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AREA OF LEAST RESISTANCE TO FLUID MOVEMENT

AND PRESSURE RISE

Paradox Valley Unit
Salt Brine Injection Project
Bedrock, Colorado

BUREAU OF RECLAMATION

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September 24, 1988

by

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INTRODUCTION

The 100 year designed life of the Bureau of Reclamations' (BOR) Paradox Valley Unit salt brine deep injection project requires definition of the geographic area and the rock formations that will be affected. This report is submitted for the purpose of defining, on a geological bases, these two requirements.

The Paradox Valley Unit deep injection project is designed to reduce the salinity in the Colorado River resulting from near surface salt brine flow into the Dolores River tributary. The project is located on the Dolores River approximately 110 miles south of Grand Junction, Colorado, Figure 1. Salt brine taken from 12 shallow wells along the Dolores River will be injected into selected deep reservoirs at a designed rate of 650 gpm.

Drilling of the BOR Injection Test Well No. 1 was completed in 1987 at a total depth of 16,000 feet. The deep test penetrated rocks from Triassic into the Precambrian, Figure 2 and 3. Based on core and log data the Mississippian Leadville carbonate was selected as the prime injection zone and the upper Precambrian as a secondary zone. Other possible reservoirs will be tested.

Intermatrix porosity of the Leadville carbonate is poor in the area of the subject injection well. Prior existing Leadville DST data indicated that fracture porosity and permeability was a significant reservoir characteristic. The cores and fracture logs of the Injection Test Well No. 1 proved existance of a well developed fracture system in both the Leadville and upper Precambrian. A DST of the Leadville carbonate indicates the unit will be a viable injection zone.

The Paradox Valley unit is located on the northwest-southeast trending Wray Mesa fault system. Extreme structural movement along the fault system created a fracture field coexistent with the fault system. Injected brine at the Paradox Valley Unit well will move in the direction of least reservoir resistance and lowest hydrostatic pressure. The least resistance to fluid movement is the reservoir area of best fracture permeability developed northwest-southeast along the Wray Mesa fault system.

A definitive prediction of the Paradox Valley Unit brine injection pattern is technically impossible because of the complex structure associated with the Wray Mesa fault system. However, the

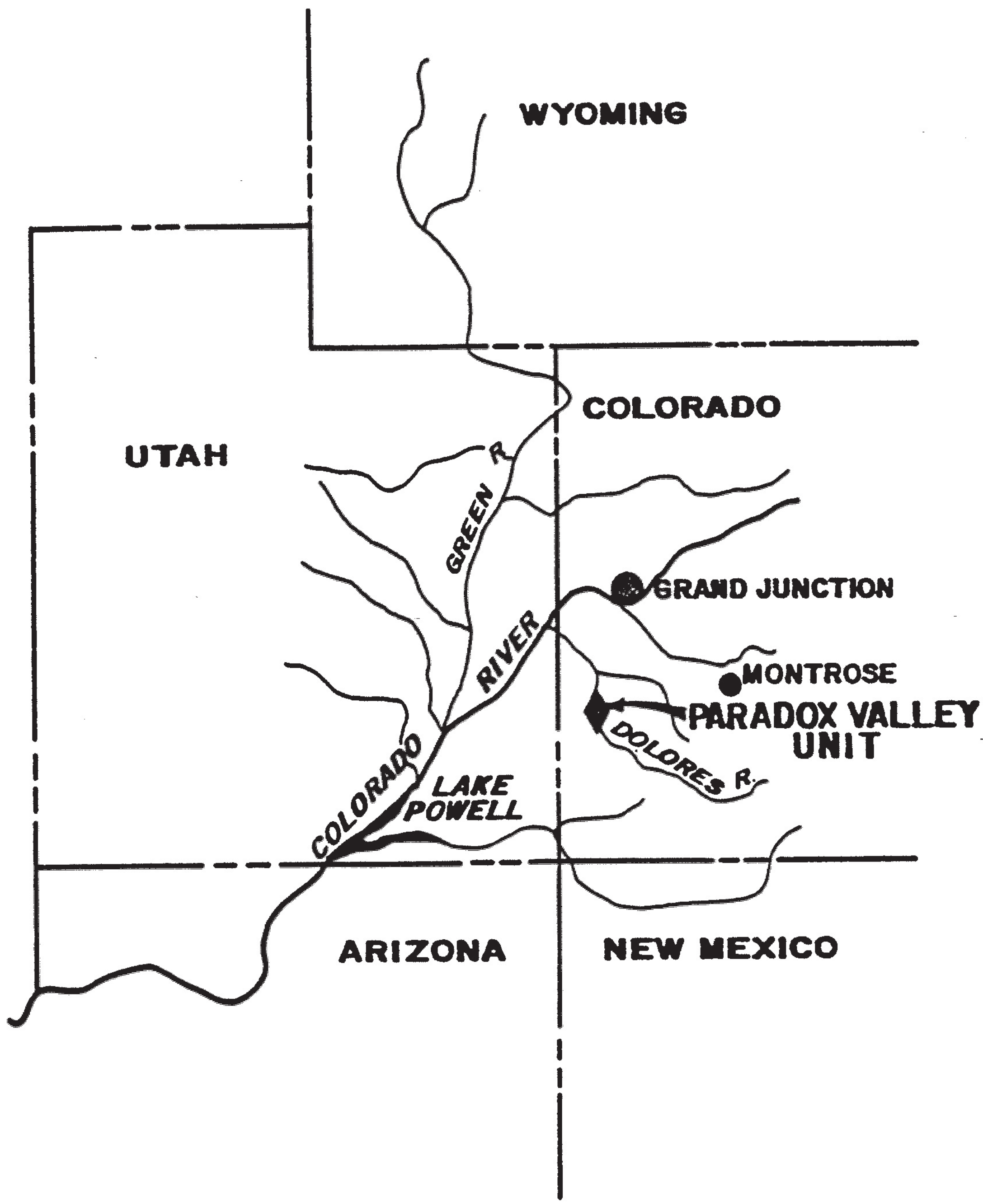


FIGURE 1. INDEX MAP SHOWING THE COLORADO RIVER SYSTEM AND LOCATION OF THE PARADOX VALLEY UNIT ON THE DOLORES RIVER TRIBUTARY.

FIGURE 2. STRATIGRAPHIC CHART OF PARADOX VALLEY UNIT: TRIASSIC/PERMIAN

PERIOD	FORMATION	LITHOLOGY	DRILLED THICKNESS
TRIASSIC	CHINLE		400
	MOENKOPI		749
PERMIAN	CUTLER		7190

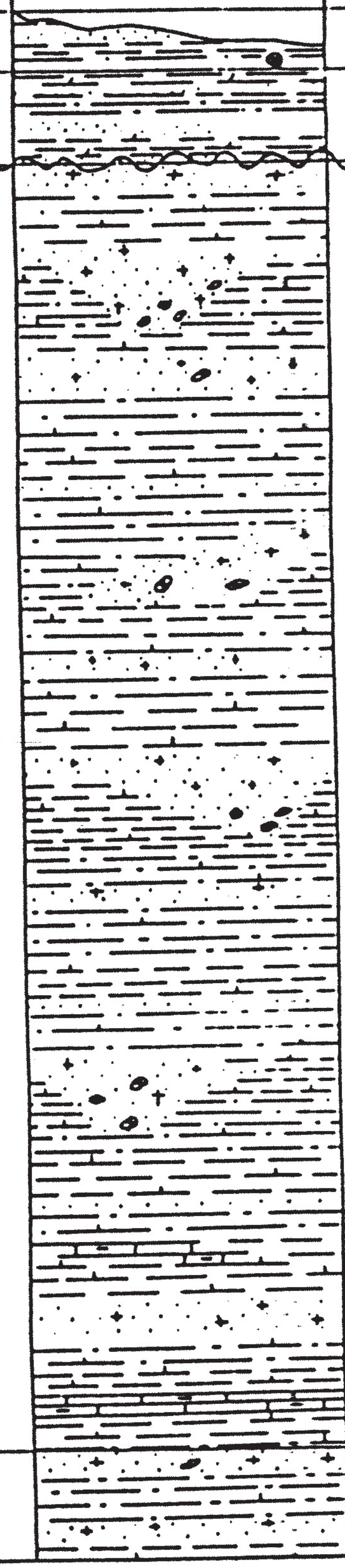
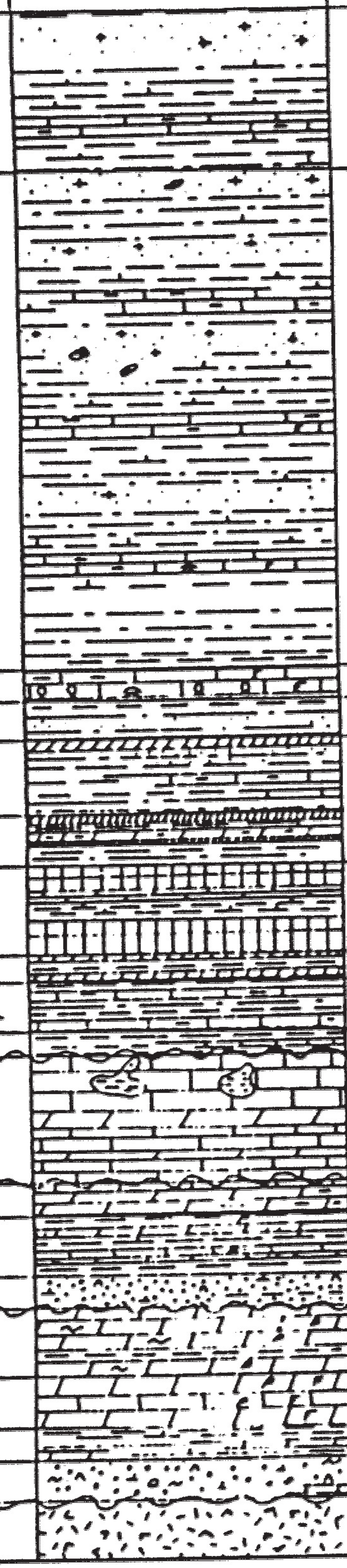


FIGURE 3. STRATIGRAPHIC CHART OF PARADOX VALLEY UNIT: PENNSYLVANIAN/PRECAMBRIAN



PERIOD	FORMATION	DRILLED THICKNESS
PENN.	HONAKER TRAIL	3710
	LA SAL	74
		270
	PARADOX	488
	ISMAY	268
	SALT	FLOWAGE ZONE 466
		125
	PINKERTON TRAIL	253
	MOLAS	40
MISS.	LEADVILLE	416
DEVONIAN	OURAY	40
	ELBERT	172
	McCRACKEN	71
CAMBRIAN	LYNCH	225
	MUAV	107
	BRIGHT ANGEL	178
	IGNACIO	175
PRECAMBRIAN		511+

interpretation presented is factually valid and will serve as a model for the monitoring of injection rate and pressure changes during the two year injectivity test. The injectivity test will be the first significant evaluation of the reservoir disposal capabilities and should aid in defining direction of fluid movement and pressure rise.

QUALITY AND TYPE OF RESERVOIRS

Early investigations for a potential disposal reservoir for the Paradox Valley Unit project centered on the Mississippian Leadville carbonate. Subsequent geological work substantiated the consideration of the Leadville. Data and information gained from the coring, logging and testing of the Paleozoic rocks in the BOR Injection Test Well No. 1 confirms the Leadville as the prime injection unit.

The 30 foot core recovered from the Precambrian diorite-gabbro schist contained a moderate number of open fractures and apparent intergranular porosity in the top fifty feet. The upper 190 feet of Precambrian is considered as a probable injection zone. The underlying 170 feet is a potential zone.

Devonian and Cambrian rocks are considered as injection targets with questionable potential. Injection tests will be run on the Devonian McCracken sandstone and the Cambrian Ignacio sandstone to determine if they should be considered as a secondary injection zone.

Intermatrix porosity in either the Mississippian and or Precambrian objectives is of secondary importance to injection performance. The northwest-southeast regional fracture system associated with the Wray Mesa fault system is the dominate contributor to the quality of the two injection reservoirs. The magnitude of structural movement along the Wray Mesa fault zone during the Pennsylvanian and Permian periods was sufficient to form the fracture system in evidence.

Mississippian Leadville Carbonate Porosity And Permeability

Mississippian Leadville reservoir quality is considered excellent regionally throughout most of the Paradox basin. However, in the northeast portion of the basin near its' eastern limits the Leadville reservoir was affected detrimentally by pre-Des Moines weathering and erosion. Not only was the Leadville thickness reduced by truncation along the old structural highs but the quality of the reservoir was reduced appreciably. "Karst-type" weathering of the exposed Leadville limestone occurred during early Pennsylvanian uplift. Figure 4 is a subsurface isopach map of the Mississippian Leadville in the area of the Wray Mesa structure (T. 47 N., R. 19 W.) and the Paradox Valley Unit (southwest corner T. 47 N., R. 18 W.). The Leadville isopach exhibits local pre-Des Moines thinning by truncation over a post-Leadville regional horst. In the immediate area of the Shell Wray Mesa No. 1 (Sec. 32, T. 47 N., R. 19 W.), the entire Mississippian and a portion of the Devonian has been removed. The southeast trend of thinning off of the denuded area is not substantiated by well control, nor can it be supported by seismic; however, it fits logically with the "ancient" Sneffels horst trend.

"Karst-type" weathering occurred during uplift and exposure of the Leadville carbonate unit throughout the Paradox Basin, but was intensified along the Wray Mesa-Sneffels trend, the flank of the Uncompaghre Uplift and through the southeastern end of the basin proper. Contemporaneous with and subsequent to the "karsting", red shales and clays of the Molas infilled the solution cavities and channels. The shale and clay infill sealed off the "karsted" chalky limestone portion of the upper Leadville carbonate eliminating any preexisting effective porosity. Regionally, this "karsted" interval varies between 100 and 300 feet in thickness. If the Leadville is sufficiently thin, the "karsting" negates any chance for quality reservoir.

The prime reservoir beds of the Leadville are dolomitized zones immediately underlying the "karst" interval. Effective porosity improves with the degree of diagenetic dolomitization. Dolomitization coincided with flooding of the Leadville limestone by the Pennsylvanian Des Moines seas. The quality and quanity of porosity was dependent primarily on the relative position of the Leadville carbonate to the water table at the time of "karsting". The position of the water table determined the depth of the vadose zone (zone of solution channels and cavities) and consequently the depth of Molas infill which retarded subsequent dolomitization and porosity development. Due to the radical structural relief on the Leadville at time of exposure, "karsting" depth and porosity development was highly variable. In areas of "old" structural highes within which the Paradox Valley Unit exists effective porosity trends in the Mississippian Leadville carbonate are difficult to predict.

It was determined prior to drilling the BOR Injection Test Well No. 1 that adaquate reservoir for injection of 650 gallons per minute of salt brine for a project life of 100 years could not depend on the Leadville intercrystalline and vugular porosity alone. Subsurface well data in the project area suggested the probability of a well developed highly permeable fracture field along the Wray Mesa fault system which would connect local areas of good dolomite matrix and vugular porosity, thereby enlarging the total reservoir system, sufficient to contain the desired volume of

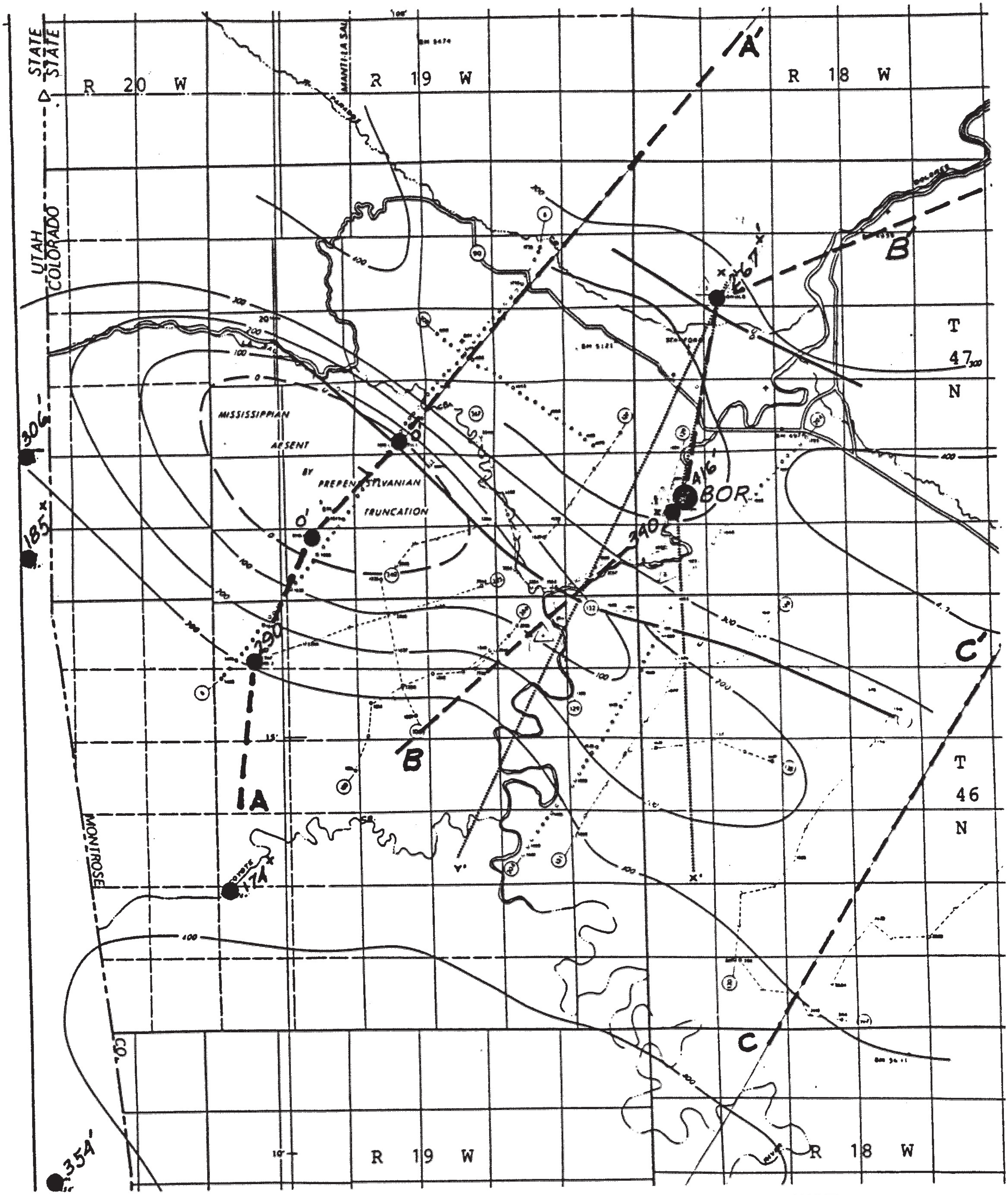


FIGURE 4. SUBSURFACE ISOPACH MAP MISSISSIPPIAN LEADVILLE: DRAWING NO. 5 3-CS-40-0146B GEOPHYSICAL INTERPRETATION PARADOX VALLEY UNIT - BY HARR 1984; Rev. 1988

brine. Fracture data obtained from the Injection Test Well No. 1 supports that early contention.

The BOR Injection Test Well No. 1, located in the SW SE Sec. 30, T. 47 N., R. 18 W., encountered 416 feet of limestone and dolomite in the Mississippian Leadville. Nearly all of the 164 feet of 3 percent or higher porosity penetrated, was contained in dolomite zones. Porosity calculated from the sonic log based on 43.5 microseconds per foot for dolomite amounted to:

Percent Porosity Equal or Greater	Thickness Feet
10	2
8	12
5	86
4	116
3	164

Leadville porosity determined by visual binocular examination of 192 feet of recovered core and selected drill cuttings amounted to:

Percent Porosity Equal or Greater	Thickness Feet
18	4
10	8
8	14
5	30
4	76
3	106

The dolomite intercrystalline and vugular porosity was scattered through the entire 416 feet of Leadville which is atypical. In the central part of the Paradox Basin Leadville porosity generally develops in a 100-150 foot zone directly beneath the "karsted" interval at the top. There are two broken zones of the higher porosity in the Injection Test Well No. 1 which can rather weakly be defined. The zone at 14096-14112 feet with sonic porosity up to 8 percent underlies the intensely "karsted" interval at the top of the Leadville. A layered zone of sonic porosity, up to 8 percent, is present at 14232-14266 feet. This second porosity zone underlies an interval from 14188 to 14200 feet of Leadville limestone which is highly cut with solution channels and cavities. Numerous channels were developed along preexisting fracture planes. Within the same interval and subsequent to the "karsting" there exists tectonic induced fractures which show no indication of solution action. Evidence of solution action sufficient to consider it as "karsting" exists in the cores to a depth of 14340 feet, 75 percent of the total Leadville. The last Leadville core sample recovered was 3 feet lower at a depth of 14343 feet, suggesting the probability of solution action below.

The core data indicates, strongly, that the fault block which contains the BOR Injection Test No. 1 was both structurally and topographically high during the Pennsylvanian Morrow and Atokan time of erosion and weathering. "Karsting" is evident through 315 feet of the Leadville and probably extends an additional 160 feet into the top of the relatively shaly Devonian Elbert. The effect of the "karsting" and partial infill did substantially reduce the chance for development of effective dolomite and vugular porosity. However, by movement of fluids through the existing fracture system there is the probability of intersecting areas of extensive solution cavities and caverns, void of Molas infill, that would serve as prime brine reservoir.

Supporting evidence of the probability of existing solution caverns in the Leadville was encountered in the CNG 16,053 ft. Devonian McCracken well drilled in Sec. 35, T. 48 N., R. 20 W. Confirmed reports say that while drilling the Mississippian Leadville carbonate the bit and drill pipe had a 6 foot free drop, a typical reaction to a 6 foot solution cavern.

The CNG test is located 10 miles northwest from the BOR injection well. Drawing 1 shows the BOR well on the downthrown side of Fault 4 and the CNG test on the upthrown block. Due to the deep "karsting" of the Leadville in the general area there is the strong probability that additional cavernous porosity is present and would significantly improve the storage capacity of the Leadville reservoir.

The 164 feet of 3 percent or greater intercrystalline and vugular porosity in the BOR Injection Test Well No. 1 is scattered through 18 different zones in the 416 feet of Leadville carbonate. Without the natural fracturing that allows communication between the zones of matrix porosity the Leadville would have a minimal effective volumetric capacity and very low permeability for storage and transmission of injected brine. Combining the extensive fracture system indicated by both mechanical logs and cores with the injection of salt brine at fracture propagation pressure should produce an excellent positive reservoir response.

Prior to running the 5 1/2" 60N, injection liner, a DST was run on the open hole from 14,050 to 16,000 feet, on August 20, 1987. The test included the Leadville formation, Devonian, Cambrian and 511 feet of the Precambrian. The DST data recovered is as follows:

DST No. 1 14,050 to 16,000 feet.
Open 5 min., shut in 1 hr.; open 2 hrs.; shut-in 6 hrs.
Recovered 9736 ft. wtr. - 2060 ft. wtr. cushion and 7676 ft. drl. fluid and fm. wtr.
IFP 2337-1426; FFP 1618-4464 psi.
ISIP 6139 psi.; FSIP 6112 psi.
BHT @ 217 ; Rec. 122 BW
Gradient fluid recovered = .468 psi/ft. (Otis)

The Horner plot of the build up pressures did not indicate stratified layering, suggesting the total fluid recovery was from the fractured Leadville carbonate. Based on log and core data most of the fluid was probably recovered from 14,066 feet to 14,352 feet (286 feet) which contains the best matrix porosity and is the most highly fractured. The interval from 14,352 feet to 14,504 feet (152 feet) has lower value matrix porosity, but is considered as highly fractured and probably gave up some of the recovered fluids.

Several interpretations of the DST data were submitted to the BOR for evaluation of the injection reservoir. The following test data and interpretations are from Otis Services test analysis report. The Otis analysis is the most detailed.

Initial reservoir pressure was calculated to be 6146 psia at gauge depth of 14,043 feet. The pressure gradient is .438 psi/ft. Original Leadville reservoir pressure at the mid-point depth of 14,209 calculates to be 6219 psia, which is a normally pressured reservoir. The 2 hour flow rate was 1404 BWPD. Multiple analysis using analytic radial flow and dual porosity reservoir models indicates a dual porosity flow system. This supports the Leadville cores which exhibited an extensive fracture system with moderate to poorly developed intercrystalline and vugular porosity.

The calculated water permeability - thickness from the pressure data ranged from 375 to 440 md. ft. within a 400-500 ft. radius of the wellbore. The skin value of +4 to +5.3 suggest's the formation did not clearup during its' short flow period.

In a letter to the BOR through KEDA, dated February 14, 1988, Gene Collins of Research and Engineering Consultants, Inc. explains the necessity for using a variable flow rate analysis rather then the conventional Horner plot for calculating the permeability - thickness. During the 2nd open period of 2 hrs. the formation flow decreased from 60 gpm to 25 gpm negating the use of the conventional analysis which requires constant flow. The variable rate determination for permeability - thickness is 2280 md. ft. Based on a 100 ft. thick reservoir the permeability would equal 22.80 md. As previously stated the prime Leadville reservoir is 286 feet thick (14,066-14,504 ft.) The permeability would then be 7.97 md. Collins does not consider his skin factor of +13.5 relavent to injectivity performance because injection will be at fracture propagation pressure.

Considering all known factors, the core data, the log data and the DST analysis, I feel the Leadville carbonate is a viable reservoir for the injection of salt brine. At fracture propagation pressure the formation should accept the programmed 650 gal. per minute rate. The validity of the data used and the longevity of the Paradox Valley injection project will be more accurately determined during the two year injectivity test.

Data and information from the following six wells is shown on Figure 5 (three pages) for use as a comparison of local and regional Leadville reservoir quality to that encountered in the BOR Injection Test Well No. 1. The wells selected show the typical reservoir character variations of the Leadville and the response of fluid movement to these variations. Tabulation of porosity data, gross thickness and either DST or production information is shown. The Union-Ayers test is the 400 foot south offset which was twinned by the subject well. The Continental-Scorup well is located 3 miles north. Pure and Union (Unocal) wells are in the Lisbon Oil Field which produces from the Leadville, 27 miles southwest.

Log calculated porosities of the Leadville in the Union-Ayers well indicate there is no effective porosity in the 340 feet of penetrated section, however, the 6680 feet of salt water, plus 4150 feet of water cushion recovered in 1 hour on DST against a flow pressure of 2558-5318 psi and a 2 hour shut in pressure of 6220-6201 psi indicates good permeability and the probable presence of an extensive fracture system in the near vicinity of the Ayers well.

The Otis test analysis for the Union-Ayers well gave a permeability-thickness of 718 md. ft. within a 873 foot radius of the well bore and with a skin factor of +5.6. This is twice the flow capacity of the BOR injection test well as calculated by the standard Horner method. These calculations maybe invalid due to a variable flow rate. The original reservoir pressure is 6237 psia at the gauge depth of 14,122 feet. The pressure gradient is .442 psi/ft. The reservoir is considered as of low volume with relatively high permeability.

The best reservoir porosity quality and thickness in the mapped area was exhibited by the Conoco-Scorup well in Sec. 8, T. 47 N., R. 18 W. Conoco's well is located on the Paradox Valley floor 3 miles north of the BOR deep injection well and in close proximity to the shallow brine intake wells. Conoco penetrated 267 feet of the Leadville formation. Total thickness is estimated at 340 feet. The 267 feet contained 118 feet of 3% porosity or better, 86 feet of 5% porosity or better and 31 feet of 10% porosity or better. A DST of the Leadville recovered 8500 feet of salt water and 4950 feet of water cushion in 2 hours of flow time against a pressure of 3440-6400 psi. The shut-in pressure after 1 hour was 6510 psi. Based on the reported shut-in pressure and mid-point of the test the reservoir pressure gradient is .437, which is equal to the BOR well gradient of .438 and the Union-Ayers of .442. The reservoir in the vicinity of the Conoco-Scorup is considered as of high to moderate volume and high permeability. The lateral extent of the reservoir is unknown, however the southwest limit is controlled by the 1000 foot fault southwest of the well, Figure 12 and Drawing 1. The exact location of the fault is not defined. The recommended location for the second deep brine injection well, if required, is offsetting the Conoco-Scorup well.

FIGURE 5. LEADVILLE POROSITY, THICKNESS AND DST OR PRODUCTION DATA FOR WELLS IN GENERAL AREA OF PARADOX VALLEY UNIT.

Well Data	Gross Thickness Feet	Feet of Porosity 3%	5%	10%
BOR INJ. TEST NO. 1	416'	164'	86'	2'
30-47N-18W Colorado DST 14050-16000: Op. 2 hrs. Rec. 7676' SW plus 2060' Wtr. cush.; FP 1618-4464; SI 6 hrs.; SIP 6136	(Comparatively moderate to low volume, high permeability reservoir.)			
UNION NO. 1-0-30- AYERS	340'	33'	7'	0
30-47N-18W Colorado DST 14114-14200: Op. 1 hr., Rec. 6680' SW plus 4150' Wtr. cush.; FP 2558-5318: SI 2 hrs., SIP 6220-6201	(Comparatively low volume, high permeability reservoir.)			
CONOCO NO. 1 SCORUP	264'+	118'	86'	31'
8-47N-18W Colorado DST 14780-15000: Op. 2 hrs., Rec. 8500' SW plus 4950' Wtr. cush.; FP 3440-6400; SI 1hr., SIP 6510	(Comparatively high to moderate volume, high permeability reservoir.)			

FIGURE 5. (Cont.) LEADVILLE POROSITY, THICKNESS AND DST OR PRODUCTION DATA FOR WELLS IN GENERAL AREA OF PARADOX VALLEY UNIT.

Well Data	Gross Thickness Feet	Feet of Porosity 3%	5%	10%
PURE NO. C-92 LISBON	459'	67'	4'	0
2-30S-24E Utah DST 9659-9823: Op. 30 min., Rec. 30' mud; FP 45-45; SI 30 min., SIP 712-202 (Two other tests nearly identical.)	(Comparatively low volume reservoir with no permeability.)			
UNION NO. B-624 LISBON	430'	250'	98'	0
24-30S-24E Utah Water Disposal Well 20 Yrs. Cumulative Inj. 24,679,497 Bbls. wtr. 136,906 Bbls. wtr. inj. during Sept. 1984 (Avg. 133 gpm.)	(Comparatively high volume, low permeability reservoir.)			
UNION NO. C-93 LISBON	404'	163'	107'	11'
3-30S-24E Utah Gas Injector (SI) Cumulative 77,734,847 MCFG at 2250-2581 PSI	(Comparatively moderate volume, moderate permeability reservoir.)			

FIGURE 5. (Cont.) LEADVILLE POROSITY, THICKNESS AND DST OR PRODUCTION DATA FOR WELLS IN GENERAL AREA OF PARADOX VALLEY UNIT.

Well Data	Gross Thickness Feet	Feet of Porosity 3%	5%	10%
UNION NO. B-815 LISBON	460'	247'	99'	37'
15-30S-24E Utah 22 Yrs. Cumulative Prod. 3,756,895 Bbls. Oil 32,569,910 MCFG 2,421,248 Bbls. wtr.	(Comparatively high volume, high permeability reservoir.)			
UNION NO. D-89 LISBON	508'	313'	187'	33'
9-30S-24E Utah 23 Yrs. Cumulative Prod. 5,491,066 Bbls. Oil 85,947,315 MCFG 421,266 Bbls. wtr.	(Comparatively high volume, high permeability reservoir.)			

Porosity calculations are based on a dolomite matrix velocity of 43.5 microseconds per foot.

48 microseconds per foot = 3% porosity
51 microseconds per foot = 5% porosity
58 microseconds per foot = 10% porosity

Porosity calculations from the neutron log of the Conoco No. 1 were based on a sonic derived shale porosity of 19% and salt/anhydrite porosity of zero.

The Pure No. C-92 Lisbon is a dry hole located approximately 1/4 mile northeast of the main trapping fault at the Lisbon Oil Field. The well is on the down thrown side, adjacent to the apex of the structure. Maximum fault displacement is 2500 feet. Log calculations of porosity indicate a very poor quality reservoir. The lack of fluid recovery and the extremely low pressure data obtained from three DST's of the Leadville indicates no permeability and an absence of fracturing in the near vicinity of the Pure No. C-92.

The Union No. B-624 was drilled as a dry hole and converted to a disposal well for produced salt water brine. Based on the 250 feet of 3 percent porosity or greater and the 98 feet of 5 percent or greater calculated from the No. B-624 sonic log, the Leadville reservoir is considered as of high volume as compared to other Paradox Basin Leadville penetrations. However, the lack of porosity greater then 10 percent and the fact that cores showed no enhancing fractures, indicates the original natural permeability was low. In approximately 20 years, 24,679,497 bbls. of water have been injected into the Leadville reservoir at the B-624 location. Average injection rates range near 150 gpm, well below the BOR desired rate of 650 gpm.

Porosity encountered in the Union D-89 and B-815 wells at Lisbon is comparable to the Conoco-Scorup well in Paradox Valley. Refer to Figure 5. Both wells have produced over 5 million barrels of liquid each and 118 MMMCFG in approximately 23 years. The D-89 and B-815 reservoirs are considered as comparatively high volume and high permeability.

Mississippian Leadville Fracture Zones

The dominate factor in the functional and economic success of the Paradox Valley Unit salt brine disposal system was the availability of a deep reservoir which would accept, transmit and store 650 gpm of brine for a designated life of 100 years. The most valid determination of reservoir character capable of such a stipulation, except for extended injection tests, is the direct analysis of the actual reservoir rock. The drilling program included coring of the Pennsylvanian Paradox aquiclude, coring of the total Leadville, selected cores through the lower Paleozoics and a core in the upper part of the Precambrian. Data and discussion of the cores taken in the aquiclude is carried in the geological well completion report. Discussion of the cores from the contended injection interval follows.

Two hundred ninety-nine feet of Leadville carbonate was cut in 19 cores between the depth of 14,024 feet (top Leadville) and 14,398 feet (base Core No. 21). Only 182 feet of the 299 feet was recovered for examination. Recovery factor for the total Leadville coring was 60 percent. The coring runs were short due to repeated jamming of the barrel. When the recovery factor for the last 5 Leadville cores dropped to 37 percent, the Leadville coring program was terminated. Fortunately for overall project results, the coring difficulties were directly related to the anticipated extensive fracturing along the Wray Mesa fault system.

The 182 feet of recovered Leadville core contained 78 open fractures extending through 49.5 vertical feet of core. Twenty-seven percent of the 182 feet of core contained one or more open fractures. Numerous hairline fractures bleeding salt water were present through out the recovered portion of the core, but are not included in the fracture count. However, they would be open for transmission of fluid under fracture propogation pressure. The dominate fracture inclination ranged between 65 degrees and 85 degrees. Vertical fractures and some horizontal fractures were present, but minimal in number. The 65 degree and 85 degree dip of the fractures which in most cases transected the 4 inch core, greatly increases the vertical fracture footage of the Leadville over the 49.5 feet of fractured interval measured within the core.

There were three fracture logs, the microscanner image log, fracture identification log and the sonic wave form log, run in the BOR injection test well. The logs are considered as indicators of fractures, but their validity quite often remains in question. Using the three logs together and accepting as fractured that interval indicated by at least two of the logs, there is 190 feet of probable fractures through the Leadville.

Through the Leadville interval from 14,066 feet to 14,352 feet, where there is fracture log data and core data, there is 255 feet that is considered as heavily fractured. Supporting evidence is from either the core or the logs, or both. The fractures are present in two intervals, 14,066-14,163 feet and 14,194-14,352 feet, which coincide with the two zones of "better" developed intercrystalline dolomite and vugular porosity. This coincidence of fracturing and dolomite porosity is consistent with the regional characteristics of the Leadville carbonate through the Paradox Basin.

There is an additional interval from 14380 feet to 14490 feet which spans the lower Leadville, the Devonian Ouray and the top of the Devonian Elbert that is a contended zone of heavy fracturing. There is no core or fracture log data that supports the presents of this fractured interval, but the caliper curve indicates extreme hole rugosity. The 8.5 inch bore hole has enlarged to 12 inches over the entire 110 feet and to over the log scale of 16 inches through 46 feet of the zone. The erosion of 7.5+ inches of competent carbonate rock by drilling action is undoubtedly due to rather intense fracturing. Drill hole enlargement of the lower Leadville, Ouray and top of the Elbert is unrecognized in the Paradox Basin. It should also be noted that the contended basal fracture zone is coincident with what is considered as the third (least developed) zone of dolomite porosity.

Core 6 was the only oriented core taken in the Mississippian Leadville. Within the oriented Leadville interval a set of two fractures were encountered at 14,028.5 feet and 14,051 feet. The two sets of fractures are illustrated in Figure 6. Their numerical strike and dip is presented in the following tabulation.

Core 6 14,014.5-14,057.2 Cut 42.7 ft. - Rec. 41.6 ft.
Molas-Leadville: Top Leadville @ 14,024 ft.

Fracture Depth: 14,028.5 - 14,029.4 ft.
Shot Depth: 14,028 - 14,029 ft.

Set A-1
Fracture Strike N 42 E
Fracture Dip S 48 E @ 22

Set A-2
Fracture Strike N 38 W
Fracture Dip S 52 W @ 12

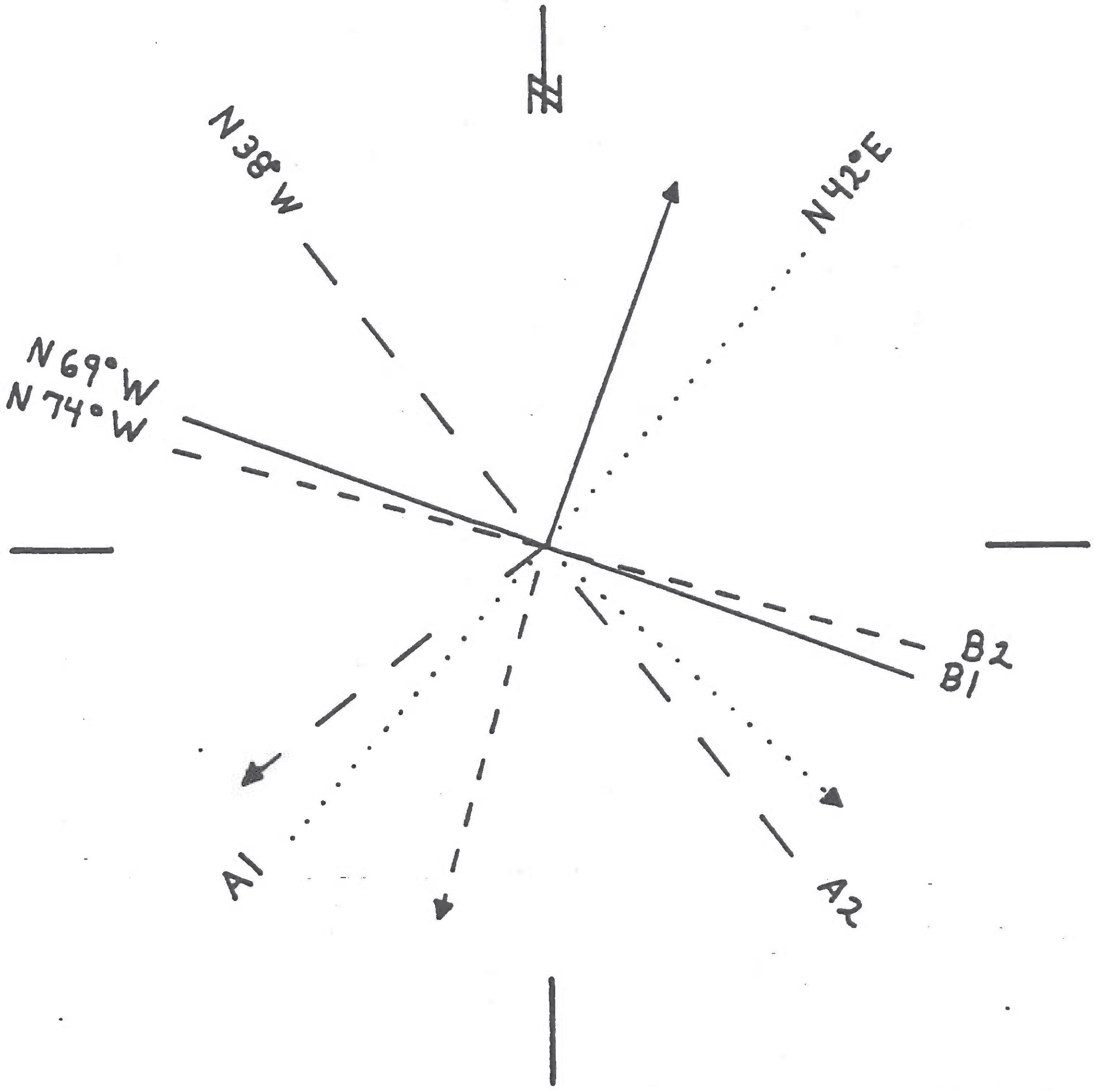
Fracture Depth: 14,051 - 14,052 ft.
Shot Depth: 14,051 ft.

Set B-1
Fracture Strike N 69 W
Fracture Dip N 21 E @ 30

Set B-2
Fracture Strike N 74 W
Fracture Dip S 16 W @ 27

Fracture planes A-2, B-1 and B-2 are strike oriented in a general northwest direction which parallels the regional Wray Mesa fault system. The northwest strike orientation of the open fractures fits the stress-strain ellipsoid that has a compressive stress from the west-northwest coupled with northeast-southwest "fracture-opening" tension.

This concept fits both the local and regional structure and tectonics, but is based on weak data. The three oriented northwest trending fractures are too few in number and the fracture dip ranges between 12 degrees to 30 degress. The majority of open fractures which are considered as tectonic in origin have dips that range between 65 degrees and 85 degrees. It is also possible that the 4 oriented Leadville fractures are associated to the "karsting" at the top of the carbonate unit, immediately overlying the fractures.



Core 6 14,014.5-14,057.2 Cut 42.7 ft. - Rec. 41.6 ft.
Molas-Leadville; Top Leadville @ 14,024 ft.

Fracture Depth: 14,028.5-14,029.4 ft.
Shot Depth: 14,028-14,029 ft.

Set A-1
Fracture Strike N 42° E
Fracture Dip S 48° E @ 22°

Set A-2
Fracture Strike N 38° W
Fracture Dip S 52° W @ 12°

Fracture Depth: 14,051-14,052 ft.
Shot Depth: 14,051 ft.

Set B-1
Fracture Strike N 69° W
Fracture Dip N 21° E @ 30°

Set B-2
Fracture Strike N 74° W
Fracture Dip S 16° W @ 27°

FIGURE 6. STRIKE - DIP PLOT OF FRACTURES FROM ORIENTED CORE NO. 6, UPPER MISSISSIPPIAN LEADVILLE CARBONATE.

Devonian-Cambrian Reservoir Potential

• Reservoir characteristics of the Devonian and Cambrian rocks in the eastern portion of the Paradox fold and fault belt are of poor quality. Sonic log derived porosities and porosity-feet for each formation from the individual wells is tabulated in Figure 7 (three pages) for comparison with that encountered in the BOR Injection Test Well No. 1. Total dolomite porosity-feet, total sandstone porosity-feet and their respective weighted average percent porosity is shown. General lithologies of the formations and thickness for the gross interval are also included for reference.

Devonian Ouray reservoir qualities are developed by the same geologic processes that develop the Mississippian Leadville reservoir. The two units are generally considered as one reservoir under identical pressure regimes. The Ouray and the top of the Elbert in the BOR well, are considered as potential reservoirs due to fracturing. Combined they contained 14 feet of 5 percent porosity. The units are discussed in the report section, Mississippian Leadville Fracture Zones. In the general area of the Paradox Valley Unit the Ouray is an objective reservoir, but not equal to the Leadville potential.

The BOR Injection Test Well No. 1 contains 74 feet of Devonian McCracken sandstone with 16 feet of 3 to 5 percent porosity. The sandstone is fine to medium grained. Porosity and reservoir deterioration is due to secondary silica and dolomite cementation. The unit is considered as tight except for the possibility of fracturing. No valid fracture data was recovered across the McCracken. The caliper shows enlargement of the bore hole from 8.5 inches to over maximum scale of 16 inches through 50 feet of the sandstone. The sandstone was sufficiently cemented so that drill cuttings returned as "glass-like" shards through much of the penetration. Hole enlargement is probably due to fracturing and not washout of loose sand grains.

Thirty-four feet of sandstone was penetrated in three separate sands of the Cambrian Ignacio formation. The lower two sandstones contained 23 feet of 4 to 7 percent porosity. The upper sandstone is tight. The three Ignacio sands are shaly and have no effective porosity. They are silicious and kaolinitic. Hole size has enlarged from 8.5 inches to over 16 inches through the three sandstone intervals indicating possible fracturing. The sandstones are thin, tight and show no regional continuity.

In the east end of the Paradox fold and fault belt the McCracken and Ignacio units carry an average porosity of 7.3 percent. Total porosity feet for individual wells range from 0 to 69 feet. Refer to Figure 7 (three pages). Core porosities from the McCracken and Ignacio in the Shell Wray Mesa No. 1 ranges from 1.6 to 3.3 percent with only .01 to .08 millidarcys of permeability. There were no valid drill stem tests of the eight wells with

FIGURE 7. DEVONIAN TO PRECAMBRIAN THICKNESS AND POROSITY VALUES IN GENERAL AREA OF PARADOX VALLEY UNIT.

Well Data	Dev-Precambrian Gross Thickness	Sonic Porosity	Formation
BOR	1049	4' - 5%	Ouray dolomite
Inj. Test Well No. 1		10' - 5%	Elbert dolomite
30-47N-18W		16' - 4%	McCracken sandstone
Montrose, CO		10' - 2%	Lynch limestone
		4' - 2%	Mauv limestone
		32' - 6%	Ignacio sandstone
		54' - 7%	Precambrian

Dolomite sonic porosity: Total 28' - 4% wtd avg.
Sandstone sonic porosity: Total 48' - 5.5% wtd avg.
Precambrian sonic porosity: Total 54' - 7% (Precambrian diorite-gabbro schist sonic calculation is questionable.)

Well Data	Dev-Precambrian Gross Thickness	Sonic Porosity	Formation
Shell	583	————————	Ouray absent
Wray Mesa 1		0 - 0	Elbert dolomite
21-47N-19W		21' - 3/6%	McCracken sandstone
Montrose, CO		————————	Lynch absent
4 mi. northwest		17' - 3/4.5%	Mauv dolomite
		0 - 0	Ignacio sandstone

Dolomite sonic porosity: Total 17' - 4% wtd. avg.
Dolomite core porosities: .9/2.7% with .01/3.2 millidarcys of permeability, several vertical fractures noted.
Sandstone sonic porosity: 21' - 4% wtd. avg.
Sandstone core porosities: 1.6/3.3% with .01/.08 millidarcys of permeability.

Well Data	Dev-Precambrian Gross Thickness	Sonic Porosity	Formation
Shell	998	————————	Ouray absent
Wray Mesa 2		40' - 3/7%	Elbert dolomite
32-47N-19W		12' - 4/6%	McCracken sandstone
Montrose, CO		31' - 3/4.5%	Lynch dolomite
4.5 mi. west		56' - 3/7%	Mauv dolomite
		28' - 3/8%	Ignacio sandstone

Dolomite sonic porosity: Total 127' - 4.5% wtd. avg.
Sandstone sonic porosity: Total 40' - 6% wtd. avg.

FIGURE 7. (Cont.) DEVONIAN TO PRECAMBRIAN THICKNESS AND POROSITY VALUES IN GENERAL AREA OF PARADOX VALLEY UNIT.

Well Data	Dev-Precambrian Gross Thickness	Sonic Porosity	Formation
Mobil	650	0 - 0	Ouray dolomite
Moon Mesa 1		0 - 0	Elbert dolomite
31-49N-16W		0 - 0	McCracken sandstone
Montrose, CO		---------	Lynch absent
16 mi. northeast		---------	Mauv absent
		0 - 0	Ignacio sandstone
		Poss. Frac.	Precambrian
Miami	893	32' - 4.5/6%	Ouray dolomite
Kirby 1		0 - 0	Elbert dolomite
10-47N-15W		5' - 10/16%	McCracken sandstone
Montrose, CO		---------	Lynch absent
		---------	Mauv absent
		29' - 10/18%	Ignacio clean ss.
		35' - 6/12%	Ignacio shaly ss.
		64' - 6/18%	Total Ignacio ss.

Dolomite sonic porosity: Total 32' - 5% wtd. avg.
Sandstone sonic porosity: Total 69' - 12% wtd. avg.

Well Data	Dev-Precambrian Gross Thickness	Sonic Porosity	Formation
Shell	----	7' - 3%	Ouray dolomite
Fed. 21-19		0 - 0	Elbert dolomite
19-45N-13W		18' - 5.5/10.5%	McCracken sandstone
San Miguel, CO		---------	Cambrian not penetrated
31 mi. southeast			
Tidal	650 est.	0 - 0	Ouray dolomite
Stephens 1		0 - 0	Elbert dolomite
9-44N-13W		16' - 10/13.5%	McCracken sandstone
San Miguel, CO		---------	Lynch absent
35 mi. southeast		---------	Mauv absent
		---------	Ignacio not penetrated

Sandstone sonic porosity: Total 16' - 12% wtd. avg.

FIGURE 7. (Cont.) DEVONIAN TO PRECAMBRIAN THICKNESS AND POROSITY VALUES IN GENERAL AREA OF PARADOX VALLEY UNIT.

Well Data	Dev-Precambrian Gross Thickness	Sonic Porosity	Formation
Amoco	633	----------	Ouray absent
Naturita Ck. 1		No	Elbert
34-44N-13W		Porosity	McCracken
San Miguel, CO		Log	Lynch absent
37 mi. southeast		----------	Mauv absent
		----------	Ignacio
Union	876 est.	18' - 3/4%	Ouray limestone
MacIntyre Cy. 1		0 - 0	Elbert dolomite
5-44N-19W		4' - 8/10%	McCracken sandstone
San Miguel, CO		All < 3%	Lynch dolomite
14 mi. south		----------	Ignacio sandstone

Carbonate sonic porosity: Total 60' - 4% wtd. avg.
Sandstone sonic porosity: Total 4' - 9% wtd. avg.

Well Data	Dev-Precambrian Gross Thickness	Sonic Porosity	Formation
Union	1291	65' - 3/6%	Ouray dolomite
Lisbon A-2		0 - 0	Elbert dolomite
10-30S-24E		40' - 6/12%	McCracken sandstone
San Juan, Ut		69' - 3/6%	Lynch dolomite
15 mi. southwest		71' - 3/6%	Mauv dolomite
		log not valid	Ignacio sandstone

Dolomite sonic porosity: Total 205' - 4% wtd. avg.
Sandstone sonic porosity: Total 40'+ - 8% wtd. avg.

Ouray-Ignacio porosity values were calculated from sonic logs based on a matrix velocity of 43.5 microseconds per foot for dolomite and 51.3 microseconds per foot for sandstone.

Percambrian diorite-gabbro schist porosity in the BOR test was calculated from a sonic log based on a matrix velocity of 50 microseconds per foot.

porosity data shown in Figure 7, to evaluate relative permeability from the average 7.3 percent porosity sandstone reservoirs. The McCracken sandstone at Lisbon has produced 421,000 BO from essentially one well in 24 years. Net pay is 25 feet averaging 8 percent porosity and 2.6 millidarcies of permeability. Natural fracturing would enhance the quality of McCracken and Ignacio reservoirs in the area, but at best the storage volume for the injected brine will be low.

The Cambrian Lynch formation penetrated in the BOR injection well is 225 feet thick, but contains only 93 feet of limestone. The Paradox Valley Unit is near the eastern depositional limit of the upper carbonate units of the Cambrian where the carbonates are transitional into shale. The BOR test has an upper 73 foot shale, a 93 foot limestone and a lower 59 foot shale. The limestone contains only 10 feet of 2 percent porosity. FIL and sonic waveform logs did not indicate the presents of fractures.

The Cambrian Muav is 115 feet thick at the BOR location. The lower 60 feet contains interbedded shale which is transitional into the underlying Bright Angle shale. Logs indicated only 4 feet of 2 percent porosity and a possibility of fracturing in the top 16 feet.

The gross thickness of the combined Lynch-Muav interval in the Union Lisbon A-2 (23 miles southwest) is 443 feet. Net sonic porosity is 140 feet, ranging between 3 and 6 percent. Gross thickness of the equivalent interval in the Shell Wray Mesa No. 2 (4.5 miles west) is 407 feet with 87 feet of 3 to 7 percent porosity. There is no drill stem test or production data available on the Lynch-Muav unit which could indicate the fluid movement response to 3 to 7 percent porosities.

The Cambrian Lynch-Muav limestone section in the subject injection well is 208 feet thick with just 14 feet of 2 percent porosity. There is questionable log indication of only minimal fracturing. The Lynch and Muav limestones are not considered as an objective reservoir in the BOR Injection Test Well No. 1 or in the general area of the Paradox Valley Unit.

Precambrian Reservoir Potential

Prior to drilling the Precambrian in the Injection Test Well No. 1, it was anticipated that the rock would be granitic in composition. Shell Wray Mesa No. 1 (Sec. 21, T. 47 N, R. 19 W) and Wray Mesa No. 2 (Sec. 32, T. 47 N, R. 19 W), located approximately 5 miles southwest on the Wray Mesa-Sneffels horst trend, both encountered granite in the Precambrian at a depth of approximately 10,800 feet. The BOR well at 15,489 feet drilled into a low grade metamorphosed dioritic-gabbro (schist). The geologic relationship of the two rock types is discussed in the section on the paleosetting for the Paradox Valley Unit fracture system.

The upper 100 feet of Precambrian consisted mainly of the potash and light green plagioclase feldspars with associated quartz, specularite (cherry red hemitite), limionite and greenish-black pyroxene minerals. Core 23 at 15,600-15,630.2 feet contained a mineral composition that is primarily plagioclase feldspars, olivine and pyroxenes. Quartz and the potash feldspars are negligible. Moderate foliation at an inclination of approximately 70 degrees is prevalent. Similar rocks known as the Irving Greenstone are exposed in the San Juan Mountains to the southeast.

Based on a matrix velocity of 50 microseconds per foot the sonic log indicates 42 feet of 3 percent or greater porosity, 30 feet of 5 percent or greater and 10 feet of 9 percent or greater porosity. Fifty microseconds per foot matrix velocity was estimated from an average of Schlumberger's interval transit times for quartz, dolomite and calcite.

The 50 microsecond velocity for a diorite-gabbro schist and 10 percent effective porosity maybe in question, but porosity is present in the upper 65 feet of the Precambrian. On visual eye and binocular examination of the wet cuttings under a heat lamp, the chips definitely exhibited evaporation of free water from within the matrix micropores.

Thirteen open fractures and several hairline fractures were observed through the 30 feet of recovered core (15,600-15,630.2 feet). Fracture dip ranged from 22 degrees to sixty-five degrees. Fractures near the 55 degree inclination, with a near common azimuth from the red-black orientation stripes were dominate. The consistancy in direction and amount of dip indicates a tectonic origin related to the Wray Mesa fault system. The core was not oriented to north, but due to the 70 degree foliation, the relative rotation position between core segments was decipherable.

The open fracture at 15,601.4 feet exhibited slickensides, indicating structural movement. There is a textural difference in the core above and below the fractures suggesting at least minor fault movement.

Positive indications of fracturing are visible in the microscanner image log, the fracture identification log and the sonic wave form log from the top of the Precambrian to 15,650 feet. All present geological indications are that the upper 160 feet of the Precambrian diorite-gabbro schist will be a viable brine injection zone, dependent on water/rock compatibility of the injected brine.

There is minimal indication of fractures in the Precambrian interval from 15,650 feet to total depth. Fracture response is indicated at 15,790 feet, 15,865 feet, 15,905 feet and 15,910 feet on the sonic wave form log, however the much more creditable fracture identification log shows no response.

Selected Injection Zones

Seven zones in four separate reservoirs have been targeted for testing their injectivity potential. Two separate zone tests of the Precambrian diorite-gabbro schist, one test of the Ignacio sandstone, one test of the McCracken sandstone, one test of the upper Elbert, Ouray and lower Leadville and two tests of the upper Leadville will be conducted to identify the primary intervals for initial long term injection evaluation and secondary intervals that would be viable for future injection and storage. Consideration in selection of test intervals was given towards an evaluation which will support depth determination in any subsequent injector well.

The formation reservoir characteristics were defined and discussed in the preceding sections of the report. Information regarding the seven test intervals are summarized in the order of testing as follows:

Interval 15,710-15,850 (140ft.) Lower Precambrian Zone

- Rock type : Diorite-gabbro schist (low grade metamorphism)
- Sonic porosity: None recognized
- Fractures : None recognized
- Type test : Flow test for water sample compatibility; 1.5 hr. step-rate test to 5000 psi.
- Reason : Validity of deeper Precambrian injectivity for depth determination of any subsequent well.

Interval 15,489-15,680 (191 ft.) Upper Precambrian Zone

- Rock type : Diorite-gabbro schist (low grade metamorphism).
- Sonic porosity: 42 ft. of 3-10 percent
- Fractures : Good fracture log indications between 15,500-15,650; 13 open fractures in core 15,600-15,630.
- Type test : Flow test with lower zone for water sample compatibility; 1.5 hr. step-rate test to 5000 psi.
- Reason : Considered as objective injection zone secondary to Leadville reservoir.

Interval 15,372-15,406 (34 ft.) Ignacio Zone

- Lithology : Sandstone, silicious, kaolinitic and shaly, tight, 27 ft. thick.
- Sonic porosity: 23 ft. of 4 to 7 percent

Fractures : Indicated by hole rugosity and size
Type test : Observe flow; 1.5 hr. step-rate test to 5000 psi.
Reason : Low potential as injection zone; depth determination on any subsequent well.

Interval 14,648-14,722 (74 ft.) McCracken Zone

Lithology : Sandstone, silicious and dolomitic, tight, 74 ft. thick.
Sonic porosity: 16 ft. of 3 to 5 percent
Fractures : Indicated by hole rugosity and size
Type test : Observe flow; 1.5 hr. step-rate test to 5000 psi.
Reason : Low potential as injection zone; depth determination on any subsequent well.

Interval 14,380-14,504 (105 ft.) Upper Elbert, Ouray, lower Leadville Zone

Lithology : Dolomite and limestone
Sonic porosity: 33 ft. of 3 to 6 percent, 5 ft. to 11%
Fractures : Indicated by hole rugosity and size
Type test : Flow test for water sample compatibility; 1.5 hr. step-rate test to 5000 psi.
Reason : Considered as injection reservoir with fluid-pressure continuity by fractures to prime reservoir of upper two zones.

Interval 14,215-14,350 (135 ft.) Middle Leadville Zone

Lithology : Dolomite and limestone
Sonic porosity: 42 ft. of 3 to 7 percent
Fractures : Good indication on fracture logs 14,238-14,355; 19 open fractures in 44.9 ft. of recovered core.
Type test : Flow test for water sample compatibility; 1.5 hr. step-rate test to 5000 psi.
Reason : Considered as prime injection reservoir with fluid-pressure continuity by fractures to lower Leadville zone and upper Leadville prime zone.

Interval 14,080-14,185 (124 ft.) Upper Leadville Zone

Lithology : Dolomite and limestone
Sonic porosity: 45 ft. of 3 to 8 percent
Fractures : Good indication on fracture logs 14,090-14,150; 36 open fractures in 64.7 ft. of recovered core.
Type test : Flow test for water sample compatibility; 1.5 hr. step-rate test to 5000 psi.

Reason : Considered as prime injection reservoir with fluid-pressure continuity by fractures to middle and lower Leadville zones.

The three Leadville zones and the upper Precambrian zone have the greatest potential as long-life disposal reservoirs for injection of the Paradox Valley salt brine. Their potential rests almost entirely on the existence and lateral continuity of their fracture systems. The lateral extent of existing fracture systems was dependent on regional paleotectonic elements and local holocene structure.

PALEOSETTING FOR THE PARADOX VALLEY UNIT FRACTURE FIELD

Regional reservoir characteristics of the subsalt Paleozoic rocks in the eastern portion of the Paradox fold and fault belt must in general be considered as of poor quality. Although locally present, porosity - permeability zones within the carbonate intercrystalline or vugular reservoirs and sandstone intergranular reservoirs lack sufficient long distant lateral continuity to be considered as valid injectors on those characteristics alone. However, fracture systems associated with the major fault trends which cut the carbonate or sandstone porosity zones enlarge the total reservoir system sufficient to contain the desired injection volume. Therefore, definition of the main fault trends and the related fracture systems is important to the life of the project as well as for determining the distribution pattern of fluid movement and pressure buildup.

The general trend of the Paleozoic fault system of the Paradox fold and fault belt, which is the prime control for the existing fracture fields in the Paradox Valley Unit, owes its' origin to the Precambrian Olympic-Wichita Lineament. Baars in 1976 discribed the lineament as a major rift with large fault blocks which are segments of a continental-scale wrench fault system with right-lateral strike-slip displacement. The Olympic-Wichita Lineament trending northwest out of Oklahoma crosses the southwest corner of Colorado through the Paradox Valley Unit area and continues on to the Pacific Ocean through the state of Washington. Refer to Figure 8.

A second major rift with left lateral strike-slip movement, the Colorado Lineament, trends northeast through southeast Utah, cuts the Olympic-Wichita Lineament in the vicinity of the LaSal Mountains and then passes through northwest Colorado. Both Precambrian rift trends date back to approximately 1,700 m.y.b.p., but have expressed rejuvenated movement in Cambrian and Devonian rocks, and most vividly in Mississippian, Pennsylvanian and Permian rocks.

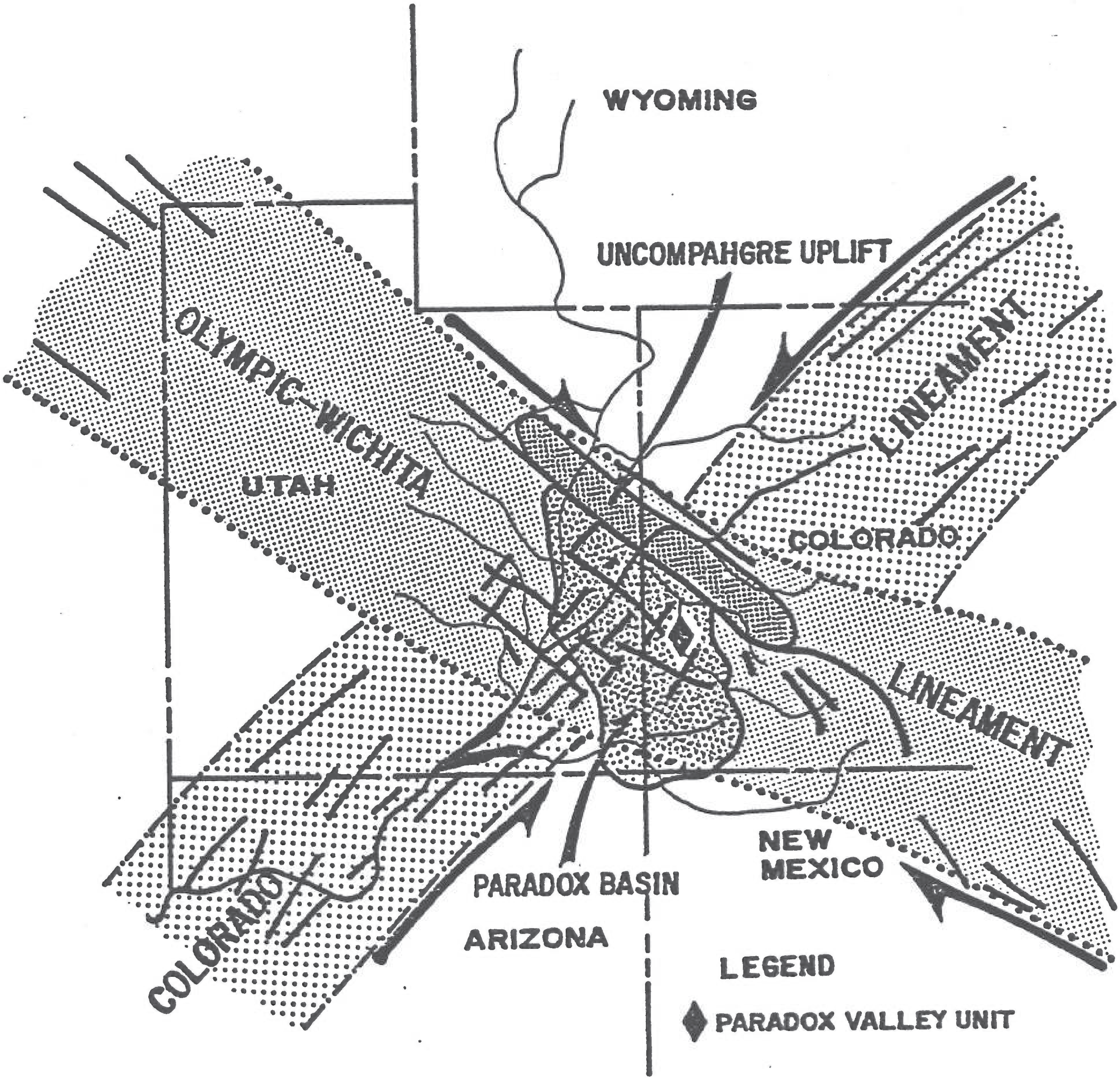


FIGURE 8. SCHEMATIC MAP ILLUSTRATING PRECAMBRIAN LINEAMENTS WHICH CONTROLLED PALEOZOIC TECTONICS AND STRUCTURE, THE MAIN DELINEATORS OF PARADOX FOLD AND FAULT BELT FRACTURE FIELDS. LOCATION OF PARADOX VALLEY UNIT SHOWN.

The northwest trending Olympic-Wichita Lineament during its' rejuvenation was of prime influence in developing the northwest trend to the Paleozoic faults in the eastern Paradox Basin. Coupling of the right-lateral strike slip movement of the northwest wrench fault system with the left lateral movement of the northeast system produced an east-west extensional force which on a major scale opened up the Paradox Basin and on a minor scale developed the open fracture system encountered in the BOR Injection Test Well No. 1.

The northwest trending system of faults designated as the Wray Mesa Fault System on Drawing No. 1, structure map top Leadville, and Figure 6, form the northeast down faulted flank of the Wray Mesa-Sneffels structural high trend. Cross sectional view is shown on Drawings No. 3, 4 and 5 and also in Figures 9, 10 and 11. There is approximately 8000 feet of present day structural relief between the Wray Mesa-Sneffels trend and the structurally low step-fault blocks in the area of the BOR Injection Test Well No. 1 (Sec. 30, T. 47 N., R. 18 W.). The few wells which have penetrated into the Precambrian along the Wray Mesa-Sneffels trend have encountered basement granite. Precambrian rock encountered in Core No. 23 (15,600 ft.-15,630 ft.) was a moderately metamorphosed "diorite-gabbro" schist. Fifteen miles to the northeast Mobil Oil drilled into a Precambrian quartz-diorite. Mobils' well is located on the southeast down-faulted flank of the Uncomphagre Uplift. Foliated metamorphic rocks (metasediments), gneissic granitic rocks and some granitic intrusives comprise the Precambrian of the Uncompahgre. The granitic Wray Mesa - Sneffels "high", the gneissic and schistic metasediments of the Uncompahgre-Uplift and the mildly metamorphased dioritic rock in the intervening structural trough are each large segments of the Olympic-Wichita wrench fault system.

The major zones of structural displacement within the eastern end of the Paradox Basin occurred along the Wray Mesa fault zone and along the southwest flank of the Uncompahgre Uplift as indicated on Drawing No. 1. Movement was intensive during Precambrian, moderate through early Paleozoic and then very active again during the Pennsylvanian and Permian periods.

Record of continued movement along the Wray Mesa fault trend is documented in the rocks penetrated by the BOR Injection Well No. 1 (Sec. 30, T. 47 N, R. 18 W) located on the deep trough side of the fault system and the Shell Wray Mesa No. 1 (Sec. 21, T. 47 N, R. 19 W) on the structurally high Wray Mesa-Sneffels trend. Cambrian sediments thin over the high to 449 feet and thicken to 685 feet in the Injection Well No. 1. Ordovician and Silurian rocks are regionally absent in the Paradox Basin. Devonian and Mississippian sediments were deposited over the entire basin. Four hundred sixteen feet of Devonian and 364 feet of Mississippian were encountered in the BOR test. Pre-Pennsylvanian erosion stripped the entire Mississippian and much of the Devonian off the top of the

Wray Mesa "high". Only 134 feet of lower Devonian was penetrated in the Shell Wray Mesa No. 1.

The greatest stratigraphic thickness variation along the Wray Mesa fault trend is in the Permo-Pennsylvanian rocks due to a more rapid rate of basin subsidence during deposition in the trough area northeast of the Wray Mesa-Sneffels "high" as compared to the "high". BOR Injection Test No. 1 encountered 12,884 feet of Permo-Pennsylvanian sediments. The equivalent section is only 8054 feet thick in the Shell Wray Mesa No.1 on the top of the Wray Mesa-Sneffels trend. Cross sections A-A' (Drawing No. 3 or Figure 9), B-B' (Drawing No. 4 or Figure 10) and C-C' (Drawing No. 5 or Figure 11) illustrate the Paleozoic rock thickness variations across the Wray Mesa fault trend.

Geological and geophysical evidence strongly supports the concept of the Wray Mesa fault trend being a regional structural hinge-line which experienced repeated structural stress and movement from the Precambrian through the Paleozoic. BOR Injection Well No. 1 proved the early concept of a significant fracture field developed by tectonic stresses occurring along the Wray Mesa structural hinge.

HOLOCENE STRUCTURE IN NORTHEAST PARADOX BASIN

Within the general area of the BOR Paradox Valley Unit salt brine project there are three distinct layered structural horizons; surface structure, the structural top of the Paradox salt and the structural top of the Mississippian Leadville. They vary in age, style, magnitude, complexity and importance. Refer to Cross Sections A-A', B-B' and C-C' in Drawings 3, 4 and 5 or Figures 9, 10 and 11.

Surface structure is primarily the result of Larimide diastrophism and expresses the true surface form if mapped on post-Cutler beds and if they are not associated to the collapse features around the salt anticlines. Surface structure expresses the location of the salt anticlines, but gives no expression of the vertical magnitude. There is no reflection of pre-salt Paleozoic structure in surface beds.

Structure as mapped on top of the salt is the most radical due to the vertical height of the salt diapirs and the shape of their flanks. Although the salt anticlines of the Paradox fold and fault belt did originate along the major fault systems the salt configuration does not indicate the position or magnitude of the underlying faults. Knowledge of the configuration of the salt bodies is necessary for determining velocity contrasts of the Cutler-Honaker Trail/salt interface for seismic mapping of the Mississippian Leadville. Salt velocities are approximately 14,700

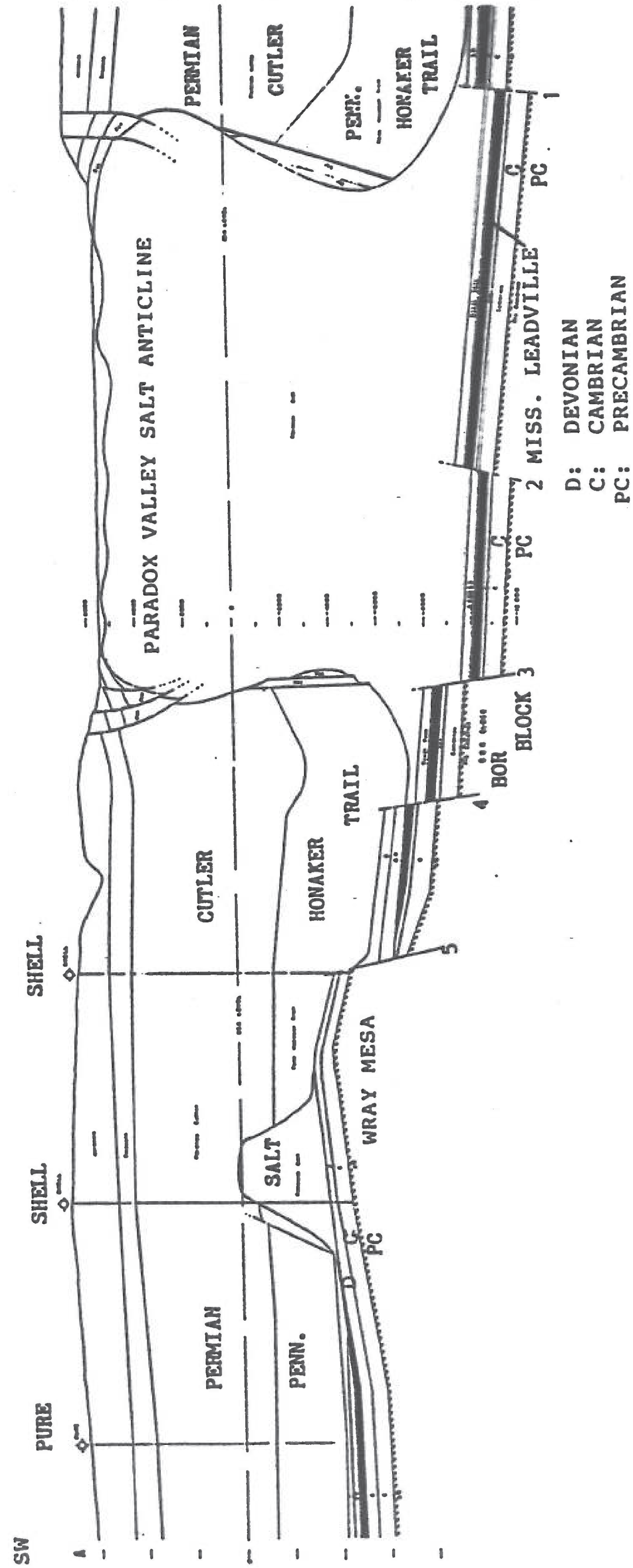


FIGURE 9. CROSS SECTION A-A': NORTHEAST - SOUTHWEST SECTION THROUGH NORTHWEST PORTION PARADOX VALLEY UNIT AREA

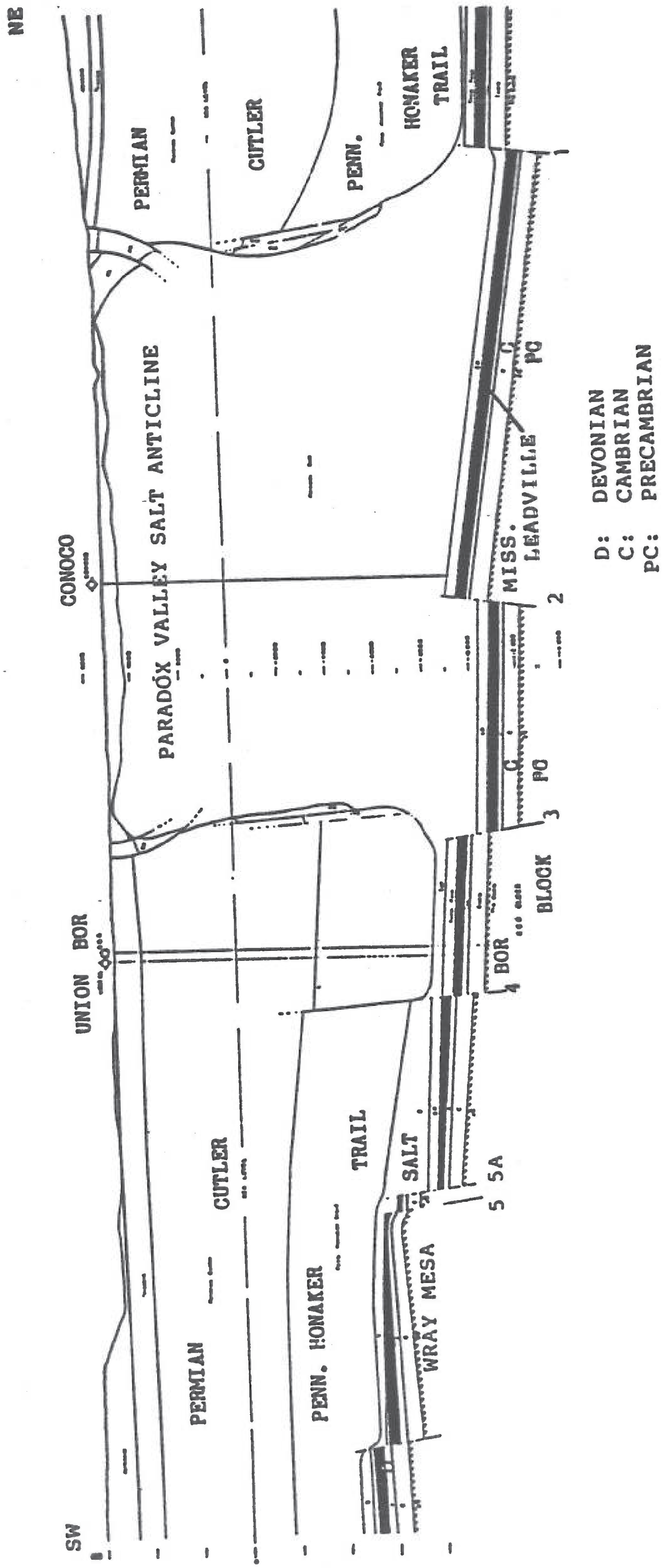


FIGURE 10. CROSS SECTION B-B': NORTHEAST - SOUTHWEST SECTION THROUGH MIDDLE PARADOX VALLEY UNIT AREA

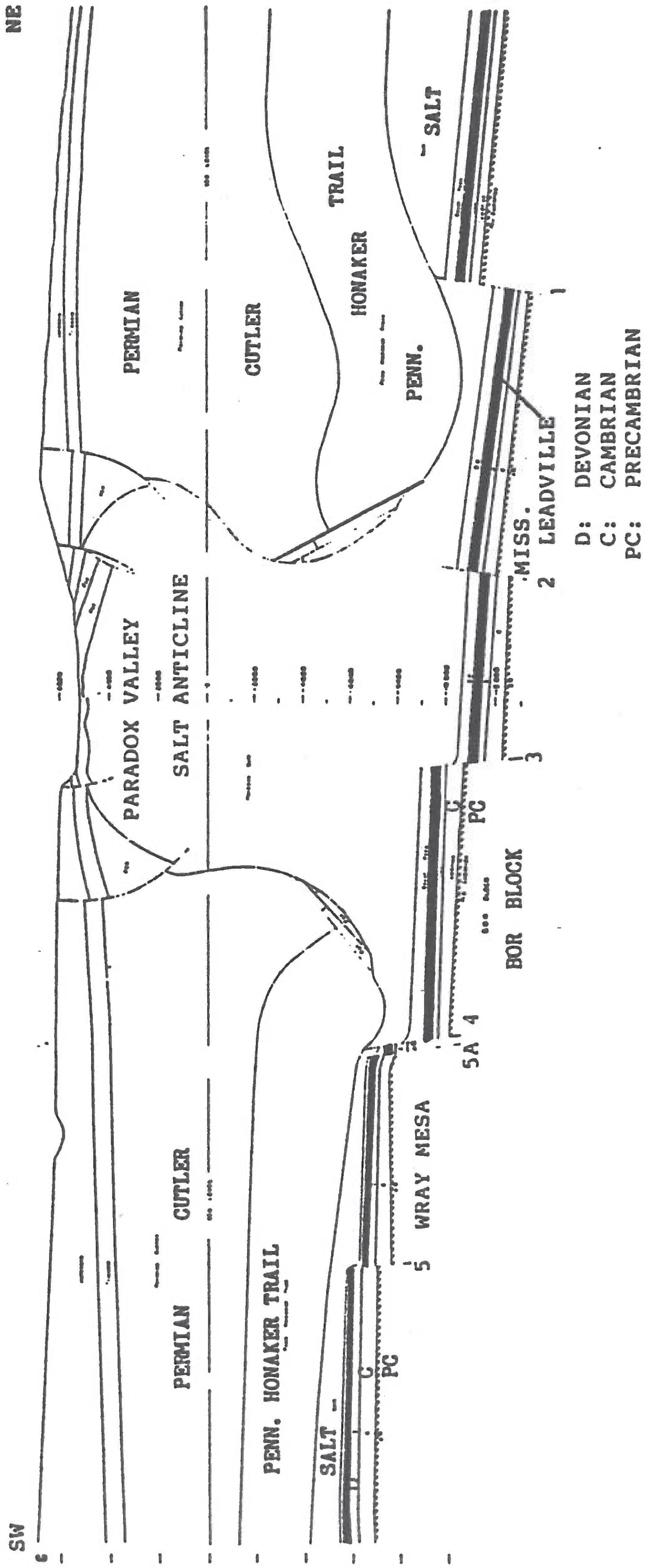


FIGURE 11. CROSS SECTION C-C': NORTHEAST - SOUTHWEST SECTION THROUGH SOUTHEAST PORTION PARADOX VALLEY UNIT AREA

ft./sec. while Cutler velocities are as high as 15,400 ft./sec. On the southeast flank of the Paradox Valley anticline adjacent to the BOR injection well, the interface goes from 14,000 feet of salt to 14,000 feet of primarily sandstone and shale with only 250 to 300 feet of salt in three quarters of a mile.

The optimum stratigraphic horizon to use as the structural datum for seismic mapping of the Paleozoic reservoir beds, is the top of the Mississippian Leadville. Infact, within the Paradox fold and fault belt it is the only seismic reflector with reasonable lateral continuity.

Drawing No. 1 is a structure map drawn on the top of the Leadville formation. The map is laid out on a 45 degree bias to north, paralleling the structural grain. Surface faults are shown by a fine solid line. Those which are due to salt solution collapse, defining the shape of the salt diapirs, extend only into the Paradox salt section. Surface frontal faults, defining the southwest flank of the Uncompahgre Uplift cut the total rock section into the Precambrian basement. Faults which are illustrated by the hashered strip, termed Leadville faults, extend through the Mississippian Leadville into the Precambrian. Leadville faults, patterned by rejuvenation of the prexisting Precambrian fault system, are Paleozoic in age. The majority of the faults formed during the subsidence of the Paradox Basin in early Pennsylvanian with some extending into the Permian period. Undoubtably some were developed during the pre-Pennsylvanian uplift and truncation of the Leadville as well as during older Paleozoic movement. What ever the age most Leadville faults die-out in the overlying plastic salt beds. The few that may extend into the post-salt Pennsylvanian are completely sealed by the plastic flow of the salt and by the impermeable beds of late Permian, deposited subsequent to basinal faulting.

The Leadville structural contours and regional structural configuration as shown on Drawing No. 1 are based on subsurface well data, seismic data and mental reference to 27 years of seismic experience in the Paradox fold and fault belt. Leadville faults and structural contours shown within the stippled block outline are identical to and were taken from Bremkamps' geophysical interpretation of the BOR Paradox Valley Unit seismic data (Refer to Figure 12) submitted to the Bureau of Reclamation in 1984 under 3-CS-40-0146B. The structural interpretation as presented in the area of the map outside of the BOR seismic data area is based on all available 1987 well data and Bremkamps' recall knowledge from his previous seismic mapping in the Paradox fold and fault belt. The contours northeast of Fault 1 are based on subsurface well data and a geological understanding of the structural attitude of the southwest flank of the Uncompahgre.

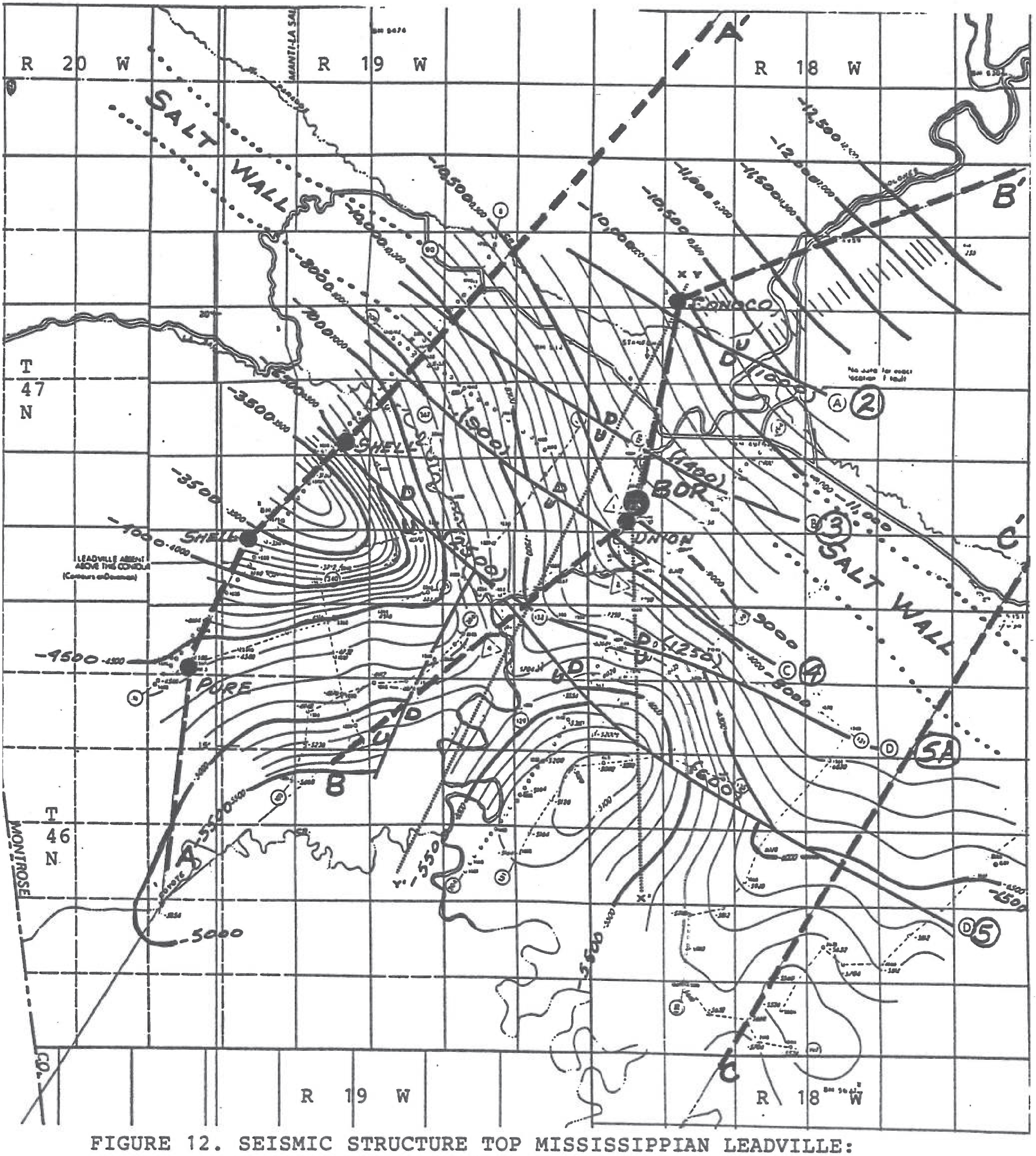


FIGURE 12. SEISMIC STRUCTURE TOP MISSISSIPPIAN LEADVILLE: DRAWING NO. 3 3-CS-40-0146B GEOPHYSICAL INTERPRETATION PARADOX VALLEY UNIT - BY BREMKAMP 1984

Due to complex structure, radical stratigraphic changes, the variation in magnitude of each of these features and the extreme topographic relief, the Paradox fold and fault belt is difficult to map accurately in structural detail. However, the structural configuration of the Leadville as shown within the stippled block is the best that can be interpreted from the existing BOR seismic data. The structure as shown along the Wray Mesa fault system adjacent to the Paradox Valley Unit is reasonably correct. It is an extension of the BOR seismic data and it is an area which was extensively mapped by Bremkamp in previous work. The structural picture presented to the northwest and west in the LaSal Mountain area and to the south and southeast is correct in general as to the contour shape and to the position and displacement of the faults shown. Amount of fault displacement maybe questionable locally.

The exact position of Fault 2 is not defined. Seismic was not shot across the fault. Refer to Figure 12. Data on S.P. 1715 of Line 8 and S.P. 1695 on Line 204 places the fault block between Fault 3 and Fault 2 structurally at -10,150 feet to -10,900 feet, dipping northeast at 400 feet per mile. The Conoco-Scorup well (Sec. 8, T. 47 N., R. 18 W.) penetrated the Leadville at a -9946 feet. The Conoco-Scorup fault block dips northeast at approximately 700 feet per mile. The northeast dip of both fault blocks and the structural difference between the seismic control points and the well requires a fault of nearly 1000 feet.

There is approximately 9800 feet of structural relief on the Mississippian Leadville from the crest of the Wray Mesa closure across the Paradox Valley Unit to the synclinal trough of the basin, a distance of 17 miles. Refer to the Leadville structure map, Drawing No. 1. Between Fault 2 and Wray Mesa, a distance of 5 miles, there is 8100 feet of structural relief. Forty eight hundred feet is taken up by displacement of normal northeast step-down fault blocks (Faults 5, 5A, 4 and 3 of cross section B-B', Figure 10 and Drawing No. 4) across the Wray Mesa fault system. The tectonic force that created the structural movement of the three fault blocks in five miles across the Wray Mesa fault system, undoubtedly created the fracture system encountered in the BOR Injection Test Well No. 1 and the Union-Ayers well. The greatest structural movement in the most confined space should develop the most intensive fracture system. The area of greatest structural movement as defined by the Leadville structure map of Drawing 1 is between Faults 1 and 5-5A in the Paradox Valley Unit area. Northwest and southeast along the Wray Mesa fault system the greatest structural movement took place between the extension of Faults 1 and 4. The most likely lateral development of an intensive fracture system is along the Wray Mesa fault system. The more stable areas, such as the Wray Mesa-Sneffels horst and the area between Fault 1 and the Uncompahgre structural front should logically have fewer fractures.

SUPRAJACIENT AQUICLUDE TO INJECTION ZONES

The Injection Test Well No. 1 encountered 234 net feet of salt and 92 net feet of anhydrite in the Paradox formation overlying the proposed injection zones. The 326 net feet of plastic evaporite section exceeded the EPA requirement for an impermeable barrier necessary for permitting an injection well to operate at fracture propagation pressure. Overlying the Paradox formation there is an additional 12,400 feet of Permo-Pennsylvanian shale, tight limestones and tight shaly, arkosic sandstones which in a gross interval are impermeable. They are an effective barrier over the Leadville and deeper injection zones.

AREA OF LEAST RESISTANCE TO FLUID MOVEMENT AND PRESSURE RISE

Rate of fluid movement depends on relative permeability. Due to the lack of effective rock matrix porosity, permeability in the northeastern portion of the Paradox fold and fault belt is dependent on rock fractures.

Present geological information defines the Mississippian Leadville carbonate and the upper 200 feet of the Precambrian as the most highly fractured units in the proposed area for brine injection. The fact that intensive tectonic movement occurred when each of these competent rock units were exposed to the surface without overburden weight, caused abrupt faulting and fracturing rather then the gentle bending associated with deep buried structural movement. Present geological information, also defines the Wray Mesa fault system as the area that the Leadville and upper Precambrian will most likely have a laterally extensive fracture system.

Brine fluids injected into the Leadville and Precambrian will move initially along the most permeable formational fracture zones within each fault block. Brine fluids will move between fault blocks if permeable zones are in juncti-position across the fault plane. The most permeable path would be across minor fault displacement which leaves a portion of the Leadville next to Leadville. Unless the fault is a seal, Leadville faulted against fractured Upper Precambrian would allow brine movement. Fractured Leadville faulted against the unfractured lower Precambrian would not be conducive to brine fluid movement.

A definitive prediction of where the Paradox Valley Unit injected brine will move is technically impossible because of the surrounding complex structure. Determining the vertical and lateral relative susceptibility to fluid movement, in different areas is possible, whether under hydrostatic pressure or fracture propagation pressure. That area is defined as the "area of least resistance to fluid movement" and is shown on Drawing 1 and 2 within the stippled pattern. It is based on: 1) the local continuity of fractured reservoir across fault blocks where fracture zones are in juncti-position; 2) the regional continuity of fractured reservoir within the confines of the Wray Mesa fault system. The area outlined defines the fracture continuity of the prime injection zone, Leadville carbonate, but it closely coincides with the "area of least resistance to fluid movement" within the upper Precambrian fracture zone.

Drawing 2 is a hydrostatic pressure map based on the BOR and Unocal well Leadville reservoir pressure gradients of .44 psi per foot. The hydrostatic pressure contours conform to the structure at the top of the Leadville carbonate. Refer to Drawing 1. The contour interval is 440 psi (.44 psi/ft. x 1000 structural ft. = 440 psi). The pressure contouring, although hypothetical, is logical. Regionally, the Leadville pressure is generally close to a normal gradient. Variations in the hydrostatic pressure is more closely tied to the extreme structural changes then other factors.

Salt brine injected into the Mississippian Leadville would move through the most permeable reservoir, either effective matrix porosity or fractures. If permeability was equal in all directions, fluid movement would be towards the lower hydrostatic pressure southwest of the well. Cross section B-B', Drawing 4 or Figure 10, shows Fault 4 displacement that puts Leadville in the BOR injection block adjacent to the Devonian on the up thrown fault block. Slight throw variation along the fault would place the Leadville reservoir adjacent to the lower Leadville-Ouray fractured zone on the up thrown side. Fluid movement would continue through the second fault block until it reached the tight deep Precambrian of the Wray Mesa-Sneffels horst. The tight relatively unfractured horst retards fluid movement along the entire southwest edge of the Wray Mesa fault system.

The northern boundary of fluid movement from the injection well is Fault 3 which places the Leadville in the BOR injection block against salt on the northeast. Cross section A-A' and B-B' illustrate the same conditions, but with increased throw along Fault 4.

Continued brine injection and movement of fluid into relative tight areas of the reservoir will increase reservoir pressure up to an induced fracture pressure. Flack in his report, dated Sept. 18, 1987, on the Leadville DST of the subject injection well, places the Leadville fracture extension gradient, as determined by leak-off test, at .67 psi/ft. Dewan-KEDA letter, Jan. 27, 1988, gives a Leadville fracture extension gradient range, based on log calculations, of .8 to 1.1 psi/ft. The Precambrian diorite-gabbro schist has a fracture extension gradient average of .65 psi/ft. Upon reaching fracture propagation pressure and opening the formation, fluid movement will continue in the direction of least resistance. If the Wray Mesa fault system is highly fractured as contended, brine movement with subsequent pressure rise will be northwest and southeast along the fracture corridor between Faults 5 and 3. Through the projected 100 year life of the Paradox Valley Unit, injected brine should remain within the 2 mile corridor. Pressure rise due to injection will extend through the fault controlled corridor out into the northwest and southeast fan shaped "areas of least resistance to fluid movement and pressure rise".

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