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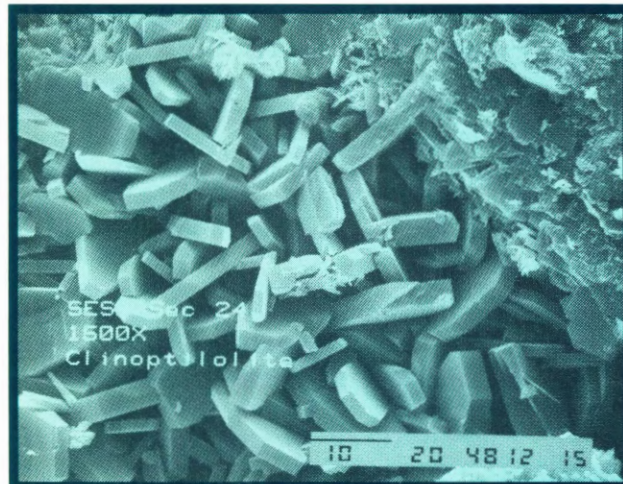


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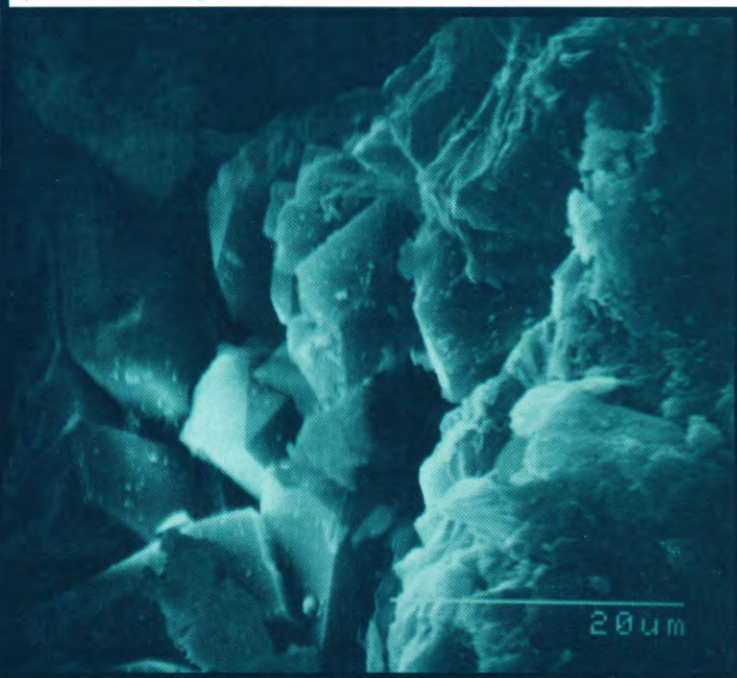
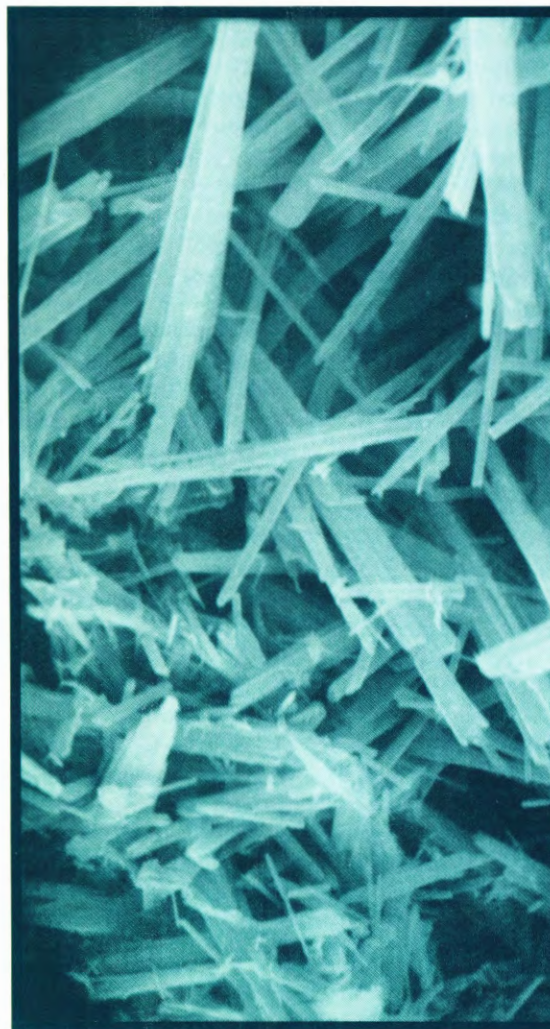


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ZEOLITE

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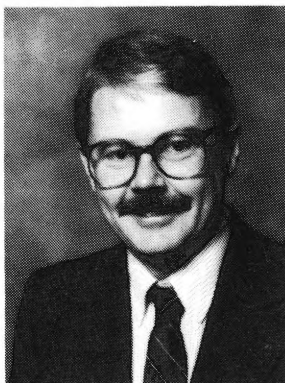
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THE DIRECTOR'S PERSPECTIVE *by M. Lee Allison*

On October of this year Genevieve Atwood stepped down after eight years as Director of UGMS to pursue educational and other career goals. In doing so, UGMS lost an incredibly dynamic, outspoken, innovative leader who broadened the scope of the Survey's role in understanding geologic hazards and mapping the geology of the state. It will be difficult to fill her shoes.

The transition period from announcement of my appointment as her replacement to the day I actually took over was remarkably smooth as Genevieve sought and accepted my recommendations on budget requests for the coming fiscal year, and consulted me on all major managerial decisions. It was clear that her concerns are with the health and vitality of the UGMS and not with the fact that I would be changing some aspects of her programs. I thank her and join with the rest of the staff in wishing her the best of luck.

The biggest change at UGMS will be a renewed emphasis on oil and gas and other energy resources. Due to a variety of factors, that program had suffered over the past few years, so that when I joined the Survey there was no one left working on petroleum even though it is the largest mineral revenue source to the state. Since then we have developed a strong petroleum team. Bill Stevenson has joined UGMS as Associate Director-Development to work with industry in focusing our efforts and encouraging exploration and development. Bill comes to us with over 25 years as an oil and gas independent in Utah. He will also take on some administrative responsibilities from Doug Sprinkel (Deputy Director-Technical), freeing Doug to work on some long-desired petroleum projects. Tom Chidsey is our new petroleum geologist, having spent 13 years in exploration with Celsius and Exxon, much of it in Utah. One of Tom's first projects is to generate information on the potentially huge Precambrian oil play developing in southern Utah. Another new scientist, Roger Bon, has filled the Industry Outreach position, to get UGMS data and information out to industry. Roger was a senior mining executive with extensive knowledge of coal resources throughout the western U.S. In addition, Alec Keith, our resident coal expert, is finishing up a series of nine maps showing coalbed methane resources of the Book Cliffs. These will be released as open-file reports as soon as complete so that exploration companies can take advantage of the "hot" methane play currently underway. Lastly, we are hiring one more petroleum geologist with an expected start date of February, 1990. I am confident that this team will have a dramatic effect on the petroleum business in Utah.

The Loma Prieta earthquake of October 17 was definitely felt in Utah. If not physically, at least emotionally and politically. Starting at 6 a.m. the next morning, UGMS scientists and staff were deluged with information demands from the public, state and local officials, and the media concerning earthquake danger in Utah.

UGMS, in cooperation with Comprehensive Emergency Management (CEM), and the University of Utah Seismograph Stations (UUS) had previously prepared an 8-point plan to deal with earthquake hazards in the state. One aspect of this is a seismic instrumentation program to upgrade seismograph recording equipment and to install a state-wide network of strong-motion instruments to start to learn how buildings and structures respond to earthquakes in this area. At present all our design criteria are based on California conditions. We know that

Continued on page 14

ZEOLITE OCCURRENCES OF UTAH

by Bryce T. Tripp and Bea H. Mayes

INTRODUCTION

Zeolites are a group of naturally occurring hydrated aluminum silicate minerals consisting of aluminum, silicon and oxygen with cations such as calcium, sodium, potassium, and magnesium. These atoms are arranged in a three-dimensional crystalline framework enclosing atom-sized tubes or channels. This arrangement gives zeolites interesting physical and chemical characteristics which have a number of commercial applications. Although exploration for zeolites has occurred since the 1950s, little information exists on Utah's resources since zeolites are difficult to recognize in hand samples and require X-ray diffraction for positive identification. In addition, zeolite exploration has not "boomed" as was predicted since synthetic zeolites can be manufactured for buyer's specific needs and companies have been reluctant to commit resources to exploration without a clearly defined market. Zeolites, however, are so useful and versatile that there is a high probability of future development of the very large resources of these natural zeolites in Utah.

ZEOLITE HISTORY AND MARKET DEVELOPMENT

The term zeolite, which means "boiling stone" in Greek, was coined by Cronstedt (1756) to designate a group of minerals which became frothy or appeared to "boil" during rapid heating. Mineralogists in subsequent years catalogued many of these zeolites, which occurred as well-formed crystals in vugs and fractures in igneous rocks associated with hydrothermal activity. These occurrences were mineralogically significant but economically unimportant. There were some early observations of zeolites occurring in sedimentary rocks; von Seebach (1862) noted 1 mm diameter analcime crystals in a clay, Murray and Renard (1891) mentioned 1 mm diameter phillipsite crystals in deep sea sediments and many geologists in the period 1914-1936 discussed zeolite mineralization. However, few people suspected the relative abundance of sedimentary zeolites. It wasn't until the 1950s when geologists from Union Carbide and other geologists in America, Japan, Italy, New Zealand and elsewhere began exploration for microcrystalline zeolites (figure 1) in altered tuffaceous sediments. Union Carbide's substantial investment in developing synthetic zeolites lead them to investigate naturally occurring zeolite deposits of the western United States. The specter of abundant, inexpensive, naturally occurring zeolites obviously concerned Union Carbide (Olsen, 1983). In following years, geologists located hundreds of occurrences in the western United States, Japan, Italy and other countries. Sheppard (1971) compiled a list of 147 known occurrences of the six most common zeolite species in the United States. The distribution of these occurrences in the western U.S. is shown in figure 2. Most of these occurrences do not have economic potential but many do and can be very large, measuring in the millions of tons. Zeolites are now known to be one of the most abundant authigenic minerals in sedimentary rocks with more than a thousand occurrences known world-wide.

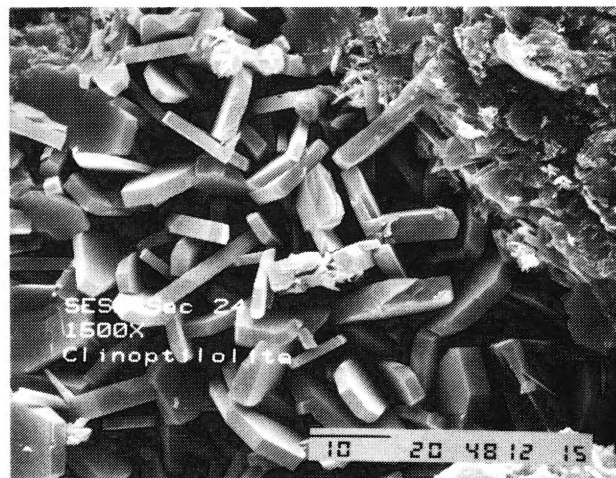
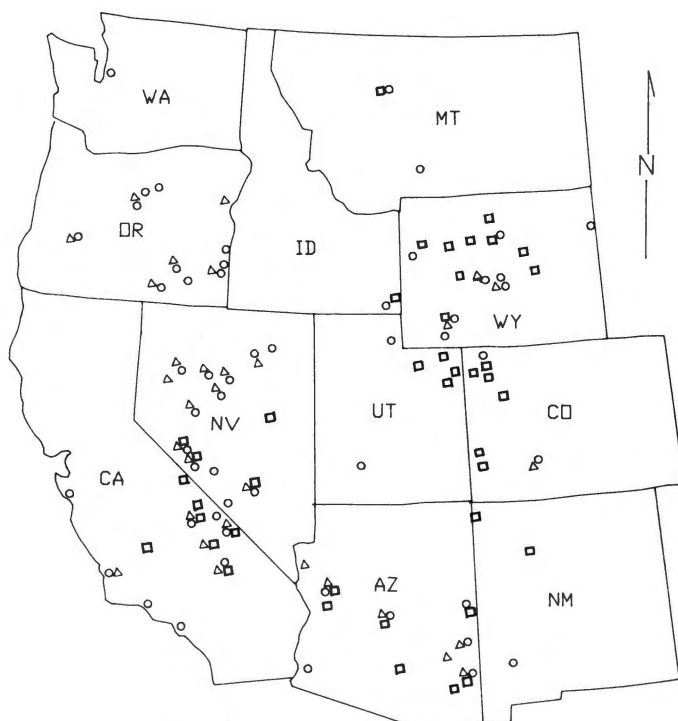


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Figure 1. Scanning electron microscope image (x1500) of tabular clinoptilolite crystals in zeolitized air-fall tuff from the Mountain Green occurrence (courtesy of Tom Sharps).



- Clinoptilolite occurrences in sedimentary rocks
- △ Chabazite, erionite, mordenite and phillipsite in sedimentary rocks
- Analcime occurrences in sedimentary rocks

Figure 2. Zeolite occurrences of the western U.S. (modified from Sheppard, 1971).

MOLECULAR STRUCTURE

The basic framework of zeolites is formed of tetrahedral building blocks consisting of silicon or aluminum atoms bonded to four oxygen atoms (figure 3). These basic building blocks interconnect through shared oxygen atoms to form three-dimensional, infinitely extended crystalline structures (figure 4). Silica tetrahedra predominate with minimum Si/Al ratios of 1:1. In figure 4, the intersections of the lines mark locations of silicon or aluminum atoms, and oxygen atoms occur at the midpoints of the lines. The large open channels and spaces in the crystalline lattice contain loosely held "extraframework" cations and water. Extraframework cations generally include K, Na, Ca, Li, Mg, Sr and Ba. These positively charged ions help balance the net negative charge created by substitution of trivalent aluminum atoms for tetravalent silicon atoms in the framework. The tetrahedra and extraframework cations can be assembled in a bewildering variety of combinations, resulting in a very large number of possible zeolites. Forty-six distinct, naturally occurring zeolite species (table 1) had been identified by 1985 with an average of one new species discovered every three years (Gottardi and Galli, 1985).

Table 1. List of naturally occurring zeolite species known as of 1985, with typical unit cell content. Underlined zeolites occur in sedimentary rocks. *Italic type indicates common species and an asterisk follows zeolites of greatest commercial interest (modified from Gottardi and Galli, 1985; and Sheppard, 1983).*

Amicite	$\text{Na}_4\text{K}_4(\text{Al}_6\text{Si}_6\text{O}_{32}) \cdot 10\text{H}_2\text{O}$
<u>Analcime (analcite)</u>	$\text{Na}_{16}(\text{Al}_{16}\text{Si}_{24}\text{O}_{96}) \cdot 16\text{H}_2\text{O}$
Barreite	$\text{Na}_6(\text{Al}_6\text{Si}_{28}\text{O}_{122}) \cdot 26\text{H}_2\text{O}$
Bikitaite	$\text{Li}_{12}(\text{Al}_2\text{Si}_4\text{O}_{22}) \cdot 2\text{H}_2\text{O}$
Brewsterite	$\text{Sr}_2(\text{Al}_4\text{Si}_{12}\text{O}_{52}) \cdot 10\text{H}_2\text{O}$
<u>Chabazite*</u>	$\text{Ca}_2(\text{Al}_4\text{Si}_8\text{O}_{24}) \cdot 12\text{H}_2\text{O}$
<u>Clinoptilolite*</u>	$(\text{Na}, \text{K})_6(\text{Al}_6\text{Si}_{30}\text{O}_{122}) \cdot 20\text{H}_2\text{O}$
Cowlesite	$\text{Ca}_6(\text{Al}_{12}\text{Si}_{18}\text{O}_{80}) \cdot 36\text{H}_2\text{O}$
Dachiardite (Svetozarite)	$(\text{Na}, \text{K}, \text{Ca}_{0.5})_4(\text{Al}_4\text{Si}_6\text{O}_{48}) \cdot 18\text{H}_2\text{O}$
Edingtonite	$\text{Ba}_2(\text{Al}_4\text{Si}_6\text{O}_{20}) \cdot 8\text{H}_2\text{O}$
Epistilbite	$\text{Ca}_3(\text{Al}_3\text{Si}_{18}\text{O}_{68}) \cdot 16\text{H}_2\text{O}$
<u>Eriolite*</u>	$\text{NaK}_2\text{MgCa}_{1.5}(\text{Al}_9\text{Si}_{28}\text{O}_{122}) \cdot 28\text{H}_2\text{O}$
<u>Faujasite*</u>	$\text{Na}_{20}\text{Ca}_{10}\text{Mg}_6(\text{Al}_{60}\text{Si}_{24}\text{O}_{360}) \cdot 235\text{H}_2\text{O}$
<u>Ferrierite</u>	$(\text{Na}, \text{K})\text{Mg}_2\text{Ca}_{0.5}(\text{Al}_6\text{Si}_{30}\text{O}_{122}) \cdot 20\text{H}_2\text{O}$
Garronite	$\text{NaCa}_{2.5}(\text{Al}_5\text{Si}_{10}\text{O}_{52}) \cdot 13\text{H}_2\text{O}$
Gismondine	$\text{Ca}_4(\text{Al}_8\text{Si}_8\text{O}_{32}) \cdot 16\text{H}_2\text{O}$
Gmelinite	$\text{Na}_6(\text{Al}_6\text{Si}_{18}\text{O}_{68}) \cdot 22\text{H}_2\text{O}$
Gobbsite	$\text{Na}_6(\text{Al}_5\text{Si}_{11}\text{O}_{52}) \cdot 11\text{H}_2\text{O}$
Gonnardite	$\text{Na}_2\text{Ca}_2(\text{Al}_2\text{Si}_{11}\text{O}_{40}) \cdot 12\text{H}_2\text{O}$
Goosecreekite	$\text{Ca}_2(\text{Al}_4\text{Si}_{12}\text{O}_{52}) \cdot 10\text{H}_2\text{O}$
Harmotome	$\text{Ba}_2(\text{Ca}_{0.5}\text{Na})(\text{Al}_5\text{Si}_{11}\text{O}_{52}) \cdot 12\text{H}_2\text{O}$
<u>Heulandite</u>	$(\text{Na}, \text{K})\text{Ca}_4(\text{Al}_5\text{Si}_{17}\text{O}_{72}) \cdot 24\text{H}_2\text{O}$
Hsianghualite	$\text{Li}_{16}\text{Ca}_{24}\text{O}_{96} \cdot \text{F}_{16}$
<u>Laumontite</u>	$\text{Ca}_4(\text{Al}_6\text{Si}_6\text{O}_{32}) \cdot 16\text{H}_2\text{O}$
Levyne (Levyne)	$\text{NaCa}_{2.5}(\text{Al}_5\text{Si}_{12}\text{O}_{58}) \cdot 18\text{H}_2\text{O}$
Mazzite	$\text{K}_2\text{Ca}_{1.5}\text{Mg}_2(\text{Al}_{10}\text{Si}_{28}\text{O}_{122}) \cdot 28\text{H}_2\text{O}$
Merinoite	$(\text{K}, \text{Na})_4(\text{Ba}, \text{Ca})_2(\text{Al}_2\text{Si}_{22}\text{O}_{84}) \cdot 24\text{H}_2\text{O}$
Mesolite	$\text{Na}_{16}\text{Ca}_{16}(\text{Al}_{40}\text{Si}_{20}\text{O}_{240}) \cdot 64\text{H}_2\text{O}$
<u>Mordenite*</u>	$\text{Na}_3\text{KCa}_2(\text{Al}_5\text{Si}_{10}\text{O}_{52}) \cdot 28\text{H}_2\text{O}$
Natrolite	$\text{Na}_{16}(\text{Al}_6\text{Si}_{18}\text{O}_{68}) \cdot 16\text{H}_2\text{O}$
Offretite	$\text{KCaMg}(\text{Al}_5\text{Si}_{10}\text{O}_{52}) \cdot 15\text{H}_2\text{O}$
Paranatrolite	$\text{Na}_6(\text{Al}_6\text{Si}_{18}\text{O}_{68}) \cdot 24\text{H}_2\text{O}$
Partheite	$\text{Ca}_6(\text{Al}_6\text{Si}_{18}\text{O}_{68}) \cdot 16\text{H}_2\text{O}$
Paulingite	$\text{Na}_{12}\text{K}_{68}\text{Ca}_{41}(\text{Al}_{122}\text{Si}_{207}\text{O}_{1344}) \cdot 705\text{H}_2\text{O}$
<u>Phillipsite</u>	$\text{K}_2(\text{Ca}_{0.5}\text{Na})_4(\text{Al}_6\text{Si}_{10}\text{O}_{52}) \cdot 12\text{H}_2\text{O}$
Roggianite	$\text{Ca}_{16}(\text{Al}_{16}\text{Si}_{28}\text{O}_{160})(\text{OH})_{16} \cdot 26\text{H}_2\text{O}$
Scolecite	$\text{Ca}_6(\text{Al}_6\text{Si}_{18}\text{O}_{68}) \cdot 24\text{H}_2\text{O}$
Stellerite	$\text{Ca}_4(\text{Al}_4\text{Si}_{12}\text{O}_{52}) \cdot 28\text{H}_2\text{O}$
Stilbite	$\text{NaCa}_4(\text{Al}_5\text{Si}_{17}\text{O}_{72}) \cdot 30\text{H}_2\text{O}$

Thomsonite
Tetragonal natrolite
Viseite
Wairakite
Wellsite
Willhendersonite
Yugawaralite

$\text{Na}_4\text{Ca}_6(\text{Al}_{20}\text{Si}_{20}\text{O}_{80}) \cdot 24\text{H}_2\text{O}$
 $\text{Na}_{16}(\text{Al}_{16}\text{Si}_{24}\text{O}_{96}) \cdot 16\text{H}_2\text{O}$
 $\text{Na}_2\text{Ca}_{10}(\text{Al}_{20}\text{Si}_{10}\text{O}_{80})(\text{OH})_{38} \cdot 16\text{H}_2\text{O}$
 $\text{Ca}_6(\text{Al}_6\text{Si}_{12}\text{O}_{58}) \cdot 16\text{H}_2\text{O}$
Ba — bearing phillipsite
 $\text{K}_2\text{Ca}_2(\text{Al}_6\text{Si}_6\text{O}_{24}) \cdot 10\text{H}_2\text{O}$
 $\text{Ca}_2\text{Al}_4\text{Si}_{12}\text{O}_{32} \cdot 8\text{H}_2\text{O}$

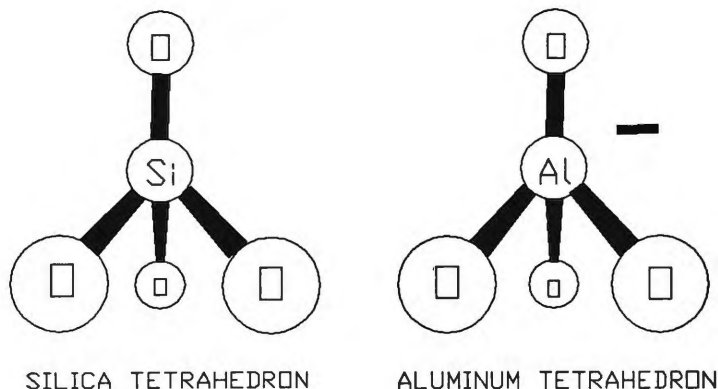


Figure 3. Tetrahedral building blocks of natural zeolites showing negative charge of aluminum tetrahedra.

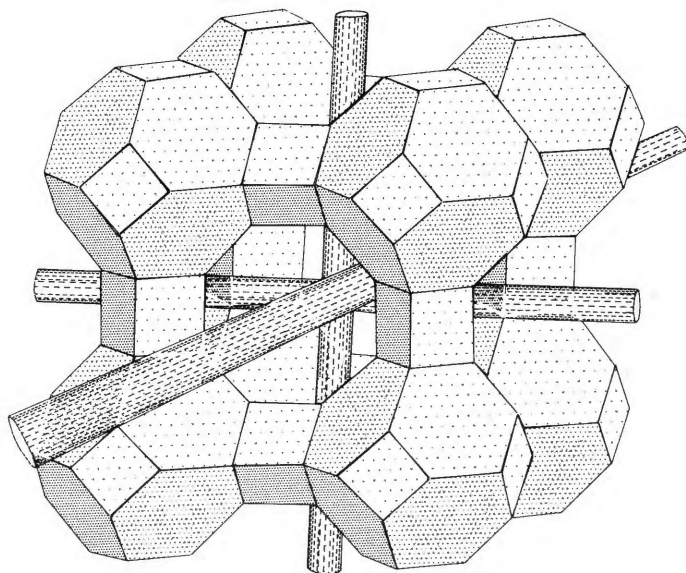


Figure 4. Open molecular structure of synthetic zeolite A showing large enclosed channels. The dashed cylinders emphasize the location of the mutually perpendicular channels (modified from Meier, 1968).

CHEMICAL AND PHYSICAL PROPERTIES

The unique molecular structure of these minerals allows interesting interactions between the zeolites and surrounding solutions and gases. One characteristic of zeolites is that the extraframework cations are exchangeable at low temperatures; for example, a high potassium clinoptilolite placed in a solution containing ammonia will lose some potassium and adsorb - take up and retain - ammonia. This cation exchange is not permanent, the adsorbed ammonia can be replaced by another cation. The ability of a zeolite to exchange cations freely is known as cation exchange capacity (CEC), a quantity expressed in milliequivalents per gram (meq/g). Greater CEC values indicate more valuable material. Table 2 lists maximum cation exchange capacities of common zeolites. Another characteristic of zeolites is that the water filling pore spaces is very mobile; zeolites liberate water during moderate heating and rapidly reabsorb it at a lower temperature, making some zeolites very effective desiccants. A third characteristic of zeolites is that each species has pores of a specific diameter (table 2); to be absorbed into the zeolite, molecules must be smaller in diameter than the pores. This has the effect of allowing some compounds into a particular zeolite lattice while excluding others, for instance a straight-chain hydrocarbon may pass through the external pores into the internal channels of the zeolite but a branched hydrocarbon containing the same number of carbon atoms might not pass through the pores due to its larger diameter. This phenomenon, which chemists refer to as molecular sieving, allows the separation of the two different molecules from a mixture. Myriad other possible uses of zeolites take advantage of other characteristics such as light color, light weight (specific gravity 2-2.3), silica content, etc.

Table 2. Zeolite cation exchange capacities and pore diameters (in Angstroms Å or 10⁻¹⁰ meters) (modified from Mumpton, 1981).

Zeolite Species	Pore Diameters (Å)	CEC (meq/g)
Analcime	2.6	4.54
Chabazite	3.7 x 4.2	3.81
Clinoptilolite	3.9 x 5.4	2.54
Erionite	3.6 x 5.2	3.12
Faujasite	7.4	3.93
Ferrierite	4.3 x 5.5	2.33
Heulandite	3.4 x 4.8	2.91
	4.0 x 5.5	
	4.4 x 7.2	
Laumontite	4.1 x 4.7	4.25
	4.6 x 6.3	
	2.9 x 5.7	
	6.7 x 7.0	
	4.2 x 4.4	
Natrolite	2.8 x 4.8	5.26
Phillipsite	3.3	3.87
Wairakite	—	4.61
Linde A (synthetic)	4.2	5.48
Linde X (synthetic)	7.4	4.73

USES

Dyer (1984, 1988), Mumpton (1981, 1983), and Sand and Mumpton (1978) describe many of the thousands of uses and potential uses of zeolites. Capsule summaries of some of these uses are listed below:

AIR POLLUTION CONTROL—Mordenite and clinoptilolite can adsorb SO₂, NO₂ and NO from power plant smoke stack gases and from other industrial waste gases. Mordenite acts as a catalyst in the presence of ammonia to convert nitrous oxides to nitrogen and water in nitric acid plants and nuclear fuel reprocessing plants.

AIR SEPARATION—Mordenite preferentially absorbs nitrogen from the air, leaving a nitrogen-depleted oxygen-enriched atmosphere around the zeolite. Appropriate pressure swing equipment, employing mordenite, produces either a concentrated nitrogen stream or a concentrated oxygen stream. Clinoptilolite and chabazite possess similar characteristics. Oxygen-generating units, designed in Japan and Europe, provide relatively pure oxygen for smelters, industrial consumers, hospitals, welding shops, bedridden patients and even for restaurants in cities with air pollution problems.

AQUACULTURE—Clinoptilolite effectively adsorbs the ammonia waste products of fish in fish hatcheries, thus reducing pollution of the streams flowing through the hatcheries. Zeolites for ammonia adsorption are also important for fish farms, fish transport trucks, and public and private aquaria. Zeolite-based oxygen generating equipment provides additional oxygen at fish hatcheries.

CONSTRUCTION—Cement manufacturers utilize analcime, laumontite, and clinoptilolite as an ingredient in light-weight pozzolanic cement. Manufacturers add chabazite and clinoptilolite as inexpensive fillers in some construction plastics; in some flammable plastics the addition of zeolites helps suppress smoke during building fires.

DESICCANT—Industrial chemists have used clinoptilolite's affinity for water to remove H₂O from organic liquids such as methanol, toluene, xylene, transformer oil and freon. Petroleum feedstocks can be desiccated, by using clinoptilolite, to below one part per million water content.

DETERGENT—Zeolites are finding increasing use as cleansing agents in detergent formulations to replace phosphates which are alleged to be serious water pollutants. Synthetic zeolites such as zeolite A and X have secured most of this market since public demand for a very high level of detergent performance justifies the higher cost of synthetic zeolites.

LIVESTOCK—Addition of chabazite and clinoptilolite as a dietary supplement for pigs seems to increase weight gain, decrease incidence of some diseases and reduce odor in feedlots and pens. Addition of zeolites to the diet of chickens, cows, goats, sheep and rabbits may provide similar benefits but research results have been less definitive.

MINING AND METALLURGY—Metallurgists investigated the use of mordenite to regulate consumption of reagents in minerals flotation. Zeolites can reduce lead fumes during

base-metal smelting and have found use in trapping heavy metals in mine drainage, tailings ponds and in smelter and mill waste water.

NUCLEAR WASTE DISPOSAL— Clinoptilolite, chabazite, mordenite and phillipsite selectively adsorb radionuclides. Cs^{137} and Sr^{90} are actively adsorbed by clinoptilolite from low-level nuclear waste water at power plants. Some methods of processing high- and medium-level nuclear waste employ chabazite and mordenite. Technicians at the Three Mile Island nuclear power plant accident utilized chabazite to adsorb Cs^{137} from contaminated water in the containment building. Soviet workers added clinoptilolite to the feed of sheep grazing in the region surrounding the Chernobyl site to reduce Cs absorption by the sheep. American scientists added clinoptilolite to soils in test garden plots at Bikini Atoll, the site of an early hydrogen bomb test, to reduce the radionuclide uptake by vegetables and hence reduce the risk to the relocated local population.

ODOR CONTROL— Chabazite and clinoptilolite absorb odors in personal and household uses. Body powders and shoe insoles contain zeolites. Manufacturers add zeolites to products for odor control in garbage compactors, refrigerators, cat litter boxes and bathrooms.

PAPER PRODUCTS— Clinoptilolite and mordenite have potential as fillers in paper manufacture. They have the proper combination of high-whiteness, low abrasiveness and other characteristics to produce kraft, light-weight and high brightness papers.

PETROLEUM REFINING— The petroleum industry employs zeolites in many phases of petroleum production and refining. Uses include removal of carbon dioxide, hydrogen sulfide, and water vapor from natural gas and methane. However, the major use of zeolites is as acid cracking catalysts to enhance gasoline production. Nearly all the world's gasoline production from crude oils uses zeolitic catalysts. Dyer (1988) estimates that hydrocarbon cracking consumes over 85 percent of the 400,000 tons of synthetic and natural zeolites consumed annually world-wide for gasoline production. Of the 350,000 tons used for cracking, the Western world uses natural zeolites only in selectofining, a process that increases the octane number of the gasoline. The shape-selective selectofining process cracks C5-C9 *n*-paraffins to liquid propane gas which separates easily into low- and high-octane fractions. Erionite and an erionite/c clinoptilolite mixture containing nickel have specific sized pores through which branched hydrocarbons cannot pass. Thus the high-octane components, branched paraffins and aromatics remain unchanged by the process since they do not come in contact with the catalytic sites on the interior of the zeolite. In other areas of the world, natural clinoptilolite and mordenite may be used for catalytic cracking.

SOLAR ENERGY— Zeolites have potential as a media in low-maintenance solar energy panels. Clinoptilolite enclosed in a rooftop solar collector absorbs heat during dehydration and liberates heat during rehydration. By controlling the cycling of hydration/dehydration, significant quantities of

heat can be recovered for domestic space heating, water heating and air conditioning.

SOIL AMENDMENT— Zeolites control pH and moisture content in soils at Japanese farms. Research indicates several formulations for zeolitic fertilizers: ammonium-saturated clinoptilolite, a clinoptilolite and ammonium nitrate mixture and a high-potassium clinoptilolite and ground phosphate rock mixture have been investigated. The addition of clinoptilolite to fertilizer slows the rate at which nitrogen is released into the soil, thus reducing the problem of leaching and water pollution. The combination of high-potassium clinoptilolite and phosphate rock yields a time-release fertilizer in which the zeolite supplies potassium and sequesters calcium which greatly increases the solubility of the phosphate rock.

WASTE WATER TREATMENT— Natural zeolites such as clinoptilolite, mordenite, phillipsite and chabazite can be used to remove ammonia from effluent at waste water treatment plants. Ammonia is a serious pollutant responsible for algae blooms and low oxygen content of polluted lakes and estuaries. Waste water treatment plants at Lake Tahoe, Nevada; Tillamook Bay, Oregon; and Reston and Alexandria, Virginia use clinoptilolite. Natural zeolites have some advantages over synthetic ones in this application since they tend to be more durable and are significantly less expensive in the western United States where waste water treatment plants are often close to zeolite deposits.

World-wide production of natural zeolites in 1988 amounted to roughly 275,000 tons with Japan, Hungary, and the United States being the largest producers. Building and construction use and paper manufacture consumed most of this production (Eyde, 1989).

ZEOLITE EXPLORATION AND DEPOSIT TYPES

Successful zeolite prospecting since the 1950s has centered on altered Tertiary volcanoclastic deposits in the western United States. While geologists have identified clays, feldspars, feldspathoids and gels as parent materials for zeolites, volcanic glass shards are the main precursor for authigenic zeolite formation. Chemicals in ground water or surface water alter glass to zeolites in a short period of time, forming zeolite beds. These zeolite beds can be white, yellow, grey, green or brown. They tend to be more resistant than surrounding unaltered tuff, often forming overhanging ledges in drainages. The zeolite beds do not necessarily have to be very thick to be of commercial interest. For example, the Bowie deposit, an unusually pure chabazite deposit in Arizona, is mined despite being only six inches thick and overlain by up to 30 feet of overburden. Zeolitically altered tuffs may also contain glass shards, quartz, clays, K-feldspar, opal, chalcedony, calcite, cristobalite, evaporites, mafic minerals, searlesite, fluorite, dawsonite, and other authigenic minerals, so little definitive information can be obtained simply by hand sample examination. A field test, designed by Helfferich (1964) to identify zeolites by their ion-

exchange and molecular sieve properties, can be employed but general practice is to collect samples of any altered tuff for later laboratory analysis. Mineralogists employ a wide variety of laboratory techniques for zeolite characterization including scanning electron microscopy (SEM), differential thermal analysis (DTA), thermogravimetric analysis (TGA), cation exchange capacity (CEC), oxygen absorption, and others, but X-ray diffraction (XRD) is the primary method of determining the zeolite species present and the purity of the material. CEC is a very important test since it gives a direct indication of how effective a particular zeolite sample will be in ion exchange applications.

Most significant zeolite occurrences form in one of the six following, general geologic/hydrologic environments: saline alkaline lakes, saline alkaline soil and land surfaces, deep sea sediments, open hydrologic systems, hydrothermal alteration zones and burial metamorphic occurrences (Hay, 1977).

Saline alkaline lake deposits (also known as closed hydrologic system deposits) form where saline alkaline lake waters alter volcanic ash deposited into the lake. Saline alkaline lakes typically occur in arid climates in block faulted or rifted terrains surrounded by igneous or metamorphic bedrock without significant pyritic shales or evaporites (Surdam, 1977). The combination of saline, alkaline waters and highly reactive volcanic material seems to be very favorable for zeolite growth. Zeolites in these deposits may be traced horizontally for several kilometers and are often laterally zoned according to the salinity gradient in the original lake water. Mineral zonation from the shoreline toward the center of the lake consists of unaltered glass; a zone of one or more of the following zeolites: chabazite, erionite, phillipsite, mordenite or clinoptilolite; an analcime zone and finally, at the center of the lake, a K-feldspar zone (Sheppard and Gude, 1969). Mineral zonation may not be apparent in rift valley settings because the long, narrow geometry of the valley compresses the mineral zones. Nonetheless, rift valley settings contain some of the purest, monomineralic concentrations of commercial zeolites known. High-grade beds are usually a few centimeters to a few meters thick.

Saline alkaline soil and land surface deposits form through the interaction of alkaline brines with tuffaceous and non-tuffaceous sediments such as claystones. Meteoric water percolating through sediments enriched in sodium carbonate-bicarbonate (by evapotranspiration) transform sediments to zeolites. Phillipsite, chabazite, natrolite and analcime are known to occur in these types of deposits (Hay, 1977).

Deep sea sediment deposits may form through the low-temperature alteration of volcanic glass, biogenic silica or poorly crystalline clays by pore water, although the exact mode of formation and required precursor minerals is still a matter of conjecture (Bass, 1976; Boles, 1977a). Major zeolites formed in deep sea sediments are phillipsite and clinoptilolite; analcime is a minor component and erionite, natrolite and mordenite occur only occasionally. Zeolites can constitute as much as 80% of some deep sea drilling cores. The type of zeolite encountered varies with the age of the sediments; phillipsite is more common in late Tertiary and younger sediments; clinoptilolite is most common in early Tertiary and Late Cretaceous sediments while analcime becomes more prevalent in Early

Cretaceous sediments. Authigenic clays often occur with the zeolites (Hay, 1977).

Open hydrologic system deposits form by percolation of meteoric water through nonmarine or shallow marine tuffaceous sediments. These occurrences can be several hundred meters thick and be traced laterally for tens of kilometers. These deposits show a vertical mineral zonation with zones consisting, in descending order, of volcanic glass and clay minerals; zeolites such as clinoptilolite, mordenite, and minor phillipsite; and finally, analcime and/or potassium feldspar. Contacts between zones are either horizontal or slightly inclined and cut bedding planes (Hay and Sheppard, 1977).

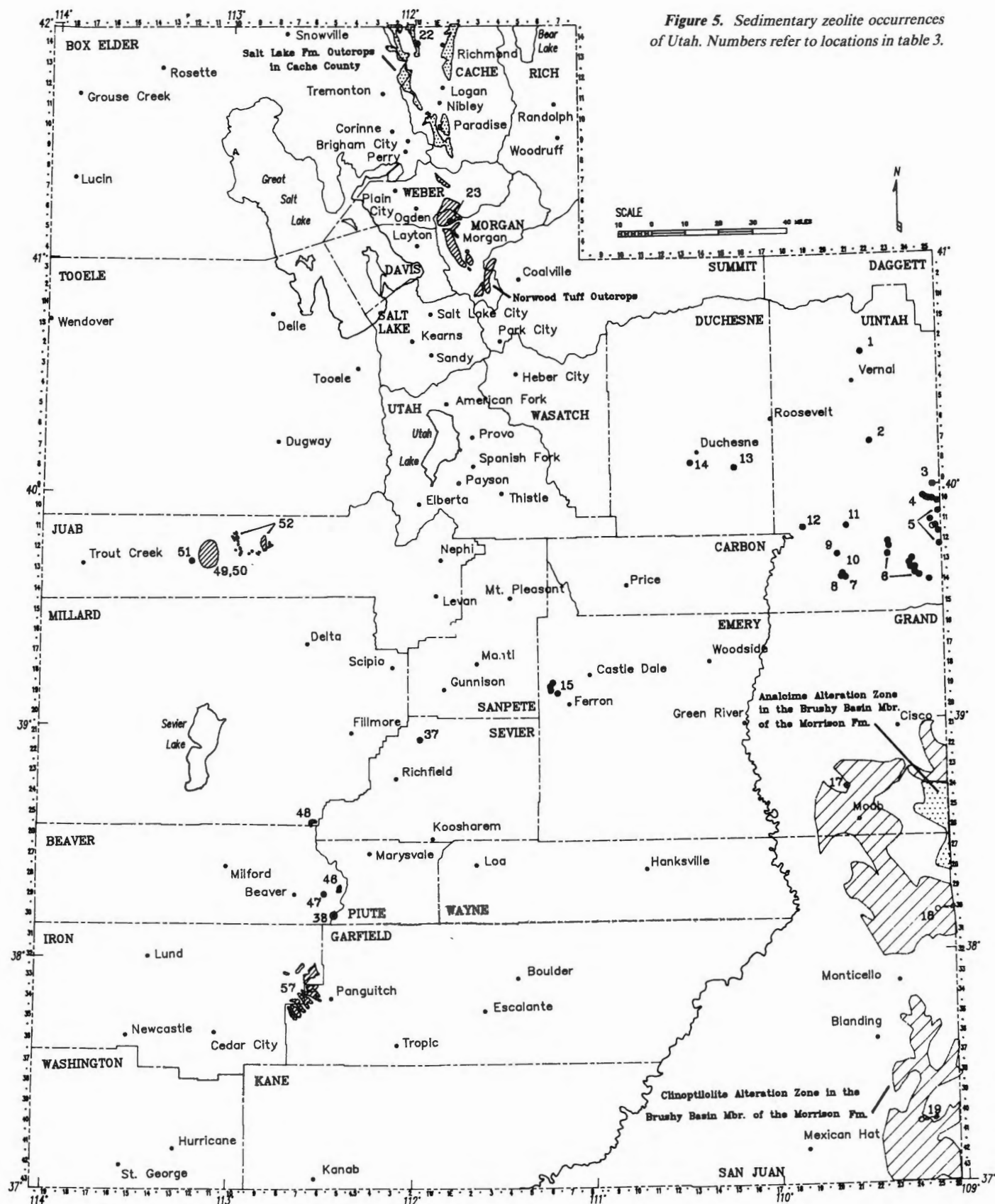
Hydrothermal alteration zone deposits occur in areas of hydrothermal activity where hot fluid alters rock along its migration route. Zeolites are zoned according to the temperature of the altering fluid in the hydrothermal system. Clinoptilolite and mordenite occur in cooler, shallower parts of the system while analcime, heulandite, laumontite and wairakite occur in deeper, hotter areas of the system (Hay, 1977).

Burial diagenetic deposits (also known as low-grade metamorphic deposits) originate by authigenic growth of zeolites due to increased temperatures associated with burial in sedimentary basins. Zeolites and other authigenic minerals in these deposits show vertical zonation with increasing alteration corresponding to increasing depth of burial. Volcanic glass or calcic plagioclase is a precursor to the zeolite. Clinoptilolite, heulandite, analcime and laumontite predominate although in Tertiary and younger rocks mordenite, erionite, chabazite, and phillipsite are significant. Together, zeolites may comprise up to 25 percent or more of the rock volume in non-tuffaceous, metamorphosed rocks and much higher proportions in altered tuffs. Associated minerals include authigenic quartz, albite, adularia, calcite, phyllosilicates and occasionally sphene, prehnite and pumpellyite (Boles, 1977b).

SELECTED UTAH OCCURRENCES

Utah contains 58 known zeolite deposits of which 27 are igneous/hydrothermal and 31 are sedimentary occurrences. Table 3 summarizes the 31 sedimentary occurrences. The locations of these occurrences are plotted in figure 5. A few of the sedimentary occurrences of special interest include: Three Creeks Reservoir, Cove Fort, Trenton, Bear Valley, Courthouse Wash, Topaz Mountain/Southern Thomas Range, Keg Mountains, and Mountain Green.

The Three Creeks Reservoir occurrence (table 3, loc.46) contains zeolites in a 0.8 square mile area of ash flows. The ash flows are in the Joe Lott Tuff and an unnamed crystal-rich member, both units of the Mount Belknap volcanics. One particularly high-grade unit in the area is 10 to 30 feet thick and crops out over a length of .9 mile (Steven and Cunningham, 1979). Zeolitic matrix comprises about 90% of the samples. Selected samples yielded XRD results of 65% and 66% calcium clinoptilolite with respective CEC's of 1.7 and 1.5 meq/g. Steven and Cunningham (1979) estimate that millions of tons of zeolitic tuff are present in this area. More study would be necessary to delineate its actual potential.



The Cove Fort occurrence (table 3, loc. 48) consists of a two mile by two mile outcrop of unnamed, altered 24 Ma, calc-alkaline ash-flow tuff (Steven and Cunningham, 1979). The unit is 100 m or more thick and contains roughly 1.8 billion tons of zeolitized rock. Selected samples taken by Steven and Cunningham (1979) showed high-potassium clinoptilolite to be the major component of the ash-flow matrix, comprising 78 to 87 percent of the rock volume with the remainder consisting of phenocrysts and lithic fragments. Two composite samples of float collected over the entire 100 meter thickness of the unit yielded X-ray diffraction results of 27% and 25% clinoptilolite. Cation exchange capacities (CEC) of these samples were .75 meq/g and .85 meq/g respectively (Mayes and Tripp, in prep.). These XRD and CEC numbers are fairly low, presumably representing inclusion of substantial amounts of non-zeolitic material. More selective sampling is necessary but because this material weathers easily, outcrops are sparse.

formation (Anderson and Rowley, 1987). Two grab samples yielded 48% and 47% clinoptilolite with CEC's of .20 and .21 (Mayes and Tripp, in prep). These samples were taken from existing dimension-stone quarries and do not adequately represent the resource. A large-scale sampling program would be necessary to begin to characterize the deposit but the potential exists for substantial tonnages.

The Courthouse Wash/Lisbon Valley/Montezuma Creek occurrence (table 3, loc. 17, 18, 19) contains clinoptilolite and analcime and is found in the Brushy Basin Member of the Morrison Formation. Up to 30% clinoptilolite occurs in this closed hydrologic basin deposit (Turner-Peterson, 1987). The clinoptilolite facies (figure 5) covers a very large area of Utah but information on purity and continuity of the zeolite deposit is unavailable.

The Topaz Mountain/Southern Thomas Range occurrence



Figure 6. Photo of a house at the main highway intersection in Trenton, Utah built upon an outlier of green, granular-weathering zeolite tuff.

The Trenton occurrence (table 3, loc. 22; figure 6) crops out in the southern end of the Malad Range immediately west of Trenton. Potassium clinoptilolite occurs as an alteration product in the 19 Ma Cache Valley Formation of the Salt Lake Group of Williams (1964). Exposures are generally poor but the tuff is known to be at least 25 feet thick and assays up to 67% clinoptilolite with CEC up to 1.8 meq/g. One of the most accessible exposures is in the town of Trenton (figure 6). Other zeolite occurrences known in the Salt Lake Group include a deposit near Oneida Narrows, Idaho (Danzl, 1985) and one near Richmond, Utah where the zeolitized tuff is 40-60 feet thick (J. Brummer, personal communication, 1989). The Salt Lake Group, with its great aerial extent and frequent zeolite occurrences, merits more detailed study.

The Bear Valley occurrence (table 3, loc. 57; figure 7) covers a large area of the Markagunt Plateau. Clinoptilolite-cemented eolian sandstone occurs in the 500 to 800-foot-thick Bear Valley Formation (25 Ma). The clinoptilolite content varies laterally but is widespread in both upper and lower members of the

(table 3, loc. 49,50) crops out over an area greater than 70 square miles. Potassium clinoptilolite occurs in a stratified tuff at the base of the Topaz Mountain Rhyolite, (Lindsey and others, 1974; Lindsey, 1975a). This tuff is discontinuous, ranging from 0 to 300 feet thick, and varies in zeolite content. Thirty-eight of the 160 random samples taken by Lindsey (1975a) contained 60% or more clinoptilolite.

The Keg Mountain occurrence (table 3, loc. 52) covers a large area of the Keg Mountains. Zeolite occurs in stratified tuffs of the Keg Mountains Rhyolite and the Topaz Mountain Rhyolite. Lindsey (1975b) collected samples containing 90% potassium clinoptilolite. One quarter of his 43 samples contained 60% to 80% clinoptilolite. A large volume of high-quality zeolite is probably present.

The Mountain Green occurrence (table 3, loc. 23) covers an area of four by six miles in northern Morgan County. Five altered air-fall zones in the Norwood Tuff (36-38 Ma) contain potassium clinoptilolite. One 38-foot-thick bed averaged 52 percent clinoptilolite with an average CEC of 1.98 meq/g.



Figure 7. Zeolitized tuffaceous sandstone of the Bear Valley Formation exposed in a dimension-stone quarry in the foreground.

Table 3. Utah Sedimentary Zeolite Occurrences
(modified from Mayes and Tripp, in prep.)

County	Loc. No.	Location	Zeolite Species/Occurrence	Age
Beaver	46	THREE CREEKS RESERVOIR T29S, R5W, sec. 3, 9(?), 10 Quad.: Shelly Baldy Peak 7.5'	CLINOPTILOLITE. Ash-flow tuffs in Mount Belknap Volcanics: a) altered Joe Lott Tuff Member, b) younger, crystal-rich tuff	Miocene 19 Ma (approx.)
	47	TELLURIDE POWER PLANT #2 T29S, R6W, sec. 24 Quad.: Shelly Baldy Peak 7.5' See also #38, below.	CLINOPTILOLITE.	
Beaver, Millard	48	COVE FORT T26S, R6W, sec. 3, 5, 8, 9 and other outcrops Quad.: Cove Fort 15'	CLINOPTILOLITE. Part of unnamed calc-alkalic ash-flow tuff, source unknown.	Oligocene?, Miocene >22 Ma, prob. 24 Ma
Cache	22	TRENTON T14N, R1W, sec. 34. Quad.: Trenton 7.5'	CLINOPTILOLITE. Tuff of Salt Lake Group.	Tertiary

Carbon		See #15, below.		
Duchesne	13	ELMER MOON NO.1 WELL T4S, R3W, sec. 8, center SW of SE sec. 8 (USM) Location from Milton et al. (1960) Quad.: Bridgeland 7.5'	ANALCIME. In dolomitic oil shale of the Green River Formation. Sample taken from drill core at depth of 3371-3373 feet.	Eocene
	14	INDIAN CANYON T4S, R5W, sec. 21 (approx.) Quad.: Duchesne SW 7.5'	ANALCIME. Beds in saline facies of upper Green River Formation.	Eocene
Emery, Carbon, Sevier	15	WASATCH PLATEAU COAL FIELD, T15-22S, R4-8E Quad: Acord Lakes 7.5', Castle Dale 15', Emery West 7.5', Flagstaff Peak 7.5', Heliotrope Mtn. 7.5', Hiawatha 7.5', Mahogany Point 7.5', Red Point 7.5', The Cap 7.5', Wattis 7.5'	ANALCIME. Analcime in coal cleats. Samples from selected mines and core holes, most contain analcime, the bulk of which occurs as fracture fillings. The stratigraphic interval covered by sampling includes the beds in which most Wasatch Plateau coals occur. Of eight seams sampled, most are somewhat analcimized, for example, those from the Upper Hiawatha and Hiawatha of South Horn Mountain, T19S, R6E, sec. 11, 15, 22, 35.	Cretaceous
Garfield, Iron	57	BEAR VALLEY T33S, R5W, sec. 18, 30 Quad.: Panguitch NW 7.5'	CLINOPTILOLITE. Tuffaceous sandstones of the Bear Valley Formation are poorly to moderately cemented by clinoptilolite.	Oligocene, Miocene(?)
Grand	17	COURTHOUSE WASH T24S, R20E, sec. 2, 3, 11, 14, 15, 16, 22 Quad.: Moab 15'	CLINOPTILOLITE, ANALCIME. In altered tuff beds of Brushy Basin Member of the Morrison Formation. Tuff is less than 30% clinoptilolite.	Jurassic
Iron		See #57, above.		
Juab	49	TOPAZ MOUNTAIN T13S, R11W, sec. 5 Quad.: Topaz Mtn. 15"	CLINOPTILOLITE. Tuff in unnamed formation. Beds at least 1 ft. thick and 75% clinoptilolite. (see Southern Thomas Range location below.)	Miocene
	50	SOUTHERN THOMAS RANGE T12, 13S, R11, 12 W Quad.: Topaz Mtn. 15', Dugway Range 15', Dugway Pass 7.5'	CLINOPTILOLITE. Tuff generally stratified, well exposed, and commonly zoned inward from periphery of Thomas Range (vitric outward, zeolitic medial, feldspathic towards center). Some samples contain 90% clinoptilolite.	Miocene
	51	SPOR MOUNTAIN T13S, R12W, sec. 5, 8 Quad.: Topaz Mtn. 15'	CLINOPTILOLITE. Remnant clinoptilolite in drill cuttings of two holes at Roadside beryllium deposit in mineralized tuff, 22% or less clinoptilolite.	Miocene
	52	KEG MOUNTAIN T11-13S; R8-10W Quad: Keg Mtn. Ranch 7.5', Keg Pass 7.5', Picture Rock Hills 7.5', The Hogback 7.5'	CLINOPTILOLITE. Tuff generally stratified. Maximum thickness 100 ft. Clinoptilolite comprises nearly 90% of some samples. Normalized sample station mean 87% in T12S, R9W, sec. 25; 12 other station means greater than 60%.	Miocene
	53	GUNNISON PLATEAU T16S, R1E, sec. 12 Quad.: Chriss Canyon 7.5'	CLINOPTILOLITE. In sandstone of Colton Formation.	Eocene
Millard		See #48 above.		
Morgan, Weber	23	MOUNTAIN GREEN T5N, R1E, sec. 24 Quad.: Snow Basin 7.5'	CLINOPTILOLITE. Tuff in Norwood Tuff. Thick zeolitized air-fall tuffs with individual beds containing up to 80% clinoptilolite.	Tertiary
Piute, Beaver	38	CIRCLEVILLE T29-31S; R4-6W Quad: Circleville 7.5', Circleville Mtn. 7.5'	CLINOPTILOLITE (?). Sandstone member of the Mount Dutton Formation is tuffaceous and poorly cemented by zeolite (clinoptilolite?). Exposures are few and poor.	Miocene
San Juan	18	LISBON VALLEY T30S, R25E, sec. 23, 24 (approx.) Quad.: Lisbon Valley 15'	CLINOPTILOLITE, ANALCIME. In altered tuff beds of Brushy Basin Member of the Morrison Formation. Tuff contains less than 30% clinoptilolite.	Jurassic
	19	MONTEZUMA CREEK T40S, R24E, sec. 31, 32 33, 34 (approx.) Quad.: Montezuma Creek 15'	CLINOPTILOLITE, ANALCIME. In altered tuff beds of Brushy Basin Member of the Morrison Formation. Tuff contains less than 30% clinoptilolite.	Jurassic

Sevier	37	AURORA BENTONITE PIT T21S, R1W, sec. 31 Quad.: Aurora 7.5' See also #15, above.	HEULANDITE (?). In bentonite, associated with rhyolite ash, tuffaceous sandstone, agglomeratic tuff. Zeolite postulated from recalculation of chemical analysis.	
Uintah	1	BRUSH CREEK T3S, R22E, sec. 5 Quad.: Donkey Flat 7.5'	ANALCIME. In ochreous oolitic beds in the Chinle Formation. Keller (1953) found analcime in four colored zones near the top of the formation in a Highway 44 roadcut, 10 miles north of Vernal.	Triassic
	2	RED WASH NO. 32 COREHOLE T7S, R22E, sec. 22 Quad.: Red Wash NW 7.5'	ANALCIME. Core recovered at a depth of 3989 feet in the Parachute Creek Member of the Green River Formation shows bluish analcime bands in dark brown dolomitic shale. Thin section shows sub-spheroidal analcime above a tension crack.	Eocene
	3	CANYON OF THE WHITE RIVER T9S, R25E, sec. 27 Quad.: Walsh Knolls 7.5'	ANALCIME. Analcime lenses or beds at five levels. A sample from a thin asphalt-saturated ash bed 750 feet above the base of the Green River Formation calculated 65.84% wt % analcime.	Eocene
	4	HELLS HOLE CANYON T10S, R25E, sec. 18, 20, 21 22, 25 Quad.: Weaver Ridge 7.5', Southam Canyon 7.5'	ANALCIME. Lenses about 700 feet above the base of the Green River Formation (Bradley, 1929, 1931). Wavy-bedded analcimized tuff, Mahogany marker tuff bed, contorted tuff bed of the Parachute Creek Member of the Green River Formation (Cashion, 1967).	Eocene
	5	EVACUATION CREEK T11S, R25E, sec. 1, 21, 34, 35 T12S, R25E, sec. 1, 25 Quad.: Davis Canyon 7.5' Dragon 7.5', Rainbow 7.5' Southam Canyon 7.5'	ANALCIME. 1) Wavy-bedded analcimized tuff, 2) Mahogany marker tuff bed, 3) contorted tuff bed, all in the Parachute Creek Member of the Green River Formation. Cashion (1967) shows "tuff, or altered tuff" in 20 stratigraphic sections of the Mahogany zone or ledge composed of drill cores or outcrop in the southeast Uinta Basin, including sections from Big Canyon, Green Canyon, and Willow Canyon.	Eocene
	6	BITTER CREEK (TWO WATER CREEK) T12S, R23E, sec. 21, 28 T13S, R23E, sec. 4 T13S, R24E, sec. 15, 21, 34, 35 T14S, R25E, sec. 21 Quad: Archy Bench 7.5' Burnt Timber Canyon 7.5', Cooper Canyon 7.5', Rat Hole Ridge 7.5', Tom Patterson Canyon 7.5'	ANALCIME. 1) Wavy-bedded analcimized tuff, 2) Mahogany marker tuff bed, 3) contorted tuff bed, all in the Parachute Creek Member of the Green River Formation. Cashion (1967) shows "tuff, or altered tuff" in 20 stratigraphic sections of the Mahogany zone or ledge composed of drill cores or outcrop in the southeast Uinta Basin, including sections from Big Canyon, Green Canyon, and Willow Canyon.	Eocene
	7	CHIMNEY ROCK SOUTH T14S, R21E, NW part Quad.: Agency Draw NE 7.5' Wolf Point 7.5'	ANALCIME. Sedimentary dikes in the Parachute Creek Member (redefined) Dikes cut several tens of feet of section in the stratigraphic interval that extends 200 feet above and 200 feet below the Horse Bench Sandstone. Geological setting similar to locations 8, 9, 11, 12.	Eocene(?)
	8	CHIMNEY ROCK SOUTHWEST T14S, R21E, sec. 6 (approx.) Quad.: Agency Draw NE 7.5'	ANALCIME. A "sedimentary" dike traces upward along a steep slope a vertical distance of 150 feet to a point where it merges with a contorted tuff bed. The intersection is about 20 feet below the Horse Bench Sandstone. Geological setting similar to locations 7, 9, 11, 12.	Eocene
	9	CHIMNEY ROCK T14S, R21E, sec. 6, NE of NE Quad.: Agency Draw NE 7.5'	ANALCIME. 600-foot long "sedimentary" dike, Green River Formation. Geological setting similar to locations 7, 8, 11, 12.	Eocene
	10	SOUTH UINTAH COREHOLES Agency corehole: T13S, R20E sec. 1; Southam corehole: T10S, R24E, sec. 29 Quad: Agency Draw NE 7.5' Southam Canyon 7.5'	ANALCIME. Identification in samples from drill core of the interval surrounding the Mahogany zone. No analcime was detected in any samples from Western Oil Shale, Wosco corehole EX-1, T9S, R20E, sec. 36.	Eocene

11	WEST FORK T11S, R21E, SW part Quad.: Big Pack Mtn. SE 7.5'	ANALCIME. Sedimentary dikes in the Parachute Creek Eocene(?) Member (redefined) of the Green River Formation. Dikes cut several tens of feet of section in the stratigraphic interval that extends 200 feet above and 200 feet below the Horse Bench Sandstone. Geological setting similar to locations 7, 8, 9, 12.
12	ALGER PASS T11S, R19E, SW part Quad.: Nutters Hole 15'	ANALCIME. Sedimentary dikes in the Parachute Creek Eocene(?) Member (redefined) of the Green River Formation. Dikes cut several tens of feet of section in the stratigraphic interval that extends 200 feet above and 200 feet below the Horse Bench Sandstone. Geological setting similar to locations 7, 8, 9, 11.
Weber	See #23, above.	

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von Seebach, K., 1862, Notiz über ein neues Vorkommen des Analzims:
K. Ges Wiss Gottingen Nachr, p. 334-335.

Utah Earthquake Activity

by Susan J. Nava

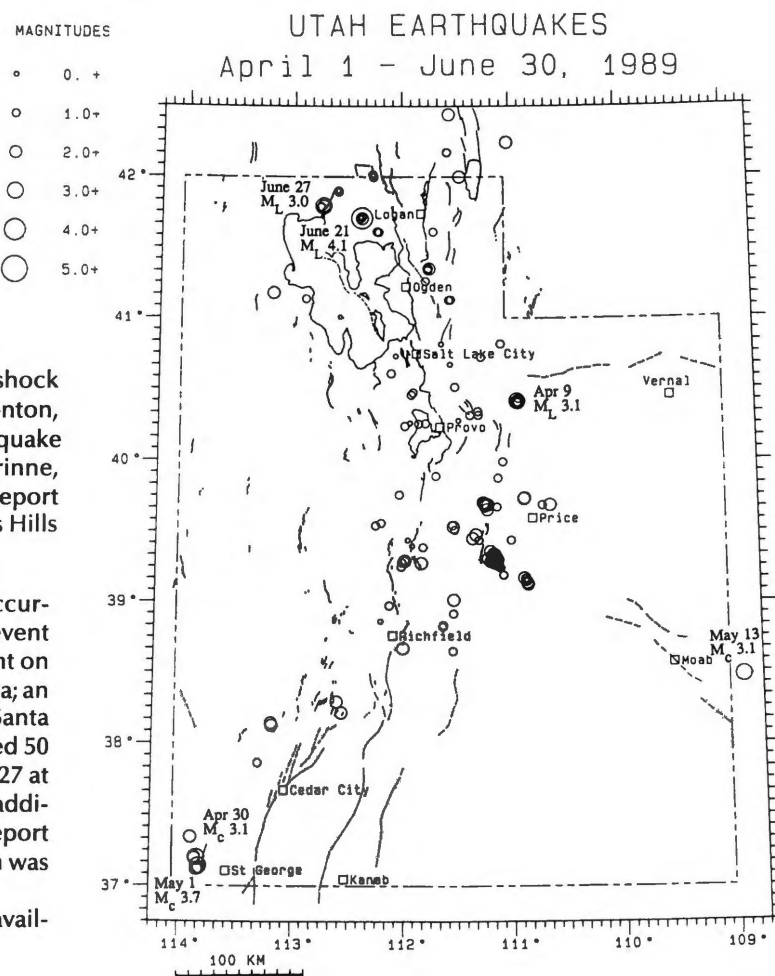
University of Utah Seismograph Stations, Department of Geology and Geophysics

During the three-month period April 1 through June 30, 1989, the University of Utah Seismograph Stations located 190 earthquakes within the Utah region (see accompanying epicenter map). Of these earthquakes, 97 had a magnitude (either local magnitude, M_L , or coda magnitude, M_C) of 2.0 or greater, six had a magnitude of 3.0 or greater, and four were reported felt.

The largest earthquake during the report period was a shock of $M_L 4.1$ on June 21 at 03:54 PM MDT, 16 km west of Tremonton, in the Blue Springs Hills of north-central Utah. This earthquake was reported felt in Tremonton, Howell, Riverside, Corinne, Garland, Plymouth, and at the Thiokol Plant. During the report period, ten earthquakes associated with the Blue Springs Hills sequence have been located.

Five other earthquakes of magnitude 3.0 and greater occurred in the Utah region during the report period: an M_L 3.1 event on April 9 at 05:24 AM MDT, felt in Tabiona; an M_C 3.1 event on April 30 at 03:20 AM MDT, located 10 km west of Santa Clara; an M_C 3.7 event on May 1 at 12:35 PM MDT, which was felt in Santa Clara; an M_C 3.1 event on May 13 at 03:01 PM MDT, located 50 km east-southeast of Moab; and an M_L 3.0 event on June 27 at 09:51 AM MDT, located 25 km south of Snowville. One additional earthquake was reported felt in Utah during the report period: an M_L 2.7 event on April 3 at 09:06 PM MDT, which was felt in Emery County.

Additional information on earthquakes within Utah is available from the University of Utah Seismograph Stations.



Teacher's Corner

by Sandra N. Eldredge

Earthquake Fault Maps are available at the Utah Geological and Mineral Survey for Salt Lake, Davis, and Weber Counties. Utah County will be included at a future date. The fault maps are on convenient 8½ x 11 handouts and are good general references to locate faults in these counties. The handouts are free!

"Utah's Geologic Hazards" and "Plate Tectonics (Earthquakes and Volcanoes)" will be the subjects of two teacher workshops to be held at the Utah Museum of Natural History located at the University of Utah. "Utah's Geologic Hazards," for 7-12 grade teachers, will be taught by Bill Case (Utah Geological and Mineral Survey) on March 16 and 17, 1990. "Plate Tectonics (Earthquakes and Volcanoes)," for 4-9 grade teachers, will be taught by Sue Nava (University of Utah Seismograph Stations) on March 9 and 10, 1990. Please contact Deedee O'Brien at the Museum for more information (801) 581-4887.

Once you've taken one of these workshops, or if you have taken a prior workshop, you can borrow an excellent earth-

quake kit from the Museum. The kit includes a model of the Wasatch Fault and a good slide presentation.

Teacher packets are now available through the U.S. Geological Survey. "Selected Packet of Geologic Teaching Aids" is available to elementary- and secondary-school teachers of courses in geography, social studies, general science, environmental education and oceanography. "Teacher's Packet of Geologic Materials" is available to secondary-school teachers and includes map indexes, leaflets and booklets on geologic topics. To receive these packets, the U.S. Geological Survey requires compliance with the following procedures:

1. Send your request on school letterhead to:
U.S. Geological Survey
Geologic Inquiries Group
907 National Center
Reston, Virginia 22092
2. Indicate the subject(s) and grade level(s) you teach.
3. Enclose your mailing label.

Director's Perspective
continued from page 1

soils and rocks in Utah will behave differently, but we do not have local data. This program is being submitted as a bill to the state legislature.

Four of the points in the hazards proposal have received wide support and may become a second bill for the legislature to consider. These include: mandatory site investigations for critical government facilities (UGMS already offers this service free to any government entity on a voluntary basis); geologic hazards elements in master plans at local levels; disclosure of geologic hazards in real estate transactions; and education of school children in how to respond to earthquakes and understanding of other geologic hazards in Utah.

We have a long way to go in Utah to be fully prepared for the big earthquake. We see how such preparation paid off in California and there is no question that it must be done in Utah.

Industrial rocks and minerals, the main emphasis of this issue of *Survey Notes*, played a crucial role in the economic development of Utah from pioneer times to the present. Despite their importance, most of us have only a vague idea of what industrial rocks and minerals are and how essential they are to maintaining our standard of living. The term industrial rocks and minerals includes all geological products not utilized as fuels, not associated with hydrocarbon generation

(such as gilsonite and coal resin), not mined primarily for processing into metals, or not primarily used as gemstones. These materials are ubiquitous in everyday life. For example, an average breakfast might consist of eggs and bacon from chickens and pigs whose feed may contain mineral fillers such as clays, calcite or zeolites; toast and cereal made from grain fertilized with potash and phosphate and containing salt and vegetable oils bleached with fuller's earth; the plate on which the food rests probably contains feldspar, clays and silica; the water glass was manufactured from silica, limestone and sodium carbonate; the utensils, made of stainless steel smelted with limestone and fluorspar as fluxes, were ground and polished with mineral abrasives such as aluminum oxide, iron oxide, pumice, silica, diatomite and tripoli. Industrial rocks and minerals produced in significant amounts in Utah currently include sand and gravel, limestone, potash, gypsum, salt, clays, phosphate, crushed stone, industrial sand and dimension stone — altogether valued at nearly \$200 million per year.

The UGMS has many responsibilities in dealing with geologic hazards and many opportunities to enhance our economic resources. I am quite impressed with the expertise and motivation of our staff and am honored to be associated with such a quality organization. I am confident that we will carry out our duties with the highest level of professionalism.

Allison Named Director of UGMS

Dr. M. Lee Allison, senior geologist at the University of Utah Research Institute, has been named director of the Utah Geological and Mineral Survey.

Dr. Allison succeeds Genevieve Atwood, director since 1981, who has resigned to pursue a master's degree in public administration.

Among Dr. Allison's intended directives will be renewed emphasis on Utah's oil and gas potential. In keeping with this new policy, two vacancies will be filled with petroleum geologists.

Utah's basins appear to have a little bit of everything in terms of geologic reservoirs and diversity," he said. "There's a tremendous untapped petroleum potential left in this state. We intend to play a role in making the industry aware of it.

Because of the sharp cutback by the major petroleum companies in exploration in the Rockies, there is much opportunity for the independent and smaller companies," he said.

"They usually don't have resources or staff to take on these projects. The UGMS can provide the infrastructure that will show them geologic potential."

Dr. Allison, 41, was born in Philadelphia and raised in Southern California.

He earned a degree in geology and geophysics in 1970 from the University of California at Riverside.

In 1971, he joined the California Division of Oil and Gas as an engineer.

He earned a master's degree in geology from San Diego State University which included seismological studies on the Elsinore fault. In 1974, he joined Standard Oil of California (now Chevron Corporation) in San Francisco as an exploration geologist, assigned to Alaska for three years, with emphasis on seismic interpretation.

He resigned in 1979 to pursue a doctorate, and studied for one year at Brown University, then transferred to the University of Massachusetts, Amherst, where he earned his PhD in structural geology. During one summer he worked for NASA at

CalTech's Jet Propulsion Laboratory, helping develop remote sensing capabilities for mineral and petroleum exploration.

He joined Standard Oil Production Office (now BP Exploration) in Dallas in 1984, where he was engaged in exploration in Oklahoma and Texas. He was later lead geologist for exploration in Nevada.

Transferring to Houston, he was assigned to a team exploring the Wind River Basin of Wyoming.

He joined the U. of U. Research Institute in 1987. The institute was then engaged primarily in geothermal investigations. Dr. Allison was assigned to develop an oil-and gas-research program.

At the institute, he took part in a geothermal study for the federal government on Ascension Island in the South Atlantic. The purpose was to develop geothermal energy for a major air base and satellite-tracking station on the 34-square-mile volcanic island. As part of the project, he monitored and interpreted microearthquakes.

Dr. Allison also set up the institute's Center for Dipmeter Research. The dipmeter is a borehole logging device. Information it yields includes the shape and orientation of subsurface formations and determinations of *in situ* stress. It also is a major tool for locating fractures, which are often major factors in petroleum traps. Dr. Allison was the institute's representative to the organization of Western

Earth Science Technologies, Inc. (WEST), a consortium of 12 universities in six Rocky Mountain states. WEST is engaged in multi-disciplinary geoscience research in the Rocky Mountain region in cooperation with industry and the federal government.

As first president of WEST, he will continue in that post, concurrent with his administrative capacity at UGMS. He also will carry on one of the major thrusts of the survey: understanding, documenting, and reporting the earthquake and other geologic hazards in Utah.

(We would like to thank R.H. Woody of the Salt Lake Tribune for the use of material from his column in the September 26, 1989 edition.)

"There's a tremendous untapped petroleum potential left in this state. We intend to play a role in making the industry aware of it."

Staff Changes

The UGMS has acquired both a new director *M. Lee Allison* (see the write-up) and a new Associate Director for Development, *William Stevenson*. Bill has long experience as an independent in oil exploration and, among other projects, will be working on our sales and distribution as well as our image.

Mark Jensen, geologist in the Mapping Program, is going to the Utah Department of Health Bureau Drinking Water/Sanita-

tion, as a geologist. We wish him all the best, but he has to finish the Brigham City quad before we speak to him again.

Roger Lee Bon has recently joined the UGMS in the Industry Outreach Program. Roger recently worked as a minerals consultant and has a lengthy background in the coal industry.

Thomas C. Chidsey is our new petroleum geologist in the Economic Section. Tom has worked as a production geologist in south Texas and for the last ten years as a petroleum exploration geologist working various Rocky Mountain geologic provinces.

Books & Papers

- Landslides and debris flows in Ephraim Canyon, central Utah**, by R.L. Baum and R.W. Fleming. 1989, p. C1-C12. 1 plate in pocket. U.S.G.S. Bulletin 1842-C.
- Mineral resources of the Indian Creek, Bridger Jack Mesa, and Butler Wash Wilderness Study Areas, San Juan County, Utah**, by C.G. Patterson and others. 1989. p. A1-A25. U.S.G.S. Bulletin 1754 A.
- Mineral resources of the North Stansbury Mountains Wilderness Study Area, Tooele County, Utah**, by M.P. Foote and others. 1989, U.S.G.S. Bulletin 1745-B.
- Studies of geology and hydrology in the Basin and Range province. Southwestern United States, for isolation of high-level radioactive waste; basis of characterization and evaluations**, by M.S. Bedinger and others. 1989, p. A1-A41. U.S.G.S. Bulletin 1370-A.
- Mineral resources of the Swasey Mountain and Howell Peak Wilderness Study Areas, Millard County, Utah**, by D. A. Lindsey and others. 1989, p. A1-A21. U.S.G.S. Bulletin 1749-A.
- Mineral resources of the Wah Wah Mountains Wilderness Study Area, Beaver and Millard counties, Utah**, by L.J. Cox and others. 1989, p. B1-B21, 1 plate in pocket, U.S.G.S. Bulletin 1749-B.
- Map showing 1983 landslides in Utah**, by E.E. Brabb, G.F. Wiczorek and E.L. Harp. Prepared in cooperation with Utah Geological and Mineral Survey. 1989, scale 1:500,000. U.S.G.S. Miscellaneous Field Study 2085.
- Geologic map of the Newfoundland Mountains of northwestern Utah**, by R.W. Allemendinger and T.E. Jordan. 1989. Scale 1:31,680. U.S.G.S. Miscellaneous Field Study 2087.
- Gamma-ray composite-color maps of the Tushar Mountains and adjoining areas, Marysvale volcanic field, Utah**, by T.A. Schutter and others. Scale 1:100,000. U.S.G.S. Miscellaneous Investigation 1430-H.
- Analytical results and sample locality maps of stream-sediment, heavy-mineral-concentrate, magnetic concentrate, and rock samples from in and adjacent to the Wah Wah Mountains Wilderness Study Area, Beaver and Millard counties, Utah**, by B.M. Adrian and others. 37 p., scale 1:62,500. U.S.G.S. Open-File Report 88-0535.
- Analytical results and sample locality maps of stream-sediment and heavy-mineral-concentrate samples from the Deep Creek, La Verkin Creek, North Fork Virgin River, Orderville Canyon, and Parunuweap Canyon Wilderness Study Areas, Kane and Washington counties, Utah**, by J.H. Bullock, Jr., et al., 24 p., U.S.G.S. Open-File Report 88-0581.
- Models, data available, and data requirements for estimating the effects of injecting saltwater into disposal wells in the Greater Altamont-Bluebell oil and gas fields, northern Uinta Basin, Utah**, by G.W. Freethy. Prepared in cooperation with Utah Division of Oil, Gas and Mining. 30 p., U.S.G.S. Open File Report 88-0475.
- Bedrock geologic map of the Promontory Mountains, Box Elder County, Utah**, by M.D. Crittenden, Jr., scale 1:100,000. U.S.G.S. Open-File Report 88-0646.
- Preliminary geologic map showing igneous-related breccias in Cambrian and older quartzites, Drum Mountains, Utah**, by C.J. Nutt and R.A. Yambrick. 1989. Scale 1:12,000. U.S.G.S. Open-File Report 89-0099.
- Several papers occur in *Geology of Cataract Canyon, including Mesozoic rocks of Canyonlands country. Field Symposium - Guidebook of the Four Corners Geological Society*, by C.M. Molenaar, 1987, p. 19-24. **Basal Tertiary conglomerate sequence, southeastern Uinta Basin, Utah; a preliminary report**, by K.J. Franczyk and J.K. Pitman, 1987, p. 119-126. **Sedimentology and new fossil occurrences of the Upper Triassic Chinle Formation, southeastern Utah**, by R.F. Dubiel, p. 99-107.
- Oligocene caldera complex and calc-alkaline tuffs and lavas of the Indian Peak volcanic field, Nevada and Utah**, by M.G. Best and others. Geological Society of America Bulletin, v. 101, no. 8, August 1989. p. 1076-1090.
- Geologic setting, depths of emplacement, and regional distribution of fluid inclusions in intrusions of the central Wasatch Mountains, Utah**, by D.A. John, Bulletin of the Society of Economic Geologists, v. 84, no. 2, April 1989, p. 386-409.
- Architecture and evolution of a Whiterockian (early Middle Ordovician) carbonate platform, basin ranges of Western U.S.A.**, by R.J. Ross, Jr., N.P. James, L.F. Hintze and F.G. Poole. Special Publication - Society of Economic Paleontologists and Mineralogists.
- Seepage study of a 15.3-mile section of the Central Utah Canal, Pahvant Valley, Millard County, Utah**, by Michael Enright, Technical Publication, Department of Natural Resources, Report no. 91, 1987. 12 p.
- Overview: Geologic history and carbonate platform reservoirs of the Basin and Range Province, Western United States**, in *Occurrence and petrophysical properties of carbonate reservoirs in the Rocky Mountain region*. by H.E. Cook (S.M. Goolsby, editor). Rocky Mountain Association of Geologists, 1988, p. 213-228.
- Developing a state water plan, ground-water conditions in Utah, spring of 1988**, by G.E. Cordy and others, Cooperative Investigations Report, Department of Natural Resources, Report no. 28, 1988. 81 p.
- Mineral resources of the Spring Creek Canyon Wilderness Study Area, Iron County, Utah**, by R.E. Van Loenen, H.R. Blank, Jr., E.G. Sable, G.K. Lee, K.L. Cook, (U.S.G.S.), and J.E. Zelten, (U.S. Bureau of Mines), 1989. P. F1-F17. 1 plate in pocket, U.S.G.S. Bulletin 1746-F.
- Geologic map of the Crystal Peak Caldera, west-central Utah**, by T.A. Steven. 1989 Lat 38°40' to 38°50', long 113°15' to 113°45'. Scale 1:100,000. U.S.G.S. Investigation 2002.

The Tooele 1° x 2° Mineral Occurrence Map: *First of a Series to Cover the State*

by
Michael Shubat and Bryce Tripp

In 1976 the UGMS began an ambitious program to inventory the state's mineral resources in conjunction with a national initiative sponsored by the U.S. Geological Survey and Bureau of Land Management. Through the efforts of UGMS geologists and geotechs over the past 13 years, we now have detailed information on over 11,000 mines and prospects. As one can imagine, the volume of the information contained in this database is staggering, and often intimidating to the uninitiated user. It occupies about ten megabytes of computer storage and is continually growing as we add information on new mineral occurrence discoveries. In comparison to most other western states, Utah's data base is one of the most complete and up-to-date, making it a valuable asset to explorationists, land-use planners, and resource assessors. To make this information more accessible to the public and easier to use, the UGMS initiated the Mineral Occurrence Map project.

This year we prepared a mineral occurrence map and accompanying text for the Tooele 1° x 2° quadrangle, located in west-central Utah, as a prototype for this series. It is currently available as a UGMS Open-File Report and consists of 85 pages of text and three plates (Tripp, B.T., Shubat, M.A., Bishop, C.E., and Blackett, R.E., 1989, Mineral occurrences of the Tooele 1° x 2° quadrangle, west-central Utah: Utah Geological and Mineral Survey Open-File Report 153). This temporary format will be replaced by a full-color map and text in the near future. The map consists of dots of various shapes, sizes and colors, each with an associated index number. Each dot represents a mineral occurrence, and its shape, size and color refer to the type of deposit, size of deposit, and the commodities contained in the deposit, respectively. If more specific information on a particular occurrence is needed, the name, list of commodities present, and literature references for the deposit are listed in a series of tables that are keyed to the map by an index number. Information in the text is arranged by mining district and consists of a brief summary of the history, mineral production, and geology of each district, followed by a table of the mines and prospects that occur in the district. At the end of the report is a bibliography, cross-referenced to the mineral occurrence tables, containing literature relating to the economic geology of the region. The Gold Hill, Mercur, and Ophir districts contain so many occurrences that we made separate maps at a larger scale for these areas.

One of the major obstacles in preparing the Tooele 1° x 2° map was deciding how to best group the 638 occurrences into meaningful categories. For industrial rocks and minerals, we decided to group deposits by their principal commodity. We classified deposits as carbonate rock, silica (consolidated),

phosphate, clay, surface brine, subsurface brine, sodium sulfate, sand and gravel, silica dune, or gypsum deposits. For metallic mineral deposits we elected to use an organization-scheme developed by the U.S. Geological Survey that employs mineral deposit models (Cox, D.P., and Singer, D.A., editors, 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, 379 p.) These models "describe the essential characteristics of groups of similar deposits" and come under such familiar names as "porphyry copper," "skarn," and "epithermal gold." Most of the metallic occurrences in the Tooele quadrangle fell into six of these model classifications. We lumped all mineral occurrences with adequate available geological information, but which defied easy classification, into an "other" category. We used the term "unidentified" to note prospects that had insufficient data to classify. Of the 638 occurrences, 15 percent were classed as "unidentified" and 14 percent as "other."

The Tooele quadrangle contains huge resources of industrial rocks and minerals, which are described in our Open-File Report. Saline minerals have been an important part of Utah's economy since 1917 and occur as surface brines in the Great Salt Lake and as subsurface brines located around the lake and in the West Desert. Several billion tons of dissolved solids are contained in these brines, most of which are potassium, sodium, and magnesium chlorides and sulfates. Sodium sulfate, also known as mirabilite and Glauber's salt, occurs as a cement in recent sands near the southern end of the Great Salt Lake.

Bedded industrial rock and mineral deposits in the Tooele quadrangle include carbonate rock, high-silica quartzite, phosphatic shale, and clay. High-calcium limestone, used for cement production, lime production, and as a smelter flux, occurs in the Mississippian Great Blue Limestone and Deseret Formations. Dolomite is produced from Silurian and Ordovician formations and has been used in the production of hydrated lime, quicklime, and dead-burned dolomite. Production from aragonite veins has been used for decorative stone, roofing granules, poultry grit, and livestock feed supplement. Oolitic carbonate sands rimming parts of the Great Salt Lake represent a largely untapped resource of calcium carbonate. High-silica quartzite occurs in Cambrian, Ordovician, and Devonian formations and has been used to produce siliceous refractories. Phosphatic shales occur in Mississippian and Permian rocks, including the famous Meade Peak Member of the Phosphoria Formation. Large clay deposits located in the Manning Canyon Shale have been used to produce brick, tile, and sewer pipe. The clay formed as a result of regional hydrothermal alteration and is present over a broad area.

continued on page 20



STATE OF UTAH
NATURAL RESOURCES
Utah Geological & Mineral Survey

606 Black Hawk Way • Salt Lake City, UT 84108-1280 • 801-581-6831

Dear Fellow Geologists:

We have many inquiries regarding Utah geology in areas where published geologic coverage is unavailable or inadequate, and where unpublished field mapping or other geologic studies have been done, are being done, or are planned. Therefore, the Utah Geological and Mineral Survey is soliciting your cooperation for our computerized listing of those areas in Utah being studied by geoscientists in your university or agency during the upcoming field season (Summer, 1989) and next season (Summer, 1990).

Please circulate this form among your staff for the required information, and return the information as soon as possible. On the map on the reverse side of this page, indicate the quadrangles covered (or to be covered). More copies are available on request.

If you know of any other universities or organizations who are doing geological work in Utah, please send us their names.

To assist those doing geological work in Utah, the Utah Geological and Mineral Survey has compiled a bibliography of the Geology of Utah on computer. Special searches can be made by quadrangle, formation, commodity, type of study, etc. Please write for more information.

Many thanks for filling out this form. A copy can be obtained by request at no charge.

Utah Geological and Mineral Survey

(Please pull out insert, fill out information and return to the UGMS)

Investigator: _____

Organization/School: _____

Address: _____
City State Zip

Title/Subject: _____

Scope and class (i.e., detailed, reconnaissance, photo interpretation - with or without field checking, etc.): _____

Date of inception: _____

Date of proposed completion: _____

Probable location of information (i.e., University thesis, open-file - where; release date and provisions, where; state or technical agency - where; publication - where; company confidential.): _____

May we have a copy of the completed report and map for our library: ☐ Yes ☐ No

What type of study? _____ ☐ Paleontology
Formation, age: _____

☐ Geologic Mapping
Scale of map: _____ ☐ Quaternary Soils ☐ Petrology ☐ Volcanology

☐ Economic Geology
Commodities: _____ ☐ Sedimentology ☐ Structural geology
☐ Stratigraphy
Formation, age: _____

☐ Environmental Geology ☐ Engineering Geology

☐ Geochemistry ☐ Geophysics ☐ Other (please specify): _____

☐ Hydrology ☐ Mineralogy ☐ Hard rock geology

(Seal or Staple Here)

PLACE
STAMP
HERE

Utah Geological and Mineral Survey
606 Black Hawk Way
Salt Lake City, Utah 84108-1280

Attn.: Michael Ross

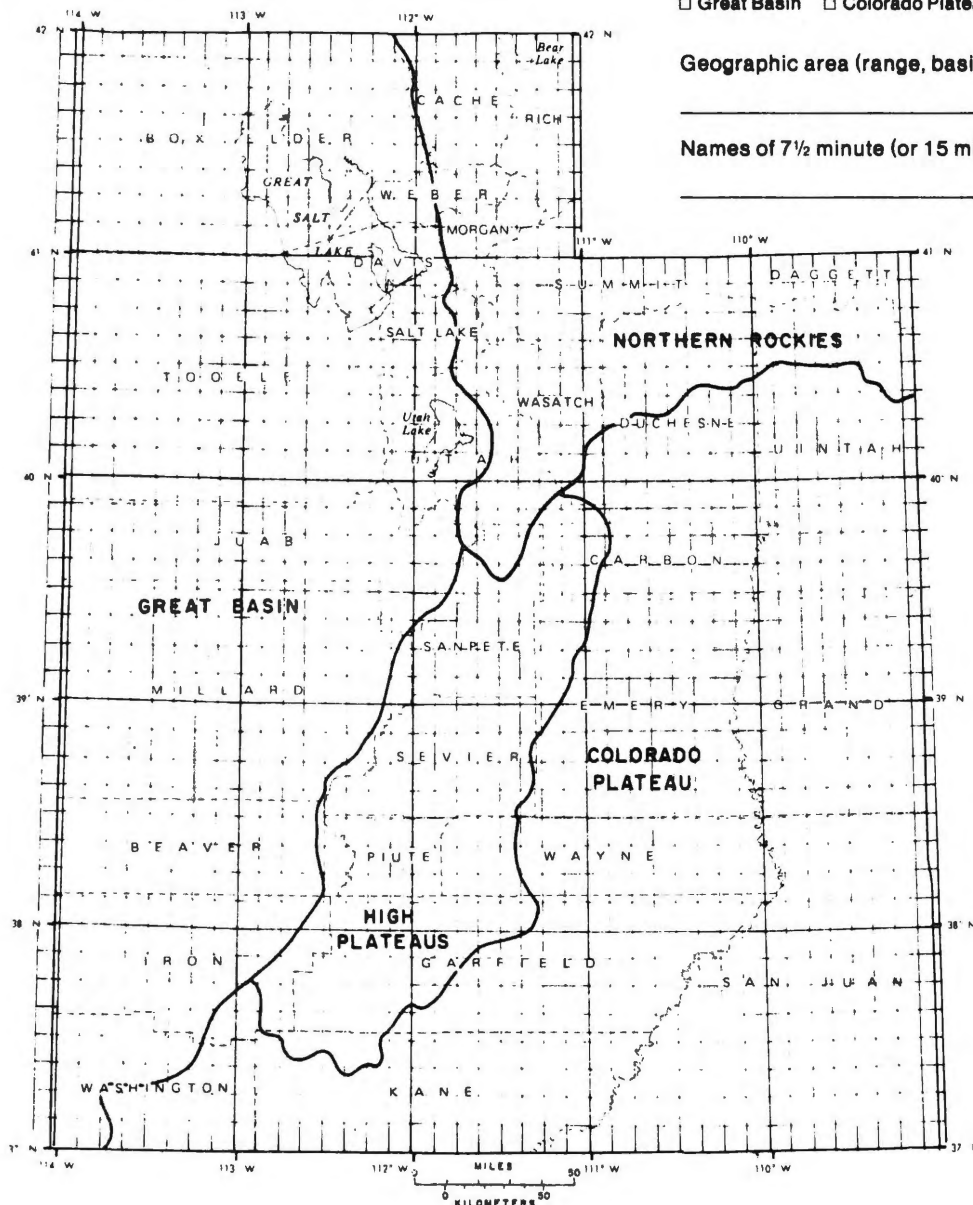
Please supply the following information, if applicable:

Principal physiographic provinces of Utah covered by this study:

☐ Great Basin ☐ Colorado Plateau ☐ Northern Rockies ☐ High Plateaus

Geographic area (range, basin, etc.): _____

Names of 7½ minute (or 15 minute) quadrangles: _____



Which Counties are covered
by this study?
(please circle)

All Counties	Morgan
Beaver	Plute
Box Elder	Rich
Cache	Salt Lake
Carbon	San Juan
Davis	Sanpete
Daggett	Sevier
Duchesne	Summit
Emery	Tooele
Garfield	Uintah
Grand	Utah
Iron	Wasatch
Juab	Washington
Kane	Wayne
Millard	Weber

If possible, please fill in location
of study area on this map of Utah.
Each small square equals one 7½
minute quad.

UGMS Industrial Mineral Publications

compiled by R.W. Gloyd

This listing includes all UGMS publications that discuss some aspect of industrial minerals.

The designation OP indicates an out-of-print publication which is available for public inspection at the UGMS Library.

MAPS— Does not include quadrangle maps — many of which discuss industrial minerals.

No.		
29	Industrial minerals of Utah, by H.H. Doelling, approx. scale 1:1,800,000, 1969.	\$1.00
54-D	Mineral resources of central Wasatch Front, Utah, compiled by F.D. Davis, approx. scale 1:1,800,000, 1985. 24 p., 2 pl.	\$6.00
55-D	Mineral resources of the southern Wasatch Front, Utah, by F.D. Davis, with a section on petroleum by F.D. Moulton and R.L. Kerns Jr., scale: 1:100,000, 1988, 17 p., 2 pl.	\$6.00
71	Non-metallic mineral resources of Utah, by H.H. Doelling, scale 1:750,000, 1983.	\$5.00

BULLETINS — Bulletins 1-35 were not published by UGMS and are, therefore, not listed.

No.		
36	Directory of Utah mineral resources and consumer's guide, by A.M. Buranek and C.F. Needham, 1949, 95 p.	\$1.00
52	Geologic atlas of Utah, Emery County, by W.L. Stokes and R.E. Cohenour, 1956, 92 p.	\$10.00
55	Clays of Utah County, Utah, E.P. Hyatt, 1956, 83 p.	\$2.00
59	Phosphate in Utah, by T.M. Cheney, 1957, 54 p.	\$1.00
64	Geologic atlas of Utah, Cache County, by J.S. Williams, 1958, 104 p.	\$10.00
66	Geologic atlas of Utah, Daggett County, by H.R. Ritzma, 1959, 116 p.	\$10.00
69	Geology of Salt Lake County, compiled and edited by A.L. Crawford, 1964.	O.P.
71	The mineral resources of Uintah County, by R.G. Pruitt Jr., 1961, 101 p.	\$5.00
73	Mineral and water resources of Utah, edited by L.S. Hilpert, 1964.	O.P.
79	Directory of the mining industry of Utah, 1965, compiled by R.F. Gavin, 1966.	O.P.
82	Guidebook of northern Utah, edited by M.L. Jensen, 1969.	O.P.
84	A directory of the mining industry of Utah, 1967, compiled by N.S. Goeltz, assisted by N. Nielsen and R.L. Graham, 1970, 37 p.	\$1.00
85	Land and mineral resources of Sanpete County, Utah, by A.R. Pratt and E. Callaghan, 1970, 69 p.	O.P.
99	Mineral deposits of the Deep Creek Mountains, Tooele and Juab Counties, Utah, by K.C. Thomson, 1973, 76 p.	O.P.

101	Utah mineral industry operator directory, compiled by C.H. Stowe, 1973, 66 p.	O.P.
102	Mineral resource potential of Piute County, Utah and adjoining areas, by E. Callahan, 1973, 135 p.	O.P.
105	Utah's mineral activity: An operational and economic review, by C.H. Stone, 1974, 35 p.	O.P.
106	Utah mineral industry statistics through 1973, compiled by C.H. Stowe, 1975, 121 p.	\$5.00
107	Geology and mineral resources of Garfield County, Utah, by H.H. Doelling, 1975, 175 p.	\$10.00
108	Utah mineral industry operator directory, 1975, compiled by C.H. Stowe, 1976, 58 p.	\$1.00
110	Fluoride occurrence in Utah, by K.C. Bullock, 1976, 89 p.	O.P.
113	The geology and uranium-vanadium deposits of the San Rafael River mining area, Emery County, Utah, by L.M. Trimble and H.H. Doelling, 1978, 122 p.	\$10.00
116	Great Salt Lake; a scientific, historical and economic overview, edited by J.W. Gwynn, 1980, 424 p.	\$15.00
117	Minerals and mineral localities of Utah, by K.C. Bullock, 1981, 177 p.	\$10.00
122	Salt deformation in the Paradox region by H.H. Doelling, C.G. Oviatt and P.W. Huntton, 1988, 93 p.	\$9.50

SPECIAL STUDIES

No.		
1	Glauber's salt bed, west of Promontory Point, Great Salt Lake, by A.J. Eardley, 1962, 12 p.	\$1.00
2	Gypsum dunes and evaporite history of the Great Salt Lake, by A.J. Eardley, 1962, 12 p.	\$1.00
4	Hydrothermal alteration in the southeast part of the Frisco Quadrangle, Beaver County, Utah, by B. Stringham, 1963, 24 p.	O.P.
6	Geology and hydrothermal alteration in northwestern Black Mountain and southern Shauntie Hills, Beaver and Iron Counties, Utah, by Max P. Erickson and E.J. Dasch, 1963, 32 p.	O.P.
9	Alteration area south of Horn Silver Mine, Beaver County, by B. Stringham, 1964, 20 p.	O.P.
12	Hydrothermal alteration and mineralization, Staats Mine and Blawn Mountain areas, Central Wah Wah Range, Beaver County, Utah, by J.A. Whelan, 1965, 32 p.	O.P.
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			72	Utah mineral industry activity review, 1981-82, by M.R. Smith, 1984.	\$3.00

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1	Report on the copper and asbestos deposits of Bear Canyon, Davis County, Utah, by A.M. Buranek, 1942.	O.P.
2	Tremolite deposits of the Mineral Range, Millard County, Utah, by A.L. Crawford and A.M. Buranek, 1942.	O.P.
14	Report on the magnesite deposits of the Silver Shield Mining and Milling Company, Juab County, Utah, by A.M. Buranek and A.L. Crawford, 1942,	O.P.
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25	The occurrence of celestite on the San Rafael Swell, Emery County, Utah, by A.L. Crawford and A.M. Buranek, 1943 (reprinted 1957)	O.P.
31	The fluor spar deposits of the Wildcat Mountains, Tooele County, Utah, 1945, by A.M. Buranek, 1945 (supplement to Circular 5).	O.P.
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35	A reconnaissance of the geology and mineral deposits of the Lake Mountains, Utah County, Utah, 1948, by A.L. Crawford and A.M. Buranek, 1948 (reprinted 1951).	O.P.
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3	Reconnaissance report on Great Salt Lake with a discussion on the disposal of mill tailings from Kennecott Copper Corporation concentrators into Great Salt Lake, by R.E. Cohenour, A.J. Eardley, W.P. Hewitt and H.R. Bradford, 1963, 52 p., maps.
4	Mineral appraisal and valuations of lands of the Glen Canyon withdrawal involved in litigation — State of Utah vs. United States of America, by R.E. Cohenour, R.E. Eardley and W.P. Hewitt, 1963, 52 p., maps.
5	Mineral appraisal of lands in the Grantsville area, Tooele County, Utah, by R.E. Cohenour, 1963, 14 p., maps.
6	Mineral appraisal of lands in the Lake Mountain area west of Utah Lake, Utah County, Utah, by R.E. Cohenour, 1963, 14 p., maps.
9	Mineral appraisal of lands in T2N, R4W, USM, Yellowstone Creek area, Duchesne County, Utah, by R.E. Cohenour, 1963, 6 p., maps.
14	Part I — Mineral appraisal and comparison of state exchange lands situated in the Canyonlands Park area with available lands in the Spanish Valley area; Part II — Mineral appraisal of lieu lands within the Canyonlands Park area, by R.E. Cohenour and E.B. Heylman, 1964, 10 p., maps.
16	Classification of base lands in the area of southwest quadrant of the Salt Lake Base and Meridian, by R.E. Cohenour, 1964, 42 p.
17	Classification of base lands in the area of southeast quadrangle of the Salt lake base and meridian, by R.E. Cohenour, 1964, 86 p.
21	Mineral appraisal of state lands within the Navajo Indian Reservation, San Juan County, Utah, and comparison with mineral appraisal of possible exchange

- lands in Grand and San Juan Counties, Utah, by R.E. Cohenour, 1965, 25 p., maps.
- 23 Appraisal of mining claims in Section 2, T13S, R 12W, Salt Lake Base and Meridian, by R.E. Cohenour, 1965, 16 p., illus.
- 24 Part I — The January 1966 estimate of the mineral value of the restricted lands of Great Salt Lake lying between the lake shore and its surveyed meander line, 8 p., illust.:
Part II — The January 1966 estimate of the mineral value of selected state lands in the Great Salt Lake Desert and in Emery, Garfield, San Juan, Utah and Wayne Counties, Utah, by R.E. Cohenour, 1966, 15 p., map.
- 28 Appraisal of a proposed selection of coal lands in the Emery Coal Field of Emery and Sevier Counties; also appraisal of selected phosphate lands in Rich and Uintah Counties, by R.E. Cohenour, 1966, 11 p., maps.
- 30 Mineral examination of federal lands in areas classified by the U.S. Bureau of Land Management as being favorable for acquisition by the State of Utah, Part I — Salt Lake District, by R.E. Cohenour, 1966, 40 p.
- 30 Mineral examination of federal lands in areas classified by the U.S. Bureau of Land Management as being favorable for acquisition by the State of Utah, Part I — Salt Lake District, by R.E. Cohenour, 1966, 40 p.
- 31 Phosphate lands in the Crawford Mountains, Rich County, Utah, by W.D. Byrd, 1967, 7 p., maps.
- 34 Examination of federal lands for natural resource value in areas classified by U.S. Bureau of Land Management as being favorable for acquisition by the State of Utah, Southeast Utah, by H.R. Ritzma, 1967, 7 p.
- 35 Bonneville Salt Flats hydrogeological study near Wendover, Utah, by B.N. Kaliser, 1967, 15 p., maps.
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- 71 Dugway Range fluorite leasing problem, Tooele County, Utah, by H.H. Doelling, 1972, 12 p., maps.
- 85 Normal fluorspar deposit, Weber, Utah, by L.I. Perry, 1973, 9 p., photos, maps.
- 117 Mineral potential of the Deep Creek Mountains, by H.H. Doelling and L.I. Perry, 1977, 12 p., illus., maps.
- 138 Diatom Gulch diatomaceous earth deposit, Tooele County, Utah, by H.H. Doelling, 1979, 7 p., maps.
- 143 Mineral resource inventory of the Paradox Salt Basin, Utah and Colorado, by H.W. Merrell and staff of the UGMS, 1979, 67 p., illus., maps.
- 171 Identification and discussion of AMAX solar pond harvest salts, Great Salt Lake, Utah, by J.W. Gwynn, 1981, 24 p.
- 184 Mining conditions and problems encountered within the Texas Gulf-Cane Creek potash mine near Moab, Utah; and potential mining conditions at Gibson Dome, Utah, by J.W. Gwynn, 1984, 12 p.
- 200 Mineral occurrences in the emergency withdrawal areas and adjacent lands in the Great Salt Lake Desert, by J.W. Gwynn, Keith Clem, M.A. Shubat, B.T. Tripp and P.A. Sturm, 1985, 41 p., figures, maps.

Tooele Occurrence Map
continued from page 17

Quaternary deposits of sand and gravel, deposited in Pleistocene Lake Bonneville, contain enormous quantities of high-quality aggregate. The most significant deposits formed in beach environments caused by long-term still stands of the lake (the Stansbury, Bonneville, and Provo shorelines). Much of this resource occurs in the sparsely inhabited central and western parts of the Tooele quadrangle and probably will not be developed for many years. Quaternary dune deposits flank many of the mountain ranges and consist of either silica or gypsum, the minerals having been separated by eolian (wind) action. Gypsum dunes also blanket a large area of the eastern flank of the Great Salt Lake, the gypsum grains being produced by evaporation of brine.

In conclusion, the Tooele quadrangle contains vast resources of industrial rocks and minerals that will be developed as the population of the region continues to grow. We hope that mineral occurrence maps such as the Tooele quadrangle will help extractive industries and land-use planners wisely develop these natural resources.

Miners Take Note!

Salt Lake City will welcome the annual meeting and exhibit of the Society for Mining, Metallurgy, and Exploration from February 26 to March 1. This year's theme is "Increased Competitiveness Through Technology," reflecting the positive attitude and atmosphere of innovation that characterize today's resurgent mining industry. Over 600 speakers will present their views, and all aspects of the minerals industry will be covered.

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The Saline Resources of Utah

by
J. Wallace Gwynn

INTRODUCTION

The saline resources of Utah consist of the numerous occurrences of brines (salty water) and readily soluble crystalline salts that exist both at and below the earth's surface, throughout the state. The most obvious of these resources is the Great Salt Lake, which is known throughout the world as a scientific and scenic attraction and as an abundant source of multi-mineral wealth. The other saline occurrences found throughout the state, though less obvious and not as well known, also represent a vast and diversified resource. In addition to the natural occurrences of salts and brines, there are also saline products that are or may be produced through industrial processes or environmental reclamation projects.

This article will give a brief overview of each of the major saline occurrences in the state. Each of the overviews will include the geologic setting, chemistry and/or mineralogy, current or potential uses, and other applicable data or points of interest for each occurrence. The importance of the saline resources to the state and some of the problems associated with them also will be discussed.

GREAT SALT LAKE

The Great Salt Lake, a terminal lake, is the largest body of water in Utah and a remnant of Pleistocene Lake Bonneville. It is located in the northwestern quarter of the state (figure 1) and occupies one of the lowest depressions within the Basin and Range physiographic province. The lake's drainage basin as shown in figure 1 includes parts of northern Utah, southeastern Idaho and southwestern Wyoming and covers more than 30,000 square miles. Four main tributaries, the Bear, Jordan, Weber and Ogden Rivers, provide the majority of the water to the lake.

The size, volume and salinity of the Great Salt Lake change with time and vary with its surface elevation, which in turn is governed by the regional climatic conditions. Historically, the surface elevation of the lake has varied through a vertical range of over 20 feet, as shown in figure 2. Table 1 gives the lake's stage, area and volume relationships which cover this range.

Table 1. Great Salt Lake Stage, Area and Volume Relationships*
(Assuming uniform elevation throughout).

Elevation (ft)	Area (acres)	Volume (acre feet)
4190	579,700	7,792,000
4195	724,000	10,990,000
4200	1,034,000	15,390,000
4205	1,216,000	21,010,000
4210	1,426,000	27,560,000
4215	1,925,000	35,590,000

*From Cruft (1986)

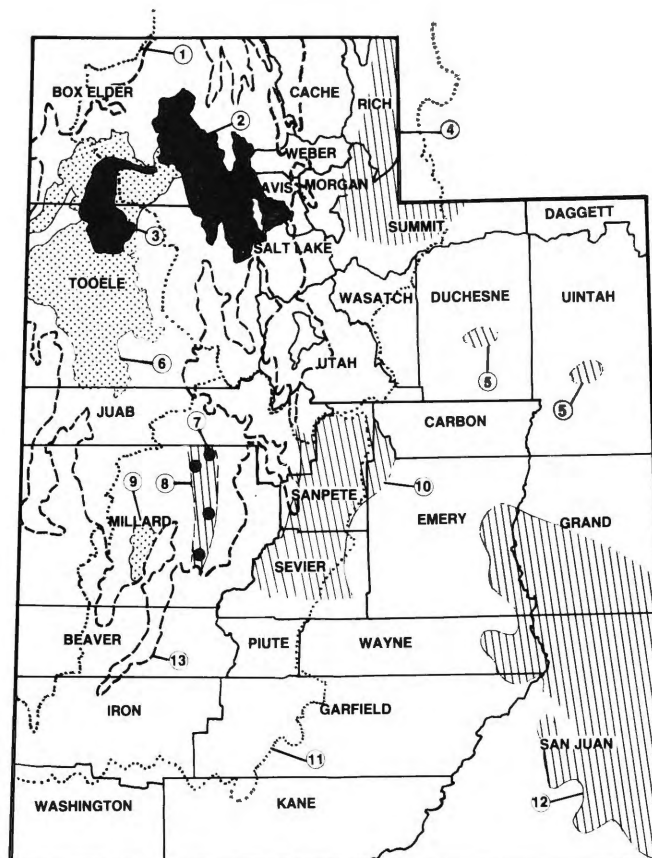


Figure 1. Index map of Utah showing areas of selected saline features, drainage basins and of Pleistocene Lake Bonneville.

(Features keyed to circled numbers.)

1. Drainage Basin of Great Salt Lake.
2. Great Salt Lake.
3. Man-made brine evaporation pond.
4. Inferred area underlain by Jurassic Pruess Fm. salts (modified from Hite, 1964).
5. Selected areas underlain by Tertiary Green River Fm. and Uinta Fm. salts (from Dyni et al., 1970).
6. Outline of Great Salt Lake Desert.
7. Wells (4) which cut Tertiary salts (from Mitchell and McDonald, 1987).
8. Inferred area underlain by Tertiary salts.
9. Sevier dry lake.
10. Inferred area underlain by Jurassic Arapien Shale salts (Modified from Moulton 1975 and Standlee, 1982).
11. Drainage Basin of Sevier dry lake.
12. Inferred area underlain by Permian Paradox Basin salts (from Hite, 1982).
13. Area covered by Pleistocene Lake Bonneville.

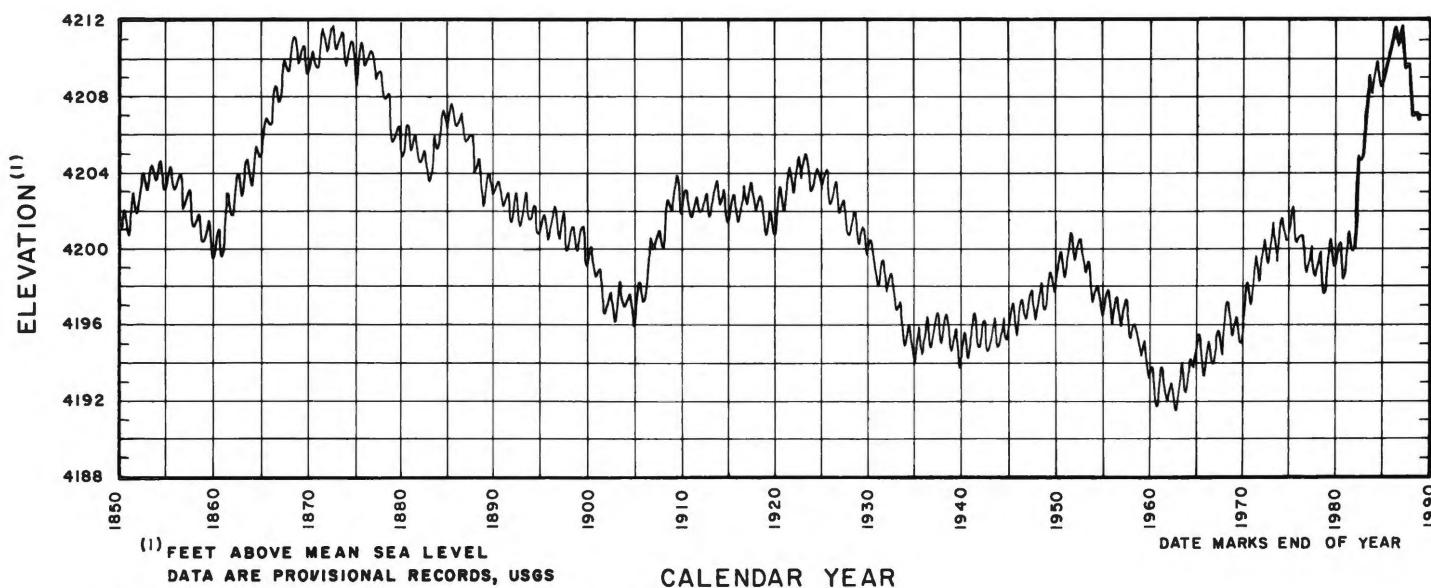


Figure 2. Variations in the surface elevation of the Great Salt Lake.

The salinity of the Great Salt Lake is not homogeneous throughout, but varies laterally from place to place within the lake, varies with depth, and varies with time. Since the completion of the Southern Pacific Railroad's rock-fill causeway across the entire width of the lake in 1960, the main northwestern (northern) portion of the lake has become much more saline than that south of the causeway. The reasons for this change are 1) the majority of the lake's fresh-water inflow enters the southern portion of the lake, 2) the northern portion of the lake receives mainly salty water from the south, through the causeway, and 3) the causeway restricts circulation throughout the lake.

Salinity differences have also developed vertically within each portion of the lake. After the completion of the causeway, the southern portion soon became stratified as illustrated in figure 3. This was due to the slow movement of northern brine, through the causeway, into the bottom of the southern basin. The northern portion of the lake was not stratified during this time.

Later breaching of the causeway by the state in 1984 caused dramatic changes in the salinity distribution within the lake, resulting in the stratification of the northern part of the lake. These changes are described by Gwynn and Sturm (1987).

The salinity of the lake also varies with time, on both an annual and a long-term basis. Annually, it varies inversely with lake level. This change reflects the high influx of water into the lake during the spring and the increased evaporation of water during the hot, dry summer months. Long-term changes in salinity are related inversely to the long-term trends in lake level. These trends are illustrated on figure 2 between the high in 1873 and the low in 1963 and are due to more gradual, regional climatic trends.

Since the solid rock-fill portion of the causeway was completed in 1960, the densities in the lake have ranged from less than 5% salt in the upper brines south of the causeway in 1987

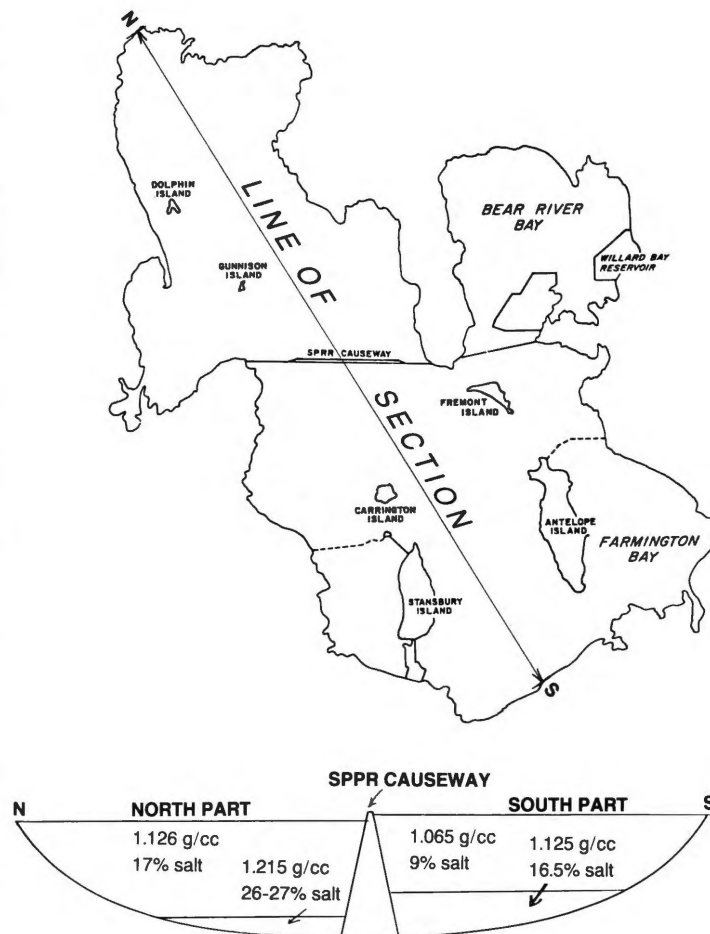


Figure 3. Density stratification and salinity distributions in the brines of the Great Salt Lake as of March 3, 1989 (UGMS data). The stylized section is not to scale.

to near saturation (27% salt) north of the causeway from 1966 until 1983. Figure 3 illustrates the brine-density distribution and stratification that existed within the northern and southern portions of the lake as of March, 1989.

The chemical composition (the ratio of one ion to another) of the brines remains relatively constant throughout the lake, though some slight differences have been noted. Some annual changes in chemistry are related to temperature. For example, as mirabilite ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$) precipitates from fairly concentrated brines during the cold winter months, the percentage of sodium and sulfate in the brine drops. Other changes are not temperature related but are due to changes in salinity. Halite (NaCl), for example, precipitates from saturated brines which develop during extended dry periods, when the lake is low. This reduces the percentage of sodium and chloride in the brine. Halite precipitation is not greatly influenced by temperature.

Table 2 gives the average chemical composition of the salts dissolved in the lake brine. Lithium, bromine, and boron are the main trace elements in the lake waters, and hydrogen sulfide is abundant in the deep brines south of the causeway. Calculations indicate that there are about 4.5 billion tons of dissolved salts in the lake, with about 2 million tons entering it annually through tributary inflow.

The history of salt production from the Great Salt Lake dates back to the mid-1800s and is well documented by Clarke and Helgren (1980). Today, there are 5 mineral extraction plants operating on the Great Salt Lake. Table 3 lists these plants and the products they can produce from the brine.

Table 2. Chemical composition of dissolved solids in Great Salt Lake brines, south and north of causeway, for December, 1988 (Weight Percent of Total Dissolved Solids).

	Na	Mg	K	Ca	Cl	SO_4
South	32.91	3.35	1.85	0.23	56.22	5.44
North	32.73	2.90	1.77	0.14	56.56	5.90

Table 3. Mineral extraction plants operating on the Great Salt Lake and the products they can produce. *Sodium sulfate is produced depending on market and winter climatic conditions.

Company	Product Capabilities
Great Salt Lake Minerals and Chemicals Corp.	Potassium sulfate, sodium sulfate*, sodium chloride and magnesium chloride (brine and flake).
AMAX Magnesium Corp.	Primary and alloyed magnesium metal and chlorine gas.
Morton Salt Company	Sodium chloride.
Sol-Aire Salt & Chemical Company	Sodium chloride.
American Salt Company	Sodium chloride.

Crystalline salts are not normally found within the lake except during the cold winter months, or when the level of the lake is low, as previously discussed. Even under these conditions, these salts normally disappear as the lake waters warm, or as the level of the lake eventually rises and freshens. Under special circumstances, however, beds of mirabilite and halite have been formed and preserved, which are now found buried

beneath the protective floor and beaches of the lake. These deposits are described as follows:

Eardley (1962) reports a bed of Glauber's salt or mirabilite ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$), which starts from about a mile west of Promontory Point and continues westward for 9.5 miles. This bed is about 32 feet thick, and lies 15 to 25 feet below the floor of the lake. During the initial construction of the Southern Pacific Railroad causeway, it was used as a footing for the causeway throughout this distance.

Two other deposits of mirabilite occur on the southeastern shore of the lake (figure 4). Their physical dimensions and locations are described as follows by Wilson and Wideman (1957). They are "hard, brittle beds of Glauber's salt mixed with sand and clay,...and...seem to have been formed by variations in seasonal climatic conditions." These beds range from 3 to 6 feet in thickness and are covered by 1 to 3 feet of overburden. The easternmost of the two areas, near the marina in Salt Lake County, runs eastward for about 2.5 miles along the shoreline. The westernmost deposit begins about 3 miles west of the Salt Lake-Tooele County line and extends westward about 4.5 miles along the shoreline.

Several core holes were drilled by the AMOCO Production Company in the Great Salt Lake, as part of its 1975-1976 oil exploration program. Massive salt beds were encountered in four of the holes. The thickest composite section of salt totaling 75 feet was encountered in the Promontory hole (No. 2), located in the northwest quarter of T. 5 N., R. 6 W. Composite thicknesses of 6 to 10.5 feet were found in the other three holes, numbers 3, and 4 and 4A, located 9.5 miles and 16.5 miles respectively to the northwest of Hole No. 2 (Vanderbeck 1975).

Aside from being a saline resource, the Great Salt Lake represents a land-use planning problem since it is bordered on its eastern and southern shores by major population centers. Within these populated areas, residential, industrial, wildlife, public utility, and recreational facilities have been built adjacent to the lake. Between 1983 and 1987, serious flooding problems were experienced around the Great Salt Lake as its level rose nearly 12 feet. To combat these problems, Utah reviewed several lake-level control options and in 1984 opted to breach the Southern Pacific Railroad. This action involved making a 300-foot opening in the causeway near Lakeside near the western edge of the lake (figure 4). The purpose was to equalize the head or elevation differential of nearly four feet that had developed across the causeway. The higher elevation occurred south of the causeway because the impervious nature of the causeway slowed down the flow of water to the north. It was also because the lake's four main tributaries all enter the southern part of the lake. The southern area of the lake poses the greatest potential for property damage.

Although this project was successful in reducing the head differential, the lake level continued to increase, and in 1986 the state initiated its second control measure. This consisted of pumping the water out of the lake into a shallow, 320,000-acre impoundment in the West Desert (figures 1 and 4). On April 10, 1987, pumping began and by December 1987 the Newfound-land Evaporation Basin was filled to capacity. This project has

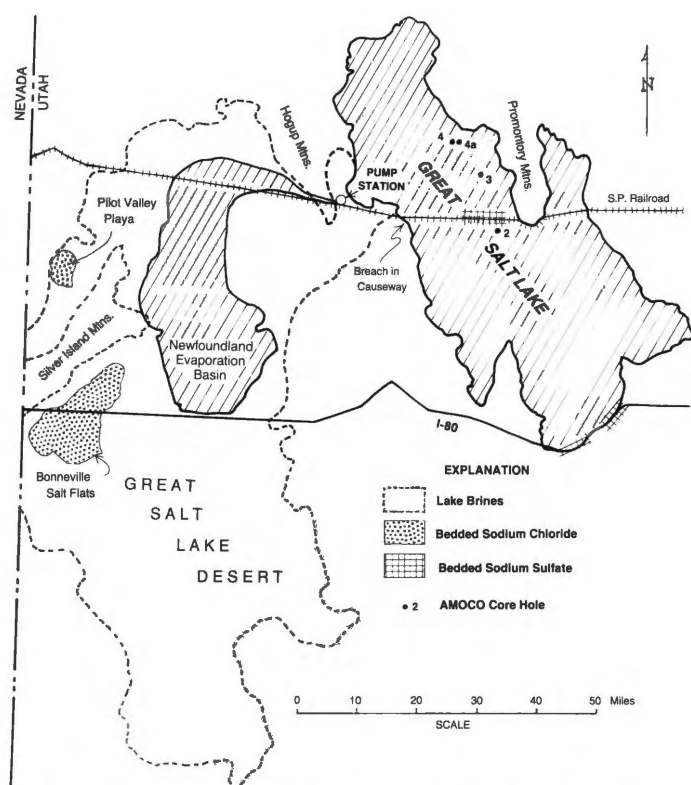


Figure 4. Saline resources of the Great Salt Lake and the Great Salt Lake Desert.

also been successful and has helped to lower the level of the lake more than 5 feet in its first two years of operation. Having accomplished its purpose, the West Desert Pumping Project was shut-down on June 30, 1989.

With this shut-down, many millions of tons of the lake's salt resource will likely be left on the West Desert floor. The brine which cannot be drained from the Newfoundland Evaporation Basin will precipitate salt, due to evaporation, and thus salt will be left on the basin floor. The salt crust that existed on the basin floor at the time of the shut-down will also remain and be lost for an indefinite period of time from the lake.

SUBSURFACE BRINES

GREAT SALT LAKE DESERT

The Great Salt Lake Desert is a large playa covering nearly 4,000 square miles in western Utah (figure 1). It is located

within the Basin and Range physiographic province and its flat surface and deep sediments are products of its predecessor, Pleistocene Lake Bonneville.

The saline resources of the playa consist of both salts and brines. Salt accumulations of significant thickness are restricted to two main areas, the Bonneville Salt Flats and the Pilot Valley playa (figure 4). Lines (1979) reported that the Bonneville salt crust covered about 40 square miles and Pilot Valley about 7 square miles. The evaporite minerals in both of these areas are concentrated in the following three horizontal zones, from bottom to top: "1) a carbonate zone composed mainly of authigenic clay-size carbonate minerals, 2) a sulfate zone composed mainly of authigenic gypsum, and 3) a chloride zone composed of crystalline halite (the salt crust)." Lines identified five different types of salt crust at Bonneville but only one at Pilot Valley.

Throughout the Great Salt Lake Desert playa, sub-surface brines are found at the surface or within just a few feet. Lines, in his 1979 study of the Bonneville Salt Flats, states that these brines exist in three distinct aquifers: "(1) a basin-fill aquifer, which yields water from conglomerate in the lower part of the basin fill, 2) an alluvial-fan aquifer, which yields water from sand and gravel along the western margins of both playas, and 3) a shallow-brine aquifer, which yields water from near-surface carbonate muds and crystalline halite and gypsum. The shallow-brine aquifer is the main source of brine used for the production of potash on the salt flats." Representative chemical analyses of subsurface brines from these three aquifers, and from Pilot Valley are given in table 4. Analyses from near the Bonneville and Newfoundland dikes are also given.

Potash (KCl) was first produced from the subsurface brines of the Great Salt Lake Desert in 1917 by the Solvey Process Co. at Salduro, located about 8 miles east of Wendover, Utah (Hite, 1964). In 1918, Utah-Salduro Potash Co. acquired the plant and was the largest producer in the United States until it was shut down in 1921. In 1938, potash production was again started at a new plant some 5 miles west of the Salduro site. Production of potash has continued to date at this site, first by Bonneville Ltd., and now by Reilly, Wendover Inc.

SEVIER DRY LAKE PLAYA

Sevier dry lake playa is located in the central portion of Millard County (figure 1). It lies within the Basin and Range physiographic province and is yet another remnant of Pleistocene Lake Bonneville. Its drainage basin covers about 16,000

Table 4. The average chemical compositions of the dissolved salts in the brines from the Bonneville Salt Flats, Pilot Valley, and two other areas of the Great Salt Lake Lake Desert.

Location/TDS*	Na	K	Mg	Ca	Cl	SO ₄	HCO ₃
B.S.F. Aquifers ¹							
Shallow/260	35.18	2.02	1.14	0.45	59.41	1.76	0.05
Basin-fill/135	34.33	1.52	1.13	1.25	57.14	4.53	0.10
Alluvial Fan/6	33.78	1.88	1.15	1.45	54.69	3.91	3.15
P.V. Aquifers ¹							
Shallow/195	34.98	2.20	0.72	0.92	59.72	1.43	0.04
Alluvial/0.6	19.47	0.97	5.70	8.56	47.58	1.90	15.81
Bonneville Dike ²							
T5, 6S, R 14, 15W	35.13	2.31	1.30	—	59.58	1.64	—
Newfoundland Dike ²							
T2-4S, R 12W	34.82	0.86	2.20	—	55.88	6.11	—

¹Lines, 1979 ²Eckhoff and others, 1985 *TDS in grams per liter (g/l)
 — no TDS values given for these sample averages.

square miles in southwestern Utah. The Sevier Lake playa itself covers about 190 square miles. During times when the playa's surface is dry, salt crusts composed of thenardite (Na_2SO_4) and halite (NaCl) have been observed to cover areas of low relief.

Beneath the surface of the playa, the sediments contain a large reserve of brines. These brines have been tested extensively throughout the playa to a depth of 20 feet, and to a limited degree to a depth of nearly 1,000 feet. The average chemical composition of the dissolved salts contained within the shallow playa brines is given in table 5 (data provided by Crystal Peak Minerals Corp.).

Table 5. Average chemical composition of dissolved salts in shallow Sevier Lake brines, total dissolved solids = 17.7%; (following figures are in weight percent).

Na	Mg	K	Ca	Cl	SO_4	Other
33.79	1.83	1.41	0.05	52.51	10.24	0.17

The saline resources of Sevier Lake are presently being developed by Crystal Peak Minerals Corp. The construction of earthen dikes to form 3,000 acres of first-phase solar evaporation ponds, the excavation of an 8-mile brine-collection canal, and the deposition of salt for competent pond floors have all been completed (M.C. Godbe, personal communication, 1989). It is anticipated that halite and eventually potassium sulfate will be produced and marketed.

SALINE BRINES FROM WELL AND SPRING SOURCES

GEOHERMAL—SALINE FLUIDS

Geothermal-saline fluids are spring and well waters which are both warm and saline. The term geothermal-saline water, as used herein, refers to waters at 15.5°C or greater which contain 5,000 ppm or more of dissolved salts.

Most of the geothermal waters in Utah do not contain enough dissolved solids to be classified as more than slightly saline in nature. Of those that are moderately saline or greater (i.e. > 3000 ppm), many come from well-known hot springs. The locations identified by Goode (1978), where geothermal-saline water is found, are shown in figure 5. The areas in which low-temperature geothermal resources are found throughout the state (Doelling, 1983, Figure 2) are also shown. Most of the state's geothermal-saline resources are found within the Basin and Range physiographic province, and to a lesser degree within the Colorado Plateau.

The chemical composition of these waters varies throughout the state but is predominantly of a sodium chloride type. The highest total-dissolved-solids content for spring waters is about 54,000 mg/l and nearly 200,000 mg/l for well brines (Goode, 1978). Some of these fluids are now being used as a source of heat, for heating green houses, or for recreational facilities. At the present time, none are being used for their salt content.

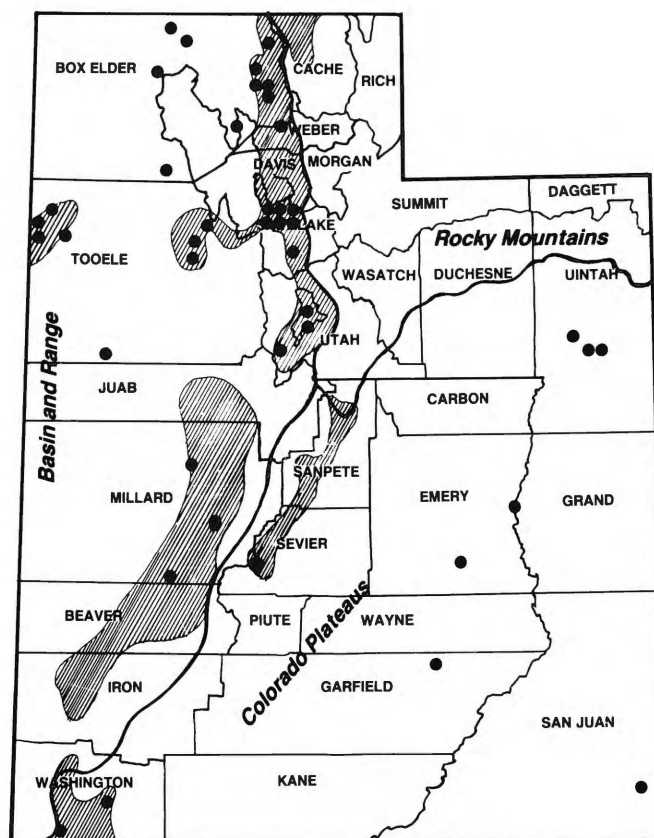


Figure 5. Geothermal saline resources of Utah.

● Wells and springs containing >5000 ppm TDS and $>15.5^\circ\text{C}$. (from Goode, 1978).

▨ Area of low-temperature geothermal resource (from Doelling, 1983).

SALINES FROM OIL WELL BRINES

During the production of hydrocarbon fluids from oil and gas wells, water normally is also produced as well. Most of this production comes from the Colorado Plateau and Middle Rocky Mountains physiographic provinces in eastern and northeastern Utah.

The Utah Division of Oil, Gas and Mining records report the state's cumulative production of water through May 1988 as 2.18×10^9 barrels (42 US gallons per barrel). During the same period, only 0.781×10^9 barrels of crude oil (36 percent of the water volume) were produced. Historical production data show that the ratio of water to oil is increasing with time.

Because most of the produced water is saline, it must be properly handled to prevent polluting the earth's surface or surface and ground-water supplies. About 55.2% of the produced water is reinjected back into oil-bearing formations as part of enhanced-recovery programs. Another 19.7% is simply returned through salt water disposal wells to formations containing comparable brines. Another 2.3% is discharged into large pits where the water evaporates, leaving the salt, or is used in drilling operations. The surface discharge of good-quality water, by special permit, accounts for the remaining 22.8% of the produced water.

Most of the oil-well brines produced in the state are of the sodium chloride type. Within a given formation and area, however, as in the Green River Formation within the Uinta Basin for example, the composition of the brines varies laterally. At the edges of the basin, the brines are much richer in calcium and bicarbonate. Basinward, however, sodium replaces calcium and chloride replaces bicarbonate. The quantity of sulfate in the brines within a given formation or area will also change. Magnesium and potassium are minor constituents in most of the brines. The percentage of potassium in the brines is highest in the southeastern part of the state.

With few exceptions, little use is made of the salt content of this saline resource. Recent laboratory tests at the Utah Geological and Mineral Survey (UGMS) show that potentially valuable products such as sodium, potassium, and magnesium chlorides can be produced from these brines. The hydrogen sulfide found in some of the brines may also be converted into usable or non-polluting substances, and trace elements such as lithium or bromine may also be recovered. The commercial production of salts or other products from these brines would require an economic evaluation of the extraction process and of the marketability of the final products.




SUBSURFACE BEDDED SALT DEPOSITS

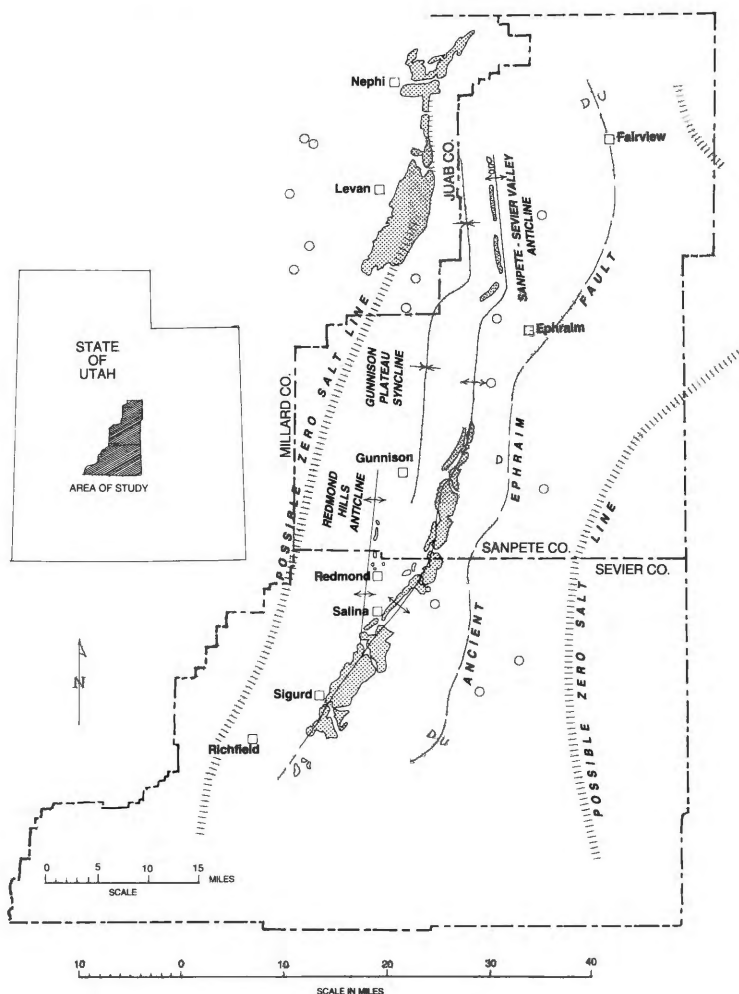
SALTS OF THE SEVIER-SANPETE VALLEY ARAPIEN SHALE

Thick sequences of salt are present within the Jurassic Arapien Shale through much of Sevier and Sanpete Counties of central Utah (figures 1 and 6). This area, described by Baer (1976), Spieker (1946), Witkind (1982), and Standlee (1982), occurs in the Cordilleran Hingeline or within the transition zone between the block-faulted Basin and Range province to the west and uplifted Colorado Plateau province to the east.

The main geologic structure within this area, as described by Gilliland (1963), is the Sevier-Sanpete Valley anticline. "It ... is a very large, slightly sinuous anticline with a highly mobile shale core, trending north-south in Sanpete and Sevier counties of central Utah. It is 65-70 miles long and has structural relief perhaps as great as 20,000 feet." The axis of this anticline is shown in figure 6. Another similar but much smaller spur is the north-south-trending Redmond Hills anticline, also shown on figure 6.

Figure 6. Jurassic Arapien Shale salt resources in the Sevier-Sanpete Valley Area.

-  Arapien Shale outcrops (from Hintze, 1980).
-  Possible zero salt line (from Moulton, 1975).
-  Wells cutting Jurassic salt (from Standlee, 1982).
- Other data from Gilliland, 1963.



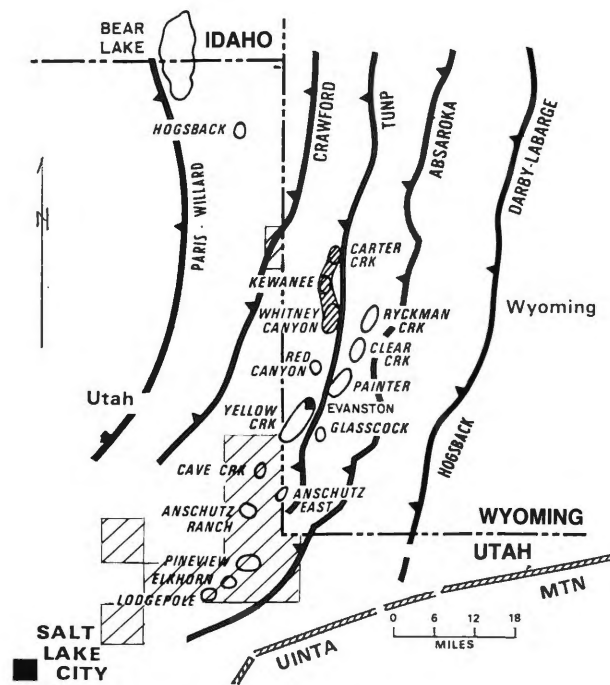


Figure 7. Basic structures and oil fields in the Utah-Wyoming-Idaho overthrust area. (Modified from Bishop, 1982).

- Thrust fault (teeth on upper plate).
- Oil Field
- Gas Field
- Township containing at least one well cutting salt in the Jurassic Preuss Fm.

The oldest exposed rocks along the anticlinal structure are the Arapien Shale, shown on figure 6. These rocks, because of their incompetent nature, and the mobility of the salts and other evaporites, are thought to contain diapiric structures.

The salt which is present in the Jurassic Arapien Shale is well bedded and coarsely crystalline. Its color is brick-red because of its clay and iron oxide content. The chemical composition of the salt, as given by Hardy (1952), is given in table 6.

The thickness of the Arapien salt varies throughout the area because of the flowage and deformation. Moulton (1975) reports that 2,038 feet of salt were penetrated in Sanpete County, and salt pit operators of the Redmond Hills deposits estimate the total thickness in that area to be 800 to 1,200 feet (Pratt and others, 1966). The potential areal extent of the salt

within the Sevier-Sanpete Valley was estimated by Moulton to lie within the "possible zero salt lines" shown on figure 6. Work by Standlee (1982) extends this area to the northwest to include the six well locations some 10 miles west of the town of Levan.

Salt has been mined from both surface and shallow underground workings along the Redmond Hills anticline for more than 50 years. Now the Redmond Clay and Salt Pit, located in section 25, T. 20 S., R. 1 W., is the only operating property in the area (Bryce T. Tripp, personal communication, 1989). The halite is produced mainly for livestock salt and as road salt, though some is produced for human consumption.

PREUSS SALT ZONE IN THE WYOMING-UTAH-IDAHO THRUST BELT

A thick salt zone lies at the base of the Jurassic Preuss Sandstone throughout much of the Wyoming-Utah-Idaho thrust belt (figure 7). Bishop (1982) describes this area as follows: "The Wyoming-Utah-Idaho thrust belt embraces an area of 15,000 square miles, extending from Jackson, Wyoming on the north, 180 miles south to the Uinta Mountains of Utah, and from Tip Top LaBarge, Wyoming on the east, 60 miles west to west of Bear Lake in northeast Utah and southeast Idaho. To the petroleum geologist, it is an area of major north-south-trending faults, thrust from the west with stacking displacements totaling possibly 60 miles. Folding, associated with and generally parallel to the strike of the faults, has provided traps for many of the oil and gas fields of the province."

The Jurassic stratigraphy, in order of decreasing age, consists of the Nugget Sandstone, Twin Creek Limestone, the Preuss salt zone, the Preuss Sandstone and the Stump Formation. Within Utah, data (Petroleum Information, 1986) suggest that the salt zone encountered in 43 wells varies in thickness from 49 to 7,584 feet with an average of 733 feet. The townships within which salt has been penetrated by oil wells are shown in figure 7. The depth to the top of the salt varies from a minimum of 38 feet to a maximum of over 5,000, with an average of slightly more than 1,700 feet. Maher (1976) describes the salt zone in the Pineview area as consisting "...primarily of salt and anhydrite with light grey to grey, moderately soft, micaceous shale." The areal extent and distribution of the Preuss salt zone, beyond the wells in which it has been penetrated, is not known.

Standlee (1982) suggests that the widespread Preuss salt zone is almost certainly represented in central Utah by unit 4 of Spieker (1946) and unit E of Hardy (1952), which they place at the top of the Twelvemile Canyon member of the Arapien Shale.

Table 6. Chemical composition of Arapien salt from pit north of Redmond, Utah. (weight percent)

NaCl	SiO ₂	SO ₄	Ca	Fe, Al Oxide	Mg	I ₂
95.60	2.16	1.10	0.51	0.04	0.04	0.03

SALTS OF THE PARADOX BASIN

Thick beds of salts are found within the Paradox Basin and are described as follows by Hite (1968): "The Paradox Basin is a Pennsylvanian sedimentary basin with boundaries usually determined by the extent of the Paradox Member. The basin is

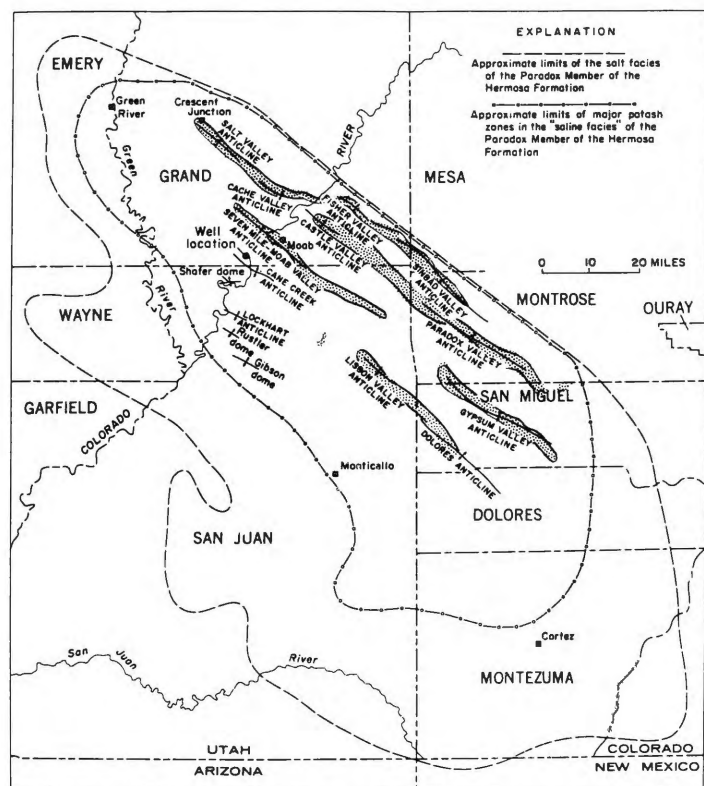




Figure 8. Salt anticlines and areal extent of Paradox Member of Hermosa Formation, Utah and Colorado. (Modified from Raup 1966 and Elston and Shoemaker, 1962).

 Composite anticlinal structures (Elston and Shoemaker, 1962).
 Individual anticlines (Raup, 1966).

part of the Colorado Plateaus province and is bordered by several uplifts, including the Uncompahgre, Defiance, and Monument uplifts and the San Rafael Swell. These uplifts may have started to form in Mississippian or Pennsylvanian time but attained maximum relief during the Laramide orogeny. The Paradox Basin is sometimes referred to as the Paradox salt basin, and in this sense the basin boundaries are determined by the outer limits of the salt deposits. The basin consists of a deep, elongate trough that trends northwest along the southwest shelf area to the west and southwest. This trough, here called the Uncompahgre trough, is characterized by thick accumulations of evaporite beds and by a series of northwest-trending salt anticlines." See figure 8 for the regional relationship.

The salts occur within the Pennsylvanian Paradox member of the Hermosa Formation. The Paradox is further subdivided into the upper Paradox member, consisting of the Ismay and the underlying Desert Creek zones; the middle Paradox member or the salt zone; and the lower Paradox member or the Barker Creek zone (Hite, 1968).

Hite (1968) describes the saline facies of the Paradox member as follows: They "... consist of 29 known evaporite cycles. An informal system of nomenclature, in which the halite units of the evaporite cycles are distinguished numerically, has been applied to the saline facies (Hite, 1960, p. 86). In this system, the salt beds are numbered in sequence from youngest to oldest. Each cycle of the saline facies, if complete and given in ascending order, consists of: 1) carbonate rock, 2) anhydrite, 3) halite with or without potash salts, 4) anhydrite, and 5) carbonate rock, to complete the cycle."

The many individual anticlines shown on figure 8 can be grouped into five main anticlinal structures which are briefly described by Elston and Shoemaker (1962) as follows: "Five elongate northwest-trending salt structures occur within a deep trough in the northeastern part of a depositional basin of evaporites of Middle Pennsylvanian age known as the Paradox basin...." The individual salt structures are from 30 to 70 miles long, and they have cores of evaporites that range from about 4,100 to more than 14,000 feet in thickness. Structural relief at the top of salt ranges from about 1,000 to about 9,000 feet." Besides the halite that is present in each of the 29 cycles, some of the cycles also contain potassium minerals, described by Hite (1961) as follows: "In about 18 of the 29 evaporite cycles, chemical sedimentation proceeded to the point of potash precipitation. Of these 18 cycles, 11 contain potentially valuable potash deposits. These are found in salt beds 5, 6, 9, 13, 16, 18, 19, 20, 21, 24, and 27 of Hite (1960). In several of these cycles the average content for specific intervals of some deposits may exceed 30 percent K_2O . Only two potash salts, sylvite (KCl) and carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$), are present in large quantities. Minor amounts of polyhalite ($2CaSO_4 \cdot MgSO_4 \cdot K_2SO_4 \cdot 2H_2O$), kieserite ($MgSO_4 \cdot H_2O$), and rinneite ($FeCl_3 \cdot 3KCl \cdot NaCl$) have been reported."

The only commercial development of the potash resources is being done on the Cane Creek anticline by Moab Salt, Inc. Initially, the potassium-bearing salts were mined underground. This technique was later replaced by solution mining, whereby water from the Colorado River is pumped down into the potash-bearing horizon where it dissolves the salts, and forms a concentrated brine. The brine is pumped to the surface

into large solar evaporation ponds where it is concentrated and the mixed salt sylvinite (sylvite and halite) is precipitated. The final product sylvite is produced by separating it from the halite by froth flotation. Halite also is processed at the Cane Creek facility and marketed.

SALINE MINERALS IN THE UINTA BASIN

Saline minerals are found in both the Eocene Green River and Uinta Formations of the Uinta Basin in eastern Utah. They are found mainly within the saline facies of the Uinta Formation (figure 1). In describing the saline facies, Dane (1954) states the following: "Although originally included in the Green River Formation, the saline facies is laterally equivalent to more characteristic beds of the Uinta Formation, and is also sufficiently distinctive from the underlying beds of the Green River Formation to warrant its exclusion therefrom." Picard (1957) indicates that the saline facies ranges from 500 to 1,555 feet in thickness. Picard (1955) also suggests that the occurrences of salts within the saline facies mark the beginning of the retreat of Lake Uinta and affirm the restricted nature of the lake.

The main salts found within the saline facies of the Uinta Formation and within the Green River Formation are shortite $\text{Na}_2\text{Ca}_2(\text{CO}_3)_3$ and nahcolite NaHCO_3 . Dane (1954) notes that, in some areas, these salts are evidenced only by empty molds of "salt" crystals or calcite pseudomorphs after "salt." In other areas, salts are present as blobs, streaks, and as beds up to 5 feet in thickness, containing up to 60 percent nahcolite (Hite, 1964). A thorough review of the mineral assemblages of the Green River Formation is given by Milton and Eugster (1959). Chloride salts, such as halite and sylvite, are not present within the Green River-saline facies mineral suite (Milton, 1957). Milton and Eugster (1959) indicate that northupite, a chloride-carbonate, is the only chlorine-bearing mineral known in the Green River Formation. They also make the following observation: "The uncommon mineralogy of many beds of the Green River, particularly the saline ones, is a direct consequence of special conditions prevailing during sedimentation and diagenesis, and the unusual composition of the waters in which precipitation and sedimentation took place. The mineral assemblages of the saline beds bear no resemblance to the usual salt deposits."

The saline minerals within the Uinta Basin are not being developed. They are, however, of value in helping to understand the complex nature of the Green River Formation and the conditions under which it developed.

SALTS IN THE SEVIER DESERT REGION-WESTERN UTAH

Salt has been encountered in at least four wells drilled within the Sevier Desert basin of western Utah (figure 1). The following summary about the origin and extent, etc. of the salts is provided by Doug Sprinkel (written communication, 1989).

The Sevier Desert basin of western Utah is one of many evaporitic basins that occupied Utah in geologic time. Similar to other evaporitic basins in Utah and around the world it has been the focus of hydrocarbon exploration. Although economic success in this basin has not yet been achieved, most of what is known about the Sevier Desert basin and its future potential is the direct result of that exploration. Additional insights were also gained from the activities of the Consortium for Continental Reflection Profiling (COCORP).

The evaporite-bearing strata in the Sevier Desert are dated as late Oligocene (Lindsey and others, 1981). The evaporites appear to occur along a north-trending belt as much as about 50 miles long and about 3 to 5 miles wide. The belt appears confined to near the depositional center of the Sevier Desert basin (Mitchell and McDonald, 1987). The shallowest evaporites encountered to date are at a depth of 2,550 feet in the Argonaut Energy No. 1 Federal well and the deepest at about 8,790 feet in the ARCO Oil and Gas Co. No. 1 Pavant Butte.

The thickness of the evaporites varies from a few thin nodular beds of anhydrite (Lindsey and others, 1981) to 5,152 feet of predominantly massive halite (Mitchell, 1979). The erratic thickness of the evaporites is believed by Mitchell (1979) to be caused by diapirism. Also, seismic reflection data from Mitchell (1979), and Mitchell and McDonald (1987) show other possible undrilled diapiric structures.

SUMMARY

Within the state of Utah, salts and brines constitute a major mineral resource. Many of the individual occurrences are being developed. These would include the brines of the Great Salt Lake, the Great Salt Lake Desert and Sevier Lake, and the bedded salts near Redmond and Moab. From these, a variety of products are being made. Included are common salt, potash, sodium and potassium sulfate, magnesium chloride (brine and flake), magnesium metal and chlorine gas. Lithium, bromine, boron and other valuable elements are potential products from these resources. Deep Paradox Basin salts have been considered for the storage and isolation of high-level nuclear waste.

Utah's salts and brines can occasionally represent a liability rather than an asset. They contribute to the roughly nine million tons of salt which flow past Hoover Dam annually, causing severe problems to downstream users of water from the Colorado River (Utah Department of Water Resources, 1987). Other problems are those related to drilling through salt-bearing formations, the mandatory and proper disposal of produced oil-well brines, and the recent flooding caused by the Great Salt Lake.

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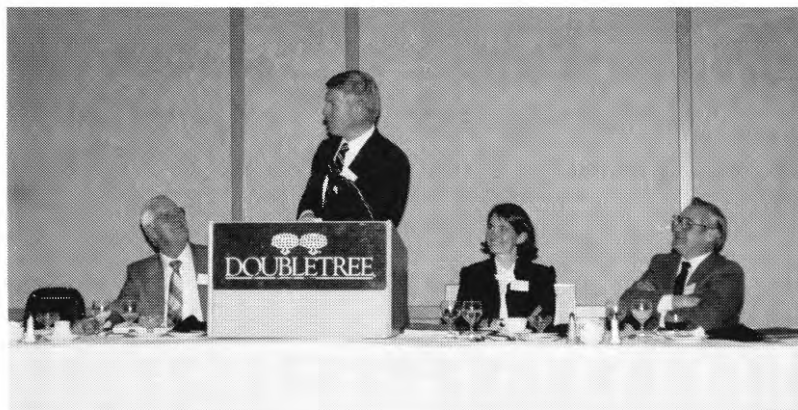
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The Last Map Ceremonies

December was a good month for map aficionados. It was the time to make a statement about the U.S. Geological Survey program to topographically map the entire United States, but specifically it celebrated the completion of the final 7.5-minute topographic quadrangle in Utah. There are 1512 maps this size, covering 7.5 minutes of latitude and longitude at a scale of 1:24,000. Besides being the most accurate map available for most hunters and hikers, they provide bases for nearly all other information overlays. We use them for our quadrangle mapping — the geology is printed over the 7.5-minute base — and as the basis for almost all other mapping. They are an indispensable tool.

The "Last Map Ceremony" held at the Doubletree on December 6. Dee C. Hansen (left) acted as moderator to the speakers: Val Oveson, Lt. Governor for Utah, Genevieve Atwood, past Director of UGMS, and Dallas Peck, Director of the United States Geological Survey.



Governor Bangerter signs a proclamation on December 4 designating Dec. 6 as "Utah Map Recognition Day."

From left, Clem Heagren, head of the U.S.G.S. Earth Science Information Center, Kenneth Osborn, U.S.G.S. Division Liaison, Governor Bangerter, Carl Fannesbeck, Deputy Manager at Geometronics Service Center, and Dee C. Hansen, Director of Natural Resources.

Recent Publications of the UGMS

Quaternary Geology of part of the Sevier Desert, Millard County, Utah, by Charles G. Oviatt, 41 p., 1 pl.; UGMS Special Studies 70. This report describes the Quaternary geology and Quaternary geologic history of part of the Sevier Desert in east-central Millard County, Utah. The geologic work reported on here was undertaken as a Cooperative Geologic Mapping (COGEMAP) project, funded by the U.S. Geological Survey and the Utah Geological and Mineral Survey. Surficial deposits in the map area consist of fine-grained lacustrine deposits of Lake Bonneville and of pre-Bonneville lakes, vast areas of fine-grained alluvium deposited by the Sevier and Beaver Rivers, and coarser grained lacustrine and alluvial deposits in piedmont areas. Thin deposits of eolian sand or silt and clay are present throughout the map area but are concentrated in dunes in favorable localities. The map area also contains Quaternary basalt flows and volcanic vents; Quaternary faults cut deposits of all ages. The Sevier Desert basin has been periodically occupied by lakes throughout the Quaternary Period, and the geologic record of these lakes is exceptionally good. The lake deposits have been dated by interbedded volcanic ashes, lava flows, and various geochronometric methods. This report is one of the first attempts to map in a systematic way the Quaternary deposits and landforms in a large area of the Basin and Range physiographic province of western Utah.

Geology of the Porcupine Reservoir quadrangle, Cache County, Utah, by Lea Campbell Berry, 17 p., 2 pl., UGMS Map 113. The Porcupine Reservoir quadrangle contains one of the most complete and best exposed sections of Paleozoic rocks in the Bear River Range, totalling 14,000 feet (4267 m) of marine strata. Thicknesses of marine strata mapped include, by age, Precambrian-Cambrian basal quartzite, 2900 feet (884 m) thick; Cambrian, 4610-5220 feet (1405-1590 m) thick; Ordovician, 1400-1650 feet (426-503 m) thick; Silurian, 1240-1610 feet (378-490 m) thick; Devonian, 2190-2280 feet (667-695 m) thick; Mississippian, 2600-2900 feet (792-884 m) thick; and Pennsylvanian, 600-900 feet (183-274 m) thick. Non-marine sediments unconformably overlie the Precambrian and Paleozoic sediments and include conglomerate, siltstone, and sandstone of Eocene age, 0-200 feet (0-61 m) thick; Quaternary terrace deposits, 20-50 feet (6-15 m) thick; colluvium and talus, 30+ feet (9+ m) thick; and alluvium.

Proterozoic and Paleozoic strata, part of the Bear River Range and Cache allochthon, are gently folded in the Logan Peak syncline, with minor folds complicating the limbs. Northeast- and northwest-trending normal faults, cut by north-trending normal faults, suggest an intermediate phase of faulting between Mesozoic folding and late Cenozoic basin-and-range faulting.

Hyrum Dolomite and Beirdneau Sandstone are possible reservoir rocks for gas. Other commodities with possible economic interest include phosphate pellets from the Little Flat Formation, calcium carbonate, pure silica, and water.

Quaternary and Tertiary units slide on underlying Devonian and Mississippian Formations to form a landslide, 1300 feet (396 m) long and 1500 feet (457 m) wide, north of Porcupine Reservoir in 1983-1984. The reservoir was not damaged.

Geologic map of the Geyser Peak quadrangle, Wayne and Sevier Counties, Utah, by Stephen T. Nelson, 18 p., 2 pl., UGMS Map 114. The Geyser Peak quadrangle is underlain by a thick sequence of Mesozoic sedimentary rocks locally intruded by dikes and partially covered by lava flows of Tertiary age. These igneous rocks reflect two episodes of alkaline magmatism at the eastern end of the Marysvale-Pioche volcanic belt. Late Oligocene, potassium-rich shoshonite and trachyte lava flows exhibit phenocrystic disequilibrium textures which indicate a complex magmatic history of magma mixing or polybaric crystallization. Miocene-Pliocene trachybasalt magmas were emplaced as lava flows and dikes.

Structurally, the quadrangle lies at the eastern margin of the Basin and Range-Colorado Plateau transition zone as defined by the eastern termination of significant normal faulting. Two major folds of post-Laramide age involve the entire stratigraphic section exposed within the quadrangle except Miocene-Pliocene trachybasalt flows and Quaternary units.

Four huge composite landslide masses, covering altogether 18.5 square miles (47.9 km²), developed during the Pleistocene when elevated precipitation triggered movement along major tectonic or erosional escarpments with as much as 3000 feet (915 m) of relief. Failure of two landslides was localized in shales on the limb of a large anticline.

Multi-characteristic correlation of upper Cretaceous volcanic ash beds from southwestern Utah to central Colorado, by B.J. Kowallis, E.H. Christiansen, and Alan Deino, 22 p., 1989, UGMS Miscellaneous Publication 89-5. Precise correlation of volcanic ash beds, common over wide areas in continental and marine sedimentary sections, has wide application in stratigraphic, tectonic, and paleontologic studies. To establish a protocol for direct correlation of ash beds, two bentonitic volcanic ashes (PBC-5 and PBC-11 of Elder and Kirkland, 1985) were examined from the uppermost Cenomanian strata of the lower Bridge Creek Limestone Member of the Greenhorn Formation near Pueblo, Colorado. The same ashes were sampled at several other localities from central Colorado at southwestern Utah from the time-equivalent lower Mancos shales in the Four Corners region and lower Tropic Shale farther west into Utah. The ash beds are about 1-2 m apart in Colorado and eastern Utah, with greater separation in western Utah. Precise ⁴⁰Ar/³⁹Ar laser probe dating of these ashes indicates that PBC-5 is 94.7 ± 0.4 Ma and PBC-11 is 94.5 ± 0.2 Ma. The errors overlap so that other features must be used to distinguish and correlate them. Kauffman et al. (1987) correlated these ashes using biostratigraphy and key lithologic mark-

ers, but no direct correlation of the ashes has been done using characteristics of the ashes themselves. We used types and abundances of phenocrysts, zircon crystal morphologies, types and abundances of mineral inclusions in zircons, average aspect ratios of zircon crystals, uranium distribution patterns in zircons and apatites, and trace element concentrations and patterns to help distinguish the ashes. For example, both ashes contain quartz, biotite, sanidine, apatite, and zircon, but PBC-5 also contains monazite and subhedral pink zircon. PBC-5 zircons typically have small (100) prism faces and large (110) prisms, whereas PBC-11 zircons are just the opposite. Inclusions are abundant in PBC-11 zircons, but less abundant in PBC-5 zircons. Zircons from PBC-5 have average aspect ratios (length/width) of 3.2 ± 0.4 or more, whereas zircons from PBC-11 have average aspect ratios of 2.7 ± 0.4 or less. Variation diagrams of Th versus Ta or U produce easily distinguished tight clusters for each ash. However, REE patterns are not as distinctive. The correlation of these ash beds over 700 km shows the potential for these techniques.

Quaternary faults, folds, and selected volcanic features in the Cedar City 1° X 2° quadrangle, Utah, by R.E. Anderson and G.E. Christenson, 29 p., 1 pl.; UGMS Miscellaneous Publication 89-6. The Cedar City 1° X 2° quadrangle in southwestern Utah is traversed by several major Quaternary structures and numerous lesser faults and folds which all trend generally north-northeast. The major structures include, from west to east, the Gunlock, Washington, Antelope Range, and Hurricane faults; the Cedar City-Parowan monocline; and the Red Hills, Paragonah, and Sevier faults. These structures generally range in age of last movement from middle to late Pleistocene. The most recent movement and highest slip rates occur on the Hurricane and Paragonah faults. Both are principally range-front faults which locally cut Quaternary volcanic rocks. Scarps on alluvium mappable at the 1:250,000 scale occur only on the Hurricane and Antelope Range faults. The Sevier fault is the longest of the major structures and is also principally a range-front fault.

Shorter, less prominent faults and folds are scattered throughout the quadrangle, but are concentrated along the northern edge in the Escalante Desert, Cedar and Parowan Valleys, and Sevier Valley. These structures are principally in alluvium and Quaternary basalt and are generally of middle to late Pleistocene age. The faults and folds are particularly well developed near Cedar City and in the Sevier Valley near Panguitch on the hanging wall blocks of the Hurricane and Sevier faults. The youngest (latest Pleistocene, possible Holocene) scarps on alluvium are near Enoch and in Parowan Valley. Other suspected young (late Pleistocene) scarps are in the Escalante Valley and in Sevier Valley north of Panguitch.

Few data are available to determine average recurrence intervals between surface-faulting events and the time of the last event. Long-term slip rates calculated from offset volcanic rocks of known age average about 5 m/m.y. for the Gunlock fault, 300-470 m/m.y. for the Hurricane fault, 455

m/m.y. for the Paragonah and associated faults, and 357 m/m.y. for the Sevier fault. Despite these relatively high long-term slip rates, the lack of evidence for Holocene faulting indicates that the probability of a surface-faulting earthquake at a particular point along any fault in the Cedar City quadrangle is relatively low compared to the Wasatch fault or other Holocene faults in northern Utah.

Geochemical Characteristics of Hydrothermally Altered Black Shales of the Southern Oquirrh Mountains and Relationships to Mercur-Type Gold Deposits, by Paula N. Wilson and W.T. Parry, 64 p.; UGMS Open-File Report 161.

Alteration of the Manning Canyon and Long Trail Shales in the southern Oquirrh Mountains has resulted in (1) oxidation of organic matter and pyrite; (2) replacement by phyllosilicates; (3) silicification; (4) porphyroblast growth; (5) fossil replacement by phyllosilicates; (6) phyllosilicate veins of various combinations of illite, chlorite, pyrophyllite, kaolinite, and Fe-oxides; (7) depletion of organic carbon, calcium carbonate, alkali and alkaline earth metals; and (8) enrichment of aluminum and hydrogen. This alteration has been accompanied by formation of an unusual type of illite, termed pseudo-illite, which is anomalously low in K₂O and Na₂O, and is probably enriched in bound water. Alkali metal, rare earth element, gold and other heavy metal, and Al₂O₃, H₂O+, Sc, Th, Ta, Hf, and Zr mobility also accompanied alteration. Correlations among these elements, along with similar Eu and/or Tb depletions in both high Sc and gold-bearing samples, and the high Sc contents in gold or gold-pathfinder-rich, predominantly pseudo-illite veins, indicate the Sc and H₂O+ rich, alkali metal poor, and highly oxidized hydrothermal fluids responsible for formation of pseudo-illite were gold bearing. Whether this hydrothermal system was responsible for the ore-grade gold mineralization at Mercur, Sunshine, and West Dip is still not certain. The depletion of shales in organic carbon, calcium carbonate, alkali and alkaline earth metals and enrichment of aluminum also make these altered shales suitable for brick manufacturing.

K/Ar age dates on vein and clay-sized fractions of whole rock indicate that the hydrothermal alteration of these shales is 193 to 122 m.y. in age and suggests that the Mercur gold deposits may be Mesozoic in age.

We propose that a large scale, gold-bearing hydrothermal system existed throughout much of the southern Oquirrh Mountains during the mid-Jurassic to earliest Cretaceous and that this system occurred at varying stratigraphic levels throughout the area. The Mercur Mine is in an area where the hydrothermal system was stratigraphically lower and so most hydrothermal activity occurred well below the Long Trail Shale. In areas surrounding the Mercur Mine, the hydrothermal system reached much higher stratigraphic levels, at least into the Long Trail Shale and possibly into upper Great Blue Limestone and lower Manning Canyon Shale.

The results of this study suggest modification of exploration models for Mercur-type gold deposits to include areas higher in the stratigraphic section and areas remote from igneous rocks.

Dating methods applicable to Quaternary geologic studies in the western United States, edited by S.L. Forman, 80 p.; Miscellaneous Publication 89-7. A persistent problem in Quaternary studies is determining the timing of climatic, tectonic, volcanic or anthropogenic events as recorded in terrestrial records. The ability to understand regional mechanisms of environmental change is severely limited if an independent chronology cannot be established for disjunct areas. Without a secure geochronology one cannot address the causal relationship between changes in the hydrologic, tectonic, climatic and anthropogenic systems.

During the past decade there have been significant advances in geochronology, with the refinement of (e.g., thermoluminescence dating, tephrostratigraphy) and the development of (e.g., accelerator mass spectrometry radiocarbon dating) many techniques. Many of these methods are currently used to constrain the timing of geological events. However, often the application of these methods and interpretation of results is not straightforward. It is becoming necessary for the field geologist to have a basic understanding of the limitations and requirements of potential dating methods, initially to collect optimal samples for each technique, and subsequently for the judicious interpretation of the results.

The emphasis of this special paper is on the application and limitations of dating methods, concentrating on field aspects pertinent to geologic studies. This miscellaneous paper is a refined text used for a two-day short course in May, 1989 on Quaternary Dating Methods for the Utah Geological and Mineral Survey. Topics covered include conventional and accelerator mass spectrometry radiocarbon dating techniques, thermoluminescence dating, dendrochronology, amino acid racemization, fission track and K/Ar methods, soil morphology and slope morphometric techniques. These dating techniques are most often used or have the greatest potential for constraining the timing of geologic events in the Basin and Range Province.

Techniques not mentioned in this contribution, but show promise, such as U/Th series dating applied to secondary carbonate, cosmogenic radionuclides, and cation exchange ratio are developmental and not readily available to most geologists.

These papers provide a basic understanding of the principles, potential, problems and limitations of various techniques and serves as a guidebook into the dynamic world of geochronology.

Geologic map of the Redmond Canyon quadrangle, Sanpete and Sevier Counties, Utah, by Grant C. Willis, UGMS Open-File Report 163, 65 p., 1 pl.

Geologic map of the Swasey Peak NW quadrangle, Millard County, Utah, by Dorothy Sack, UGMS Open-File Report 164, 28 p., 1 pl.

Geologic map of the Coyote Knolls quadrangle, Millard County, Utah, by Dorothy Sack, UGMS Open-File Report 165, 27 p., 1 pl.

A re-evaluation of the volcanic history and mineral potential of the central East Tintic Mountains, Utah, by J.D. Keith, R.D. Dallmeyer, Choon-Sik Kim, and B.J. Kowallis, 86 p., 2 pl., 1989. This report documents several new findings concerning the geology and mineral potential of the central East Tintic Mountains, Utah. For example, fission-track ages and $^{40}\text{Ar}/^{39}\text{Ar}$ ages which we report suggest that some of the volcanism and alteration in this area is as old as 37.4 to 35.3 Ma. This early episode of volcanism was contemporaneous with lacustrine deposition; the overlying volcanic rocks and cross-cutting intrusions range in age from about 34.5 to 33.6 Ma. This implies that a large caldera related to the eruption of the younger Packard Quartz Latite and Fernow Quartz Latite is not present in this area. However, our data suggest that a smaller caldera related to the eruption of the tuff member of the Copperopolis Latite may be present. We note that many monzonite dikes and intrusions in this area are hornblende bearing and are correlative in modal and chemical composition with the productive Silver City Stock rather than the barren Sunrise Peak Stock. The large areas of hydrothermal alteration which surround these intrusions exhibit many similarities to the well-studied alteration halos in the East Tintic District. The age, composition, and field relationships of the post-lacustrine volcanic rocks suggest that they may represent, in part, the extrusive equivalents of the monzonite dikes and Silver City Stock. Our work suggests that the Silver City Stock and related intrusions may be part of one of the youngest (33.6 ± 0.2 Ma) igneous events in the central East Tintic Mountains, but not as young as previously suggested (ca. 31.5 Ma).

In addition, our recent work has documented the existence of unusually large (and abundant) *magmatic* sulfides in lava vitrophyres and vent-facies biotite latite dikes, which are the surface expressions of the Silver City Quartz Monzonite intrusions in this area. In addition, preliminary analytical data suggest that the sulfides host most ($\sim 75\%$) of the Ag present in the latites. The East Tintic Mountains are potentially the first locality, worldwide, where Ag in meso-veins can be demonstrated to be derived from degassed Ag-bearing magmatic sulfides. Consequently, the central East Tintic Mountains are a favorable area for exploration for Ag (Pb-Zn-Cu-Au) ore bodies because: 1) productive monzonite intrusions are present, and 2) Paleozoic rocks favorable for ore deposition may be present beneath relatively thin volcanic cover because the area is not entirely enclosed within a caldera.

Generalized geologic map of Utah, UGMS Map 92. Scale 1:500,000. This is a reprinting of the 1985 postcard that has proven popular. The state's geology is depicted in color in 15 age designations. All this geology is available for only 25 cents.

Probabilistic liquefaction severity index maps of the state of Utah, by Matthew A. Mabey and T. Leslie Youd, 28 p.; UGMS Open-File Report 159. This report by two members of the Civil Engineering Department at Brigham Young University contains liquefaction severity index maps for the state of Utah generated using probabilistic analysis. The Liquefaction Severity Index (LSI) expresses the maximum magnitude of differential deformation expected as the result of soil liquefaction. LSI is defined as the maximum displacement, in inches, occurring in Holocene flood plain deposits and is a function of distance from the causative earthquake and the magnitude of that earthquake.

Maps of LSI have been prepared for 10% probability of exceedence in four different exposure periods, 10 years, 50 years, 250 years, and 1000 years. The latter is intended to approximate a deterministic case. While the Wasatch fault is assumed to be the greatest source of earthquake shaking to cause liquefaction, these maps clearly show that a very broad area has a significant liquefaction hazard arising from the numerous other earthquake-generating faults in the state. The occurrence of liquefaction requires shallow ground water, the absence of which reduces the LSI to near zero. The LSI maps quantify the probable maximum hazard due to liquefaction and can be used to reduce the risk of lifelines and other engineered structures by planning for the maximum probable effects of liquefaction.

A hydrocarbon exploration model for the Cretaceous Ferron Sandstone Member of the Mancos Shale, and the Dakota Group in the Wasatch Plateau and Castle Valley of east-central Utah, with emphasis on post-1980 subsurface data, by Carol N. Tripp, 81 p., 15 plates; UGMS Open-File Report 160. This study incorporates subsurface, surface, structural, and stratigraphic data from the Cretaceous Ferron Sandstone Member of the Mancos Shale and the Dakota Group into a hydrocarbon exploration model. Using this model, specific recommendations are made for locating and drilling oil and gas wells. While numerous investigations have been conducted in the Wasatch Plateau and Castle Valley, most of these have focused on either the subsurface or the outcrop, with very few integrating both outcrop and subsurface data. Additionally, most studies have addressed either the structure or the stratigraphy of the region and not attempted to incorporate both into an exploration model. The existing studies are primarily oriented towards facies descriptions, coal exploration, and gross paleoenvironmental interpretations and do not delineate potential hydrocarbon-producing trends.

ERRATA

Page 9, column 1 of Vol. 23 No. 2 stated that work on two Utah coal beds suggested as much as 2 million cubic feet of gas per square mile could be extracted from a six-foot coal seam.

It should read 2 billion.
