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REPORT

FINAL REPORT
DEEP WELL INJECTION OF BRINE
PARADOX VALLEY UNIT

prepared for
UNITED STATES DEPARTMENT OF INTERIOR
BUREAU OF RECLAMATION
Denver, Colorado

April 1982

WILLIAMS BROTHERS ENGINEERING COMPANY

A Resource Sciences Company

RESOURCE SCIENCES CENTER • TULSA, OKLAHOMA 74177

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SECTION 1

EXECUTIVE SUMMARY

1.1 CONCLUSIONS

- The Mississippian and the Devonian formations in the vicinity of the brine well field in the Paradox Valley have the desired characteristics for satisfactory long-term disposal of the brine.

- Formations above the Mississippian and Devonian, notably the Hermosa Paradox Member, a massive salt formation interbedded with other facies, provide a positive barrier to upward brine migration.

- With a properly engineered installation and appropriate operation, the injected brine will remain in the designated disposal formations with no breakthrough to the surface or to fresh water zones.

- The required number of disposal wells to inject the specified brine rate of 900 gpm cannot be established until the first well is completed and tested. The limited information available indicates that one well may have sufficient capacity for the entire 900 gpm rate.

- There is a possibility that the wellhead pressure will increase faster than the calculated rate, requiring a second well within a few years. This could occur even though the two-week injection test results indicate that one well will suffice. An accelerated rate of pressure buildup would indicate undesirable fault barrier(s).

- A second well, drilled on the southwest side of the fault, would penetrate the Mississippian and Devonian at a total depth of only 9000 feet.

- The proposed brine disposal system can be operated indefinitely with no significant negative impact on the environment. No change in seismic activity in the area is anticipated; however, if an increase does occur, the recommended monitoring program will permit early detection.

1.2 RECOMMENDATIONS

- Plans should be made immediately for installation of the disposal well system. Because of the escalation of drilling and other oil field related costs, delay of the program will result in a significant cost increase.

- A contract should be negotiated with the landowner to provide purchase or long-term lease of the Continental Well, Scorup No. 1.

- Assuming a satisfactory lease or purchase agreement for the Continental well, the surface casing in this plugged well should be inspected. If the casing is satisfactory, the well should be re-entered and used as the No. 1 disposal well as soon as approval is obtained from the Colorado Department of Health.

- The complete, permanent filter system should be installed along the pipeline right-of-way between the brine field and the well. This is an optional item. If preferred, the two-week injection test can be performed prior to installing the filter system.

- Additional well requirements, if any, should be determined by evaluation of the two-week injection test.

- A network of eight sensitive seismometers should be installed in the project area as soon as possible to obtain baseline seismic data.

- If the wellhead pressure buildup in the first well during the first few years is faster than expected, consideration should be given to drilling a second well on the southwest (the uplift) side of the major fault near the Chicago Corporation No. 1 Ayers well.

SECTION 2

INTRODUCTION

2.1 LOCATION OF PROJECT AREA

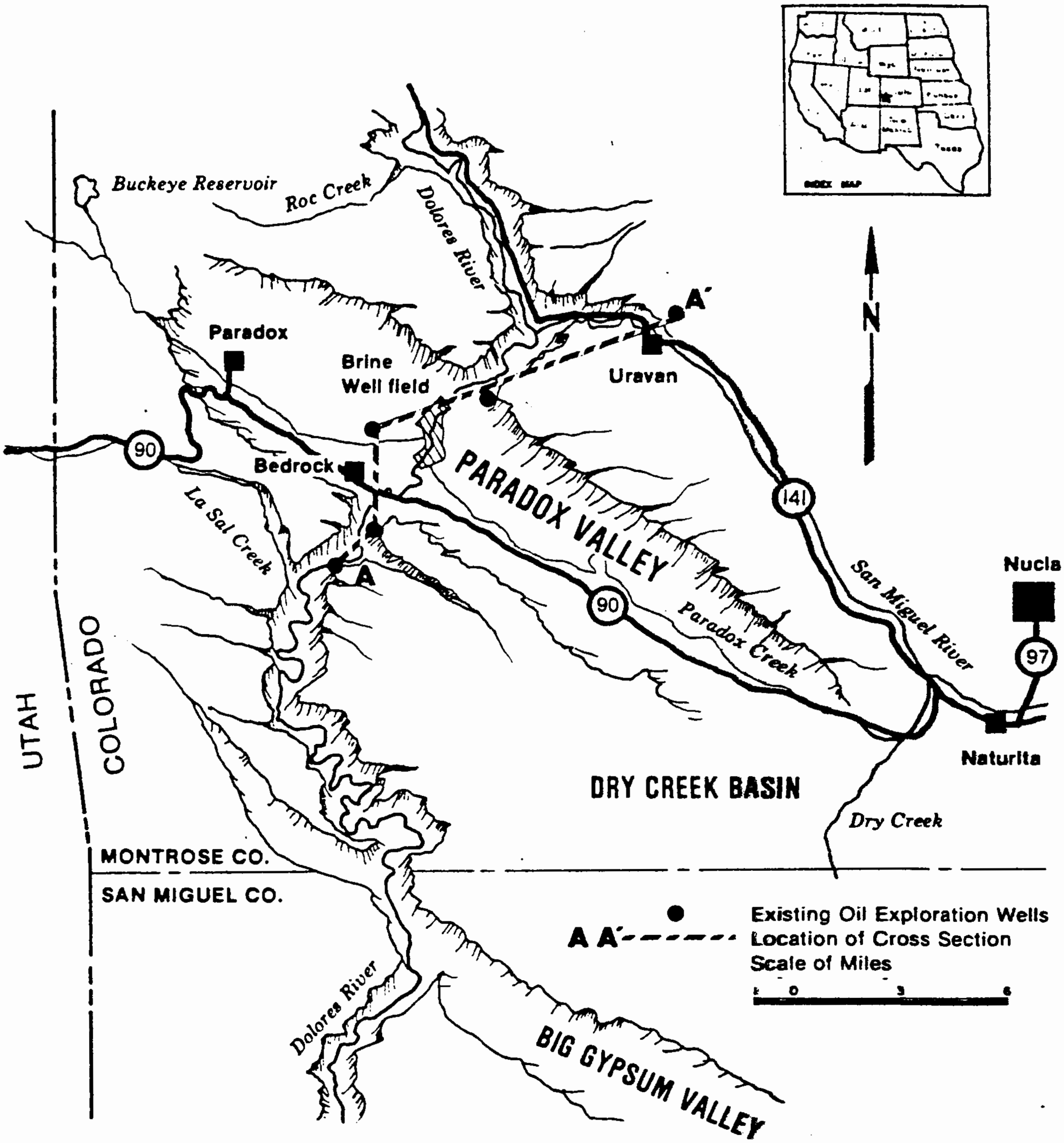
The study area of Paradox Valley is located in Montrose County of southwestern Colorado just east of the Colorado-Utah State line in Township 47 North and Range 18 West (Figure 2-1). The valley is trenching northwest-southeast to the Utah Border and has several hundred feet of rock walls rising on either side. The Dolores River cuts through these walls and flows to the north-east toward the Colorado River.

The project area is served from the east and west by State Highway 90, from the east by State Highway 145, and from the north and south by State Highway 141.

Communities in the Paradox Valley include the small farming towns of Paradox (population 200) and Bedrock (population 80). The nearest commercial center is Moab, Utah, 60 miles to the northwest of Bedrock.

2.2 PREVIOUS INVESTIGATIONS & DATA BASE

All available sources of potentially usable information on geologic, hydrogeologic and related subjects on or adjacent to the study area were reviewed. References are listed in Section 15 of this report.



Source - Bureau of Reclamation (9)

Figure 2-1
Location Map of Paradox Valley Unit Project Area

Numerous geologic evaluations have been performed in or adjacent to the study area by the U.S. Geologic Survey. Additional evaluations have been made by individuals, consulting geologists and engineers and local, state and federal agencies. Useful information and data were derived from these sources. Also utilized were well logs of various oil companies and results of drill stem tests as compiled by Petroleum Information Corporation, Midland, Texas.

The most significant work in the study area is in the four volumes of "Colorado River Basin Salinity Control Project, Paradox Valley Unit" prepared by the Bureau of Reclamation in 1978.

Additional information was obtained by physical inspection of the area and from analysis of water and suspended solids samples taken from the well field.

2.3 OBJECTIVE, PHASE I

The Dolores River, during its course across the valley, receives approximately 200,000 tons of salt annually from the surfacing of highly saline groundwater and carries this load to its confluence with the Colorado River. The salt content of the Colorado River is deleterious to irrigation and other usages. The economic value of the removal of 1 mg/l of salt from the Colorado River is reported to be $472,000 per year, based upon January, 1981 prices. (Additional comments: Section 11.3).

To cope with this salt problem, a system of intercepting and collecting this brine using a well field has been developed by the Bureau of Reclamation. Determination of the feasibility of deep well disposal of this collected brine into suitable formations was the objective of Phase I of this study. A break-down of the objectives is as follows:

- Evaluate the geologic conditions.
- Evaluate the hydrogeologic conditions.
- Evaluate the selected rock formations which are to be used as a disposal zone.
- Assess the impact of deep well injection on the local environment.
- Prepare feasibility level construction cost estimates of the brine treatment, pumping, well drilling and other associated operating and maintenance cost.

2.4 SCOPE OF WORK, PHASE I

The scope of work was defined as follows:

- Collect and evaluate all available geologic, hydrogeologic, geophysical and engineering data in the study area.
- Conduct a surface and subsurface geologic reconnaissance of the Paradox Valley and vicinity.
- Determine geological structure and hydrologic conditions.

- Select potential disposal formation(s).
- Evaluate reservoir properties that are pertinent to the injection process.
- Evaluate existing petroleum exploration wells for possible use as injection wells.
- Assess the impact of deep well injection on the local environment.
- Identify the potential problems in injecting the Paradox Valley brine.
- Prepare feasibility level construction cost estimates of the brine treatment, pumping, well drilling, pipeline, and other required facilities and associated operating and maintenance cost.
- Prepare a final report that includes all conclusions and recommendations.

2.5 CONCLUSION, PHASE I

It was concluded upon completion of the Phase I study that deep well disposal of the Paradox brine is technically and economically feasible. Approval to procede with the Phase II effort was received May 7, 1981.

2.6 OBJECTIVES, PHASE II

- Design a test program.
- Design injection facilities and equipment.

- o Provide assistance for permit application.
- o Prepare environmental monitoring program.

2.7 SCOPE OF WORK, PHASE II

The scope of work was defined as follows.

- o Prepare design and drilling specifications for drilling of a new well or rehabilitation of an existing well that would be used as the injection well.
- o Specify an injection rate for the testing program.
- o Design the pipeline and facilities that will transport the brine from the existing well field pipeline system to the injection test site.
- o Design a treatment system if applicable.
- o Design the injection well head, injection pumping system and connection to treatment system.
- o Design methods and procedures that will be followed for the actual injection testing.
- o Design and specify an appropriate environmental monitoring program which can be used during the injection testing.
- o Furnish a complete handbook of interpretation methods specifically formulated for the injection testing and environmental monitoring program.

- Assist and direct the Bureau with the required permit applications for the testing program and long-term deep well injection of brine.

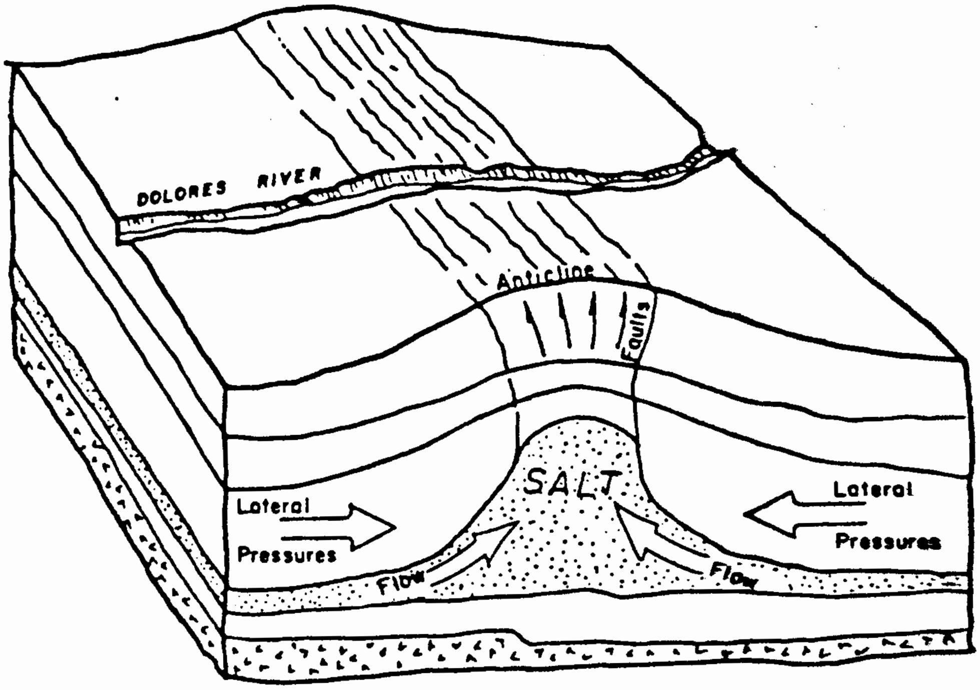
SECTION 3

GEOLOGY

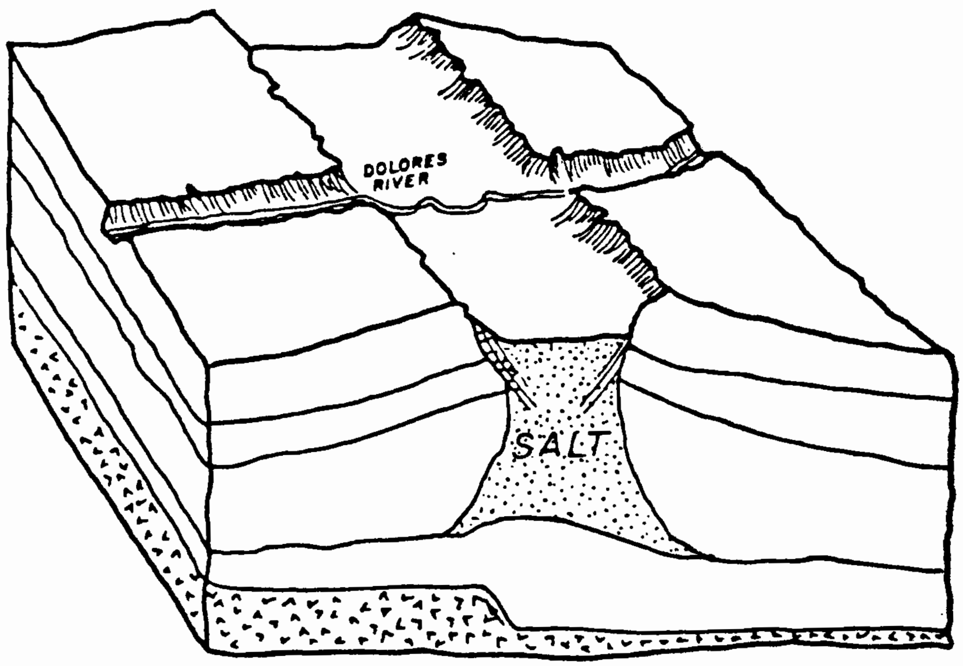
3.1 MAJOR GEOLOGIC FEATURES

The Paradox Basin is an asymmetric depression with a deep trough on the northeast side adjacent to the Uncompahgre Uplift. Rocks of Mississippian age have about 16,000 feet of structural relief between the Uncompahgre Uplift and the trough. The structural relief between the shallower, southwest part of the Paradox Basin and the deep trough is about 9,000 feet. About 16,000 feet of Pennsylvanian, Permian and lower-to-middle Triassic beds fill the trough and pinch out abruptly against the Uncompahgre front, which forms the northeast margin of the basin. Younger beds of Mesozoic age that extend from the basin across the front are flexed and broken in a complexly faulted monocline at the front.

Paradox Valley lies along one of five major salt anticlines present in the Paradox Basin. The valley was formed by the erosion of faulted and uplifted formations exposing a residual gypsum cap. Figure 3-1 illustrates the development of the valley. The emergence of distant mountains on each side of the area placed lateral pressures on the intervening sedimentary formations, resulting in warping and fracturing along weak zones. Consequently, a deeply buried layer of salt began to flow upward into the fractured area, creating an anticline. The crest of the anticline has gradually collapsed as a result of the fracturing. The Dolores River, combined with other erosional forces, worked to remove the collapsing materials and give the valley its present form.



EARLY STAGE



PRESENT STAGE

FIGURE 3-1 PARADOX ANTICLINE STAGES OF DEVELOPMENT
Source: Reference (9)

Rocks of the salt-bearing unit crop out at places along the axes of the salt anticlines. The exposures consist of laminated gypsum and clastic and carbonate rocks interbedded with clayey gypsiferous masses resulting from the residue of leached salt beds. The greatest thickness of salt-bearing rocks was penetrated along the axis of the Paradox Valley anticline by the Continental Oil, Well No. 1 Scorup.

Pennsylvanian and Permian beds of the Paradox Valley are composed of marine evaporites and carbonates. About half of the total volume of these beds in the deep part of the basin consists of salt and minor interstratified carbonate and clastic rocks of the Paradox member of the Hermosa formation.

The Triassic, Jurassic and Cretaceous formations crop out in and around a series of northwest trending faulted anticlines. Figure 3-2 is a reconnaissance scale map showing the location of the brine well field and five of the exploratory oil wells which have been drilled in the area.

Figure 3-3 shows the general geology of the area. Symbols for the interpretation of Figure 3-3 are displayed on Figure 3-4. A regional geologic cross section of the Paradox Valley area is shown on Figure 3-5.

3.2 STRATIGRAPHY AND NOMENCLATURE

Stratigraph relationships in the Paradox Basin are complex. The same formation or equivalent stratigraphic unit will

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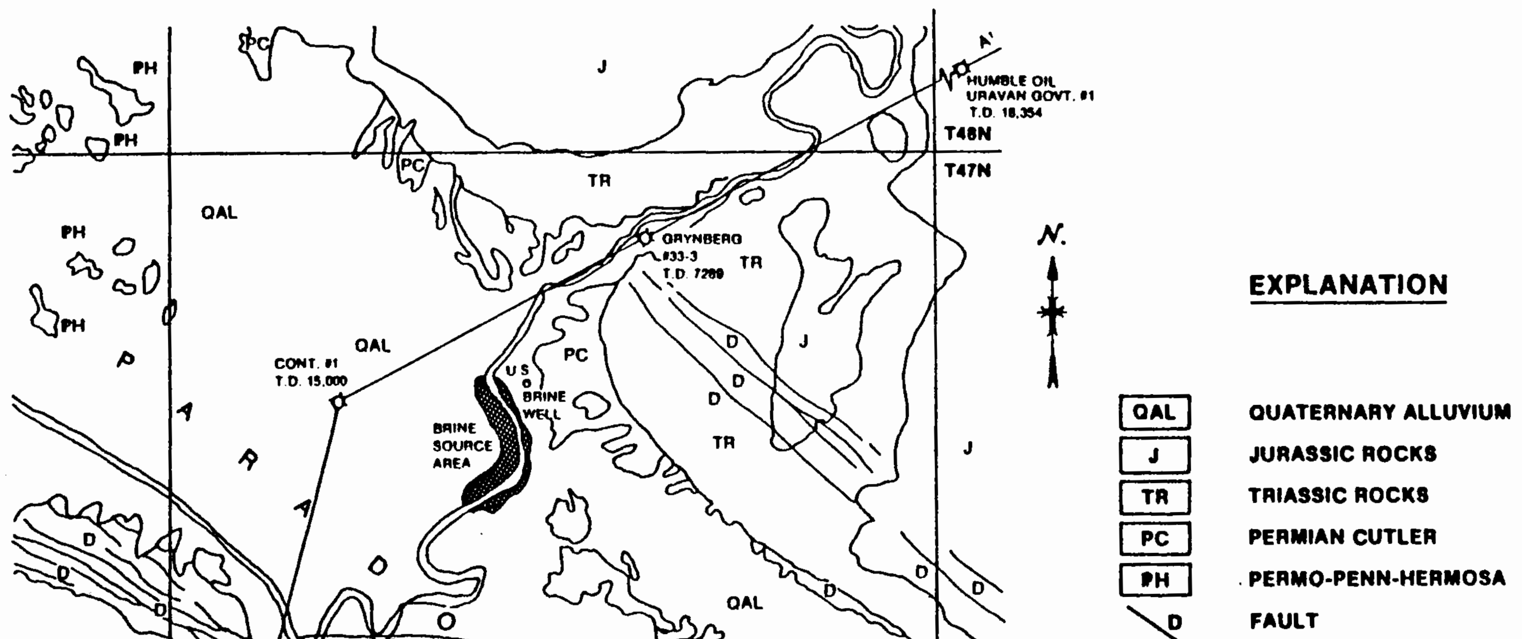


have different ages and names in other places. The purpose of this section is not to resolve the nomenclature differences, but to present the stratigraphic terminology used in this report. Figure 3-6 presents the stratigraphic framework used and explains the rock relationship with reference to age, system and formation.

3.3 PRECAMBRIAN

Rocks of Precambrian age exposed on the Uncompahgre Plateau are predominantly granite gneiss and a variety of massive granite, pegmatite, and subordinate micaceous schist (43). The Precambrian rocks exposed on the Uncompahgre Uplift may not be representative of the Precambrian rocks under the deep part of the Paradox Basin.

3.4 PALEOZOIC

3.41 Cambrian

No Cambrian rocks crop out within the Paradox Valley or Paradox Basin region. Several deep wells have penetrated the sequence, providing a regional picture of the Cambrian environment. In the San Juan Mountains of southwestern Colorado, the Ignacio quartzite is exposed forming the basal formation of the Cambrian. The Ignacio is considered to be of late Cambrian age (14). Barnes (2) suggested that the quartzite may be late Devonian in age. These rocks record the earliest marine invasion of the area during Paleozoic time (13). It is believed that the weathered Ignacio quartzites,

GEOLOGIC TIME UNITS		FORMATION	LITHOLOGY
AGE & SYSTEM			
CENOZOIC	QUATERNARY	ALLUVIUM	QUATERNARY AND TERTIARY FLUVIAL AND AEOLIAN DEPOSITS TERTIARY VOLCANICS AND INTRUSIVE ROCKS
MESOZOIC	CRETACEOUS	DAKOTA FORMATION BURRO CANYON FORMATION	SANDSTONE, CONGLOMERATE AND SHALE SANDSTONE, CONGLOMERATE AND SHALE
	JURASSIC	MORRISON FORMATION SUMMERVILLE FORMATION ENTRADA FORMATION	SANDSTONE, SILTSTONE AND CLAYSTONE SHALE AND SILTSTONE DUNE SANDSTONE
		GLEN CANYON GROUP- NAVAJO FORMATION - KAYENTA FORMATION - WINGATE FORMATION	DUNE SANDSTONE SHALE AND SANDSTONE DUNE SANDSTONE
	TRIASSIC	CHINLE FORMATION MOENKOPI FORMATION	SILTSTONE RED SHALE AND SILTSTONE
	PERMIAN	CUTLER FORMATION	ARKOSIC SANDSTONE, CONGLOMERATE, CRYSTALLINE LIMESTONE AND SILTY SHALE
		RICO FORMATION	SANDSTONE, LIMESTONE AND SHALE
	PENNSYLVANIAN	HERMOSA GROUP - HONAKER TRAIL MEMBER - PARADOX MEMBER - PINKERTON TRAIL MEMBER	DOLOMITE AND BLACK SHALE SALINE DEPOSITS DOLOMITE AND BLACK SHALE

together with the granite of the Precambrian, eroding from the Uncompahgre Uplift, is the source of the Cutler formation and arkosic beds in this section.

3.42 Ordovician - Silurian

Presence of Ordovician and Silurian in the area is controversial. Some geologists believe that they were not deposited in this area.

3.43 Devonian

Rocks of Devonian age have been encountered in several wells in the Paradox Basin. The earliest rocks deposited in the Devonian age have been named the Aneth formation. The formation consists of dense, dark-colored sandy dolomite, generally argillaceous and containing numerous interbeds of dark gray shale. The shales are gray-green and brown, and some are carbonaceous (36).

The Aneth sediments represent an early phase of deposition by the encroaching post-Cambrian Cordilleran Seas. A portion of these segments may have been eroded by a minor retreat of the sea. The formation is found in the Aneth-Bluff fields of San Juan County, Utah, but it is not known whether it is present in the Paradox Valley area.

The age of the overlying Elbert formation is late Devonian (36). In the Paradox Valley area, the Elbert consists of the lower McCracken Sandstone member and an upper member which is sandy, thin-bedded, and has streaks of dolomite and gray-green and red sandy shales. This upper member becomes more sandy near the base and grades into the underlying McCracken Sandstone.

The Ouray formation of latest Devonian and earliest Mississippian age conformably overlies the Elbert formation. The depositional change from the Elbert to the overlying Ouray formation, from sandy dolomite to clean limestone, seems to be gradational.

The Ouray is a dark brown, light gray, dense limestone often oolitic, locally dolomitized and massive, composed of micrite, pelleted micrite, and skeletal material suggesting a quite water marine environment of deposition (1).

3.44 Mississippian

The Mississippian consists of four members. From top to bottom these are:

- Thin-bedded, very fine graned limestone and chert beds.
- Thick-bedded, massive limestone ranging from aphanitic (very fine grained) to coarse grained, largely crinoidal.
- Alternating thin limestone and chert beds.
- A thick-bedded unit composed of limestone and some dolomite.

The upper portion of the Mississippian is the limestone phase and the lower the dolomite phase. The most commonly used terms in the Paradox Basin are Leadville for the upper limestone beds and Madison for the lower dolomite beds, so these terms are used in this report.

The Leadville limestone of Kinderhookian age ranges in thickness from 300 feet to 400 feet in the Paradox Valley area. It unconformably overlies the Devonian in some places. The Leadville is similar to the Ouray formation in that it is light colored, dense and sometimes oolitic. The zone is usually porous and permeable in part and contains oil and gas in some areas. Several wells have been drilled through this formation in Paradox Valley. None of them showed presence of oil and gas.

The Madison limestone constitutes the dolomite phase. It consists of a massive dolomite which is tan, brown, gray and occasionally pink. Its texture is coarsely crystalline to finely sucrosic. The section usually exhibits both granular and vugular porosity. It is often cherty, and in some areas thin beds of limestone appear near the top. It is a clean dolomite. Thin shales that appear here and there are very local in nature. Most of the oil and gas shows of the Mississippian in the Paradox Basin have been found in the dolomite phase. The porosity in the dolomite phase of the Mississippian is widespread and is generally scattered throughout the section.

After the deposition of this phase of the Mississippian, the surface was deeply eroded and the red soils of the Molas (Pennsylvanian) were deposited.

3.45 Pennsylvanian

During the Pennsylvanian period, the land mass of the region was a positive area of low relief and low elevation. On this low-lying land, mainly underlain by Mississippian limestone, a Karst topography and fairly deep soil cover formed (24). This Paleokarst surface is overlain by the beds of fluvial conglomerate of the Molas formation.

The Molas is a clastic red bed sequence of reddish-brown to variegated siltstone, red shale, calcareous sandstone and some gray-to-reddish limestone lentils. The basal part of the formation is comprised of boulders and cobbles. The formation is considered to be the result of reworking the underlying limestone regolith. The thickness varies from a few feet to over 150 feet. In the Paradox Valley area, it is 50 to 60 feet thick.

The Hermosa formation can be divided into three main units; the Lower Hermosa, known as Pinkerton Trail formation, the Paradox members, and the Upper Hermosa, known as a Honaker Trail.

The Pinkerton Trail is the lowest formation of the Hermosa group. This formation is a fine to medium-grained, crystalline, fossiliferous marine limestone, interbedded with gray, silty shales and anhydrite. The thickness varies from a few feet to 195 feet in the Paradox Basin. In the Continental Scorup well of Paradox Valley, only 41 feet of Pinkerton Trail was encountered (Laterlog in cover pocket).

The Paradox member is composed of interbedded salt, black shale, black limey siltstone, evaporite, gypsum, anhydrite and dolomite. The depositional thickness of the Paradox formation along the axis of the Paradox Basin is greater than 4,000 feet. Subsequent upward flow has thickened it to approximately 14,000 feet.

The Honaker Trail formation is the uppermost member of the Hermosa group. In general, it is a sequence of interbedded limestone, shales and sandstones of marine and fluvian origin.

The Pennsylvanian-Permian Rico formation is composed predominantly of red-buff to blue-gray, dense to calcarenitic marine limestone, reddish-brown siltstone and limey sandstone. The facies lie conformably on and intertongue with Honaker Trail strata below.

3.46 Permian

Permian stratigraphy in the Paradox Basin is characterized by the interfingering of sediments, mostly light-colored sandstones and red beds, that grade into one another from source areas in opposite directions. Permian rocks appear to grade conformably upward from Pennsylvanian strata adjacent to the Uncompahgre Uplift.

The entire basin was eroded prior to the deposition of Triassic tocks. Folding, parallel to the trend of the Uncompahgre, took place in the eastern part of the area as a result of salt flowage within the Paradox member of the Hermosa formation. The resulting anticlines were eroded so that Triassic sediments rest upon upturned beds of Permian and Pennsylvanian age, adjacent to the salt anticlines (31).

The Cutler formation is a complex assemblage of interbedded coarse red, pink, brown and maroon conglomeratic to fine-grained arkosic sandstone, coarse red and pink arkosic granite wash, micaceous silty shale and tan, finely crystalline limestone (31). The arkosic material is poorly sorted, forms cross-bedded layers and lenses and consists of quartz, fresh feldspar, dark minerals, and pebbles of granite, gneiss, schist and quartzite, the material derived from the Precambrian crystalline rocks. The base of the Cutler, when recognizable, is called the Rico formation and is placed at the top of the fossiliferous limestone bed. This represents the transitional bed between the Hermosa and Cutler formation.

The formation thickness varies widely because of the nature of their deposition. The formations have a maximum known thickness of 13,000 feet. The three wells drilled in the Paradox Valley area encountered 3,500 to 4,500 feet of Cutler formation. Carter and Craig estimated some 9,000 feet of Cutler to be on the flanks of the Paradox Valley.

3.5 MESOZOIC

3.51 Triassic

The Triassic system of the salt anticline region consists, in ascending order, of the Moenkopi formation, Chinle formation, and Glen Canyon group. These formations crop out in and around a series of northwest-trending faulted anticlines.

The Moenkopi formation occurs on all of the major salt anticlines with the exception of Lisbon Valley, Gypsum Valley, and Dolores anticline. In most of the region, it rests unconformably on the Cutler formation. The Moenkopi is divided into three units (47). The lower unit consists of pale, reddish-brown sandy siltstone to silty sandstone with thin gypsum bed and abundant scattered medium-to-coarse quartz grains. The middle unit consists of pale red and pale reddish-brown cross-stratified sandstone and conglomerate and interstratified reddish-brown siltstone. The upper unit consists of a homogeneous sequence of horizontally-laminated to thick-bedded, pale, reddish-brown and light brown siltstone containing veinlets of white gypsum. The thickness of all three units of the Moenkopi are between 200 and 1,000 feet.

The Chinle formation crops out throughout the Salt Anticline and Uncompahgre Plateau regions, except where it is absent locally on the crest of some of the anticlines.

The Chinle formation consists dominantly of reddish-brown siltstone and sandstone. A thin discontinuous coarse sandstone and conglomeratic sandstone layer is present at the base of the formation in most of the region. The thickness of Chinle ranges between 200 and 750 feet.

The Glen Canyon group consists of three members. They are, in ascending order, Wingate sandstone, Kayenta formation and Navajo sandstone.

The Wingate sandstone, the basal formation of the Glen Canyon group, ranges in thickness from 200 to 300 feet and is exposed along the walls of the Salt Anticlinal valleys. The formation consists of fine-grained, orange-red, tan-to-white sandstone. It is considered to be largely an eolian deposit composed of dune sand.

The Kayenta lies conformably over the Wingate and is composed of bedded fluvial red sand, silt and limestone. The thickness of Kayenta ranges from 60 to 320 feet.

The Navajo is the uppermost formation of the Glen Canyon group and lies conformably on the Kayenta. It consists of fine-grained, well sorted, light buff, gray-to-white sandstone.

3.52 Jurassic

The lithology of overlying Entrada is generally red, buff and orange, horizontally-bedded sandstone. It grades laterally, westward in Utah, into a red, earthy siltstone. The thickness of formation ranges from 40 to 200 feet.

The Summerville formation is red siltstone and claystone, evenly interbedded with thin beds of white, very fine sandstone. The formation is about 75 feet thick and pinches out in many places along the crests of the anticlines.

The Morrison formation is commonly divided into two members: the lower Salt Wash and the upper Brushy Basin member. The Salt Wash member consists of highly lenticular sandstone and claystone, white, gray, buff and red in color with scattered thin limestone beds. The Brushy Basin member consists of claystone, bentonitic clay, and minor lenses of sandstone. The thickness of Morrison in this area ranges from 600 to 800 feet.

3.53 Cretaceous

The Burro Canyon formation is a basal conglomerate, unconformably overlying the Morrison formation. In general, the Burro Canyon consists of a gray-to-brown conglomerate or conglomeratic sandstone, fine-to-very-coarse grained, subrounded to subangular. The thickness of the formation is about 150 feet in the Paradox area.

The Dakota sandstone unconformably overlies Burro Canyon. The Dakota formation is often separated into three different lithologies. The basal member consists of medium-to-fine grained sandstone with some conglomeratic lenses. The middle unit consists of thin-bedded carbonaceous siltstone and coal, and the uppermost unit is defined as a silty, thin-bedded sandstone. Total thickness of the Dakota is about 150 feet.

3.6 CENOZOIC

3.61 Quaternary

Alluvial deposits fill most of the Paradox Valley floor and are composed of talus, piedmont and alluvium. They range in thickness from 1 to 300 feet. The alluvial deposits are stratified, varying from fine, poorly-graded sand to clay-filled gravels.

3.7 STRUCTURE

The Paradox Valley area falls in the Paradox fold and fault belt of the northeastern Paradox Basin (Figure 3-7). The area is dominated by northwesterly-trending folds and faults which are commonly staggered and in places broadly curved.

Most of the folding and piercement probably occurred before Triassic time, and the degree of compression and flowage of salt was much greater than appears superficially. Flowage of the salt began as early as the time of deposition of the upper part of the Hermosa formation (20). The stratigraphy and structure of younger Paleozoic beds flanking the salt cores reflect the upwelling of salt from the area peripheral to the cores. During the earlier stage of the collapse, portions of the crest of the anticlines dropped, as grabens, as much as several hundred feet. These grabens may have formed during relaxation of stresses that caused the folding.

Rise of the salt continued through Triassic and Jurassic times, as did the topographic expression of the piercements (Figure 3-3). By the end of the Jurassic time, salt flowage appears to have ceased and the anticlines were gradually buried in Morrison time. In late Cretaceous and early Tertiary times, folding and faulting occurred again following closely along the lines of the deeply buried salt anticlines and piercements.

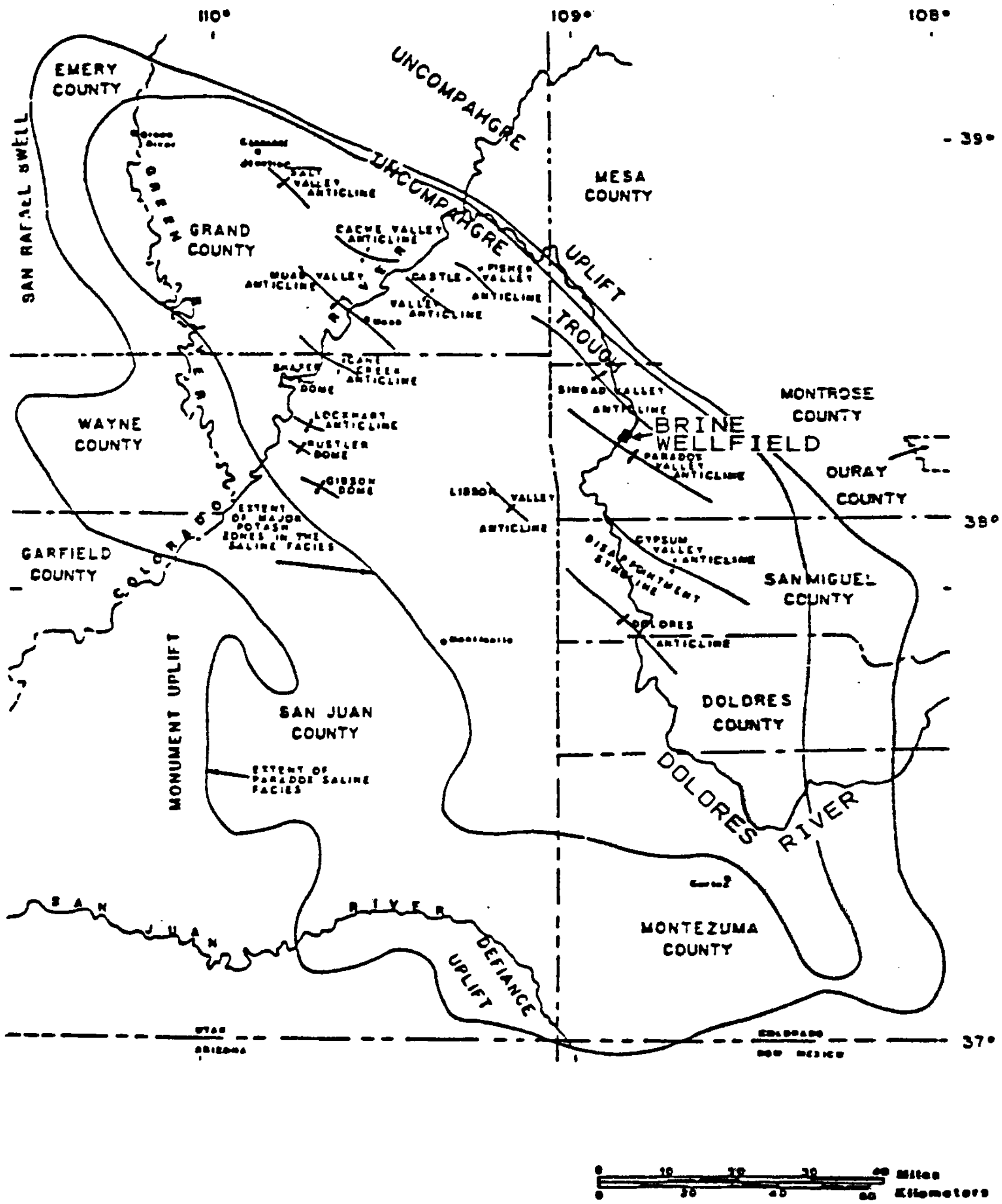


FIGURE 3-7

TECTONIC INDEX MAP OF PARADOX BASIN SHOWING SALT ANTICLINES AND LIMITS OF SALINE FACIES AND POTASH IN THE PARADOX MEMBER OF THE HERMOSA FORMATION (FROM HITE, 1961).

The trace of collapse-faults and subsidiary folds, coupled with the pattern of thinning and pinch out of formations over the salt core, indicate the core of the Paradox Valley is divided into at least two major structural units or cells, the "Core Oven" cell and the "Davis Mesa" salt cell. These cells are linked together like a chain. Many of these cell-like plugs and composite masses are probably connected at depth to a low ridge of salt that is continuous for the length of the anticline.

At the northwest end of the Paradox Valley, the structural features of the faulted anticline are even more complex, where the laccolithic, igneous intrusives form the La Sal Mountains. The alignment of late Paleozoic salt intrusives with the south mountain group of igneous intrusions in the La Sal Mountains indicates this group was intruded along a zone of previous structural activity.

Drill hole information indicates that there is a general rise or subsurface ridge of the Paradox member extending along the middle of the Paradox Valley.

The three structurally distinct units in the Paradox Valley anticline are characterized by the types of structural feature developed during collapse of the crest of the anticline. There is 1) a unit at the southeast end of the anticline where the crest has downsagged to form a structural basin, 2) a large central unit occupying most of Paradox Valley where the crest has collapsed by downfaulting, and 3) a unit at the northwest end of the valley that collapsed by both downsagging and downfaulting. Mesozoic rocks are preserved in the downsagged crest of the anticline at either end of the valley, but in the central part of the valley they have been largely removed above the core of the anticline.

The unit at the southeast end of the anticline overlies a distinct cell or cupola of the underlying salt mass and forms a structural basin. The basin is bordered on its northwest end by northeast trending faults. The northeast and southwest sides of the basin are bordered by anticlines between which a syncline formed because of sagging of the crestal part of the Paradox Valley anticline.

The central structural unit of the Paradox Valley anticline, the largest and most complex of the three units, appears to have a salt core from which a number of cupolas rise. Numerous closely spaced faults on both sides of the valley cut the rocks into long narrow slivers trending parallel to the length of the valley. Southwest of the Dolores River, grabens have formed back from the rims on both sides of the valley. Several northeast-striking transverse faults cut the northwestern part of the central unit. Because the Paradox beds were partly intrusive into the core of the anticline, stratigraphic relations vary considerably in the central structural unit.

The northwest structural unit of the Paradox Valley anticline consists of downwarped and faulted rocks that dip valleyward. The northeast flank of the anticline below Carpenter Ridge is highly faulted, and fault blocks are commonly downdropped toward the valley.

A regional tectonic map covering the Paradox Basin area is shown on Figure 3-8. Regional anticlines, synclines, and monoclines are shown along with the intrusive areas of the Paradox formation. Also included are small directional cross sections of the seven most significant valleys, including the Paradox Valley.

The two most significant structural features affecting the disposal well operation are the pinchout of the Mississippian to the northeast (the Uncompahgre Uplift) and the major fault about 4 miles southwest of the brine well field. Both features will tend to cause wellhead injection pressure to increase somewhat faster than they would in an isotropic formation. They also will have some effect on the shape of the injected brine bubble.

3.8 GEOPHYSICAL WORK

Several companies conducted geophysical work in the general vicinity of the project area. Geodata and North American Exploration Company (NAE) were contacted to determine what geophysical records were available for Township 47 North, Range 18 West. In Section 8, where the Continental well is located, Continental ran both 100 percent (on tape) and Common Depth Points (CDP). The CDP offers more coverage by utilizing more shots and receptors. NAE and Texaco conducted CDP in Sections 7, 8, 17 and 18.

Cost of these data varies from $850 per mile for Texaco's CDP to $1150 per mile for Conoco's CDP, each requiring a ten-mile minimum. The 100 percent tape data sells for $45 a shotpoint.

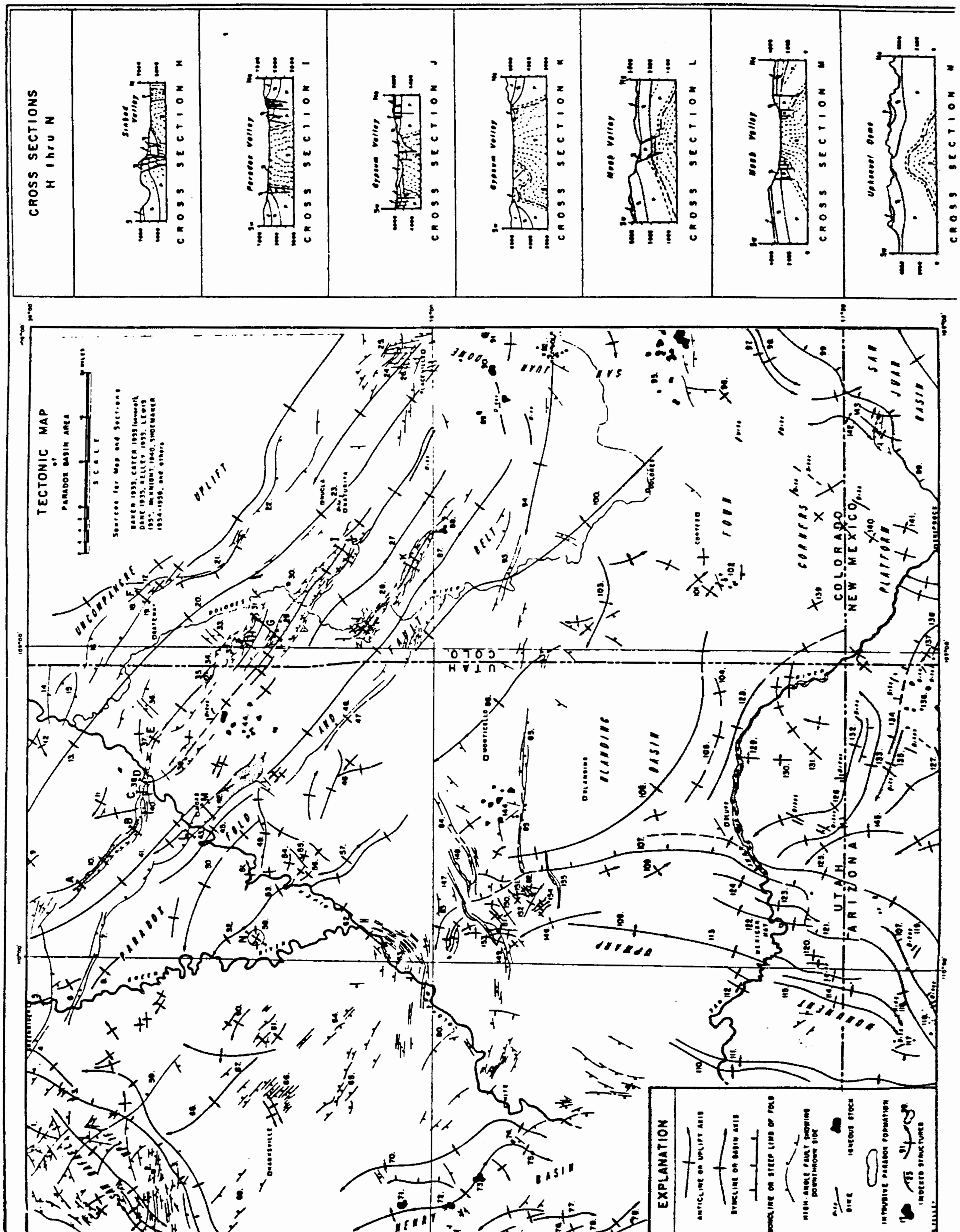


Figure 3-8
TECTONIC MAP OF PARADOX BASIN AREA

With the thick (14,000'+) salt and total depth of over 15,000 feet, it was considered unlikely that these geophysical records would have sufficient resolution to permit make up of an accurate isopach of the Mississippian and/or Devonian formations.

In consideration of the $10,000 to $25,000 cost of obtaining the information for the necessary cross sections and the small probability of obtaining a good isopach, decision was made to not purchase the data.

Samples of the available data were obtained, and subsequent analysis confirmed that construction of an accurate isopach was improbable.

The investigation was of considerable value for another reason: additional data were obtained regarding the major fault which was known to exist about 4 miles southwest of the Continental well.

The reconnaissance quality seismic map supplied to us from Geodata Corporation, combined with data from other sources, indicates that the major fault which traverses the area between the Chicago Corp. No. 1 Ayers well and the Union Oil Co. No. 1-0-30 Ayers well has a displacement of about 6,000 feet. Therefore, depth to the top of the Mississippian on the upthrow side of the fault will be about 9,000 feet. The four-mile distance to this area is a negative factor, but it may be an appropriate area to drill an additional well if excessive pressure buildup is encountered in the Project Area after long-term operation of the 15,000 foot disposal well(s).

SECTION 4

HYDROLOGY

4.1 GROUNDWATER

The Dolores River has deposited alluvia over the Paradox member of the Hermosa formation. The alluvial deposits are stratified, varying from fine, poorly graded sand to clay-filled gravels just above the residual gypsum cap. The Paradox member of the Hermosa formation underlies the entire valley and is exposed in the eastern part as gypsum hills extending along the axis of the anticline. Along the river, this member lies below the alluvial deposits.

Two types of shallow groundwater zones are identified in the Project area. The fresh water zone overlies a heavy brine water zone. An artist's concept of the brine-freshwater interface with and without the well field in operation is shown in Figure 4-1.

Brine groundwater, which apparently underlies all of the Paradox Valley at varying depths, surfaces in and near the Dolores River channel in two areas extending from the middle of the valley, downstream to the river's exit from the valley. The depth to brine appears to increase upstream and west of the river, where the brine zone is approximately 100 feet deep. To the east of the river along the valley floor, the top of the brine layer is at about the same level as the river and extends up to 50 feet beneath the surface. It is estimated that the brine flow to the river varies from 0.2 to 2.1 cfs and averages 0.8 cfs (9).

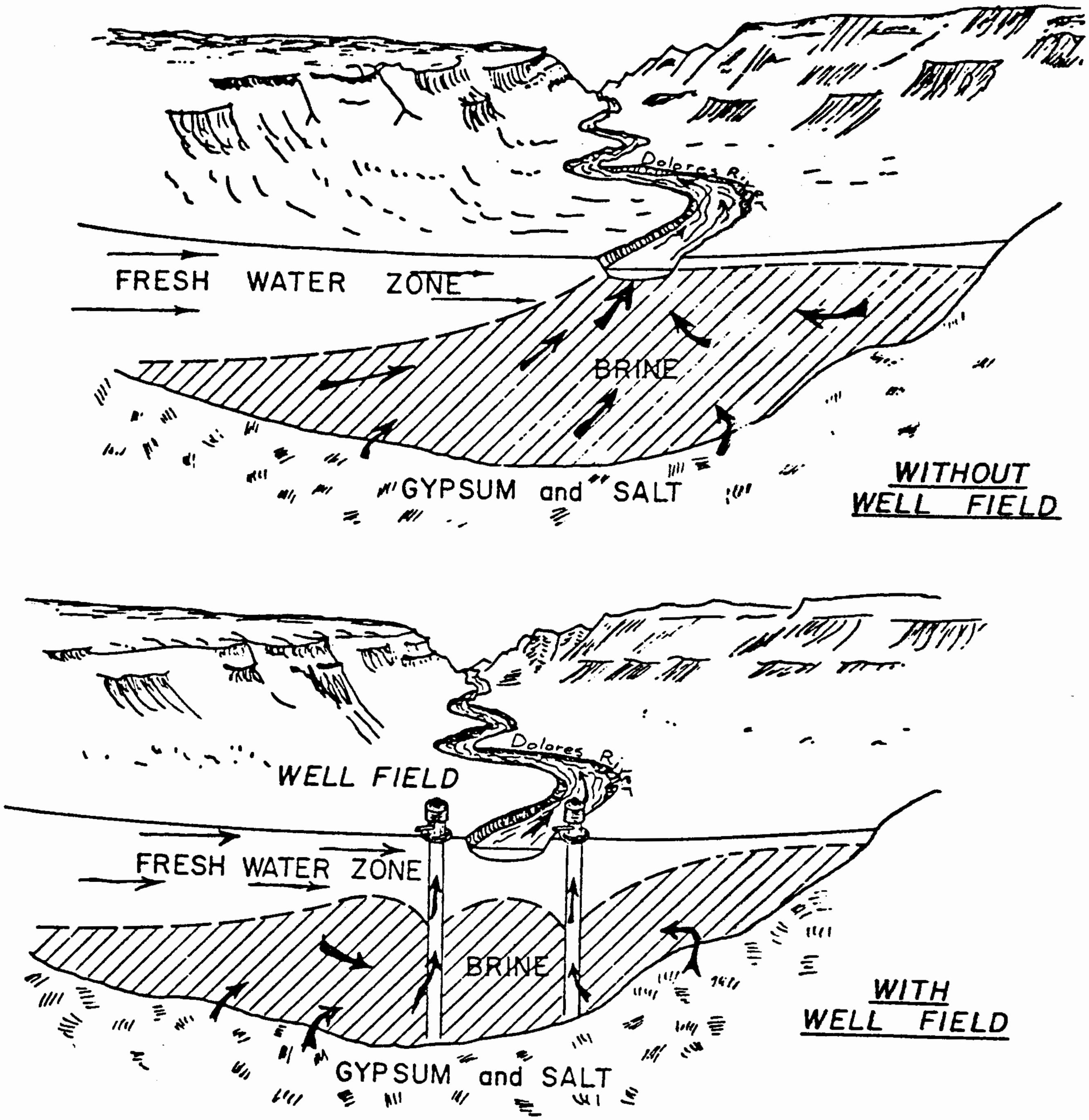


Figure 4-1

BRINE - FRESHWATER INTERFACE

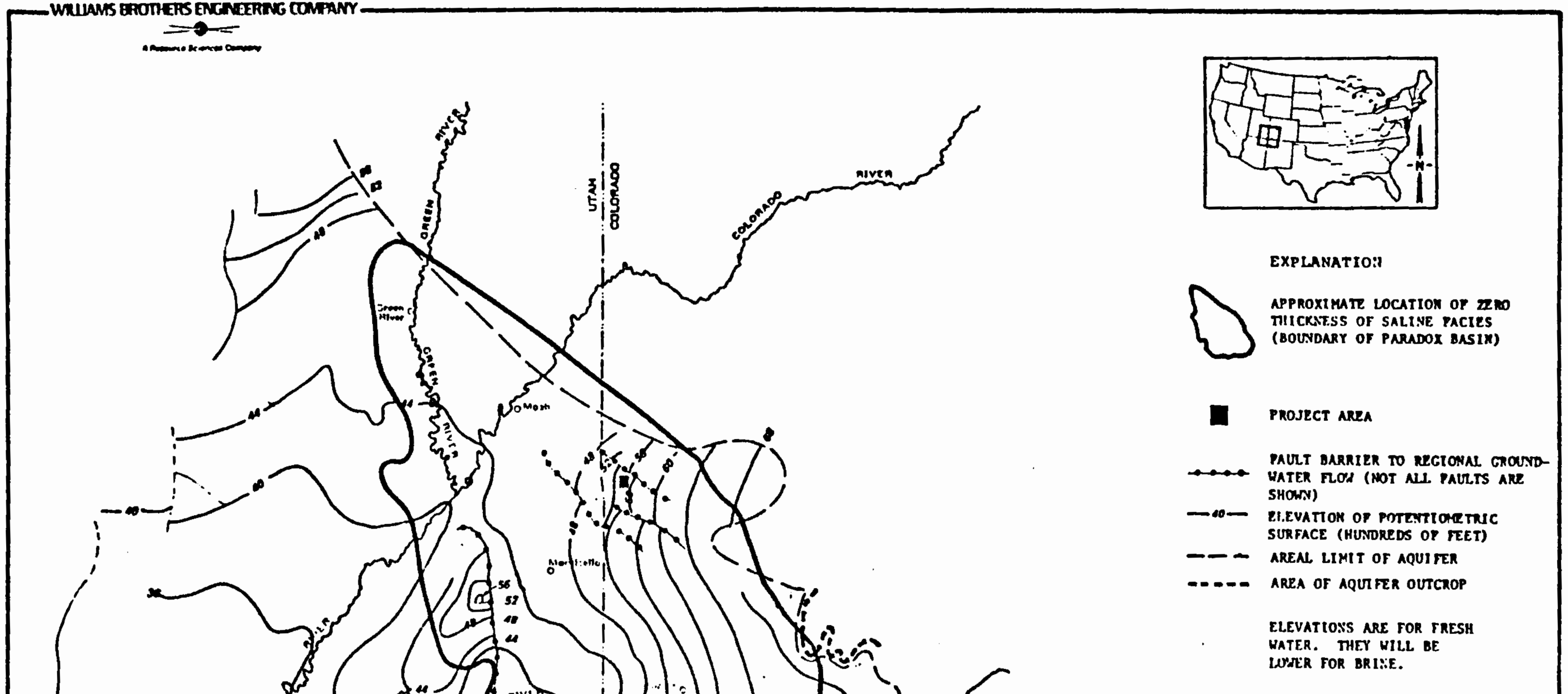
Colorado River Basin Salinity Control Project
Paradox Valley Unit, Colorado
(from Final Environmental Statement, BOR, 3-20-79)

The most permeable brine aquifers are in the alluvial deposits (8). The brine aquifer consists of fine, poorly graded sand and sandy gravel. The brine is derived from groundwater circulating through fractured zones in the extensively faulted, folded and brecciated residual gypsum cap until it comes in contact with the underlying salt core and thereby becomes brine. The predominance of sodium chloride in the brine indicates that the source of the salt is in the halite-rich salt core.

The possibility that brine may be derived from deep sources below the Paradox member is negligible because salt beds have a low hydraulic conductivity and could not transmit the water at a significant rate.

The Mississippian Leadville formation is the only significant deep aquifer in the area (30). A potentiometric map, Figure 4-2, indicates that the brine movement in the project area is northwestward. The potentiometric surface apparently is influenced by the regional dip which slopes to the southwest (23). The Leadville is overlain by Molas and Pinkerton Trail formation which is predominantly shale. This shale formation forms an effective barrier between the Paradox member and the Leadville formation.

The discharge areas from the Mississippian are from the canyon walls along the Little Colorado River in Northeastern Arizona approximately 220 miles from the project area. Brine pressure wave calculations indicate that the pressure wave will advance only 83 miles from the project area after 100 years of disposal at the rate

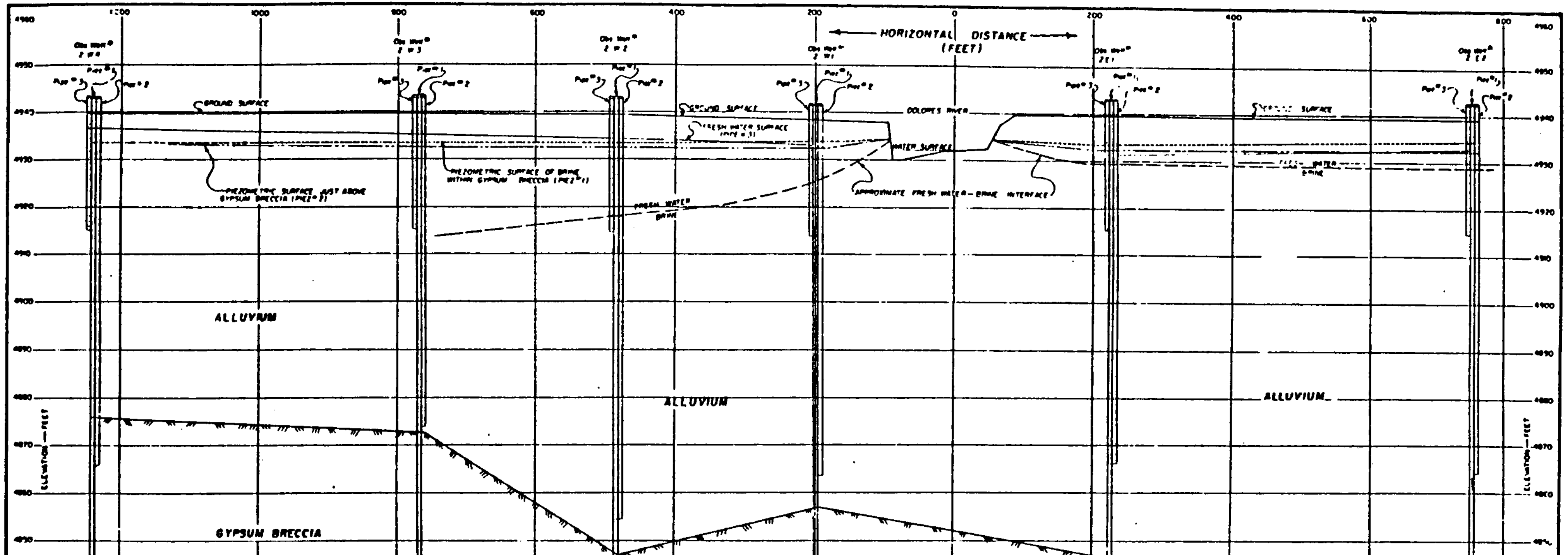

WILLIAMS BROTHERS ENGINEERING COMPANY
A Resource Sciences Company
GREEN RIVER
UTAH
COLORADO
COLORADO RIVER
Green River
Moab
EXPLANATION
APPROXIMATE LOCATION OF ZERO THICKNESS OF SALINE FACIES (BOUNDARY OF PARADOX BASIN)
PROJECT AREA
FAULT BARRIER TO REGIONAL GROUND-WATER FLOW (NOT ALL FAULTS ARE SHOWN)
ELEVATION OF POTENTIOMETRIC SURFACE (HUNDREDS OF FEET)
AREAL LIMIT OF AQUIFER
AREA OF AQUIFER OUTCROP
ELEVATIONS ARE FOR FRESH WATER. THEY WILL BE LOWER FOR BRINE.

of 900 gpm. Calculations for the 220-mile radius indicate that it would take up to 500 years of operations before the leading edge of the pressure wave will reach the vicinity of the Little Colorado River.

The potentiometric heads shown on Figure 4-2 are based on feet of fresh water. Heads are conventionally given in feet of fresh water to facilitate comparisons between various aquifers in a region. The water presently in the Mississippian and Devonian has a specific gravity of about 1.18. This combined with a pressure of 6500 psi in the Continental well at a depth of 14,780 feet (9730 feet sub sea level) results in a potentiometric head of 2,982 feet for the Mississippian brine versus 5,270 feet for fresh water.

The specific gravity of the brine from the well field is about 1.164, resulting in a potentiometric head of 3,157 feet. The difference in the potentiometric head of the injected brine and the elevation of the well collar will assist the injection. This "free" available head will be: 5050 feet - 3157 feet or 1893 feet. The available head of 1893 feet x 0.5044 psi/ft. is equal to 955 psi which will assist the injection pumps. The pressure at the wellhead of the injection well will be less than zero, i.e., "on vacuum" when the disposal rate is less than that required to fill the well to the surface.

A fresh water zone overlies the brine in western Paradox Valley with a hydraulic gradient toward the river. Figure 4-3 is a cross section of the well field showing


HORIZONTAL DISTANCE (FEET)
GROUND SURFACE
PIEZOMETRIC SURFACE JUST ABOVE GYPSUM BRECCIA (PIEZ # 2)
PIEZOMETRIC SURFACE OF BRINE WITHIN GYPSUM BRECCIA (PIEZ # 1)
DOLORES RIVER
WATER SURFACE
APPROXIMATE FRESH WATER – BRINE INTERFACE
ALLUVIUM
GYPSUM BRECCIA
ELEVATION — FEET

ground level, piezometric surface and the approximate freshwater-brine interface. The depth of the aquifer varies from 10 to 40 feet below ground level (9). Thickness of this zone increases toward the west with the maximum of 100 feet and gradually thins out closer to the river in the area of the surfacing brine. This water also contributes to the river flow as seeps and springs. The combined fresh water and brine flows make a total contribution to the river of 1.5 to 4 cfs (9).

Recharge to these aquifers is from precipitation, runoff from the La Sal Mountains, irrigation return flows from western Paradox Valley, and seepage from West Paradox Creek.

Recharge to the brine is probably from the most distant recharge sources, circulating across the top of the dome where the more soluble salts have been leached, thus creating a permeable zone. The fresh water originates from nearer recharge sources.

Available data are inadequate to evaluate the deep bedrock aquifers. However, the oil well drilling and drill stem tests indicate that the Ouray and Elbert formations of Devonian age, the Leadville limestone of Mississippian age, and the Cutler sandstone of Permian age contain brine water. These formations are not considered as a source of water supply because of their extensive depth and poor water quality. Sandstone of Jurassic and Cretaceous age are either eroded or seem to be dry in the Paradox Valley area.

4.2 SURFACE WATER

The Dolores River is the major stream in the project area with the San Miguel River as its largest tributary. The Dolores River originates on the south slopes of the San Juan Mountains and the west slopes of the La Plata Mountains. From its headwaters to the southeast of the project area, the river flows in a southwesterly direction and then turns to flow in a northwesterly direction to its confluence with the Colorado River near Cisco, Utah. Under normal conditions, the flows in the Dolores River are relatively low from July through March and high in April, May and June.

The average annual flow of the river at Bedrock was 300,000 acre-feet for 1972 through 1976 (9). For the same period, the average annual flow of the Dolores across the Paradox Valley was 313,000 acre-feet (9). The increase in the flow is due to the tributary inflow from the West and East Paradox Creeks and groundwater inflow from springs and seeps.

West Paradox Creek originates on the eastern side of the La Sal Mountains. East Paradox Creek originates at the eastern end of Paradox Valley. Both empty into the Dolores River at the brine well field.

4.3 WATER QUALITY

4.31 Groundwater

The groundwater quality of shallow aquifers in Paradox Valley ranges widely from brine to saline to fresh water. The brine water has a density of 1.164 and

and a salt content (mostly sodium chloride) of approximately 23 percent. The moderately saline water is predominantly on the east and west sides of the Dolores River. A very small fresh water zone exists along the edges of the East and West Paradox Valley. The chemical quality of water obtained from the three different shallow aquifer zones of the project area shows that most of the irrigation wells in Paradox Valley can be classified as slightly to moderately saline with total dissolved solids (TDS) values ranging from 1,400 to 3,500 mg/l (8).

The subsurface brine has a salt content range of 230,000 to 296,000 mg/l (TDS). A gamma radiation measurement with detection sensitivity of 0.47 x 10-12 ci/ml found no indication of the presence of gamma-emitting radioisotopes. Similarly, no indication of alpha or beta radiation was found (8). More extensive radioactivity test results are shown in Section 9.34.

Analysis of samples collected from seeps which flow into the Dolores River indicate a total dissolved solids content of 220,000 mg/l (9). Table 4-1 presents the results of the chemical analysis by the Bureau of Reclamation of brine from wells in the well field. This sample had a slightly higher TDS concentration of 258,000 mg/l (9). Hydrogen sulfide content was 74 mg/l when the sample was kept under pressure and not exposed to the atmosphere. Oil content was 1 mg/l. Results of additional

TABLE 4-1

CHEMICAL ANALYSIS BY THE BUREAU OF RECLAMATION OF BRINE WATER FROM WELLS PARADOX VALLEY BRINE FIELD

Constituent	Total (mg/l)
Calcium	1,340
Magnesium	1,720
Sodium and Potassium	105,000
Chloride	165,000
Sulfate	5,590
Bicarbonate	120
TDS	258,000
pH	7.9
Iron	2.4
Strontium	2.3
Zinc	.62
Manganese	.37
Nickel	.23
Copper	.22
Lithium	.13
Sulfide	74.4
Oil in Water	1

SECTION 5

POTENTIAL DISPOSAL AND CONFINING FORMATIONS

5.1 DISPOSAL FORMATIONS

Several basic criteria were used to select the potential disposal formations. The formations which have the following characteristics were considered as potential disposal formations:

- o A thick injection interval with adequate porosity and permeability and large areal extent.
- o Overlying and underlying confining beds sufficiently thick and impermeable to confine waste to the injection interval.
- o A relatively simple geological structure.
- o Formation water in the disposal formation of no value, i.e., not potable and not suitable for municipal, agricultural or industrial use.

Utilizing the above criteria, the Devonian, Mississippian and Permian formations were selected as potential disposal formations.

Figure 5-1 is an isopach map of the Devonian and Figure 5-2 is a structure map showing the contours on top of the Devonian. Figure 5-3 is an isopach of the Mississippian

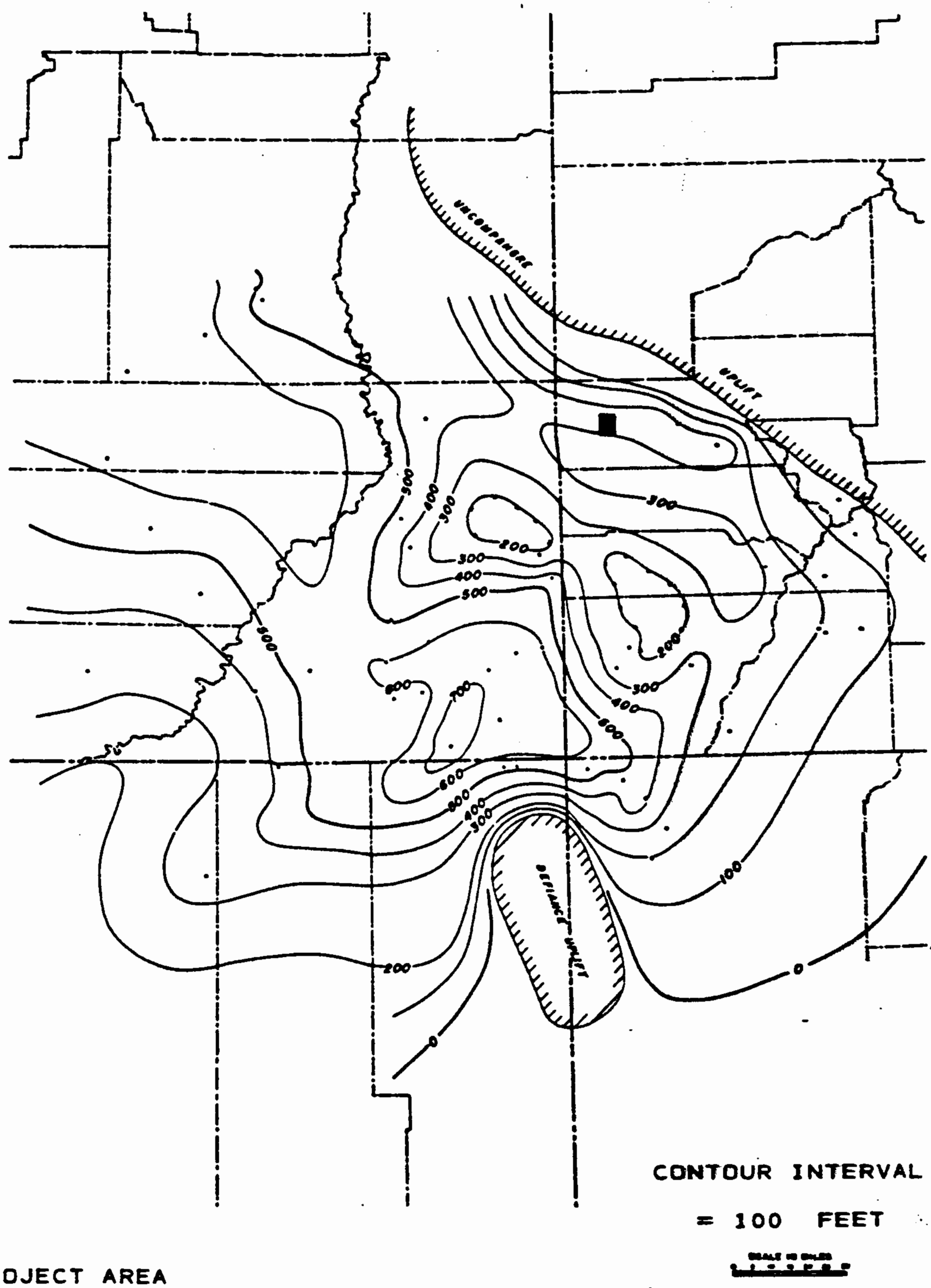
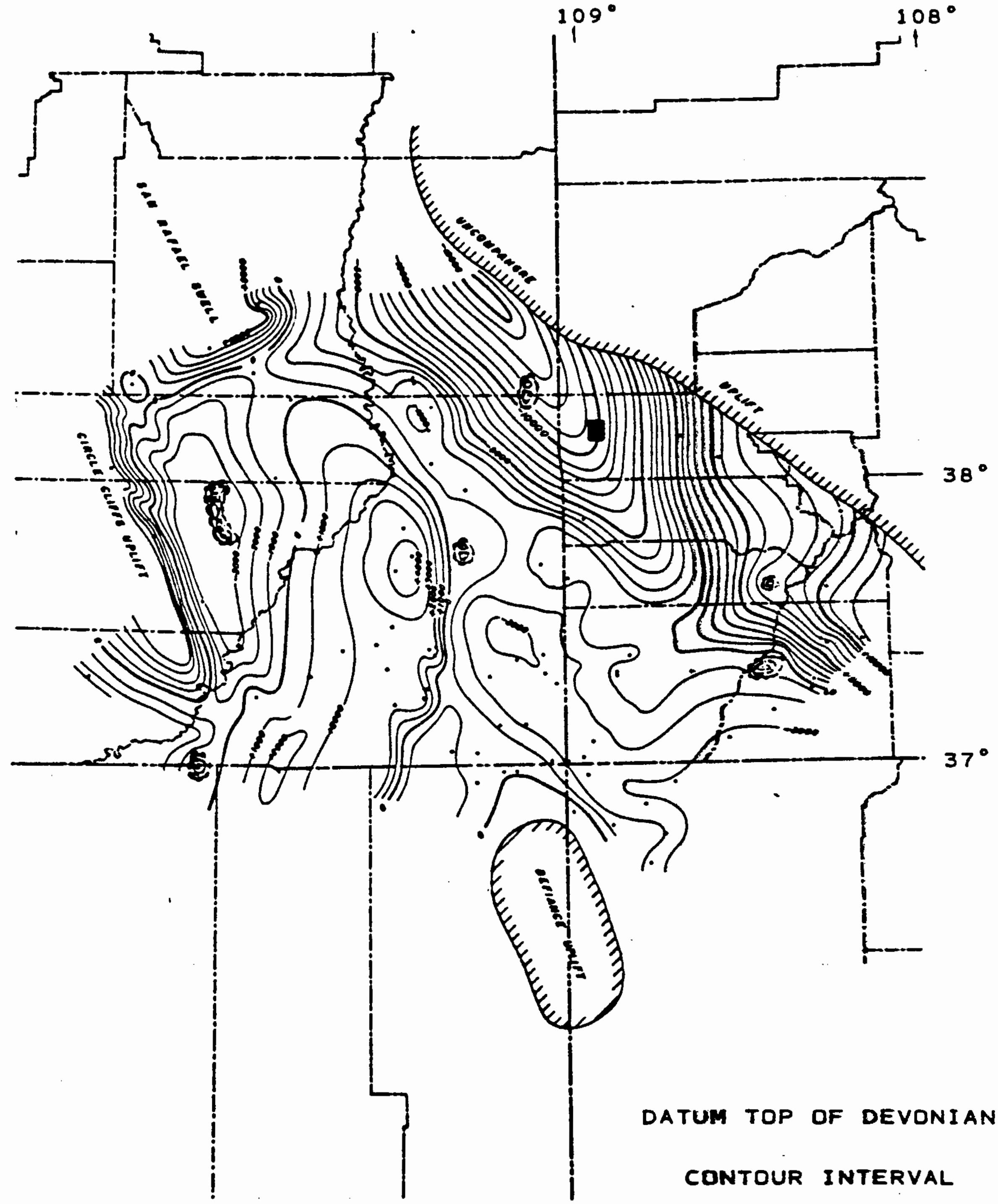


Figure 5-1 Isopach Map of Devonian - Paradox Basin

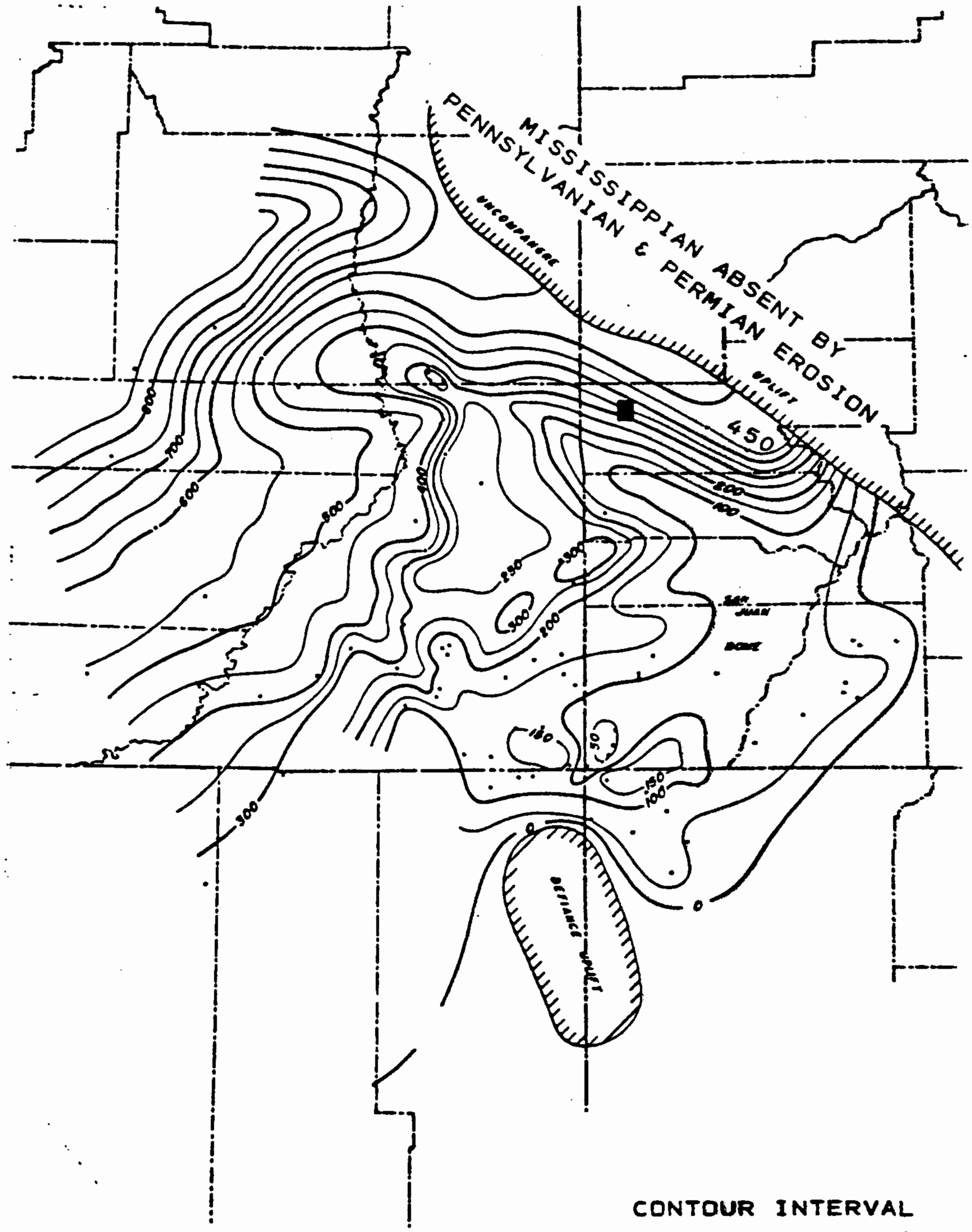
Modified from A.W. Neff & S.C. Brown



■ PROJECT AREA ELEVATION = 4940 TO 5030 FEET
ELEVATION OF THE TOP OF
DEVONIAN = -10,000 FEET

FIGURE 5-2 STRUCTURE MAP - PARADOX BASIN

Modified from A.W. Neff & S.C. Brown



CONTOUR INTERVAL = 50 FEET

■ PROJECT AREA
THICKNESS OF MISSISSIPPIAN
IN PROJECT AREA = 300 FEET TO 400 FEET

Figure 5-3 Isopach Map of Mississippian - Paradox Basin

Modified from A.W. Neff & S.C. Brown

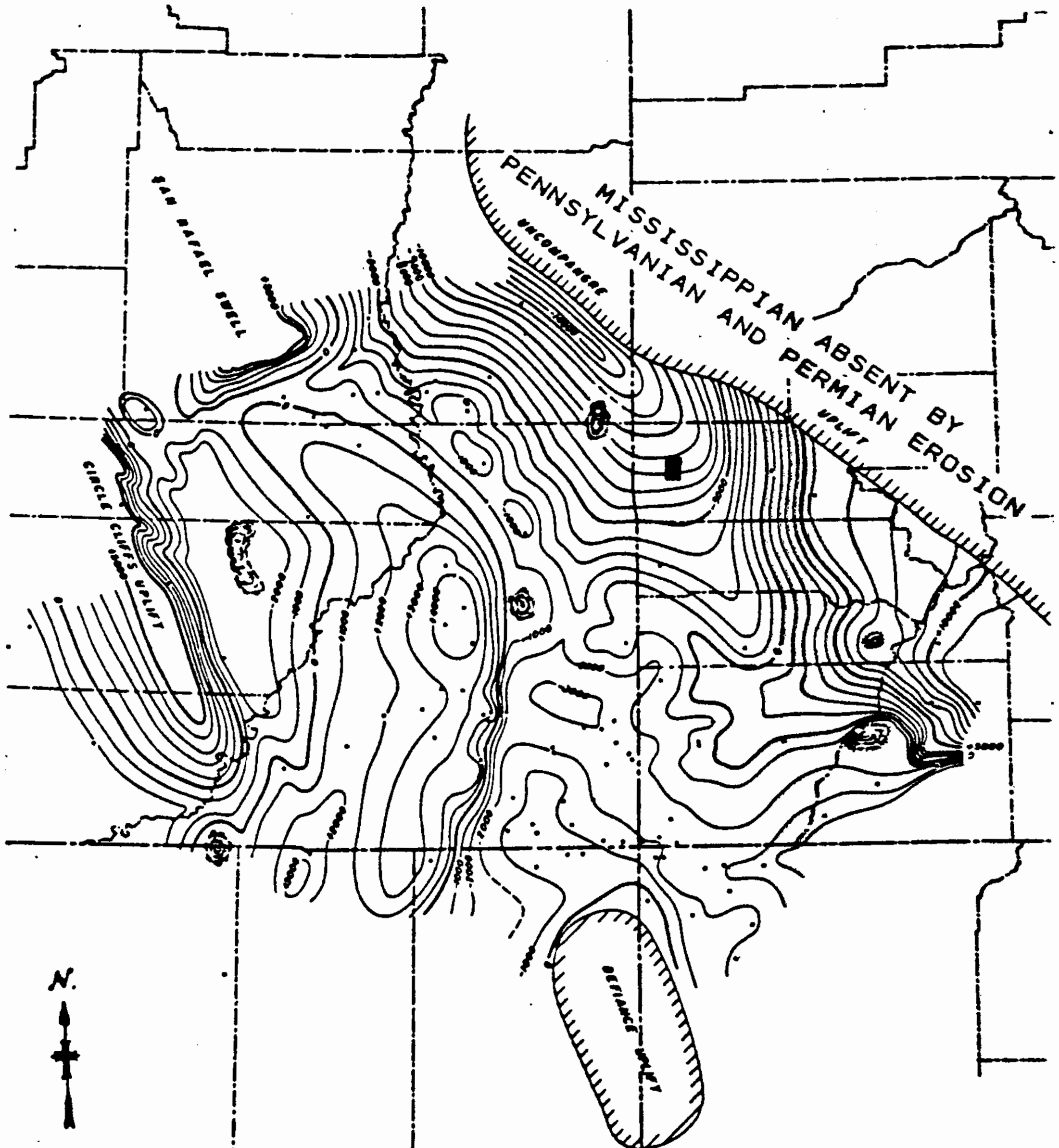
and Figure 5-4 is a structure map of the Mississippian. Figure 5-5 is a site specific structure map of the Mississippian based on the two data points available for the area. A major fault causes a 6000-foot displacement southwest of the Union well. A geologic cross-section and stratigraphic column showing the overlying and underlying beds and structure are presented in Figures 3-5 and 3-6 in Section 3 of this report.

The Ordovician and Silurian formations probably are not present in this area. This cannot be confirmed until deeper drilling is completed. Rocks younger than Permian were not considered for disposal because they are above the valley floor. Other formations of Paleozoic generally do not have the basic reservoir properties. Table 5-1 shows formations which were considered for disposal.

5.11 Devonian (Elbert & Ouray)

The Elbert is reported as a gray, crystalline arenaceous sandstone with some dolomite and a few thin shale beds. Porosities of 15 and 20 percent and permeabilities of 500 to 800 millidarcies have been reported (47).

The upper portion of the Ouray formation is a tan-to-cream, dense, lithographic limestone. In the lower portion of the Ouray, the limestones become a medium crystalline rock, with associated intercrystalline porosity. The porous portion of the Ouray contained condensate and gas in the Lisbon area. Several tests of the Devonian section in the Paradox Basin show it to be very porous in some places. However, these quartzitic sandstones and limestones are expected to be less porous than the Mississippian rock above the Ouray.



DATUM TOP OF MISSISSIPPIAN

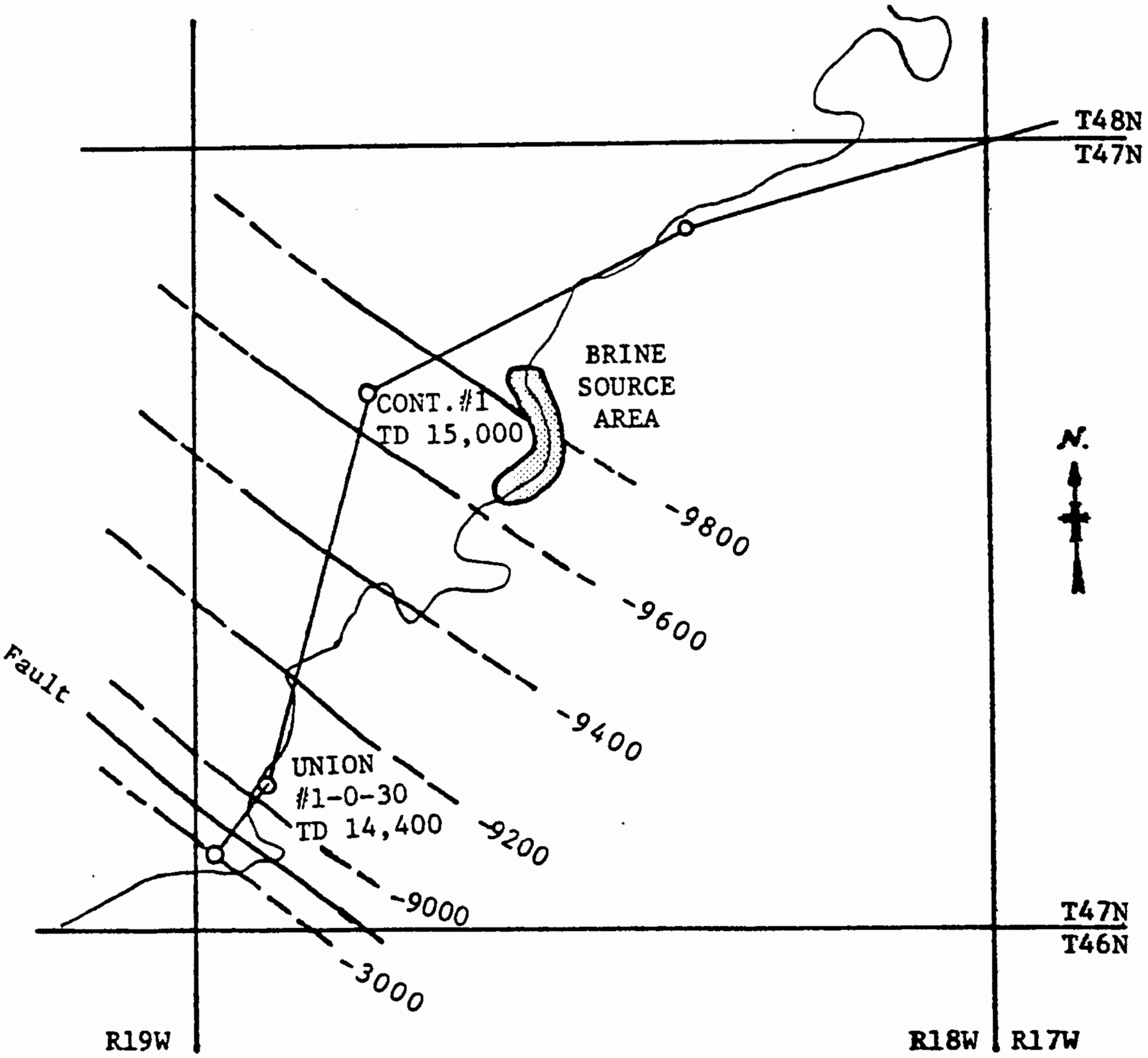
CONTOUR INTERVAL

= 1000 FEET

■ PROJECT AREA ELEVATION = 4940 to 5030 FEET
ELEVATION OF THE TOP OF
MISSISSIPPIAN = -9660 FEET

FIGURE 5-4 STRUCTURE MAP - PARADOX BASIN

Modified from A.W. Neff & S.C. Brown



Datum, Top of Mississippian
Contour Interval
= 200 Feet

Figure 5-5

SITE SPECIFIC STRUCTURE MAP

TABLE 5-1

SUMMARY
POTENTIAL FORMATIONS FOR BRINE DISPOSAL
PARADOX VALLEY AREA

Formation	Age	Lithology	Thickness	Depth From G.L.	Areal Distribution	Confining Bed
Cutler	Permian	Interbeded, coarse, red, pink, brown and maroon conglomerate to fine grained arkosic sandstone and arkosic granite wash, poorly sorted and cross-beded.	3,500-9,000'	200- 1,000'	Widely Distributed	Moenkopi & Chinle formations (siltstone and shale)
Leadville & Madison	Mississippian	Limestone and dolomite massive, tan, brown, and gray. Coarsely crystalline to finely aucrosic texture; granular and vugular porosity.	300- 400'	14,000-14,600'	Widely distributed	Molas & Pinkerton Trail (siltstone and shale)

According to the USGS Ouray Quadrangle (GQ-152), the Devonian Limestone is between 100 and 200 feet in thickness. The generalized, regional isopach shown in Figure 5-1, indicates 200 to 300 feet, but contour control is not good in this area. The depth is from 14,500 to 15,500 feet (Figure 5-2). The formation is widely distributed in the project area. A gross thickness of 200 feet of Devonian formations was estimated for the location at the Continental well.

Water samples from locations in the Paradox Basin show a dissolved solids content of 30,000 to 84,000 mg/l; however, it is expected to be higher at the Continental well location.

5.12 Mississippian (Madison & Leadville)

The undifferentiated Madison and Leadville formations consist of fractured carbonates; tan, brown and gray, coarsely crystalline to finely sucrosic texture with granular and vugular porosity. The formation is considered as a blanket-type reservoir with fairly consistent porosities and permeabilities. The neutron curves of well logs in the area indicate good porosities and thickness of the Mississippian. Porosities of 30 to 40 percent and a permeability of 1,000 millidarcies have been recorded (47).

The areal extent of the formation is widespread, attaining the greater thickness to the northwest (Figure 5-3). The thickness in the project area ranges from 300 feet to 400 feet and the depth from 14,000 to 14,600 feet (Figure 5-4).

The overlying Molas formation and the Pinkerton Trail of the Hermosa group form an effective barrier to fluid exchange. The formation is deep enough to be unaffected by faults or other structures that could cause leakage to the surface.

Chemical analyses of the Mississippian water samples showed TDS contents ranging from 7,200 to 327,000 mg/l. (Table 4-2).

5.13 Permian (Cutler)

The Cutler formation is 3,500 to 9,000 feet thick and consists of interbedded, coarse, red, pink, brown conglomerate to fine-grained arkosic sandstone and arkosic granite wash. The formation is 200 to 1,000 feet deep and widely distributed in the Paradox Valley. The great thickness of the formation is an attractive feature.

The overlying Moenkopi and Chinle formation, consisting of shale and siltstone, probably are sufficiently thick and impermeable to act as confining beds for the Cutler formation. The water samples obtained from the Cutler formation indicate 5,000 to 16,000 mg/l of dissolved solids. Federal EPA regulations require a dissolved solids content of more than 10,000 mg/l, so the Cutler formation waters are too fresh for EPA approval of the Cutler as a disposal formation.

5.2 CONFINING FORMATIONS

5.21 Overlying Confining Formations

The proposed Mississippian and Devonian injection zones are overlain by four formations, deposited during Pennsylvanian time, having very low permeability. Each of the four formations is an aquiclude and will prevent the upward migration of either the connate Mississippian and Devonian brines or the injected brine.

The wells drilled to or through these aquicludes in the vicinity of the project area were exploratory wells for oil and/or gas; therefore, drill stem tests and core analyses were not run so quantitative permeability and porosity figures are not available. However, qualitative geological information, available from various sources, is included herein. An isopach map of the Pennsylvanian System is shown on Figure 5-6.

5.211 Molas Formation

The Molas formation lies immediately above the Mississippian and forms the basal redbed unit of Pennsylvanian time. Merrill and Winar (1958) divided the Molas into three members:

- An upper transported marine unit of well-stratified calcareous shale, siltstone, and sandstone, fossiliferous in the upper part.

- A middle transported non-marine unit of silt-mudstone, sandstone, and conglomerate.

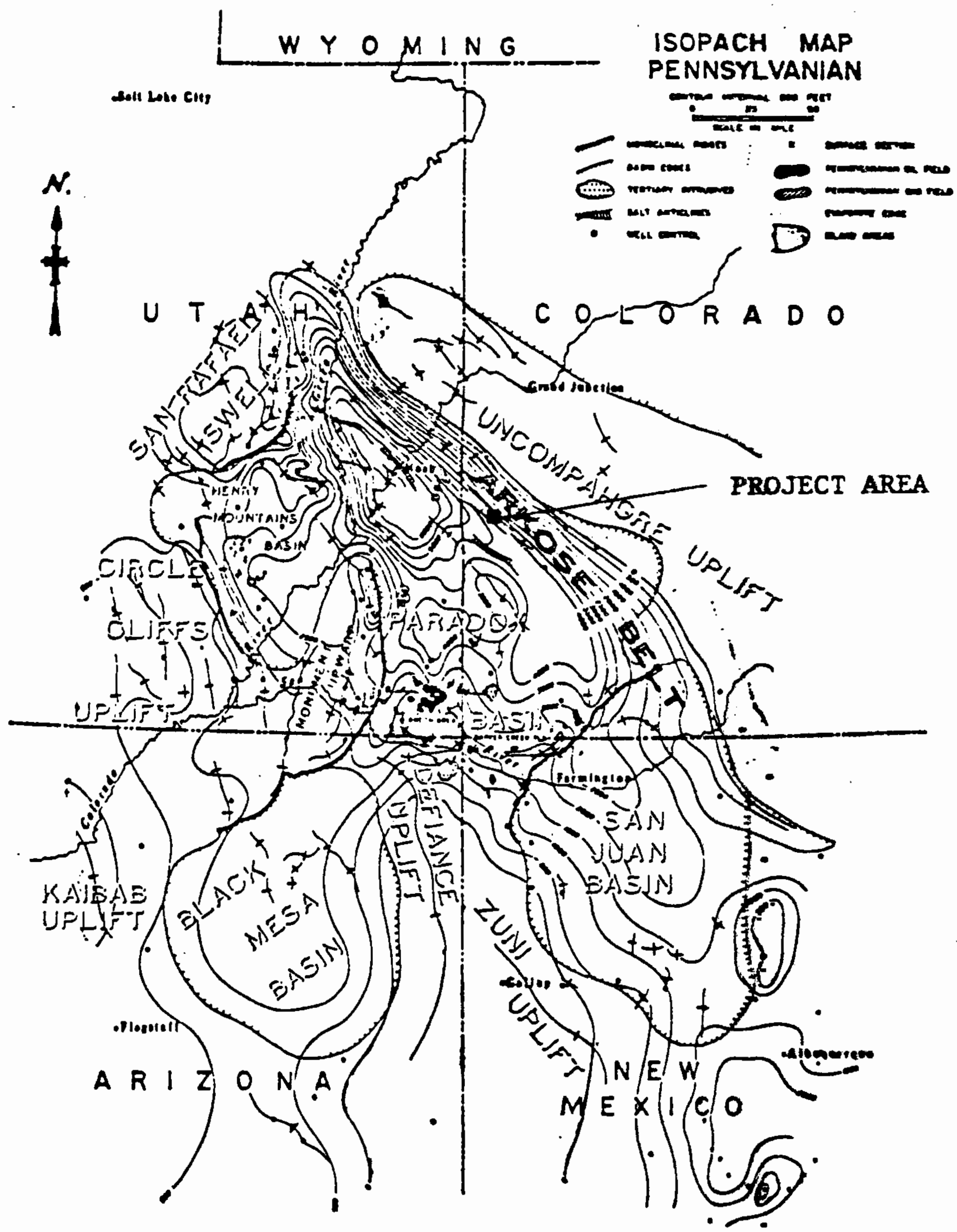


Figure 5-6

Isopach map. Pennsylvanian System. Four Corners area (after Peterson, 1959). Edge of Paradox basin evaporites are shown by stippled band. Arkose belt on east side of basin grades rapidly westward to salt and black shale facies.

- A lower, residual, non-marine "transition zone" of unstratified silt-mudstone, layers of limestone rubble, and chert boulders.

The thickness of the formation ranges from 50 to 60 feet in the Paradox Valley area.

5.212 Pinkerton Trail

The Molas formation is overlain by the Pinkerton Trail, a marine sequence of predominant limestones and interbedded shales. The shales are silty and range from light to dark gray, while the major limestone bed is gray crystalline and medium to fine grained (47). The low potentiometric gradient within this unit is indicative of low transmissivity. Figure 5-7 is a potentiometric map of the limestone aquifer. Data are lacking in the immediate project area.

5.213 Paradox Formation (Evaporite Beds)

The evaporite beds of the Paradox formation consists of halite, potash and other evaporite minerals, are dense and have low permeability. The evaporites found in the central portion of the Paradox Basin grade laterally into a arkosic elastic section near the major uplifts in the east and into carbonates to the southwest. Figure 5-8 is an isopach map of the salt formation. The deposition of this unit was cyclic and 30 to 40 separate cycles can be distinguished. Hite (26) found brine

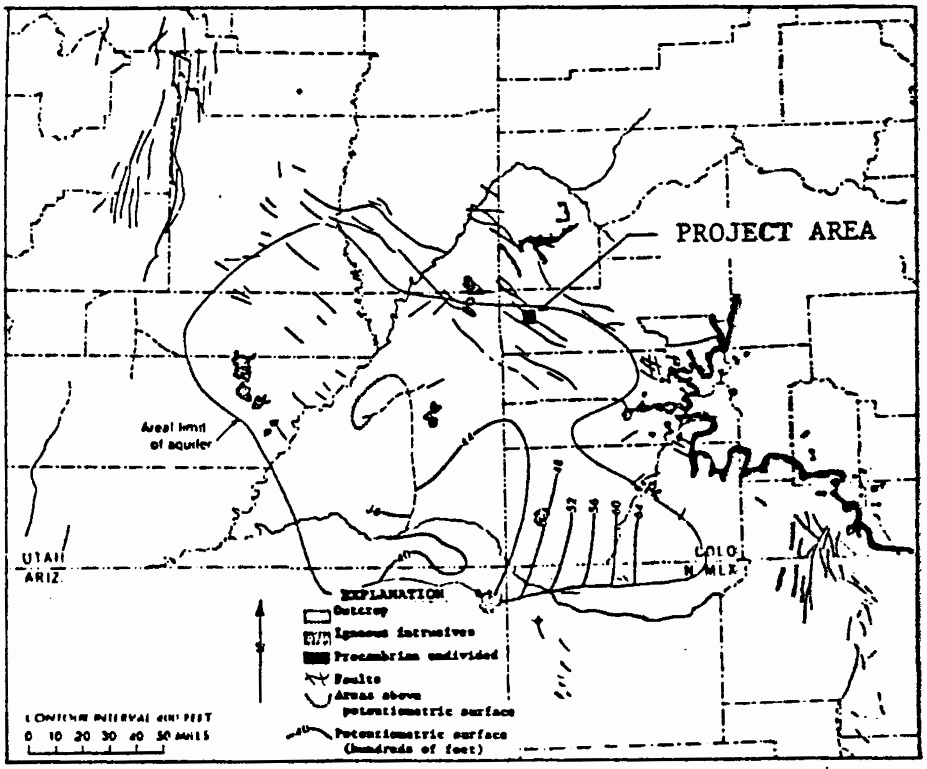


Figure 5-7

Potentiometric map of the Pennsylvanian Pinkerton Trail Limestone aquifer. Datum is sea-level.

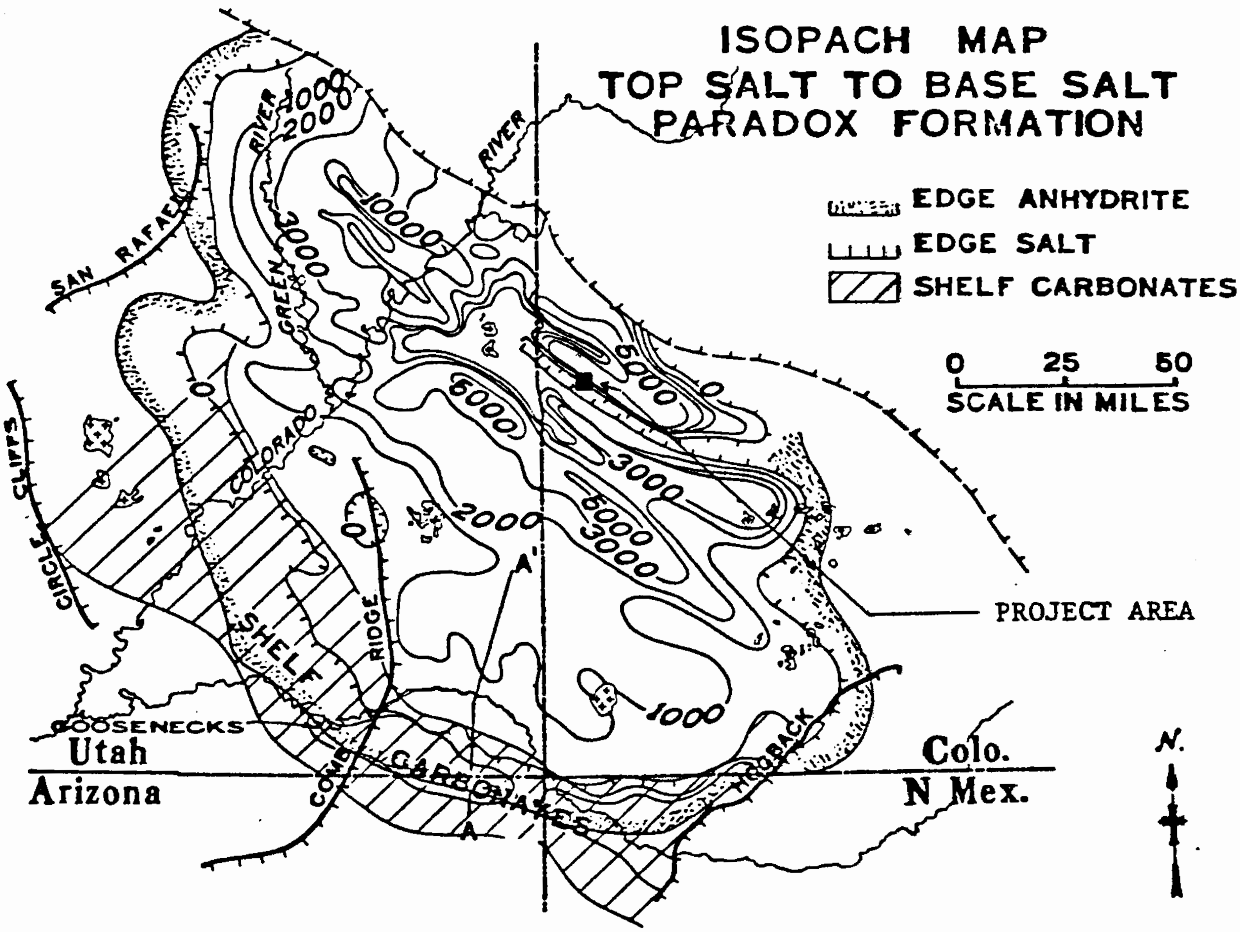


Figure 5-8

Isopach map, Paradox salt, showing relationship with age-equivalent shelf carbonates.

and hydrocarbon inclusions in evaporite beds and inferred that pressures in these inclusions are high. The high pressures of the inclusions suggest the impermeable and confining nature of the evaporite beds and are strong evidence of the effectiveness of the evaporite beds as barriers to vertical fluid movement in the Paradox formation (53). Investigation of the hydrodynamics of the Paradox Basin Region showed that the potentiometric head of geologic units below the evaporites are unaffected by the surface hydrology. This further establishes the evaporites as being an impervious fluid barrier.

The injection well site is located on the Paradox Valley anticline where the evaporites beds are nearly 14,000 feet thick. Thus, in the immediate project area where the rise information pressure due to injection of the brine will be highest, upward migration of fluids will be blocked by a massive impervious evaporite formation.

Most drill-stem tests have indicated low permeabilities and limited reservoir conditions. In salt anticlines, abnormally high shut-in pressures are sometimes encountered; however, the return of fluid pressure after release, is extremely slow. These abnormally high pressure zones are best explained as the result of salt flowage and deformations within the interbeds which transfers part of the lithostatic loading to the pore fluids. (46) Figure 5-9 is a potentiometric map of the Paradox formation. Gradient in the project area is to the northwest.

5.214 Hermosa Group

The undifferentiated Hermosa group consists of carbonate reefs and banks, shale, siltstone, anhydrite and sandstone. Laterally, the carbonate reefs of the undifferentiated Hermosa group grade into the evaporite rock of the Paradox formation.

Porosity development in the undifferentiated Hermosa group is largely restructed to the carbonate reefs and banks within the unit. Locally, the pores have been filled with calcite and anhydrite, resulting in greatly reduced permeabilities (12), (34).

5.22 UNDERLYING CONFINING FORMATIONS

5.221 Cambrian

The proposed injection zone is underlain by part of the Cambrian formations. The Silurian and Ordovician deposits normally found beneath the Devonian are most likely not present in the Paradox Valley area. The Ignacio formation is present and is comprised of quartzite, quartzitic sandstone, and friable sandstone. With the exception of fracture zones, the unit is of low porosity and permeability.

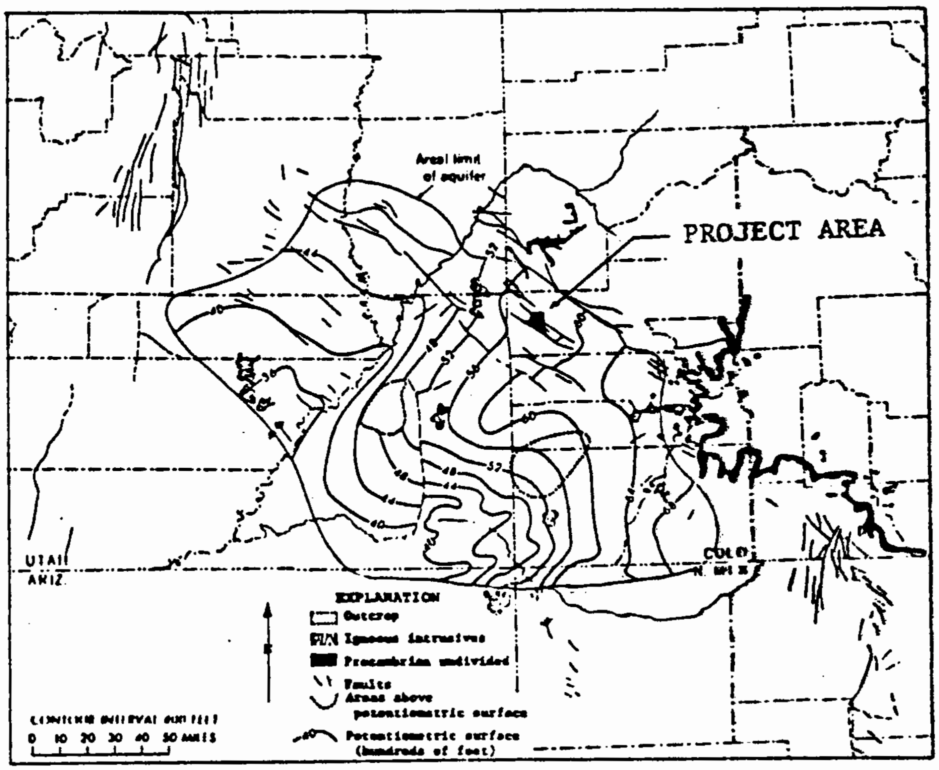


Figure 5-9

Potentiometric map of the Paradox Member of the Pennsylvanian Hermosa Formation. Datum is sea-level.

Few discharges from this unit are known with the exception of saline seeps near the mouth of the Little Colorado River. Other members of the Cambrian are present in the far southern and western parts of the Paradox Basin Region. Figure 5-10 is an isopach of all Cambrian rocks (Ignacio, Bright Angel Shale, Mauv Limestone, and Lynch Dolomite). Indicated thickness is about 450 feet in the Project Area.

5.222 Precambrian

The Precambrian is a heterogeneous complex of metamorphic and igneous rocks. Subsurface control is quite limited but in general the porosity and permeability are quite low. These formations are excellent confining zones preventing the downward movement of fluid.

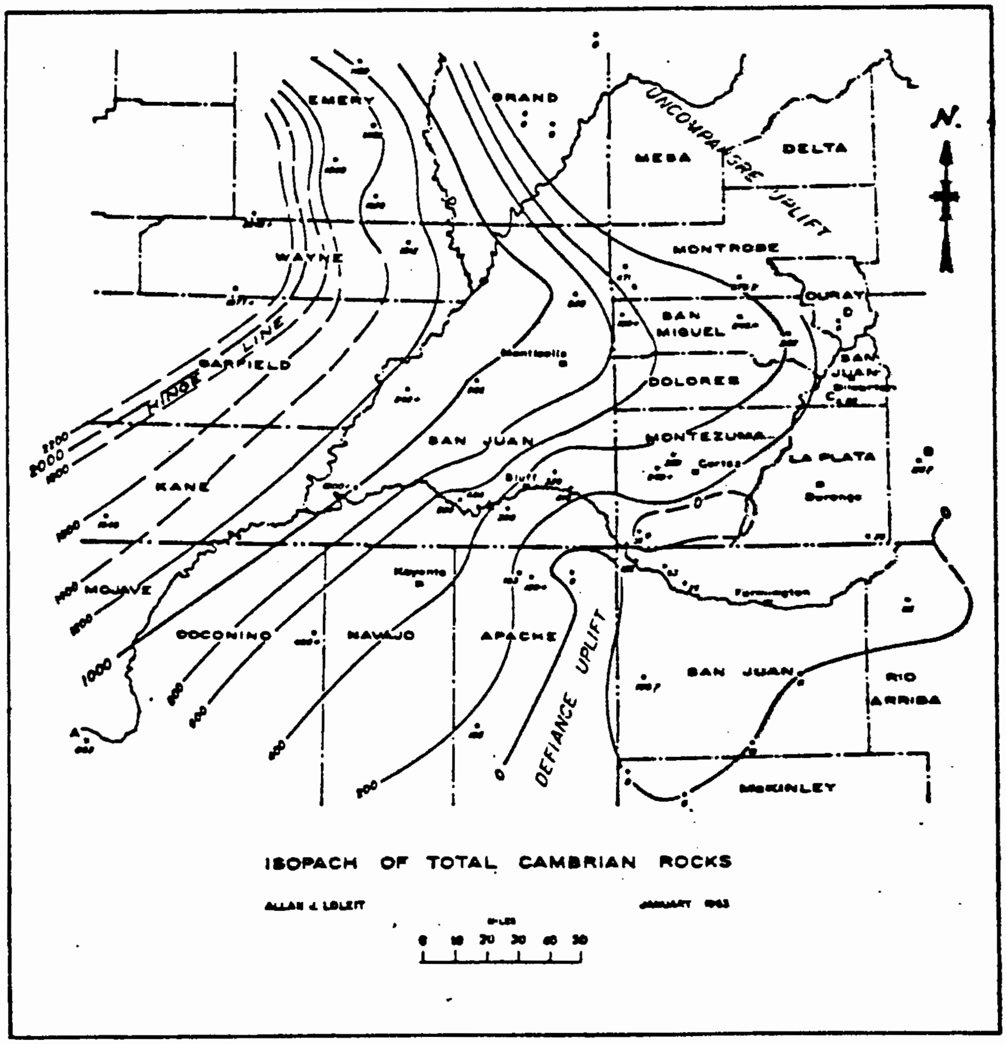


Figure 5-10

Isopach of Total Cambrian Rocks

SECTION 6

RESERVOIR PROPERTIES AND EXPECTED DEEP WELL PERFORMANCE

6.1 RESERVOIR PROPERTIES

Information on the properties of the targeted disposal reservoirs at the Continental well location is limited. The three characteristics needed for prediction of injection well performance, formation thickness, permeability, and porosity are not known. Data from nearby areas were used to obtain best estimates. The estimate for formation thickness is believed to be the most accurate of the three.

6.11 Thickness

The Laterlog (enclosed in pocket in Final Report Draft, October 1981) from the Continental well indicates that 274 feet of Mississippian formation was drilled and that drilling was stopped before reaching the bottom of the Mississippian. As reported in Section 5, the expected gross thickness of the Mississippian is 300 to 400 feet. A gross thickness of 350 feet was used for our well performance calculations. A gross thickness of 200 feet was used for the Devonian.

There is some possibility of the Silurian or Ordivician formations being present below the Devonian; however, the conservative assumption was made that they are absent. Therefore, the total gross thickness used was 500 feet.

The gross thickness was discounted heavily in estimating the net thickness. Log data indicate that approximately 22 percent of the Mississippian is porous so a net thickness of 120 feet was used for the combined Mississippian and Devonian.

6.12 Porosity

Porosity cannot be determined in the Continental well but an average of about three percent was indicated by the sonic log from the Union well. It should be noted that limestones and dolomites with a relatively low porosity of three percent can have very high injection capacities because of extensive fracture porosity which is not detectable with the sonic log.

The indicated porosity of three percent is considerably less than the 30 to 40 percent reported in the Feasibility Study by Frank Turner. Considering all available data and our experience elsewhere with the Mississippian, we are estimating a porosity of eight percent. Accuracy of this estimate does not significantly affect the calculated rate vs pressure of the injection well. However, the volume of the cylindrical shaped "bubble" of injected brine is indirectly proportional to the porosity.

6.13 Permeability

Insufficient data are available to determine permeability so an accurate injection rate vs pressure relationship cannot be established. However, to permit some reasonable predictions of injectivity, permeabilities of 100 millidarcies to 500 millidarcies were assumed. The actual permeability of the deepened Continental well probably will be bracketed by these two assumed values.

6.2 EXPECTED DEEP WELL PERFORMANCE

6.21 Radius of Frontal Edge of Injected Brine

An estimate of the minimum travel distance of the injected brine was calculated by assuming the injected brine will occupy a vertical cylinder centered on the injection well. The height of the cylinder is the effective (net) thickness of the formation receiving the brine.

The properties of the disposal formations are shown in the following table.

TABLE 6-1

Formations	Thickness, ft Gross	Thickness, ft Net	Porosity, Percent
Madison & Leadville (Mississippian)	350	76	8
Ouray & Elbert (Devonian)	200	44	8
Total for Injection Interval	550	120	8

For the purposes of these calculations the formations are assumed to be of equal permeability and therefore each will accept an equal volume of injected brine per vertical foot of effective thickness.

The Paradox brine injection rate is 900 gpm or 63.24 million cubic feet a year.

The following formula was used to calculate the minimum travel distance:

$$r = \sqrt{\frac{v}{\pi h \phi}}$$

r: radial distance of the injected brine front in feet

v: volume of injected waste in cubic feet

h: effective thickness of the injection formations in feet

ϕ: average porosity of the injection formations

The minimum travel distances as shown in Table 6-2 indicate 1400 feet in one year, 4600 feet in 10 ears and 14,500 feet in 100 years.

6.22 Displacement Mechanism

All connected pore spaces in the Mississippian-Devonian formations are filled with brine (except in isolated areas of "highs" where occasional small pockets of hydrocarbons could be present.) Injection of well field brine requires displacement of an equal volume of Mississippian-Devonian brine radially outward from the injection well.

The disposal formation brines and the disposal formation rock have a slight degree of compressibility. Estimated combined value for the reservoir is 7×10^{-6} per psi of increased pressure. Although this compressibility factor is small, the available volume for brine storage is very large because of the enormous volume of the disposal formation.

6.23 Variations in the Radius of the Frontal Edge

Actual position of the frontal edge of the injected brine bubble may be similar to the minimum radial calculations at some positions around the disposal well. However, in most locations around the circumference the actual edge will be more or less than the theoretical minimum. The three factors which may cause changes in the minimum circumference of the frontal edge are the influence of dispersion, fault barriers, or other discontinuities of the disposal formation such as the Uncompahgre Uplift.

6.231 Influence of Dispersion

The injected brine will travel farther than the calculated minimum travel distance because of dispersion (Injected brine does not completely displace the brine in every pore space in the formation). Variations in formation porosity and channeling through zones of higher permeability or fractures result in some "pockets" of formation brine (connate water) being bypassed. A standard equation for estimating the increase in travel distance due to dispersion is:

$$r_d = r + 2.3 \sqrt{Dr}$$

r: minimum radial distance of travel, feet

r_d: radial distance of travel with dispersion, feet

D: Dispersion coefficient, 65 feet for limestones

The calculated travel distances after adjustment for dispersion are presented in Table 6-2 along with the minimum radii.

The minimum travel distance and travel distance after adjustment for dispersion are plotted with respect to time on Figure 6-1, "Injected Brine Frontal Movement vs. Time".

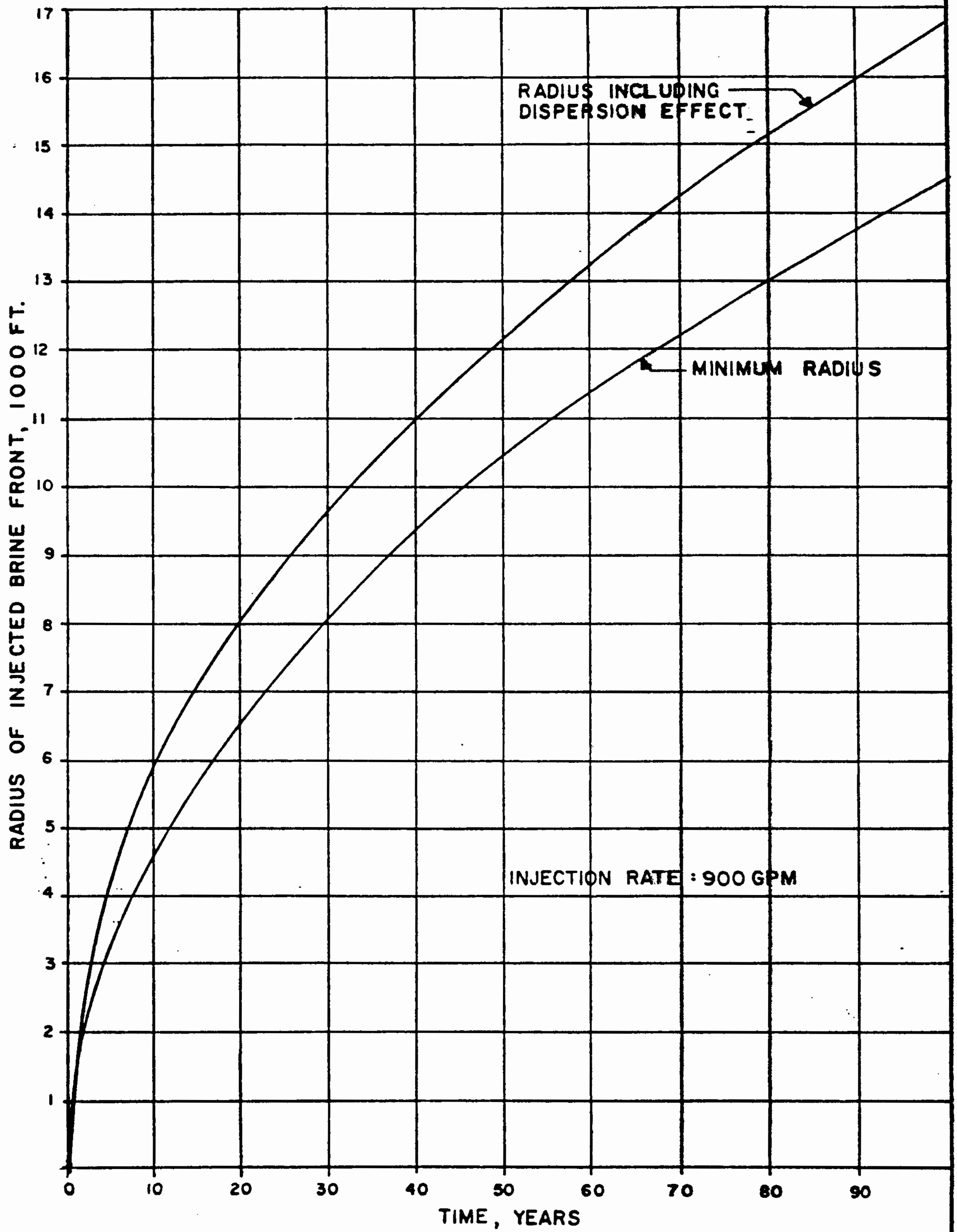
TABLE 6-2

Time	Injected Volume ft	Radius of Bubble, feet		
			Dispersed	
		Minimum*	Increase	Total
3 mo	15.81×10^6	724	499	1,223
1 yr	63.24×10^6	1,448	706	2,154
5 yr	316.2×10^6	3,238	1,055	4,293
10 yr	632.4×10^6	4,579	1,255	5,834
25 yr	$1,581. \times 10^6$	7,240	1,578	8,818
50 yr	$3,162. \times 10^6$	10,239	1,876	12,115
100 yr	$6,324. \times 10^6$	14,481	2,231	16,712

*Assuming isotropic conditions

6.232 Fault Barriers

There are several major faults in the northeastern part of the Paradox Basin, some within a few miles of the Project Area. The effect on the shape of the injected bubble of salt water is expected to be minimal because, as indicated in Figure 6-1, it will take about 35 years for the dispersed bubble to reach a radius of two miles. Some distortion of the circular shape of the bubble will occur as the advancing pressure wave encounters a fault barrier. Radius of the pressure wave will be considerably larger than the radius of the injected bubble. Meaningful calculations of the distortion would require that a detailed study be made to determine the exact distance, strike and dip angles of all faults in the vicinity of the Project Area. Purchase and detailed study of several (possibly all) of the seismograph traverses would be required.



INJECTED BRINE FRONTAL MOVEMENT VS. TIME

FIGURE NO. 6-1

6.233 Uncompahgre Uplift

The Mississippian formation is absent about 10 miles northeast of the Project Area, cut off by the Uncompahgre Uplift. This discontinuity is too far removed for the bubble to reach it; however, the shape of the bubble will be flattened on that side after the pressure wave reaches it.

6.234 Mississippian - Molas Paleokarstic Interface

The paleokarstic interface at the top of the Mississippian formation and the bottom of the Molas formation was examined to determine its influence on the injection pressures and flow of the injected brine. Logs from the Continental well and Union well indicated that the upper zone of the Mississippian has several thin layers of low permeability which effectively separate the permeable zone of the Mississippian from the paleokarstic bottom of the Molas.

The well completion plan calls for the casing to be set and cemented in place through the upper zones (74 feet into the Mississippian) which would prevent direct injection of brine into the upper zones.

A worst case evaluation of these upper zones was done by assuming these highly permeable and porous zones are open directly to the well bore.

The first step was to calculate pressure rises for brine injection based on a composite formation including either a 5-foot or 10-foot thick zone with a permeability of 200 md and a porosity of 20 percent.

The greatest volume/ft of thickness occurred in a 5-foot thick zone with a permeability of 200 md and a porosity of 20 percent evaluated in combination with 120 net feet of Mississippian and Devonian with 100 md permeability and 8 percent porosity. This resulted in 43 percent of the 900 gpm of brine injection entering the high permeability, high porosity upper zone. The high porosity greatly offsets the thinness of the zone, but the minimum 100-year bubble still would have a relatively large radius of 29,400 feet or 5.6 miles. Since these calculations are based on the zone having direct communication with the well bore (highly unlikely) no additional work to account for fingering was done. The actual volume of brine entering the upper zone would probably be significantly less than indicated in this worst case calculation.

6.24 Drill Stem Test Data, Exploration Wells

When the oil exploratory wells were drilled in the project area, drill stem tests were run on two of the wells. Objective of the tests was to detect the presence of oil or gas, so they are not detailed enough to give reliable permeability data. However, they were of some benefit in evaluating the reservoirs.

The limited available data are as follows:

6.241 Continental, Well No. 1 Scorup

Mississippian interval from 14,780 to 15,000 feet (220 feet) was tested. Tool was open for two hours then shut in for one hour. A strong blow was reported throughout the test. Water recovery consisted of 4,950 feet of water cushion and 8,500 feet of salt water. Formation pressure ranged from 3,440 to 6,400 psi. The one-hour shut-in pressure was 6,510 psi and the hydrostatic pressure was 8,760 psi.

6.242 Union, 1-0-30 Ortho Ayers

Interval from 14,114 to 14,200 feet (86 feet) was tested. Tool opened with a weak blow, increasing to 12 inches in five minutes. After a one-hour shut-in, it opened with a weak blow which increased to 12-inches then decreased slightly at the end of two hours. Shut-in time was four hours. Water cushion recovery was 4,150 feet and recovery of salt water was 6,680 feet. Total dissolved solids content was 200,000 ppm at the top and 137,000 ppm at the bottom.

Initial hydrostatic pressure was 7,674 psi. Initial flowing pressure was 2,245 to 2,558 psi. Initial shut-in pressure was 6,220 psi and final flowing pressure was 2,558 to 5,318 psi. Final shut-in pressure was 6,201 psi. Final hydrostatic pressure was 7,710 psi and the bottom hole temperature was 229° F.

6.25 Pressure Wave Front, 100 Years

There is known brine discharge from the Mississippian formation seeping from the canyon walls of the Little Colorado River near the confluence of the Colorado and the Little Colorado Rivers. This point of discharge is approximately 220 miles from the site of the proposed injection well(s).

There is at least one partial fault barrier which will lengthen the pathway of the pressure wave from the injection well(s) to the Little Colorado River. On the other hand, the pinch-out of the Mississippian formation at the Uncompahgre Uplift northeast of the injection well(s) will cause the pressure wave to move faster toward the Little Colorado River. There is not sufficient subsurface geological information to determine which of these opposing conditions will have the strongest influence. If they are assumed to be approximately equal, the following table which is for isotropic conditions will apply.

After 100 Years of Injection at 900 gpm

Assumed Permeability, md	Radius of Edge of Pressure Wave: Feet	Radius of Edge of Pressure Wave: Miles
100	280,000	53
200	390,000	74
300	440,000	83
500	600,000	114
1000	890,000	169

SECTION 7

EVALUATION OF EXISTING PETROLEUM EXPLORATION WELLS FOR USE AS INJECTION WELLS

There are four oil exploration wells located within approximately four miles of the brine well field. Locations and depths of these wells are shown on Figure 3-2. A summary of the pertinent data for each of the four wells is shown in Table 7-1.

7.1 CHICAGO CORPORATION, NO. 1 AYERS

The Chicago Corporation well was drilled to 6860 feet. A schematic cross section of the well is shown on Figure 7-1. This abandoned well has 527 feet of 9 5/8-inch surface casing cemented in with 40 sacks of cement. The small diameter of this surface casing would restrict the diameter of the long string of casing to 7 inches and the tubing diameter to 4 1/2 inches. Friction loss in this small tubing would be about 3000 psi for only one-half of the required flow rate (450 gpm). Therefore, utilization of this well is not feasible.

7.2 UNION OIL COMPANY, NO. 1-0-30 AYERS

The Union well was drilled to an attractive depth of 14,400 feet. However, plugging records show that 1,182 feet of cemented 9 5/8-inch casing was left in

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TABLE 7-1

SUMMARY OF EXISTING PETROLEUM EXPLORATION WELLS, PARADOX VALLEY, MONTROSE COUNTY, COLORADO

Company & Well Number	Location	Land Status	Distance From Brine Wellfield	Total Depth Drilled In Feet	Elevation Sea Level Datum	Casing Left in Hole	Deepest Formation Penetrated
Chicago Corporation No. 1 Ayers	156 FSL 330 FWL Sec. 31-47N-18W	Patented	4 miles	6,860	5,000' GL	527' of 9-5/8" dia 40 lb.	Hermosa
Union Oil No. 1-0-30 Ayers	1790 FEL 1303 FSL Sec. 30-47N-18W	Patented	3½ miles	14,400	5,010 GL 5,029.5KB	1182' of 9-5/8" dia 40 and 43.5 lb.	Devonian
Continental Oil No. 1 Scorup - Somerville - Wilcox	632 FSL 1300 FWL Sec. 8-47N-18W	Patented	1½ miles	15,000	5,050 GL 5,064 KB	1220' of 13-3/8" dia 48 lb. H-40	Mississippian
Jack Grynberg No. 33-3, Martin Mesa	NW-SE Sec. 3-47N-18W	Federal	2 miles	7,289	4,960 GL 4,972 KB	321' of 13-3/8" dia 54.5 lb.	Hermosa-Paradox

Distance to Brine Well Field: 4 Miles   Elevation 5,000' GL   Land: Patented

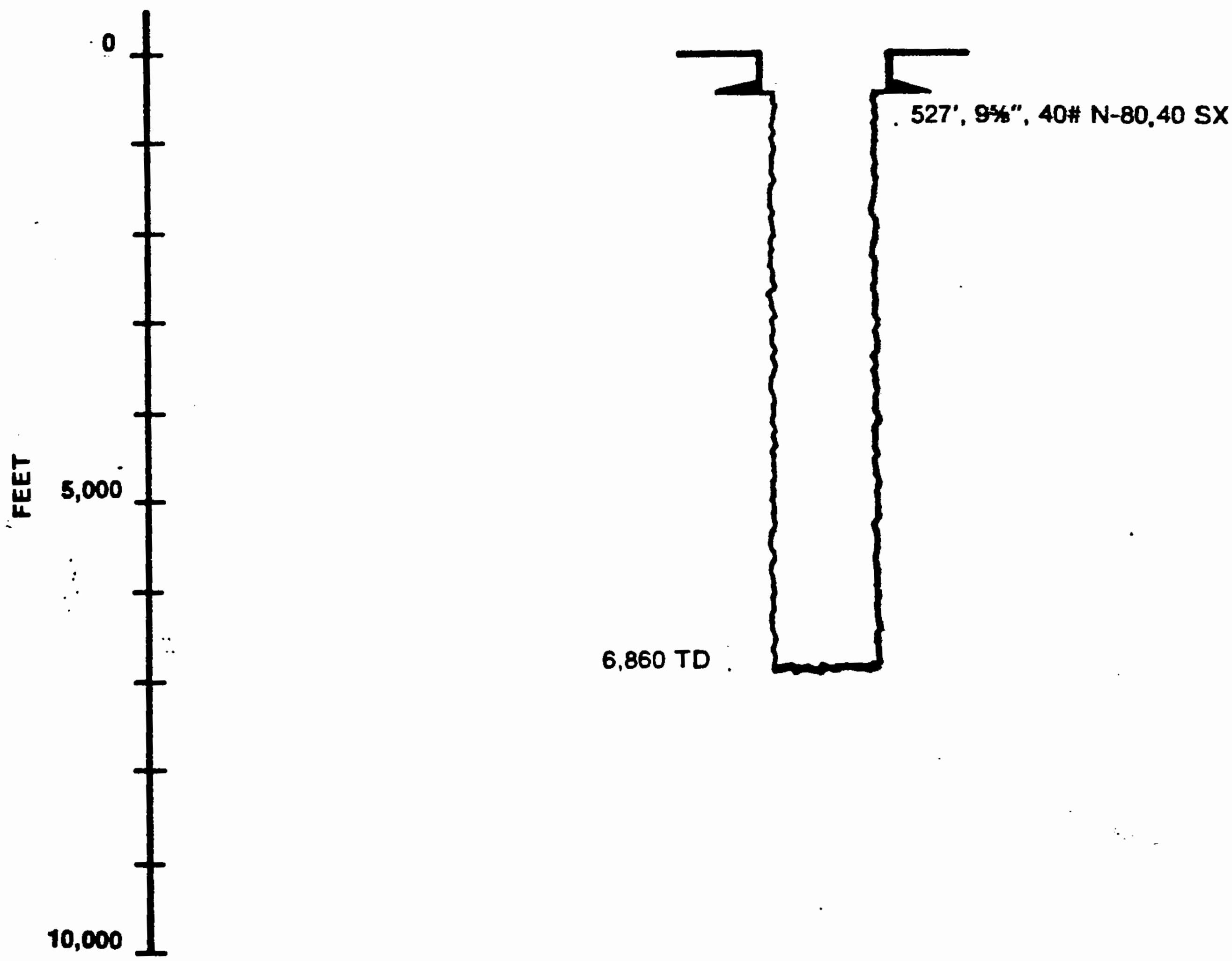

Figure 7-1
Chicago Corp. Exploration Well #1 Ayers

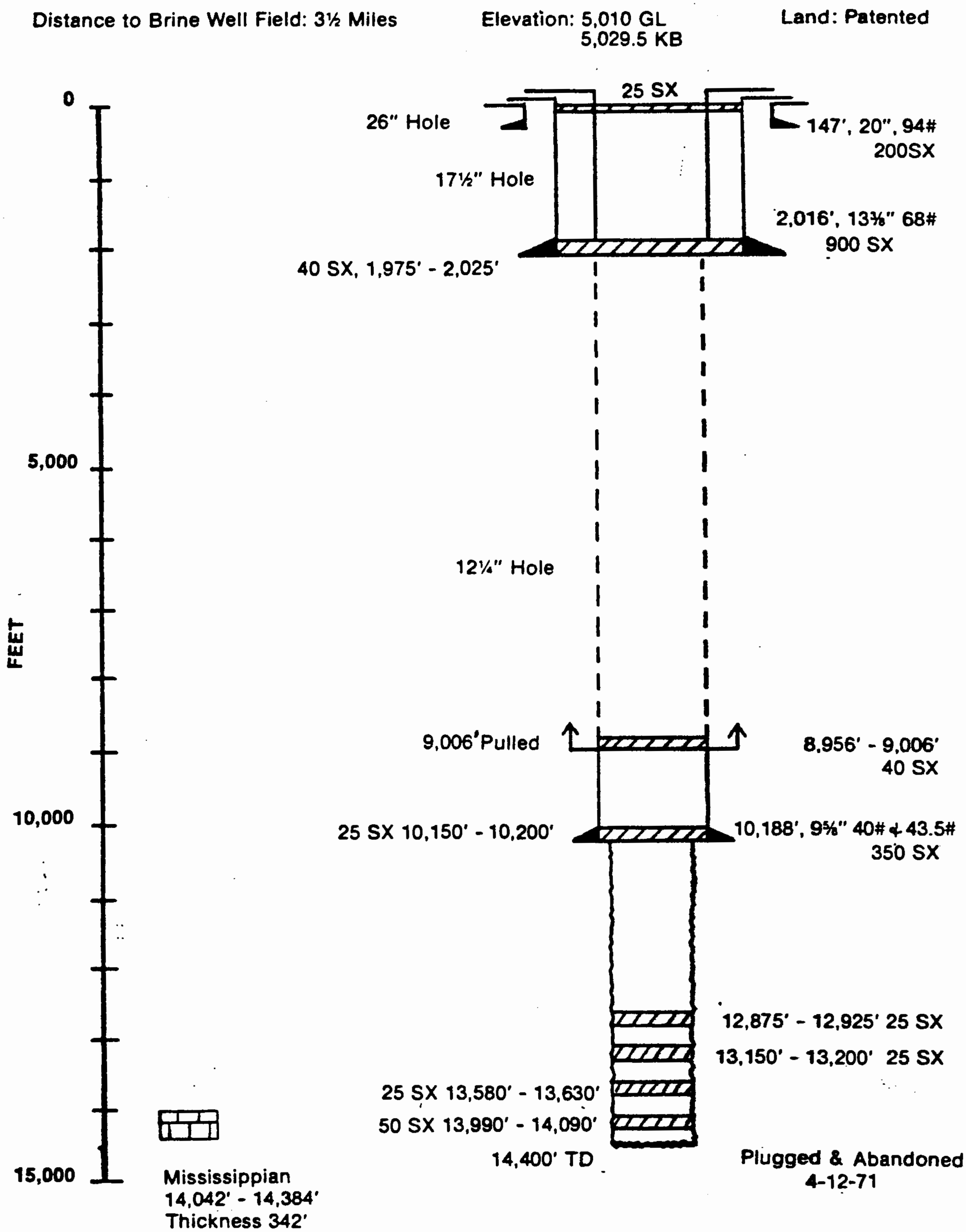

Figure 7-2
Union Oil Co. Exploration Well #1-0-30 Ortho Ayers

the hole from the depth of 9,006 feet to 10,188 feet. This abandoned casing precludes the installation of 9 5/8-inch casing to the top of the Mississippian, thereby preventing the use of adequate size (7-inch) injection tubing. Use of this well would result in an unacceptable restriction of the disposal rate. The 4-mile distance from the well field to the Union well is another negative factor for use of the Union well. Schematic cross-section of this plugged and abandoned well is shown in Figure 7-2.

7.3 JACK GRYNBERG, NO. 33-3 MARTIN MESA

The status of the Grynberg well as plugged and abandoned is shown in Figure 7-3. The relatively shallow total drilled depth of 7,289 feet makes it less attractive than the Continental well. However, if a second well is needed, it should be considered as an alternative to drilling a new well near the injection plant. The cost for drilling a new well should be compared with the costs for reworking the Grynberg well which include deepening to the Precambrian, installing a pressure pipeline from the injection plant to the well and the additional electrical costs for pumping the brine through the longer line to the Grynberg well.

Estimated cost of re-entering the Grynberg well is included in the cost estimate report.

7.4 CONTINENTAL OIL COMPANY, WELL NO.1 SCORUP

The Continental No. 1 Scorup Well is the most attractive well for re-entry and completion as a disposal well. It is the closest well (about 1-1/2 miles). It is the deepest of the four wells (15,000 feet) and it has large enough pipe in the hole to permit installation of a satisfactory tubing size (7-inch tubing in 9 5/8-inch casing). The condition of this well when plugged and abandoned is shown in Figure 7-4.

It is concluded that the Continental well, Scorup No. 1, should be re-entered, cleaned out and completed as a test well for brine disposal.

7.5 OTHER WELLS

Records indicate that there are four small diameter shallow holes of unspecified origin in the area. These shallow holes (less than 6000 feet) are located in sections 6, 18, and 19 of T47N R18W and are not suitable wells for re-entry.

Distance to Brine Well Field: 2 Miles

Elevation 4,960' GL
4,972' KB

Land: Federal

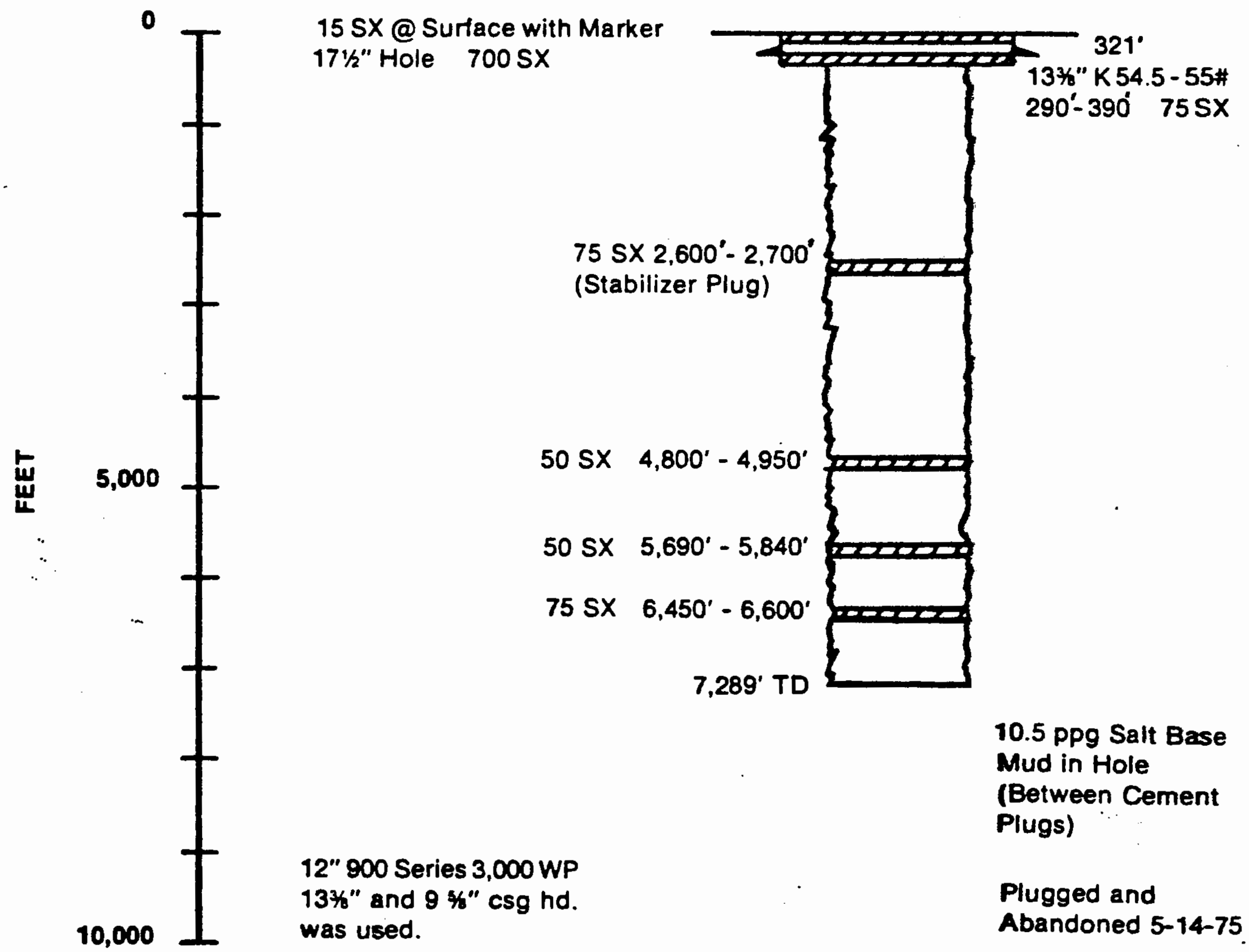

Figure 7-3
Jack Grynberg Exploration Well #33-3 Martin Mesa

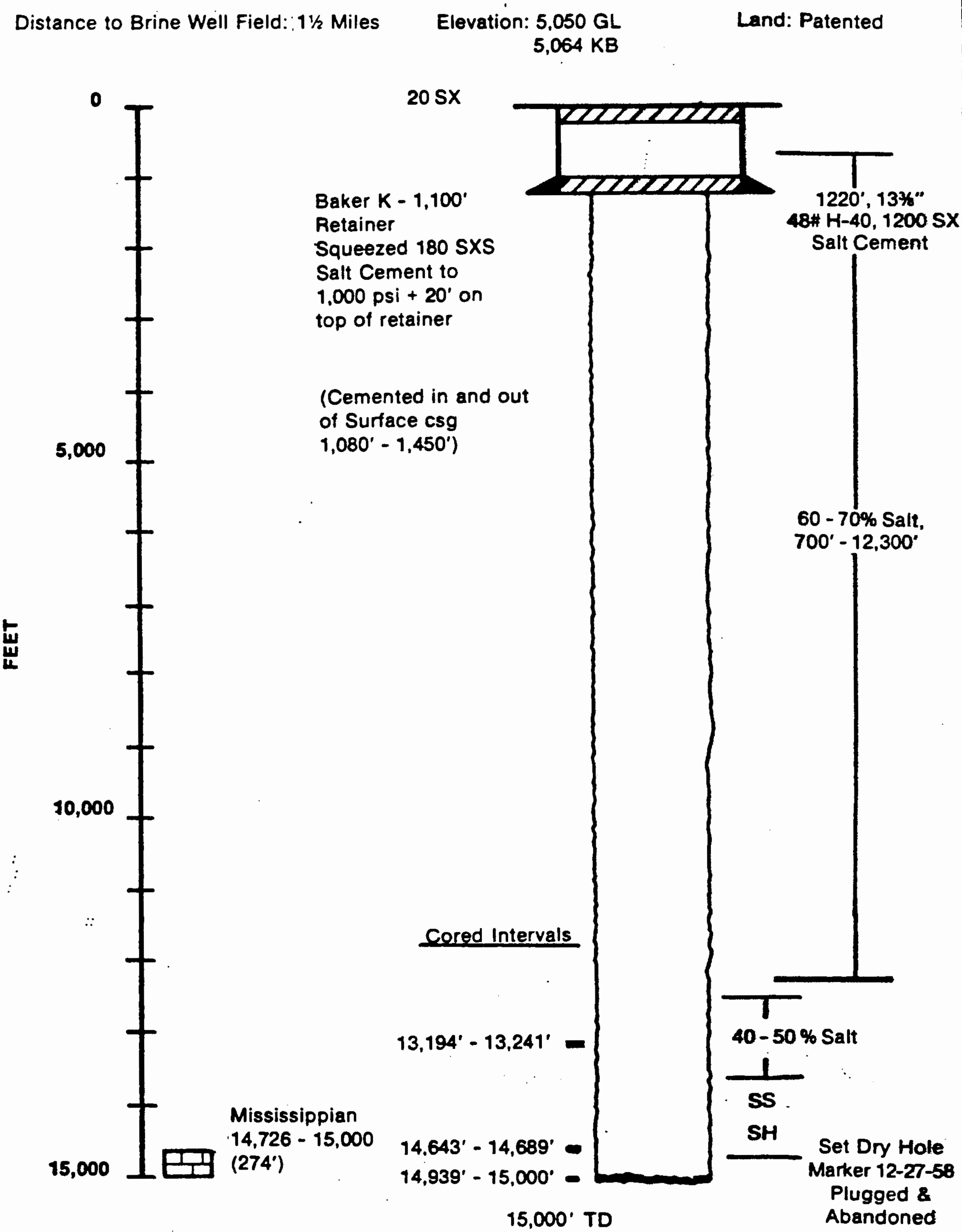

Figure 7-4
Continental Oil Exploration Well #1 Scorup-Somerville-Wilcox

SECTION 8

RECOMMENDED REWORK OF CONTINENTAL WELL, SCORUP NO. 1

Re-entry and completion of the Continental well instead of drilling a new well is recommended. However, this recommendation is contingent upon the surface casing in this 23-year old well being in good condition. There is a possibility of severe wear and/or severe corrosion. The condition of this casing should be determined prior to installing any of the pipeline or surface treatment systems. Recommended procedure is as follows:

- o Drill the top cement plug and the lower cement plug to the bottom of the surface casing using a small oil-field pulling unit with a power swivel.

- o Run a casing inspection tool to determine condition of the 13-3/8-inch casing.

- o If casing condition in the Continental well is satisfactory, move out the pulling unit and move in a deep well rig to re-open the hole and drill to the Precambrian. Test the Mississippian and lower sedimentary formations by injecting brine with portable pumps for two weeks. If the permeability is high enough to permit injection of 900 gpm of brine into an affordable number of injection wells, complete the Continental well and, if needed, drill a second well.

- If casing condition of the Continental well is unsatisfactory, plug the well and move out the pulling unit. Move in a deep well rig at the No. 2 well location near the plant site. Drill to the Precambrian and test inject for two weeks. If the permeability is high enough to permit injection of 900 gpm of brine into an affordable number of injection wells, complete this first well, drill the additional well(s) if needed, and install the surface system.

Drilling prognosis and specifications for materials for drilling and completing the disposal wells are included in the Engineering Design Package.

SECTION 9

TREATMENT REQUIREMENTS AND CHARACTERIZATION OF THE WELL FIELD BRINE

9.1 TREATMENT REQUIREMENTS

Successful long-term deep well disposal of the brine requires:

- o prevention of plugging of the disposal formations with suspended solids, and
- o adequate corrosion control to prevent excessive loss of exposed equipment, i.e., pipeline, pumps, valves, filter shells and the deep well tubing.

Plugging problems usually are the more serious of the two. Some types of severe plugging can result in loss of the well. Severe corrosion typically requires replacement of exposed equipment, i.e., pumps, well tubing, etc., but not the loss of the well.

Causes of well plugging include the following:

(a) excessive suspended solids which plug the well bore,

- o organic matter or clays, silts, precipitates, including iron sulfide, calcium or magnesium carbonates, barium or calcium sulfates, etc., which are present in the brine as it is pumped from the well field, o suspended solids that form in the flowing stream of brine, including microbiological growths, inorganic mineral precipitations, corrosion products, or sloughed particles of protective coatings,

(b) precipitation of minerals within the disposal formations,

(c) reactions between the injection fluid and clays in the disposal formation.

Item (c) is not expected to be a problem in this brine disposal system. Clay dispersion and swelling typically occur in certain conditions where fresh water rather than brine is being injected into sandstone containing montmorillonite. These conditions will not be present in this system.

Item (b) requires some consideration. There will be a significant rise in temperature of the brine as it moves down the tubing and into the disposal formation. Chemical analysis indicates that the two concerns are precipitation of calcium sulfate or calcium carbonate. The solubility of calcium carbonate decreases with increased temperature The solubility of calcium sulfate increases with increased temperature to about 95° F then decreases with additional temperature rise.

The temperature rise will be accompanied by an increase in pressure to more than 7,000 psi. These large pressure increases typically increase the solubilities of calcium compounds by several hundred parts per million, which more than compensates for the decreased solubility caused by heating. Some iron from the Mississippian brine will precipitate as iron sulfide but only at the limited mixing zone at the injection front. This will not create an operational problem. It can be prevented around the well bore by injecting a few thousand gallons of clean fresh water as a buffer before any of the well field brine is injected. This will displace the Mississippian brine from the well bore area.

Item (a) is significant in this disposal system. An investigation of the suspended solids concentrations from various wells in the well field was made by collecting the suspended solids on Millipore filters. The adherent characteristics of the iron sulfide (with traces of oil) present in the brine will cause plugging of the disposal formations if not removed prior to injection.

Hydrogen sulfide content of the brine is another contaminant requiring specific design features. Hydrogen sulfide causes excessive corrosion of mild steel when subjected to long-term exposure. Reports from the well field operations indicate that 316 stainless steel provides satisfactory service.

The pipelines, pumps, well tubing, bottom joint of the casing and all other equipment exposed to the brine is designed for corrosion protection. Materials specified are plastic, plastic coated steel or 316 stainless steel.

It is recommended that corrosion coupons made of 316 stainless steel and additional plastic coated mild steel coupons be installed in the existing well field to provide quantitative data on the resistance of these materials to the corrosive effects of the brine-sulfide environment.

9.2 SUSPENDED SOLIDS LIMITATIONS

Plugging problems with suspended solids are a result of accumulated deposition of solids in the disposal formation. Particle size, cohesiveness, etc., affect the degree of plugging. Although plugging severity is not a linear function of suspended solids concentration, for practical purposes it can be assumed that a suspended solids concentration of 1.0 mg/l for one month will cause damage that is similar to that caused by a concentration of 30 mg/l for one day.

From an operational viewpoint it is desirable to reduce the suspended solids content to as near zero as possible; however, cost effectiveness is a factor. The recommended diatomaceous earth filter installation is expected to reduce the suspended solids content several tenths of a mg/l. i.e., from 0.8 mg/l to 0.1 or 0.2 mg/l. Even less than 0.1 mg/l may be achieved with use of optimum filter aid material.

Based on present knowledge of solids characterization, it is believed that satisfactory long term brine disposal will be achieved if the average suspended solids content is reduced to 0.3 mg/l or less.

9.3 CHARACTERIZATION OF THE WELL FIELD BRINE

9.31 Suspended Solids, Chemical Analyses First Group, March 3, 4, 1981

Thirteen Millipore samples from six wells in the brine field were collected and examined. Type HA Millipore filters with a pore size of 0.45 micron were used so virtually all of the suspended solids were trapped on the filters. An analysis was run on brine samples from some of the wells and on some of the removed suspended solids.

Tests for total sulfide in the brine samples (Table 9-1) showed a range of <1 to 82 mg/l. Tests for precipitated iron on the Millipore filter papers (Table 9-2) indicated a range of less than .01 mg/l to 0.28 mg/l. The precipitated iron probably was present as iron sulfide at the time of sampling. Acid insolubles on the filter papers ranged from 0.02 mg/l to 1.28 mg/l. The larger differences in suspended solids from well-to-well plus evidence that startup and shutdown of the wells increased the suspended solids content indicated that additional testing would be advisable.

Preliminary conclusion was that the concentrations of suspended solids in the unfiltered water were sufficiently high that the total volume of suspended solids entering a well would cause increased pressures due to plugging.

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RESOURCE SCIENCES CENTER | 6600 S. YALE AVE. | TULSA, OKLAHOMA 74177
PHONE (918) 496-6026 or (918) 496-6027 | TELEX 49-7493 WBEC-TUL

TABLE 9-1.

ANALYSIS OF BRINE SAMPLES

Submitted By: Bureau of Reclamation
Project #4611

Assigned Laboratory No: 811521 thru 811532

Date Received: 3/9/81 **Date Reported:** 3/24/81 (Confirming)

Sample Identification: Listed Below

Test	Results*			
	811521	811522	811523	811524
Well No., Sample No.	3W#1	3W#2	3W#3	4W
Filter #	1,365	1,366	1,354	1,353
pH, units	5.8	6.3	5.7	5.8
Total Sulfide	71	82	69	82
m-Alkalinity as $CaCO_3$	236	234	240	234
	811525	811526	811527	811528
	7W	1E	5E#1	5E#2
Filter #	1,367	1,357	1,361	1,362
pH, units	6.6	6.5	5.6	5.5
Total Sulfide	15	12	71	55
m-Alkalinity as $CaCO_3$	150	180	206	206
	811529	811530	811531	811532
	5E#3	8E#1	8E#2	8E#3
Filter #	1,529	1,530	1,531	1,532
pH, units	6.2	5.5	6.3	5.6
Total Sulfide	66	76	<1	<1
m-Alkalinity as $CaCO_3$	200	216	216	214

***The above results were obtained by APHA Standard Methods, 14th Ed., EPA Methods for Chemical Analysis of Water and Wastes and/or ASTM Standards, unless otherwise indicated. Results are in milligrams per liter unless otherwise indicated**

TABLE 9-2

SUSPENDED SOLIDS CONTENT

BRINE WELLS IN THE WELL FIELD
March 3, 4, 1981

Well No.	Sample No.	Filter Paper No.	Vol. Brine Filtered, Liters	Filter Plugged	Precipitated Iron, Mg/1	Acid Insolubles, Mg/1	Barium Mg/1	Boron Mg/1	Calcium Mg/1
1E	1*	1357	28	Yes	0.30	0.06	0.01	<0.01	<0.01
1E	2	1358	25	No	0.28	0.05			
5E	1	1361	40	No	<0.01	-			
5E	2	1362	40	No	<0.01	0.08			
5E	3	1356**	6	Yes	damaged	damaged			
8E	1	1359	40	No	0.03	0.11			
8E	2	1360	40	No	0.03	0.04			
8E	3	1355**	8	Yes	0.53	1.28	<0.01	0.05	0.13
3W	1	1365	40	No	0.01	0.05			
3W	2	1366	40	No	0.03	0.05			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

9.32 Suspended Solids, Chemical Analyses May 21, 22, 1981

Filtered and unfiltered brine samples and Millipore filter samples were collected from the main disposal line carrying the brine from the well field to the temporary disposal pond. Sampling point was where Well 7-W connects to the line. Results of the Millipore suspended solids tests are plotted on Figure 9-1.

Average concentration of suspended solids during continuous well operation was 0.8 mg/l. This is equivalent to 260 pounds per month of dry solids or 1000 pounds per month of solids with 75 percent moisture.

Shutdown of the wells because of power outages averages 4.4 times per month. Calculations based on the test results indicate that the increased suspended solids load caused by startups is only 36 pounds per month of solids with 75 percent moisture.

It is concluded that the suspended solids load caused by startups is relative insignificant but that the load during constant operation of 1000 pounds per month will necessitate installation of efficient filters.

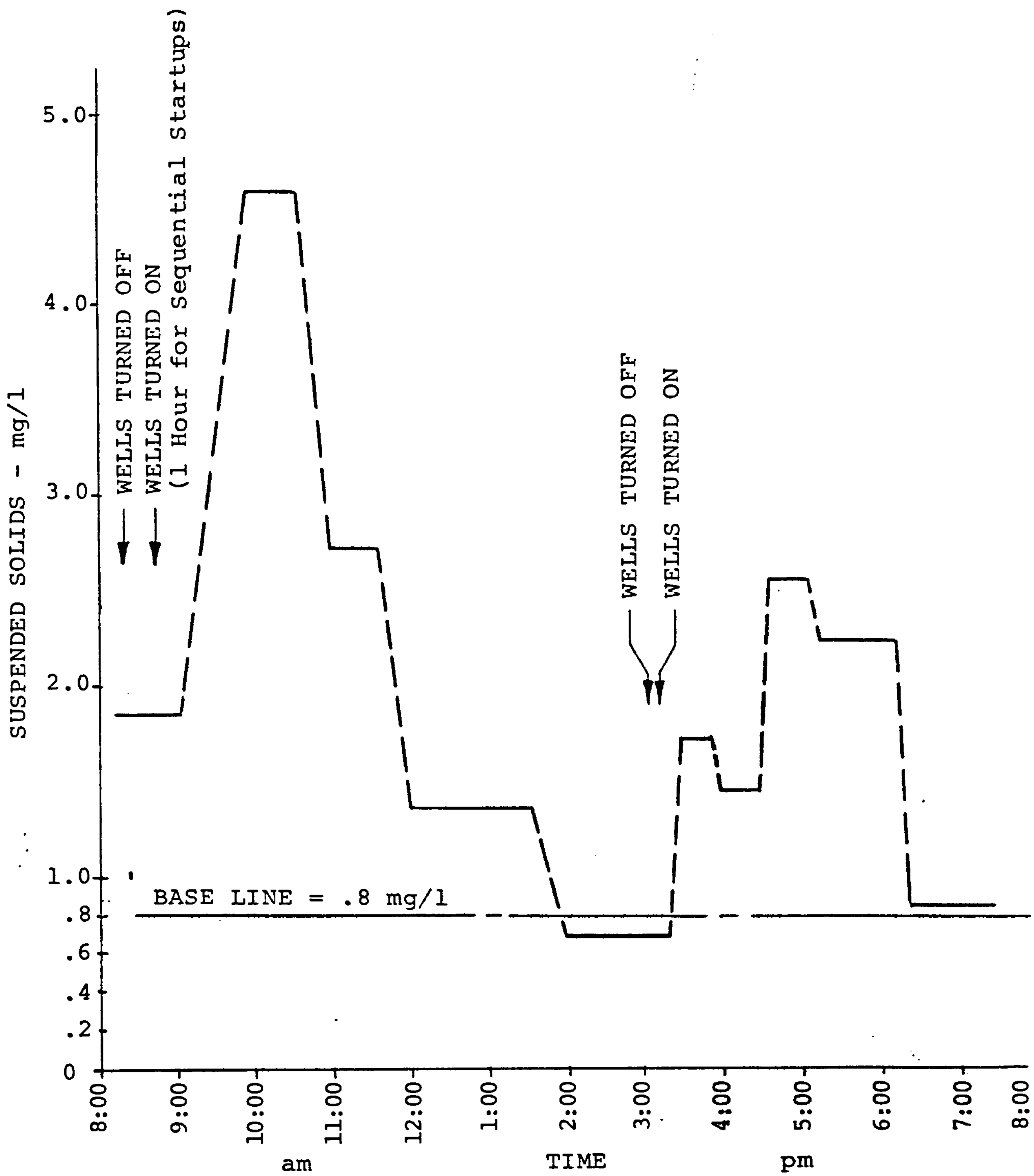


FIGURE 9-1 CHANGES IN SUSPENDED SOLIDS CONCENTRATION RESULTING FROM SHUTDOWN AND STARTUP OF BRINE WELLS

9.33 Hazardous Waste Analyses

9.331 Brine Samples

Two samples of well field brine, one filtered and one unfiltered were analyzed for hazardous waste evaluation. Samples were secured by Williams Brothers Engineering Company, May 21, 1981, at the pipeline through which the composite brine flows to the temporary disposal pond.

Results are shown in the laboratory report, Table 9-3. Concentrations of all of the eight elements tested are below the Federal EPA limits specified for hazardous waste classification. It is concluded that the brine from the well field is not a hazardous waste and requires no special handling precautions.

9.332 Suspended Solids

A sample of suspended solids was analyzed for hazardous waste determination. Sample consisted of the suspended solids which were collected on 43 Millipore filters by BOR personnel in August, 1981. All of the papers were combined into one sample thereby obtaining sufficient sample weight to obtain definitive results.

Results of analysis of the acid extractions of the composite sample are shown in Table 9-4. All test results were below the specified limits.

TABLE 9-3

WILLIAMS BROTHERS LABORATORIES

RESOURCE SCIENCES CENTER | 6600 S YALE AVE | TULSA OKLAHOMA 74177
PHONE (918) 496-6026 or (918) 496-6027 | TELEX 49-7493 WBEC-TUL

HAZARDOUS WASTE ANALYSIS FILTERED AND UNFILTERED WELL FIELD BRINE

Submitted By: Bureau of Reclamation
Project 4611

Assigned Laboratory No: 812506 and 812508

Date Received: 5/28/81 **Date Reported:** 7/7/81

Sample Identification: See Below

Test **Results***

Conc of EP Toxicity Extract

812506 - #2, Pipeline 7W 5-21-81 8:30-9:30 AM #1 Millipore E. Well - 1E - 8E **Filtered**

812508 - #4, Pipeline 7W 5-21-81 10:45 AM 15°C #2 Millipore Filtrate, all wells down about one hour earlier **Unfiltered**

	Silver	Chromium	Lead	Cadmium	Barium	Arsenic	Selenium	Mercury
812506	0.17	0.13	1.1	0.27	0.25	< 0.03	< 0.001	< 0.0001
812508	0.16	< 0.05	0.97	0.30	0.25	< 0.03	< 0.001	< 0.0001
EPA Limits	5.0	5.0	5.0	1.0	100.	5.0	1.0	0.2

***The above results were obtained by APHA Standard Methods, 14th Ed., EPA Methods for Chemical Analysis of Water and Wastes and/or ASTM Standards, unless otherwise indicated. Results are in milligrams per liter unless otherwise indicated.**

WILLIAMS BROTHERS LABORATORIES

TABLE 9-4

RESOURCE SCIENCES PARK | 6600 S. YALE AVE. | TULSA, OKLAHOMA 74136
PHONE (918) 496-6026 or (918) 496-5020 | TELEX 49-7493 WBEC-TUL

HAZARDOUS WASTE ANALYSIS, SUSPENDED SOLIDS FROM WELL FIELD BRINE

Submitted By: Ray Amstutz

Assigned Laboratory No: 3455

Date Received: ____________ Date Reported: 9-9-81

Sample Identification: DOI, Bureau of Reclamation, Paradox Valley #4611, Millipore Filters (Suspended Solids)

Test	EPA Limits, (Federal Register)	Results*
Hazardous Waste		
EP Toxicity		
Arsenic as As	5.0	.08
Selenium as Se	1.0	< .001
Barium as Ba	100.	< .14
Total Chromium as Cr	5.0	0.1
Cadmium as Cd	1.0	0.76
Lead as Pb	5.0	0.4
Silver as Ag	5.0	0.1
Mercury as Hg	0.2	.003

*The above results were obtained by APHA Standard Methods, 15th Ed., EPA Methods for Chemical Analysis of Water and Wastes and/or ASTM Standards, unless otherwise indicated. Results are in milligrams per liter unless otherwise indicated.

so the suspended solids which will be removed by filtration will be classified as non-hazardous wastes. Also, the quantity per month is too low for hazardous waste classification.

9.34 Radioactivity Analyses

Composite brine samples for radioactivity analysis were collected May 21 and 22, 1981. Samples of suspended solids collected at that time were not of sufficient volume for radioactivity tests. Additional suspended solids samples were collected during the subsequent two-month period ending July 21, 1981. Both brine and suspended solids were analyzed by Eberline Laboratories in Albuquerque.

Test results for the filtered brine, the unfiltered brine and the suspended solids are compared in Table 9-5 with permissible limits set by the Federal EPA. The permissible limits used by the Colorado Department of Health and those published in the Nuclear Regulatory Commission's Title 10 - Energy, Chapter 1 are identical with those set by the Federal EPA.

Where there is a mixture of more than one radionuclide in water, the limiting values are determined by the following procedure from the Notes at the end of Part 20, Appendix B, Title 10 - Energy, Chapter 1, Nuclear Regulatory Commission:

"If the identity and concentration of each radionuclide in the mixture are known, the limiting values should be derived as

Rev. 11/16/81

TABLE 9-5

Sample	Type of Analysis	Analyses Results, pCi/liter	Maximum Permissible Limit, Federal EPA Standards pCi/liter	Maximum Permissible Limit, Federal EPA Standards micro Ci/ml
#2509	U-234	1.1 ± 0.5	30,000	3×10^{-5}
Filtered	U-235	0.00 ± 0.25	30,000	3×10^{-5}
Brine	U-238	0.74 ± 0.48	40,000	4×10^{-5}
3100 ml	Th-228	0.00 ± 0.52	7,000	7×10^{-6}
	Th-230	-0.06 ± 0.18	2,000	2×10^{-6}
	Th-232	-0.15 ± 0.21	2,000	2×10^{-6}
	Ra-226	13 ± 3	30	3×10^{-8}
	Ra-228	17 ± 2	30	3×10^{-8}
#2512	U-234	0.31 ± 0.41	30,000	3×10^{-5}
Unfiltered	U-235	-0.16 ± 0.18	30,000	3×10^{-5}
Brine	U-238	0.67 ± 0.43	40,000	4×10^{-5}
3100 ml	Th-228	0.00 ± 0.50	7,000	7×10^{-6}
	Th-230	0.30 ± 0.19	2,000	2×10^{-6}
	Th-232	0.06 ± 0.17	2,000	2×10^{-6}
	Ra-226	13 ± 3	30	3×10^{-8}
	Ra-228	11 ± 2	30	3×10^{-8}
		pCi/gram	pCi/gram	micro Ci/ml
Solids	U-234	0.0071 ± 0.0020	30	3×10^{-5}
462 g,	U-235	0.0003 ± 0.0005	30	3×10^{-5}
(Includes	U-238	0.0066 ± 0.0009	40	4×10^{-5}
filter	Th-228	0.0028 ± 0.0018	10	1×10^{-5}
papers)	Th-230	0.0090 ± 0.0032	30	3×10^{-5}
	Th-232	0.0062 ± 0.0026	40	4×10^{-5}
	Ra-226	0.0064 ± 0.0019	30	3×10^{-5}
	Ra-228	0.0020 ± 0.0093	30	3×10^{-5}

follows: Determine, for each radionuclide in the mixture, the ratio between the quantity present in the mixture and the limit otherwise established in Appendix B for the specific radionuclide when not in a mixture. The sum of such ratios for all the radionuclides in the mixture may not exceed '1' (i.e., 'unity')

"EXAMPLE: If radionuclides A, B, and C are present in concentrations C_A, C_B, and C_C, and if the applicable MPC's are MPC_A, and MPC_B, and MPC_C respectively, then the concentrations shall be limited so that the following relationship exists:

$$(C_A/MPC_A) + (C_B/MPC_B) + (C_C/MPC_C) \leqq 1$$

"For purposes of this note, a radionuclide may be considered as not present in a mixture if (a) the ratio of the concentration of that radionuclide in the mixture (C_A) to the concentration limit for that radionuclide specified in Table II of Appendix 'B'. (MPC_A) does not exceed 1/10, (i.e. $C_A/MPC_A \leqq 1/10$) and (b) the sum of such ratios for all the radionuclides considered as not present in the mixture does not exceed 1/4 i.e.

$$(C_A/MPC_A + C_B/MPC_B \ldots . + \leqq 1/4)."$$

9.341 Filtered Brine

Results for filtered brine sample No. 2509 were evaluated using the above procedures. The value for the results for the filtered brine sample was 1.00006. Following the directions in the last note, the value, based on Ra 226 and Ra 228, drops to 1.0. (All other terms drop out because each is < 1/10 and total is <1/4). Therefore, the filtered brine sample is classified as a non-radioactive waste.

9.342 Unfiltered Brine

Results for the unfiltered brine sample No. 2512 were analyzed in the same manner as those for the filtered sample and the value was found to be less than 1.0. Therefore the unfiltered brine sample also is classified as a non-radioactive waste.

9.343 Suspended Solids

Results for the insoluble solids were similarly evaluated and the value was below 1. The value actually was zero because all components were less than 1/10 and their summation was less than 1/4, so all components were dropped leaving a value of zero. Therefore, the suspended solids are classified as a non-radioactive waste.

9.344 Conclusions

Comparison of the results of tests for each of the eight isotopes with the EPA limits shows that, individually, each is classified as non-radioactive. This is true for the samples from the filtered and unfiltered brine and the suspended solids.

Likewise, when all eight isotopes are considered together, using the prescribed NRC formula, results for each of the filtered and unfiltered brine and suspended solids samples indicate a non-radioactive classification.

SECTION 11

IMPACT OF DEEP WELL INJECTION ON THE LOCAL ENVIRONMENT

11.1 HISTORY

Paradox Valley has been identified as a significant contributor to the salinity of the Colorado River. The Bureau of Reclamation is conducting a basin-wide program to reduce salinity levels in the Colorado River system.

Title II of the Colorado River Basin Salinity Control Act (Public Law 93-320) of June 24, 1974, authorized the Secretary of the Interior to construct, operate and maintain the Paradox Valley Unit. The implementation of measures to control this source of salt should reduce the annual salt inflow by an average of 180,000 tons and lower the salinity of the Colorado River by approximately 18.2 milligrams per liter (mg/l) at Imperial Dam near Yuma, Arizona (9).

The inflow of salt into the river has been substantially reduced by drilling a field of wells into the brine zone on both sides of the Dolores River and pumping brine groundwater from the wells to lower the interface between the relatively fresh groundwater and the underlying brine. The brine currently is pumped to a temporary disposal pond. This section addresses the impacts of the proposed installation and operation of a deep well disposal system.

11.2 BIOLOGICAL IMPACTS

Impacts of the installation upon the local environment would be both short and long-term. Restoration of the small amount of native vegetation, particularly the pinyon-juniper woodland, disturbed during pipeline construction would be prolonged due to the arid climate, as would revegetation of native grasses and shrubs. Inasmuch as the pipeline from the well field to the Continental well will follow the road right-of-way, damage to vegetation will be minimal.

Aquatic habitat of the Dolores River is dependent on stream flow. During periods of low flow, salt concentrations are high enough to be toxic to fish and invertebrates. Reduction in the salt levels in the Dolores River will significantly benefit the aquatic biota by eliminating toxic levels of brine and thereby enhancing species diversity and abundance of aquatic organisms.

Temporary disturbance of wildlife habitat will occur during the pipeline construction and well drilling operations. Because of the arid climate, restoration of this habitat will be slow, but no permanent destruction of habitat is anticipated. The reduction of brine in the Dolores River will result in increased growth of riparian vegetation, principally tamarisk, and will consequently provide a higher productivity within the riparian community.

Populations of game and non-game birds could be temporarily reduced during the construction activities;

however, pre-construction populations should be restored quickly upon completion of the construction. The overall long-range impact of the project will be beneficial.

The Fish and Wildlife Service (FWS), in compliance with Section 7 of the Endangered Species Act, has analyzed the project area for possible impacts on threatened and endangered plant and animal species. No rare or endangered species of plants exist within the project area. The Colorado River squawfish and the humpback chub are found in the Colorado River only and constitute the only threatened or endangered fish species found within the range of project impact. FWS has determined that no negative impact is expected on these species as a result of decreased flow, and a beneficial impact is possible, due to improvement in water quality.

Threatened or endangered wildlife within the project area consists of one active peregrine falcon aerie and use of the area during winter by the northern bald eagle. FWS has determined that the proposed project will not adversely impact the falcon or its critical habitat. No adverse impact on the northern bald eagle is foreseen. The ultimate increase in riparian vegetation along the Dolores River due to decreased salt levels will benefit both species by enhancing hunting areas and increasing prey populations.

11.3 ECONOMIC AND SOCIAL CONDITIONS

The improvement of the water quality resulting from this brine interception operation would have a positive economic benefit in the lower Colorado Basin.

It has been projected that without mitigation, salinity levels in the Colorado River will continue to increase, possibly reaching levels as high as 1,225 mg/l, as the Basin States continue to develop their compact appropriated water. The economic benefits of salt removal from the system are based on the projected economic losses that would occur to agriculture and municipal and industrial water users by the projected increases in salinity levels. Projected benefits of the removal of 1 mg/l of salt as measured at Imperial Dam is reported to be $472,000 per year, based upon January 1981 prices (Project value: $8,590,000 per year).

The influx of construction workers would increase the number of personnel in the area for a short period, probably for less than one year. In the long term, the project would have essentially no impact on population. The expenditures of the unit construction would temporarily stimulate the economy of the area and of nearby commercial areas. Reclamation experience with similar projects indicates that most of the direct employment would be filled by workers from outside the area. Most of the indirect employment would occur in nearby commercial centers and would be filled by residents of those areas.

11.4 WATER RESOURCES

Based on a pumping rate of 2 cfs, the unit would deplete the lower Dolores and Colorado Rivers by a maximum of approximately 1,450 acre-feet annually. This is less than 0.5 percent of the average annual stream flow of the Dolores River. Effects of this depletion would be most noticeable during late summer and early fall when stream flow frequently falls below 5 cfs. During spring high flows, the depletion effect would be negligible.

11.5 WATER QUALITY

By removing the quantities of salt predicated, there would be a dramatic and beneficial reduction of the salt concentration in the Dolores River. A reduction in hydrogen sulfide contamination, iron and lead concentrations and small reductions in concentrations of some of the other heavy metals also would occur. The disposal system would have no effect on concentrations of nutrients or coliform bacteria. It would also have no significant effect on the turbidity in the long term.

11.6 LAND USE

Additional land required for the deep disposal well system is minimal. The well field already exists, and the pipeline would be installed along the existing road right-of-way. Land surrounding the existing Continental well would be purchased or leased. Land for the filtration system and pump station will be adjacent to the pipeline, resulting in a minimum of disruption of present land usage.

11.7 UNAVOIDABLE ADVERSE EFFECTS

The permanent pipeline to the disposal well would be buried so it would not create any permanent detrimental visual effects. The Continental well is located on a small hill. The wellhead will not be visible from the county road. The injection plant and filter system will be installed in a sparsely populated area.

The influx of construction workers would affect social conditions by increasing the demand for motels/apartments and eating facilities for the construction period.

11.8 SHORT AND LONG-TERM ENVIRONMENTAL USES

Since the proposed facilities are being designed for an indefinite long-term operational life, the installation will result in long-term gains obtained at the expense of small long-term environmental losses. Short-term gains or losses would be minor in comparison and would not present any significant options.

These benefits would include the additional job opportunities and the stimulation of the local economy during the construction period. Short-term loss would consist of the temporary clearing of some wildlife habitat for the pipeline. The most significant benefit would be the improved economic condition in the Lower Colorado Basin that would result from the reduced salinity.

Another significant gain from the improved water quality would be the enhancement of fish and aquatic habitat in about 70 miles of the lower Dolores River.

11.9 DISPOSAL FORMATIONS

Because of its extensive size, massive thickness and noted porosity, the Mississippian formation and possibly some underlying formations will provide a suitable subsurface reservoir for permanent storage of the brine. The depth of the formation is a favorable factor, since it is far below and adequately isolated from all fresh waters. Natural brines have been stored in the Mississippian limestone for more than 300 million years.

Long-term storage of a relatively small amount of additional brine is an economical, environmentally safe method of removing these deleterious fluids from man's environment.

From the environmental viewpoint, the proposed deep well disposal system presents the least disruption and damage to the area. The closed circuit design will give the environment an excellent chance of recovery and re-establishment. This system can be designed to have minimal negative aesthetic effects on the surrounding area.

11.10 WELL DESIGN

Design and installation of the well is being engineered to conform with requirements as set forth in the "Underground Injection Control Plan" (UIC) under the 1974 Safe Drinking Water Act. Conformance with all other requirements of the Federal EPA and all applicable regulatory agencies in the State of Colorado will assure safe installation and operation.

11.11 MONITORING FACILITIES

11.111 Brine

The brine is not a hazardous waste; however, large leaks would be detrimental to surface vegetation. The brine supply tank could be moved farther from the plant and surrounded by a containment dike; however, this is typically done only for hazardous wastes, flammable liquids, etc.

A low pressure shut off switch will be installed on the discharge side of the injection pumps to effect immediate shut down in case of a significant pipeline break.

Small leaks or seeps at the plant or in the pipelines can be detected visually before serious damage occurs to the surrounding area.

11.112 Hydrogen Sulfide

A fixed-location hydrogen sulfide detector will be installed at a strategic location in the injection plant area. The alarm instrument has the capacity for the addition of five more detectors if desired.

There could be slight seepages of hydrogen sulfide from the top of the brine reserve tank. However, at the 30-foot height, there will be adequate dispersion before it reaches the ground to prevent dangerous concentrations to personnel.

The only other areas of concern are when personnel enter the empty vessels, i.e., the brine supply tank, the filter shells or the precoat mixing tanks. Each empty vessel should be adequately vented and tested for hydrogen sulfide content prior to entering.

11.12 CONCLUSIONS

- The environmental impacts of this type of system will have negligible effects on the environment.

- With the monitoring required on the systems, controls effect immediate shut down of operation if a break or leak should occur.

- Any adverse impacts upon the flora and fauna of the area will be of short-term duration and in most respects the ultimate impact upon the environment will be beneficial because of decreased river salinity.

SECTION 12

POTENTIAL PROBLEMS OF INJECTING THE WELL FIELD BRINE

12.1 INSTALLING THE SYSTEM

12.11 Excessive Drilling Costs

Excessive drilling costs could be encountered because of problems in cleaning out the plugged Continental well, lost mud circulation, etc. The biggest risk will be the possibility of the drill bit not following the old hole in the Hermosa Paradox (salt) member. Accurate quantification of this risk is not possible.

12.12 Low Injectivity

Encountering lower than expected injectivity capacity because of less than expected disposal formation thickness, or lower permeability would necessitate the drilling of two or more wells. Available information indicates that one or two wells will provide the required capacity.

12.13 Local Opposition

Severe opposition by local individuals or citizen's groups sometimes creates a hostile political environment. BOR's credibility image and local receptivity to a deep disposal well installation seem to be good. Severe opposition is not expected.

12.12 OPERATING THE SYSTEM

12.21 Plugging of the Cartridge Filters

Plugging of the cartridge filters can result from improper operation of the precoat filters. Selection of optimum cycle times and precoat materials plus good operator training will reduce cartridge filter problems.

12.22 Corrosion Problems

Corrosion problems can occur because of higher than expected corrosion rates, poor performance of corrosion resistant alloys or failing of protective coatings. Monitoring the system with representative corrosion coupons and setting up a routine inspection program should provide good control of corrosion problems.

12.23 Power Outages

Power outages will cause loss of the precoat material from the filter leaves. Recoating has been determined to be less expensive than providing a standby circulating pump.

Stopping and starting injection into the disposal well(s) will not be detrimental. Although continued power outages will be an operational inconvenience, they will not prevent successful operation of the system.

12.24 Seismic Activity

Increased seismic activity resulting from the disposal operation is not expected. If it should commence, the continuous monitoring program will provide early detection thereby preventing any serious problems.

12.25 Closure of Continental Well, Scorup No. 1

An accurate determination of the degree of deformation of salt into the hole is not possible.

The vertical stress near the bottom of the salt zone is significantly greater than required for inelastic flow under uniaxial loading.

At greater depths, the salt formation will exhibit some closing after 23 years. The drilling fluid left in the hole will significantly reduce the amount of closure provided it cannot escape into fractures or other porous formations. It typically causes the hole axis to be weaker than the surrounding formation.

SECTION 13

SEISMIC ACTIVITIES

13.1 PUBLIC CONCERN

The general public often has serious concerns about deep well injection operations, especially in the Rocky Mountain areas. This is a justifiable concern which stems largely from the publicized efforts of the U. S. Army to dispose of chemical wastes into a disposal well at the Rocky Mountain Arsenal near Denver. This disposal well system had some unique characteristics that were different from the other 70,000 disposal wells which are being operated satisfactorily throughout the nation. These differences should be carefully noted. The history of that well is as follows:

- The well was completed in a manner that resulted in injection of the waste fluids into the fractures of Precambrian crystalline rocks at a depth of 11,936 feet.

- Injection of fluids began March 8, 1962, and continued intermittently until February 20, 1966.

- The number of earthquakes within five miles of the disposal well showed a sharp increase during the four-year period of disposal well operation.

- Most of the qualified investigators concluded that the disposal well operation caused the increased earthquake activity.

The striking difference between the Rocky Mountain Arsenal well and the other disposal wells in the United States is that this injection well was drilled into non-porous, non-sedimentary, Precambrian rocks of extremely low permeability (40). The Rocky Mountain Arsenal well is the only known well where an attempt has been made to dispose of the waste liquid into the fractures of a non-porous zone. The fractures provided a formation permeability of only .029 millidarcies. Injection wells typically are completed in formations which have permeabilities of 10 to 2000 millidarcies. These permeable, sedimentary formations, unlike Precambrian rocks, provide tremendous volumes for storage.

Residents of Colorado may also be aware of the earth tremors near Rangely which have been linked to the waterflooding of the Rangely oil field by Chevron Oil Company. This secondary recovery project began in 1958. Earth tremors have been occurring in the vicinity of the oil field at least since 1962 when the seismological observatory was installed. The USGS recorded earth tremors at a frequency of about one per day between 1969 and 1972. The earth tremors occur along a pre-existing, pre-stressed fault. The injection zone is the Weber sandstone member of the Mesa Verde formation.

A test to determine the pressure necessary to fracture the Weber sandstone indicated a bottom-hole pressure of 4750 psi at breakdown. Laboratory data in tests by Raleigh, Healy and Bredehoeft (36) indicated a pore pressure of 3730 psi would reduce the effective normal stress sufficiently to induce slippage. The pore pressures in the seismically active part of the reservoir were 4000 psi during times of high activity. The pore pressure rise due to the waterflood injection was not sufficient to further fracture the formation; however, it was high enough to permit slippage in the fault zone. It should be noted that the objective of the waterflood operation was to significantly increase the formation pore pressure. This was feasible because of the limited lateral extent of the partially confined injection formation.

It is concluded that the swarm of earth tremors at Rangely was related to the injection-induced pressurization of the oil bearing formation. The investigation indicated that this occurred because the fluids were injected along the fault plane of a pre-existing fracture that was pre-stressed to a level of near-slippage.

13.2 LISBON VALLEY INJECTION WELL

The disposal well in Lisbon Valley (approximately 20 miles southwest of Paradox Valley) is of seismic interest. This well has been in operation for 16 years using wellhead injection pressures of 800 to 2500 psi. Cumulative injection is about one billion gallons. The well is close to one major fault. The zone of injection is partially confined by faults. The Mississippian disposal zone is overlaid by the same massive salt formation that is present in the Paradox Valley.

Records for the area through 1978 (after 13 years of well operation) show no increased seismic activity in the Lisbon area. Data show that the operation of this well at high pressures near a major fault have not affected the seismic stability of the area.

13.3 INDUCED SEISMICITY

In the report "Overview of the Regional Geology of the Paradox Basin Study Region" by Woodward-Clyde Consultants (53), it is stated that "In all cases, the local area must be pre-stressed to a substantial fraction of the stresses necessary for failure in order for seismicity to be induced". Induced seismicity was defined as the artificial occurrence of earthquakes caused by reservoir impoundment, fluid injection, mine excavations or underground explosions.

It is concluded that injection of fluids into disposal wells cannot cause increased seismic activity unless there is an existing pre-stressed fault that will be lubricated by the fluid. Furthermore, the magnitude of the pre-stressed forces must be close to the level required to cause slippage.

13.4 PARADOX VALLEY CONDITIONS

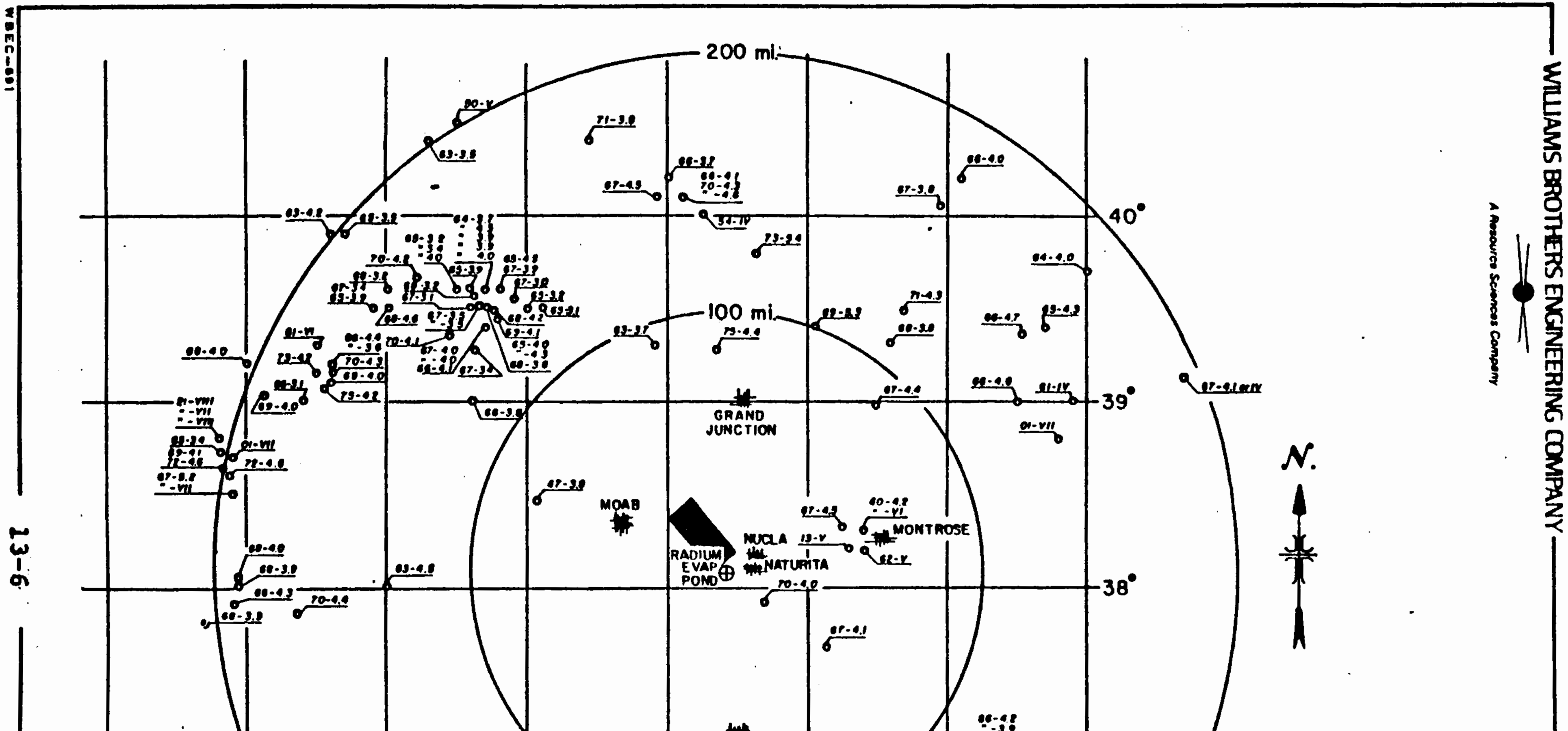
Structural geologic conditions in the Paradox Valley are as follows: The proposed Paradox Valley well will penetrate more than 14,000 feet of salt dome before reaching the targeted injection formations. The outcrop of the salt dome is more than 2-1/2 miles long at the surface and increases in size with depth. It is more than five miles at 5050 feet of depth (sea level). This massive salt dome has excellent seismic buffer characteristics. Salt exhibits elastic behavior at a depth of several hundred feet but becomes inelastic at depths greater than several thousand feet (37). This property can be better visualized if one considers the formation process of a salt dome. The salt dome is directly above the injection formations. In addition, a layer of salt nearly 2000 feet thick extends for more than 15 miles from the injection wells. A massive inelastic formation such as this salt will creep or flow when subjected to significant changes in pressure.

New fractures, or movements along existing fractures, in the injection zone will diminish to zero displacement in the salt as the salt deforms. Furthermore, if any seismic activity were triggered in the Mississippian or Devonian formations as a result of the injection of brine, the shock waves would be dampened as they pass up through the massive salt formation.

The injection of brine into the Mississippian and Devonian formations with one or two proposed Paradox Valley injection wells is not expected to increase the seismic activity above the microseismic level which now exists. This conclusion is based on the fact that: (1) existing evidence indicates that the area is seismicly stable (Figure 13-1); therefore, the formations probably are not pre-stressed to the degree that would result in induced seismicity and (2) the lateral extent of the disposal formations is large enough to preclude the buildup of sufficient pore pressure to induce slippage. The proposed minifrac test will establish the maximum injection pressure that can be used without risking induced seismicity.

13.5 SEISMIC MONITORING

The proposed Paradox Valley disposal wells were discussed with Dr. James Dieterich, Program Coordinator for Earthquake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A Resource Sciences Company

Predictions, USGS, Menlo Park, California, and Dr. Barry Raleigh, former Coordinator at Menlo Park but now director of Lamont Research Group at Columbia University, New York. Four procedures were recommended to confirm that operation of the proposed disposal wells will not result in induced seismic activity in the area.

- Stress measurements should be made on a section of core from the disposal zone(s).

- Test injection pressures should be increased to provide a minifracture of a small section of the disposal formation.

- If the disposal formation can be artificially fractured, an impression packer should be run to measure the magnitude and direction of the fracture(s).

- Sensitive seismometers should be installed as soon as possible in an 11-location network, thereby providing a base line record of seismic activity in the area. Continued operation of the seismometers during the test injection period and during the first few years of disposal operation will provide early detection of artificially induced earth tremors if they should occur.

The installation of seismometers is the most important of the four recommendations. The onset of seismicity would be detected immediately. Injection operations could then be reduced or stopped, thereby preventing a significant buildup of seismic activity.

Additional discussion on Seismic Monitoring is included in the Handbook for Injection Testing.

SECTION 14

INJECTION WELL TEST PROGRAM

This section includes a description of and the recommendations for an injection well test program. The piping and instrument diagram, engineering specifications and recommended materials for the test program are included in the separate Engineering Package.

Evaluation of available data on permeability of the potential disposal formations, the Mississippian and Devonian, indicate a probable range of 100 to 500 millidarcies. From an operational viewpoint, this is a very wide range. If the permeatility is 100 millidarcies, wellhead pressures eventually will increase to about 1200 psi; however, at 500 millidarcies, one well would still be accepting 900 gpm with a vacuum at the wellhead after 30 years of operation.

It is apparent that the pressure requirements for the pipeline, pumps,etc. are extremely sensitive to the formation permeability. Inasmuch as the formation permeability cannot be determined until brine is pumped into the well, it is recommended that the well be drilled, tested and results evaluated before the permanent brine injection system is installed. This recommendation is most important for the high pressure portion of the system, i.e., the injection pumps and motors and the high pressure line from the injection plant to the injection well(s).

General plan for the test injection program is as follows:

- o Drill to the Precambrian following the drilling prognosis as shown in the Engineering Package. Complete in the Mississippian and all lower permeable formations.

- o Test inject clean fresh water from a tank truck(s) for up to two hours using an oil-field, high-pressure, high-volume pump truck.

- o If test is favorable, complete the cementing of the 9-5/8-inch casing and move out the rig for the 2-week test.

- o Lay a temporary line from the brine well field to the injection well (or from the plant site if the low pressure pipeline is already installed).

- o Lower two Amerada-type pressure bombs into the injection well to a depth of about 2500 feet (It must be below the static fluid level). A two-week clock should be used in the pressure bombs, a pressure recorded at the wellhead.

- o Install a temporary high pressure injection pump at the wellhead. Install a second temporary low pressure pump at the plant site (or the well field), if needed, to transfer 200 gpm of filtered brine to the injection well, high pressure pump. If the permanent filters are not installed and operational, rent temporary cartridge filters from an oil-field acidizing service company.

- o Test inject for two weeks at a constant rate of 200 gpm, recording the pressure changes down hole and also at the wellhead if the wellhead is pressured (it may be on vacuum for the entire two-week period).

- o Remove the pressure bombs. Determine that satisfactory data have been recorded before dismantling the test equipment, i.e., the temporary pumps and pipeline.

- The preferred procedure is to drill and test the injection well before any of the permanent brine injection system is constructed. An alternate procedure is to have the low pressure and the filter portion of the brine injection system completed by the time the injection well is ready for testing. With this scenario, a temporary line large enough to carry 900 gpm could be laid to the injection well. This would permit injection of the entire 900 gpm of filtered brine, after the injection test, while the permanent, high pressure portion of the system is being constructed.

The foregoing recommended procedures provide a good compromise between earliest possible completion of the brine injection system and minimum risk of installing equipment that is improperly sized.

Additional information on the injection tests is shown in the Handbook for Injection Testing.

SECTION 15

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