PUBLISHED QUARTERLY BY UTAH GEOLOGICAL AND MINERAL SURVEY

SURVEY NOTES

Vol. 16, No. 2 Service to the State of Utah Summer 1982

HISTORY OF PARADOX SALT DEFORMATION

as Related to Nuclear Waste Isolation

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INTRODUCTION

The Paradox Basin has interested geologists for several reasons: Economic (oil, gas, uranium, potash), scientific (ages of deformation, tectonic history, sedimentary environments), and most recently as a potential repository site for high-level nuclear waste. The Paradox Basin contains thick deposits of salt, which have been deemed favorable for the disposal of nuclear wastes by the U. S. Department of Energy (DOE) and scientists studying nuclear materials. Favorable salt characteristics include structural soundness, easy mining, good thermal properties and high inherent plasticity, which allows the salt to heal itself when shattered. Some possible shortcomings of rock salt include its low shear strength and its solubility in unsaturated waters. Scientists are quick to point out, however, that these bedded salt deposits are very old features (about 250 million years) and that geologic processes that might destroy them are apparently not in effect.

The DOE studies were at first concentrated on four areas in the Paradox Basin: Salt Valley, Lisbon Valley, Gibson Dome, and Elk Ridge (Figure 1). Their choice of these areas considered the locations with respect to depth of salt from the surface, ease of mining, proximity to rail transportation, and suitability of the salt formations as repositories (adequate thickness and areal continuity). The studies have now zeroed in on the Gibson Dome area. The first two areas were rejected because of the structural complexity of the salt formations or because of conflicting economic interests (petroleum and uranium production), the latter was rejected because of salt bed thinness and distance to rail transportation. The Gibson Dome area has some shortcomings as well including its proximity to Canyonlands National Park and its distance from an existing railroad line.

Some of the first geologic and geographic descriptions of the area resulted from Major Powell's river expeditions in 1869 and 1871. Since then, many geologists have worked in southeastern Utah and southwestern Colorado, several of whom have worked on unraveling the sedimentary sequences and subsequent deformational history of the Paradox Formation: During the 1920s, T. S. Harrison, H. W. Prommel, H. E. Crumm; during the 1930s, A. A. Baker, C. H. Dane; during the 1940s, E. T. McKnight; during the uranium exploration times of the late 1940s and 1950s, W. L. Stokes, E. M. Shoemaker, J. E. Case, D. P. Elston; and during the 1970s F. W. Cater, E. Szabo, S. A. Wengerd, R. H. Hite, R. J. Baars. Exploration work for oil and gas has increased in the

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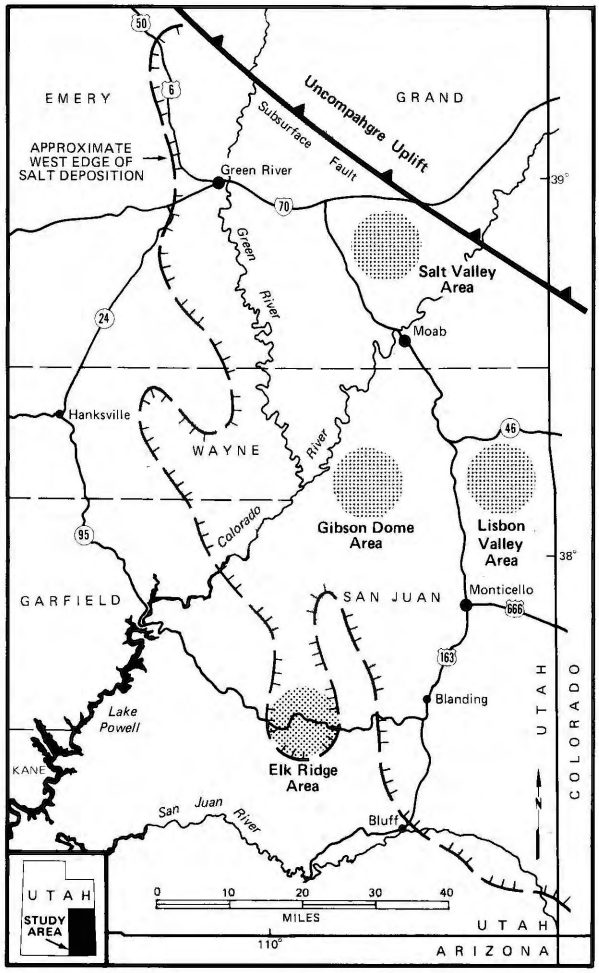

FIGURE 1. DOE study sites in Paradox Basin area, Utah.

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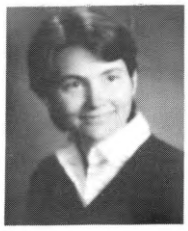

FROM THE DIRECTOR'S DESK

PARADOX BASIN STUDY OF PROPOSED NUCLEAR WASTE REPOSITORY

Investigations to locate sites suitable for radioactive waste repositories have been underway for many years in several countries. The U. S. national program for highlevel waste disposal is emphasizing disposal of such wastes in mined repositories deep underground. No such repository has yet been developed and temporary storage of commercial waste consists of water-filled pools adjacent to nuclear power plants; defense wastes are in double-walled steel tanks on federal reservations.

Five geographic areas in the United States are being considered for the first repository for commercial high-level radioactive wastes: basalts at Hanford, Washington; tuffs at the Nevada Test Site, Nevada; Permian Basin salts in Texas; salt domes along the Gulf Coast; and salts of the Paradox Basin, Utah. It has become the UGMS' responsibility to review the geologic work being performed in Utah under the auspices of the Department of Energy to ascertain whether the Paradox Basin is, indeed, an adequate or "the best" geologic repository. This oversight responsibility includes the review of the assumptions and geologic aspects of the national program for nuclear waste disposal, oversight of the geologic activity performed by the Department of Energy and its subcontractors in Utah, and reviews of the reports that summarize these activities. The UGMS has participated on the Governor's High-Level Nuclear Waste Repository Task Force and provides staff support for the Geologic Work Group which has been reviewing geologic documents.

The criteria and guidelines for a high-level nuclear waste repository are still being defined. The geolgoic criteria are based on the assumptions of (1) the more multiple and independent geologic barriers, the better, and (2) the less complicated the site, the better. The concept of multiple barriers is fundamental to today's criteria for high-level nuclear waste disposal. Such barriers can be chemical, structural, or stratigraphic impediments to radionuclide transport. Not only should barriers be multiple, they should be independent of each other.

More specifically, it is assumed that the site must be located in a geologic environment that physically separates the radioactive waste from the biosphere. Ideally, the host rock would provide an environment with an absence of free water to prevent dissolution and transport of radionuclides from the repository. Below the water table, the host rock ideally should have high porosity, very low hydrologic conductivity, and be under low hydrologic gradient. The host rock will be more effective when it contains minerals that are known to sorb radionuclides (clays, and zeolitic minerals are notably sorptive). Ability to be excavated, thickness, and permeability are important intrinsic rock properties. The host rock/site must have adequate geometry for emplacing the waste in the repository and must be located at a depth sufficient to prevent surficial processes from exposing the waste. The thicker and more homogeneous the section, the greater the confidence in model calculation of radionuclide transport. Also, the greater the buffer zone between the repository and any overlying and underlying aquifer, the greater the confidence that the host rock can contain the waste beyond the minimum period.

Typically, location studies in the United States have focused on a specific type of host rock. Most early studies concentrated on salt as the host rock. The favorable characteristic of many salt deposits include: the ability of salt to dissipate large quantities of heat, its ability to "self heal" fractures which might develop in it, its very undisturbed presence can be indicative of its long-term integrity and non-exposure to ground water, it is comparable to concrete as a gamma-ray-shielding medium, its compressive strength is similar to that of concrete, it occurs in areas characterized by low levels of seismicity and low levels of tectonic activity, it is a resource common enough that using it as a repository would not deplete the resource base, and it can be mined easily at a relatively low cost. Certain characteristics of salt are potentially unfavorable: salt is soluble in unsaturated water, it has the potential for mobility which could cause engineering or safety problems over a long period of time, it has low shear strength, water contained in rock salt tends to migrate toward a heat source, bedded salts may not have consistent pathology, and some salt sequences may have high concentrates of methane.

For the past five years, the DOE's national program has worked to identify the first nuclear waste repository for the United States. By successive screenings, the United States has been divided into regions, areas, and locations. Within the resulting five locations (listed above) sites have been or will be identified. In the Paradox Basin, it is the Gibson Dome site that has been identified (see map on p. 1).

The UGMS is taking the responsibility to review the national high-level nuclear waste isolation program in the Paradox Basin seriously. Geologists from virtually every

Genevieve Atwood

UGMS Activities in Paradox Basin

Compiled by SANDRA N. ELDREDGE

Eleven of the 27 UGMS geologists are performing geologic investigations in Paradox Basin and providing oversight of the geologic work being carried out by the Department of Energy and their contractors. Sections within UGMS have been reviewing related DOE research and have developed independent studies now underway in Paradox Basin.

PETROLEUM SECTION

A study of oil and gas fields in Paradox Basin is being carried out by Karl W. Brown and Keith Clem under the direction of Howard R. Ritzma.

Definitive, accurate information on the oil and gas fields of southeast Utah is being assembled and it is intended that this work will be extended into other oil and gas producing areas and eventually the entire state.

Among the data being assembled are published oil and gas field maps and production information for all fields in the Paradox Basin, an annotated bibliography of oil and gas field mapping and reservoir and production data, as well as complete and accurate geologic records of all wells in the basin. The data are being arranged to conform to, supplement, and update the penetration chart of oil and gas fields (**UGMS Oil and Gas Field Studies 14, 1976**) and drilling records for oil and gas (**UGMS Bulletins 50 and 74, 1955 and 1965, respectively**). Structural data will also be compiled to construct a tectonic and structure contour map of the basin. Eventually, that mapping effort will also be extended across the entire state.

The assemblage of data will be made available to the public and industry in publication form. The materials will also be placed in a format compatible for ready storage and future retrieval by computer.

ENERGY SECTION

Hasan Mohammad has been investigating active and inactive uranium mines in southeastern and southern Utah. Among the information being studied are the nature and age of host rocks, types and controls of mineralization, characteristics and mineralogy of ores, trends in mining methods, production figures, and reserves of the mines.

Hasan will assist Helmut H. Doelling in mapping in detail the Salt Valley anticline to further define the age of salt flowage. In addition, uranium mines in the Lockhart Basin - Indian Creek area will be studied and mapped. The deposits will be evaluated to determine the potential for uranium ore.

MINERALS SECTION

Wally Gwynn is examining the DOE salt cores. Thin sections are being prepared for a petrographic examination of the inter- and intra-salt bed anhydrites found within the Gibson Dome No. 1 core.

Other research programs may include the following: 1) a characterization of the salt stratigraphy at Gibson Dome; 2) an investigation of the mining practices, successes, problems, and issues of the Texas Gulf Sulfur Company on the Cane Creek anticline near Moab; and 3) a study of the environment of deposition of the Paradox Formation.

HAZARDS SECTION

Bruce N. Kaliser is studying the geoseismic environment of Paradox Basin to determine the significance of lineations and faults. Included in these studies will be an investigation of trenches across lineations to identify the movements and recurrence intervals of the faults.

The seismic and microseismic data and interpretations that will be examined will supplement material for the statewide seismic zonation program of UGMS.

SITE INVESTIGATIONS SECTION

Gary Christenson has undertaken a study of Quaternary deposits in Montezuma and Recapture creeks in southern San Juan County, to evaluate the erosional history of this part of Paradox Basin. The study will concentrate on mapping and dating of alluvial and eolian deposits in order to reconstruct the chronology of erosional and depositional events in the area. The study will also make possible an evaluation of the relative importance of climatic, tectonic, lithologic, and base level controls on erosion and deposition.

William Lund has performed a reconnaissance survey of the three proposed railroad routes to Davis and Lavender canyons to identify geotechnical issues and geologic hazards that will need to be addressed by the Department of Energy.

GEOLOGY WORK GROUP

A Geology Work Group was formed in August, 1981 as part of the Utah Nuclear Waste Repository Task Force. The task force has been replaced by the Utah Office of Nuclear Waste and the geology group now provides their input to this office.

This group is comprised of ten geologists: William Lee Stokes, Hank Goode, Howard Ross, Robert Norman, David Tillson, Thure Cerling, David Bird, Charles B. Hunt, and Jeffrey Keaton. Genevieve Atwood chairs the committee and Sandra Eldredge provides staff support.

The work group reviews the geologic documents and comments on studies being carried out by the Department of Energy and its contractors, the Office of Nuclear Waste Isolation/Battelle Memorial Institute; their subcontractors, Woodward-Clyde Consultants; and others. The group makes monthly reports on the progress of oversight activities and recommends changes, additions to and deletions from the Department of Energy program. ■

("From the Director's Desk" cont. from page 2)

section of the UGMS are studying the Paradox Basin area. We are obtaining the information generated by the federal studies and putting this information onto the state's computer system, and we shall publish a series of reports during the next two years describing geologic aspects of the Paradox Basin. The UGMS will continue to participate on the Geologic Work Group as long as the DOE continues to be interested in the Paradox Basin.

The UGMS is in the enviable position of being able to study the geologic aspects of the high-level nuclear waste program without having to take a political stand on the issue. At the present time, a great deal more information is being gathered on the region's hydrology and on the characteristics of the salts of the Paradox Formation. As yet, there have been no major geologic indications that the Paradox Basin is an unacceptable site, but it is important to emphasize that some of the most essential geologic information has not yet been gathered and the acceptability of the Gibson Dome site cannot be evaluated until this information has been gathered and evaluated. ■

1980s and geologic work associated with the siting of a nuclear repository has been performed by Woodward-Clyde consultants and the geologists of the USGS. In 1981, the UGMS, as a subcontractor to the Office of Nuclear Waste Isolation (Battelle), reviewed the work of prior researchers, and completed a stratigraphic investigation of several Paradox Basin structures as a means of determining the rates and geologic age of salt induced deformation. It becomes readily apparent that if the salt can be deformed or dissolved by natural means, that a study must be undertaken to determine whether such natural processes are still at work. If nuclear wastes cannot remain suitably isolated for long periods of time because of future or very slow acting natural hazards working upon the salt, then the salt would have to be eliminated from consideration. All previously published stratigraphic sections and released drill hole data were used by the UGMS to construct isopach and structural maps and to plot thickness data for key stratigraphic intervals. Additional sections were measured in the field.

A generalized column of rock strata exposed in the Paradox area is given in Figure 2. If the area were chosen, mining would begin near the top of the Cutler Formation of Permian age and the repository would be placed in Salt 6 of the Pennsylvanian Paradox Formation at depths between 2,500 and 3,500 feet beneath the surface.

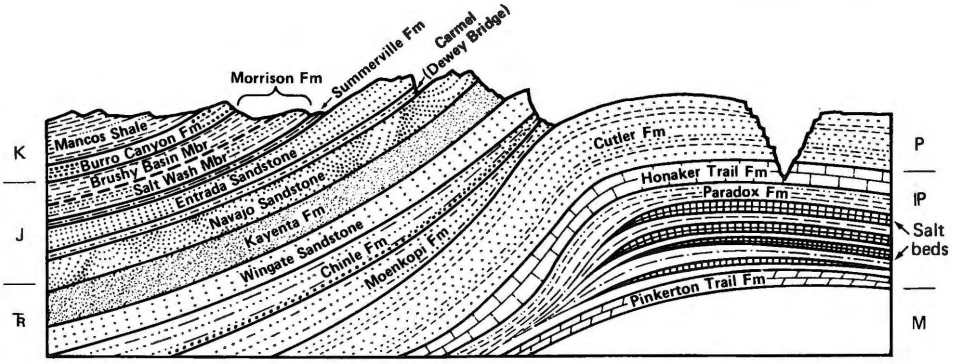

FIGURE 2. Diagrammatic section of rock formations, Paradox Basin area, Utah. Salt sections are thickened under anticlines.

BRIEF, GENERAL GEOLOGIC HISTORY OF THE PARADOX BASIN

The Paradox Basin of southeastern Utah and southwestern Colorado is defined as that geographic area underlain by salts deposited during Middle Pennsylvanian time (the Paradox Formation) (Figure 1). The long axis of the asymmetric basin trends northwesterly. The northeast and east flank of the basin is faulted along the Uncompahgre Uplift segment of the Ancestral Rockies. To the north, west, and south the basin is bordered by more gently dipping flanks.

The basement rocks of the area consist of deformed Precambrian metamorphic and igneous rocks. These rocks are not exposed in the Paradox Basin in Utah but have been described where they outcrop in the Uncompahgre block in Colorado. Tweto (1980) has interpreted these rocks as originally of sedimentary and igneous origin associated with a continental margin. Structural trends such as the northeast/southwest trending Colorado lineament and northwest/southeast-trending Olympic/Wichita lineament have been postulated by Baars (1981) as two major Precambrian rift systems that transect the present basin in the vicinity of Moab, Utah. These rifts resulted in major structural deformation during Precambrian time and may have influenced the region's tectonics since then.

The Early Paleozoic of Utah was dominately a time of marine platform sedimentation. The Paradox area was no exception. From Cambrian to Mississippian time the Paradox Basin area was part of a foreland shelf as marine sequences transgressed from the west. The Leadville (Redwall) Limestone, deposited as a carbonate shelf during Mississippian time, was exposed by uplift in Mississippian or Early Pennsylvanian time. Its deeply weathered soil horizon became the Early Pennsylvanian Molas Formation.

In Early Pennsylvanian time the Ancestral Rocky Mountains began to develop and by Middle Pennsylvanian time the Uncompahgre Uplift was emergent and the Paradox Basin was subsiding along its boundary fault system. The Paradox Basin subsided in excess of 5,000 feet along a series of northwest/southeast trending faults along its northeast margin: Marine incursions from the southwest, followed by periods of dessication, resulted in cyclic evaporite deposits. Twenty-nine cycles of repeated sequences of evaporites, shales, and carbonates form the Paradox Formation (Hite, 1960; 1961) (Figure 3).

During the Late Pennsylvanian and Permian time, erosion of the Uncompahgre Uplift along the northeast margin of the Paradox Basin and transgressions of marine seas from the southeast resulted in intertonguing sedimentary sequences of marine limestones and shales, and continental red/purple arkosic sandstones of the Cutler Formation. During Mesozoic time 8,000 to 10,000 feet of rocks buried the Paleozoic sequences. These sediments were deposited in a variety of environments. In Triassic time there were continental windblown and waterlaid deposits of fluvial and shallow marine origin. Later (Jurassic and Cretaceous time) shoreline/delta sandstone sequences were deposited as inland seas transgressed and regressed from the east and northeast. During the Permian Period and earlier parts of the Mesozoic Era intermittent tectonic activity continued along the northwest-trending faults along which the Paradox Basin had subsided, locally uplifting or downfolding the sediments and subjecting them to erosion and/or slowing or speeding up the rate of sedimentation.

In Late Cretaceous time another episode of basement deformation began. Uplift, subsidence, and volcanism associated with the Laramide Orogeny continued through Middle to Late Eocene time. In the Colorado Plateau that time was characterized by faulting and folding and by igneous intrusions (La Sal Mountains). Regional uplift of the Colorado Plateau followed and continued into Late Miocene/Pliocene time. In Quaternary time erosion continues to cut into the sedimentary sequences and expose the older rock sequences.

ISSUES CONCERNING GEOLOGIC AGE AND THE RATE OF SALT-INDUCED DEFORMATION

The Paradox Basin is characterized by several northwest-trending elongate depressions which are the present ero-

sional expressions of anticlines formed originally by upward flowage of the thick bedded salts along the northwest-trending faults within the basin. Breaching of some of the anticlines allowed the underlying salt to dissolve and resulted in collapse of the overlying sediments. These sediments, exposed in steep scarps along the flanks of the anticlines, record the periods of anticlinal growth, the varying rates of deposition, various erosional events, provide clues for unravelling the tectonic and depositional history of the region. Other sources of information for interpreting the geologic history of the Basin are found in many wells drilled for oil and gas.

Almost all explanations for the formation of salt anticlines in the Paradox Basin involve 1) differential loading on the salt sequences; 2) regional folding and faulting due to tectonic forces; and 3) uplift, erosion and dissolution. However, geologists working in the Paradox have not consistently agreed concerning 1) the relative continuity of salt anticline growth; 2) the time and initiation of salt flowage; 3) the time of cessation of salt flowage; 4) the geologic control of location of salt anticlines; 5) the influence of northeast trending fractures; and 6) the relative age and influence of Colorado River dissection relative to anticlinal growth such as the Meander anticline.

Based on the geologic evidence acquired by prior work of geologists plus additional information from more recent drill holes and measured sections, Doelling (1982) documented the following history of salt movement in the Paradox Basin as UGMS Open-file Report No. 29:

1. Salt was deposited in the Paradox Basin during Pennsylvanian time. The basin was produced as faulting downdropped blocks of Mississippian and older rocks along northwesterly faults. The down-side of each dominant fault was on the northeast side except for the northeast boundary of the basin where the northeast block was adjacent to the Uncompahgre Uplift. Eroded sections from the Uncompahgre intertongued with marine sediments near the uplift. Thicker salt sections are presumed to have laid down immediately adjacent to the faults on the downthrown blocks.

2. After salt deposition ceased (Middle Pennsylvanian time) these evaporites were covered by the carbonates of the Honaker Trail Formation. At the end of Pennsylvanian time, movement of the faults was revived and the trapped salt and other sediments were compressed. The renewed faulting did not reach the surface in most areas and was absorbed by recrystallization, squeezing, and folding in the thicker salt sequences. The greatest pressure relief was achieved along the downthrown blocks adjacent to the faulting to which squeezed salt migrated. Areas between the faults developed into synclines. The steepest dips of the folding were formed over the deep faults.

3. The Cutler Permian Formation developed as a large fan across the southwest flank of the Uncompahgre Uplift. The formation's thickness and sediment's grain size appear to be controlled by distance from the Uncompahgre Uplift; sediments are finer and thin southwestward. Farther to the southwest the Permian continental and marine beds intertongue with the Cutler and is more uniform in thickness. At the end of Permian time deposition ceased and structural activity was resumed along the Mississippian faults and the Uncompahgre Uplift. The synclines deep and salt was squeezed into the anticlinal areas. In the areas of the Cutler fan the form of the anticlines were narrower and more parallel to the dominant Mississippian faults. Anticlines to the southwest were gentler and broader. Anticlines were uplifted and subjected to erosion. The Cutler may have been completely removed locally and the Paradox Formation exposed to erosion and solution.

4. The Triassic Moenkopi Formation began to be deposited after the upper parts of the Cutler Formation had been eroded. Some areas of the Moenkopi depositional basin received thicker than normal sedimentation, such as on both sides of the Salt Valley anticline and along the northeasterly trending axis subparallel to the Roberts lineament of Hite (1975). It has not been proven whether this greater subsidence occurred because of salt movement although it is assumed that anticlinal areas gained in salt at the expense of the synclinal areas. Thick Moenkopi may have been deposited over much of the Salt Valley anticline as well as over the east end of Cache Valley and the north end of Castle Valley. A bed of evaporites is present in the Moenkopi in these areas.

Although incomplete, stratigraphic and lithologic work on the Moenkopi

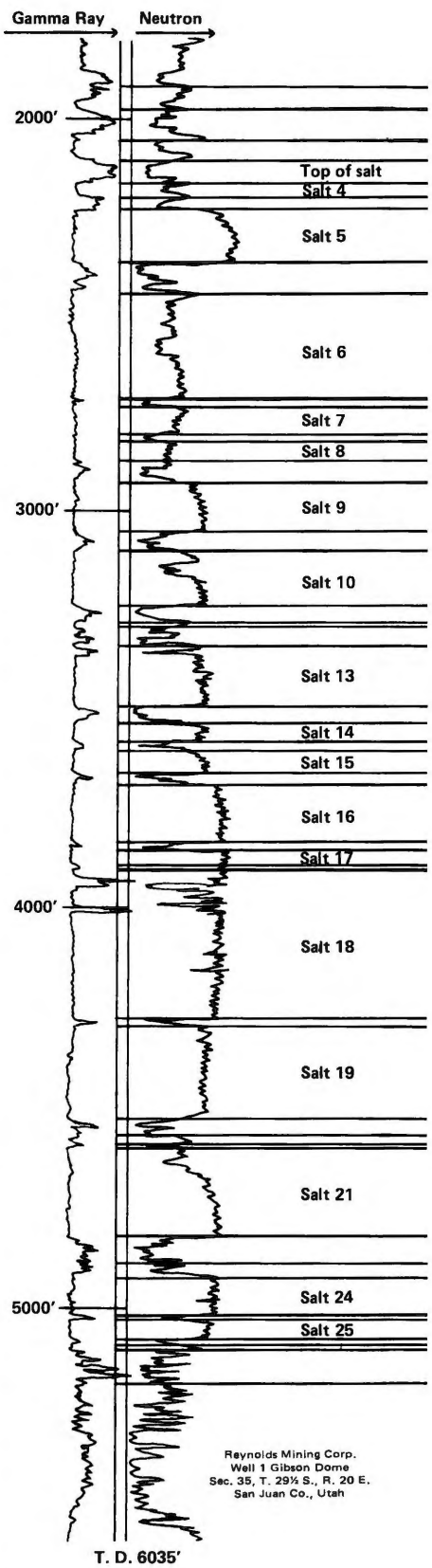

FIGURE 3. Salt cycles in the Paradox Formation. Proposed siting of nuclear waste is at Salt 6 level (apr. 2500-3500 feet below surface).

Formation verifies depositional thickening in the aforementioned areas. At the end of Moenkopi deposition the area again was subjected to deformation based on movements of basement faults. Missing and thin Moenkopi sections over anticlinal areas are principally due to erosion rather than diminution of sedimentation. As with previous episodes of deformation, the synclines deepened forcing more salt into the anticlines. This erosional episode may also have removed more of the underlying Cutler and Hermosa formations. In some of the anticlines, the Paradox Formation became exposed and some of the salt removed by solution. During the post-Moenkopi period of activity the steepest parts of the limbs in the area of thick Cutler Formation were even more steeply folded and faulting probably occurred close to the salt, dying out upward in the Moenkopi sequences. The anticlines continued to be held to narrow-elongate configurations in the thick Cutler areas and were broader and more irregular to the southwest.

5. The Triassic Chinle Formation was unconformably deposited on the irregular topography of the Moenkopi Formation and other underlying units, including the Paradox Formation. The many irregularities in its thickness indicate not only that the underlying surface had some relief but that differential irregular subsidence continued. Thicker Chinle sections east and west of the Salt Valley Anticline and near Mat Martin Point along the Colorado River show that the subsidence that occurred during Moenkopi time persisted into Chinle time. The unit is thinner over the other anticlines and there is evidence of local unconformity and penecontemporaneous deformation along the axial areas of the anticlines. Salt movement continued during Chinle deposition, but at a diminishing rate. The eroded surface of the Uncompahgre Uplift began to receive sediments as did the area southeast of the boundary fault. Only locally can it be definitely demonstrated that the Chinle was either never deposited or completely removed by erosion.

6. The Triassic Wingate Sandstone was deposited over the Chinle and covered most of the anticlinal areas. There is evidence, however, that limited continuation of salt movement occurred. Areas of thicker Moenkopi and Chinle formations appear to be areas of thicker Wingate deposition. The Wingate is slightly thinner over the axial areas of several anticlines and missing over some salt plugs due to reduced sedimentation.

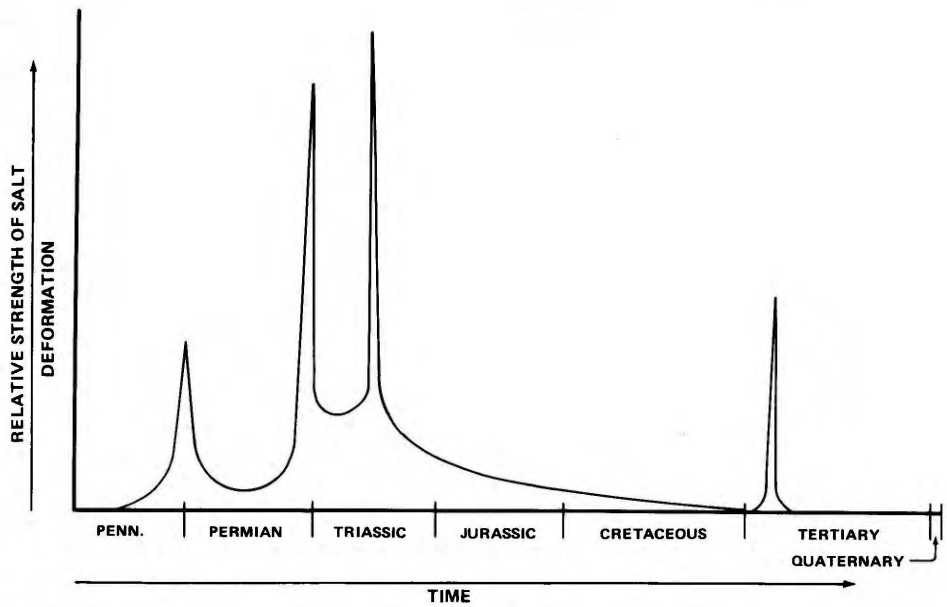

FIGURE 4. Relative strength of salt deformation activity as related to geologic time. Compressive stresses generated by the formation of the Paradox Basin and uplift of the Uncompahgre Highland were gradually relieved by salt movement and ended at the end of Cretaceous time. Renewed tectonic activity during Early Tertiary time did not create any new lasting compressive stresses to affect the area beyond that time. The end of salt movement by compression may also be related to the exhaustion of salt under the synclinal areas. With the differential loading theory, the movement of salt is continuous until the salt under the synclinal areas has been exhausted.

7. Normal thicknesses of the Triassic Kayenta to Jurassic Morrison formations seem to have been deposited over most areas of the region. Minor salt deformation, related to salt, occurred along the axial parts of the more prominent anticlines. This deformation, though minor, has been substantiated by missing or thin intervals in holes over salt plugs.

8. Salt movement may have been negligible during the Cretaceous. Cretaceous units, even in the collapsed areas along the axial parts of the prominent anticlines, show little or no thinning. Although minor thinning over some of the anticlines has not been ruled out, it has not been substantiated.

9. Tectonic activity again became pronounced in Late Cretaceous or Early Tertiary time and intrusive activity was superimposed into the Paradox Fold and Fault belt. The effect of the activity was the same as that which occurred at the end of Pennsylvanian, Permian, and Moenkopi time. The synclines were deepened and the anticlines were refashioned. During the episode, the salt sequences were folded and faulted with the other formations, and did not act independently. Any squeezing was probably local in its extent. Deposition ceased as the area began to be uplifted and eroded. Increased ground water activity may have accompanied the intrusion of the La Sal area and instigated collapse along some of the structures (Cater, 1970; 1972).

10. Intermittent and perhaps continued epeirogenic uplift has affected the area after the tectonic activity subsided. The Ancestral Colorado River and its tributaries began to erode the area. Uplift was accompanied by ground water activity which was undoubtedly most pronounced during the Late Tertiary and Pleistocene ice ages, dissolving the salt relatively near the surface and overlying units collapsed into the created voids.

Such collapse normally begins close to the major through-going stream, the Colorado River, and then migrates toward the source of the water. Collapse has occurred only on the south side of the Colorado River along the Moab salt structure perhaps because there was no source of ground water from the north. The source of ground water for much of the area was the La Sal Mountains. The source of ground water for the collapse at

the northern end of Salt Valley was the Book Cliffs. The collapse at Cache Valley is a little more difficult to explain, but may be related to Onion Creek and a ground water course beneath the river. Discharge of the salty waters may have occurred along northeast-trending faults to the Colorado River downstream. Ground water associated with the dissolution of Lockhart Basin possibly entered the Colorado River along northeast-trending faults (Colorado lineament). Such flow paths and processes are not at all obvious and have not been investigated in detail. The collapse along the Needles suggests a rather broad area of ground water discharge toward the Colorado River which may have been relatively recent (Pleistocene). The course of the Colorado River appears to follow zones of weakness created by the northeastward-trending lineaments as does the axis of the Meander anticline.

These geologic explanations are not shared by all. Other mechanisms for the creation of the Needles grabens include gravitational sliding (Huntoon, 1977) and salt flowage (McGill and Stromquist, 1975). Solution of the salt in the anticlinal areas and in other areas of collapse is undoubtedly minimal today considering the present relatively dry climate of the region.

CONCLUSIONS

Movement and deformation of salt in the Paradox Formation in the Paradox Basin has been irregular through its geologic history. The formation of the northwest-trending anticlines and synclines appears to have begun shortly after the deposition of the salt, being accelerated from time to time by increased tectonic activity. It is believed that slightly thicker salt and sediment were deposited along the downthrown side of the faults that formed the basin and Uncompahgre Uplift and became the loci of the future salt anticlines. Intermittent, renewed tectonic activity along these faults, such as at the end of the Pennsylvanian and Permian Periods, and after the deposition of the Moenkopi Formation, formed synclines between the faults, squeezing salt to the anticlinal areas to areas of pressure relief above the faults. Sedimentary loading can also be considered a mechanism for squeezing salt to the anticlinal areas, but cannot be verified. Thicker sediments are not present in all of the synclinal areas. However, truncation of sediments over the anticlines, so as to produce angular unconformities at specific "point-in-time" intervals, seems to favor fault induced tectonic activity.

Salt deformation continued from Moenkopi time to Morrison time, but was pronounced only in the pre-Chinle interval. Most of the stresses developed by the basining of the Paradox region had been relieved by Cretaceous time. Post-Chinle salt deformation is best explained by sedimentary loading or a general easing of fault movements in the basement. The rate of deformation was very slow and diminished with time thereafter. The deformation may have ceased entirely by the end of the Mesozoic, only to be revived again by Late Cretaceous or Early Tertiary tectonic activity (Cater, 1972). The anticlines and synclines were steepened or deepened and faulting occurred. Attitudes of all of the sedimentary strata deposited through the Tertiary were changed. It is thought that the salt behaved like its encasing strata at this time, however, and was not squeezed as "toothpaste," except locally. Epeirogenic uplift of the region during the Tertiary uplifted the salt sequences and ground water solution began to take place and caused collapse in selected areas, notably close to the surface and especially along the anticlines (Figure 4).

Stresses that would cause salt to migrate by squeezing or recrystallization are probably not present today and such salt movement has probably ceased. Solution of salt is more likely at this time, although greatly diminished when compared with Late Tertiary and Pleistocene time when wet climates prevailed.

REFERENCES CITED

Baars, D. L., 1962, Permian system of the Colorado Plateau: American Assoc. Petroleum Geol. Bulletin v. 46, No. 2, p. 149-218.

Baker, A.A., 1933, Geology and oil possibilities of the Moab district, Grand and San Juan counties, Utah: U. S. Geological Survey Bulletin 841.

Case, J. E., H. R., Joesting and P. E. Byerly, 1963, Regional geophysical investigations in the La Sal Mountains area, Utah and Colorado: U. S. Geological Survey Professional Paper 316-F.

Cater, F. W., 1970, Geology of the Salt Anticline region in southwestern Colorado: U. S. Geological Survey Professional Paper 637.

Cater, F. W., 1972, Salt anticlines within the Paradox Basin, *in* Geologic Atlas of the Rocky Mountain Region, United States of America: Rocky Mountain Assoc. of Geol., p. 137-138.

Dane, C. H., 1935, Geology of Salt Valley anticline and adjacent areas, Grand Co., Utah: U. S. Geoloigical Survey Bulletin 863.

Doelling, H. H., 1982, Stratigraphic investigations of Paradox Basin structures as a means of determining the rates and geologic age of salt-induced deformation. A preliminary Study: Utah Geological and Mineral Survey Open-file Report No. 29.

Harrison, T. S., 1927, Colorado - Utah salt domes: American Assoc. Petroleum Geol. Bulletin 11, p. 111-133.

Hite, R. J., 1975, An unusual northeast-trending fracture zone and its relations to basement wrench faulting in northern Paradox Basin, Utah in Colorado: Four Corners Geological Society GB, 8th Field Conference, p. 217-223.

Huntoon, P. W., 1977, The hydrogeologic feasibility of developing ground-water supplies in the northern part of Canyonlands National Park and Bridges National Monument, Utah: Wyoming Water Resources Research Institute and Dept. of Geology, University of Wyoming, 24 p.,

McGill, G. E. and A. W. Stromquist, 1975, Origin of graben in the Needles district, Canyonlands National Park, Utah, *in* Canyonlands country: Four Corners Geological Society, 8th Field Conference, p. 235-243.

McKnight, E. T., 1940, Geology of area between Green and Colorado rivers, Grand and San Juan counties, Utah: U. S. Geological Survey Bulletin 908.

Prommel, H. W. and H. E. Crum, 1927, Salt domes of Permian and Pennsylvanian age in southeastern Utah and this influence on oil accumulation: American Association Petroleum Geol. Bulletin 11, p. 373-393.

Shoemaker, E. M., 1954, Structural features of southeastern Utah and adjacent parts of Colorado, New Mexico and Arizona: Utah Geological Society GB, 9th Field Conference, p. 48-69.

Shoemaker, E. M., J. P., Case, and D. P. Elston, 1958, Salt anticlines of the Paradox Basin: Interm. Assoc. Petroleum Geol. GB, 9th Field Conference, p. 39-59.

Stokes, W. L. and D. A. Phoenix, 1948, Geology of Egnar-Gypsum Valley area, San Miguel and Montrose counties, Colorado: U. S. Geological Survey Map OM-93.

Stokes, W.L., 1948, Geology of the Utah-Colorado salt dome region with emphasis on Gypsum Valley, Colorado: Utah Geological Society GB, 3rd Field Conference.

Stokes, W. L., 1952, Lower Cretaceous in Colorado Plateau: American Assoc. Petroleum Geol. Bulletin v. 36, No. 9, p. 1766-1776.

Szabo E. and S. A. Wengerd, 1975, Stratigraphy and tectogenesis of the Paradox Basin: Four Corners Geological Society GB, 8th Field Conference, p. 193-210.

Tweto, Ogden, 1980, Precambrian geology of Colorado: *in* Colorado Geology, ed. Kent and Porter, Rocky Mountain Association Geologist, p. 37-46. ■

Mineral Resources of the Paradox Basin of Utah

By MARTHA RYDER SMITH

Minerals produced or present in the Paradox Basin of Utah include oil and gas, uranium, vanadium, potash, copper, gold, silver, manganese, gypsum, iron, gem stones, and coal. In addition, there are large resources of dimension stone, limestone, sand and gravel, and clay.

OIL AND GAS

The first oil production in the Paradox Basin area was from the Mexican Hat field, discovered in 1907 and producing up to the present time from the Pennsylvanian Hermosa sandstones. The Aneth field was the first major discovery, in 1956; the Lisbon field was found in 1960 (Figure 1). Many other small fields have been located, but their production has been relatively small. The total cumulative production from the Paradox Basin area through 1980 is about 396 million barrels of oil and 720 million mcf of gas.

No oil has been found in the Cambrian rocks. Silurian and Ordovician rocks are missing in the area. Devonian rocks normally have a very low porosity, but there has been some Devonian production in the Lisbon field. Major production in the Basin area is from the Mississippian Leadville Formation, from a porous dolomite; the oil-bearing structures have no surface expression but parallel the salt anticlines of the overlying Paradox salt.

Pennsylvanian production is principally from the carbonates of the Hermosa Group. At the base of this group is the marginal limestone and shale of the Pinkerton Trail Formation; overlying this is the cyclic evaporite series of the Paradox Formation. Drilling in the salt anticlines has found numerous small fields in the Paradox Formation (Figure 2), but this formation lacks suitable reservoir rocks for large production. Only one well, at the Long Canyon field, discovered in 1962, has had sustained production, totalling 780,000 barrels by the end of 1980 from within the salt unit.

The salts are in turn overlain by the carbonate bioclastic sediments of the Hermosa Group Honaker Trail Formation, which includes the algal reef host rock of the Aneth field and the Lisbon field. Total production from the Greater Aneth field, discovered in 1956, had 499 producing wells in 1980 and total cumulative production of 306 million barrels of oil and 294 million mcf of gas. The Lisbon field, discovered in 1960, had 13 wells producing in 1980 and total cumulative production of 43 million barrels of oil and 358 million mcf of natural gas. Small amounts of oil and gas have also been produced from the upper carbonates in the central and northern part of the Basin.

Some gas shows have been found in the overlying Permian Cutler Formation. Tar sands in Permian and Triassic sediments are found a few miles to the west of the Paradox Basin area. Shows of oil and gas have also been found in Jurassic continental sediments.

URANIUM AND VANADIUM

Uranium ore (carnotite) was known in the Colorado Plateau before the arrival of the settlers, and was mined primarily for radium and vanadium after 1880. After 1945, with the beginning of the atomic age, uranium became the more valuable mineral. Production continued high until about 1958; then slowed until commercial use of uranium for producing nuclear power became feasible. Production increased until 1980; then reduced demand for electricity and fear that the nuclear power plants might be unsafe, as well as the availability of cheaper sources of uranium from foreign markets, caused prices to fall. At this time the uranium mining industry is very depressed in the Paradox Basin area.

Uranium has been found in nearly every exposed geologic formation in the Paradox Basin area, but the most important production has been from the Permian Cutler Formation, the Triassic Chinle Formation, and the Jurassic Morrison Formation. There are two major producing areas in the Paradox Basin in Utah: The Big Indian mining district, in the Lisbon Valley anticline, and the Uravan Mineral belt, which extends from southeastern Utah into Colorado (Figure 1). These districts together have produced more than 150 million pounds of uranium oxide in Utah, most of it from the Big Indian district. More than 500 uranium occurrences have been located in the Paradox Basin of Utah. To the west of the La Sal and Abajo mountains important production is from the base of the Chinle, in buried stream channels, and to the east, from the Salt Wash and Brushy Basin members of the Morrison Formation. The vanadium content in this area is about 50 percent greater than that of the uranium.

POTASH

Potash was first discovered in the Paradox Formation in 1924, in wells drilled for oil. The potash is found in the area between Green River, Utah and Cortez, Colorado, and between Monticello on the south and the Uncompahgre Uplift to the northeast. It was first developed in an underground mine at Cane Creek southwest of Moab, but underground mining was later converted to solution mining because of problems with methane gas in the mine.

Eleven of the 29 evaporite cycles of the Paradox Formation contain potentially valuable deposits of potash salts. Depth to the potash zones ranges from a few hundred feet in the piercement salt structures to several thousand feet in deeper parts of the basin. The principal minerals are sylvite (KCl) and carnellite ($K{\cdot}MgCl{\cdot}6H_2O$). Estimated reserves are 254 million tons of known potash and 161 million tons of inferred ore.

COPPER, GOLD, AND SILVER

Several occurrences of copper are found in the Paradox Basin in the Salt Valley Anticline, the Lisbon Valley area, and in the Abajo and La Sal mountains. None are being actively mined at the present time.

Several mines produced copper and silver from the Salt Wash and Burro Canyon members of the Morrison Formation of Jurassic age in the Salt Valley anticline. One of these mines is reported to have produced 100,000 ounces of silver and $20,000 worth of copper between 1900 and 1930. A copper leach operation was begun on the southwest flank of the anticline in the early 1970s but proved uneconomic and is now shut

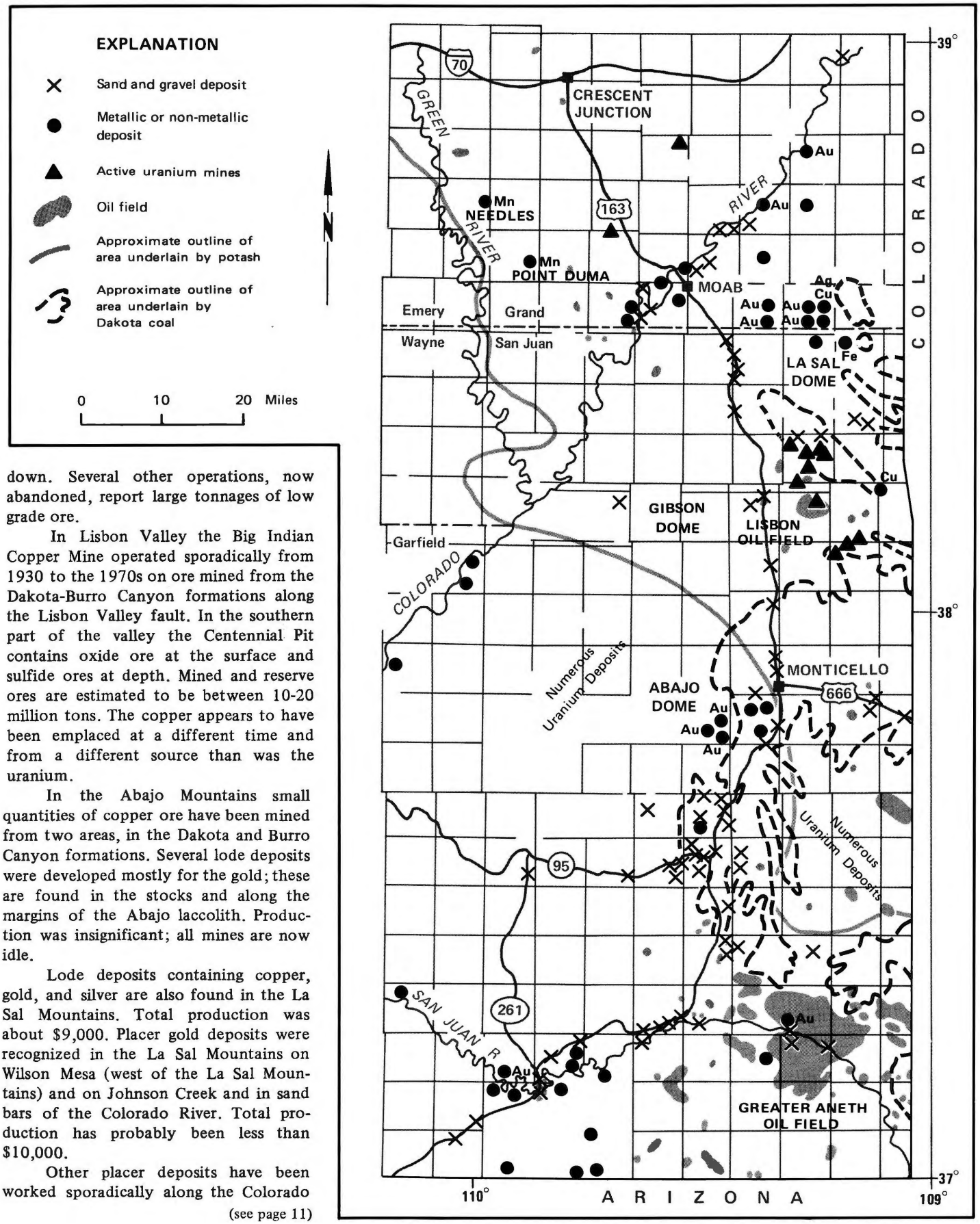

FIGURE 1. Economic deposits in the Paradox Basin area, southeastern Utah.

down. Several other operations, now abandoned, report large tonnages of low grade ore.

In Lisbon Valley the Big Indian Copper Mine operated sporadically from 1930 to the 1970s on ore mined from the Dakota-Burro Canyon formations along the Lisbon Valley fault. In the southern part of the valley the Centennial Pit contains oxide ore at the surface and sulfide ores at depth. Mined and reserve ores are estimated to be between 10-20 million tons. The copper appears to have been emplaced at a different time and from a different source than was the uranium.

In the Abajo Mountains small quantities of copper ore have been mined from two areas, in the Dakota and Burro Canyon formations. Several lode deposits were developed mostly for the gold; these are found in the stocks and along the margins of the Abajo laccolith. Production was insignificant; all mines are now idle.

Lode deposits containing copper, gold, and silver are also found in the La Sal Mountains. Total production was about $9,000. Placer gold deposits were recognized in the La Sal Mountains on Wilson Mesa (west of the La Sal Mountains) and on Johnson Creek and in sand bars of the Colorado River. Total production has probably been less than $10,000.

Other placer deposits have been worked sporadically along the Colorado

(see page 11)

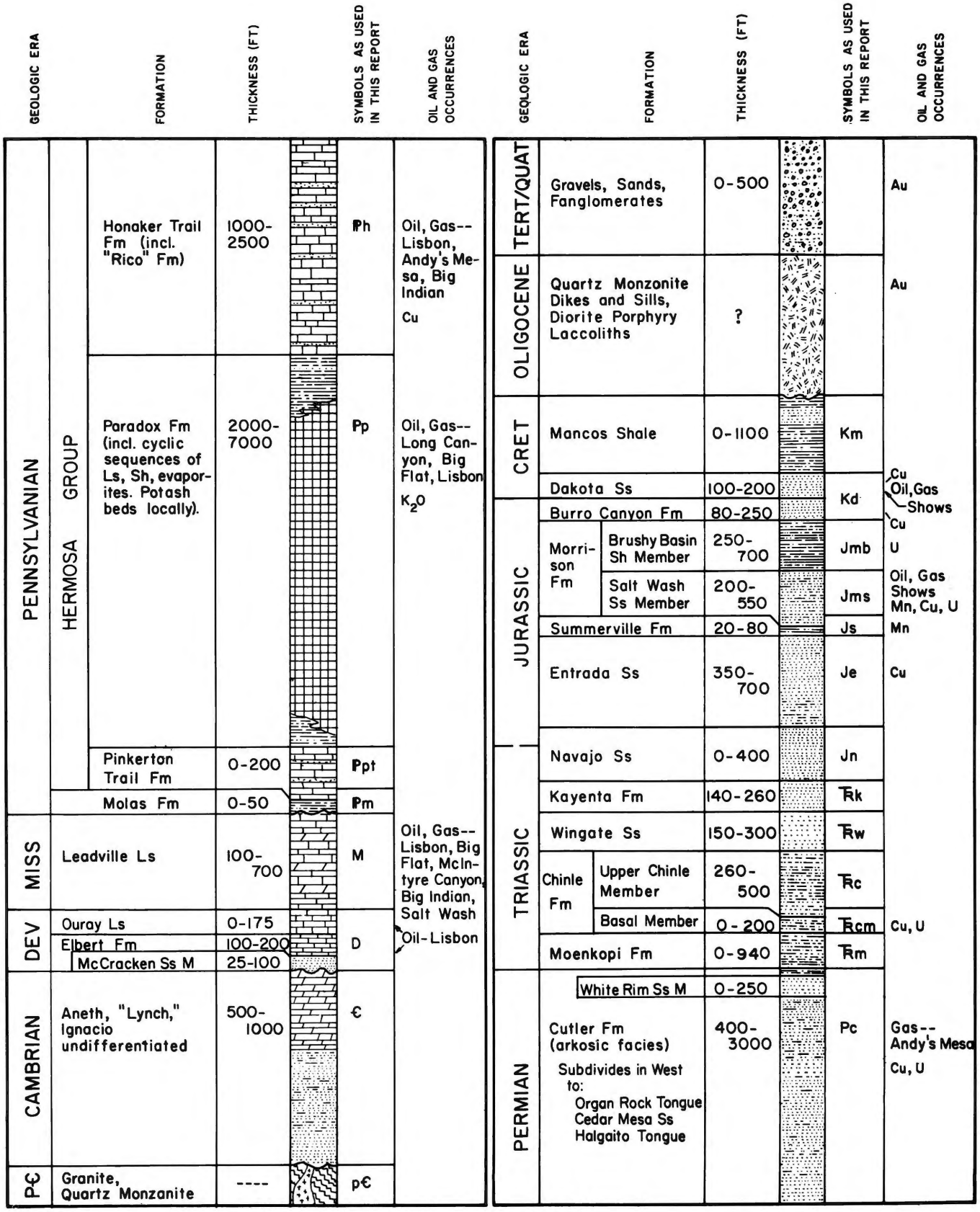

FIGURE 2. Stratigraphic section of Paradox Fold and Fault Belt.

("Mineral Resources" cont. from page 9)
River, north and south of Moab, and at the confluence of the Dolores and the Colorado rivers. The gold is very fine (flour gold) and is difficult to recover. Potential production appears to be limited.

MANGANESE

Manganese has been produced from two areas in the Paradox Basin, in the Needles district and the Point Dumas areas (Figure 1). Total tonnage produced from shallow open pits was between 12 and 16 thousand tons of 4 to 40 percent Mn. The ore is in stratified deposits of the Summerville Formation and the Salt Wash Member of the Morrison. Several hundred thousand tons of ore containing 10 percent or less Mn are estimated to remain.

IRON

Small iron deposits are found in the La Sal Mountains and north of Shooter Peak in the Gibson Dome area. The potential in both areas is very small and of poor quality.

GEMSTONES

Agate, jasper, amethyst, azurite, as well as petrified wood and dinosaur bones have been collected in the Paradox Basin. Agate and jasper are found in many formations. Azurite is found along the Lisbon Valley fault near La Sal, in the Dakota Sandstone as a coating in fractures in the rock. Petrified wood and dinosaur bones are found in the Chinle and Morrison formations.

COAL

Coal is widely distributed in the Cretaceous Dakota sandstone, from the Abajo to the La Sal mountains and eastward to the Uncompahgre Uplift in Colorado. Coal outcrops are found at many places, in flat-lying mesas, but the coal beds are thin and discontinuous and of relatively poor quality (high ash and high sulfur). There is little potential for important production.

GYPSUM

Thick beds of gypsum are found in outcrops of the Paradox Formation along the Colorado River and in the centers of the collapsed anticlines. Although present in commercial quantity and quality, none has been commercially mined.

STONE, LIMESTONE, SAND, GRAVEL, AND CLAY

Large resources of stone, sand and gravel are present in the Paradox Basin, but because of its location little has been commercially developed. Sandstone is quarried near Moab and Blanding for local use. Good quality dimension stone could be quarried from the Morrison, Kayenta, Chinle, Shinerump, and Moenkopi formations. Quaternary alluvium, produced along major streams and their tributaries, provides material for road construction. Dune sands are found in many areas near the eroding sandstone formations, and glacial deposits are present in the La Sal Mountains. Rock slides and boulder fields, plentiful in both the Abajo and La Sal mountains, are potential sources for riprap material. Clay deposits can certainly be found in the Morrison, Dakota and Mancos formations, and sources of bloating clay can be found in the bentonitic members of the Chinle Formation. As far as known, these clays have not been adequately tested.

REFERENCES

Ritzma, H. R. and Doelling, H. H., 1969, *Mineral Resources, San Juan Co., Utah, and Adjacent Areas,* UGMS Special Studies 24, Parts I and II.

Merrell, H. W. and others, 1979, *Mineral Resource Inventory of the Paradox Salt Basin, Utah and Colorado,* UGMS Report of Investigation 143.

Smith, M. R. and Brown, K. W., 1981, *Utah Mineral Industry Activity Review and Summary of Oil and Gas Drilling and Production, 1980,* UGMS Circular 71.

Hilpert, L. S., ed., *Mineral and Water Resources of Utah,* 1964, UGMS Bulletin 73. ■

CHARLESTON THRUST SHEET TO BE PUNCTURED BY PLACID

A test well, the first to penetrate the Charleston Thrust sheet, has been spudded by Placid Oil at its No. 1 Daniels Land "wildcat" in western Wasatch County. The well is in NW¼ NW¼ section 11, T. 5 S., R. 5E., about 1.5 miles south of U. S. 40 in Daniels Canyon and 8 miles (straightline) southeast of Heber City.

The test will penetrate several thousand feet of Oquirrh Formation quartzite on the thrust sheet and then enter the "Great Unknown". Guesses of what lies beneath the thrust sheet range from Tertiary formations of the western Uinta Basin to Jurassic formations. The Charleston Thrust, which is rooted beneath Mt. Timpanogos, has moved west to east thrusting older formations of central Utah as much as 30 miles over the western margin of the Uinta Basin. The well is projected to a depth of 22,000 feet. ■

NEW PUBLICATIONS

From Utah Geological & Mineral Survey:

- ***Proceedings, Fifth Symposium on the Geology of Rocky Mountain Coal, 1982,*** edited by Klaus D. Gurgel, UGMS Bulletin 118, May 1982, 319 p., x, 34 tecnnical papers, numerous figs., tables and road logs for 2-day field trip; price is $20.00 over-the-counter.
- ***Preliminary Geologic Map of the Laketown Quadrangle, Rich County, Utah,*** by Gerard L. Valenti, June 1982, scale 1:24,000 (28" x 34"), 9 p. text, in envelope; price is $7.50 over-the-counter.
- ***Preliminary Geologic Map of the Joes Valley Reservoir Quadrangle, Sanpete and Emery counties, Utah,*** by John M. Kitzmiller II, July 1982, scale 1:24,000 (28" x 34"), two-colors, 6 p. text, in envelope; price is $7.50 over-the-counter.

From the University of Utah Seismograph Stations:

- ***Earthquake Data for the Utah Region, July 1, 1978 to December 31, 1980,*** by William D. Richins, *et al*, October 1981, UUSS Special Publication, 127 p., spiral bound; available from UGMS sales office for $7.50 over-the-counter.

From Utah Geological Association:

- ***Overthrust Belt of Utah, 1982 Symposium and Field Conference,*** edited by Dennis L. Nielson, UGA Publication 10, 335 p., x, 24 technical papers, numerous figs., tables and road logs for 3-day field trip; price is $45.00 over-the-counter.

Orders must be pre-paid. Postage rates: Orders less than $10.00, add $1.50; $10.00 - 24.00, add $3.00; $25.00 - $100.00, add $5.00; more than $100.00, add $10.00; add $1.50 for tube for rolled map (maximum of four map sheets per tube). ■

LARGEST HISTORIC SALT LAKE COUNTY EARTH FLOW

A 150,000 cubic yard landslide occurred on the east bench of Salt Lake City on Sunday afternoon, May 9, taking out 400 feet of paved road leading to the Holladay Gun Club (Figure 1). Fine to coarse, unconsolidated Lake Bonneville sediment and pre-Bonneville glacial outwash deposits failed in the landslide. The failure occurred during a three-hour rain and snow storm that dropped 0.4 inches of moisture at a nearby weather station in Big Cottonwood Canyon.

UGMS Hazards Section personnel, Bruce N. Kaliser and William F. Case, arrived on the site early Monday. The slide area was particularly hazardous with soft, saturated sediments, asphalt road overhangs, considerable relief, and unstable headwalls. Perched groundwater flows aggregating over 1½ second-feet discharged from the slide walls but diminished somewhat with time.

With the cooperation of the Salt Lake City Water Department, UGMS introduced fluoroscene dye into a "sink" in the Dry Hollow drainage, approximately 1,700 feet upgradient from the slide in an attempt to determine the source of water in the slide area.

Vertical relief on the slide's headwalls averages 45 feet. Fortunately for the county public works and residents, a retention basin existed immediately downslope from the slide in the form of an operating gravel pit. Resulting damage to the gravel pit alone however, measured in excess of one million dollars because several pieces of extraction equipment were buried in debris. The water discharge has been diverted into the storm sewer system.

The slide occurrence proves to be particularly timely for UGMS's Earthquake Microzonation Program which is currently active in Salt Lake County. Though not earthquake triggered, this earth failure may have significant repercussions on the slope stability element of the geologic hazards mapping of the county and perhaps the Wasatch Front.

It appears that the earth flow occurred because greater than normal snowmelt and precipitation accumulated in Lake Bonneville sediments resulting in a loss of shear strength. (For details concerning this occurence, *see* UGMS Report of Investigation No. 173, forthcoming October 1982). ■

MILK POND DAM FAILURE

A small earth dam broke on June 23 in Big Cottonwood Canyon, Salt Lake County, at elevation 8780 feet (see map below). Cause of the failure has been determined to be blockage of the 6-inch outlet pipe by insertion of a log which allowed the crest to be overtopped and the embankment breached. The failure occurred just before 5:00 p.m.

The state's Division of Comprehensive Emergency Management immediately notified Bruce N. Kaliser, Chief of UGMS's Hazards Section, who reported to the site vicinity to meet with emergency response officials. He accompanied the State Engineer's Office of Dam Safety engineer, county and state comprehensive emergency management personnel, and U. S. Forest Service officials in the field that evening and the following morning.

Situated in glacial terrain in Mill F South Fork, the 15 acre-foot Milk Pond Reservoir filled from this year's above-average snowfall and the week's heavy rainfalls. The breach in the earth embankment occurred in its center. Damage was confined to erosion of terrain, including one ski run, and heavy impact on water quality in a watershed which serves the metropolitan area with culinary water.

UGMS's reconnaissance of the failure revealed a landslide 75 feet in length, with up to 4 feet of headwall exposed, on the west bank of the reservoir, just below the high water mark. From the appearance of the morphology of the slide, it appears that the failure resulted from the rapid drawdown of the reservoir at the time of the dam breach rather than subaqueously into the high reservoir.

The significant downstream erosion of private, resort-owned property will require considerable grading and channel stabilization work.

A check of the larger, glacial cirque-situated Lake Solitude Reservoir, some 1300 feet to the south and 280 feet higher in elevation, revealed no problems. On Thursday, July 8th, however, an alarm did go out when workers, on clearing trees and brush from the embankment, observed what they believed to be excessive embankment leakage. In fact, the discharge has remained the same, only previously it was less conspicuous.

Because neither embankment structure is registered with the state Office of Dam Safety, construction records could not be found. The field reconnaissance located a third earthen structure between Milk Pond and Lake Solitude, one that had apparently been breached many years earlier.

The Hazards Section of UGMS is currently developing a methodology for inundation mapping so that the hazard from impoundment failures can be depicted in Earthquake Microzonation Program maps. Also, Salt Lake County is the geographic region currently undergoing microzonation mapping in Utah by UGMS. ■

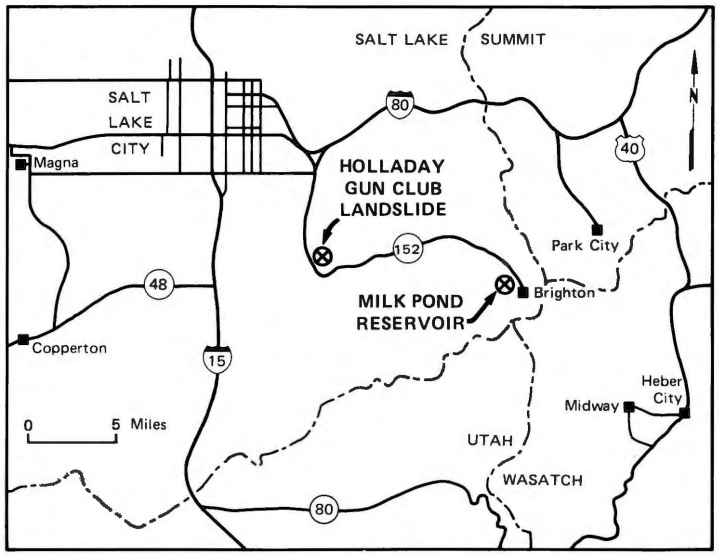

FIGURE 1. Location map showing Holladay Gun Club and Milk Pond Dam site.

Utah Earthquake Activity

By WILLIAM D. RICHINS

The University of Utah Seismograph Stations records a seismic network monitoring local earthquake activity within Utah, southeastern Idaho and western Wyoming. At the end of 1980, an on-line computer facility became operational providing digital central recording of 60 stations. Beginning with this issue of *Survey Notes*, the Seismograph Stations will provide a brief summary and map of earthquake activity within the Utah region on a quarterly basis.

During January to March 1982, 92 earthquakes were located within Utah (Figure 1). The two largest events were apparently associated with the southern Sevier fault near Glendale (20 miles north of Kanab), on February 12 at 3:44 AM and March 4 at 10:50 PM with magnitudes of 3.6 and 3.7, respectively. No felt reports were received. A smaller earthquake 20 miles west of Kanab on the Arizona border on January 7 at 9:21 AM (magnitude of 2.6) was felt in Colorado City, Arizona.

Earthquakes during 1981 are shown in Figure 2, a total of 659 events. Significant earthquake activity included a swarm sequence near Kanaraville (15 miles south of Cedar City), two felt earthquakes near Orem, and considerable activity within Hansel Valley and surrounding areas north of Great Salt Lake. The most significant earthquakes during 1981 occured on February 20 near Orem (magnitude 3.9) and on April 5 south of Cedar City (magnitude 4.5).

On May 24, 1982 at 6:14 AM, a moderate earthquake of magnitude 4.0 was widely felt by residents of Richfield and surrounding communities. The earthquake was located approximately 3 miles southeast of Richfield near Annabella. The Richfield area has been one of Utah's most seismicially active in historic time including a magnitude 6.5 earthquake in 1901 and two magnitude 6 shocks in 1921. Researchers from the University of Utah Seismograph Stations operated 9 portable instruments for eight days in the epicentral region to monitor aftershock activity. Approximately 230 locatable events were recorded, apparently associated with the Sevier fault on the east side of Sevier Valley. Preliminary results will be available late this summer.

Additional information on earthquake data within Utah are available by contacting the University of Utah Seismograph Stations, Salt Lake City, Utah 84112. ■

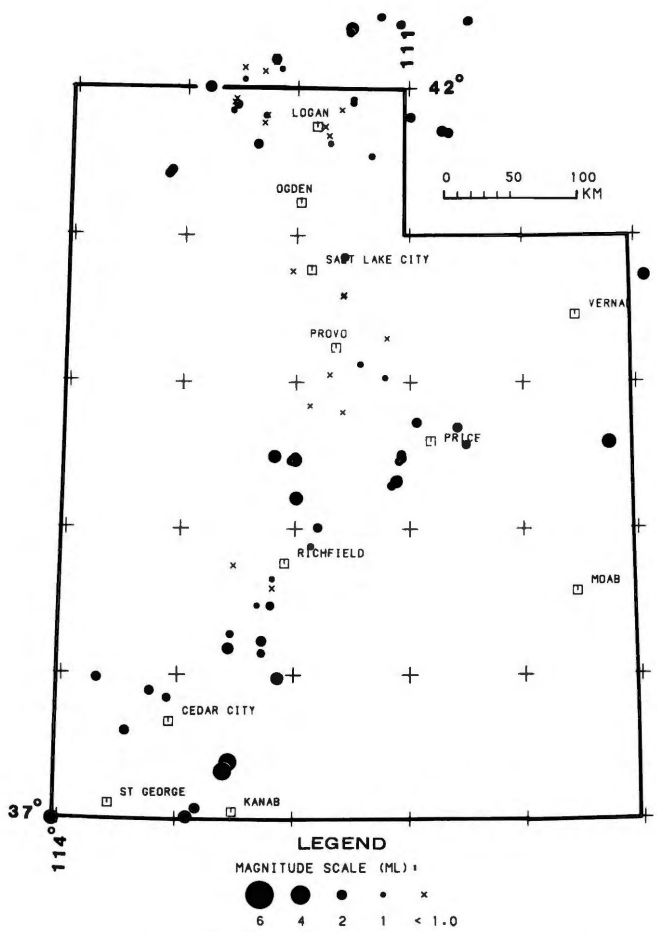

FIGURE 1. Utah earthquakes, January - March 1982.

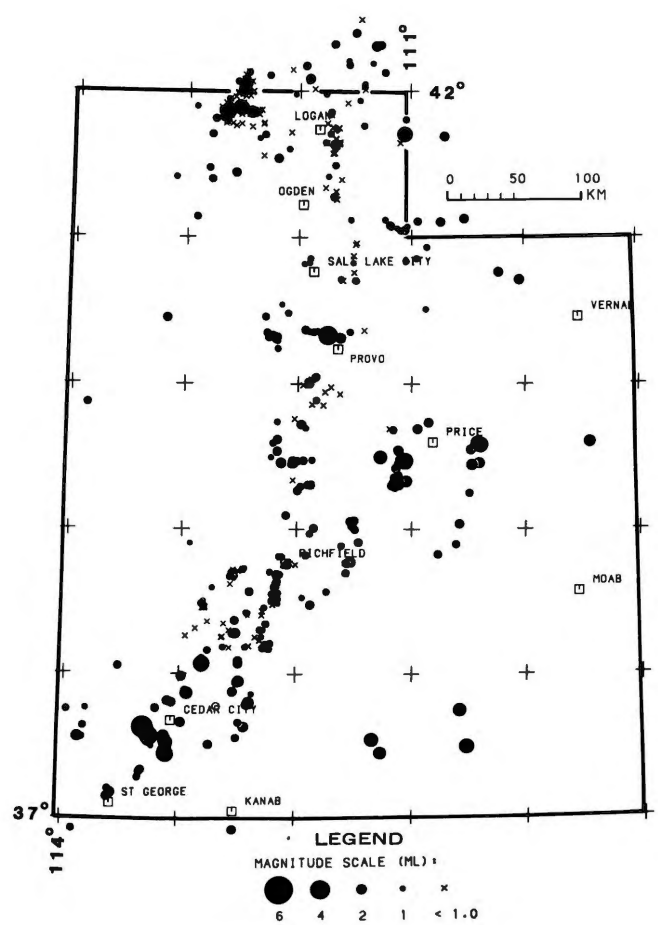

FIGURE 2. Utah earthquakes, 1981.

Buried Fuel Tanks

By BRUCE N. KALISER

Many public entities require their own storage facilities for liquid fuels. Such entities include the state Department of Transportation, Highway Patrol, Wildlife Resources Division, Corrections Division, Parks and Recreation Division, State Aeronautics Division, as well as nearly all municipal and county governments and many federal agencies. These agencies recognize the many advantages of buried fuel tanks over surface facilities. In the subsurface, however, geologic conditions which might affect the tanks are frequently not appreciated. Geologic conditions to be considered are: Groundwater, corrosive soils, cemented soil or rock, and earthquake response.

SIGHTS ON PUBLIC FACILITY SITES
Eighth article in a continuing series

The important subsurface parameter in the siting of buried fuel tanks is that of groundwater because the greater conductivity of saturated soils aggravates potential corrosion problems, and because a fluctuating shallow water table poses problems where expansive soils exist. Swell pressures on the tank's pipe connections caused by a rising water table saturating fine soils can result in spills. Spills of petroleum products to the groundwater regime are becoming increasingly more common events in Utah. Not only is the groundwater contaminated by such spills but the vapors that collect in underground openings are highly combustible and a hazard to public health and safety. Since the fuel pumps are electrically operated, potential exists for an explosion.

High water tables prevail under much of Utah's urban environment. In Salt Lake County, for example, some 44 percent of the county is underlain with a water table shallower than five feet; over 50 percent with a water table shallower than ten feet; and almost two thirds of its area underlain with a water table less than 20 feet in depth.

Corrosive soils generally exhibit: (1) resistivity less than 2,000 ohm-cm; (2) pH less than 4.0 or greater than 8.5; (3) oxidation-reduction potential less than 100 mV; (4) presence of sulfides; (5) high moisture content; and (6) fine texture. In these soils, the additional presence of strong, direct electric current in the soil will normally prove to be quite deleterious to buried tanks. Direct current may come from cathodic protection systems which are employed to protect buried piplines from corrosion. In recent years, this latter threat has grown as federal requirements have dictated cathodic protection for natural gas and petroleum lines. Corrosive conditions may therefore have to be combated by installation of an individual cathodic protection system for the buried tank.

Excavation conditions may not always be easy in tank placement. As with any subsurface installation, the presence of resistant cemented soil or rock, *in-situ*, will increase the facility cost. In a limited working space environment, as between existing facilities, adverse excavation conditions become more significant. Temporary excavations in moist clay or saturated sand pose a hazard of wall caving (collapse) that one should be aware of. Shoring of excavation walls may be required, depending upon their depth.

Finally, it must be recognized that, in shallow groundwater environments, earthquakes may cause buried tanks to lift out of the ground, thus severing connections. Fuel and vapors that would escape would then aggravate the overall earthquake hazard situation.

In conclusion, therefore, one must not ignore geologic conditions when siting a buried fuel tank any more than in the siting of any other type public facility. Being considered "critical" facilities, buried tanks will be a valuable source of fuel following a destructive earthquake. ■

NEW ASSOCIATE DIRECTOR AT DNR&E

Lorin P. Nielsen has been named Associate Director for Energy and Minerals with the Utah Department of Natural Resources and Energy. He replaces Brec Cooke, who recently resigned.

In this capacity, Mr. Nielsen will coordinate the activities of the Divisions of Utah Geological and Mineral Survey, State Lands and Forestry, Utah Energy Office, and Oil, Gas and Mining. He will also be involved with coal leasing, nuclear waste siting issues, and oil shale and tar sands development.

Formerly director of administration and special services of the Pacific Northwest River Basins Commission in Vancouver, Washington, Mr. Nielsen also was head of the planning staff and a construction budget analyst with the budget office of the Bonneville Power Administration in Portland, Oregon. In addition he was public works specialist in Seattle, Washington, with the Economic Development Administration.

Mr. Nielsen worked for the Interior Department as a staff assistant to the Office of the Secretary of the Interior in Seattle, Washington, as an administration officer and staff assistant in the Office of Land Use and Water Planning in Washington, D.C. Also in Washington, D.C., he served as a budget examiner with the President's Office of Management and Budget.

Mr. Nielsen was raised in Davis County, graduating from Bountiful High School. he graduated from the University of Utah in 1966 with a B.A. degree in history and earned a M.A. in philosophy in 1973 from George Washington University. ■

Cold Water in Utah: Spring Runoff

During May, 1982, average stream flows were 32 percent greater than normal for May, according to a U. S. Geological Survey Public Offices announcement.

The flow of Big Cottonwood Creek near Salt Lake City, at 251 cubic feet per second (or 163 million gallons per day) was 28 percent greater than normal for May.

The water-surface elevation of Great Salt Lake was 4,200.09 feet above sea level, 0.5 feet higher than in April and 0.5 feet higher than May, 1981.

Ground water levels declined throughout the state, except in the Blanding area, San Juan County, where they remained above average. All other areas were below average. ■

"Sevier Valley Earthquake"

By BRUCE N. KALISER

A 4.0 magnitude earthquake shook Sevier Valley at 6:13 a.m. on May 24. Initial news reports indicated that the event was felt as far away as Salt Lake City on the north and Cedar City on the south. A reconnaissance made by the writer later revealed that the felt area was much smaller and was confined to a portion of the Sevier Valley between Aurora (16 mi. NNE of the epicenter) on the north and Joseph (11 mi. SW of the epicenter) on the south. Damage to buildings (not reported in the popular press) was found during the reconnaissance in the towns of Monroe, Elsinore, Central, Anabella, Richfield, Glenwood, and Sigurd. Most of the damage was recorded in Anabella, Monroe, and Elsinore. Damaged houses ranged in age between 5 years and more than 80 years. One curious phenomenon was the turning on of stereo and T.V. appliances in homes in Anabella, quite near the epicenter. In one unit, all three elements (tape, AM-FM, and phonograph) went on and required unplugging to turn off.

A double garage of one house in Anabella (5 years old) shows evidence of considerable horizontal forces, the top having shifted over one inch to the north. The west and south walls were cracked and the north wall bowed outward in the upper half. Window separation in the north wall was about 1½ inches. In the attached home a child's metal chair was overturned to the north and cinder blocks, stacked seven high outside, were dislodged, also to the north. Another house in town, probably over 80 years old, appeared to have structural damage along with several broken windows.

A teenager who was leaning over an irrigation line in the field at Sigurd was pitched to the ground. A number of farmers south of Joseph who were milking at the time of the earthquake reported neither having felt the tremor nor having observed any anomalous cow behavior.

Objects on shelves were tipped over in Anabella, Central, Monroe, Glenwood, and Sigurd. There was no affect to the Hot Springs Resort in Monroe. The owners checked for change in spring flow and turbidity but found none. Monroe City, however, reported three distribution line leaks after the earthquake and cobbles and small boulders across the road in one location up Monroe Canyon just over a mile from the canyon mouth. No ground effects were reported or observed on the reconnaissance, other than rocks moving onto the Monroe Canyon road from bedrock ledges to talus deposits above.

A more detailed report of the observations made during the reconnaissance is being prepared. ■

Utah's Highest Lake

The highest lake in Utah is a glacial tarn about 8.5 acres in area located 0.8 mile south of Kings Peak in the Uinta Mountains. Elevation of the lake is 13,302′. Utah's second highest lake, elevation 12,010′, appears to be another glacial tarn perched on a rocky shelf on the northeast flank of an unnamed peak (13,263′) midway between Kings Peak and Gilbert Peak. Neither lake is named.

Kings Peak, elevation 13,528′, is Utah's highest, and Gilbert Peak ranks second, (or third) at 13,442′ (depending on whether South Kings Peak, 13,512′, is counted separately). Both are named for noted U. S. Geological Survey geologists of the past century. ■

ROMOCO SYMPOSIUM – A GREAT SUCCESS

The Fifth Symposium on the Geology of Rocky Mountain Coal, co-sponsored by UGMS, USGS, the Utah Mining Association, the Colorado Geological Survey and the Energy Minerals Section of the AAPG, brought more than 350 geologists from Utah and other parts of the U. S. to Park City during its 2-day conference in May. A record number of 34 technical papers were presented during the various sessions. Topics discussed included: depositional environments, mine geology, computer applications, coal characterization, applied geophysics and geophysical well logging, and coal reserves and resources. (All papers have been published in the **Proceedings**, UGMS Bulletin 118, *see* p. 11 for additional information).

A train ride on the Heber Creeper and a 2-day long field trip to the Muddy Creek Canyon area (Emery County) as well as visits to coal fields and mines located in the Northern Wasatch Plateau coal field of central Utah afforded the participants a most memorable experience.

In Memoriam

Howard W. Balsley, 95, mining industry pioneer, died in April, 1982, in Moab, Utah. Born in 1886 in Connellsville, Pennsylvania, he completed business college before coming west in 1907. During his early years in Moab he became interested in mining and was deeply involved with and much respected by the uranium and vanadium mining industry. In 1974 the Colorado Mining Association named him the "Mining Man of the Year," an award rarely given to a non-Coloradoan. ■

FEDERAL REGULATIONS REDUCED

Coal - Federal Regulations for coal management, exploration and mining have been reduced by 30 percent, according to an announcement by Secretary of the Interior, James Watt on July 30. The new regulations were published in the July 30, 1982 *Federal Register*. ■

GREAT SALT LAKE LEVEL

DATE	BOAT HARBOR (South Arm)	SALINE (North Arm)
1981		
September 1	4198.65	4197.55
September 15	4198.45	4197.40
October 1	4198.20	4197.20
October 15	4198.40	4197.35
November 1	4198.45	4197.25
November 15	4198.50	4197.30
December 1	4198.50	4197.35
December 15	4198.55	4197.35
1982		
January 1	4198.70	4197.50
January 15	4198.80	4197.55
February 1	4198.90	4197.60
February 15	4198.95	4197.70
March 1	4199.20	4197.80
March 15	4199.55	4198.00
April 1	4199.90	4198.15
April 15	4200.20	4198.35
May 1	4200.40	4198.40
May 15	4200.70	4198.60
June 1	4200.85	4198.65
June 15	4200.85	4198.65
July 1	4200.60	4198.60
July 15	4200.50	4198.50
August 1	4200.40	4198.55
August 15	4200.05	4198.40
September 1	4199.90	4198.30
September 15	4199.80	4198.15

UGMS Staff Changes

Keith Clem has recently been added as a geologist to the Petroleum Section. He received his B.S. degree in 1982 in geology from Fort Lewis College. He has worked one-and-a-half years as a mud-logger and well site geologist in the Piceance Basin of Colorado and in the Uinta and Paradox basins of Utah. Keith's departmental responsibility is the compilation of petroleum data for the Paradox Basin Nuclear Waste Depository Site.

Sandy Eldredge is a staff addition to the Geology Work Group of Utah's Nuclear Waste Repository Task Force. She graduated from Skidmore College in 1978 with a B.A. degree in geology and anthropology/sociology. Sandy taught high school math and science for two years in Vermont, and worked with an anthropologist in Montana before moving to Utah in 1981.

James W. Parker has accepted a position as a cartographer in the Editorial/Illustrations department. He graduated from the University of Maine with a B. S. in biology in 1973 and has worked for the UGMS as a geological draftsman since early 1979. ■

DRILLING DEPTH RECORD SURPASSED

By HOWARD R. RITZMA

Texaco, Inc. has broken the drilling depth record for Utah at its No. 1 Thousand Peaks Ranch wildcat in Summit County. The well passed the previous record depth, 21,845 feet, on August 23, and drilling continues toward a possible total depth of 22,600 feet. The former record was set in 1980 by Placid Oil at its No. 1 WXC-Barton dry hole in eastern Juab County.

The Texaco deep well is located at an elevation of 9897 feet in the foothills of the Uinta Mountains about 10 miles southeast of the Pineview Field and about 20 miles east of Coalville, county seat of Summit County. Official location is SE¼ NW¼ section 12, T. 1 N., R. 8 E. The well is about one mile north of the surface trace of the North Flank fault (Uinta Overthrust complex) in the vicinity of Moffit Pass where Mesozoic and Paleozoic rocks are exposed on the overthrust flank of the Uinta uplift. Although Texaco has not indicated what formations are being penetrated by the well, the depth indicates the great thickness of sediments that lies just in front of and that presumably extends to the south beneath the thrusted mountain flank. The North Flank fault is thought to have about 25,000 feet of vertical displacement and 5 to 8 miles of horizontal displacement (outward thrust to north).

About $13 million has been spent on the costly venture to date including an 11 mile access road and a winterized camp at the drill site. ■

UTAH GEOLOGICAL AND MINERAL SURVEY
SURVEY NOTES

State of Utah . . . . . Scott M. Matheson, Governor
Department of Natural Resources and Energy . . . . . Temple A. Reynolds, Executive Director
Utah Geological and Mineral Survey . . . . . Genevieve Atwood, Director
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Address Correction Requested

Account No. 016103
Approval No. 810047