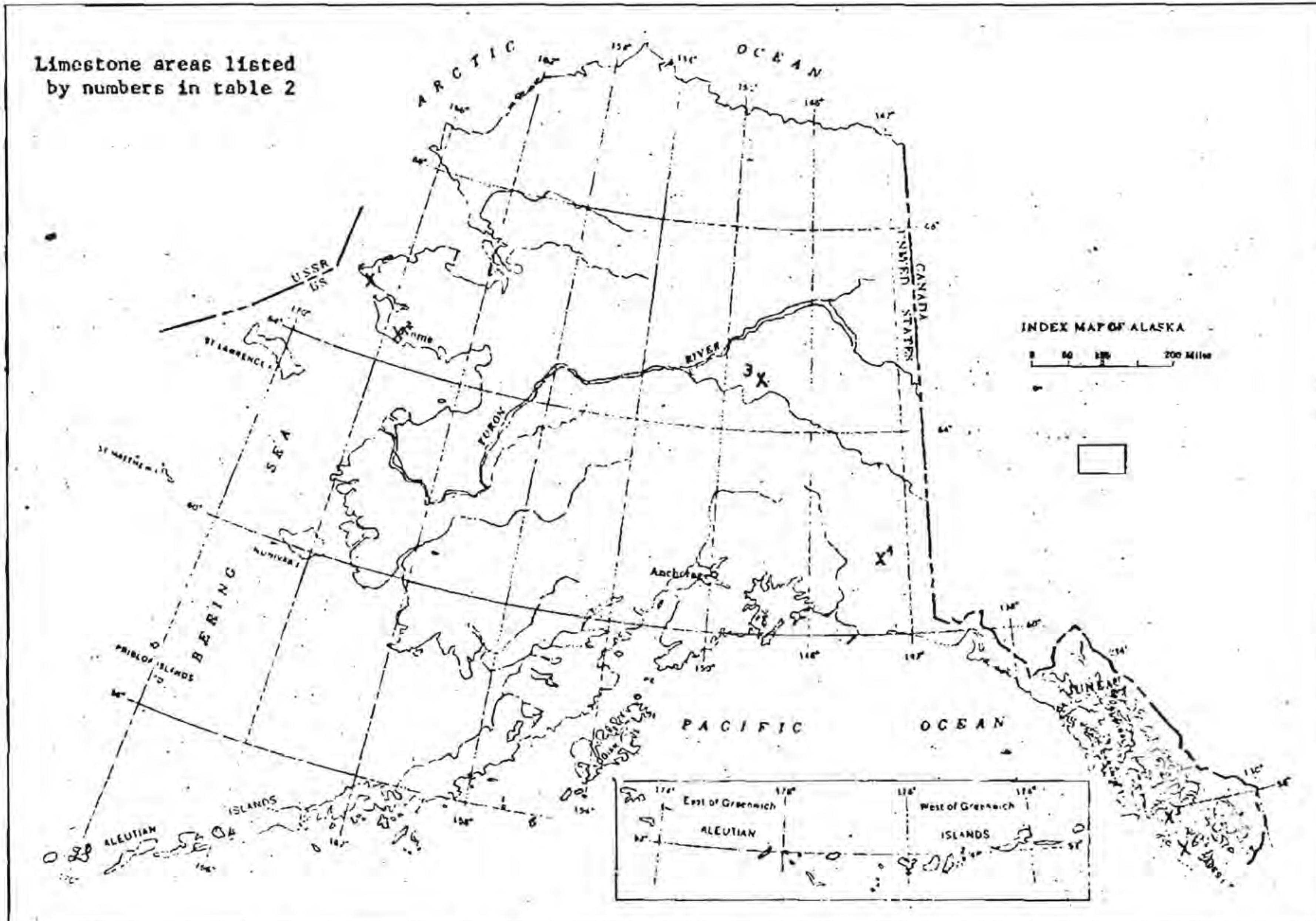

FIGURE 2.--LOCATIONS (X) OF SIX POSSIBLE HIGH-CALCIUM THICK LIMESTONE DEPOSITS IN ALASKA

Port Clarence is tilted and broken by a few faults; thus the structure is thought to be relatively simple, but complete structural homogeneity may not be obtainable. Reasonable homogeneity throughout a 500-foot radius sphere might be possible within the massive black limestone member.

Nome area.--The Mount Distin limestone that crops out between the upper Nome River and ridges south of Salmon Lake appears to approach the requirements stated (fig. 2). The purity of the Mount Distin limestone is not known with certainty, but it appears to be very clean. It is nonmagnesian according to C. L. Hummel (oral communication). There are some micaceous and quartzose interbeds, but it appears that zones at least several hundred feet thick are free of such interbeds.

The stratigraphic thickness of the Mount Distin, according to Moffit (1907) and Hummel, ranges from 2,200 feet to more than 3,200 feet. A depth of burial of 1,000 feet could be attained from horizontal tunnels 3,000 to 5,000 feet long. In such places there would be at least 500 feet of material between zero point and boundary of the limestone, but there probably would be micaceous or quartzose limestone interbeds within the 500-foot interval. The formation is compact and thick bedded. With the exception of the micaceous layers, it is about as massive as limestone can be. The structure in this particular area appears to be quite simple and free from large faults and dikes. There may be some internal crumpling and there almost surely are many minor faults.

Central Alaska

Minto Flats-Dugan Hills area.--The Tolovana limestone of the Minto Flats-Dugan Hills area may offer a suitable site for the proposed test (fig. 2).

There are no chemical analyses of the Tolovana limestone but X-ray analyses of seven samples over a strike length of approximately 6 miles and from the bottom to the top of the formation show no dolomite. The water content is not known but the limestone appears to contain as much as 99 percent calcite. Within the limits of existing outcrop controls, deleterious rock types are not known to be present, and the entire formation is apparently a pure calcite limestone.

From continuous exposures on the ridge between the Tolovana and Tatalana Rivers in the northeast corner of the Minto Flats, the limestone beds are generally massive and dip 60° to 80° southward. Two cross sections through the ridge show a minimum thickness of at least 1,500 feet. The maximum thickness is probably less than 3,000 feet. The southwest end of the ridge is probably cavernous.

Less is known about the Tolovana limestone in the Dugan Hills. Two parallel limestone units are present in the western half of the hills, but only one occurs in the eastern half. The two units present in the western half of the hills may represent a duplication by folding and/or faulting. The beds are generally massive and nearly vertical. The known outcrop width is approximately 1,000 feet. The total thickness could be much greater.

The Tolovana limestone is also present in the White Mountains. Very little is known geologically about the White Mountains. The Tolovana may be structurally more complex but its purity is likely to be the same as in the Dugan Hills and on Tolovana Ridge. Furthermore, the physical requirements as to volume may be more easily met in the White Mountains because the relief is greater.

Southern Alaska

Wrangell Mountains area.--The Chitistone and Nizina limestones are sporadically distributed along the southern flank of the Wrangell Mountains, Alaska, in an east-west belt that is about 65 miles long and a maximum of 14 miles wide (fig. 2). Although some of the physical requisites for the proposed limestone experiment probably exist in the Chitistone limestone areas of McCarthy Creek and near the Nizina and Chitistone River, several detrimental qualities, particularly impurities and fractures, occur in both the Chitistone and Nizina limestones and probably eliminate these rocks from practical consideration as sites for the proposed experiment.

Southeastern Alaska

Glacier Bay area.--In general, the limestone deposits in the northern part of southeastern Alaska do not meet the qualifications set forth. Deposits on Admiralty and Chichagof Islands, and those on the mainland, commonly contain schist or chert layers, are dolomitic and are cut by numerous dikes. Many of the limestone units are too thin.

The marble deposits which most nearly qualify are found in Glacier Bay (fig. 2). Willoughby Island and North and South Marble Island are almost entirely composed of marble. The few analyses we have of the Willoughby Island marble indicate that it contains between 97 and 99 percent of $CaCO_3$. These analyses are of samples collected on the southeast shore of the island from the north side of the small cove where ridges rise abruptly to a height of several hundred feet and reach an altitude of more than 1,000 feet a short distance to the north. There is essentially no overburden.

The largest occurrences of limestone on the mainland are south of Sandy Cove. Chapin (1920) reports a chemical analysis of mottled marble south of Sandy Cove contains: $CaCO_3$, 96.16 percent; $MgCO_3$, 0.89 percent; insoluble residue, 2.56 percent. Other analyses of marble in the vicinity of Sandy Cove showed between 96 and 98.5 percent of $CaCO_3$. Diabase dikes are plentiful in the area.

Heceta-Tuxekan Islands area.--High-calcium limestone of Middle(?) and Late Silurian age underlies most of Heceta and Tuxekan Islands and appears to approach the requirements (fig. 2). The limestone is typically massive, sublithographic, and for the most part probably contains in excess of 95 percent $CaCO_3$. A zone of discontinuous lenses and pods of conglomerate and finer grained clastic rocks occurs near the middle of the formation, but locations probably can be selected where these rocks will not be a deleterious factor.

Chemical analyses of the limestone on Heceta Island indicate that in the area around Warm Chuck Inlet, a stratigraphic thickness of about 1,000 feet between the top of a relatively magnesian zone and the base of a zone containing interbedded clastic rocks may be chemically suitable. Another area, in the vicinity of Port Alice, may contain as much as 3,400 feet of chemically suitable limestone.

Ground-water conditions cannot be stated with certainty without exploratory drilling, but underground waterflow may be a serious problem. However, it may be possible to locate sites that are free of active waterflow.

The stratigraphic thickness of the limestone is extremely variable. The thickest known section is on western Heceta Island where a minimum thickness of 15,800 feet can be demonstrated. Approximately 2 miles east of Warm Chuck Inlet the formation is about 9,500 feet thick. Approximately 8,700 feet of limestone is exposed on the south half of Tuxekan Island.

The purest limestone is compact and thick bedded. The structure is quite simple. The beds dip gently northward between 25° and 40° and are folded into broad north-plunging structures. These are cut by several high-angle faults along which there has been considerable displacement. Jointing is common and numerous minor faults also undoubtedly are present. Furthermore, the limestone is cut by numerous steeply dipping diabasic and lamprophyric dikes.

The same limestone beds crop out on adjacent Prince of Wales Island and on Kosciusko Island to the north across Sea Otter Sound. We known very little about the geology of Kosciusko Island, but it is known that the limestone at Edna Bay was extensively drilled and sampled for metallurgical purposes by Alcoa in 1946 and 1947. Accordingly, it is believed that the limestone on Kosciusko Island may also qualify both physically and chemically for the proposed nuclear reaction experiment.

Dall and Long Islands area.--Areas underlain by limestone and marble on Dall and Long Islands may meet the requirements. Folding and faulting may duplicate and add to or reduce the effective thickness. The limestone and marble of Long Island probably is not as thick as it appears from mapped distribution and is considerably folded and faulted.

The only chemical analyses of limestone from Dall and Long Islands are those published by J. C. Roehm (1946). These suggest that the carbonate rocks contain 95 percent or more of $CaCO_3$. The principal mineral is calcite, although dolomite in amounts up to about 10 percent, is locally present, as reported by Roehm in one sample from Waterfall Bay.

The specified physical requirements for device placement probably would be close to critical in most places on either Dall or Long Island. The greatest potential working thickness of limestone probably occurs west of Rose Inlet, southwest of the head of View Cove, or perhaps along the south shore of Diver Bay. Maximum relief in these areas ranges from 2,000 to 2,500 feet. Rose Inlet, Gold Harbor, Waterfall Bay, and possibly Diver Bay appear to offer the best possibility for tunneling from points close to shoreline. Access to the higher areas is everywhere difficult. The limestone and marble of Dall and Long Islands are massive, extensively faulted and fractured, and contain many mafic dikes of various spacing and size. The Silurian limestone is massively bedded; the Wales marble is generally somewhat thinner bedded. The Wales rocks are both broadly and intricately folded.

Table 3. --Physical and chemical characteristics of limestone on Dall and Long Islands, Alaska

	$CaCO_3$	$MgCO_3$	Stratigraphic thickness (feet)	Maximum elevation (feet)	Remarks
Waterfall Bay					Mafic dikes 200 to 300 feet apart.
1. Dark blue-gray	96.8	--)			
2. Light-gray to white	89.7	9.7)	2,000±	2,500	
3. Blue-white mottle	91.6	6.2)			
4. White marble	99.6	--)			
Cleva Bay					
5. Blue-gray	96.0	--)	Prob. total	600	--
6. Blue-white	97.8	--)	<1,500		
Quarry, View Cove					
8. Blue-gray to white	96.6	--	2,000±	700	A few dikes.
Green Bay, View Cove					
9.-	95.8-	--	1,500+	--	Large mafic dikes.
11. Dark-gray	97.6				

The Silurian limestones are more massive and somewhat less contorted. Granitic or dioritic intrusions are known to cut the Silurian limestone on Dall Island.

The known physical and chemical characteristics of limestone at possible localities are summarized in table 3.

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