# EXPORING FOR NEW OIL IN OLD FIELDS, SALT WASH FIELD: A CASE STUDY

*by*
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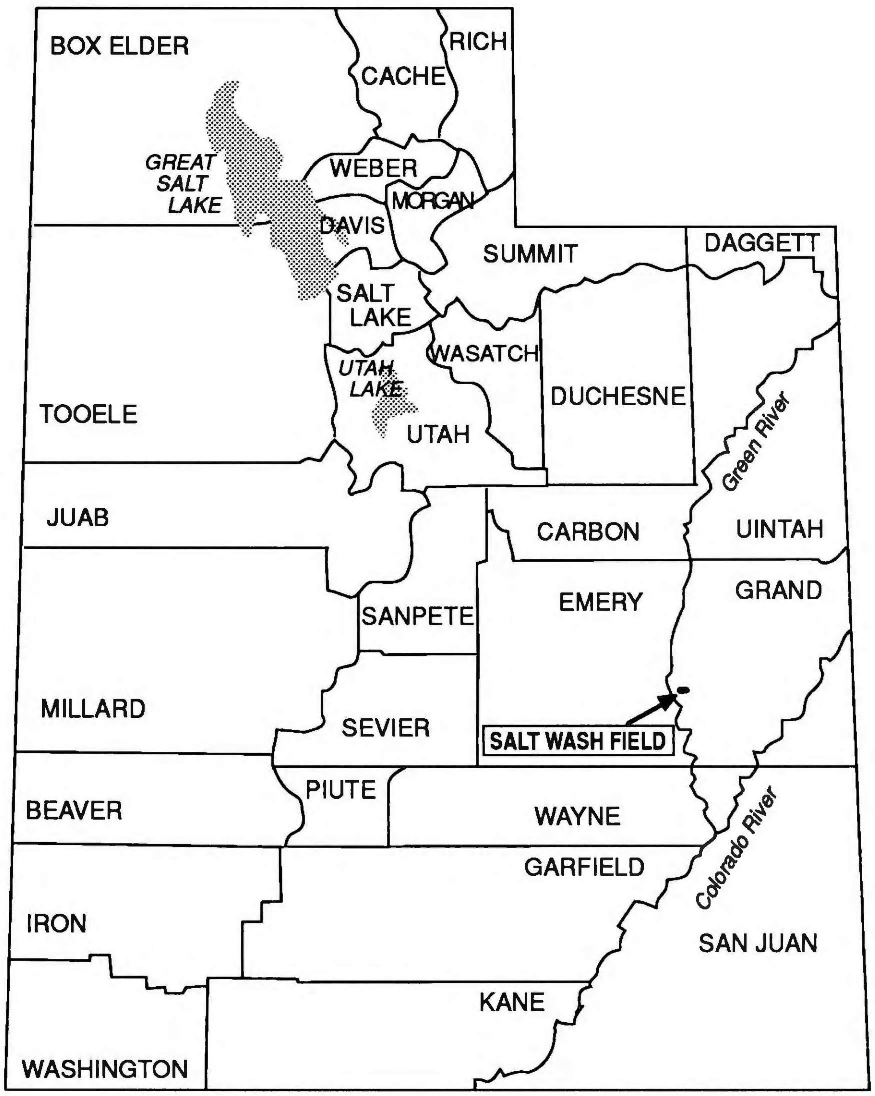


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The Utah Geological Survey Integral*gim database of wells drilled in the Salt Wash field area.

# ABSTRACT

Over 1.4 million barrels (0.2 million $m^3$) of oil and 11 billion cubic feet (0.3 billion $m^3$) of gas have been produced from the Salt Wash field since its discovery in 1961. The field is an asymmetrical west-trending anticline productive from the Mississippian Leadville Limestone. Three to six million barrels (0.5 to 0.9 million $m^3$) of oil may still be recoverable from the Salt Wash field. A poor understanding of the reservoir heterogeneity combined with mechanical problems in the wells and unmarketable inert gases have resulted in the field being incompletely developed more than 30 years after its discovery.

The discovery well was completed in the lower Leadville Limestone. Cores from the well contain porous crystalline dolomite with abundant vertical fractures. The operators believed the Leadville was a single reservoir with a large gas cap and a thin, 15-foot (4.6-m) oil column. The wells were perforated just above the oil/water contact in an attempt to produce the oil ring. Vertical fractures provided pathways for water resulting in early abandonment of most of the wells. Recompletion was rarely attempted because the casing was collapsed in most wells by the thick salt section in the Pennsylvanian Paradox Formation overlying the Leadville.

Recompletions have resulted in oil production from what was originally believed to be gas cap in both the lower and upper Leadville. In the majority of the wells, casing collapse prevented recompletion in the higher porosity zones. As a result, the majority of the Leadville reservoir (lower and upper) may be virtually undrained.

The Cane Creek shale of the Paradox Formation drill-stem tested oil in one well but has never been exploited at Salt Wash field. An updip porosity pinchout in Cycle 1 of the Paradox

Formation creates an untested trap across the western plunge of the anticline.

Many Leadville prospects in the northern Paradox basin were abandoned after testing high volumes of inert gas and no oil, or producing small quantities of oil. Drill-stem tests of the upper Leadville at the Salt Wash field recovered gas and no oil. However, once perforated, over 300,000 barrels (47,700 $m^3$) of oil were produced from the interval in one well. Many of the Leadville tests that were plugged and abandoned may represent by-passed potential.

## INTRODUCTION

The Salt Wash field is located in parts of section 7, 8, 15, 16, 17, and 18, T. 23 S., R. 17 E., Salt Lake Base Line, in the northern Paradox basin, Grand County, Utah (figures 1 and 2). The field is 10.5 miles (16.9 km) south of Interstate 70 and is accessible by improved county road.

The field was discovered by Pan American Petroleum Corporation (Amoco Production Company) in 1961 with the completion of the 1 Salt Wash well (figure 1) drilled to a total depth of 9,523 feet (2,902.6 m) in the Cambrian Lynch Dolomite. The well was completed flowing 115 barrels (18.3 $m^3$) of oil (BO) per day from perforations (8,693 to 8,707 feet [2,649.6 to 2,653.9 m]) in the Mississippian Leadville Limestone. Wells have also been drilled in the field by Shell Oil Company, Texaco Oil Company, Consolidated Oil and Gas Incorporated, Megadon

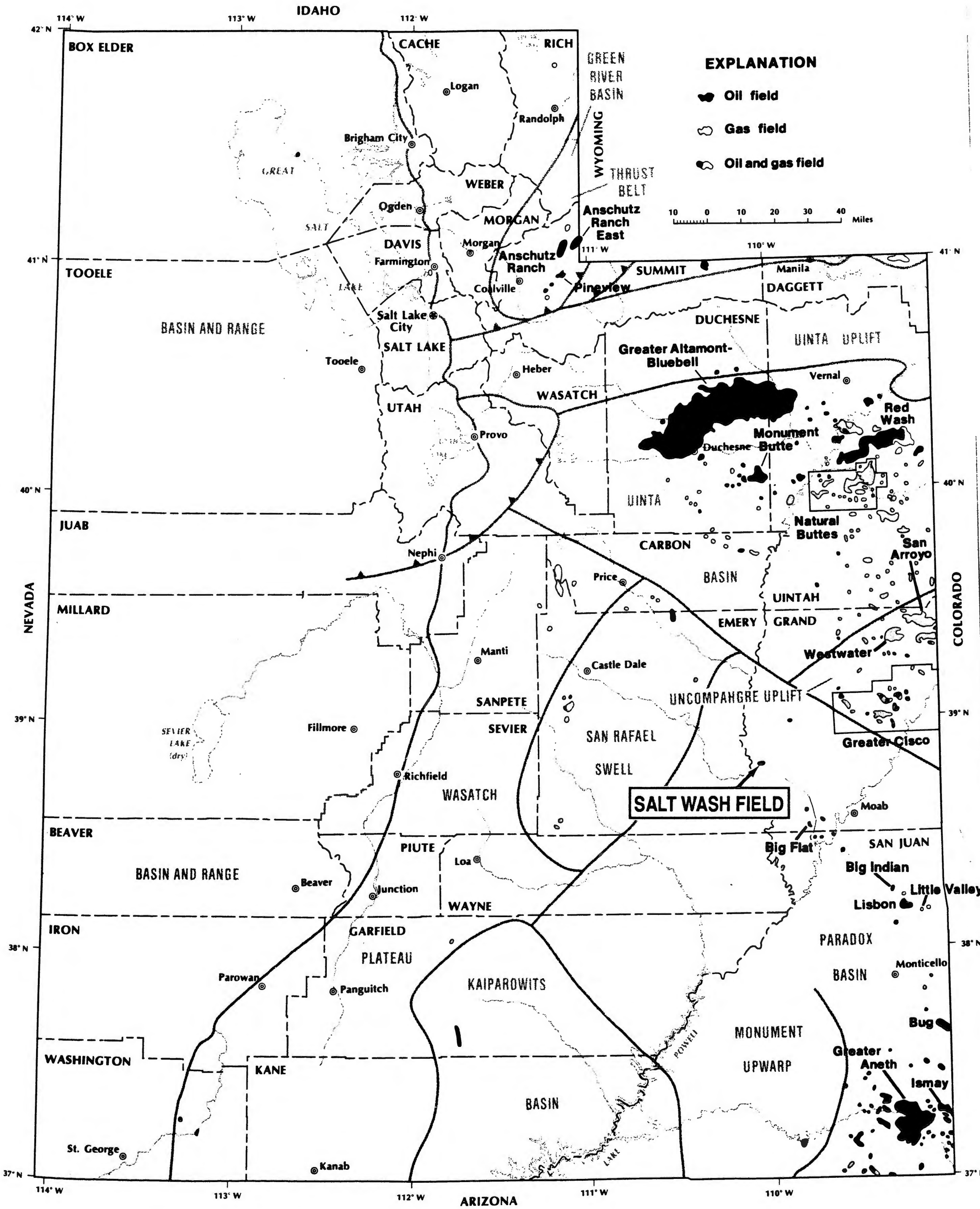


Figure 1. Oil and gas fields of Utah.

Energy Company, and SW Energy Company. Additional tests have been drilled in the area outside the field boundaries, by Reserve Oil and Gas Company, Belco Oil and Gas Company, and Willard Pease.

The Salt Wash field is an asymmetrical anticline with 300 to 600 feet (91.4 to 182.8 m) or more of closure on the top of the Leadville Limestone (figure 3). Cumulative production from the field is over 1.4 million barrels (0.2 million $m^3$) of oil (MMBO) and 11 billion cubic feet (0.3 billion $m^3$) of gas (BCFG) with an approximate average production of 1,000 BO (159 $m^3$) per month since 1977 (figure 4). Eleven wells have been completed as oil producers in the Salt Wash field. Eight wells were completed in the Leadville Limestone, two in the Devonian Elbert Formation, and one in the Pennsylvanian Paradox Formation. Most wells had a short production history due to high water production and collapsed casing. The majority of the production from the field has come from two wells, the 22-16 CF&I (<500,000 BO [79,500 $m^3$]) and 3 Govt. Smoot (<300,000 BO [47,700 $m^3$]) (figure 2).

The field currently (12/93) contains six active wells, but only the 3 Govt. Smoot produces on a regular basis. A short-radius horizontal leg was recently drilled in the upper Leadville Limestone in the 1-15 Federal well (figure 2). This well is currently shut-in and results of the drilling and completion attempt have not been released.

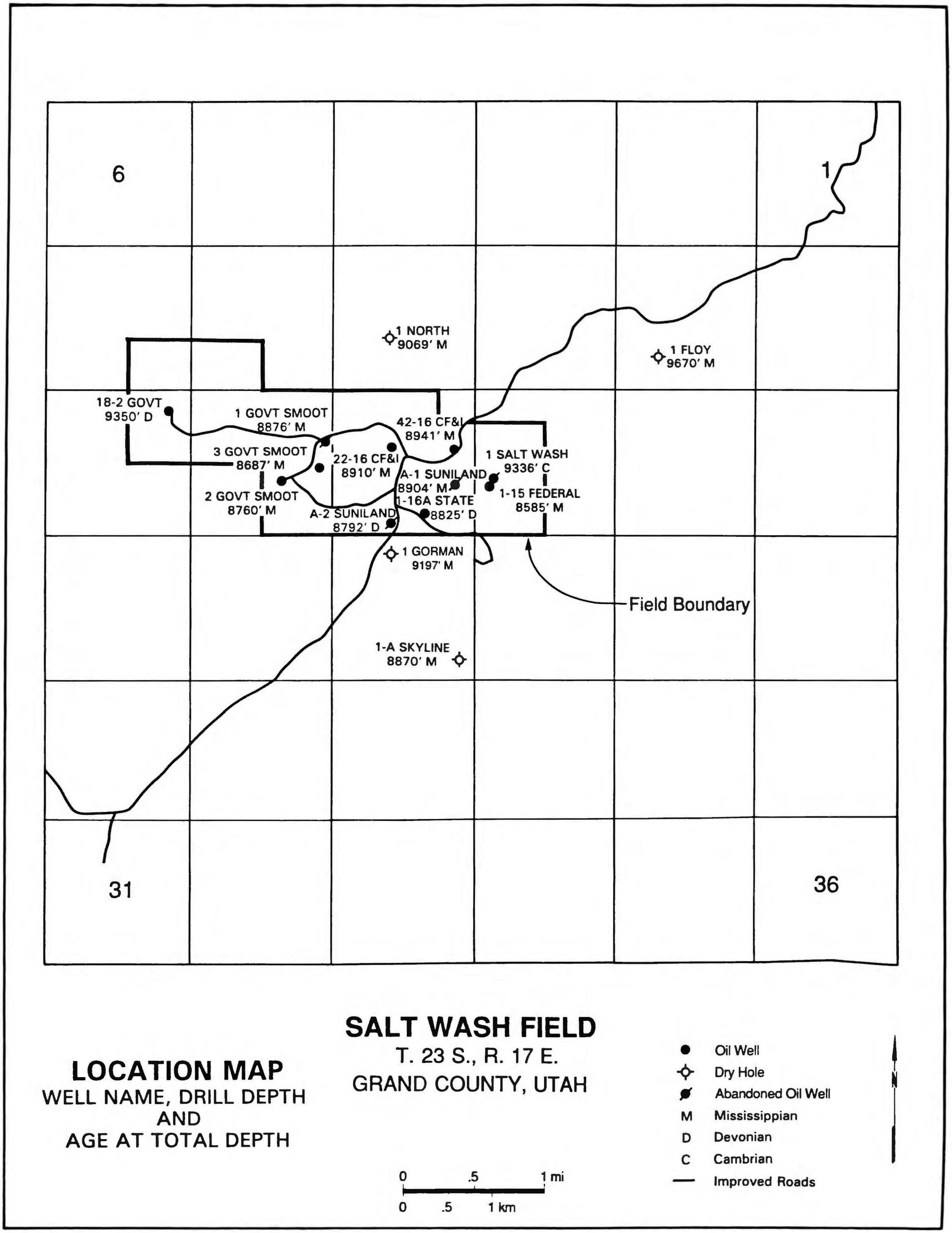


Figure 2. Drill hole location map of Salt Wash field.

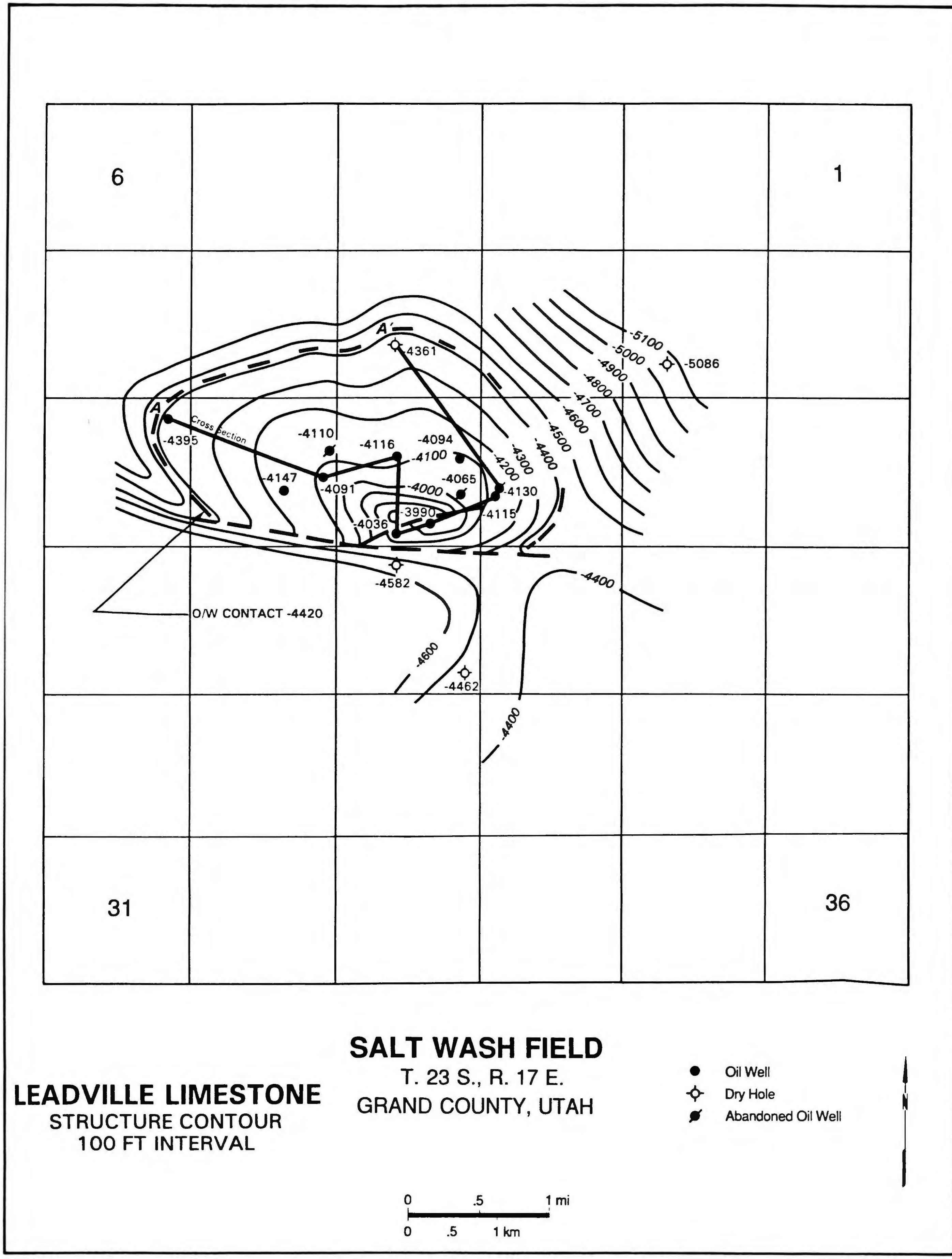


Figure 3. Top of upper Leadville Limestone structure contour map. Faults (dashed) are highly interpretative.

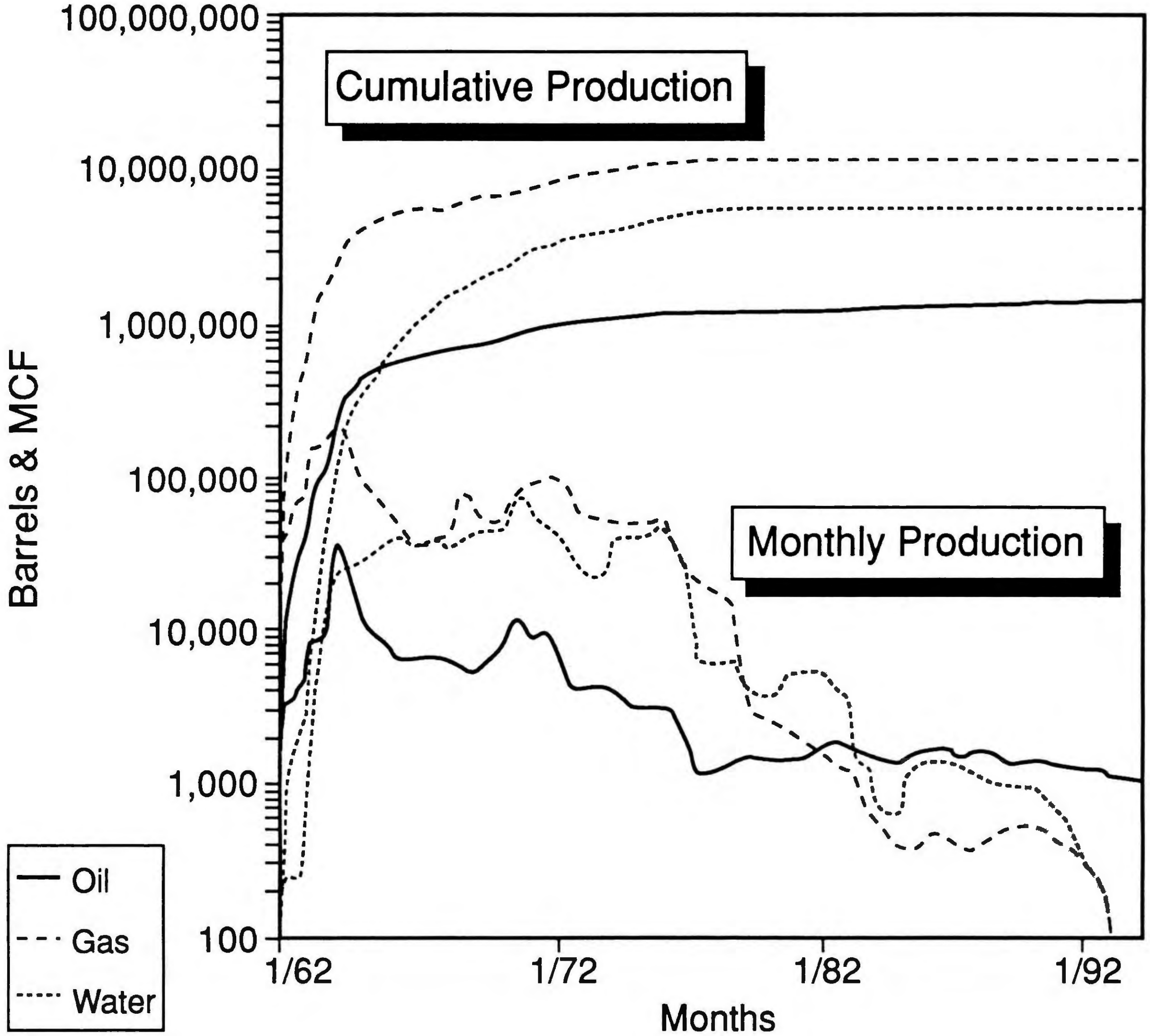


Figure 4. Generalized monthly and cumulative-production curves of the Salt Wash field. Over 1.4 million barrels (0.2 million m$^3$) of oil and 11 billion cubic feet (0.3 billion m$^3$) of gas have been produced from the field. The current production (12/31/93) is approximately 1,000 BO (159 m$^3$) per month, primarily from one well.

## Previous Work

Peterson (1973) wrote the first published report on the Salt Wash field. Norton (1975), Clem and Brown (1984), and Smouse (1993) also wrote brief field summaries. Chidsey and Morgan (1993), and Morgan (1993) discuss the Salt Wash field in the Atlas of Major Rocky Mountain Gas Reservoirs (Robertson and Broadhead, 1993).

## Purpose and Scope

A detailed study of the Salt Wash field was undertaken to develop a geologic model of a field that produces from the Leadville Limestone, that would aid and encourage more exploration in the Paradox basin. The Leadville Limestone was a major exploration target in the northern Paradox basin during the 1960s. During that time, the Lisbon (discovered in 1960), Salt Wash (1961), Big Indian (1961), Little Valley (1961), and Big Flat (1962) fields were discovered. Since 1962 there have not been any significant Leadville Limestone oil fields discovered and industry's interest in exploring for Leadville reservoirs in the northern Paradox basin has greatly decreased. A better understanding of the reservoir and its potential at Salt Wash field may help increase interest and improve exploration for new Leadville reservoirs in the Paradox basin.

This study uses well and field-history data, and well logs. Mud logs, sample descriptions, and core descriptions and analyses were used; drill cuttings and core were not examined by the author. The basic field-history and reservoir data were compiled for the "Atlas of Rocky Mountain Gas Reservoirs" (Robertson and Broadhead, 1993) funded by the Gas Research Institute. The field was investigated for its horizontal drilling potential in the Cane Creek shale (Pennsylvanian Paradox Formation) and Leadville Limestone as part of the "Increased Petroleum Production From Directed Horizontal Drilling in Utah" study (on-going). The horizontal drilling study is funded by the Utah Office of Energy and Resource Planning, who also provided some direct funding for the Salt Wash study.

## REGIONAL GEOLOGY

The Salt Wash field is located in the northern Paradox basin of the Colorado Plateau physiographic province. The area was the site of shallow-shelf marine deposition but was occasionally emergent, from Cambrian through Pennsylvanian time. Faulting during the Late Mississippian to Early Pennsylvanian resulted in the development of the Paradox basin and individual structures within the basin, including the Salt Wash anticline. Marine evaporites and organic-rich shales were deposited in the basin during most of Pennsylvanian time. The sea transgressed over the area during the Late Pennsylvanian and shallow marine-shelf conditions returned. This was followed by clastic terrigenous deposition from Permian through Early Cretaceous time. Salt diapirism and large salt-cored anticlines (Moab and Cache Valleys, for example) formed primarily during Permian and Triassic time. Cretaceous marine and Tertiary alluvial deposits were eroded from the Salt Wash area during regional uplift of the Colorado Plateau, beginning in Miocene time.

## STRATIGRAPHY AND PRODUCING FORMATIONS

The stratigraphic units exposed at the surface, at an average elevation of 4,400 feet (1,341.1 m), in the Salt Wash field area are the Jurassic Summerville and Curtis Formations, and Entrada Sandstone (figure 5). The deepest stratigraphic unit penetrated by drilling is the Cambrian Lynch Dolomite in the Pan American Petroleum (Amoco) 1 Salt Wash well (plate 1), which reached a total depth of 9,493 feet (2,983.5 m).

The majority of the production from the Salt Wash field is from the lower and upper Leadville Limestone. A minor amount of oil was produced from the Devonian Elbert Formation, from the A-2 Suniland and 1-16A State wells. The productive intervals in these two wells were originally correlated with the Leadville Limestone (rather than the Elbert Formation), and reported as such to the Utah Division of Oil, Gas and Mining. A minor amount of oil has been produced from the Paradox Formation in the 18-2 Govt. well.

### Devonian Elbert Formation

The Elbert Formation unconformability overlies the Cambrian Lynch Dolomite and is unconformability overlain by the Devonian Ouray Limestone. The Elbert Formation is divided into the lower McCracken Sandstone Member and an upper limestone. In the 1 Salt Wash well, the McCracken Sandstone Member is 188 feet (57.3 m) thick and the upper limestone is 201 feet (61.3 m) thick. The upper limestone was productive in the A-2 Suniland and 1-16A State wells. Total production (12/31/93) from the two wells is 8,411 BO (1,337.3 $m^3$) and 90,563 MCFG (thousand cubic feet of gas) (2,564.7 $m^3$). The low volume of production

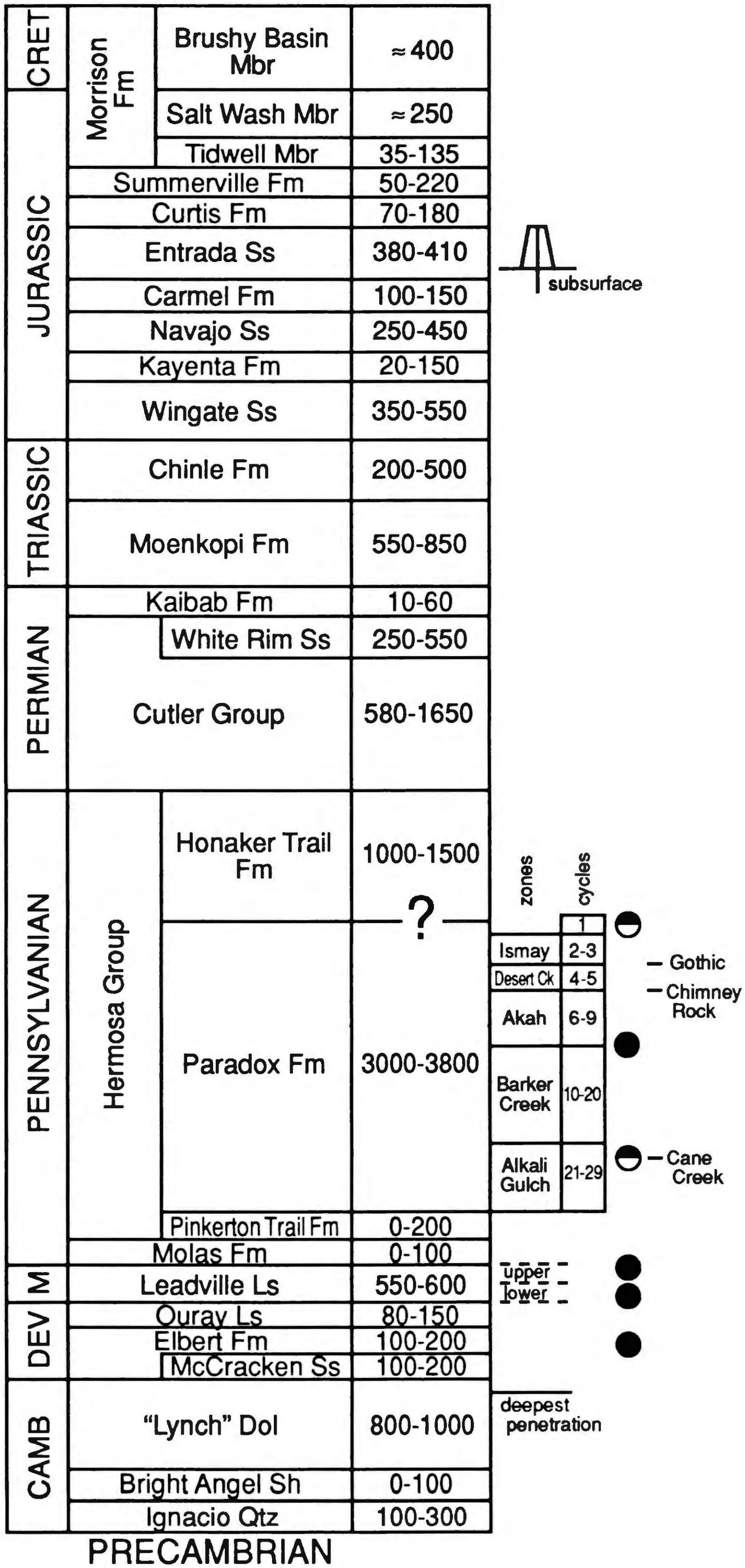


Figure 5. Stratigraphic column for the Salt Wash field area. Subsurface thicknesses determined from geophysical well logs except Cambrian, which is from Hintze, 1988. Surface thicknesses (in feet), from Doelling (verbal communication, 1994). Productive and potentially productive zones indicated with oil and show symbols, respectively.

and high water cut indicate the upper limestone reservoir has poor permeability and high water saturation. The McCracken Sandstone is a productive reservoir at Lisbon field (figure 1) but low resistivity values and a lack of drilling shows indicate the reservoir is wet in the wells drilled at Salt Wash field.

### Mississippian Leadville Limestone

The Leadville Limestone unconformability overlies the Ouray Limestone and is unconformability overlain by the Pennsylvanian Molas or Pinkerton Trail Formation. The drilled thickness of the Leadville Limestone ranges from 566 feet (172.5 m) in the 1 Salt Wash well to 596 feet (181.7 m) in the 18-2 Govt. well. A large portion of the Leadville Limestone has been faulted out of the A-2 Suniland and 1-16A State wells. As a result the Leadville Limestone is only 196 feet (59.7 m) and 183 feet (55.8 m) thick in the A-2 and 1-16A wells respectively. The Leadville Limestone is informally divided into a lower and upper member (Baars, 1966). The lower Leadville Limestone is dolomitic with crystalline and vugular porosity. Structural closure of the Salt Wash anticline mapped on the top of the lower Leadville horizon is 300 to 700 feet (91.4 to 213.4 m) (figure 6). The lower Leadville Limestone reservoir is intermittently produced in the 2 Govt. Smoot well, and was produced in the 1 Salt Wash, 22-16 CF&I, 42-16 CF&I, and 1 and 3 Govt. Smoot wells. At Salt Wash field, over 1.1 MMBO (0.17 million $m^3$) and 8.5 BCFG (0.24 billion $m^3$) have been produced from the lower Leadville Limestone reservoir (12/31/93). The majority of this production is from the 22-16 CF&I well, where 0.6 million BO (0.09 million $m^3$) and 5.1 BCFG (0.14 billion $m^3$) was produced (figure 7).

The upper Leadville is limestone to dolomitic limestone with some thin (5 to 15 feet [1.5 to 4.6 m]) porous dolomite zones. The porosity may be in post-depositional, dolomitized vadose

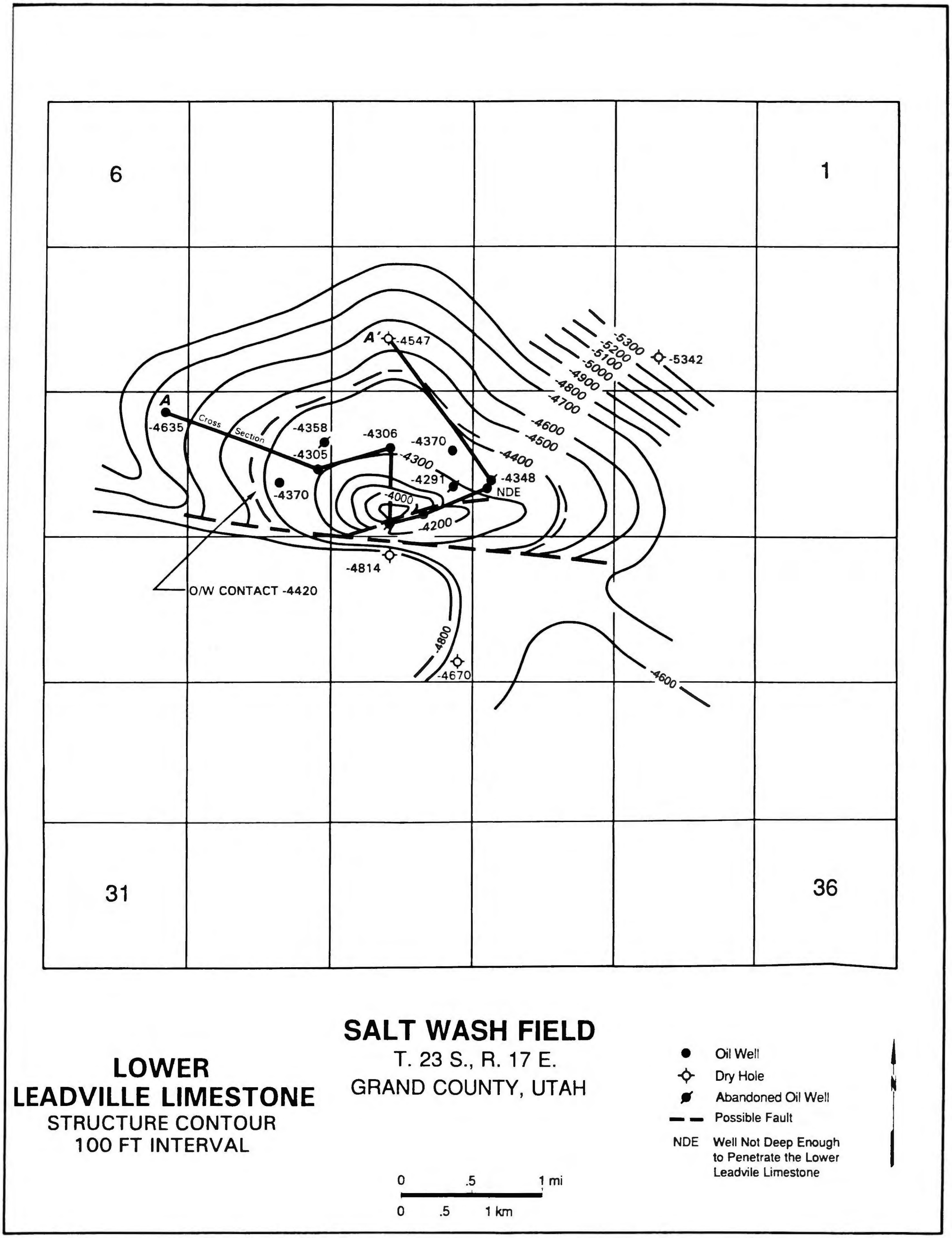


Figure 6. Top of the lower Leadville Limestone structure contour map. Faults (dashed) are highly interpretative.

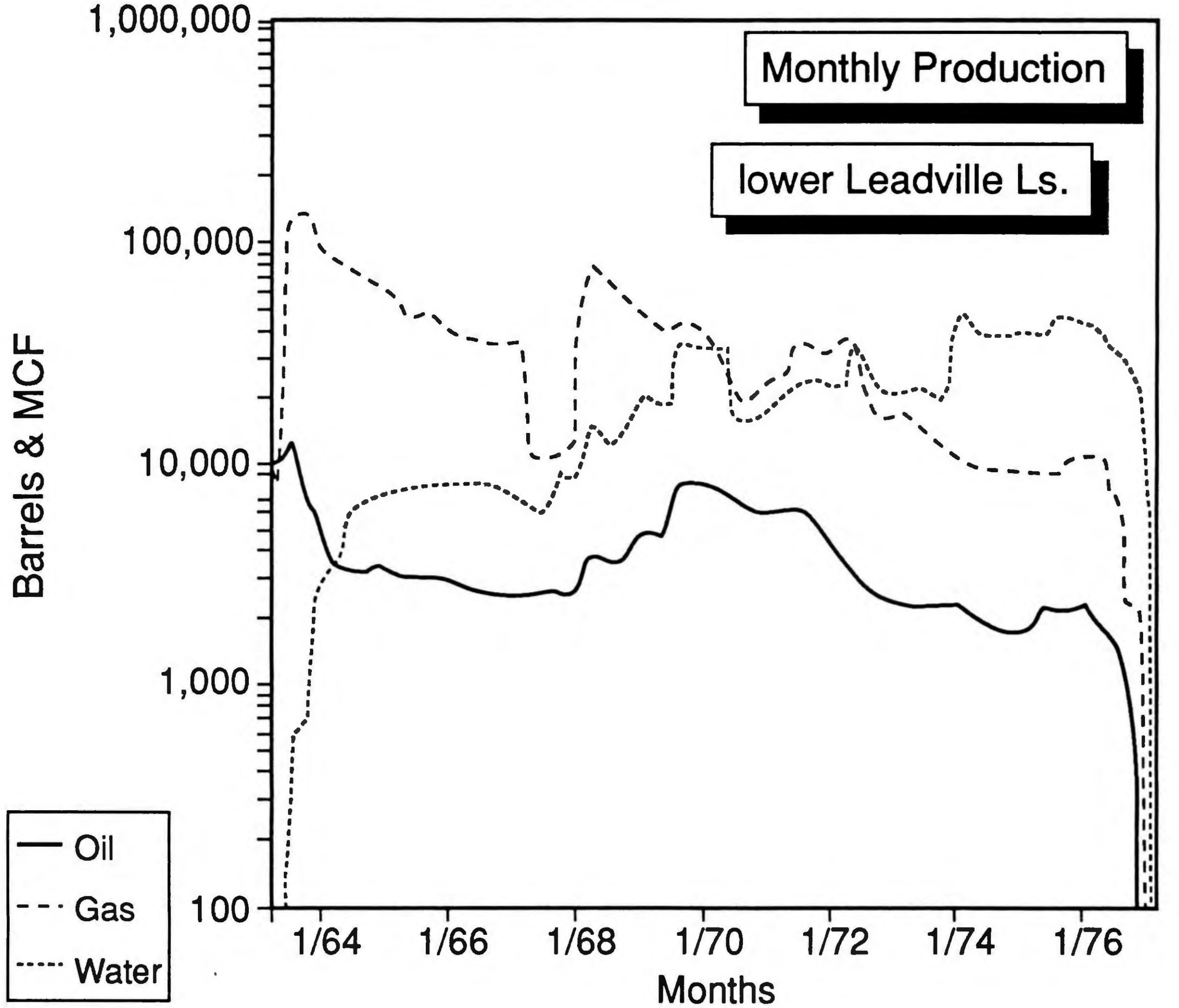


Figure 7. Generalized monthly production curves for the 22-16 CF&I well. Over 500,000 BO (79,500 m$^3$) were produced from this well in the lower Leadville Limestone.

zones. Zones with greater than 8 percent porosity occur in every well in the Salt Wash area except the 1-15 and 1 Salt Wash wells. Closure at the upper Leadville horizon is 300 to 600 feet (91.4 to 182.8 m) or more (figure 3).

The 42-16 CF&I well was recompleted in the upper Leadville Limestone reservoir in 1969. The upper and lower Leadville production was commingled. The monthly production rate increased but the casing partially collapsed a year later. The well was shut in from 1972 to 1982. From 1982 through 1991, the well was produced intermittently at an average rate of 10 to 12 BO (1.6 to 1.9 $m^3$) per day and has not been produced since May 1992. A bridge plug was set above the lower Leadville Limestone perforations in the 3 Govt. Smoot well and the upper Leadville Limestone was perforated. This well has produced over 300,000 BO (47,700 $m^3$) in 20 years and continues to flow at a relatively steady rate while the water and gas production decreased (figure 8). Cumulative production from the upper Leadville Limestone is 353,886 BO (56,267.9 $m^3$) and 3,133,468 MCFG (88,739.8 $m^3$) (11/30/93).

Completing wells in the lower Leadville reservoir is complicated by the potential for coning of the water directly below and in contact with the oil. Cores of the Leadville Limestone at Salt Wash field contain numerous vertical fractures creating high vertical permeability relative to horizontal permeability (often five to 10 times greater). As a result, wells like 1 Salt Wash, that were perforated directly above the oil/water contact began producing large quantities of water shortly after being placed in production (figure 9). Recompletion of these wells generally did not occur because the casing in the wellbore had collapsed (figure 10).

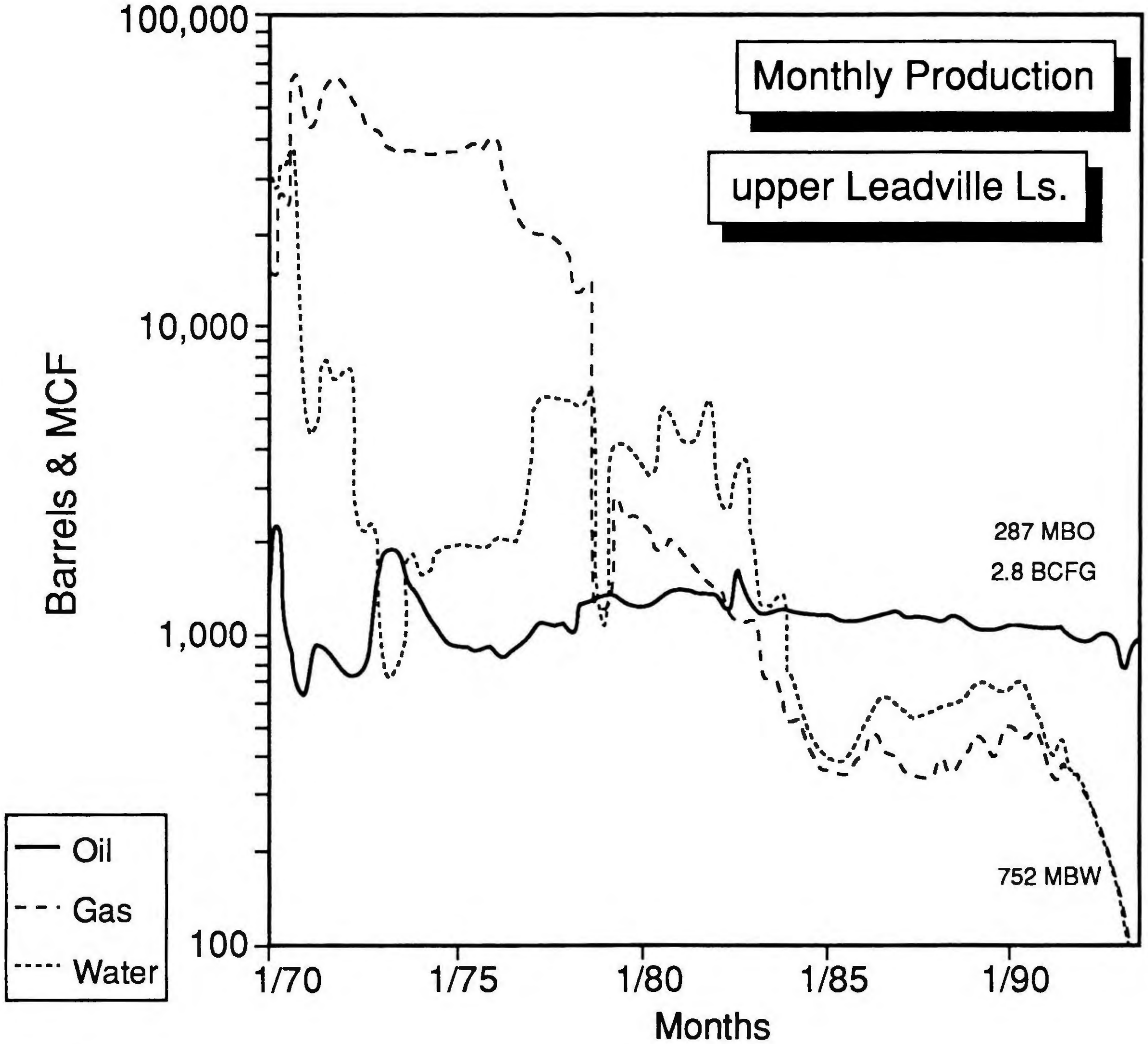


Figure 8. Generalized monthly production curves for the 3 Govt. Smoot well. Over 300,000 BO (47,700 $m^3$) has been produced from this well in the upper Leadville Limestone. The current production from this well is approximately 1,000 BO (159 $m^3$) per month. The oil rate has remained fairly constant over the years while the gas and water volumes decreased.

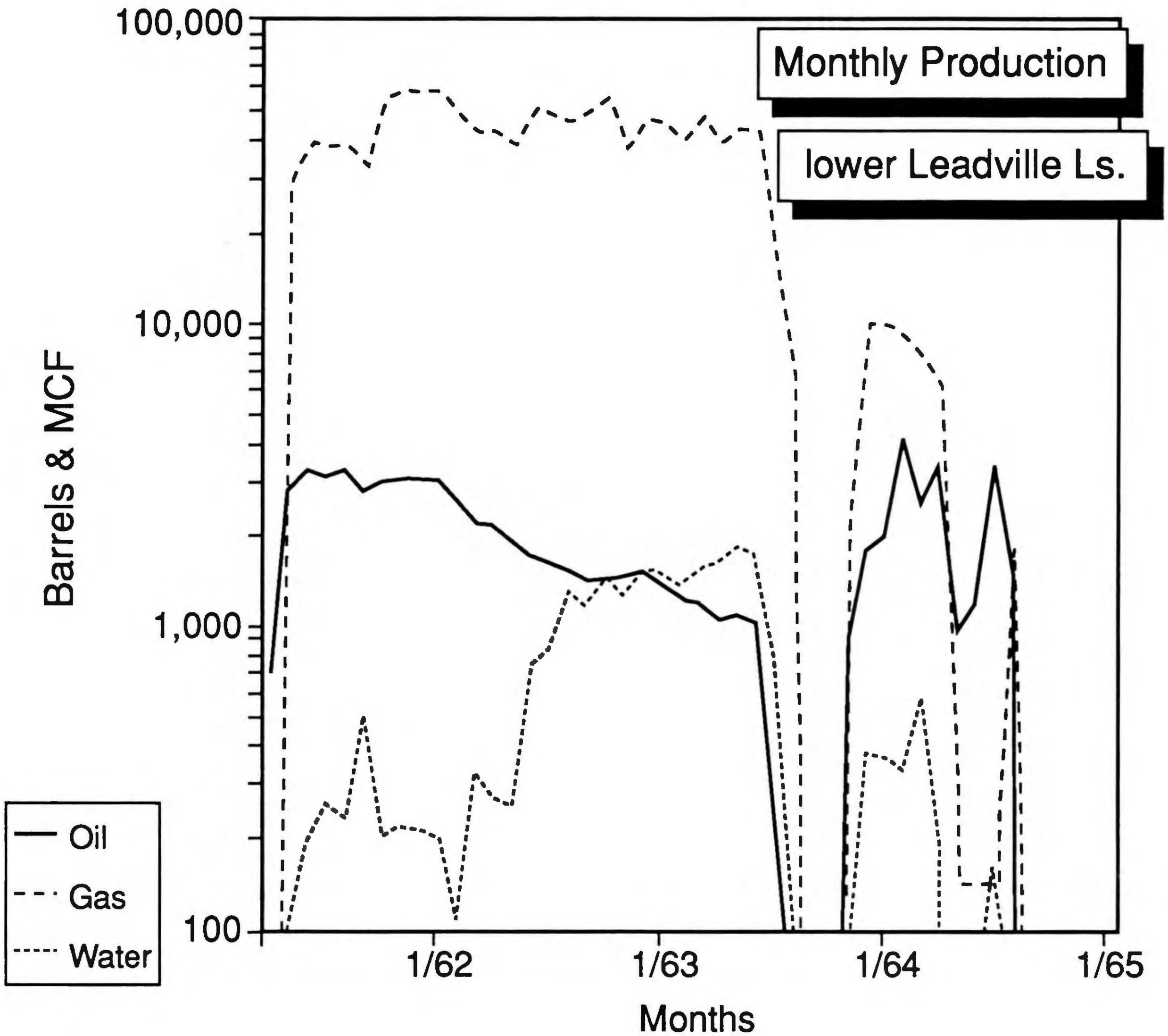


Figure 9. Generalized monthly production curves for the 1 Salt Wash well. Less than 57,000 BO (9,063 $m^3$) were produced from this well before the large water cut and collapse of the casing resulted in abandonment of the well. The large water cut, possibly due to coning, and casing collapse, were common problems in most of the wells.

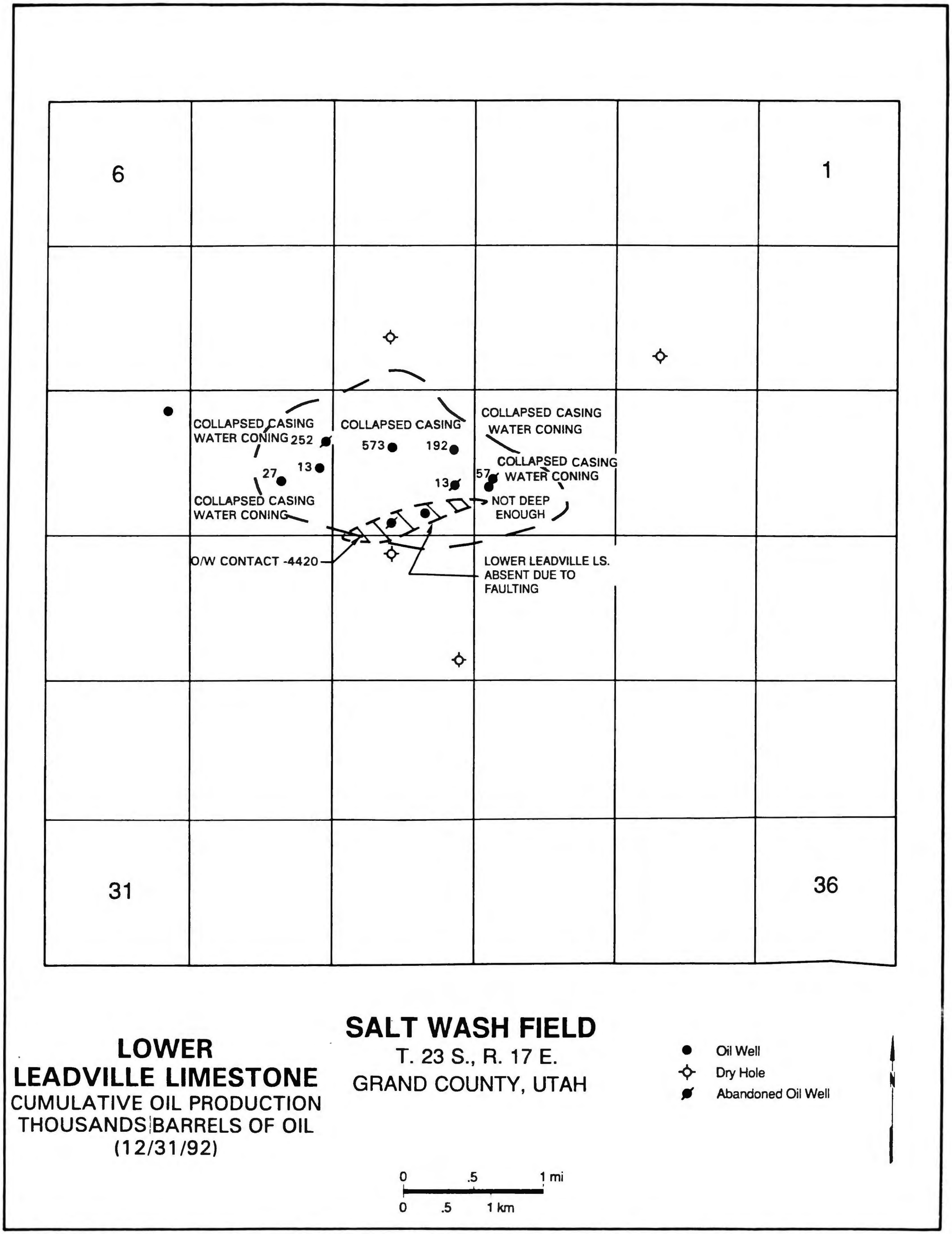


Figure 10. Status map of wells completed in the lower Leadville Limestone. Most wells were prematurely abandoned due to possible water coning and collapsed casing.

An additional problem can be the presence of water directly above the productive interval. The 1 Salt Wash well was tested at a rate of 533 MCFG (15,095 $m^3$) per day and recovered 858 feet (261.5 m) of highly gas-cut and mud-cut water from the upper Leadville overlying the productive lower Leadville reservoir. The 3 Smoot well was drill-stem tested from 8,630 to 8,687 feet (2,630.4 to 2,647.8 m). The test interval included the basal portion of the upper Leadville and upper portion of the lower Leadville. Gas, oil, and water flowed to surface (no gauge or volumes reported) during the test and the drill-pipe recovery was 4 BO (0.6 $m^3$) and nine barrels of water (BW) (1.4 $m^3$). The well was completed through perforations from 8,643 to 8,635 feet (2,634.4 to 2,631.9 m) in the upper portion of the lower Leadville. The initial potential of the well was gauged at 128 BO (20.4 $m^3$), 1,300 MCFG (36,816 $m^3$), and 1,050 BW (166.9 $m^3$) per day. In 14 months, 13,170 BO (2,094 $m^3$) and 310,256 BW (49,330 $m^3$) were produced from the well. The perforated interval is 104 feet (31.7 m) above the original oil/water contact. The high volume of water may be from a water-saturated zone at the top of the lower Leadville porosity. For water to be present at the top of the lower Leadville in this well, the reservoir must be more heterogenous than originally believed.

### Pennsylvanian Paradox Formation

The Paradox Formation conformably overlies the Pinkerton Trail Formation and is conformably overlain by the Pennsylvanian Honaker Trail Formation. The Paradox Formation is part of the Hermosa Group, which consists of, in ascending order, the Pinkerton Trail, Paradox, and Honaker Trail Formations (figure 5). The Paradox is the only formation in the group that is productive in the Salt Wash field. The Paradox Formation was deposited in an evaporitic restricted basin. The formation is composed principally of salt beds, consisting of cyclically bedded halite and lesser amounts of anhydrite and potash with interbeds of dolomite, dolomitic siltstone, and organic-rich shales that were deposited during sea level high-stands. Hite (1960) numbered the salt cycles in descending order, 1 through 29. It is now common practice to consider a complete cycle as consisting of an interbed and overlying salt or equivalent carbonate unit. The cycles are informally grouped into zones; Ismay (cycles 2-3), Desert Creek (4-5), Akah (6-9), Barker Creek (10-20), and Alkali Gulch (21-29), (Hite and Cater, 1972; Reid and Berghorn, 1981).

The 18-2 Govt. well is perforated in interbeds 3-9, 11, 16-19. Production is intermittent and the total is 862 BO (137.1 $m^3$) and 629 MCFG (17.8 $m^3$). The Cane Creek shale (interbed 21) is productive in the Kane Springs unit 10 miles (16 km) south of the Salt Wash field. Horizontal drilling has proven to be the most successful method to exploit the fractured Cane Creek shale reservoir. The 1-16A State well recovered 600 feet (182.9 m) of oil during an open-hole drill-stem test of the Cane Creek shale (figure 11). Closure at the Cane Creek horizon is 200 feet (60.9 $m^3$) (figure 12). The Cane Creek shale is currently (3/1/94) not productive at the Salt Wash field.

In cycle 1 of the Paradox Formation, a facies change from porous dolomite (over 50 feet of 12 to 14 percent porosity) to anhydrite then to halite, occurs from west to east, across the western plunge of the Salt Wash anticline (figure 13 and plate 2). The updip pinchout of porosity in cycle 1 between 18-2 Govt. and the Govt. Smoot wells is a relatively shallow (5,500 feet [1,676.4 m]) untested trap similar to the Ismay and Desert Creek plays in the Greater Aneth area in southeast San Juan County.

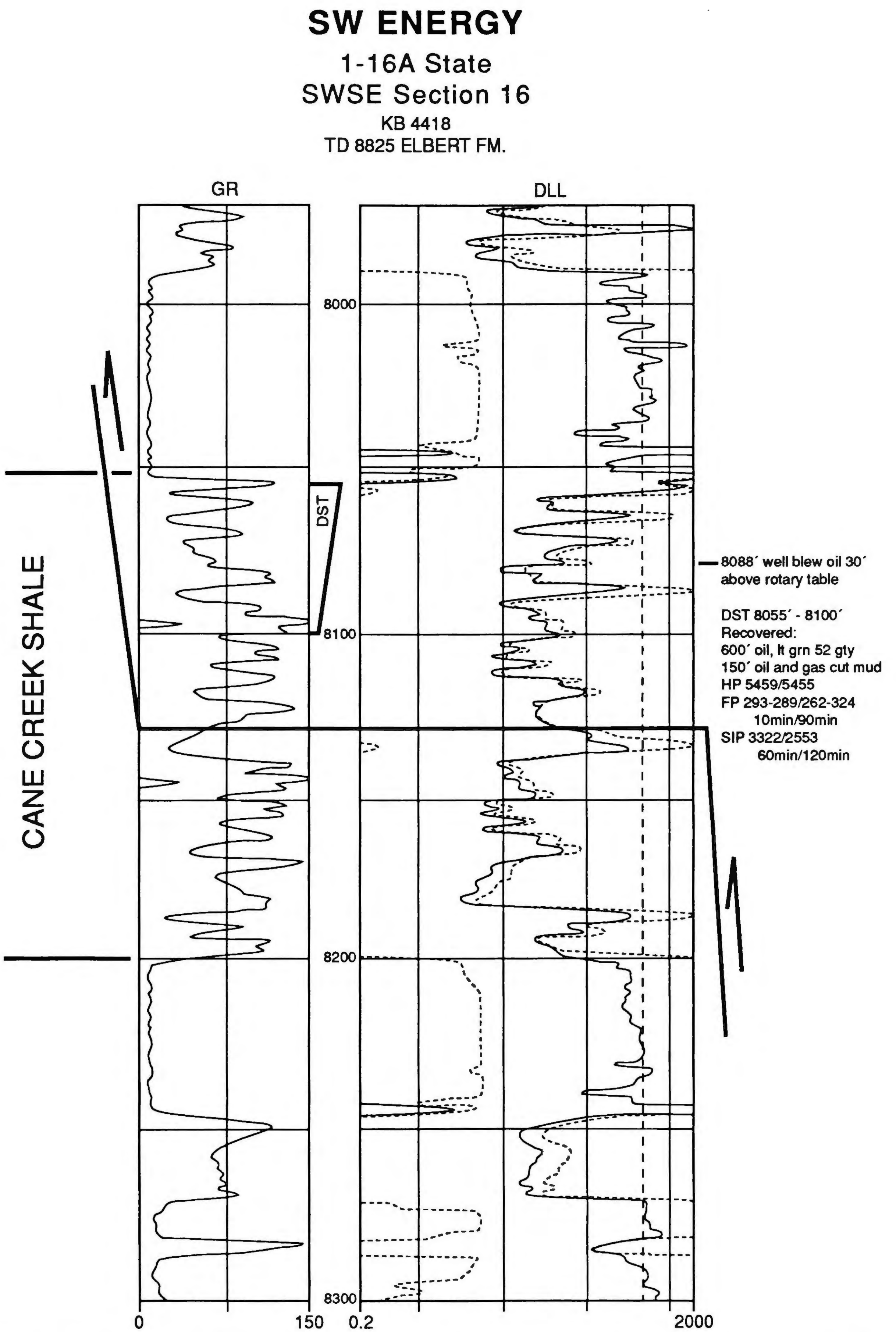


Figure 11. Geophysical log of the Cane Creek shale of the Paradox Formation in the 1-16A State well. A drill-stem test of the Cane Creek recovered 600 feet (182.9 m) of oil. The section is repeated by a reverse fault.

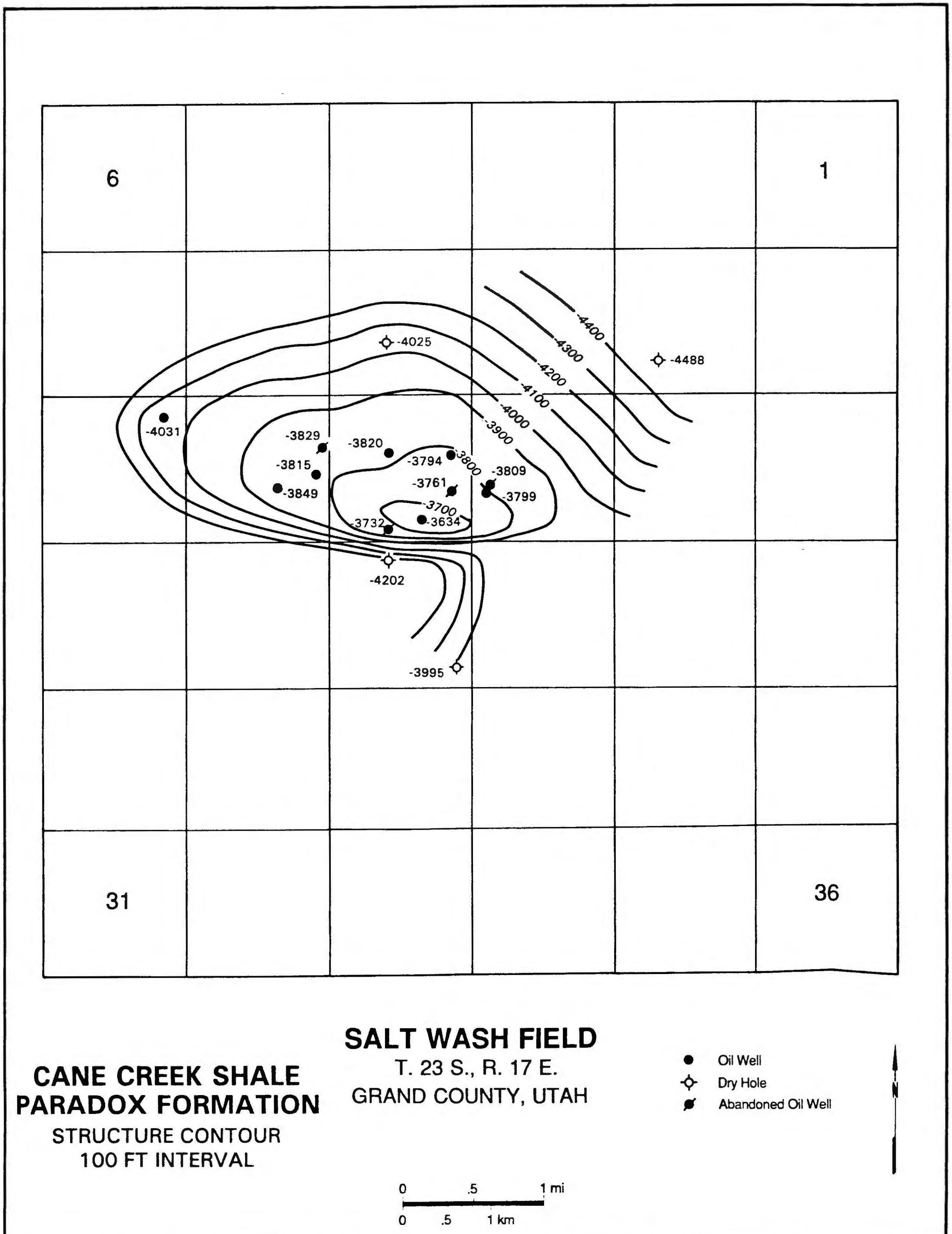


Figure 12. Top of the Cane Creek shale of the Paradox Formation structure contour map. The reverse fault causing approximately 75 feet of repeated section in the 1-16A well (figure 11) was not encountered in any other well. Therefore, the strike and extent of the fault is unknown and not shown on this map.

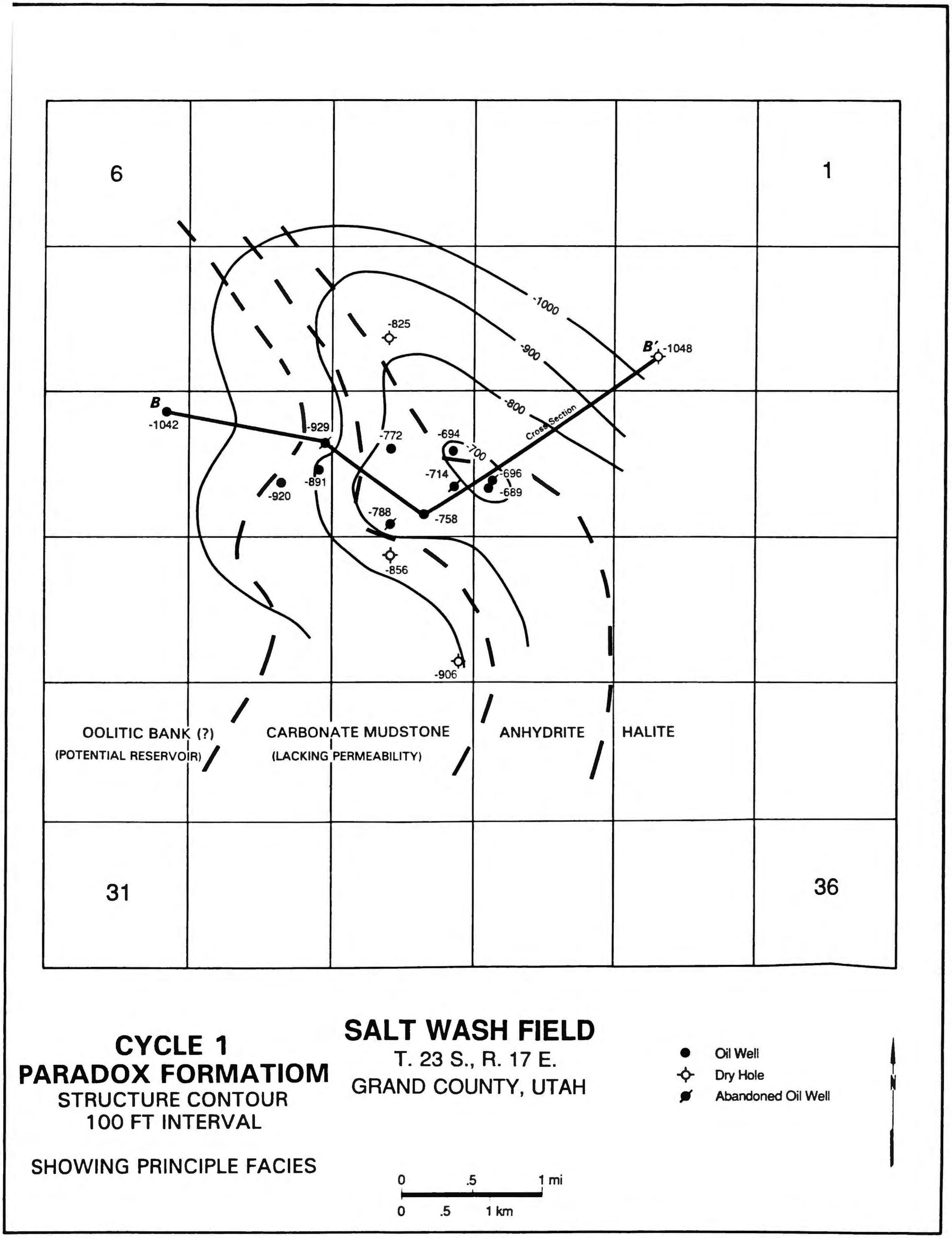


Figure 13. Top of cycle 1 of the Paradox Formation structure contour map. The principal facies of the cycle are shown. Note the updip pinchout of the porous oolitic bank(?) deposit creating a possible trap along the western plunge of the structure.

## STRUCTURE

The Salt Wash field is an east-west asymmetrical anticlinal trap. The structure is associated with a high-angle east-west fault, down-to-the-south, that moved during Late Mississippian to Early Pennsylvanian time. Additional movement may have occurred on the fault during the Pennsylvanian and again in the Late Cretaceous to Early Tertiary. The fault has not been penetrated by any wells, but is visible on seismic profiles and may die out in the lower Paradox Formation (Ken Grove, Columbia Gas Development Corporation, and Robert Gray, Thistle Inc. Geophysical, verbal communication, 1994). A normal fault was penetrated by the A-2 Suniland and 1-16A State wells. As a result, the lower Leadville (over 300 feet (91.4 m) of section), is absent in these two wells. The A-2 Suniland and 1-16A State wells are the structurally-highest penetrations of Paleozoic-aged rocks in the field (figures 3 and 6). An additional 300 feet (91.4 m) of untested closure may be present on the upthrown side of the fault.

In the 1-16A State well, a reverse fault repeats the Cane Creek shale. A recumbent fold of cycle 19 was penetrated by the 22-16 CF&I well. I believe these are highly localized structures caused by salt movement during the Permian and Triassic.

The Ten Mile graben is located 2 miles (3.2 km) north of the Salt Wash field. The normal faults forming the graben are related to an underlying salt-cored anticline in the Paradox Formation. Beneath the salt-cored anticline, subsurface, high-angle faults displace Early and Pre-Pennsylvanian rock and die out upward in the Paradox Formation (Woodward-Clyde Consultants, 1984). The deeper faults place organic-rich shales against the Leadville Limestone, providing a migration pathway for hydrocarbons into the Leadville Limestone, downdip from the Salt Wash field.

## OIL AND GAS COMPOSITION

The oil produced from the Leadville Limestone at the Salt Wash field is $50^0$ API gravity, contains 0.23 percent sulfur, has a viscosity of 32 seconds at $100^0$ F, and a pour point of $40^0$ F. (Wenger and Morris, 1971). The oil and gas compositions are similar for both the upper and lower Leadville production. The gas has an average heating value of 442 BTU/$ft^3$, and a specific gravity of 1.015. The average composition of the gas produced from the Leadville Limestone at Salt Wash field is given in table 1.

Table 1. Average composition, in mole percent, of the gas produced from the Leadville Limestone at Salt Wash field. Data from Moore and Sigler (1987).

| | | |
|---|---|---|
| Methane ($C_1$) = 11.8 | Butane ($C_4$) = 3.1 | Nitrogen ($N_2$) = 71.9 |
| Ethane ($C_2$) = 2.6 | Isobutane ($C_5$) = 1.4 | Carbon dioxide ($CO_2$) = 2.1 |
| Propane ($C_3$) = 2.8 | Higher fracs. ($C_6$+) = 0.7 | Helium (He) = 1.4 |
| | | Hydrogen sulfide ($H_2S$) = 0.0 |

## SOURCE AND MIGRATION OF HYDROCARBONS

Mass spectrometry and gas chromatography of the oil produced from the Leadville Limestone indicate that the source rock for hydrocarbons at Salt Wash field is the organic-rich shales in the Paradox Formation (Jim Palacas, U.S. Geological Survey, verbal communication, 1994). The Paradox Formation in the northern Paradox basin was not mature enough to generate oil until the Early Cretaceous or later (figure 14). The Salt Wash structural trap formed during the late Mississippian to early Pennsylvanian, long before the generation and migration of hydrocarbons.

The Paradox Formation is in fault contact with the Leadville Limestone at Ten Mile graben 2 miles (3.2 km) north of the field. The majority of the hydrocarbons may have been generated and migrated from the north and entered the Leadville Limestone at this location. The south-bounding fault between the A-2 Suniland and 1 Gorman wells (figures 2 and 6) may have been a migration pathway draining a much smaller source area.

The Paradox Formation interbeds, including the Cane Creek shale, are self-sourced fractured reservoirs. The most likely source of hydrocarbons for cycle 1 of the Paradox Formation is the organic-rich interbeds that over and underlie the reservoir.

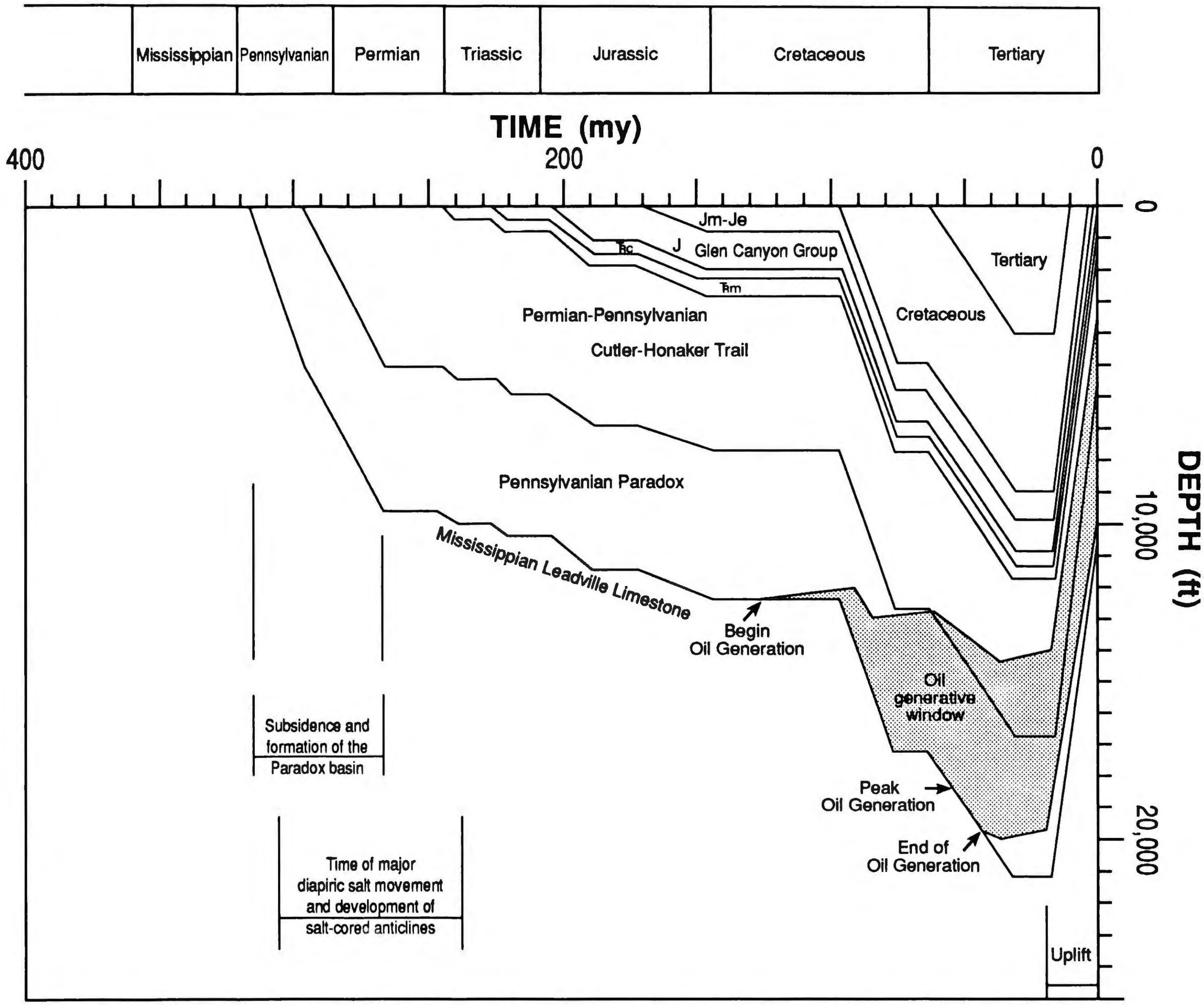


Figure 14. Burial history curve and Lopatin time-temperature interval (TTI) calculation for the 2 Gold Bar well (SW1/4 section 23, T. 25 S., R. 20 E.). A geothermal gradient of 44° F/mi (22° C/km) above the Paradox Formation, and 34° F/mi (13° C/km) through the Paradox was used (Sass and others, 1983). The 2 Gold Bar well is representative of the burial and thermal history of the Salt Wash field and northern Paradox basin. Oil generation in the Paradox Formation began in Early to Late Cretaceous time, well after the Salt Wash anticlinal trap had formed (Pennsylvanian time).

## SOURCE AND MIGRATION OF INERT GASES

The inert gases (nitrogen, carbon dioxide, and helium) produced from the Leadville Limestone at the Salt Wash field may have come from a variety of sources. Nitrogen and carbon dioxide may have generated from Paleozoic rocks in the Uinta Basin, were they were deeply buried during the Late Cretaceous and Tertiary. Helium may have derived from basement rocks locally as well as migrated in from the north. The source of nitrogen and carbon dioxide in Leadville reservoirs in the Lisbon Valley and Blanding basin is from the south. There, volcanic intrusions provided the heat source for generation of nitrogen and carbon dioxide in the Blanding basin area approximately 40 million years ago.

Nitrogen in the subsurface can be generated in large volumes by the thermal alteration of dispersed organic nitrogen compounds in redbeds (Hunt, 1979). Carbon dioxide can be produced in large volumes by thermal decomposition of limestone. Impure limestones and water-wet dolomitized limestone begin generating carbon dioxide at temperatures as low as 167° F (75° C); maximum generation of carbon dioxide occur when subsurface temperatures approach 302° F (150° C) (Germann and Ayres, 1942; Kissin and Pakhomov, 1967; in Hunt, 1979). Both nitrogen and carbon dioxide can be generated from coal (Getz, 1977) but coal is considered an unlikely source for the inert gases found in the Paleozoic reservoirs of the northern Paradox basin. Helium is produced as a by-product of the alpha disintegration of naturally occurring radioactive elements. Helium can be produced from igneous, metamorphic, and sedimentary rocks depending upon their uranium and thorium contents (Hunt, 1979).

Because it is a smaller molecule, nitrogen commonly migrates farther distances than carbon dioxide. As a result, the percentage of nitrogen in reservoirs is higher, while the percentage of carbon dioxide is lower, farther from the source (Getz, 1977). A decrease in the carbon dioxide to nitrogen ratio occurs from north to south, from the Uinta basin into the northern Paradox basin. Paleozoic-aged reservoirs at Gordon Creek field (T. 14 S., R. 7 E.) and Farnham Dome field (T. 15 S., R. 11-12 E.), Carbon County, contain approximately 99 percent carbon dioxide. Woodside field (T. 19 S., R. 13 E.), Emery County, tested 32 percent carbon dioxide and 61 percent nitrogen (Morgan and Chidsey, 1991). Salt Wash (T. 23 S., R. 17 E.) and Big Flat (T. 26 S., R. 19 E.) fields, Grand County, produced gases containing over 70 percent nitrogen and only 2 to 3 percent carbon dioxide. In the southern portion of the Paradox basin of southeast Utah and southwest Colorado, the Leadville reservoirs contain 80 percent or more carbon dioxide (Picard, 1960). Northward, in Lisbon Valley, gases in the Leadville reservoirs are composed of approximately 26 percent carbon dioxide and 12 percent nitrogen. The Cane Creek anticline may be the divide between the two source areas.

## REMAINING HYDROCARBON POTENTIAL

### Lower Leadville Limestone

The porous dolomite in the lower Leadville is the most productive reservoir in the Salt Wash field. Over 1 MMBO (0.16 million $m^3$) have been produced from this reservoir and 1.0 to 1.4 million barrels (0.16 to 0.22 million $m^3$) of recoverable oil could still exist in the field. This estimate of remaining potential assumes the production from the 22-16 CF&I well is typical of the potential from the lower Leadville reservoir. This well had the longest trouble-free production history from 1963 till 1976, and produced over 500,000 BO (79,500 $m^3$). The 22-16 CF&I well has a gross productive interval of 114 feet (34.7 m), from the top of the lower Leadville porosity to the oil/water contact, at an elevation of -4420 feet (-1,347.2 m). A 31 BO/gross acre-foot (3,974 $m^3$ oil/gross h-m) recoverable, was calculated for the 22-16 CF&I well, assuming a 160-acre (64.8-h) drainage area. The BO/gross acre-foot was gridded for the Salt Wash field and an amount equal to the cumulative production for each well was removed from the gridded database within 160 acres (64.8 h) of the respective well.

The calculated range in quantity of recoverable oil (1.0 to 1.4 MMBO [0.16 to 0.22 million $m^3$]) is strongly effected by the minimum volume per 160 acres (64.8 h) that is assumed economically feasible to justify drilling. The recovery, number of wells drilled, and drainage area per well varies with the use of vertically or horizontally drilled wells. Horizontal wells can drain a much larger area and greatly reduce the amount of water coning compared to vertical wells (Chaperone, 1986).

These calculations are intended to demonstrate that a significant volume of oil may still potentially exist in the Salt Wash field. They are highly sensitive to the assumptions used. Therefore, the values given should be considered only as preliminary estimates.

**Upper Leadville Limestone**

The upper Leadville is the second most productive reservoir in the Salt Wash field. Nearly 300,000 BO (47,700 $m^3$) have been produced from this reservoir, which may still contain 1 to 2.4 million barrels (0.16 to 0.38 million $m^3$) of recoverable oil. The assumptions used in this estimation are: 1) the production from the 3 Govt. Smoot well is the average per-well potential, 2) the drainage area is 160 acres (64.8 h), and 3) the oil/water contact is -4,420 feet (-1,347.2 m) mean sea level.

The upper Leadville reservoir has only been exploited in the 42-16 CF&I and 3 Govt. Smoot wells. In the 42-16 CF&I well, was originally completed in the lower Leadville reservoir and produced from it for six years, and then the upper Leadville reservoir was perforated and that production commingled with the production from the lower Leadville. The additional perforations in the upper Leadville resulted in an increase in the monthly production rate of the well. The casing collapsed approximately one year after the upper Leadville was perforated. The short production history of this well, after the upper Leadville was put into production, is not adequate to determine the full potential of that reservoir.

The 3 Govt. Smoot well has produced nearly 300,000 BO (47,700 $m^3$) from the upper Leadville reservoir. The well has produced for over 23 years and continues to flow at an average rate of 1,000 BO (159 $m^3$) per month. The oil rate has remained fairly constant while the gas and water volumes have declined steadily during this time (figure 8). The decline in gas and water indicates the reservoir drive is gas expansion and gravity, with a very limited water drive.

**Paradox Formation - Cane Creek Shale**

The Cane Creek shale reservoir is currently not productive in the Salt Wash field. In the Kane Springs unit 10 miles (16 km) to the south, horizontal wells completed in the Cane Creek shale are estimated to have a potential in excess of 500,000 BO (79,500 $m^3$) per well (Grummon, 1993). The Salt Wash field has the potential for at least one, possibly two, horizontally drilled wells in the Cane Creek shale. In 1981, The 1-16A State well blew oil 30 feet (9.1 m) above the rotary table while drilling the Cane Creek shale. The operator gained control of the well and ran an open-hole drill-stem test. The drill-pipe recovery from the test was 600 feet (182.9 m) of oil and 150 feet (45.7 m) of oil and gas-cut mud (figure 12). The well was later completed in the deeper Devonian Elbert Formation.

### Paradox Formation - Cycle 1

The cycle 1 reservoir is currently not productive in the Salt Wash field or any other fields in the northern Paradox basin. The reservoir has the potential for 1 million barrels (159,000 $m^3$) of recoverable oil. The assumptions used in this estimation are: (1) the potential productive area is at least 160 acres (64.8 h), (2) the drainage area is 40 acres (16.2 h), and (3) the average production will be 250,000 BO (39,750 $m^3$) per well. The productive area is based upon mapping using geophysical logs (figure 13). The drainage area and production is typical of many Ismay and Desert Creek wells. The exploratory play is the test of the updip pinchout of porosity from west to east across the western plunge of the anticline (figure 13 and plate 2).

## SUMMARY

The Salt Wash field has been producing oil for over 30 years. The remaining potential may be greater than the total volume of oil produced from the field during all those years. Production problems (increased water production and casing collapse) led to the early abandonment of many of the wells. The lower Leadville was originally believed to be a single reservoir with a 15-foot (4.6-m) oil column and a large gas-cap. The upper Leadville reservoir was believed to be part of the gas-cap, lacking the potential to produce oil. Recompletion of a few of the wells has demonstrated that the oil/gas composition and the heterogeneity of the reservoir rock is far more complex than originally believed. A better understanding of reservoir heterogeneity can result in increased recovery from older fields, like Salt Wash field, and serve as a model for exploration and re-evaluation of dry holes that may have by-passed potential.

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## APPENDIX A

Wells drilled in T. 23 S., R. 17 E., of the Salt Lake Base Line, Grand County, Utah, that were used in this report and are in the Utah Geological Survey's Integral*gim database.

*Original operator*
*Well name and number*
*Quarter, quarter, section*
*API number*

Reserve Oil & Gas Company
Salt Wash North 1
NE1/4SW1/4 section 9
43-019-30282-0000

Belco Petroleum
Floy Unit 1
SE1/4SW1/4 section 11
43-019-10086-0000

Megadon Energy Corporation
Federal 1-15
NW1/4SW1/4 section 15
43-109-30752-0000

Pan American Petroleum Corp
Salt Wash 1
NW1/4SW1/4 section 15
43-019-10831-0000

Shell Oil Company
CF&I 22-16
SE1/4NW1/4 section 16
43-019-15819-0000

Shell Oil Company
CF&I 42-16
SE1/4NE1/4 section 16
43-019-15820-0000

Pan American Petroleum Corp
Suniland A-1
NE1/4SE1/4 section 16
43-019-10832-0000

Pan American Petroleum Corp
Suniland A-2
SE1/4SW1/4 section 16
43-019-10833-0000 (PAO)
43-019-10833-0001 (WDW)

Megadon Energy Corporation
State 1-16A
SW1/4SE1/4 section 16
43-019-30783-0000

Texaco Inc
Government Smoot 1
SE1/4NE1/4 section 17
43-019-16047-0000

Texaco Inc
Government Smoot 2
NW1/4SE1/4 section 17
43-019-16048-0000

Consolidated Oil & Gas, Inc
Government Smoot 3
NE1/4SE1/4 section 17
43-019-30044-0000

Wyoco Petroleum Corporation
Government Wyoco 18-2
NE1/4NE1/4 section 18
43-019-30679-0000

Wyoco Petroleum Corporation
Gorman Federal 1
NE1/4NW1/4 section 21
43-019-30658-0000

Pease Willard Oil & Gas Co
Skyline Federal 1-A
SE1/4SE1/4 section 21
43-019-30327-0000

**APPENDIX A** (continued)

Wells drilled in T. 23 S., R. 17 E., of the Salt Lake Base Line, Grand County, Utah, that were not used in this report because of the shallow drill depths (less than 2,000 feet) but are in the Utah Geological Survey's Integral*gim database.

S W Energy Corporation
Federal 27-2
NW1/4NW1/4 section 27
43-019-30829-0000

S W Energy Corporation
Government Smoot 21-3
SW1/4NE1/4 section 21
43-019-30746-0000

Megadon Enterprises Inc
State 1-16
SE1/4SE1/4 section 16
43-019-30681-0000

Denbe
Federal Rosenblatt 1
NE1/4NE1/4 section 20
43-019-10989-0000

# APPENDIX B

## Abbreviations and symbols used in this report.

| | |
|---|---|
| API | American Petroleum Institute |
| BBLS | Barrels |
| BCFG | Billion cubic feet of gas |
| BHT | Bottom hole temperature |
| BO | Barrels of oil |
| BOPD | Barrels of oil per day |
| BTU | British Thermal Unit |
| BW | Barrels of water |
| C | Cambrian |
| C | Celsius |
| $C_1$ | Methane |
| $C_2$ | Ethane |
| $C_3$ | Propane |
| $C_4$ | Butane |
| $C_5$ | Isobutane |
| $C_{5+}$ | Fractions higher than $C_5$ |
| Camb | Cambrian |
| Ck | Creek |
| $CO_2$ | Carbon dioxide |
| Comp | Completed |
| Cond. CW | Condensate-cut water |
| Corp | Corporation |
| CF&I | Colorado Fuel and Iron |
| Cret | Cretaceous |
| D | Devonian |
| Dev | Devonian |
| DLL | Dual laterolog |
| DST | Drill-stem test |
| Dol | Dolomite |
| E. | East |
| F | Fahrenheit |
| Fm | Formation |
| FP | Flowing pressure |
| Ft | Feet |
| GCM | Gas-cut mud |
| GCM&MCW | Gas-cut mud and mud-cut water |
| GCO | Gas-cut oil |
| G&OCM | Gas and oil-cut mud |
| GO&W | Gas, oil, and water |
| Govt | Government |
| GR | Gamma ray |
| grn | Green |
| GTS | Gas-to-surface |
| gty | Gravity |
| h | Hectors |
| He | Helium |
| HGCM | Highly gas-cut mud |
| HGCW | Highly gas-cut water |
| HG&WCM | Highly gas and water-cut mud |
| HOCM | Highly oil-cut mud |
| HP | Hydrostatic pressure |
| $H_2S$ | Hydrogen sulfide |
| IPF | Initial potential flowing |
| Inc | Incorporated |
| IPP | Initial potential pumping |
| J | Jurassic |
| Je | Jurassic Entrada Sandstone |
| Jm | Jurassic Morrison Formation |
| KB | Kelly bushing |
| km | Kilometer |
| Ls | Limestone |
| lt | Light |
| M | Mississippian |
| m | Meters |
| $m^3$ | Cubic meters |
| Mbr | Member |
| MCFG | Thousand cubic feet of gas |
| MCW | Mud-cut water |
| mi | Miles |
| min | Minutes |
| MMBO | Million barrels of oil |
| MMCFG | Million cubic feet of gas |
| My | Million years |
| NE | Northeast |
| no. | Number |
| NW | Northwest |
| o/w | Oil-Water |
| p. | Page |
| Qtz | Quartzite |
| R. | Range |
| Rec. | Recovered |
| S. | South |
| SE | Southeast |
| Sh | Shale |
| SIP | Shut-in pressure |
| Ss | Sandstone |
| SW | Southwest |
| Sw | Water saturation |
| T. | Township |
| TD | Total depth |
| $T_{Rc}$ | Triassic Chinle Formation |
| $T_{Rm}$ | Triassic Moenkopi Formation |
| TSTM | To-small-to-measure |
| UO | Unit of oil |
| v. | Volume |
| W | Water |
| WCM | Water-cut mud |
|  | Dry hole |
|  | Oil well |
|  | Abandoned oil well |
|  | Fault |

## APPENDIX C

INTEGRAL*gim
Geologic Information Manager
by Douglas A. Sprinkel

### INSTALLING INTEGRAL*gim

#### System Requirements

The INTEGRAL*gim Geologic Information Manager includes the Salt Wash field data, INTEGRAL*gim application, and Paradox® Runtime. The Utah Geological Survey has a license to distribute Paradox Runtime for the purpose of running the INTEGRAL*gim application, which accesses the Salt Wash field data. Future reference INTEGRAL*gim implies Paradox Runtime and INTEGRAL*gim application.

INTEGRAL*gim may be used on a variety of stand-alone computers and local area network systems. A list of local area networks is available during the installation of Paradox Runtime. To run INTEGRAL*gim your computer must be at least a 100 % IBM-compatible with a hard disk and at least one floppy drive, protected mode capable 80286 or greater personal computer. Your computer must meet the following minimum requirements:

- DOS 3.0 or later, or OS/2 2.0 or later.
- 2MB (megabytes) RAM. 4MB or more (8MB is recommended) will significantly enhance performance and prevent errors during some operations.
- **9 MB of free disk space**. The Salt Wash field version of INTEGRAL*gim uses approximately 3MB of space and Paradox Runtime uses approximately 3MB of space. An additional 3MB of space is needed to for temporary tables created during some operations.
- INTEGRAL*gim will run on most color and monochrome monitors; however, some items displayed on monochrome or low-resolution color monitors may be difficult to read.

INTEGRAL*gim supports hardware and software options that enhance performance or allow the user to take advantage of all its capabilities. These options include the following:

- Microsoft Windows 3.0 or later.
- a bus or serial mouse (Microsoft, Logitech, IBM PS/2, or compatible).
- an 80 x 87 math coprocessor
- a dot-matrix printer (the beta test version only prints to a graphic capable dot-matrix printer).

#### System Files

INTEGRAL*gim requires that your computer have a CONFIG.SYS file residing in the root directory of the hard disk or on a start-up disk. The CONFIG.SYS file must at least contain two lines; FILES= 40 and BUFFERS = 40. In most cases, these lines are already present in the CONFIG.SYS file. An INTEGRAL.PIF file is located in the INTEGRAL subdirectory and may be used to configure INTEGRAL*gim for Windows.

INTEGRAL*gim Sublicense Agreement

The Utah Geological Survey is a registered user of Paradox Runtime and is licensed to distribute the Runtime program to run our INTEGRAL*gim application. Under our license, the Utah Geological Survey must sublicense you, the end user. Installing and using INTEGRAL*gim implies that you have read this sublicense agreement and agree to the following:

- Paradox Runtime is owned by Borland International, Inc. and may not be copied for redistribution.
- Limited support services are provided by the Utah Geological Survey. You should not look to Borland for any technical support.
- Borland International, Inc. and the Utah Geological Survey are not responsible for any damages resulting from using Paradox Runtime and INTEGRAL*gim application. These programs are provided to the end user without warranties or liabilities for any damages, actions based on its use, or quality.
- INTEGRAL*gim application may not be copied for redistribution; however, the data contained in INTEGRAL*gim are public domain and may be freely distributed outside of the INTEGRAL*gim application.

Installation Procedure

INTEGRAL*gim can be installed from DOS or from Microsoft Windows. Before you install INTEGRAL*gim, it is wise to make a backup copy of the program disks and store them in a safe place. INTEGRAL*gim consists of three disks. Disks 1 and 2 contain Paradox Runtime files and Disk 3 contains the INTEGRAL*gim application and data files. You must use the installation program on Disk 1 and not the DOS Copy command to properly install INTEGRAL*gim onto your hard disk because the program files on all three disks are compressed.

The installation procedure will create two subdirectories on your hard disk; PDOXRUN and SALTWASH. Paradox Runtime will be installed to the PDOXRUN subdirectory and INTEGRAL*gim will be installed to the SALTWASH subdirectory. SALTWASH.BAT will also be copied to the root directory on the C drive. For network installation, you will need to move the SALTWASH.BAT file from the root directory (C:\) to a mapped search drive that normally contains program .BAT files. Once the procedure starts, the user will be led through the installation with on screen instructions.

**To install INTEGRAL*gim (Paradox Runtime and INTEGRAL*gim data files) from DOS (DOS prompt, C:\>):**

1. Insert Disk 1 into a floppy drive.
2. Change to the floppy drive that contains Disk 1. If Disk 1 is in your B drive, type B: and press Enter. If Disk 1 is in your A drive, type A: and press Enter.
3. From the A:\> or B:\> prompt, type **li** and press Enter.
4. Read the Installation Instructions section below and follow the on screen instructions.

**To install INTEGRAL*gim from Microsoft Windows:**

1. Insert Disk 1 into a floppy drive
2. Click on File in the Program Manager.
3. Click on Run.
4. Enter **A:\li** (if Disk 1 is in the A drive) or **B:\li** (if Disk 1 is in the B drive) into the Run dialogue box.
5. Click on OK or press Enter
6. Read the Installation Instructions section below and follow the on screen instructions.

## Installation Instructions

The installation procedure will start by installing the Paradox Runtime, the first program, using the Paradox Installation Utility. This part of the procedure will ask you a series of questions for setup information. In most cases you should **accept the default choices by pressing the function key [F2]**. If you do need to change a setting, simply follow the instructions given and then press F2. The last item in the Paradox Installation Utility is a reminder to register Paradox Runtime. You may ignore this because this copy of Runtime is registered to the Utah Geological Survey is registered, and the Utah Geological Survey has a license to distribute the program and sublicense the end user. **Make sure you read the sublicense agreement in the previous section.** The second program installed is INTEGRAL*gim and its data files.

## Starting INTEGRAL*gim

The Salt Wash field version of INTEGRAL*gim can be started from the DOS prompt or from Microsoft Windows. To start INTEGRAL*gim from DOS, simple Type **SALTWASH**. To start INTEGRAL*gim from Windows, you must **create a new program item from the Program Manager** and include all of the information needed in the Program Item Properties dialogue box to start INTEGRAL*gim from Windows.


A
WEST
A′
NORTH
EAST:SOUTH
SW ENERGY
18-2 GOVT
NENE SECTION 18
KB 4219
TD 9350 ELBERT FM.
GR.
DENSITY/NEUTRON
SW ENERGY
3 SMOOT
NESE SECTION 17
KB 4339
TD 8687 LEADVILLE LS.
SONIC
R.P SMOOT
22-16 CF & I
SENW SECTION 16
KB 4490
TD 8906 LEADVILLE LS.
SW ENERGY
A-2 SUNNILAND
SESW SECTION 16
SALT WATER DISPOSAL
KB 4388
TD 8900 ELBERT FM.
SW ENERGY
1-16A STATE
SWSE SECTION 16
KB 4418
TD 8825 ELBERT FM.
MEGADON ENERGY
1-15 FEDERAL
NWSW SECTION 15
KB 4295
TD 8585 LEADVILLE LS.
PAN AMERICAN
1 SALT WASH
NWSW SECTION 15
KB 4283
TD 9533 LYNCH DOLOMITE
RESERVE OIL & GAS
1 SALT WASH NORTH
NESW SECTION 9
KB 4463
TD 9069 LEADVILLE LS.
PENNSYLVANIAN PINKERTON TRAIL AND MOLAS FORMATIONS
-4420
UPPER LEADVILLE LS. POROSITY ZONES (>8%)
UPPER
LOWER
MISSISSIPPIAN LEADVILLE LIMESTONE
DEVONIAN OURAY LIMESTONE
DEVONIAN ELBERT FORMATION
FAULT
OURAY LS.
ELBERT FM.
UPPER LEADVILLE LS
LOWER LEADVILLE LS
ELBERT FM.
McCRACKEN SS. MEMBER OF THE ELBERT FM.
OPEN HOLE
TRAVEL TIME
8% DOLOMITE POROSITY
20% 10% 0% POROSITY
MATRIX 2.71
GR
NEUTRON
2800 API UNITS
COMP. 8/17/82 PARADOX FM.
5736′- 8014′ (GROSS)
IPP 1 UO
CUMULATIVE PRODUCTION (12/31/92)
847 BO
629 MCFG
266 BW
ORIGINAL OPERATOR
CONSOLIDATED OIL & GAS
COMP. 12/18/69 LEADVILLE LS.
8643′- 8655′
IPF 128 BO
1300 MCFG
1050 BW
CUMULATIVE PRODUCTION
13,170 BO
398,248 MCFG
310,256 BW
RECOMPLETED 2/71
8474′- 8486′
IPF 26 BO
2,308 MCFG
173 BW
CUMULATIVE PRODUCTION
UPPER LEADVILLE LS. (12/31/92)
289,317 BO
3,475,908 MCFG
814,868 BW
ORIGINAL OPERATOR SHELL OIL
COMP. 3/23/63 LEADVILLE LS.
8900′- 8907′
IPF 1,215 BO
25 MCFG
0 BW
RECOMPLETED 1/18/68
8846′- 8847′ (8846′- 8907′ GROSS)
RECOMPLETED 2/71
8806′- 8810′ (8806′- 8907′ GROSS)
CUMULATIVE PRODUCTION (12/31/92)
572,646 BO
5,070,716 MCFG
2,702,367 BW
ORIGINAL OPERATOR
PAN AMERICAN
COMP. 12/23/63 ELBERT FM.?
8775′- 8781′ AND 8783′- 8792′
IPP 70 BO
47 BW
CUMULATIVE PRODUCTION
8,364 BO
90,363 MCFG
48,272 BW
DEEPENED 6/69 FOR SALT WATER INJECTION
ORIGINAL OPERATOR
MEGADON ENERGY
COMP. 9/17/81 ELBERT FM.?
8670′- 8690′ AND 8715′- 8750′
IPF 4 BO
400 BW
CUMULATIVE PRODUCTION (12/31/92)
47 BO
200 MCFG
0 BW
COMP. 6/30/81 LEADVILLE LS.
8500′- 8544′ AND 8555′- 8580′
IPF 300 BO
100 MCFG
200 BW
CUMULATIVE PRODUCTION (12/31/92)
24,593 BO
0 MCFG
14,448 BW
COMP. 5/28/61 LEADVILLE LS.
8693′- 8707′
IPF 115 BO
9 BW
CUMULATIVE PRODUCTION (PLUGGED 8/64)
56,989 BO
1,229,664 MCFG
43,835 BW
COMP. 6/21/76 D & A
PLATE 1
SALT WASH FIELD
T. 23 S., R. 17 E.
GRAND COUNTY, UTAH
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# PLATE 2
# SALT WASH FIELD

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GRAND COUNTY, UTAH

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