NATURAL ZEOLITES IN WYOMING

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by
Jon K. King and Ray E. Harris

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By
Ray E. Harris

INTRODUCTION

Zeolite is the name for a group of chemical compounds that have a wide variety of applications, from kitty litter to petroleum refining. Natural zeolites are a development opportunity for the state of Wyoming, similar to that of trona prior to establishment of Wyoming's trona industry in the 1950s. That is, an opportunity exists to mine a less expensive natural product as a substitute for one produced synthetically (see the trona example in Harris, 1984). In addition to this report, several efforts are presently needed to promote the development of Wyoming's zeolite resources. These include: 1) documentation of the beneficial properties of specific Wyoming zeolites (like Hulbert, 1987); 2) basic exploration in Tertiary rocks for new zeolite deposits; 3) a more complete assessment of the extent and grade of zeolite deposits in the state; and 4) a marketing plan that will enable natural zeolite products from Wyoming to fill the growing demand for chemical and radioactive pollution control, and to possibly compete with the synthetic zeolite industry (see for example Mumpton, 1988; Eyde and Eyde, 1984).

The first zeolite mineral was recognized in 1756, when the Swedish mineralogist, Cronstedt, discovered the mineral stilbite. He coined the word zeolite from two Greek words that roughly mean boiling stones; an allusion to the frothing that is characteristic when zeolites are heated with a mineralogist's blowpipe (Mumpton, 1978).

Until this century, zeolites were little more than a curiosity. In the 1930s and continuing into the 1950s many experiments were performed on natural zeolites in order to determine their physical and chemical properties (Mumpton, 1978). Since the early 1950s, the emphasis has shifted towards research on synthetic zeolites. Most of the zeolites used by industry are synthetic (see for examples Clifton, 1987). Because of the expense of synthetic zeolites and expanding applications for zeolites, like isolation of chemical and radioactive waste, an interest remains in natural zeolites. The potential also exists to inexpensively alter natural zeolites to perform the tasks of entirely synthetic zeolites. Research is also needed on the beneficiation of natural zeolite deposits.

Natural zeolites are found in a variety of igneous rocks, and in sedimentary rocks that originally contained a high percentage of volcanic glass. They form during devitrification and alteration of glass and aluminosilicate minerals. For technical reviews of the various origins of natural zeolites, see Hay (1978), Hay and Sheppard (1977), Surdam and Sheppard (1978), Boles and Surdam (1979), Iijima (1980), and Gottardi (1989).

In addition to the specific references cited in this report, several general publications on zeolites are useful. Books by Gottardi and Galli (1985), and Breck (1974) are comprehensive yet readable treatments of the chemistry and structure of natural and synthetic zeolites, respectively. The books edited by Mumpton (1977), Sand and Mumpton (1978), and Kallo and Sherry (1988) are quality collections of information on the origins, occurrences, properties and uses of natural zeolites. The best short publication on zeolites is Olson and others (1983). New information on natural zeolites is available periodically in the *Proceedings of the International Zeolite Conferences*, the *Journal of Clays and Clay Minerals*, and *Zeolites, The Journal of Molecular Sieves*.

The remainder of this report is divided into five sections: 1) zeolites and their properties; 2) uses of natural zeolites; 3) exploration for natural zeolites; 4) natural zeolite production; and 5) locations and descriptions of natural zeolite mineralization in Wyoming.

ZEOLITES AND THEIR PROPERTIES

Natural zeolite minerals and synthetic zeolites are aluminosilicate compounds that have a porous structure that permits small molecules and ions to enter and leave the zeolite. These molecules and ions can enter and be adsorped into the zeolite, and under proper conditions some can leave the zeolite through desorption. This characteristic adsorption and desorption, and porous structure gives rise to the name "molecular sieve" for zeolites. These properties impart economic value to zeolites. Summaries of the properties of natural zeolites are in Vaughn (1978), and Ma and Lee (1978).

More specifically, zeolite minerals are hydrated aluminosilicates of alkali and alkaline earth metals. Silicon-aluminum-oxygen tetrahedra $\{(Si,Al)O_4\}$ form an open aluminosilicate framework in zeolites. This porous framework has relatively large channels and cavities, so ions and small molecules may pass through without disrupting the framework. The negative charge of the tetrahedra is balanced by loosely bound alkali and alkaline earth metals, which occupy but do not fill the cavities in the framework. These openings and loose binding enable ion exchange and molecular adsorption to take place. Water is present within the framework channels, and is loosely bound to the metals and the framework; so the water can also be removed. These characteristics give zeolites their remarkable ability of nearly totally reversible dehydration, partially reversible base exchange, as well as ion and molecular adsorption (Deer and others, 1967).

The natural zeolites and their chemical formulas are listed in Table 1. The chemical formulas for some zeolite minerals are not precisely defined; the formulas shown in the table are those that are generally accepted. Though analcite is commonly included as a member of the zeolite group of minerals, it has closer affinities to feldspathoids and may have a somewhat higher temperature of formation (Deer and others, 1967). Also, the ion exchange and hydration capacity of analcite is lower than the other zeolites (Breck, 1983). For this reason, analcite seldom has a commercial value.

Several factors control the characteristics of zeolites. The narrowest portion of the channels controls the size of the ion or molecule that can be adsorbed. Zeolites are sometimes classified on the basis of this minimum aperture and the orientation of the channels. Synthetic zeolites usually have larger apertures than natural zeolites. This makes them suitable for hydrocarbon catalysis and large molecule adsorption, which endows them with greater commercial value. The common natural zeolites chabazite, erionite and mordenite also have relatively large apertures. In general, calcium zeolites have larger apertures than sodium zeolites, which have larger apertures than potassium zeolites. Calcium zeolites commonly adsorb more water, while sodium zeolites have a higher cation exchange capacity. The cation exchange capacity of zeolites, in general, decreases with water loss and with an increasing number of cations in the framework. In addition to differential cation exchange, the different aperture sizes and cation composition (Ca vs. Na vs. K) impart two more beneficial properties to zeolites. These are the ability to separate molecules and ions on the basis of aperture size, and selective adsorption of polar and unsaturated molecules (after Deer and others, 1967; Breck, 1984).

Natural erionite and mordenite have acicular to fibrous habits, with aspect ratios (length to circumference) that are usually equivalent to cleavage fragments of amphiboles. Therefore, they do not have the size and shape characteristics of asbestos fibers, and probably do not constitute a health threat. Only rare wooly erionite, known from one site in Nevada, has an aspect ratio similar to asbestos (Shedd and others, 1982).

USES OF NATURAL ZEOLITES

Because natural zeolites are molecule and ion adsorpers and exchangers, they can be used to remove unwanted molecules and ions from the environment. Japan has been the pioneer in finding uses for natural zeolites. Uses range from kitty litter and barnlot deodorizers to toxic element adsorpers in heavy-metal waste control and environmental cleanup operations, to radioactive element isolation. Zeolites can also be used in many other applications, as shown in Table 2. New uses for natural zeolites are continually being developed. Mumpton (1978), Flanigen (1980), Pond and Mumpton (1984), and Minato (1988) provide good reviews of the applications and potential uses of natural zeolites. In the late 1980s, new demand in the United States has been for natural zeolites in sewage treatment, heavy metal and radioactive element isolation, and as a filler and whitening agent in paper. In Wyoming, the gas purification properties of natural zeolites might be used in coal gasification to provide an oxygen-enriched combustion gas, and then to clean the gas produced during gasification. Natural zeolites could also be used to clean coal bed methane prior to introduction into natural gas pipelines.

EXPLORATION FOR NATURAL ZEOLITES

Extensive exploration for large deposits of natural zeolites began in the western United States in the late 1950s, when the Linde Division of Union Carbide Corporation began a search for minable zeolites as potential replacements and competition for their patented synthetic zeolites. Linde's consultants did not then believe that minable quantities of zeolites would be found. Their emphasis was on finding the natural zeolites chabazite, erionite and mordenite, which have apertures as large as some synthetic zeolites. By the start of the 1960s, several large deposits of relatively pure natural zeolites had been located in pyroclastic volcanic and volcano-sedimentary rocks. Exploration in Wyoming at this time was limited because chabazite, erionite and mordenite were reportedly rare in the state. Later in the 1960s and through the 1980s, only a few additional extensive deposits of zeolites were discovered in the western United States. The largest of these were in Wyoming. Exploration for natural zeolites in the 1980s mostly encompassed reevaluation of previously known deposits by determining grades, lateral extents and identifying beneficial properties of specific deposits (after Mumpton, 1984; Leppert, 1990; Holmes, 1990).

Sheppard (1973) noted that it is difficult to prospect for zeolites. Natural zeolites are most abundant in altered vitric tuffs. Altered tuffs are earthy rather than glassy looking. However, this earthy look can be due to zeolites as well as clays formed during alteration. Vitric tuffs are those which originally contained myriad glass particles with little diluting material, such as rock fragments, quartz and feldspar grains, and clays. Dilution often accompanies reworking of tuffs. So volcanic rocks, like air-fall tuffs, tend to be more vitric than volcano-sedimentary rocks, like water-laid tuffs. This generalization does not preclude the existence of zeolite deposits in volcano-sedimentary rocks. In fact, many zeolite deposits are in rocks that were deposited in a lacustrine environment where little sediment other than tuff was deposited in the lake. In Wyoming, portions of Eocene, Oligocene, Miocene, and Pliocene units contain lacustrine altered vitric tuffs. Potential and known hosts units are listed in Table 3. Even with these clues, it is almost impossible to identify a zeolite in the field. An X-ray diffractometer is needed to positively identify a zeolite, and this analysis would also supply semiquantitative abundance data. A truck mounted unit would be an advantage, because it could be brought to the exploration site for quicker evaluation of samples. Alternatively or in conjunction with X-ray analysis, a portable field spectrometer, that measures electromagnetic radiation in the visible and near-infrared portions of the spectrum, might be used to identify zeolite-rich rocks.

NATURAL ZEOLITE PRODUCTION

China led the world in natural zeolite production in 1999, followed by Cuba, Japan, the United States, Hungary, Slovakia, Georgia, New Zealand, Greece, and others. The estimated production of the world was about 4, 500,000 short tons (Virta, 2000). World production has doubled in the pas ten years.

Natural zeolites were mined in Arizona, California, Idaho, Nevada, New Mexico, Oregon, and Texas in the last two years. Zeolites were mined in Wyoming in the mid 1990s, and stockpiled at a location in Utah. Addwest minerals, the owner of the zeolite mining operation is studying markets and investments before considering additional mining.

Demand for natural zeolites could be increased without the discovery of any new uses. This increase could be created by promotion, standardization and improvement of the product. Natural zeolites need advertising with a marketing network and established prices for standardized zeolites. Testing standards need to be developed for natural zeolites, in order to demonstrate the specific beneficial properties of each zeolite deposit (for examples, see Sheppard and Gude, 1982; Mumpton, 1988). When a zeolite deposit has been evaluated by standard tests, buyers will know the exact and consistent properties of this natural zeolite product, just like they now know the standardized properties of synthetic zeolites. This should promote more competition of natural zeolites with their synthetic counterparts. The natural product would be improved if beneficiation methods could be found for natural zeolites. At present, natural zeolites can not be efficiently separated from other materials in altered tuffs, for example from clays. In addition, one zeolite mineral can not be separated from another at present. Production would also be enhanced if processes were found to modify natural zeolites to improve their performance.

As shown in Table 5, the interest in the United States is no longer restricted to the zeolites chabazite, erionite and mordenite. Therefore the abundant and rich clinoptilolite deposits in Wyoming warrant further investigation.

NATURAL ZEOLITE MINERALIZATION IN WYOMING

Wyoming contains several large deposits of potentially minable zeolites and numerous zeolite mineral occurrences (Figure 1). Potentially minable zeolites include, in order of importance, the clinoptilolite deposits at Fort LaClede (locality 68) in the Washakie Basin and along the Beaver Rim (locality 21), and possibly those on Lysite Mountain (locality 39).

Basic exploration might unearth extensive zeolite-bearing rocks elsewhere in the Washakie Basin (like localities 67 and 69); around the Sierra Madre in the Browns Park Formations (like localities 9-13); near Twin Buttes and elsewhere in the Green River Basin in the Bridger Formation (like localities 70-72); near Green River in the Green River Formation (like locality 73); and around the Granite Mountains where the Split Rock (like locality 51), Moonstone (like locality 50) and Bug (locality 52) Formations are exposed.

Other occurrences of zeolites are present in a variety of rocks. Up to 60 percent analcite is present in the Popo Agie Member of the Triassic Chugwater Formation; but no demand exists for analcite at the present time. Zeolites are present in the Mowry, Thermopolis, Steele and Pierre Shales, and Aspen and Frontier Formations in bentonitic and non-bentonitic material, mostly as analcite. Davis (1967a) reported that the silt fraction of Mowry bentonites contain a trace to 80 percent clinoptilolite. However, Slaughter and Early (1965) show only two bentonite samples (Greybull, locality 2; Ethete, locality 25) with greater than 1 percent zeolite in the total sample. Zeolites are present in igneous rocks in the Absaroka and Yellowstone volcanic provinces, in the Black Hills alkaline igneous province and in Jackson Hole. Zeolites are probably far more widespread in these provinces than the scattered occurrences listed in this report. Zeolites have also been reported in more clastic sedimentary Tertiary Formations such as the Wasatch, Wind and White River Formations.

The following list of zeolite mineralization in Wyoming is by county; the county order is alphabetical. The most important sites within a county are listed first. Some of these sites are no more accurately located than the description given within the listing. If the legal location is known, it has been given. Numbers by each locality in the list correspond to the numbers on the index map, Figure 1. Re-examination of many of these localities is needed because information on the percentages of zeolites and thicknesses of the zeolitic zones has not been confirmed.

Albany County

1) Middle Fork Chugwater Creek; sec. 25, T.19N., R.71W.

Davis (1967a,b) reported that phillipsite was present in one sample of shale taken from this stratigraphic section in the Mowry Shale. The zeolite was positively identified by X-ray methods (Davis, 1967a).

Big Horn County

2) Greybull area; S1/2 T.53N., R.92W.

Slaughter and Early (1965) reported that most samples of bentonite from this stratigraphic section in the Mowry Shale (Cretaceous) contained less than 1 percent analcite. They reported that a single sample did contain 1.22 percent analcite.

3) Magcobar properties, near Greybull; sec. 17, T.53N., R.92W.

Davis (1967a,b) reported that analcite and clinoptilolite, and possibly phillipsite are present in some samples taken from this stratigraphic section in the Thermopolis and Mowry Shales. Phillipsite (?) alone was present in a dark-gray, tan-weathering, soft Thermopolis Shale. Phillipsite (?) and clinoptilolite were present in samples of two separate "typical" Mowry Shales. Clinoptilolite alone was present in samples of two separate, non-siliceous Mowry Shales. Analcite alone was present in a very soft shale in the Mowry Shale (Davis, 1967a,b). The zeolites were identified by X-ray methods (Davis, 1967a).

4) Hyattville area; N1/2 T.49N., R.90W.

Slaughter and Early (1965) reported that samples of bentonite from this stratigraphic section in the Mowry Shale (Cretaceous) contained less than 1 percent analcite. Yet, this site is listed as a zeolite occurrence by Sheppard (1971a, 1971b, 1976).

5) near Hyattville; sec. 32, T.49N., R.90W.

Davis (1967a,b) reported that clinoptilolite was present in two samples of shale that might be bentonitic. The samples were taken from this stratigraphic section in the Mowry Shale (Davis, 1967a,b). The zeolite was identified by X-ray methods (Davis, 1967a).

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6) Cowley area; sec. 31, T.58N., R.95W.

Davis (1967a,b) reported that analcite was present in a sample of siliceous shale taken from this stratigraphic section in the Mowry Shale. The zeolite was identified by X-ray methods (Davis, 1967a).

7) Lovell area

Bentonite in the Cretaceous Mowry and Thermopolis Shales reportedly contains clinoptilolite (Wolfbauer oral communication, 1974 in Sheppard, 1976).

Campbell County

8) North Butte; SW1/4 sec. 13, T.44N., R.76W.

A sandstone in the Eocene Wasatch Formation on the southeast flank of the North Butte of the Pumpkin Buttes reportedly contains small amounts of heulandite (Vine and Tourtelot, 1973). Minobras (1975) adds clinoptilolite to the description, but no data support this.

Carbon County

9) Beaver Creek area; secs. 18 and 19, T.17N., R.86W.; secs. 13, 14, 23 and 24, T.17N., R.87W.; and the surrounding area.

A sample of light blue tuff, taken from this area by staff from the University of Wyoming Botany Department, was analyzed by X-ray diffraction at the Wyoming

T-9
Beaver Creek area
sec. 13, 14, 23, 24
T 17N
R 87W

State Geological Survey. The sample contained over 90 percent clinoptilolite, a little heulandite, and minor biotite, illite and chlorite. The exact sample site within the area listed above is not known. But the entire area is in the Browns Park Formation (Miocene). It was taken from the University of Wyoming sagebrush research station in an area on which no sagebrush was growing. At the legal location listed above and within a radius of two miles, there are several outcrops of blue tuff that are several feet thick. These tuffs are especially prominent on air photos. These data indicate that a large quantity of high purity clinoptilolite might be present in the Browns Park Formation on the north margin of the Sierra Madre.

10) Saratoga area; roughly sec. 12, T.17N., R.84W.

Clinoptilolite and phillipsite were reported in a tuff in the Miocene Browns Park Formation near Saratoga (Surdam, 1972). Minobras (1975) gives the legal location. This location is suspiciously close to the town of Saratoga, and would place the occurrence in the North Park Formation. Sheppard (1976) notes that the host bed is at least 1 foot thick and contains at least 75 percent zeolite. Surdam (1972) might have been referring to Ebens' (1966) Pick Ranch site (locality 11) when calling the site the Saratoga area.

11) Pick Ranch; secs. 8, 16 and 17, T.18N., R.84W.

Clinoptilolite and another zeolite, possibly phillipsite, were identified by X-ray methods in an altered, grayish-green tuff (unit PR 20) in the Browns Park Formation (Miocene) on the ranch. The description implies the tuff contains less than 10 percent zeolite (Ebens, 1966). Ebens (1966) reported numerous other tuffaceous units in southeastern Wyoming, but did not examine them for zeolites.

12) Pick Bridge; sec. 10, T.18N., R.84W.

A sample of white tuffaceous sediment from the Miocene Browns Park Formation taken by the Wyoming State Geological Survey just east of Pick Bridge on the north side of the county road contained about 20 percent clinoptilolite. Other phases identified in this sample include quartz, plagioclase, calcite, and muscovite.

13) Poison Basin area; sec. 36, T.13N., R.93W.

A sample from this section was analyzed by X-ray diffraction and found to contain heulandite (Gruner and others, 1956). As located this site is in the Browns Park Formation. This information, coupled with the other Browns Park localities, indicates that zeolite occurrences in the Browns Park Formation are very widespread.

14) West of Medicine Bow (historic Wilkinite mining area); secs. 3, 4 and 5, T.22N., R.79W.; and the W1/2 T.23N., R.79W.

Bentonite at the contact between the Cretaceous Steele Shale and Mesaverde Formation in this area stands vertical and is intricately folded along the east margin of the Hanna Basin. During recent investigations and mapping by the Wyoming State Geological Survey (unpublished), euhedral analcite crystals were discovered at the base of the bentonite. The crystals are up to 1/2 inch in diameter. The analcite composes about 25 percent of the basal inch of the bentonite. The bentonite was last mined in the 1920s and was marketed as Wilkinite by the Owyhee Mining Company of Cheyenne, Wyoming. The outcrop of this bentonite unit also extends to the southeast from the legal location listed above.

Crook County

15) Southern Bear Lodge Mountains; roughly T.52N., R.63W. and into adjacent townships.

Jenner (1984) reported up to 26.5 percent analcite as a primary mineral and an alteration product, and up to 34.2 percent natrolite as an alteration product, possibly of nepheline, within the Eocene Bear Lodge igneous complex. Wilkinson (1982) reported analcite as an alteration product in the core of this complex. It is not certain that the zeolites are less abundant in this core where the fenitization is more intense (after Jenner, 1984; Wilkinson, 1982). White (1980) reported up to several percent analcite replacing alkali feldspar, and possibly as primary analcite, with natrolite replacing nepheline on the northern margin of the complex. Calcite and analcite reportedly replace sanidine along fractures in this area (White, 1980). On the southwest margin of the complex, O'Toole (1981) reported the zeolites analcite and natrolite, both replacing alkali feldspar and sodalite. Up to about 5 percent analcite and 2.5 percent natrolite were documented (O'Toole, 1981).

16) Barlow Canyon area; NE1/4 sec. 23, T.54N., R.66W.

Halvorson (1980) noted that unspecified zeolites other than analcite and analcite are present in this small Tertiary intrusion. He reported about 2 to 3 percent primary [?] analcite phenocrysts and up to 70 percent analcite in the groundmass, with natrolite in one sample. Halvorson (1980) interpreted the groundmass and phenocryst analcite as primary despite his physical description, which indicates the mineral is an alteration product.

17) Devils Tower; sec. 7-12 line, T.53N., R.65-66W.

Halvorson (1980) reported unspecified zeolites other than analcite and analcite in this Tertiary igneous rock. Analcite replaces feldspar and makes up 4 to 29 percent of this phonolite in the thirteen samples that were examined; analcite is reportedly primary and makes up almost 20 percent of one of these samples (Halvorson, 1980). No data were presented to support this primary origin.

18) Missouri Buttes; roughly common corner secs. 33 and 34, T.54N., R.66W.: and secs. 3 and 4, T.53N., R.66W.

Halvorson (1980) reported that an unspecified zeolite other than analcite and analcite are present in these Tertiary intrusions. Analcite replaces feldspar in and makes up 8 to 27.2 percent, and possibly up to 50 percent of these rocks. The northwest Butte contains the most noticeable analcite (Halvorson, 1980).

19) Mineral Hill area; S2/3 T.51N., R.60W.; and N1/4 T.50N., R.60W.

Both Ray (1979) and Welch (1974) noted zeolites in Cenozoic alkaline igneous rocks in the Mineral Hill igneous complex. Welch (1974) noted that they were the alteration product of feldspathoids, while Ray (1979) stated that they were present in lamprophyres and pyroxenites of the Mineral Hill ring dike complex. From modal data, Ray (1979) reported that analcite made up 15 to 21 percent and thomsonite made up 10 to 13 percent of the minerals in the lamprophyres.

20) Duling Hill; secs. 23, 26, 34 and 35, T.50N., R.62W.

Zeolites are reportedly present in syenite and phonolite at Duling Hill within Black Buttes. Nepheline in the rocks has been altered to zeolites and analcite, while feldspar has been altered to clay, carbonates, sericite and zeolites (Elwood, 1978). Other Tertiary igneous rocks in the Black Hills of Wyoming might also contain zeolites.

Fremont County

21) Beaver Rim (Beaver Divide), west of Burley anticline (Figure 2)

Zeolites were first reported in this area by Deffeyes (1959a,b). Clinoptilolite with erionite, some chabazite, and lesser amounts of analcite and phillipsite are reported in tuffs in the Wagon Bed Formation (Eocene) along the Beaver Rim (Divide) west of Burley anticline to U.S. Highway 287 (Boles, 1968; Boles and Surdam, 1971).

Clinoptilolite is widespread in unit 3 of Van Houten (1964), in zeolitic zones that are 2 to at least 110 feet thick, and that are commonly 100 feet thick. Clinoptilolite is also present in unit 5 in roughly the E1/2 sec. 1, T.32N., R.95W. (Boles, 1968; Boles and Surdam, 1971); these units are numbered sequentially from oldest (#1) to youngest (#5).

Erionite is present with clinoptilolite, phillipsite and chabazite, but usually makes up less than 15 percent of the zeolite fraction. Erionite is also present in unit 4 with potassium feldspar in the W1/2 sec. 3, T.31N., R.95W., and the SW1/4 sec. 34, T.32N., R.95W. (Boles, 1968; Boles and Surdam, 1971).

Chabazite was only present in unit 3 in a 23 foot thick bed in the S1/2 sec. 3, T.30N., R.96W. (Boles, 1968; Boles and Surdam, 1971).

Phillipsite was only reported in unit 3 in a 2.5 to 5 foot thick bed in the NE1/4 sec. 2, T.30N., R.96W. (Boles, 1968; Boles and Surdam, 1971).

Analcime is present in unit 4 in roughly the W1/2 sec. 3, T.31N., R.95W. (Boles, 1968; Boles and Surdam, 1971).

Boles (1968), and Boles and Surdam(1971) did not report the percentages of zeolites in these zeolitic zones. Yet, Sheppard (1971a) noted that the host bed is this area is at least 1 foot thick and contains at least 75 percent clinoptilolite. Van Houten (1964) stated that unit 3 is mostly tuff, so the zeolite percentages could exceed 80 percent.

In contrast with their earlier reports, Boles and Surdam (1979) state that heulandite is present with clinoptilolite, and that 30 to 50 percent of the zeolites are erionite in the SE1/4SE1/4 sec. 8, T.31N., R.96W., and the SE1/4 sec. 28 and NW1/4 sec. 34, T.32N., R.95W. (the original zeolite discovery site). These zeolites are most abundant in unit 3 of Van Houten (1964), similar to the previous reports. This latter report also doesn't mention the presence or absence of phillipsite or chabazite (Boles and Surdam, 1979). Minobras (1975) incorrectly placed this Beaver Rim--Wagon Bed site where Van Houten (1964) reported zeolites in the White River Formation (see Cameron Spring area below; locality 22).

Clinoptilolite and erionite were the zeolites identified by earlier investigators in this area (Van Houten, 1964; see also Deffeyes 1959a,b). Love (1964) placed their sample site within lacustrine, oil shale bearing rocks.

In the early 1980s, the Beaver Rim area was explored by several companies, and markets were researched. As of this writing, significant amounts of zeolite resources are probably present in the area, but there was not enough demand to warrant development in the early 1980s. This area has potential for future production.

22) Cameron Spring area; NW1/4 sec. 31, T.33N., R.89W. along strike to SE1/4 sec. 10, T.32N., R.90W.

Near Cameron Spring along the Beaver Divide, the White River Formation (Oligocene) was deposited in a channel which cuts entirely through the Wagon Bed Formation into the Wind River Formation. The upper two-thirds of this valley fill contains mudstone and fine-grained sandstone with some layers with traces of clinoptilolite (Van Houten, 1964, p. 64-65).

23) Halfway Draw area; type section, roughly sec. 2, T.33N., R.96W.

Clinoptilolite is reported in the white tuff that makes up the Halfway Draw Tuff Member of the Wind River Formation (Eocene) near the type section. The tuff has been altered to mostly montmorillonite several miles to the southeast (Surdam, 1972; Boles and Surdam, 1973); so the extent may be limited. Love (1970) provides the location of the type section, and noted that the tuff is 10 to 20 feet thick in the vicinity of the type section.

24) Crowheart Butte; N1/2 sec. 23, T.4N., R.3W. (WRM)

Crowheart Butte is capped by a 30 to 40 foot thick, pumiceous, felsic tuff of Eocene age in the Wind River Formation that reportedly contains clinoptilolite (Love, 1972 personal communication in Boles and Surdam, 1973; Boles and Surdam, 1973).

25) Ethete; sec. 20, T.1N., R.1E. (WRM)

Slaughter and Early (1965) reported that most samples of bentonite from this stratigraphic section in the Mowry Shale (Cretaceous) contained less than 1 percent analcite. They reported one sample contained 3.24 percent analcite.

26) Maverick Springs; T.6N., R.3W. (WRM)

Analcite is reportedly abundant in the sand and silt fraction of one sample of Mowry Shale bentonite is this area (Slaughter and Early, 1965; appendix II).

27) Maverick Spring oil field, Circle Ridge No. 4 well

X-ray diffraction of a coarse oolitic portion of a sample from the Popo Agie Member of the Triassic Chugwater Formation from this well revealed analcite (Keller, 1952).

28) Dubois area

Analcite, as identified by X-ray diffraction, is reportedly present in six "zones", 2.5 to 15 feet thick in the Popo Agie Member of the Triassic Chugwater Formation. The abundance of analcite was not discussed. The site is about 12 miles southeast of Dubois where U.S. Highway 287 crosses the exposure (Keller, 1952).

29) Popo Agie type section; sec. 3, T.32N., R.100W.

Analcite, as identified by X-ray diffraction, is reportedly present in six "zones" in the Popo Agie Member of the Chugwater Formation (Triassic) that are up to 25 feet thick. The abundance of analcite was not discussed (Keller, 1952).

30) Maverick Springs Dome

Analcite, as identified by X-ray diffraction, is reportedly present in two samples taken from the Popo Agie Member of the Chugwater Formation of Triassic age. The abundance of analcite was not discussed (Keller, 1952).

31) Circle Ridge Dome; sec. 6, T.6N., R.2W. (WRM)

Analcite, as identified by X-ray diffraction, is reportedly present in three, 4 to at least 10 foot thick "zones" in the Popo Agie Member of the Chugwater Formation of Triassic age. The abundance of analcite was not discussed (Keller, 1952).

32) Derby Dome

Analcite, as identified by X-ray diffraction, is reportedly present in the Popo Agie Member of the Chugwater Formation of Triassic age. The site is about 13 miles southeast of Lander on the north rim of Derby Dome. The abundance of analcite was not discussed (Keller, 1952).

33) Red Grade; sec. 13, T.5N., R.6W. (WRM)

Analcite, as identified by X-ray diffraction, is reportedly present in about 50 feet of the purple and ocher colored units in the Popo Agie Member of the Triassic Chugwater Formation. The zeolite occurs as pellets and is at maximum 40 to 60 percent of the rock (High and Picard, 1965).

34) Hudson Dome; sec. 24, T.2S., R.1E. (WRM)

Analcite, as identified by X-ray diffraction, is reportedly present in about 100 feet of the purple and ocher colored units in the Popo Agie Member of the Triassic Chugwater Formation. The zeolite occurs as pellets and is at maximum 40 to 60 percent of the rock (High and Picard, 1965).

35) Dallas Dome; sec. 13, T.32N., R.99W.

Analcite, as identified by X-ray diffraction, is reportedly present in about 45 feet of the purple and ocher colored units in the Popo Agie Member of the Triassic Chugwater Formation. The zeolite occurs as pellets and is at maximum 40 to 60 percent of the rock (High and Picard, 1965).

36) Red Canyon; sec. 36, T.31N., R.99W.

Analcite, as identified by X-ray diffraction, is reportedly present in about 10 feet of the purple and ocher colored units in the Popo Agie Member of the Triassic Chugwater Formation. The zeolite occurs as pellets and is at maximum 40 to 60 percent of the rock (High and Picard, 1965).

37) Stratigraphic section 8; NW1/4 sec. 18, T.6N., R.2E. (WRM)

Davis (1967a,b) reported that analcite was present in a sample of silicified floor beneath a bentonite bed in this stratigraphic section in the Mowry Shale. The zeolite was identified by X-ray methods (Davis, 1967a).

38) Highway 16 area; sec. 11, T.42N., R.107W.

Davis (1967a,b) reported that analcite was present in a sample of hard, blocky shale taken from this stratigraphic section in the Mowry Shale. The zeolite was identified by X-ray methods (Davis, 1967a).

Hot Springs County

39) Lysite Mountain area (Figure 3)

Zeolites have been identified in two sequences of Middle and Late Eocene rocks in the Lysite Mountain area of Hot Springs, Washakie and Fremont Counties. The lower sequence is roughly equivalent in age to the Aycross Formation, while the upper sequence is roughly equivalent in age to the Tepee Trail Formation (Bay, 1969). Both are depicted as the Wagon Bed Formation by Love and Christiansen (1985). Tourtelot (1946) was the first to note a zeolite, analcite, in these rocks, and Love (1964) also reported analcite in these rocks. In the lower sequence, analcite, clinoptilolite and mordenite have been identified. In the upper sequence, erionite, as well as these other zeolites, have been identified (Bay, 1969). Sheppard (1971a) noted that the host bed is at least 1 foot thick and contains at least 75 percent clinoptilolite. This statement is not supported by Bays' (1969) work. Dunn (1979) provides geochemical information on zeolite-bearing samples from the area.

Greater than 50 percent analcite and 5 to 20 percent clinoptilolite is reported in some tuffs, with documentation by thin section analyses. The clinoptilolite rich units are reported in three stratigraphic sections (designated E, G and I): E (SW1/4 sec. 25 to NW1/4 sec. 36, T.42N., R.90W.); G (NW1/4 sec. 1, T.41N., R.90W.); and I (SW1/4 sec. 17 to NE1/4 sec. 18, T.41N., R.89W.). These tuffs also contain erionite and mordenite. In stratigraphic section E, clinoptilolite-rich tuffs are 1.2, 1.4 and 89.6 feet thick, with the top 2 feet of the thickest tuff containing mostly opal and clinoptilolite. A clinoptilolite-rich tuff in stratigraphic section G is 90.7 feet thick. Two tuffs in stratigraphic section I are clinoptilolite rich, 0.7 and 1.5 feet thick, while another is mordenite(?)-rich, 5.8 feet thick. These stratigraphic sections are separated by about six miles, so the tuffs are extensive laterally and vertically (after Bay, 1969).

Systematic sampling with an emphasis on zeolite resources might find that portions of these extensive tuffs are richer in clinoptilolite.

40) Headwaters of North Fork of Owl Creek and Cottonwood Creek; roughly NE 1/4 T.44N., R.102W.

Sundell (1985) noted that the zeolites clinoptilolite and mordenite are present in the Sugar Loaf tuff beds. These tuff beds are conspicuous and can be used as a local marker bed in the area noted above. The beds are in allochthonous Wiggins Formation and are a very tuffaceous, 165 feet thick unit, rather than actually being tuff (Sundell, 1980). Few of the numerous tuffaceous units in the Absaroka Volcanic Supergroup have been examined for zeolites due to inaccessibility, so this terrain is under explored and might contain huge deposits of zeolites. The major drawback to economic zeolite mineralization in the Absaroka Range, other than access, is the fact that most of the volcanic and volcano-sedimentary rocks in the Range were deposited in a terrain with high relief. In terrains with high relief, most tuffs are reworked and contain large amounts of diluting material. This results in dirty tuffs, that when altered, do not contain great abundances of zeolites The very existence of this occurrence implies that other similar zeolitic tuffaceous units in the Absaroka Supergroup are probably present on at least the margins of the Absaroka Range.

41) Big Horn River area; NE1/4 sec. 16, T.43N., R.94W.

Davis (1967a,b) reported that analcite was present in a sample of gray, buff-weathering siltstone taken from this stratigraphic section in the Mowry Shale. The zeolite was identified by X-ray methods (Davis, 1967a).

42) Thermopolis area; sec. 22, T.42N., R.95W.

Analcite, as identified by X-ray diffraction, is reportedly present in about 55 feet of the purple and ocher colored units in the Popo Agie Member of the Triassic Chugwater Formation. The zeolite occurs as pellets and is at maximum 40 to 60 percent of the rock (High and Picard, 1965).

Lincoln County

43) unnamed; SE portion sec. 25, T.19N., R.115W.

Clinoptilolite and heulandite reportedly occur as a red coating on fracture planes in a thin limestone in the Bridger Formation at this site (Wolfbauer, 1972).

44) Snake River Canyon

About 20 miles south of Jackson at several places in the Snake River Canyon, dark red heulandite was reported as felted films, up to 0.1 inches thick, on bedding planes of sandy grayish-black shales in the Aspen Formation (Cretaceous). The zeolite was identified by X-ray diffraction (Heinrich, 1963).

45) Little Coal Creek; secs. 10, 11, 15 and 16, T.25N., R.115W.

Analcite was reported in bentonitic material and "porcellanites" in the Aspen Formation, and clinoptilolite and/or heulandite was reported in bentonitic material and "porcellanites" in the Frontier Formation in this stratigraphic section (Horstman, 1966).

46) Fontenelle Gap; secs. 5 and 6, T.24N., R.115W.

Analcite was reported in bentonitic material and "porcellanites" in the Aspen Formation, and clinoptilolite and/or heulandite was reported in bentonitic material and "porcellanites" in the Frontier Formation in this stratigraphic section (Horstman, 1966).

47) Radiant area; secs. 15, 16 and 17, T.20N., R.116W.

Analcite was reported in bentonitic material and "porcellanites" in the Aspen Formation, and clinoptilolite and/or heulandite was reported in bentonitic material and "porcellanites" in the Frontier Formation in this stratigraphic section (Horstman, 1966).

48) Cumberland Gap; sec. 32, T.19N., R.116W.

Analcite was reported in bentonitic material and "porcellanites" in the Aspen Formation, and clinoptilolite and/or heulandite was reported in bentonitic material and "porcellanites" in the Frontier Formation in this stratigraphic section (Horstman, 1966).

49) Pomeroy Basin; secs. 29 and 30, T.23N., R.115W.; and sec. 25, T.23N., R.116W.

Analcite was reported in bentonitic material and "porcellanites" in the Aspen Formation in this stratigraphic section (Horstman, 1966).

Natrona County

50) Moonstone Formation, type section; center sec. 4 to NE1/4NE1/4SE1/4 sec. 33, T.30N., R.89W.

Clinoptilolite and lesser amounts of erionite are reportedly present in many tuffs in the Moonstone Formation (Pliocene) near Moonstone Peak, at the type section of the Formation. Phillipsite is only present in unit 44 near the top of the Formation. Roughly fifteen altered, tuffaceous, zeolite-bearing units are found in this stratigraphic section. These zeolitic tuffs are present throughout the section, and are 1 to 40 feet thick. The percentages of zeolites within theses units was not reported (Mariner, 1971). But, Sheppard (1971a) noted that the host bed is at least 1 foot thick and contains at least 75 percent clinoptilolite.

Many of these tuffs are apparently completely altered, because Love (1961, 1970) stated that many clay-bearing rocks in the Moonstone Formation contain clinoptilolite; and that phillipsite was found in appreciable amounts in one white, tuffaceous claystone in unit 44, near the top of the type section. These zeolite-bearing tuffs or claystones are probably present throughout the Moonstone Formation, east and west of the type section, because the formation was deposited in a lacustrine environment (Love, 1961, 1970). The Formation is exposed in three townships (T.30N., R.88, 89 and 90W.).

51) Split Rock area

Clinoptilolite is reported in a tuff in the Split Rock Formation (Miocene) near Split Rock (Surdam, 1972). Split Rock is located in roughly sec. 18, T.29N., R.89W. Love (1970, 1961) provided the best description of this Formation, yet he didn't mention zeolites in this Formation. Sheppard (1976) noted that the host bed is at least 1 foot thick and contains at least 75 percent zeolite. Unfortunately, this information has not been confirmed.

52) Bug Formation; exposed in SW1/4 T.31N., R.87W. and NW1/4 T.30N., R.87W.

Tuff in the Bug Formation [Pliocene and Pleistocene(?)] northwest of Independence Rock contains clinoptilolite (Surdam, 1972). Love (1970) provided the best description of this Formation, yet he didn't mention zeolites in this Formation. However, Sheppard (1976) noted that the host bed is at least 1 foot thick and contains at least 75 percent zeolite. Unfortunately, this information has not been confirmed.

53) unnamed; roughly sec. 18, T.29N., R.89W.

Clinoptilolite is reported in Oligocene rocks on the Split Rock 7-1/2 minute Quadrangle, at the location of Split Rock, by Minobras (1975). This is probably a mislocation of the Split Rock area of Surdam (1972); see locality 51 above.

54) Kidd Ranch; sec. 23, T.39N., R.82W.

Samples of bentonite in the Mowry Shale (Cretaceous) from this stratigraphic section reportedly contain less than 1 percent analcite (Slaughter and Early, 1965). Yet, the site is listed as a zeolite occurrence by Sheppard (1971a, 1971b, 1976).

55) Casper area; secs. 30 and 31, T.33N., R.80W.

Samples of bentonite in the Mowry Shale (Cretaceous) from this stratigraphic section reportedly contain less than 1 percent analcite (Slaughter and Early, 1965). Yet, the site is listed as a zeolite occurrence by Sheppard (1971a, 1971b, 1976).

56) Stratigraphic section 6; sec. 32, T.39N., R.85W.

Davis (1967a,b) reported that analcite was present in a sample of a 0.6-foot-thick porcellanite bed at the base of a bentonite in this stratigraphic section in the Mowry Shale. The zeolite was identified by X-ray methods (Davis, 1967a).

Park County

57) Deer Creek area

The decayed core of the lower Deer Creek intrusive, a quartz diorite porphyry, reportedly contains a great abundance of crystals of the zeolite thomsonite. These crystals of thomsonite are up to several inches in length, but most are about 1/2 inch long (Rouse, 1933).

58) Sunlight Creek area; roughly T.54N., R.106W. unsurveyed

Several zeolites were reported in a large area south of the sulfur deposits near Sunlight Creek Vesicles in basalt flows of the upper basic group of lavas [Wapiti Formation of Pierce and others, 1982] contain thomsonite, heulandite and analcite. Analcite was also found as an alteration product of feldspars in rocks of the lower group of andesite flows [Wapiti Formation of Pierce and others, 1982]. Stilbite was found encrusting small fissures in both the upper and lower flows (Hewitt, 1913).

59) Hoodoo Peak area

Pirsson (1890) reported that a zeolite lined amygdaloidal cavities in a mass of decomposed basalt in the basic breccia. He stated "The locality was one of the high points of the ridge running eastwardly from Hoodoo Mountain". The zeolite was originally identified as mordenite (Pirsson, 1890), but was later identified as clinoptilolite (Schaller, 1932). The exact site can not be determined; but, the rocks in this area are in the Wapiti Formation (Nelson and others, 1980).

60) Sunlight mining region

Parsons (1937) reported the zeolites heulandite and chabazite in pockets in volcanic breccia wall rock of one vein in the district.

61) Red Creek area

Dunrud (1962) reported zeolites in the Red Creek vent complex, which is located near the head of Red Creek.

62) Wood River area

Wilson (1960) reported that vesicles in a trachyte flow (?) near the top of the Pitchfork Formation are lined with thin films of natrolite (?), which surround cores of stilbite in the vesicles.

63) Cody area; sec. 21, T.52N., R.102W.

Davis (1967a,b) reported that analcite and clinoptilolite are present in some samples taken from this stratigraphic section in the Mowry Shale. Clinoptilolite was present in samples of two gray-brown, buff weathering, non-resistant to resistant shale; a sample of black, soft and fissile shale; and a sample of a light gray, non-resistant shale that is probably bentonitic. Analcite and clinoptilolite were present in a sample of "typical" Mowry Shale (Davis, 1967a,b). The zeolites were identified by X-ray methods (Davis, 1967a).

Sublette County

64) Snider Basin; sec. 10, T.29N., R.115W.

Analcite was reported in bentonitic material and "porcellanites" in the Aspen Formation in this stratigraphic section (Horstman, 1966).

65) LaBarge Creek; secs. 13 and 14, T.27N., R.115W.

Analcite was reported in bentonitic material and "porcellanites" in the Aspen Formation in this stratigraphic section (Horstman, 1966).

66) La Barge area; sec. 9, T.27N., R.113W.

Analcite was reported in minor amounts in a sandstone in the New Fork Tongue of the Wasatch Formation (Eocene) near LaBarge (Vine and Tourtelot, 1973).

Sweetwater County

67) Washakie Formation in the Washakie Basin (Figure 4)

Zeolites were first reported in the Washakie Formation in the Basin by Johannsen (1914). Roehler (1973a) reported clinoptilolite and mordenite in tuffs in the Eocene Washakie Formation in the Washakie Basin. The zeolitic units are best exposed along the margins of the basin. Clinoptilolite is particularly abundant in the robins-egg-blue tuff bed (bed 579) in the Adobe Town Member. This tuff bed is a 4 to 25 feet thick, sandy tuff or tuffaceous sandstone that splits into a series of beds that are about 100 feet thick in aggregate (Roehler, 1973a). In places, this bed contains more than 50 percent clinoptilolite (Roehler, 1973b). The robins-egg-blue tuff has been the primary exploration target in this area. The thickest exposed portion of this blue tuff is apparently near Fort LaClede (see locality 68, below). Sheppard (1976) noted that the host bed[s?] in this Formation in the Washakie Basin is at least 1 foot thick and contains at least 75 percent zeolite. Zeolites are not restricted to the robins-egg-blue tuff.

The aggregate series of zeolitic tuffaceous beds in the Adobe Town Member includes beds 570 through 586. In this interval, in addition to the robins-egg-blue tuff, five thick, very tuffaceous beds have been documented. Beds 586, 582 and 577 are very tuffaceous sandstones that are over 6.5 feet thick; bed 572 is a very hard, 7.4 foot thick tuff; and bed 576 is a 2.4 foot thick tuff (Roehler, 1973a).

Documentation exists for four other thick tuff units, presumably zeolitic, in the Washakie Formation. Two are in the Kinney Rim Member; bed 515--the white ridge marker, a limy tuff or tuffaceous limestone, 5.0 feet thick; and bed 540--a hard tuff, 7.0 feet thick. The other two thick tuffs are in the Adobe Town Member; bed 637--the chalk white marker, 8.1 feet thick; and bed 664--the white marker, 8.6 feet thick (Roehler, 1973a).

68) Fort LaClede prospect; secs. 1, 11, 12, 13, and 14 T.16N., R.98W.; secs. 6 and 7, T.16N., R.97W.; and secs. 32 and 33, T.17N., R.97W.

About 2 miles southeast of historic Fort LaClede, the robins-egg-blue tuff bed in the Adobe Town Member of the Eocene Washakie Formation reportedly contains 65 to 90 percent clinoptilolite and is several tens of feet thick. Other minerals reported include quartz, feldspar, mica and calcite, and trace amounts of the zeolite erionite. A few zones contain some unspecified clay (Rocky Mountain Energy, personal communication, 1982). A more recent report states that erionite is not present in the deposit (Rocky Mountain Energy, personal communication, 1987). An exploration program undertaken through the leadership of Rocky Mountain Energy (now Union Pacific Resources), involving subsurface examinations, outlined an area of clinoptilolite reserves. Tests of the material were also made to determine the cation exchange capacity of the clinoptilolite, mineralogy, and mining costs and market potential (Rocky Mountain Energy, personal communication, 1986). The deposit is presently controlled by U.S. Zeolite Corporation of Denver, Colorado, and production is through it's joint venture known as Rocky Mountain Zeolites.

A bulk sample was removed from section 1 by Rocky Mountain Energy and sent to International Minerals and Chemical Corporation for chemical analysis. Hulbert (1987) presents the sodium, calcium and ammonium exchange capacity for clinoptilolite from what is probably this sample. Rocky Mountain Zeolites (1990) present other technical data in their advertisement.

Curry and Santini (1983, 1986) described the robins-egg-blue tuff at this prospect as a few inches to 12 feet thick, nearly completely altered, brittle, splintery and moderately resistant. The clinoptilolite content in the tuff might exceed 90 percent, and the prospect contains an estimated one million tons of relatively high-grade material (Curry and Santini, 1983, 1986).

69) Washakie Basin, west, north and east margins (Figure 4)

Tuffs in the Laney Member of the Eocene Green River Formation, exposed along the west, north and east margins of the Washakie Basin, contain analcite, clinoptilolite and mordenite (Roehler, 1972). Analcite was first noted in these rocks by Bradley (1945). The prominent zeolitic unit is the buff marker bed which is about 5 to 60 feet thick; but the percentage of zeolite(s) in the bed was not stated. Other tuff beds, which contain 90 percent or more clays and zeolites, are thin (Roehler, 1972). Sheppard (1976) noted that the host bed[s?] in this area is at least 1 foot thick and contains at least 75 percent zeolite. This statement has not been documented by any other investigator.

It has not been determined which tuffs are the most promising exploration targets. Roehler (1973c, p. E6) implied that his 1972 publication only covered the LaClede Beds, and this 1973 publication does not mention zeolites in other beds. This is despite his depiction of zeolites in all three named beds in the Laney Member in 1972 in his figure 2.

At least seven presumably zeolitic tuff beds greater than 1 foot thick are present in the Laney Member of the Green River Formation. From youngest to oldest in the LaClede Beds these documented tuffs are: 1) bed #54--4.5 foot thick in the LaClede bed; 2) bed #40--5.3 feet thick, about 15 feet above the buff marker; 3) bed #36--the buff marker bed, here described as a very tuffaceous siltstone, 6 to 66 feet thick; and 4) bed #33--2.9 feet thick. Three other documented tuffs are present. One in the Sand Butte Beds, bed #40--1.5 foot thick. The other two are in the Hartt Cabin Beds; bed #78--1.5 feet thick; and bed #60--the flat top white layer, 2.7 feet thick (Roehler, 1973c).

A 4 to 6 inch thick, altered zeolitic tuff bed in the LaClede Beds about 13 feet above the buff marker of Roehler (1973c) is traceable for about 19 miles along outcrop (Ratterman, 1980; Ratterman and Surdam, 1981). This tuff bed might be part of bed #40 of Roehler (1973c). Samples along this traceable extent contained clinoptilolite, heulandite, a zeolite intermediate in composition between heulandite and clinoptilolite, mordenite, and analcite. Clinoptilolite and heulandite are present in the samples from trace amounts to nearly 100 percent. Mordenite generally composes less than 20 percent of any sample, while analcite content varies from a trace to over 90 percent. However, these numerical percentages of zeolites are not supported by quantitative data (Ratterman, 1980; Ratterman and Surdam, 1981).

70) Twin Buttes area; NW1/4 T.13N., R.109W.

Clinoptilolite was reported in tuffs and tuffaceous sandstone in the Bridger Formation (Eocene) near Twin Buttes (Sheppard, 1971a,b; Surdam, 1972). Minobras (1975) adds the legal location, which is around Twin Buttes. Sheppard (1971a) noted that the host bed is at least 1 foot thick and contains at least 75 percent clinoptilolite. Sheppard's (1971a,b) information on the area is original. Unfortunately, this information has not been confirmed.

71) Blue Rim area

Clinoptilolite was reported in tuffs and tuffaceous sandstone in the Bridger Formation (Eocene) near Blue Rim by Surdam (1972). Other reports on the Blue Rim area indicate that zeolites are [also?] present in the Wilkins Peak Member of the Green River Formation (see Kistner, 1973; and locality 73).

72) Stevens Flat area; SW1/4 sec. 17, T.20N., R.108W.

At this site, a sample of tuff from the Opal tuff in the Bridger Formation contained 20 percent clinoptilolite. The same tuff at Opal does not contain zeolites (Wolfbauer, 1972). The exact location of this sample is from Kistner (1973), and he described the tuff as about 11 feet thick in subsurface and white-weathering. This could be the Blue Rim area of Surdam (1972)(locality 71), because it is one township south and one-half township west of Blue Rim.

73) Green River area; roughly T.18 and 19N., R.105 and 106W.

Clinoptilolite and mordenite are present in at least two tuffs in the Tipton Tongue of the Green River Formation east of Green River. These two tuffs are only 0.1 to 0.3 feet thick and are 87.9 and 90.4 feet above the base of the Tipton Tongue, and were encountered in a drill hole (sec. 15, T.18N., R.106W.). Clinoptilolite and mordenite bearing tuffs were also found in stratigraphic sections sampled in sec. 23, T.18N., R.106W., and secs. 30 and 31, T.19N., R.105W. (Goodwin 1971; Goodwin and Surdam, 1967). Surdam and Parker (1972) stated that clinoptilolite-bearing tuffs in the Tipton Tongue of the Green River Formation contain a few to 50 percent clinoptilolite, with considerably less mordenite. Their figure 2 implies these clinoptilolite and mordenite bearing tuffs are restricted to an area between Rock Springs and Green River.

74) Green River Basin

Bradley (1928, 1929) first identified the zeolite analcite disseminated in oil shale beds in the Green River Formation; however some question exists as to his identification of the zeolite in Wyoming (see data in Bradley, 1929). Tuffs in two zones in the Green River Formation (Eocene) contain almost ubiquitous analcite, from trace amounts to almost 100 percent of the tuff. One of these two zones is present in the lower Wilkins Peak Member and the upper Tipton Tongue, and the other is in the upper Wilkins Peak Member and the Laney Member. These tuffs are widespread in the Green River Basin. However, these tuff layers reportedly rarely exceed 8 inches in thickness (Goodwin, 1971; Surdam and Parker, 1972; Iijima and Hay, 1968). Love (1964), Bradley (1964), and Culbertson (1961, 1962) added bits of information on some sites within the Green River Basin. Kistner (1973) reported two zeolitized tuffs in subsurface about 70 to 160 feet below the Laney--Wilkins Peak contact in the Big Island-Blue Rim area; they are 0.33 and about 1.2 feet thick. This is probably in the upper zone of Surdam and Parker (1972).

Measurements of thicknesses and percentages have not been documented, so these figures should only be taken as crude estimates.

75) Parnell Creek area; roughly NE1/4 T.24N., R.102W.

Surdam and Parker (1972) noted in passing a 50 foot thick tuffaceous bed in the Tipton Tongue of the Green River Formation near Parnell Creek, about 45 to 50 miles east of Farson. This strongly contradicts their statement that most tuffaceous units are less than 8 inches thick. In fact they also reported pumice bombs up to 6 inches long. It is not known if this thick tuffaceous bed is zeolitized; figure 2 in Surdam and Parker (1972) implies that the tuff does contain analcite.

76) Firehole Basin area; sec. 34, T.17N., R.106W.

Vine and Tourtelot (1973) reported small amounts of feldspar that had been altered to sericite or analcite in a sandstone in the main body of the Wasatch Formation (Eocene) in the Firehole Basin.

77) South Baxter Basin oil and gas field, unit well # 1 of Mountain Fuel Supply; sec. 21, T.16N., R.104W.

In subsurface, analcite is reportedly present in samples from the Popo Agie Member of the Chugwater Formation (Triassic). The Popo Agie Member is present at depths of 4,665 to 4,705 feet. The abundance of analcite was not discussed. The mineral was identified by X-ray diffraction (Keller, 1952).

Teton County

78) Snake River Bridge area; NE1/4SW1/4 sec. 24, T.41N., R.117W.

Heinrich (1963) reported that irregular clots of rusty-colored, coarse-grained chabazite, 1/4 to 3 inches in maximum dimension, apparently replace a gray monzonite porphyry. This granitoid igneous rock was reportedly present in the southwest corner of West Gros Ventre Butte. Zeolites are reportedly well exposed just east of the Snake River Bridge in a road cut along Wyoming State Highway 22, and in a quarry (Heinrich, 1963). Love and Albee (1972) provided a more accurate location, call the rock a Quaternary or Tertiary hornblende-rich dacite(?) porphyry intrusive, and give information on the exposures. The intrusive is probably latest Miocene in age (Love personal communication, 1991). Minobras (1975) mislocated the site.

79) Red Rocks Ranch area

This site is about 20 miles east of Moose in a cliff on the north side of the Gros Ventre River across from Red Rocks Ranch. Analcite is reportedly present in three roughly 20 foot thick "zones" in the Popo Agie Member of the Chugwater Formation of Triassic age. Analcite was identified by X-ray diffraction, but the abundance was not discussed (Keller, 1952).

80) Gros Ventre River gorge; sec. 15, T.42N. R.113W.

Davis (1967a,b) reported that analcite and clinoptilolite were present in some samples taken from this stratigraphic section in the Mowry Shale. The clinoptilolite was present in a sample of soft, silty, gray shale that contained numerous thin bentonites. The analcite was present in two samples; one of a typical Mowry shale and the other from the less resistant top of this shale (Davis, 1967a,b). The zeolites were identified by X-ray methods (Davis, 1967a).

Uinta County

81) Shelter house no. 3; secs. 1 and 2, T.17N., R.117W.

Analcite was reported in bentonitic material and "porcellanites" in the Aspen Formation, and clinoptilolite and/or heulandite was reported in bentonitic material and "porcellanites" in the Frontier Formation in this stratigraphic section (Horstman, 1966).

82) Shelter house no. 4; secs. 18, 19 and 20, T.16N., R.117W.; and sec. 13, T.16N., R.118W.

Analcite was reported in bentonitic material and "porcellanites" in the Aspen Formation in this stratigraphic section (Horstman, 1966).

Washakie County

83) Ten Sleep area; SE1/4 sec. 23, T.47N., R.89W.

Davis (1967a,b) reported that clinoptilolite was present in samples of two separate white weathering, siliceous shales, and that phillipsite (?) was present in a sample of siltstone within a dark gray, reddish-brown weathering shale, in this stratigraphic section in the Mowry Shale. The clinoptilolite was positively identified, while the phillipsite was tentatively identified by X-ray methods (Davis, 1967a).

Weston County

84) Pedro area; roughly NE corner T.45N., R.63W. and NW1/4 T.45N., R.62W.

Bramlette and Posjnak (1933) reported that clinoptilolite occurs in the thick bentonite at the base of the Pierre Shale [Pedro bentonite] at Pedro. They stated that the thick bentonite appears less altered than others in the area, that is, it appears to contain relict glass shards. Minobras (1975) mislocated the site. Sheppard (1971a) noted that the host bed is at least 1 foot thick and contains at least 75 percent clinoptilolite. But, no data support this thickness or percentage, and Davis (1967a,b), and Slaughter and Early (1965) found no where near this percentage of zeolites in bentonites in the Mowry Shale. This bentonite in the Pierre Shale needs to be reexamined.

Yellowstone National Park

Zeolites are present in most near-surface hydrothermally altered tuffs, rhyolites, and other igneous rocks. The localities listed for Yellowstone National Park are only those few areas within the Park that have been examined. These studies were confined to the examination of drill cores from active geothermal areas in Late Pleistocene volcanic rocks. Many similar thermal areas exist in the Park, and others have been active in the past. Given the igneous geology of the Park and the limited scope of previous studies, zeolites are probably much more widespread in the Park than just the active geothermal areas listed below.

Bargar and others (1987) provide more information on the drill cores that contain the zeolite dachiardite, and on the occurrence of this mineral within the cores.

85) Lower Geyser Basin, four core holes

Analcite, clinoptilolite, heulandite and mordenite, with traces of dachiardite and yugawaralite were the zeolites identified in core from research drill hole Y-2 (Bargar and Beeson, 1981). Bargar and others (1987) also identified the zeolites laumontite and wairakite in this core.

Analcite, clinoptilolite, laumontite and mordenite, with minor dachiardite, and traces of yugawaralite and stilbite were the zeolites identified in core from research drill hole Y-3 (Bargar and Beeson, 1985).

Clinoptilolite with some mordenite and traces of erionite were the zeolites identified in core from research drill hole Y-5 (Keith and Muffler, 1978).

Clinoptilolite, mordenite, analcite, wairakite, laumontite and dachiardite were the zeolites identified in core from research drill hole Y-13 (Keith and others, 1978). Bargar and others (1987) also report the zeolite epistilbite in the core.

86) Upper Geyser Basin, four core holes

Clinoptilolite, mordenite, analcite, and erionite were the zeolites identified in core from two research drill holes (Y-7, Y-8) in the Upper Geyser Basin. Clinoptilolite is by far the most abundant zeolite and mordenite only occurs in trace amounts (Keith and others, 1978).

Analcite and clinoptilolite, with some mordenite and a trace of erionite were the zeolites identified in core from research drill hole Y-1 (Honda and Muffler, 1970).

Fenner (1936), reported that clinoptilolite and analcite were present in core from drill hole C-I; analcite was found in veinlets, 1/20 to 1/10 inch wide, and as replacements.

87) Upper Firehole River

Clinoptilolite, heulandite and mordenite, and a trace of dachiardite were the zeolites identified in the core from research drill hole Y-6 in this area (Bargar and Beeson, 1984).

88) Mud Volcano area

Mordenite was the only zeolite identified in core from research drill hole Y-11 in this area. Unlike the other zeolite localities in the Park, this geothermal system is vapor dominated (Bargar and Muffler, 1982).

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Table 1. Selected zeolite minerals and their chemical formulas (modified from Deer and others, 1967; and Barrer, 1982; * indicates common natural zeolites).

Name	Chemical Formula
Analcite (Analcime)*	$Na[AlSi_2O_6]\cdot H_2O$
Chabazite*	$(Ca,Na_2)_2[Al_4Si_8O_{24}]\cdot 13H_2O$
Clinoptilolite*	$(Na_2,K_2,Ca)[Al_3Si_{10}O_{24}]\cdot 8H_20$
Dachiardite	$(Ca,Na_2,K_2)_5[Al_{10}Si_{38}O_{96}]\cdot 24H_20$
Epistilbite	$Ca_3[Al_6Si_{18}O_{48}]\cdot 16H_2O$
Erionite*	$(Na_2,K_2,Ca)_{4.5}[Al_9Si_{27}O_{72}]\cdot 27H_2O$
Faujasite	$(Ca,Na_2)[Al_2Si_4O_{12}]\cdot 8H_2O$
Ferrierite	$(K,Na)_2(Mg)[Al_3Si_{15}O_{36}](OH)\cdot 9H_2O$
Gismondite (Gismodine)	$(Ca,Na_2,K_2)[Al_2Si_2O_8]\cdot 4H_2O$
Gonnardite	$Na_2Ca[(Al,Si)_5O_{10}]_2\cdot 7H_2O$
Harmotome	$Ba[Al_2Si_6O_{16}]\cdot 6H_2O$
Heulandite*	$(Ca,Na_2)[Al_2Si_7O_{18}]\cdot 6H_20$
Laumontite*	$Ca[Al_2Si_4O_{12}]\cdot 4H_2O$
Mordenite (Ptilolite)*	$(Na_2,K_2,Ca)[Al_2Si_{10}O_{24}]\cdot 6H_2O$
Natrolite	$Na_2[Al_2Si_3O_{10}]\cdot 4H_2O$
Phillipsite*	$(K_2,Na_2,Ca)_{2.5}[Al_5Si_{11}O_{32}]\cdot 10H_2O$
Scolecite	$Ca[Al_2Si_3O_{10}]\cdot 3H_2O$
Stilbite	$Ca_2Na[Al_5Si_{13}O_{36}]\cdot 16H_2O$
Thomsonite	$Ca_2Na[(Al,Si)_5O_{20}]\cdot 6H_2O$
Wairakite	$Ca[Al_2Si_4O_{12}]\cdot 2H_2O$
Yugawaralite	$Ca[Al_2Si_5O_{14}]\cdot 4H_2O$

Table 2. Uses of natural zeolites (after Mumpton, 1978; Flanigen, 1980; Minato, 1988; Tsitsishvili, 1988; Manly and Holmes, 1989).

Application	Status
Gas purification	
oxygen separation	used in Japan
nitrogen separation	used in Japan
natural gas purification (acid resistant CO_2, SO_2, H_2O, H_2S removal)	used in United States and Europe
Pollution abatement	
ammonia removal	used in Japan and United States
pet litter	used in United States
non-phosphate detergent	used in Japan and Europe
radioactive element isolation	experimental use worldwide
heavy metal scavenging	experimental use worldwide
water softening	experimental use in United States
water filtering	experimental use in Europe
flue-stack gas clean-up (SO_2, nitrous oxides, hydrocarbons)	experimental use in Japan and Europe
oil spill clean-up	potential
Agricultural products, including aquaculture	
soil conditioner	number 1 use in Japan
dietary supplement	used worldwide
ammonia abatement	used worldwide
fertilizer enhancer	used in Japan and Europe
fungicide, pesticide and herbicide carrier	experimental use in Japan and Europe
Desiccant and decaking agent	minor use worldwide
Filler and extender	
paper	used in Japan and Canada
rubber	experimental use in Europe
polymers	experimental use in Europe
paint	potential
Construction materials	
dimension stone	used worldwide, but uncommon
pozzolanic (high silica cement)	used in Europe
lightweight aggregate	experimental use in Europe
concrete improver	experimental use in United States
Energy storage	
methane storage in a solid	experimental
hydration-dehydration of zeolite	experimental

Catalysis	experimental
Feedstock for synthetic zeolite production	experimental, possible use in United States

Table 4. Estimated United States natural zeolite production, in short tons (Eyde, 1990, 1989; Eyde and Eyde, 1988; Eyde, 1987, 1986, 1985, 1984; Virta, 1990, 1989, 1988, 1987; Clifton, 1985, 1984).

Year	Eyde Mining Engineering	Virta and Clifton U.S.B.M.
1989	13,200	12,000
1988	13,000	not reported
1987	10,000	not reported
1986	10,000	not reported
1985	not reported	13,000
1984	5,000	2,400
1983	not reported	5,000

Table 5. Probable zeolite producers in 1988 and/or 1989, including companies, mine sites, and zeolite produced (after Eyde, 1990, 1989; Holmes, 1990; Leppert, 1990; O'Driscoll, 1990, 1989; Virta, 1990, 1989).

Division	Company	State	Location	Zeolite
UOP join venture	Allied Signal Union Carbide Norton Co. GSA Resources	Arizona	Bowie	chabazite
Steelhead Specialty Minerals	Steelhead Resources	California	Mud Hills--Barstow	clinoptilolite
	East-West clinoptilolite Minerals	Nev.-Calif.	Ash Meadows-- Death Valley Junction	
	East-West Minerals	Nevada	Eastgate	mordenite
Z-Chem Inc.	Teague Mineral Products	Idaho	Chrisman Hill--(CH) Jordan Valley	clinoptilolite
Z-Chem Inc.	Teague Mineral Products	Idaho	Castle Creek--(XY)	clinoptilolite
Z-Chem Inc.	Teague Mineral Products	Oregon	Succor Creek--Adrian	heulandite
Steelhead Specialty Minerals	Steelhead Resources	Oregon	Sheaville--Jordan Valley	clinoptilolite
	Norton Co.	Oregon	Jordan Valley	clinoptilolite
ZeoTech	Leonard Resources	Texas	Tilden	clinoptilolite
Rocky Mountain Zeolites	U.S. Zeolites and Colorado Lien	Wyoming	Bitter Creek--Fort LaClede	clinoptilolite

Table 3. Potential and known lacustrine, tuffaceous host units for natural zeolites. An * indicates that the formation is known to contain zeolites.

Unit name	Location	Age
Bug Formation*	Granite Mountains and Pliocene	Pleistocene
Salt Lake Formation	Star Valley Miocene	Pliocene and
Teewinot Formation	Jackson Hole and Star Valley	Miocene
Camp Davis Formation	Jackson area	Miocene
Moonstone Formation*	Granite Mountains	Miocene
North Park Formation	around Sierra Madre	Miocene
Browns Park Formation*	around Sierra Madre	Miocene
Split Rock Formation*	central Wyoming	Miocene
Ogallala Formation	southeastern Wyoming	Miocene
Arikaree Formation	southeastern Wyoming	Miocene
White River Formation*	central and southeastern Wyoming	Oligocene
Washakie Formation*	south central Wyoming	Eocene
Bridger Formation*	southwestern Wyoming	Eocene
Wagon Bed Formation*	central Wyoming	Eocene
Absaroka Supergroup*	northwestern Wyoming	Eocene
Green River Formation*	southwestern Wyoming	Eocene
Wind River Formation*	central Wyoming	Eocene

Figure l. Index map of natural zeolite mineralization in Wyoming. Numbers by each locality indicate the corresponding numbered description of that locality in the text.

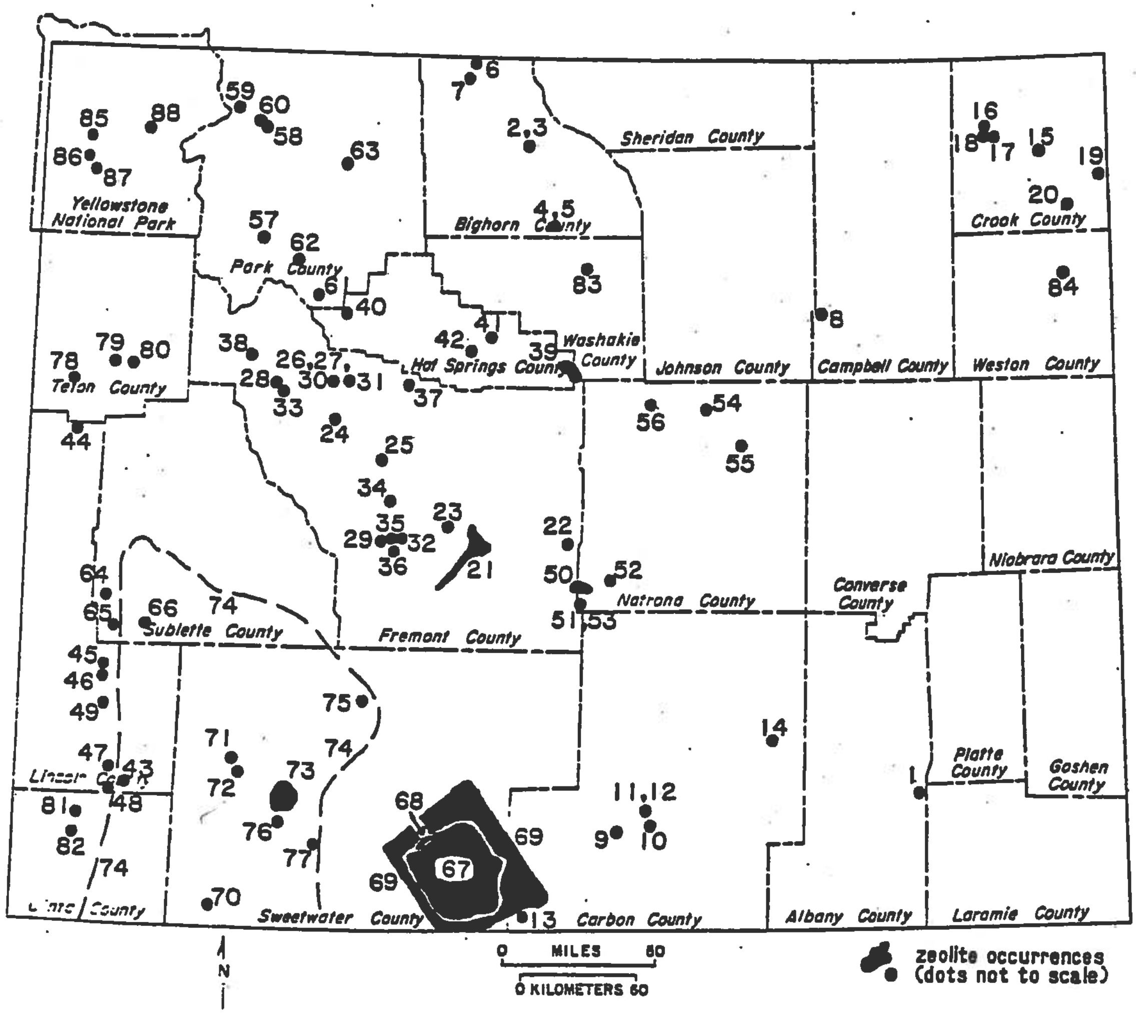

Figure 1. Index map of natural zeolite mineralization in Wyoming. Numbers by each locality indicate the corresponding numbered description in the text.

Figure 2. Extent of the zeolite-bearing Wagon Bed Formation (Eocene), Beaver Rim, Fremont County, Wyoming (locality 21 in text). Dotted area indicates zeolite-bearing extent; Eo indicates other exposures of Wagon Bed Formation in the area (after Boles, 1968; Boles and Surdam, 1971).

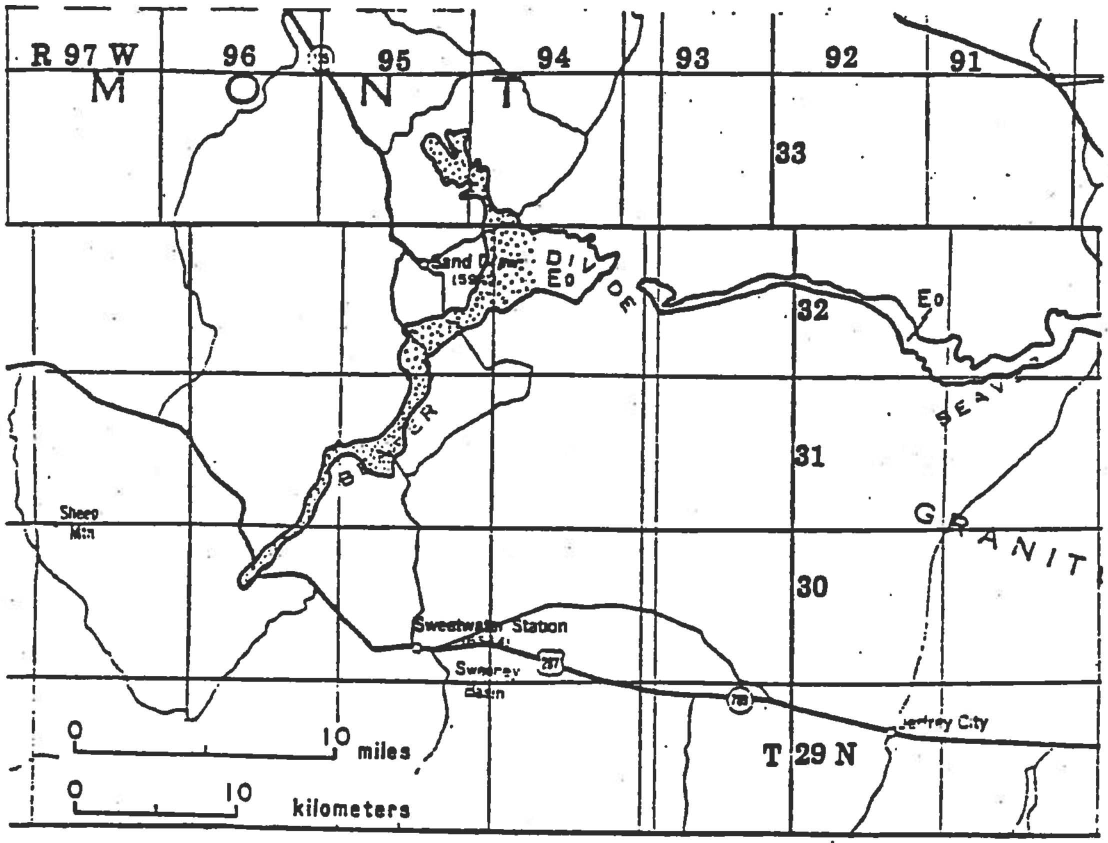

Figure 2. Extent of the zeolite-bearing Wagon Bed Formation (Eocene), Beaver Rim, Fremont County, Wyoming (locality 21 in the text). Dotted area indicates zeolite-bearing extent; Eo indicates other exposures of Wagon Bed Formation in the area (after Boles, 1968; Boles and Surdam, 1971).

Figure 3. Extent of zeolite-bearing Eocene rocks in the Lysite Mountain area, Hot Springs, Fremont and Washakie Counties, Wyoming (locality 39 in text). Dotted area indicates zeolite-bearing extent, while Eo indicates other Eocene rocks in the area (after Bay, 1969).

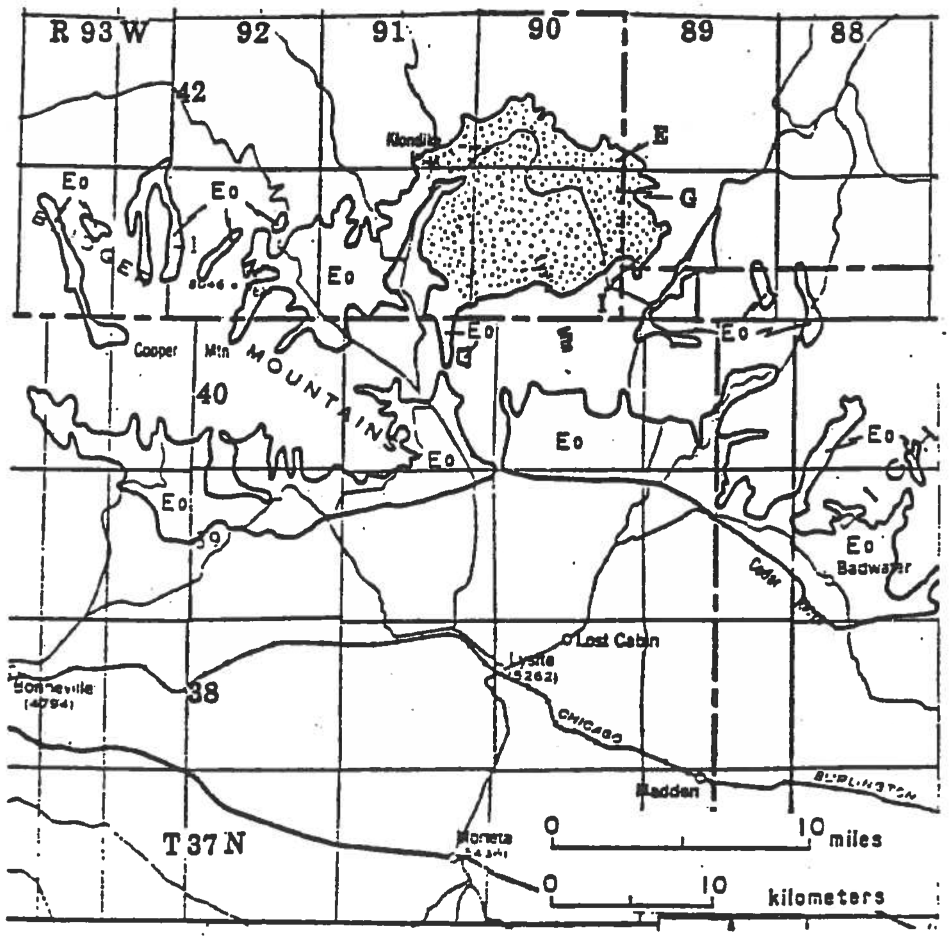

Figure 3. Extent of zeolite-bearing Eocene rocks in the Lysite Mountain area, Hot Springs, Fremont, and Washakie Counties, Wyoming (locality 39 in the text). Dotted area indicates zeolite-bearing extent, Eo indicates other Eocene rocks in the area (after Bay, 1969).

Figure 4. Geologic sketch map of the zeolite-bearing Washakie Formation and Laney Member of the Green River Formation, Washakie Basin, Sweetwater and Carbon Counties, Wyoming (localities 67, 68 and 69 in text)(after Roehler, 1972, 1973a, 1973c, 1985).

EXPLANATION

Twk Washakie Formation

Green River Formation

Laney Member

Tglh Hartt Cabin Beds

Tgls Sand Butte Beds

Tgll La Clede Beds

___ contact or bed

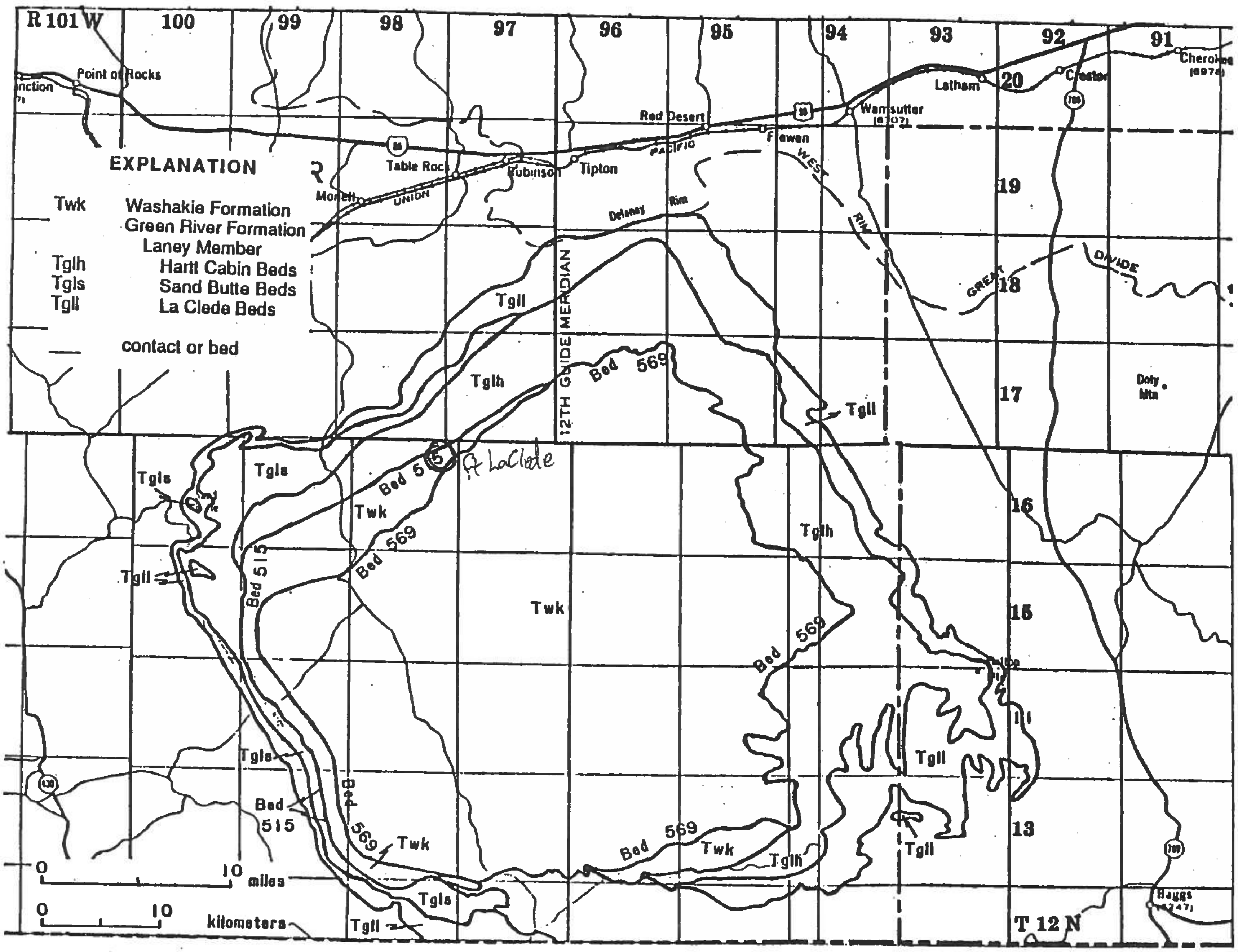

Figure 4. Geologic sketch map of the zeolite-bearing Washakie Formation and Laney Member of the Green River Formation, Washakie Basin, Sweetwater and Carbon Counties, Wyoming (after Roehler, 1972, 1973a, 1973c, 1985)