STATE OF ALASKA

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL AND GEOPHYSICAL SURVEYS

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Geological and Geophysical Surveys
standards.

July 1975

Alaska Open File Report 87
ZEOLITE DEPOSITS OF POSSIBLE ECONOMIC
SIGNIFICANCE ON THE NORTHERN ALASKA
PENINSULA
by
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ACKNOWLEDGEMENT

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ABSTRACT

Clinoptilolite, mordenite, heulandite and laumontite have been identified in possible economic concentrations on the Alaska Peninsula. Most important are: 1) a heulandite bearing water laid tuff on Agate Island, 2) a thick sequence of terrestrial volcanics containing mordenite and clinoptilolite located between Squirrel Point and Tommy Creek, 3) waterlaid tuffs containing high concentrations of clinoptilolite near Dennis Creek and 4) a heulandite bearing siltstone at Chinitna Bay.

Zeolite formation in the Iliamna Lake area was produced in "open" systems of fresh water lakes and ground water systems which have transformed vitric volcanic material into zeolites. Buriel diagenesis is responsible for alteration of early formed, low temperature-pressure zeolites into high temperature-pressure varieties.

The formation of laumontite in a tuffaceous sandstone at Chinitna Bay was the result of low grade buriel metamorphism. The mode of formation of heulandite in a welded tuff and siltstone unit also located at Chinitna Bay appears to have resulted from diagenic alteration of terrestrial sediments.

Transportation of zeolite ore from Iliamna Lake would be by lake to Pile Bay Village then by road to Iliamna Bay and, finally, by ship to the consumer. In the Chinitna Bay area ore can be loaded directly on ships for transportation to the consumer.

INTRODUCTION

The realization in the 1950's that naturally occurring zeolites could be of commercial utility triggered a reaction in the industrial and academic worlds. The new interest resulted in a flood of publications, dealing with numerous aspects of the zeolite family including new and extensive deposits, mineralogy, modes of formation, chemical reactivities, history and uses. This close inspection revealed further industrial applications of zeolites.

As a result of growing commercial utilization, mineable zeolite deposits have been developed in several countries including the conterminous United States. The possibility of economic zeolite deposits in Alaska, however, held little interest until 1972 when increased industrial use including cracking catalysts in the petroleum industry, binders for mixed fertilizers and conditioners for agricultural soil, stimulated a program to locate zeolite deposits of commercial value. The result of this research revealed extensively zeolitized beds of Tertiary volcanic tuff and sediments on the Northern Alaska Penninsula near Iliamna Lake (Madonna, 1973).

It is the purpose of this project to investigate the more important zeolitized units reported in the Iliamna Area and locate other potentially economic deposits. Examination of each deposit includes the size, semiquantitative concentration and type of zeolite present. In addition, each deposit is briefly discussed in terms of its possible economic importance.

Background

Zeolites were first described in 1756 by Baron Cronstedt. He derived the name from the Greek Zein meaning to boil, and Lithos, meaning stone, because of the apparent boiling which took place as he heated the minerals. Subsequent investigations revealed that zeolites are a group of tectosilicates which may be considered, chemically, as hydrated equivalents of the feldspars. Like the feldspars, the zeolite framework is composed of three dimensional $(Si, Al)O_4$ tetrahedra. Cavities within the framework are the sites of cations, generally Ca^{++}, Na^+ or K^+, which balance the negative charge of the structure. However, unlike the feldspars which have compact structures prohibiting removal of a cation without disrupting the structure, the zeolite framework contains wide interconnecting openings which permit easy removal of the positive ions.

An additional characteristic which differentiates zeolites from feldspars is the presence of water molecules within the cavities of the zeolite structure. This water may be removed

by heating and, unlike most hydrated minerals which collapse during the dehydration process, the aluminosilicate structures of zeolites remain stable to quite high temperatures.

In the late 1920's it was discovered that the dehydrated zeolite framework with its honeycomb of passageways is capable of absorbing large quantities of other fluids and gases in place of the water removed. Also, because each member of the zeolite family has a unique aperture size, the molecules admitted are restricted to those of appropriate dimensions. This selective nature of the zeolite structures make them extremely useful as industrial molecular sieves.

Knowledge of the geological significance of zeolites was slow in developing in comparison to advances in understanding their chemical properties. Because molecular sieve properties make zeolites highly useful for industrial purposes and because economic deposits were unknown, chemists, in the late 1930's began a program to produce synthetic zeolites. By the early 1950's, several artificial zeolites were produced which have become extremely useful as industrial molecular sieves (Breck, 1964).

About this same time (1950's) geologists began to realize the significance of zeolites formed in volcanic tuff beds deposited in marine and saline-alkaline lake environments (Hay, 1966). When several high-grade deposits were discovered, the natural zeolites were examined to determine if they might be competitive with synthetic molecular sieves. Results revealed that sedimentary zeolites have properties very similar to those of artificial zeolites, and natural zeolites showed great potential for industrial application. When the potential economic value of natural zeolites became apparent, industry began an exploration program in the conterminous United States which led to the identification of over 80 mineable deposits.

INDUSTRIAL UTILIZATION

At the same time that the United States began its program to uncover new zeolite deposits, other countries such as the Soviet Union, Bulgaria, New Zealand, Hungary, Australia, Germany and Japan began to develop their deposits. As new high grade deposits were discovered technological advances surrounding the commercial utilization of naturally occurring zeolites also flourished. In a recent study of worldwide deposits and utilization of naturally occurring zeolites by Fredrick A. Mumpton (1973) it was found that over 300,000 tons of zeolitized tuffs are mined and used annually. Notable among the producing deposits are the Japanese mines which are responsible for almost thirty percent of the worlds annual production. Several uses described by Mumpton (1973) are summerized below.

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Japanese researchers have developed numerous industrial uses for natural zeolites. The sodium-potassium zeolite, clinoptilolite, has found application as a filler in the Japanese paper industry. The paper filled with clinoptilolite, is bulkier, more opaque, easier to cut and gives less ink blotting than similar clay filled papers.

Clinoptilolite is also being used in Japan as an agglutination agent for mixed fertilizers. In addition, it tends to retain the desirable cations in the soil for longer periods of time. It is suggested that laumontite, a sodium-zeolite, may also find important use as a conditioning agent in agricultural soils (Hawkins, 1973).

Japanese researchers have found clinoptilolite and mordenite especially useful as animal nutrients. As much as 10% by weight of these zeolites have been added to the diet of pigs and chickens with significant increases in adult weight and reduction of total cost of feed. In addition, the animals' excrement is much less odorous because of the ammonium adsorption by the zeolite.

Naturally occurring mordenite has recently found use in the separation of high purity oxygen from air. The oxygen, produced at Toyohashi City, is used in the smelting of pig iron for the production of Toyoto automobiles. The Toyohashi City plant also produces 99% plus nitrogen by use of natural mordenite.

Clinoptilolite has recently proven useful in removing ammonium from sewage and agricultural effluents. In a recent test on a Lake Tahoe, California sewage stream, clinoptilolite was successful in removing 97% of the ammonium. The ammonium was then discharged into the air and the clinoptilolite regenerated for further use.

Zeolitized tuffs have, for many years, found use in pozzolanic cement and concrete. Pozzolanic concrete appears to be as strong or stronger as that produced with normal amounts of portland cement. Furthermore, hydraulic cement produced from zeolite pozzolans appears to be more resistant to underwater corrosion.

Naturally occurring clinoptilolite has found additional use as an agent in ion exchange processes which concentrate and isolate radioactive ions from waste waters generated by atomic installations. Once the clinoptilolite is saturated with the radioactive ions it can be stored or cleansed with chemicals and reused.

In addition to the uses described above, zeolites have found numerous other applications. Hungary has used refined natural mordenite as a cracking catalyst in the petroleum industry and Japan has developed a use for natural zeolites as a polishing agent for dentifrice. A list of selected references from chemical abstracts on the use and properties of natural zeolites has been assembled and presented by Hawkins (1973).

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ZEOLITE GENESIS

. The occurrence of zeolites in several types of geologic settings is reasonably well known. In the past twenty years a large number of publications have appeared dealing with the conditions and environments of formation. Based upon the work of many investigators, including R. J. Hay, D. S. Coombs, R. A. Sheppard, A. J. Gude, A. Iijima, M. Utada, L. B. Sand, R. C. Surdam and M. E. Teruggi, Fredrick A. Mumpton (1973) divided zeolite deposits into the following six classes:

1. Deposits which formed from volcanic material in "closed" systems of ancient and present-day saline lakes. (Example: zeolitic tuffs of ancient Lake Tecopa, Shoshone, California; Sheppard and Gude, 1968.)

2. Deposits which formed from volcanic material in "open" systems freshwater lakes or groundwater systems. (Example: Altered tuffs of the John Day Formation, central Oregon; Hay, 1963.)

3. Deposits which formed from volcanic material in near-shore or deep-sea marine environments. (Example: Massive, clinoptilolite-rich tuff near Kurdzali, Bulgaria; Alexiev, 1968.)

4. Deposits formed by low-grade burial metamorphism of volcanic and other material in thick sedimentary sequences. (Example: Triassic greywackes of the Turingatura District, Southland, New Zealand; Coombs, 1954.)

5. Deposits formed by hydrothermal or hot-springs activity. (Example: Altered bedded tuffs and sandstones at Wairakei, North Island, New Zealand; Steiner, 1953.)

6. Deposits formed in lacustrine or marine environments without direct evidence of volcanic precursor material. (Example: Analcime zones of the Triassic Lockatong Formation, New Jersey; Van Houten, 1960.)

Workers have found that zeolite formation is favored by fluids of high pH and high alkali-ion to hydrogen-ion ratios in contact with reactive silicate material such as vitric-volcanic ash and tuff. Deffeyes (1959) suggests that zeolites form in sedimentary tuff deposits by solution of volcanic glass followed by precipitation of the zeolite from the solution. Sheppard (1971) suggests that high pH conditions account for the solubility of the glass and that reactivity of alkali ions is responsible for precipitation of the zeolites.

Throughout the world, the thickest and most wide-spread zeolite deposits are of Triassic and younger ages. Their absence from older rocks is apparently due to the formation of authigenic albite and potash feldspar at the expense of the metastable zeolites (Hay, 1966).

Because zeolites are hydrous mineral phases of low specific gravity they are particularly sensitive to pressure and temperature changes. This gives rise to the vertical zeolite zonation found in thick sequences of tuffaceous sediments. Zonation proceeds from the

most hydrous and least dense zeolites at the top (i.e. lowest pressure-temperature conditions) to the least hydrous and most dense zeolites at the bottom (i.e. highest pressure-temperature conditions). With increasing pressure and tempreature the zeolites become unstable and are ultimately transformed to minerals such as the feldspars which are stable under these conditions.

This suggests, in a general way, that three conditions must be met before extensive zeolitization is possible:

1) Presence of reactive parent material, e.g. vitric tuffs.

2) Presence of "active" fluids e.g. marine, saline-lake, or hydrothermal fluids.

3) Passage of a geologically short time span such that previously formed metastable zeolites have not been altered to more stable phases.

These conditions are diagrammatically shown in the Venn diagram of Figure 1. The most probable localities for zeolite formation and preservation are those for which all three conditions are simultaneously satisfied.

THIS STUDY
Field Methods

Search strategy: The search for zeolites in the Iliamna area was restricted to those lithologic units which meet the three basic conditions for zeolite formation and preservation as shown in Figure 1.

Sampling: Zeolites can often be recognized in the field. Laumontite, for example, can often be identified by its white color, pearly luster, and by the friable nature of its dehydration product, leonhardite, on weathered exposures. Coarse volcanogenic zeolite crystals can, in many cases, be recognized by their wavy or radiating fibrous habit. Zeolitized sedimentary rocks may be distinguished by their pale yellow, green or orange color, chalklike appearance and low specific gravity (Hay, 1966).

Fist-sized samples, exhibiting characteristics typical of zeolitized rocks, were selected from promising lithologies exposed in the areas visited. A description of each sample is presented in Table 1.

Laboratory Methods

Samples were examined by heavy-liquid separation, x-ray diffraction, thermal analysis and quantitative field test. Results are tabulated in Table 1.
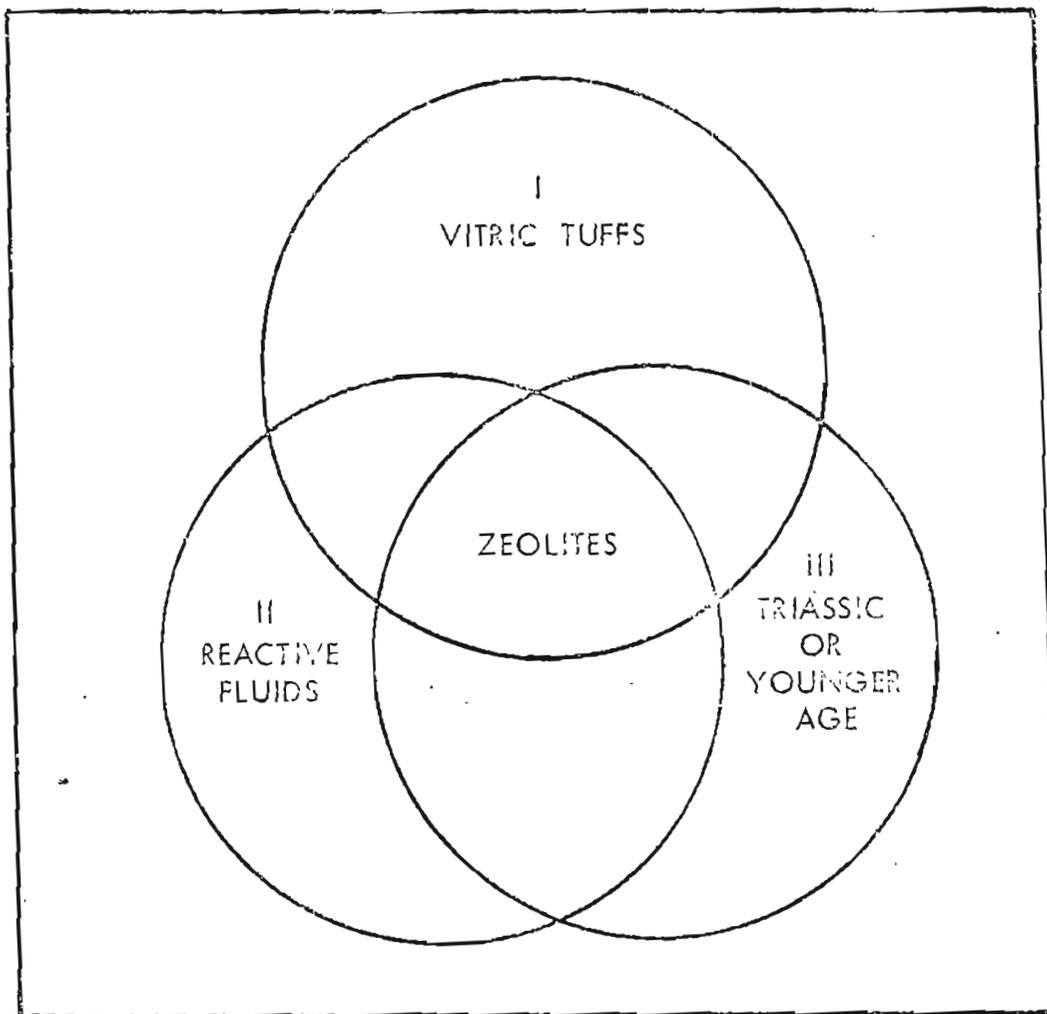
Figure 1. Venn Diagram Showing Conditions Which Favor
Zeolite Formation and Preservation.

Heavy-Liquid Separation: Because of their low specific gravity, generally between 2.0 and 2.4, the members of the zeolite family may be separated from heavier minerals by heavy-liquids. This procedure was conducted on the study samples to determine semi-quantitatively the zeolite concentrations. Selected samples were ground and sieved and the -150 to +325 mesh fraction was weighed and then separated into light and heavy components by bromoform which had been reduced to 2.4 specific gravity by addition of acetone. The light fraction was weighed and the approximate percentage of light material (less than sp.gr. 2.4) in each sample calculated.

X-ray Diffraction: Light fractions of heavy-liquid separates were finely powdered and then mixed with water and mounted on a glass slide. The samples were analyzed with a Norelco diffractometer using a copper X-ray tube with a nickel filter and a goniometer scan speed of two degrees per minute.

X-ray patterns of the samples were compared to a set of standard zeolite patterns and the A.S.T.M. card catalog to determine the possible presence and type of zeolites.

Thermal Analysis: The zeolites, heulandite and clinoptilolite, give virtually the same X-ray pattern. Mumpton (1960), introduced a test to distinguish the two minerals: "If after heating overnight at 450°C, the mineral no longer diffracts X-rays, it should be called heulandite; if however, diffraction is maintained it should be called clinoptilolite". This procedure was employed on several samples to determine which of the two zeolites were present.

Quantitative Field Test: Culfaz, Keisling and Sand suggest a simple quantitative field test for molecular sieve zeolites as summarized below:

Five grams of finely ground sample (below 10 mesh) is placed in an aluminum container and heated to 350°C. The sample container is then capped and allowed to cool to atmospheric temperature. Ten milleliters of water, also at atmospheric temperature, are added to the sample and stirred quickly with a thermometer. The temperature rises rapidly reaching a maximum within 30 seconds. A high temperature rise upon the addition of water is characteristic of the presence of zeolitic material in the sample, and the degree of temperature rise is directly proportional to the quantity of zeolite present.

Selected zeolitized samples obtained during this study were subjected to this field test in order to determine relative concentrations. The results of tests on each sample collected are listed in Table 1.

Results of Study by Area

The areas investigated and sampled include the west shore of Chinitna Bay, the Oil Bay Drainage, Iliamna Bay-Pile Bay Village Road and Iliamna Lake including portions of the periphery and several islands.

Two localities on the south shore of Iliamna Lake appeared to be highly favorable sites for extensive zeolite formation and warranted more intensive examination. The first, located northeast of Tommy Creek, encompasses approximately eight square miles. The second located approximately five-miles northeast of Big Mountain near Dennis Creek, encompasses approximately ten square miles.

A preliminary examination, in 1963, of the Chinitna Formation, exposed at Chinitna Bay, revealed the presence of zeolites. A more thorough examination of the area was undertaken during the 1974 field season. Figure 2 shows the areas examined and location of sample points.

Oil Bay Drainage and Iliamna Bay-Pile Bay Village Road: Lithologic units exposed in these areas consist mostly of plutonic igneous rocks unfavorable for zeolitization. Sample number 2 collected in the mountains east of Iliamna Bay is a quartz monzonite which contains noncommercial fracture fillings of thompsonite and chabazite. No other units condusive to zeolitization were observed.

Newhalen-Iliamna Area: Lithologic units exposed along the shore of Iliamna Lake between Newhalen and Iliamna (Figure 2) consist of green, brown and gray andesitic and tuffaceous material of Tertiary age. The outcrops are low lying, reaching a maximum of twenty feet above lake level near Iliamna.

Examination of selected samples revealed the presence of several zeolitized beds. The most important are green heulandite bearing tuffs (samples 5 & 6). The high percentage of low specific gravity material (99%) combined with the rather large temperature increase (12.0°C) produced by the field test suggests that unit 5 contains a high concentration of heulandite. Similarly unit 6 has a high percentage of low specific gravity material, however, the temperature rise produced by the field test was relatively low (5°C). The topographic characteristics of the two units, with relation to the lake level, are somewhat dissimilar. The water laid tuff of unit 5 rises only a few feet above lake level then gives way to a marshy environment to the north. In contrast, the andesitic tuffs of unit 6 rise approximately twenty feet above the lake level. However, this unit also gives way, gradually, to a marshy environment.
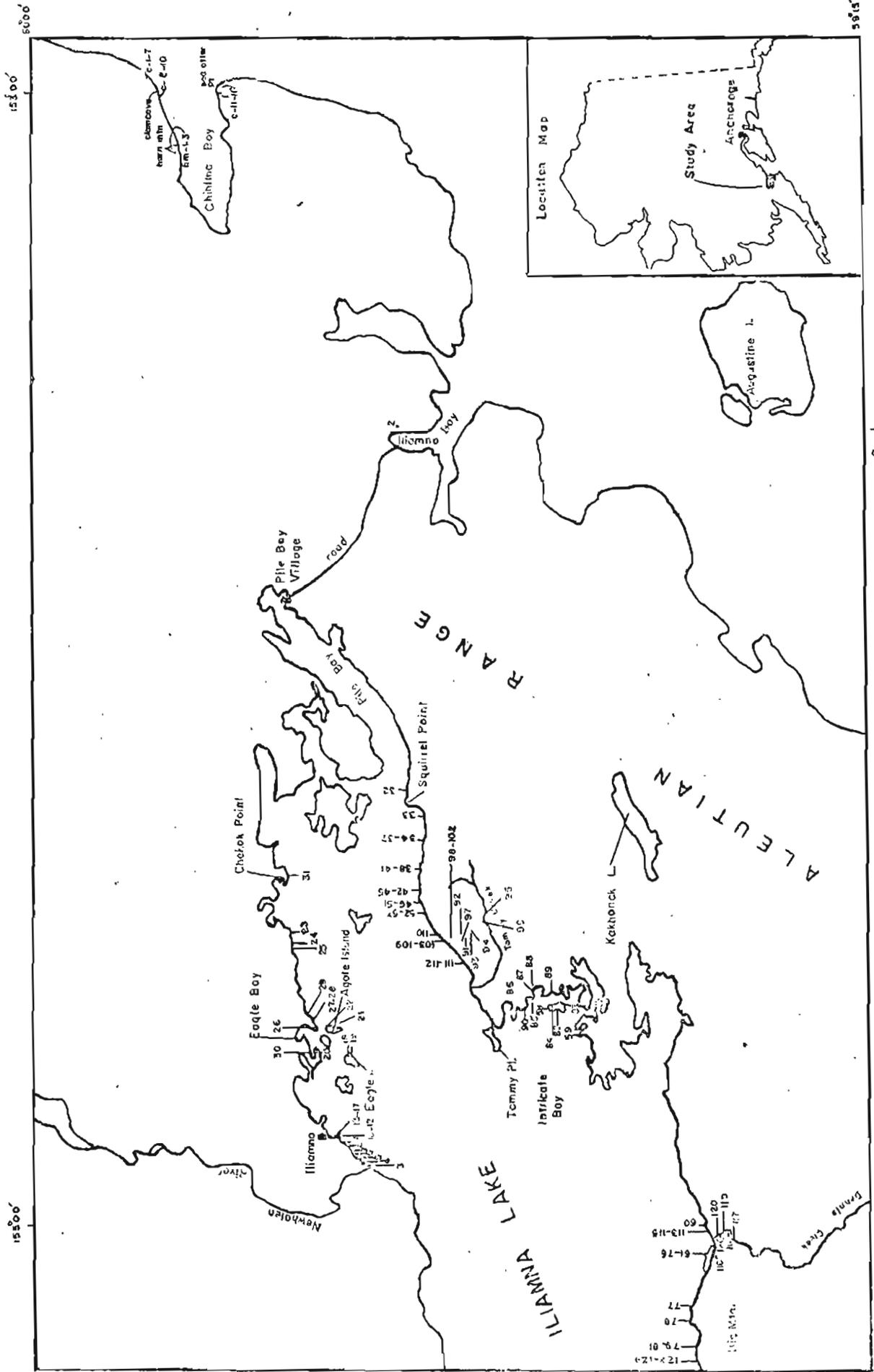
Figure 2. Location of Units Sampled During this Study.

The low comparative relief of unit 5 and the marsh boundary which surrounds both units will probably prohibit profitable utilization of these deposits.

Eagle Bay-Chekok Point: Examination of felsic tuffs, rhyolite and reworked volcanics on the lake shore, north of Agate Island, extending from Eagle Bay to Chekok Point (Figure 2) revealed several beds containing low to moderate zeolite concentrations. Of the units examined only number 25 shows economic potential. The unit consists of a bed of mordenite bearing reworked volcanics which rises thirty feet above lake level and extends approximately one-hundred feet along the lake shore. Because of excessive overgrowth it was not possible to determine the full extent of the deposit. Tests revealed 99 percent low specific gravity material in the sample and a moderate rise in temperature. This suggests that the deposit may be a possible source of mordenite.

Eagle, Eagle Bay and Agate Islands: Samples of Tertiary felsic tuffs, andesite and reworked volcanics were collected from Eagle, Eagle Bay and Agate Islands located approximately three-miles southeast of Iliamna (Figure 2). X-ray examination of these samples revealed that all but one were zeolitized. However, specific gravity separations and the results of the field test suggest that only the heulandite bearing tuff (#21) which extends approximately one-hundred and fifty yards across the northeastern end of Agate Island (Figure 3) is of possible economic value.

The unit is a gray to green tuff which forms cliffs rising between fifteen and twenty feet above shore line. The areal extent is shown in Figure 3. The extremely high percentage of low specific gravity material (98%) and moderate temperature increase (7°C) combined with the respectable areal extent suggests that this material should not be overlooked as a possible source of heulandite.

Squirrel Point-Tommy Point: The preliminary investigation in 1972 of Tertiary andesites, tuffs and tuffaceous sediments on the south shore and adjacent hills of Iliamna Lake between Squirrel Point and Tommy Creek revealed several highly zeolitized units. A more thorough investigation of the area during this study revealed extensive beds containing high concentrations of clinoptilolite, mordenite and heulandite in addition to two laumontite bearing volcanics. Figure 4 shows a number of the more important areas examined and the outcrop patterns of the more extensively zeolitized units.

Several tuffs contain abundant mordenite in the Squirrel Point area. The highest concentrations are found in samples 44 and 56 (Figure 2). Unfortunately, the unit represented by sample is a thin interlayered bed of local extent which would prohibit profitable utilization.

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EAGLE BAY

ILIAMNA LAKE

Eagle Bay Island

Agate Island

Location Map

Iliamna Lake
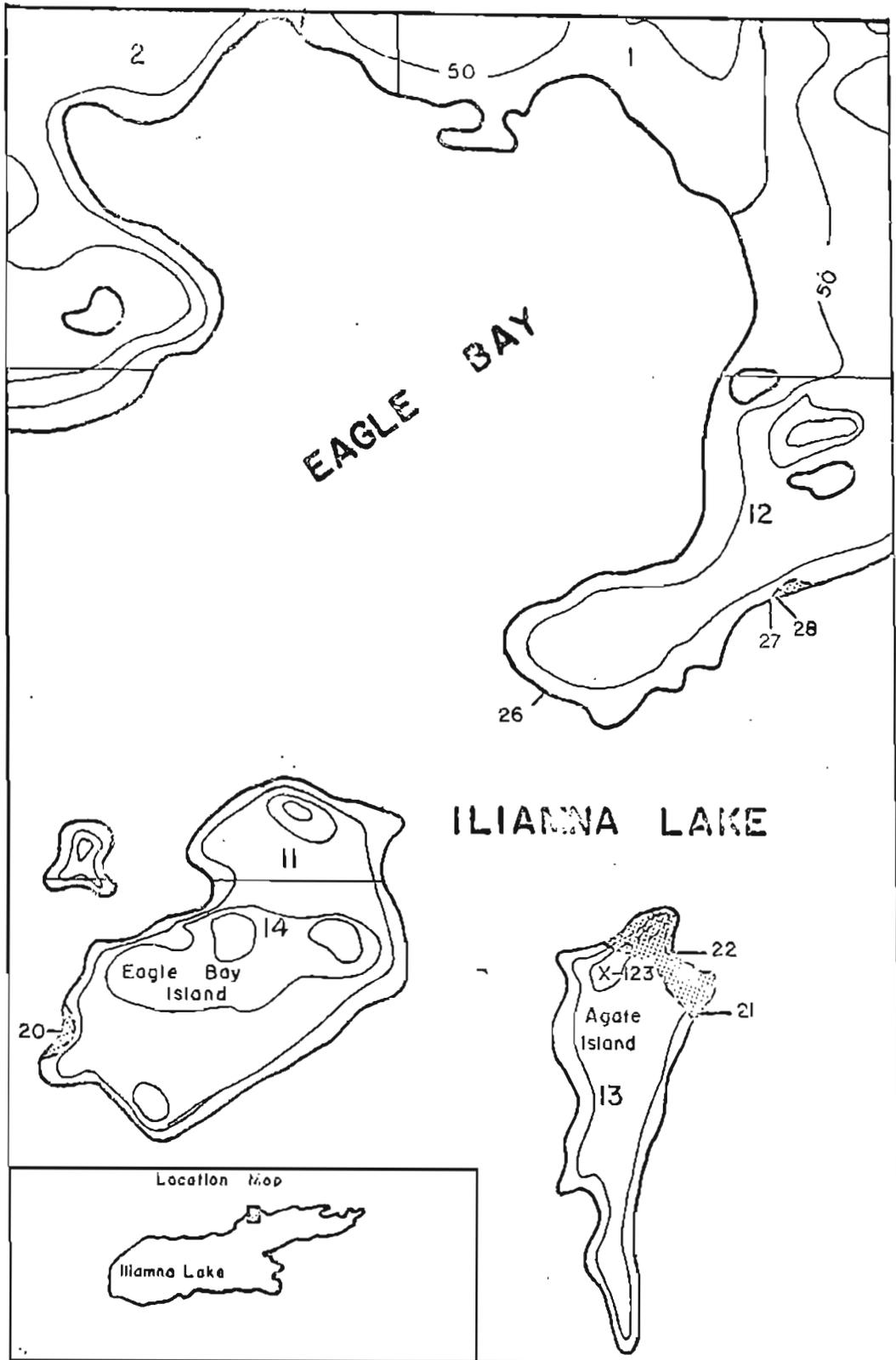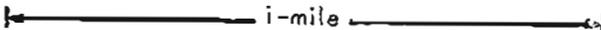
Zeolitized Units. |—————— i-mile ——————|

Figure 3. Zeolitized Units in the Agate Island Area.

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ILIAMNA LAKE

Location map

Iliamna Lake

Scole
1-mile
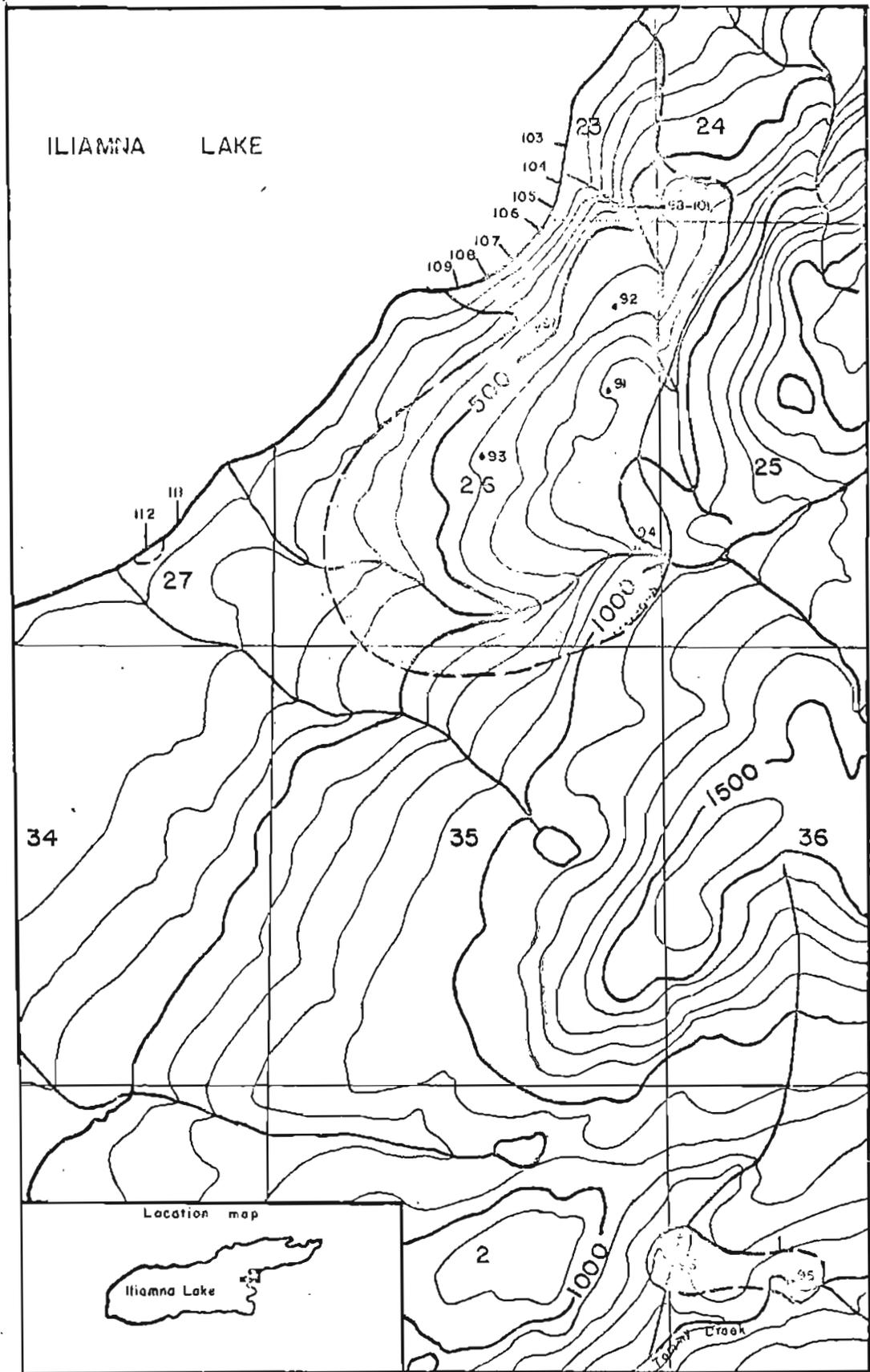
Zeolitized Units.

Figure 4.   Zeolitized Units in the Tommy Creek Area.

The unit represented by sample 56, on the other hand, is a green, fine-grained, altered tuff bed twenty feet high and one-hundred and fifty feet long. The respectable results of tests shown in Table 1 and the moderate areal extent indicate that this deposit may be of economic interest as a future source of mordenite.

Other mordenite bearing tuffs outcrop on the lake shore at sample points 110 and 112 (Figure 2). Similarity in physical and mineralogical characteristics suggest that these two outcrops were originally members of the same tuff bed. Both outcrops are light green in color and contain spherical structures suggesting aggitation in an aqueous environment. Tests show that both units contain high percentages of mordenite (Table 1). In addition, strike and dip measurements suggest that these beds are on the east and west limbs of a gently folded anticline. This is further confirmed by anticlinally folded Tertiary sediments exposed on the lake shore between the two mordenite bearing units (samples 103-109, Figure 2). The mordenite units are approximately fifteen feet thick and both are exposed for approximately one-hundred feet along the lake shore. The high zeolite concentration suggested by tests (Table 1) and the respectable areal extent indicate that these units may be among the more important mordenite deposits in the Iliamna area.

Zeolitized Tertiary sediments (samples 98-101 and 103-109) are exposed along the lake shore and approximately one-half mile up a small tributary (Figure 4). The sediments vary from fine grained tuffaceous siltstone to reworked volcanics and rough bouldery tuffaceous conglomerates. As indicated earlier the sediments are exposed in a gently folded, northsouth trending anticline. As Table 1 shows most of the sedimentary beds are zeolitized. The most important are clinoptilolite bearing tuffaceous sandstones and reworked volcanics (samples 98, 99 and 100) exposed in the small drainage trending southeast from the lake (Figure 5). The combined thickness of the three beds is approximately sixty feet. Extensive foliage prevented measurement of the length and width of the beds. However, exposures of the sediments on the lake shore suggest a length of approximately one-half mile and, from what could be observed in the drainage, a width of approximately one-quarter mile. This deposit has possibilities of becoming a source of clinoptilolite, however, more extensive mapping would be required before firm evaluation could be made.

The mountains above and adjacent to the Tertiary sediments consist of approximately four-hundred feet of mordenite bearing volcanics. These volcanics consist of gree, welded and vitric tuffs which extend approximately one-mile in a northeasterly direction and exhibit a width averaging one-half mile (see Figure 4). Tests on selected samples, both in 1972 and
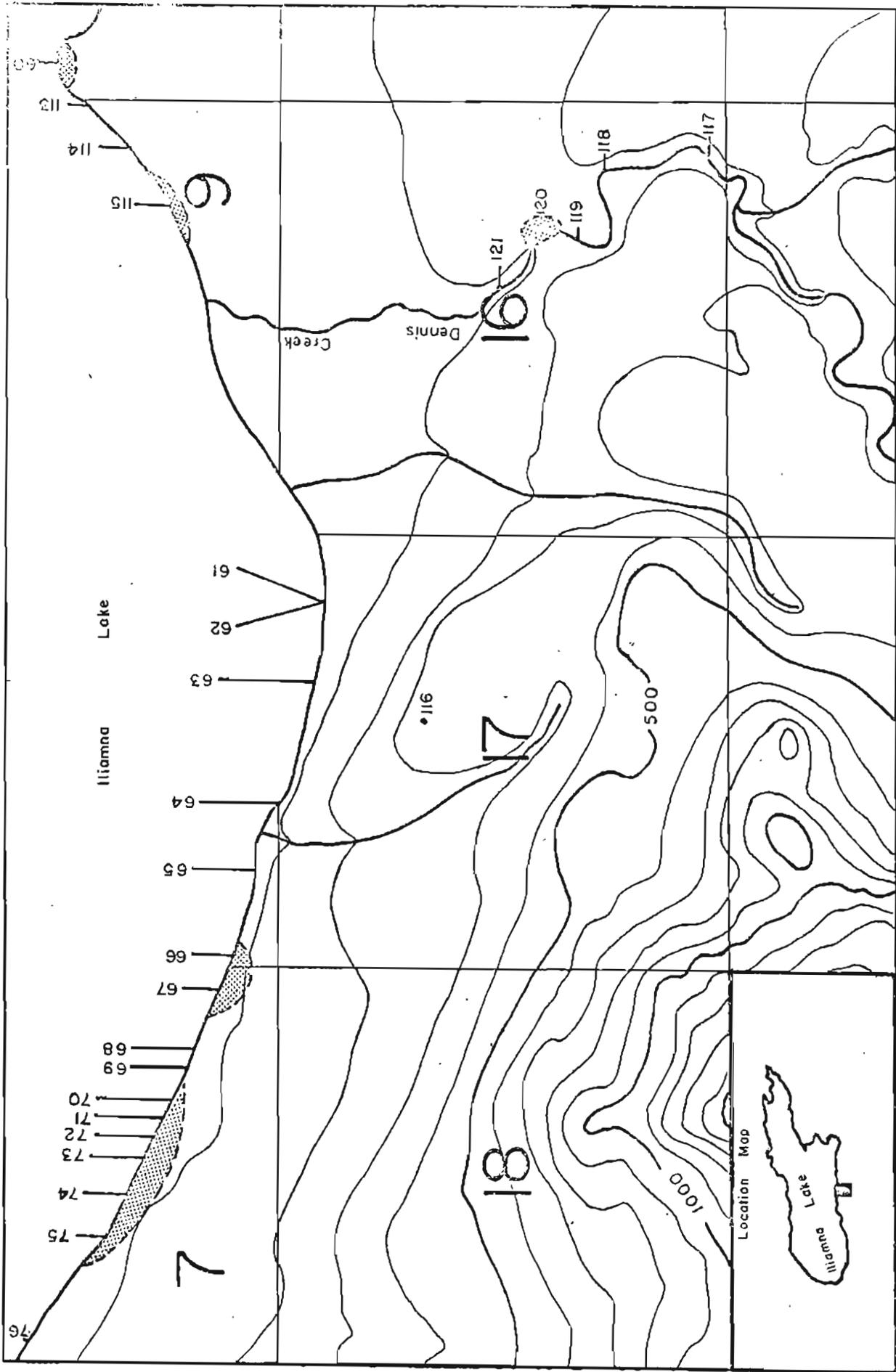
Zeolitized Units.

Figure 5. Zeolitized Units in the Dennis Creek Area.

Scale
1-mile

Location Map

Iliamna Lake

Dennis Creek

Iliamna Lake

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during this investigation indicate high percentages of mordenite in all but one case (Table 1). In the exception, clinoptilolite (#93) rather than mordenite was detected. From studies of pyroclastic rocks in Japan, Utada (1971) found that the occurrence of these two zeolites in the same rocks is not uncommon.

The large areal extent, extreme thickness and high percentage of zeolites in this volcanic sequence suggest that it has a high economical potential and should be considered as a future source of mordenite and possibly clinoptilolite.

A light-gray heulandite bearing tuff (#94) outcrops in a drainage above and to the north of the mordenite bearing volcanics. The tuff bed is thirty feet high and approximately one-hundred feet long. Examination of the material indicates that it is only moderately zeolitized. However, if the lower volcanic unit should be mined, this bed may become a convenient source of heulandite.

To the south two felsic welded tuffs are exposed. One on Tommy Creek (#95) and the other on a nearby tributary (#96). Sample 95 contains minor laumontite and #96 minor heulandite. Neither of these appear to have economic potential.

Intricate Bay: Intricate Bay is composed of numerous low lying islands and micro-bays. Table 1 shows that most of the samples of tuff selected from this area are zeolitized. Heulandite, clinoptilolite and mordenite were identified by X-ray diffraction. Additional tests as shown in Table 1 indicate that sample 85 contains significant amounts of clinoptilolite and 87 and 89 contain abundant mordenite. However, the tuff beds are low lying, rising, at the most, ten feet above lake level. This is probably the main factor which would prohibit profitable utilization of this material. On the other hand, this was only a preliminary investigation of Intricate Bay. Possibly, a more thorough examination of hills and rises visible a short distance from the lake shore would reveal more extensive zeolite deposits.

Big Mountain-Dennis Creek: Outcrops of white and light green tuffs exposed on the lake shore near Dennis Creek and Big Mountain contain notable quantities of clinoptilolite and heulandite. The distribution of the more important zeolitized units are shown in Figure 5. Because of the dense foliage in the area it was not possible to obtain the areal dimensions of the deposits.

Samples 61 through 76 were selected from a sixty foot outcrop of graded felsic tuff exposed along the lake shore. Examination of the samples revealed heulandite in only minor amounts. The deposit does not appear to be of economic value.

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Examination of several lithologic units in the Dennis Creek drainage revealed a green and pink welded tuff (#120) which contains a moderate amount of heulandite. The unit is sixty feet high and approximately fifty feet long. The local extent of the tuff combined with its distance from the lake (Figure 5) would prohibit profitable use of the deposit.

Results of tests on sample numbers 60 and 115 reveal that this material is among the most highly zeolitized tuffs examined from the Iliamna area. X-ray diffraction scans suggest that clinoptilolite is the predominant mineral. Heavy liquid separations and the field test both confirm the high concentration of clinoptilolite. The tuff from which sample 60 was selected is approximately twenty feet high and extends for one-hundred feet along the lake shore. Similarly, the tuff bed from which sample 115 was selected is fifteen feet high and extends approximately one-hundred feet along the lake shore. Unfortunately, the foliage obscures the width of these deposits and prevents a more thorough evaluation. However, because of the high concentration of zeolites in these samples they should not be overlooked as a possible source of clinoptilolite.

Chinitna Bay: Examination of the Chinitna Formation exposed on the west side of Chinitna Bay, during the 1973 field season, revealed the presence of laumontite in a four foot thick medium gray sandstone bed. X-ray examination suggested a high percentage of laumontite accompanied by minor quartz.

In addition to the laumontite bearing unit, zeolites were detected by D. B. Hawkins in a sample of welded tuff collected by J. Kienle from the Kenai Formation exposed on the northern shore of Chinitna Bay (personal communication, 1973).

Time did not permit a thorough examination of the Chinitna Bay area, in 1973, however, a more thorough examination of the area was carried out in 1974.

Detterman and Hartsock (1966) have presented the bedrock geology of the area, which is divided into several distinct formations. Those examined during the 1974 field season include the Lower Jurassic Talkeetna Formation, the Late Jurassic Chinitna and Naknek Formations and the Tertiary Kenai Formation.

The Talkeetna Formation consists of 5,900 to 9,000 feet of bedded volcanic rocks which grade from interbedded tuff and tuffaceous sandstone in the upper units to massive agglomerates, volcanic breccia and lava flows near the lower extremities.

Several samples, which exhibit characteristics favorable for zeolite formation, were selected from the Upper Horn Mountain Tuff Member which is well exposed on Horn Mountain (Figure 6). Results of tests show that each sample contains laumontite but in such low concentrations as to prohibit profitable industrial utilization of the material.

The Chinitna and Naknek Formations consist collectively of from 3,500 to 7,800 feet of conglomerates, sandstones and siltstones. Several samples were selected from outcrops near Clam Cove on the north shore of Chinitna Bay and Sea Otter Point on the south shore (Figure 2). X-ray and thermal examinations indicate that most of the samples contain either laumontite or heulandite. However, the field tests suggest that concentrations are below economic proportions (Table 2).

The Kenoi Formation is composed of approximately 1,000 feet of Tertiary conglomerates, sandstones and siltstones. An easily accessible exposure occurson the sea shore one and one-half miles east of Clam Cove (Figure 6). The outcrop is characterized by a twenty-foot thick brown siltstone bed positioned unconformably between two relatively coarse conglomerate beds. An additional characteristic is the presence of several well preserved trees which span the thickness of the siltstone bed but do not extend into the conglomerate units. Locally exposed near the base of the siltstone is a thin linticular bed of carbonaceous ash stone ranging up to two feet in thickness. The unit is exposed for approximately 100 yards on the shore line but is concealed from view by foliage inland. However, it is suspected to have a comparatively large lateral extent.

Examination of both the ash stone and the siltstone revealed the presence of heulandite. Most samples contained between 90 and 100 percent low specific gravity material and a moderate to high temperature change. This combined with its' respectable thickness and suspected large lateral extent suggests that the deposit may be of economic value.

GENESIS OF THE DEPOSITS

Tuffs, tuffaceous sediments and other volcanics, condusive to zeolite formation, exposed along the shoreline, on the islands and in the mountains adjacent to Iliamna Lake, are assigned to the Tertiary Period (Detterman and Reed, 1968). The formation of zeolites in these Tertiary rocks is inherent in the overall depositional and tectonic history of the Alaska Peninsula during that time. The close of the Cretaceous was gentle as indicated by the slight disconformable contact with overlying Tertiary rocks. The Tertiary tectonic history was not one of extensive orogenic activity; the Alaska Peninsula did not become an orogenic mountain system until the Late Pliocene. Prior to this time it was basically an area of deposition which derived its topographic relief from brief vertical movements associated with igneous intrusions and obtaining its crustal thickness from massive accumulation of volcanic debris. The volcanic debris was weathered, abraded,

transported and deposited in both marine and non-marine environments (Burke, 1965).

In the Iliamna Lake area Detterman and Reed (1968) report the presence of thick sequences of non-marine, Tertiary, volcanic siltstones, sandstones and conglomerates interlayered with volcanic flows and tuffs. Examples of these water laid tuffs and reworked volcanics are exposed in numerous outcrops on the lake shore and are inter-layered with Tertiary non-marine sediments exposed on the south shore. Tertiary vitric tuffs, exposed in the mountains adjacent to the lakes southern shore, however, do not exhibit any of the characteristics typical of water laid tuffs. This combined with their high elevation suggest deposition in a terrestrial rather than aqueous environment.

The zeolite deposits at Iliamna Lake were formed by the alteration of volcanic material. X-ray examinations revealed the presence of clinoptilolite, mordenite, heulandite and minor laumontite. Finally, the volcanic material was deposited in ter-restrial and non-marine aqueous environments. These three parameters, mode of occur-rence, mineralogy and depositional environment suggest that the Iliamna zeolites were produced from volcanic material in "open" systems of fresh water lakes and ground water systems (type 2 page 6) which transform volcanic vitric material into zeolite minerals. These deposits are characterized by the presence of clinoptilolite and mordenite, and the absence of "closed" system zeolites such as erionite and chabazite. Subsequent buriel of early formed low temperature-pressure clinoptilolite and mordenite appears to have been responsible for alteration into higher temperature-pressure forms. The sequence of formation found in piles of volcanic material in other parts of the world are, from low to high pressure and temperature: A) fresh glass, B) clinoptilolite-mordenite, C) analcime heulandite, and D) laumontite. Assemblages representing these four zones have been detected in the Iliamna area. In addition, sample number twelve contains both heulan-dite and laumontite which would be typical of the assemblage representing the isograd between the two stability fields. This suggests that buriel diagenesis has been responsible for the formation of high temperature-pressure zeolites at the expense of the lower temperature-pressure varieties.

The laumontite and heulandite bearing units in the Chinitna Bay area fit the type 4 mode of zeolite formation presented by Mumpton ($\natural \mathbf{9:93}$): formation by low-grade buried metamorphism of thick sedimentary sequenced in which laumontite is produced at the expense of low density, more hydrous zeolites such as heulandite, as well as other silicate minerals.

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TRANSPORTATION

The rugged topography and distance (180 miles) from Anchorage has made air the only practical means of transporting passengers, freight and mail to Iliamna Lake. Flights from Anchorage to Iliamna are scheduled three times a week. The aircraft stops at Iliamna and Big Mountain, then returns to Anchorage. Air and water transportation is available in Iliamna for passengers and supplies traveling to other points on the lake.

A limited amount of freight is transported to Pile Bay village first by water from Anchorage and/or Homer then across 14 miles of gravel road which connects Iliamna Bay, on the coast, with Pile Bay Village on Iliamna Lake (Figure 2). The road is maintained, between May and October each year, by the Alaska State Highway Department for portage of fishing boats from Cook Inlet to Iliamna Lake where they proceed by water to Bristol Bay. A steel bridge has been constructed across Iliamna River which is intersected by the thoroughfare. In addition to the road maintenance, petroleum products are available at both terminals with the added convenience of a garage adapted to heavy equipment and boat repair located at Pile Bay village.

Transporting ore from Iliamna Lake could be achieved by loading the ore into portable dump beds and carrying them, by barge, up the lake, to Pile Bay Village. The portable beds could then be loaded directly onto trucks for transport to Iliamna Bay. Here the ore could be stored in holding bins or loaded directly on ships for delivery to Anchorage or other ports.

It is doubtful that shipping problems would be encountered transporting the ore from the mine to Pile Bay Village or across the road which is capable of handling several hundred tons of ore per day. However, loading problems may result from tides which leave Iliamna Bay dry for several hours each day.

CONCLUSIONS

Zeolite deposits of possible economic importance exist in the Iliamna Lake area. Most important are: 1) a heulandite bearing, waterlaid tuff on Agate Island, 2) a thick sequence of terrestrial volcanics containing mordenite and clinoptilolite located between Squirrel Point and Tommy Creek, 3) waterlaid tuffs containing extremely high concentrations of clinoptilolite near Dennis Creek, and 4) a heulandite bearing siltstone at Chinitna Bay.

The deposits in the Iliamna Lake area were formed in an "open" system of fresh water lakes and ground water which transform volcanic vitric material into zeolites.

Buriel diagenesis was responsible for altering early formed low-pressure, low-temperature zeolites into more stable high-pressure high-temperature members.

The formation of laumontite and heulandite at Chinitna Bay was the result of low grade buriel metamorphism in thick sedimentary sequences.

Transporting ore from Iliamna Lake can be achieved by barging the material up the lake to Pile Bay Village then trucking across the road which connects with Iliamna Bay and then by ship to the consumer. At Chinitna Bay the material would be loaded directly on ships.

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Table 1

Results of Tests on Individual Samples
See Figure 2 for Collection Point of each Sample.

Sample Number	Rock Type	% less than 2.4 sp.gr.	Field Test ΔT in °C	Zeolites Present
1	Tuffaceous sandstone	W.R.	4.0	Laumontite
2	Fracture filling	W.R.	–	Thompsonite Chabazite
3	Cavity filling (andesite)	W.R.	–	Water Rich Heulandite
4	Andesite	19	–	–
5	Tuff	99	12.0	Heulandite
6	Reworked volcanics	89	5.0	Heulandite
7	Tuff	17	–	–
8	Tuff	9	–	–
9	Tuff	33	4.0	Clinoptilolite
10	Tuff	14	–	–
11	Tuff	45	3.5	Laumontite
12	Reworked volcanics	42	4.0	Laumontite Heulandite
13	Tuff	59	–	–
14	Tuff	11	–	–
15	Reworked volcanics	12	3.0	Heulandite
16	Reworked volcanics	76	4.5	Heulandite
17	Andesite	6.5	–	–
18	Andesite	37	–	–
19	Andesite	40	4.0	Laumontite
20	Reworked volcanics	4.1	2.0	Heulandite
21	Tuff	98	7.0	Heulandite
22	Reworked volcanics	33	3.5	Heulandite
23	Reworked volcanics	10	3.0	Heulandite
24	Tuff	5	–	–
25	Reworked volcanics	99	6.0	Mordenite
26	Reworked volcanics	50	–	–

Table 1
Continued

Sample Number	Rock Type	% less than 2.4 sp.gr.	Field Test ΔT in °C	Zeolites Present
27	Reworked volcanics	61	5.0	Clinoptilolite
28	Tuff	8.3	-	-
29	Reworked volcanics	4.3	-	-
30	Tuff	13	-	-
31	Rhyolite	14	3.0	Heulandite
32	Tuff	28	-	-
33	Reworked volcanics	5.0	-	-
34	Tuff	4.8	-	-
35	Reworked volcanics	3.3	-	-
36	Reworked volcanics	1.7	-	-
37	Conglomerate	1.1	-	-
38	Tuff	2.6	-	-
39	Tuff	1.9	-	-
40	Tuff	3.5	-	-
41	Tuff	5.5	-	-
42	Andesite	29	3.0	Laumontite
43	Tuff	50	-	-
44	Tuff	84	6.0	Mordenite
45	Reworked volcanics	1.3	-	-
46	Andesite	13	-	-
47	Tuff	84	-	-
48	Andesite	1.6	-	-
49	Tuff	0.5	-	-
50	Tuff	2.3	-	-
51	Tuff	0.5	-	-
52	Andesite	0.5	-	-
53	Reworked volcanics	6.3	-	-
54	Andesite	11	3	Clinoptilolite
55	Tuff	7.8	-	-

Table 1

Continued

Sample Number	Rock Type	% less than 2.4 sp.gr.	Field Test ΔT in °C	Zeolites Present
56	Tuff	97	9.0	Mordenite
57	Sandstone	29	4.5	Clinoptilolite
58	Tuff	54	7.0	Clinoptilolite
59	Reworked volcanics	83.5	-	-
60	Tuff	100	12.0	Clinoptilolite
61	Tuff	31	-	-
62	Tuff	89	-	-
63	Tuff	32	-	-
64	Tuff	39	-	-
65	Tuff	45	-	-
66	Tuffaceous sandstone	29	3.0	Heulandite
67	Tuff	4.5	2.0	Heulandite
68	Andesite	19	-	-
69	Tuff	19	-	-
70	Tuff	45	3.0	Heulandite
71	Tuff	23	-	-
72	Tuff	55	3.0	Heulandite
73	Tuff	30	3.0	Heulandite
74	Tuff	84	4.0	Heulandite
75	Tuff	38	4.0	Heulandite
76	Tuff	36	-	-
77	Tuff	14	-	-
78	Reworked volcanics	18	-	-
79	Tuff	23	-	-
80	Tuff	40	-	-
81	Tuff	40	-	-
82	Tuff	62	7.0	Mordenite
83	Tuff	85	5.0	Heulandite

Table 1
Continued

Sample Number	Rock Type	% less than 2.4 sp.gr.	Field Test ΔT in °C	Zeolites Present
84	Tuff	52	-	-
85	Tuff	99	10.0	Clinoptilolite
86	Tuff	85	-	-
87	Tuff	74	9.0	Mordenite
88	Tuff	52	3.0	Heulandite
89	Tuff	84	8.0	Mordenite
90	Rhyolite cavity fillings	71	-	-
91	Tuff	72	10.0	Mordenite
92	Tuff	79	11.0	Mordenite
93	Tuff	74	7.0	Clinoptilolite
94	Tuff	70	5.0	Heulandite
95	Tuff	36	2.5	Laumontite
96	Tuff	38	3.0	Heulandite
97	Tuff	85	10.0	Mordenite
98	Reworked volcanics	99	9.0	Clinoptilolite
99	Tuffaceous sandstone	64	4.0	Clinoptilolite
100	Reworked volcanics	95	5.0	Clinoptilolite
101	Reworked volcanics	93	3.5	Heulandite
102	Tuff	97	8.0	Mordenite
103	Breccia	66	4.0	Clinoptilolite
104	Sandstone	15	-	-
105	Mudstone	100	-	-
106	Tuffaceous sandstone	37	4.0	Clinoptilolite
107	Tuffaceous sandstone	50	4.0	Heulandite
108	Tuffaceous conglomerate	24	4.5	Heulandite
109	Reworked volcanics	50	-	-
110	Tuff	94	7.0	Mordenite
111	Andesite	74	-	-
112	Tuff	99	12.0	Mordenite

Table 1

Continued

Sample Number	Rock Type	% less than 2.4 sp.gr.	Field Test ΔT in °C	Zeolites Present
113	Ignimbrite	93	−	−
114	Fracture filling	96	−	−
115	Tuff	94	13.0	Clinoptilolite
116	Tuff	29	−	−
117	Tuff	59	−	−
118	Tuff	59	−	−
119	Rhyolite	66	−	−
120	Tuff	96	7.0	Heulandite
121	Tuff	88	−	−
122	Tuff	26	−	−
123	Tuff	38	3.0	Heulandite
124	Rhyolite	W.R.	−	−

Table 2

Results of Tests on Samples Collected at Chinitna Bay in 1974.

Sample Number	Rock Type	% less than 2.4 sp.gr.	Field Test Δ T in °C	Zeolites Present
C-1	Siltstone	98	9°C	Heulandite
C-2	Tuff	92	13°C	Heulandite
C-3	Tuff	43	13°C	Heulandite
C-4	Tuff	93	10°C	Heulandite
C-5	Siltstone	98	11°C	Heulandite
C-6	Siltstone	90	12°C	Heulandite
C-7	Siltstone	98	11°C	Heulandite
C-8	Sandstone	35	6°C	Laumontite
C-8'	Sandstone	30	5°C	Laumontite
C-8"	Siltstone	76	–	–
C-9	Sandstone	31	4°C	Laumontite
C-10	Sandstone	50	3°C	Heulandite
C-11	Sandstone	42	4°C	Laumontite
C-11'	Sandstone	18	4°C	Haulandite
HM-1	Tuff	72	4°C	Laumontite
HM-2	Tuffaceous S.S.	41	4°C	Laumontite
HM-3	Andesite	3	3°C	Laumontite