K. Clem — Economic Potential of the P.R. Spring Oil-impregnated Deposit

Special Studies 65

ECONOMIC POTENTIAL OF THE P.R. SPRING OIL-IMPREGNATED DEPOSIT, UINTA BASIN, UTAH

By Keith Clem

UTAH GEOLOGICAL AND MINERAL SURVEY
a division of
Utah Department of Natural Resources

Special Studies 65 **August 1984**

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UTAH GEOLOGICAL AND MINERAL SURVEY

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ECONOMIC POTENTIAL OF THE P.R. SPRING OIL-IMPREGNATED SANDSTONE DEPOSIT

By Keith Clem[1]

ABSTRACT

The P.R. Spring oil-impregnated sandstone (tar sand) deposit is located in the southeastern portion of the Uinta Basin, approximately 50 miles northwest of Grand Junction, Colorado. These oil impregnated sandstones are in the Eocene Green River Formation and five zones have been identified. These zones consist of one or more lenticular beds of lacustrine sandstone, separated by intervals of barren lithologies. The degree of impregnation of individual beds within the five zones is controlled by the lateral extent of the bed, its porosity and permeability, and the distance the oil has migrated within the bed. The degree of saturation varies both laterally and vertically.

The purpose of this report was to 1) determine the total hydrocarbon content of each zone in blocks of 640 acres or less, and 2) relate this data to current economic and mining feasibility.

This study incorporates the results of 38 measured sections and 26 core holes. The oil extracted from the P.R. Spring tar sands is a naturally occurring, brown to black, highly viscous or solid mixture of hydrocarbons. Its composition indicates that the oil was formed in situ or migrated only a short distance. The author has calculated the total barrels of oil in place for the deposit to be approximately 3.3 billion barrels. This is less than other published calculations of 3.7 and 4.0 to 4.5 billion barrels (Byrd, 1967; Ritzma, 1974).

Problems associated with the method of economic recovery of the oil remain to be solved. Only the southeastern corner of the field is strip minable. Other areas will probably have to be exploited by in situ recovery methods and several are being tested. The only known active operation in P.R. Spring is by Bighorn Oil, located in the southeastern part of the deposit. Their operation consists of an open-pit mine and a 200-barrel-per-day extraction plant utilizing a solvent solution process. Surface water availability in the area is limited, but may be sufficient if storage, reuse and ground-water potential are considered. Oil extraction will require a fuel supply, possibly from generated coke and other byproduct fuels generated by the tar refining process or by local natural gas or coal production.

Further work is needed in the area, specifically more core holes and associated analyses. Strategic drilling in T. 11 S., R. 22 and 24 E., and T. 12 S., R. 22 E., could be used to verify assumed saturation.

INTRODUCTION

Location and Access

The P.R. Spring oil-impregnated sandstone deposit is located in the southeastern portion of the Uinta Basin, in Grand and Uintah Counties, Utah (fig. 1). It is bounded on the south by the Roan and Book Cliffs, on the west by Willow Creek, on the east by Evacuation Creek, and gradually dips into the Basin to the north. These boundaries outline an area of approximately 223 square miles and include Townships 11 to 17 South and Ranges 21 to 26 East, Salt Lake Base and Meridian. The deposit is named for a spring located near the southeastern boundary of the deposit.

The area may be approached from the north by turning south off U.S. Highway 40 between Roosevelt and Vernal, Utah, onto Utah Highway 88 near Fort Duchesne, Utah. The other northern access is by way of Utah Highway 45, which joins U.S. Highway 40 to the north. There are two roads serving the area from the south: San Arroyo Canyon road which joins Interstate Highway 70 near the Utah-Colorado State line; and the Hay Canyon road which joins Interstate Highway 70 three miles northeast of Harley Dome, Utah. The Denver and Rio Grande Western Railroad is the

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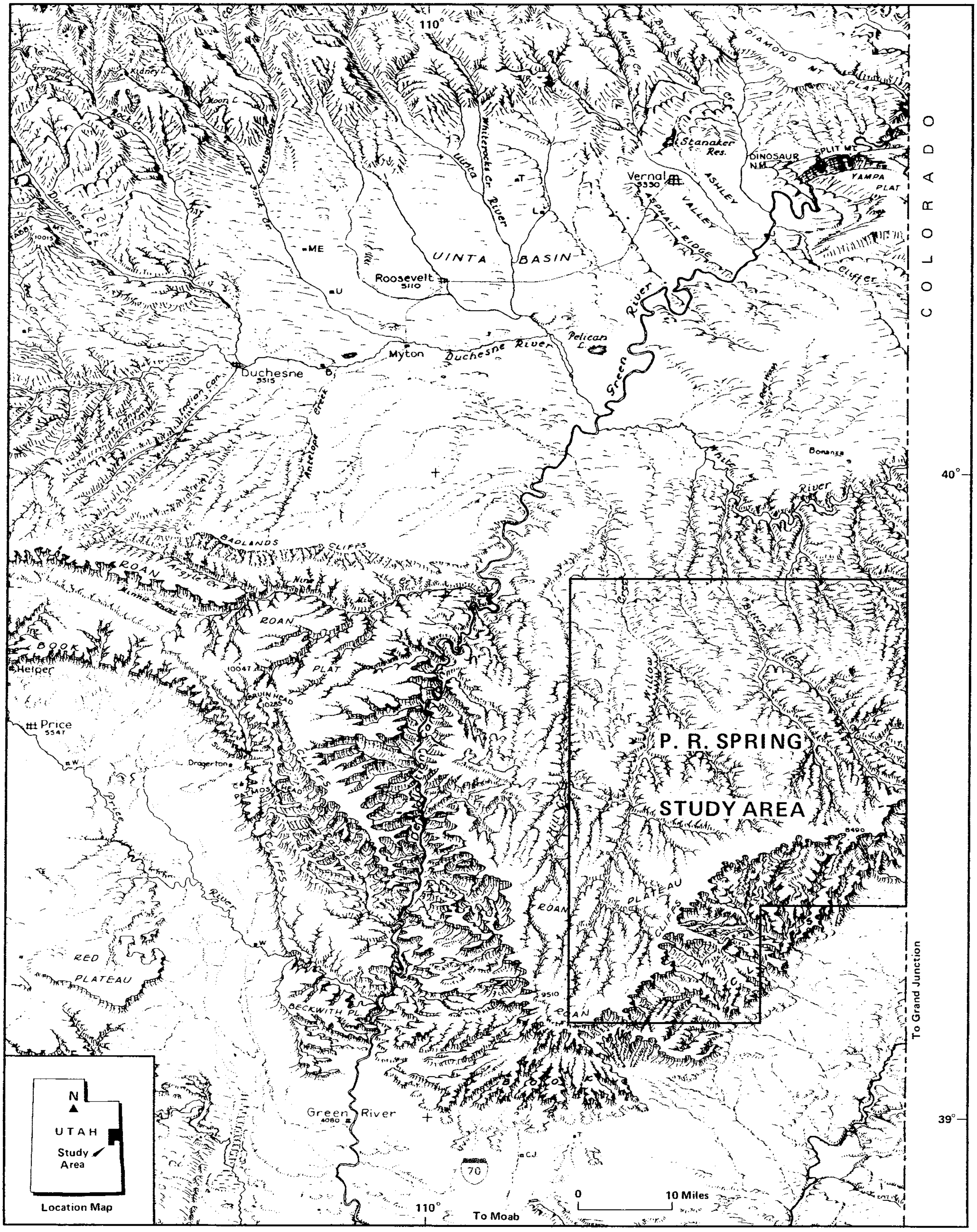


Base from Landforms of Utah, by M. K. Ridd, 1963.

FIGURE 1. Index map of P.R. Spring study area.

only railroad near the area, approximately 25 miles south of the deposit. It runs east-west from Denver, Colorado, to Salt Lake City, Utah, and passes through the Grand Valley.

Method of Study

The purpose of this report is to 1) determine the total hydrocarbon content of each zone in blocks of 640 acres or less (appendices 3 and 4), and 2) relate these data to current economic and mining feasibility. Field work, involving geologic reconnaissance of the area, was undertaken in the fall of 1982. This reconnaissance consisted of a survey of both active and inactive extraction operations in the P.R. Spring area, a survey of observed tar seeps in the area, and sampling of previously measured stratigraphic sections (figures 3 through 6). These sections were formerly located and surveyed by William Byrd (1967). Samples were sent to TerraTek Core Services, Salt Lake City, Utah, for analyses.

In-house work consisted of the integration of previously published and unpublished work into correlative cross sections and maps that represent the extent, thickness, saturation, and overburden of the five tar sand zones.

GENERAL GEOLOGY

Stratigraphy

Six geologic units, ranging in age from Cretaceous to Eocene, have been recognized in the Book and Roan Cliffs in the southern portion of the P.R. Spring area. From oldest to youngest, they are the Mancos Shale, the Mesaverde Group (Castlegate, Buck Tongue, and Price River Formations), and the Tuscher Formation (all Cretaceous), the Wasatch Formation (Paleocene-Eocene), the Green River Formation (Eocene), and the Uinta Formation (Eocene). The Mancos Shale, Mesaverde Group, and Tuscher Formation form the Book Cliffs; the Wasatch and Green River Formations are found in the Roan Cliffs, and the Uinta Formation is found on the northward dipping slope of the Roan Cliffs (Byrd, 1967). The P.R. Spring area is underlain by five zones of oil-impregnated sandstones, one of which is found in the lower portion of the Parachute Creek Member and four in the upper portion of the Douglas Creek Member of the Green River Formation (fig. 2). Other formations and nonpertinent members of the Green River Formation were not studied. The Hill Creek deposit to the west is stratigraphically related to the P.R. Spring deposit. The separation of

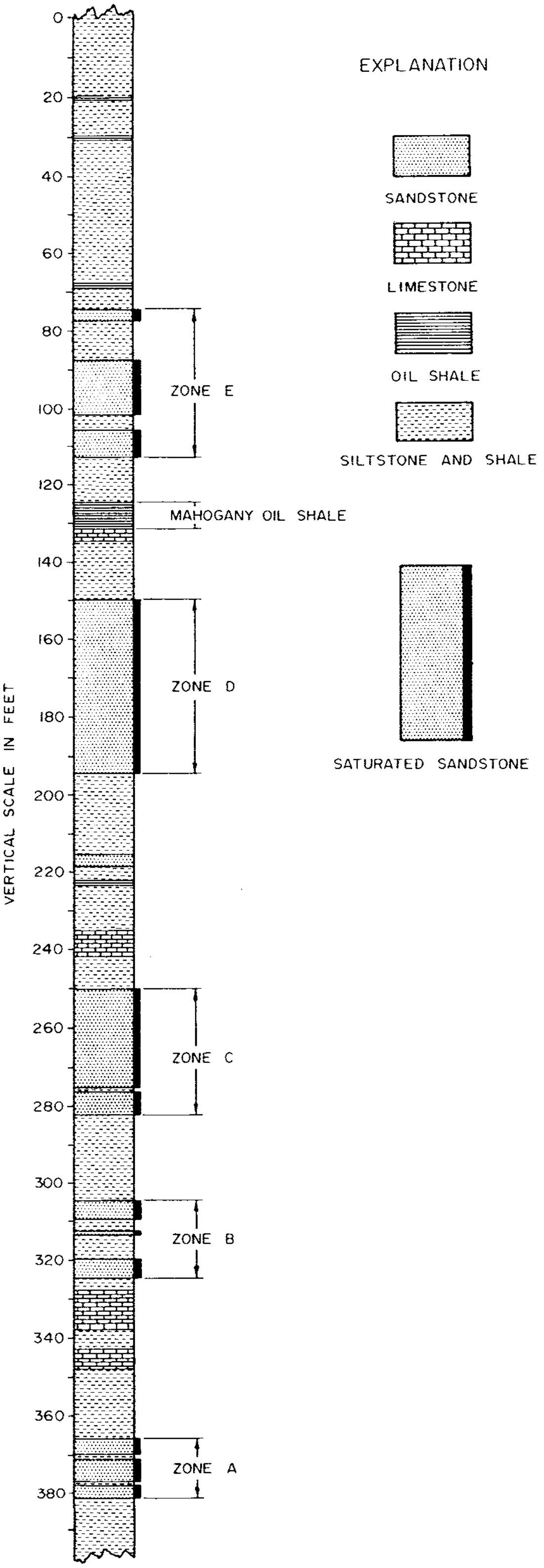


FIGURE 2. Partial composite lithologic section of the Douglas Creek and Parachute Creek Members of the Green River Formation in the area (from Gwynn, 1971).

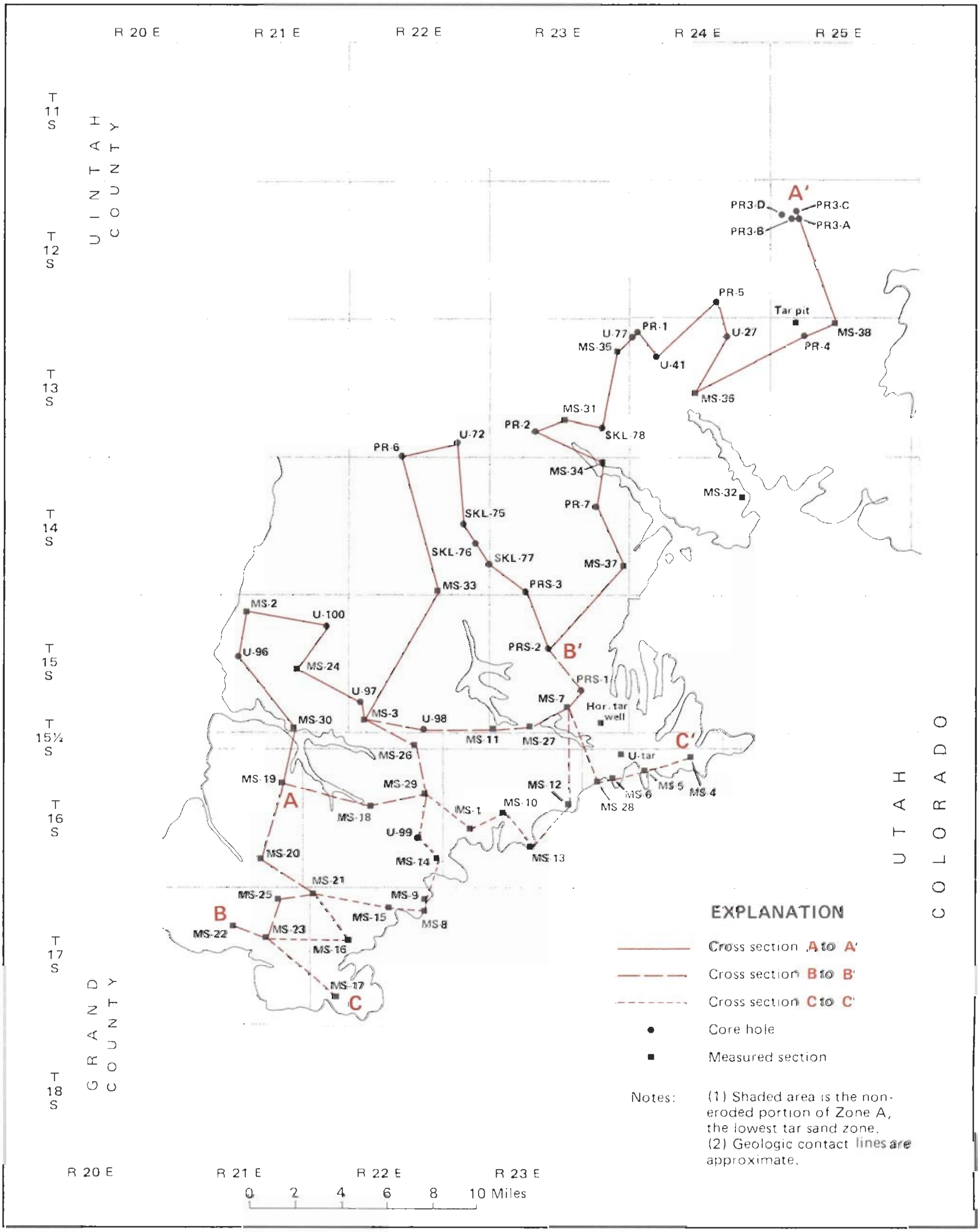


FIGURE 3. Total saturation of area and control point location plat.

these deposits is strictly erosional. A further reference to Hill Creek is Campbell and Ritzma (1979).

Green River Formation

The Green River Formation of the Uinta Basin is composed of oil shale beds, marlstone, shale, siltstone, sandstone, limestone, and tuff, and was deposited in a lacustrine environment. It consists of four members (from bottom to top): Douglas Creek, Garden Gulch, Parachute Creek, and Evacuation Creek, although the Garden Gulch and Evacuation Creek Members are absent in the study area. The upper part of the formation interfingers with fluvial beds of the Uinta Formation, and the lower part interfingers with fluvial beds of the Wasatch Formation. The lake-formed deposits of the Green River Formation are the middle facies within a continuous sequence of fluvial beds defined as the Wasatch and Uinta Formations. The major source area for most of the sediments in the Green River Formation in the study area is the Uncompahgre Uplift to the south. This is evidenced by an increase in grain size and in the number of sandstone beds southward (Cashion, 1967). The paleoclimatic conditions that prevailed during deposition of the Green River Formation included warm temperatures with abundant rainfall. The Uinta Basin during Eocene time was probably less than 1000 feet in elevation (Wiley, 1967).

Douglas Creek Member

The Douglas Creek Member is composed primarily of sandstone, siltstone, shale, and limestone, with a few oil shale beds occurring locally. The upper part of the Douglas Creek Member contain the lower four zones of the P.R. Spring tar sands (figures 7 through 10, 12 through 15).

The sandstone beds are composed primarily of fine- to medium-grained quartz and are predominantly even bedded. They are predominantly tan to gray in color and weather to gray and brown ledges. The siltstone is also gray to tan and weathers to produce tan or brown ledges and steep slopes. The shale is gray, tan, and green and weathers to form green or gray slopes. The limestones grade from thin to massive beds and are commonly gray. The oil shale beds are thin, localized, and have little economic significance.

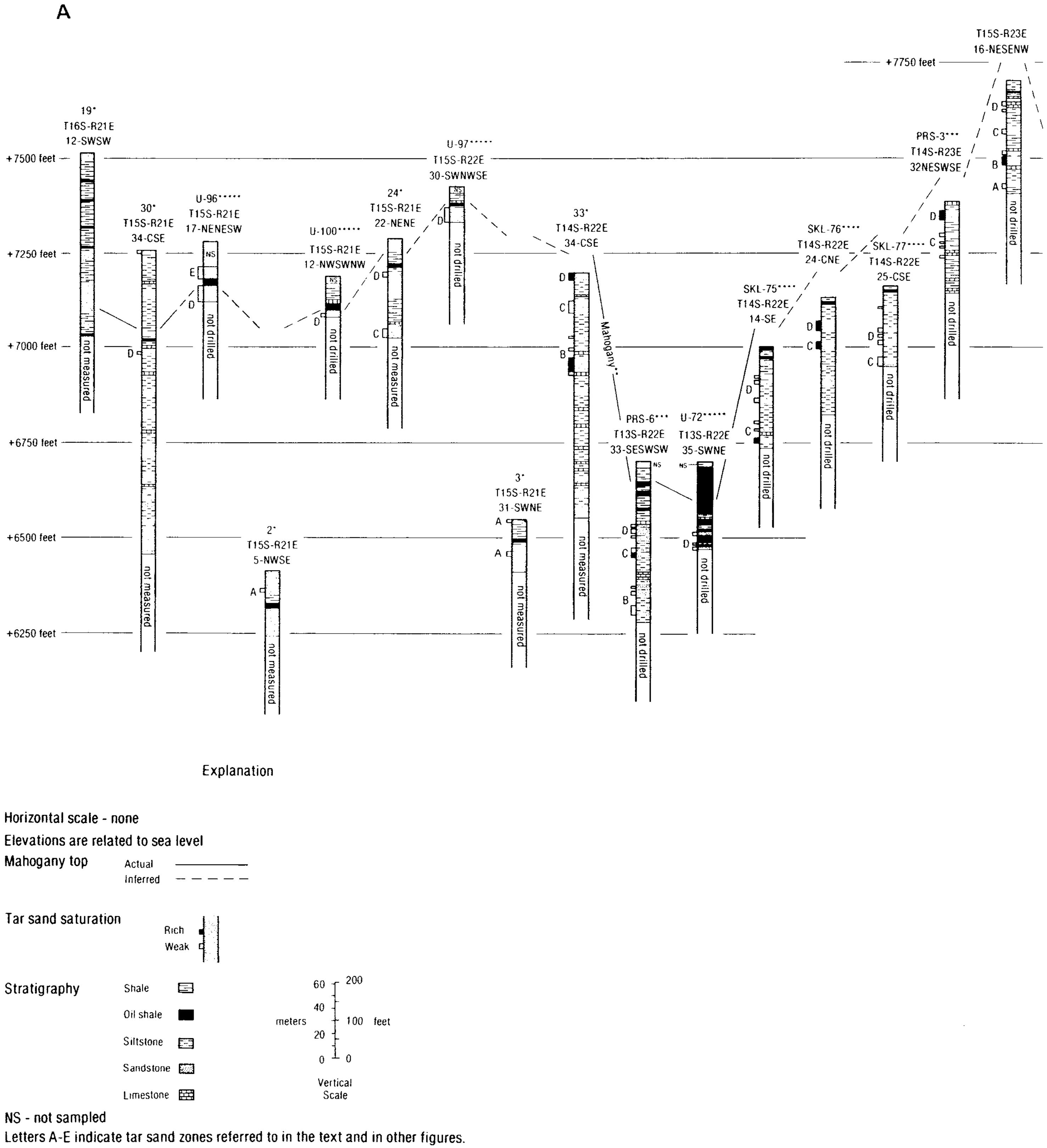
The Douglas Creek Member grades laterally into and intertongues with the Parachute Creek and Garden Gulch Members of the Green River Formation in a basinward direction. Douglas Creek sandstone grades laterally into siltstone, which in turn grades laterally into marlstone. The Douglas Creek limestone intertongues with marlstone and oil shale of the Parachute Creek Member. The Douglas Creek Member also grades laterally into and intertongues with the Wasatch Formation in a shoreward direction. Evenly bedded sandstone of the Douglas Creek Member grades into irregularly bedded, coarser grained sandstone of the underlying Wasatch Formation, and the limestone and shales intertongue with sandstone and shale of the Wasatch Formation.

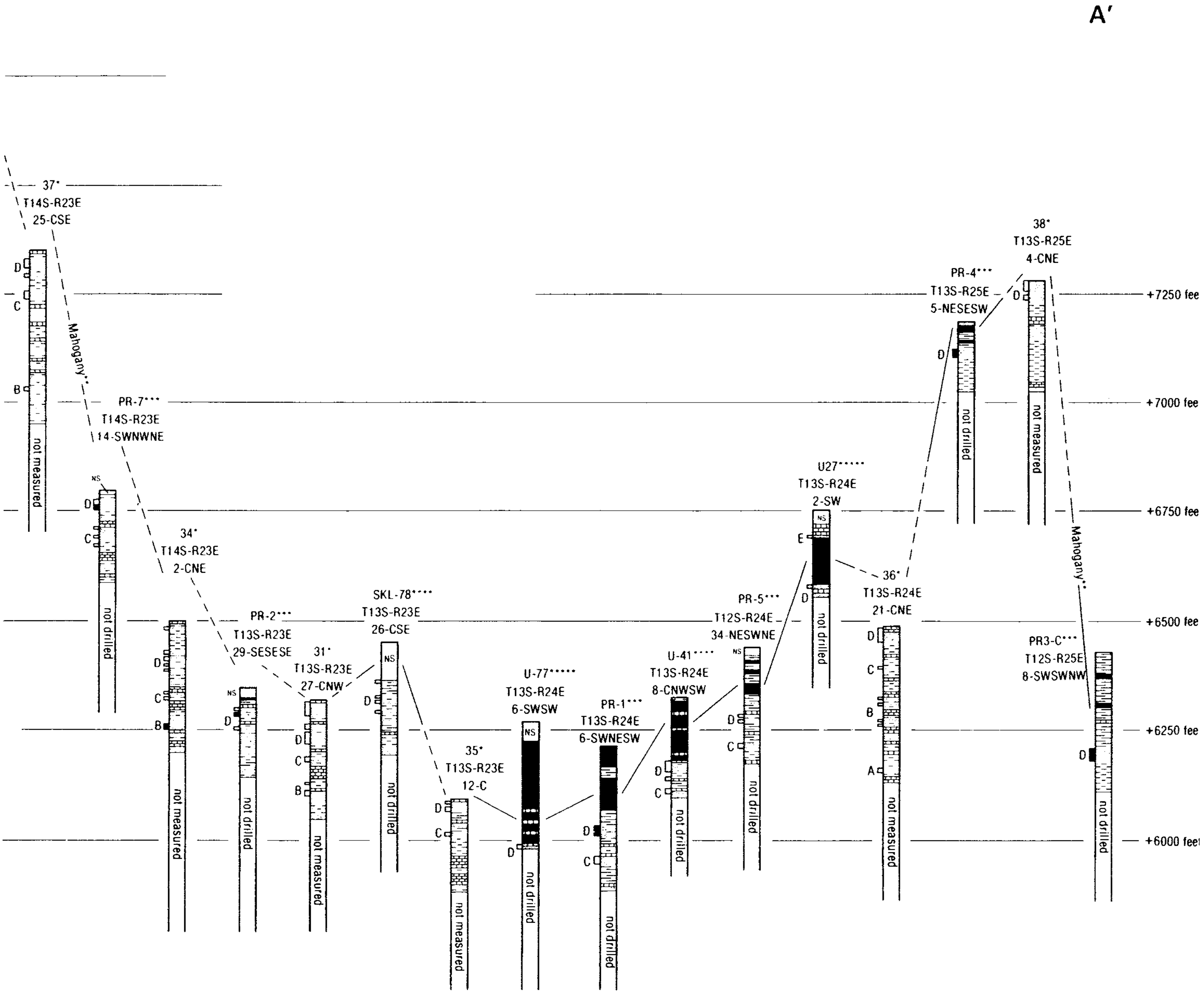
Beds of the Douglas Creek Member were deposited near the lakeshore in shallow water that was chemically favorable for the deposition of $CaCO_3$. The lower part of the Douglas Creek Member was deposited during a period of rapid water level fluctuations, while the upper part of the member was laid down during a phase in which the lake was predominantly transgressive (Cashion, 1967). During the time of deposition, streams were carrying abundant amounts of sediment into the Uinta Basin lake from the south and the southeast, and the sediment was spread over the basin floor by lake currents. The lake level may have fluctuated moderately, but it is unlikely the lake was ever critically low. In the southeastern portion of the basin, the sands were probably transported only moderate distances. There the impregnated sandstones are poor to moderately sorted, arkosic, and most of the grains are subangular (Wiley, 1967). Along the southern shore of the lake, the water was clear, warm, and shallow, as evidenced by the formation of algal reefs.

Some of these algal reefs, which were formed along the margins of the lake, were later impregnated with oil, as were the associated sandstones which generally contain much greater amounts of oil. The lake level may have fluctuated moderately, but it is unlikely the lake was ever critically low. In the southeastern portion of the basin, the sands were probably transported only moderate distances; there the impregnated sandstones are poor to moderatley sorted, arkosic, and most of the grains are subangular (Wiley, 1967). The four tar-sand zones are found in the sandstone beds in the upper 250 feet of the Douglas Creek Member (fig. 2).

Parachute Creek Member

The Parachute Creek Member is primarily composed of marlstone, oil shale, siltstone, sandstone, and tuff. The upper zone of the P.R. Spring tar sands occurs in the lower part of the Parachute Creek Member (figures 11 and 16), above the widely referenced Mahogany oil shale bed. This bed forms the lower contact with the underlying Douglas Creek


A
+7750 feet
+7500 feet
+7250 feet
+7000 feet
+6750 feet
+6500 feet
+6250 feet
19* T16S-R21E 12-SWSW
30* T15S-R21E 34-CSE
U-96***** T15S-R21E 17-NENESW
U-100***** T15S-R21E 12-NWSWNW
24* T15S-R21E 22-NENE
U-97***** T15S-R22E 30-SWNWSE
33* T14S-R22E 34-CSE
2* T15S-R21E 5-NWSE
3* T15S-R21E 31-SWNE
PRS-6*** T13S-R22E 33-SESWSW
U-72***** T13S-R22E 35-SWNE
SKL-75**** T14S-R22E 14-SE
SKL-76**** T14S-R22E 24-CNE
SKL-77**** T14S-R22E 25-CSE
PRS-3*** T14S-R23E 32NESWSE
T15S-R23E 16-NESENW
Mahogany**
NS
A
B
C
D
E
not measured
not drilled
Explanation
Horizontal scale - none
Elevations are related to sea level
Mahogany top
Actual
Inferred
Tar sand saturation
Rich
Weak
Stratigraphy
Shale
Oil shale
Siltstone
Sandstone
Limestone
meters
feet
0
20
40
60
100
200
Vertical Scale
NS - not sampled
Letters A-E indicate tar sand zones referred to in the text and in other figures.



References

*Byrd (1970)
**Cashion (1967)
***Peterson (1975)
****Gwynn (1971)
*****Laramie Energy Technology Center (1983

FIGURE 4. Section A-A' – Correlation of measured sections and drill holes to top of Mahogany oil shale and to tar sand zones (see figure 3).

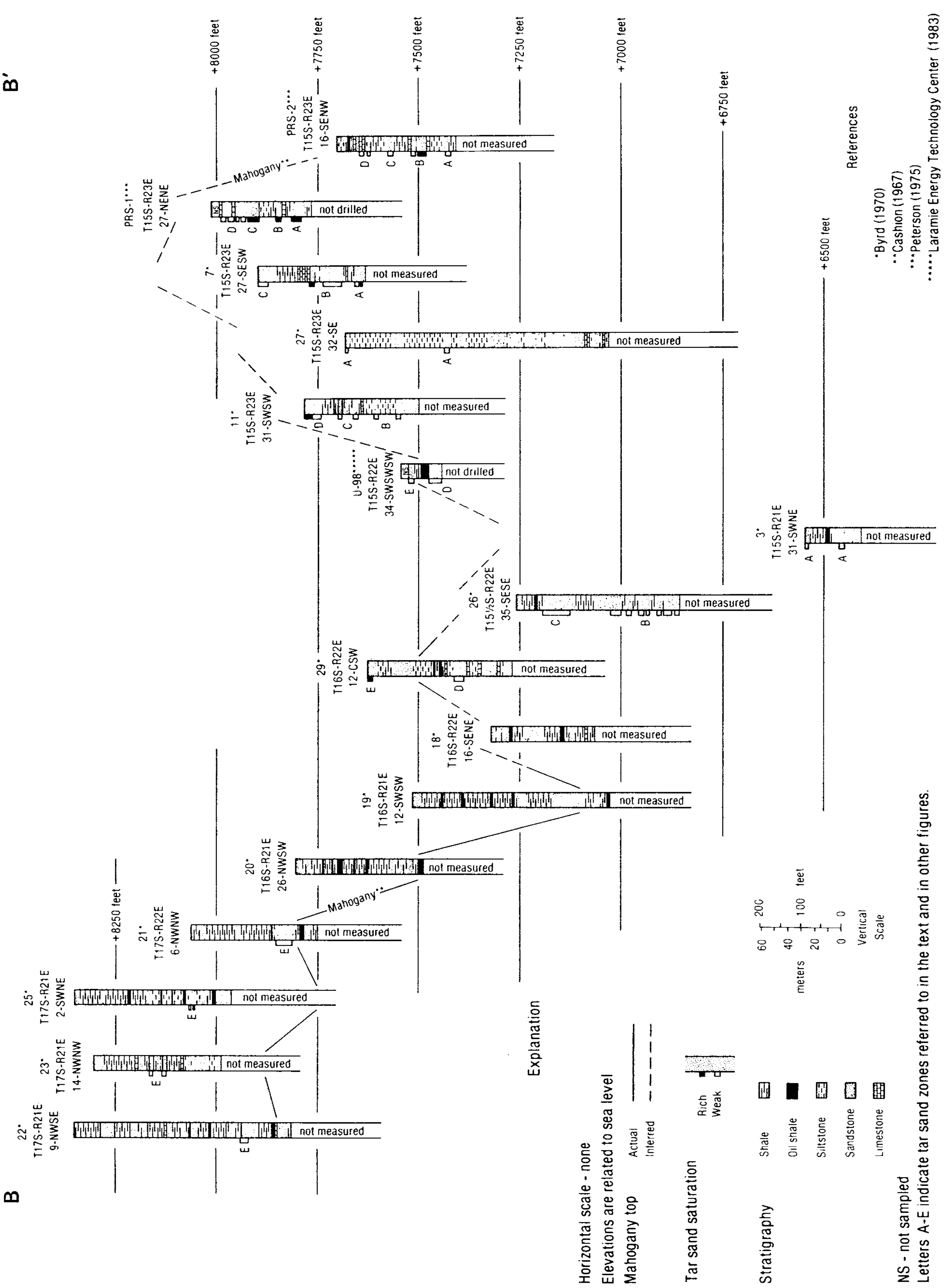


FIGURE 5. Section B-B' — Correlation of measured sections and drill holes to top of Mahogany oil shale and to tar sand zones (see figure 3).

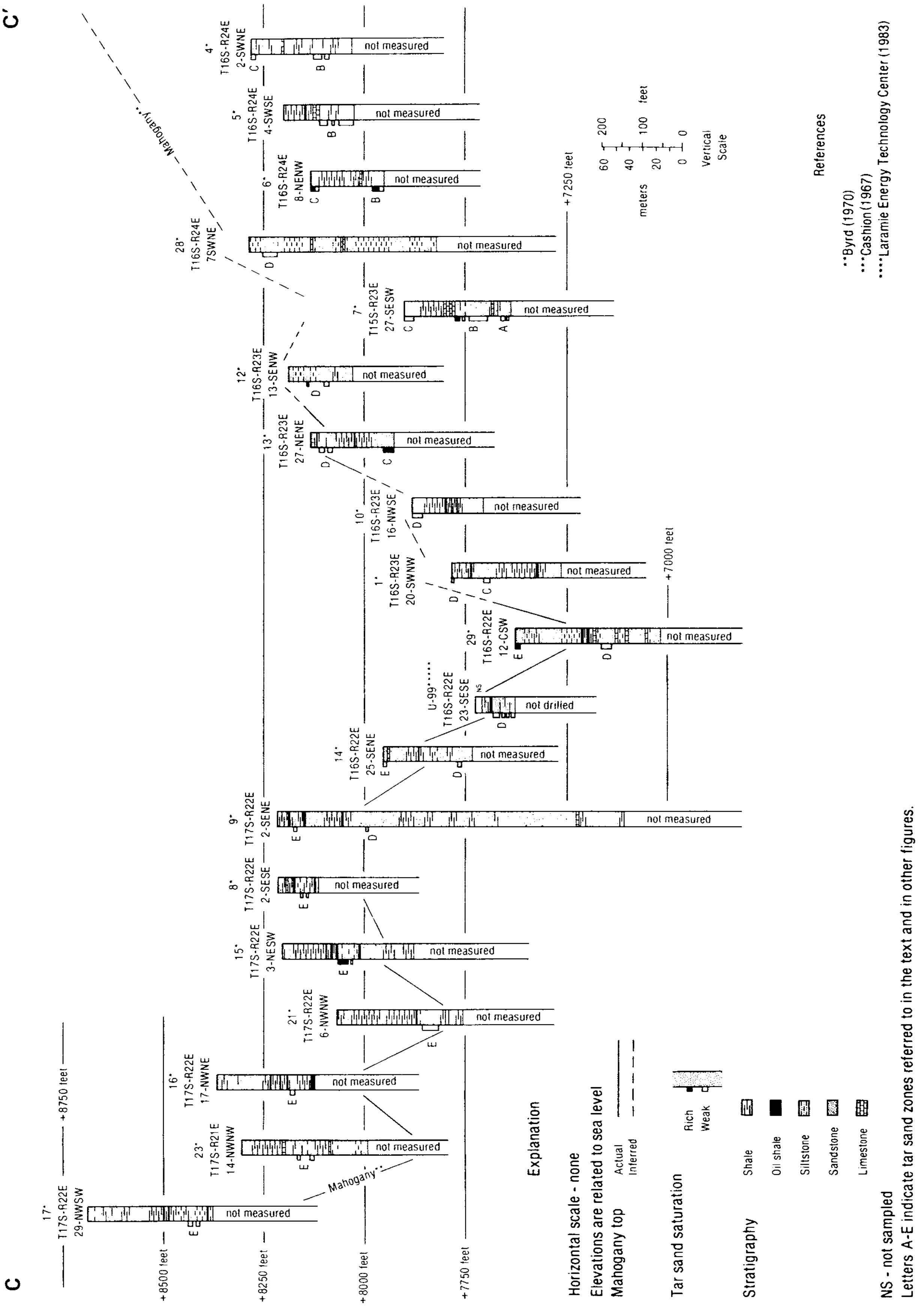


FIGURE 6. Section C-C' — Correlation of measured sections and drill holes to top of Mahogany oil shale and to tar sand zones (see figure 3).

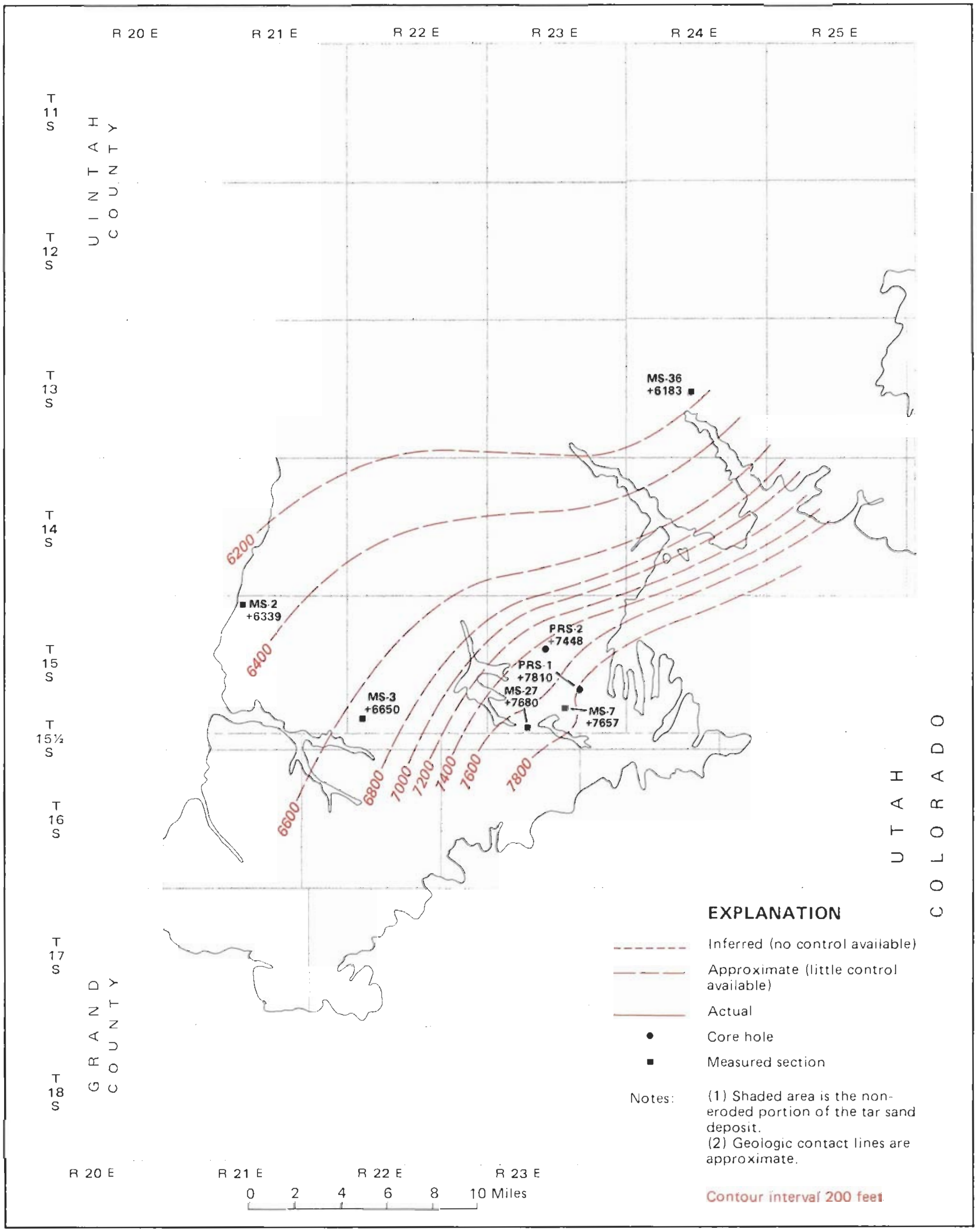


FIGURE 7. Structure contour map on top of Zone "A".

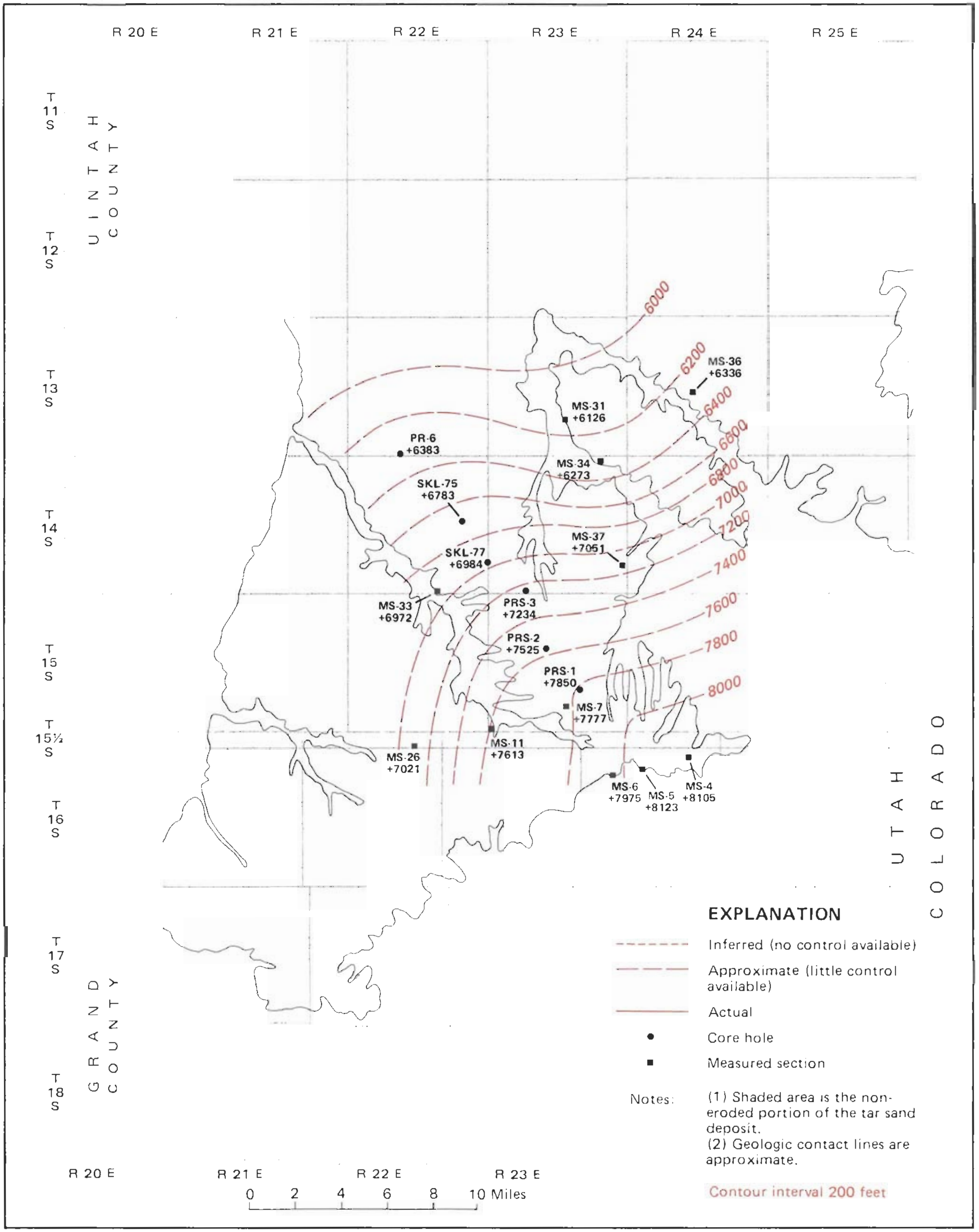


FIGURE 8. Structure contour map on top of Zone "B".

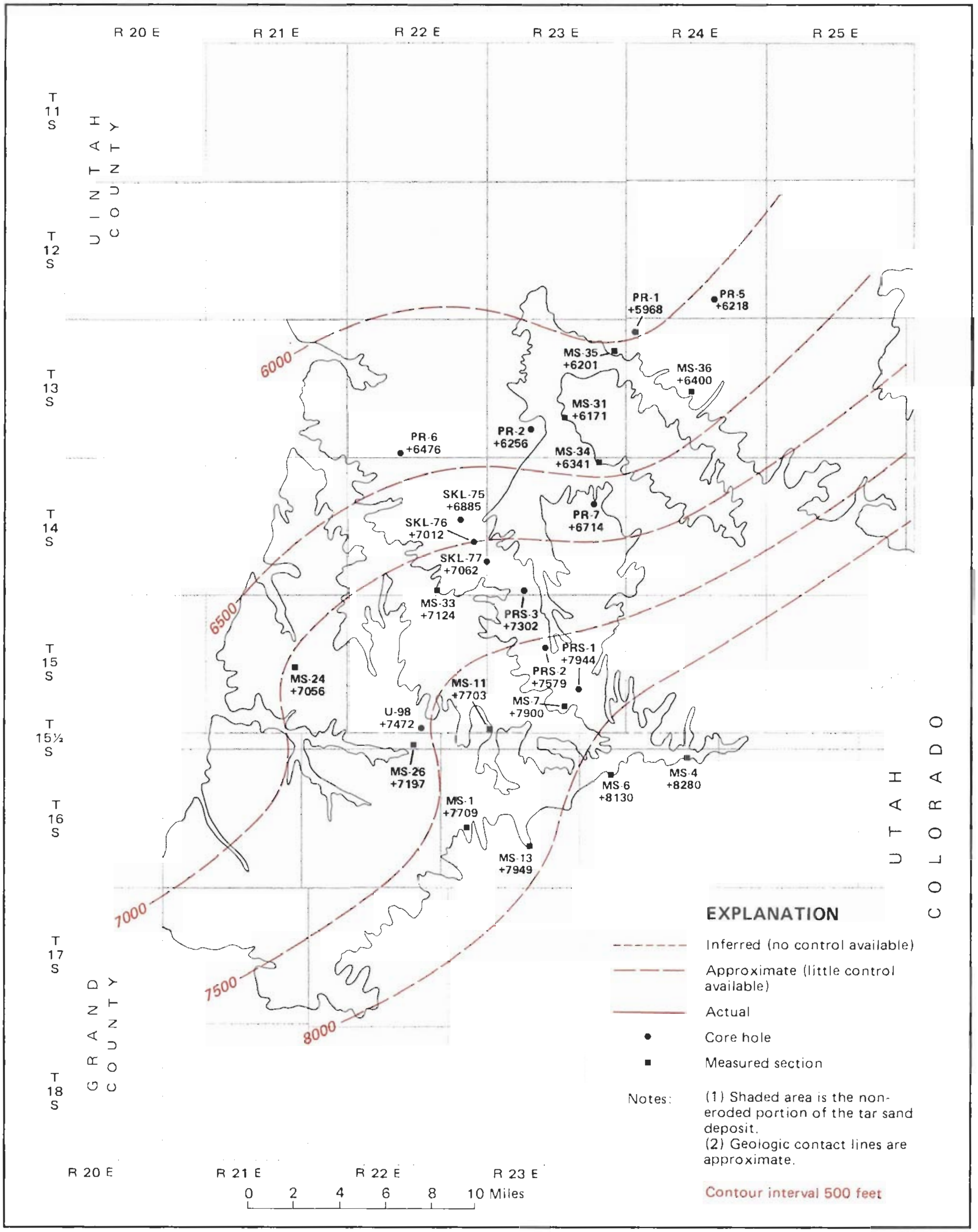


FIGURE 9. Structure contour map on top of Zone "C".

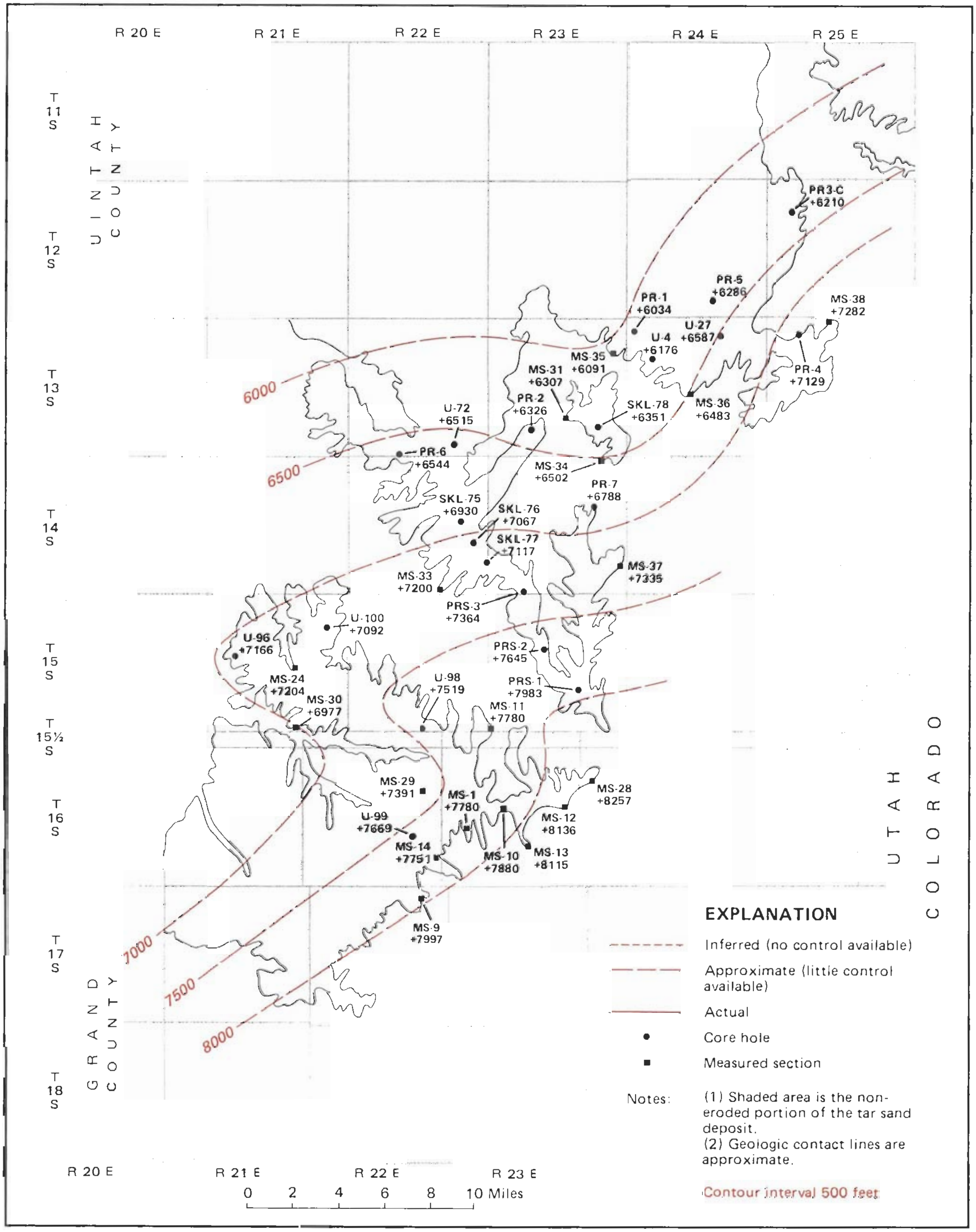


FIGURE 10. Structure contour map on top of Zone "D".

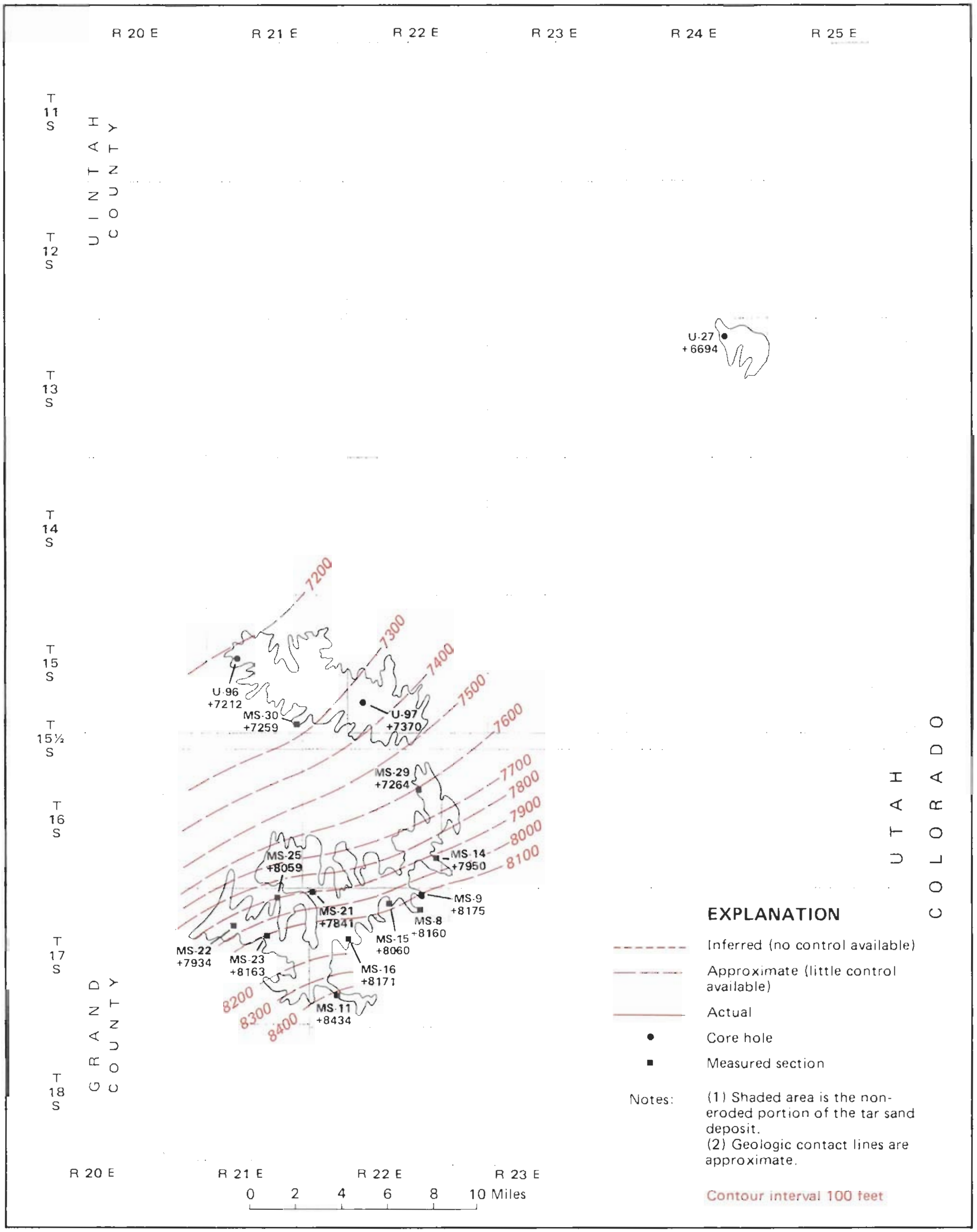


FIGURE 11. Structure contour map on top of Zone "E".

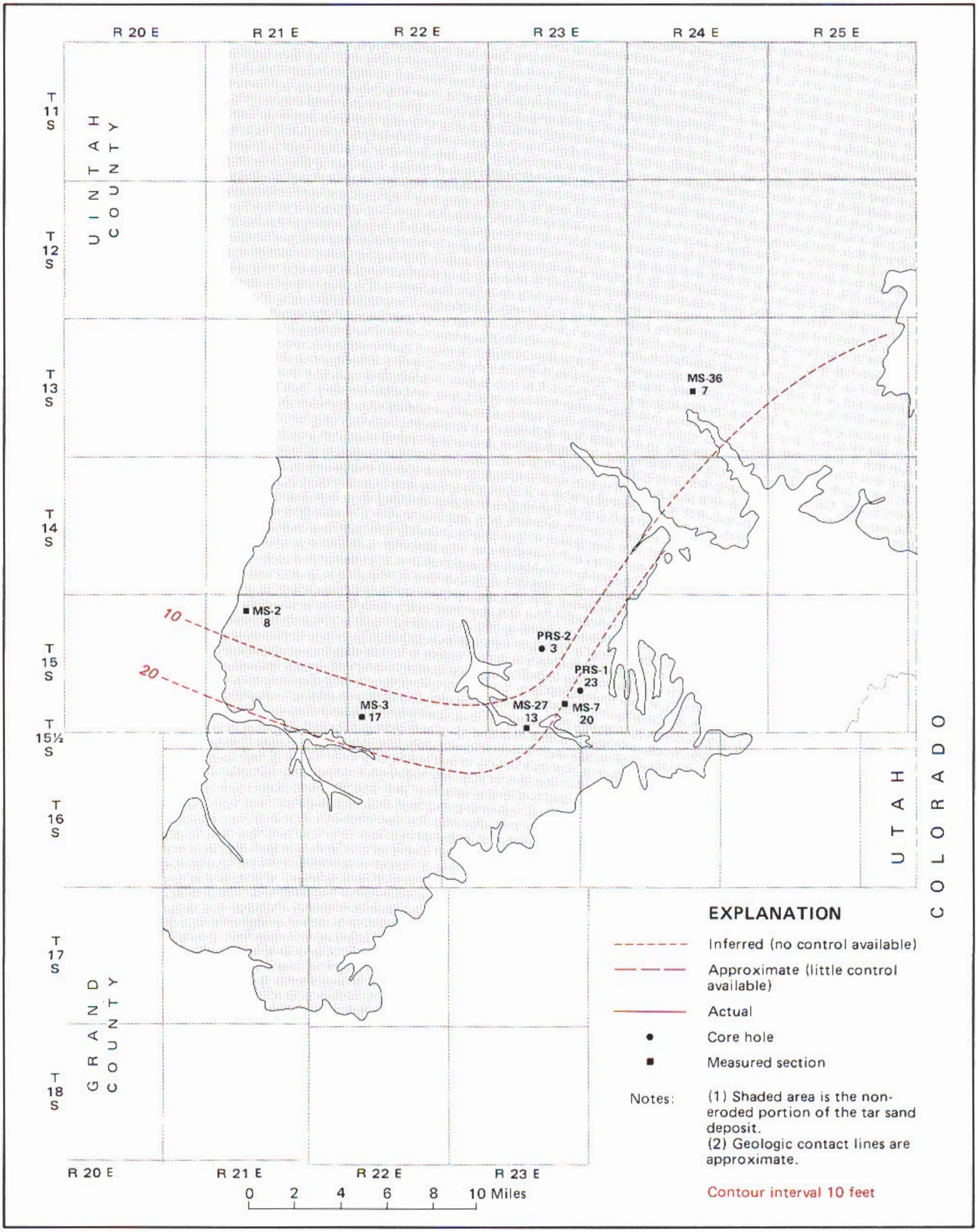
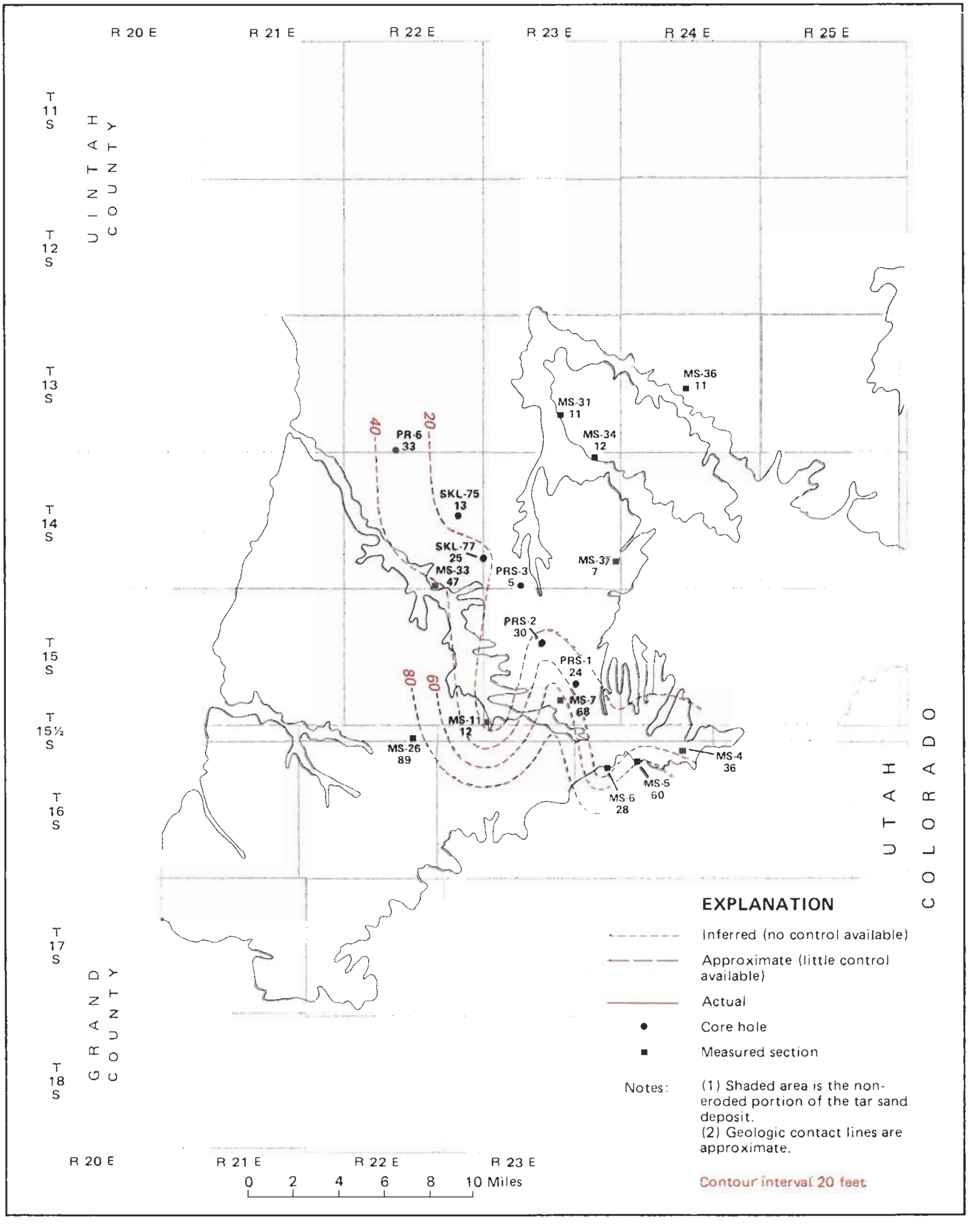


FIGURE 12. Isopach map of visibly saturated tar sand in Zone "A".



Notes: (1) Shaded area is the non-eroded portion of the tar sand deposit.
(2) Geologic contact lines are approximate.

Contour interval 20 feet

FIGURE 13. Isopach map of visibly saturated tar sand in Zone "B".

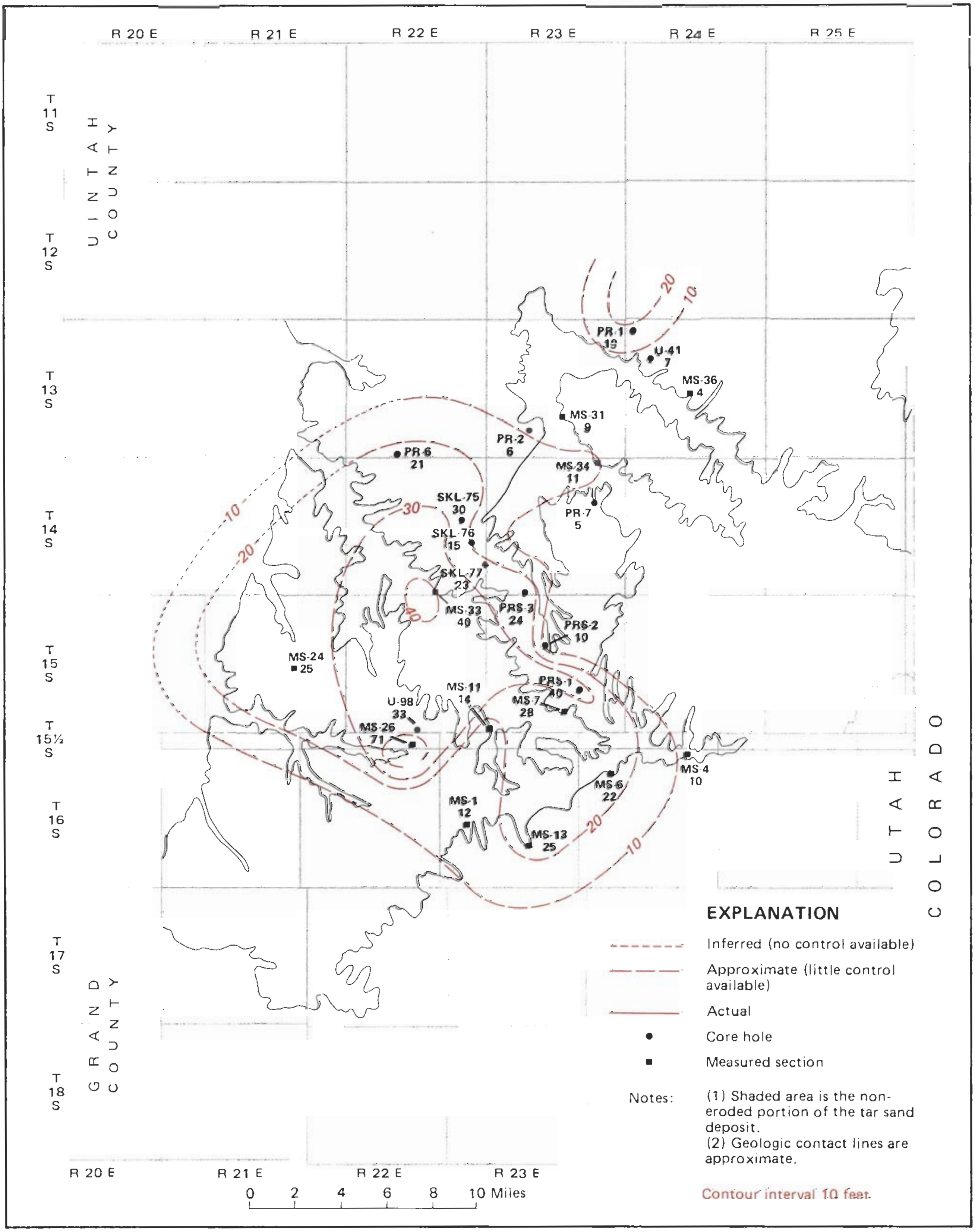


FIGURE 14. Isopach map of visibly saturated tar sand in Zone "C".

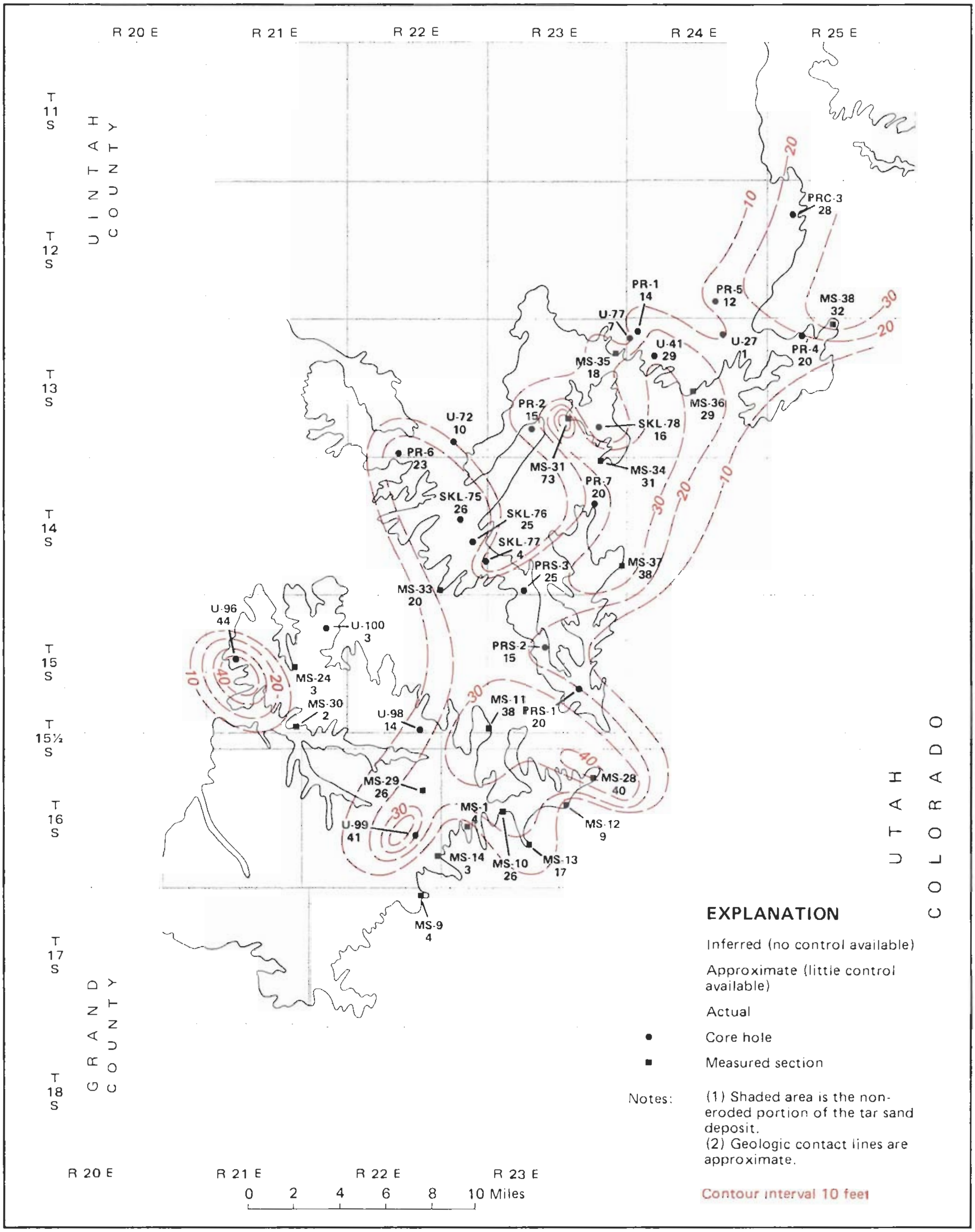


FIGURE 15. Isopach map of visibly saturated tar sand in Zone "D".

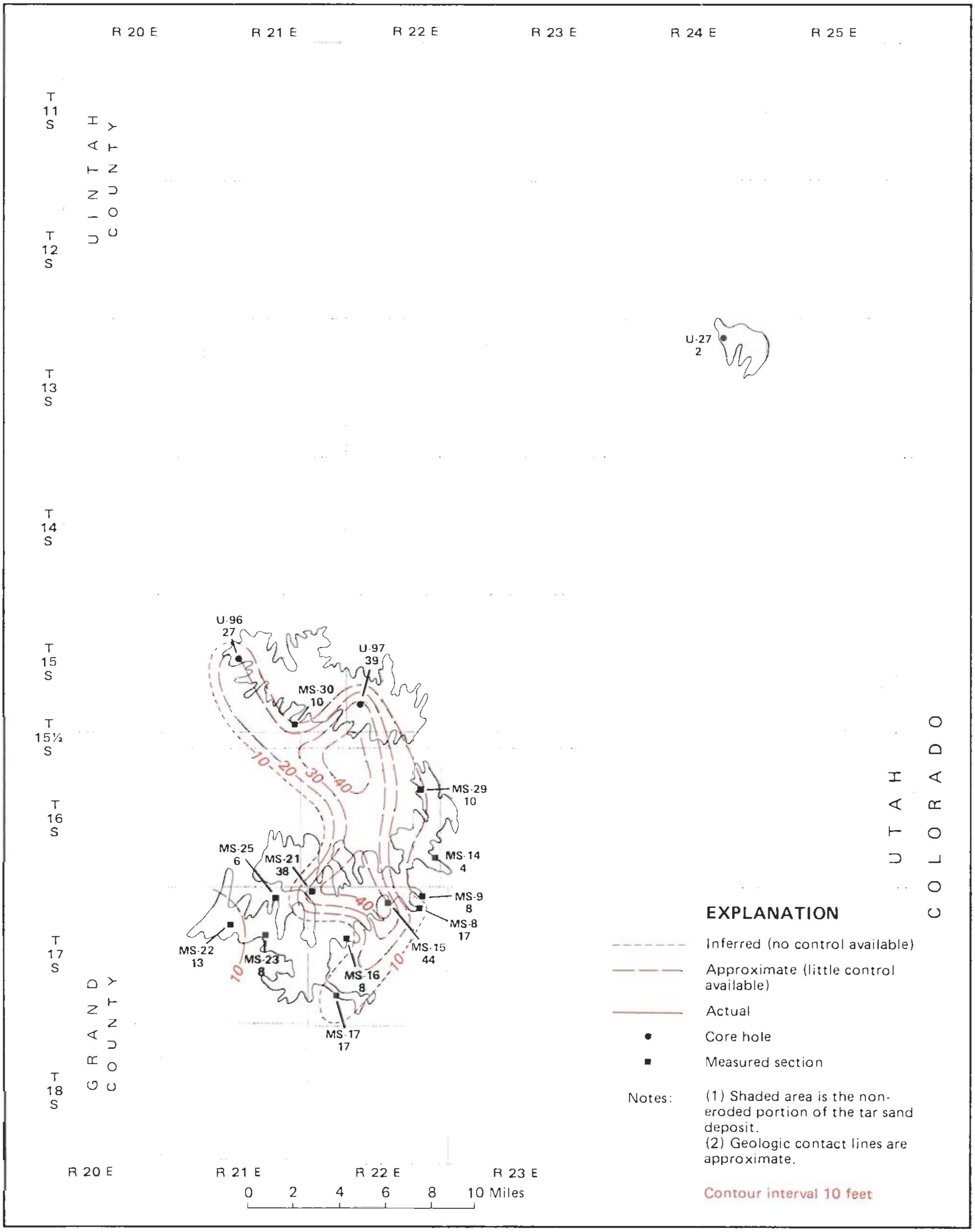


FIGURE 16. Isopach map of visibly saturated tar sand in Zone "E".

Member. Lithologic units of the Parachute Creek Member are predominantly thin and even bedded and are laterally more continuous than those of the Douglas Creek Member. The Parachute Creek Member is composed predominantly of fine-grained precipitate from the lake water with various amounts of organic matter. It also contains lesser amounts of coarser sediment, most of which was derived from a southern source or from ash falls. The tuff beds extend over much of the basin and are key beds for correlations.

In the northeastern part of the study area, the Parachute Creek Member is composed mostly of thin bedded marlstone, oil shale, and tuff. The marlstone beds are mostly thin bedded, and weather to form grey to buff ledges. Much of the marlstone contains organic matter which appears brown to "mahogany" in color. Units containing lesser amounts of organic material are gray to tan. In the southwestern part of the study area, the member is composed mostly of siltstone and sandstone, and contains a few beds of oil shale. The siltstone is calcareous and commonly contains tuffaceous material and minor amounts of organic matter. The thick oil-shale sequence at the base grades laterally into or interfingers with beds of marlstone and siltstone in the shoreward direction. In turn, the marlstone and siltstone grade into or interfinger with beds of siltstone and sandstone. The sandstone is composed of quartz, lesser amounts of feldspar, and accessory minerals such as biotite, muscovite, and zircon. The grain size is very fine to medium, with bedding grading from massive in the south to thin in the north. It is cemented by carbonate, is gray to brown in color and weathers to gray or brown ledges (Cashion, 1967).

The marlstone, oil shale, and tuff of the northeast area was deposited in an open lacustrine environment. These deposits were laid down on a nearly flat surface and in calm water. The tuff beds were deposited in lake water deep enough that the sediments were relatively undisturbed by water action. The oil shale was deposited in very shallow water as evidenced by mudcracks in the shale (Cashion, 1967). The sandstone and siltstone of the southwestern area was deposited in a marginal lacustrine environment. These fine-grained strata are even bedded and were probably laid down on a gently sloping surface also in calm water.

Structure

The Uinta Basin is a large asymmetric syncline with a steep northern limb and a gentle southern limb. The P.R. Spring area is located on the eastern portion of the southern limb. In relation to the P.R. Spring area, the regional structural features of the area are the Uinta Basin syncline to the north, the Douglas Creek arch to the east, the Uncompahgre Uplift to the south, and the San Rafael swell to the west. The only structural feature of consequence in the area is Hill Creek anticline, a northwest plunging fold located in the southwest portion of P.R. Spring. This anticline does not have any effect on the emplacement or migration of the oil in the area. Regional dip is northwesterly at 2 to 6 degrees. The abrupt termination of the deposit on the south is caused by the erosional development of the Roan Cliffs, and the absence of tar sands in the southeast is also caused by erosion which has cut to a level below the impregnated zones.

ECONOMIC GEOLOGY

Saturation

The oil-impregnated sandstones occur in five zones, one in the lower portion of the Parachute Creek and four in the upper portion of the Douglas Creek Members of the Green River Formation (fig. 2). The zones are designated from bottom to top as "A", "B", "C", "D", and "E", and can be correlated throughout the area. The extent of saturation in each of the five zones is shown in figures 17 to 21. The zones consist of one or more oil-impregnated, lenticular beds of lacustrine sandstone, separated by sequences of nonimpregnated lithologies. The impregnation of the individual beds within the five zones is controlled by the lateral extent of the bed, its porosity and permeability, and the distance the oil has migrated within the bed. The degree of oil impregnation of the sandstones varies both laterally and vertically. Vertically, all degrees of impregnation are visible in a sandstone bed at any one locality. Horizontally, variation from slightly impregnated to highly impregnated sandstone may occur within a distance of a few hundred feet along the outcrop. Cementation within the highly impregnated beds is with tar. Slightly impregnated beds are speckled with oil and cemented by carbonate. Individual tar sand beds range from 0.5 to 30 feet in thickness and saturation ranges from tar stain to more than 30 gallons per ton. Correlation of individual lithologic units throughout the area is difficult, even over short distances. The overburden, over the impregnated zones, reaches a maximum of over 370 feet over the top of zone "E".

It is evident from geologic extrapolation that the deposit extends farther north than indicated by previous studies. In general, the most numerous tar sands occur in the southern part of the deposit, probably nearest the sediment source for the deltaic complex.

Numerous tar seeps occur in the study area; the Main Canyon seep is the largest. Tar movement is caused by water pressure from the hydrostatic head of the Roan Cliffs pushing the tar down dip into the canyons. During wet seasons, the seeps become active and large amounts of water flow as well as tar. During dry seasons, both tar and water cease to flow. Ground water rather than the high temperatures influence the seepage of tar. The latter only affects stockpiles of high-grade tar sands.

The textures of the tar sands are extremely varied. The most common variations are in size and shape of the grains, in type of cement and degree of cementing, in oil content, in sorting, in packing, and in porosity. Abrupt vertical changes in textures, within short stratigraphic intervals, indicate periods of intermittent turbulence during the time of deposition. The controlling factors for determining the amount of oil the sediment can hold are the median diameter of the sediment grains and the percentage of clay- and silt-sized material. The greatest saturation occurs in sandstones with a grain size ranged between 1/4 to 1/16 millimeter diameter and with a low percentage of clay and silt. The amount of carbonate cement also greatly influences the oil content of the sandstones by reducing the porosity (Wiley, 1967).

Analysis and Quality

The tar extracted from the P.R. Spring oil-impregnated sandstones is a naturally occurring, brown to black, highly viscous or solid mixture of hydrocarbons. It is composed mainly of alkane or paraffin type hydrocarbons. The gravity of the tar ranges from 5.8° to 24.2° API, with an average of 15.5°. The pour point ranges from 50° to 60° Fahrenheit. Results from fractional distillation of the tar indicate that it does not contain the lighter, low boiling point fractions normally found in crude oil. A residium content of approximately 74 percent, consisting of highly hydrogen-deficient hydrocarbon is usually left after conventional distillation and is characteristic of low-gravity oil. This residium constitutes a large percent of the potential value in the tar and can be more fully utilized by other types of processing, such as hydrogenation. The sulphur content ranges from 0.22 to 0.42 percent, with an average of 0.323 percent, and the nitrogen content ranges from 0.16 to 0.66 percent with an average of 0.49 percent. Analyses of trace elements suggest that the trace elements in the tar were not absorbed from the adjacent lithologies, but were indigenous to the environment of oil formation. This suggests that the oil was formed elsewhere, later migrating into its present host, or that it was formed in situ under environmental conditions which were different from conditions under which the adjacent lithologies were deposited. A graphic interpretation of the trace element content does not indicate any anomalous concentrations or gradational trends within the area, nor are there any anomalous differences between the five zones of tar sand. Sulphur isotope analysis of the tar indicates that migration of the tar from a common source to its present position is unlikely, and suggests either in situ formation or migration only a short distance (Gwynn, 1970). The oil-impregnated sandstones of the P.R. Spring area are speculated to never have been buried deeper than 7,000 feet, thus making the oil thermochemically immature. A maximum burial depth of approximately 12,000 feet is needed for kerogen of the Green River Formation to reach the peak stage of oil generation (Pitman et al., 1982).

Analyses of samples taken by the author were completed by TerraTek Core Services, Salt Lake City, Utah, using the Dean-Stark low-temperature solvent extraction method. Grain densities were determined by Boyle's Law (helium technique) and bulk volumes by the Archimedes (mercury) displacement method. Natural bulk density, grain density, and residual fluid saturation determinations were used to calculate gallons per ton and barrels per acre/foot. The detailed laboratory procedures are included in Appendix 1. Analytical data is provided in Appendix 2.

Resources

In 1973, with U.S. Bureau of Mines funding, the Utah Geological and Mineral Survey drilled 14 core holes in the P.R. Spring deposit and obtained core and subsequent sample analysis data. This data were used, together with the additional samples collected and analyzed for this study, to produce a series of saturation maps (figures 17 through 21).

The author has calculated an in-place resource for the area of about 3.3 billion barrels of oil. Relative estimates by other investigators for a similar area are 3.7 billion barrels (Byrd, 1967), and 4.0 to 4.5 billion barrels, consisting of 2.5 billion barrels measured, 1.2 billion barrels indicated, and 0.3 to 0.8 billion barrels inferred (Ritzma, 1974). Dahm (1981) calculated the total barrels of oil in place for only the State lands to be 1.9 billion.

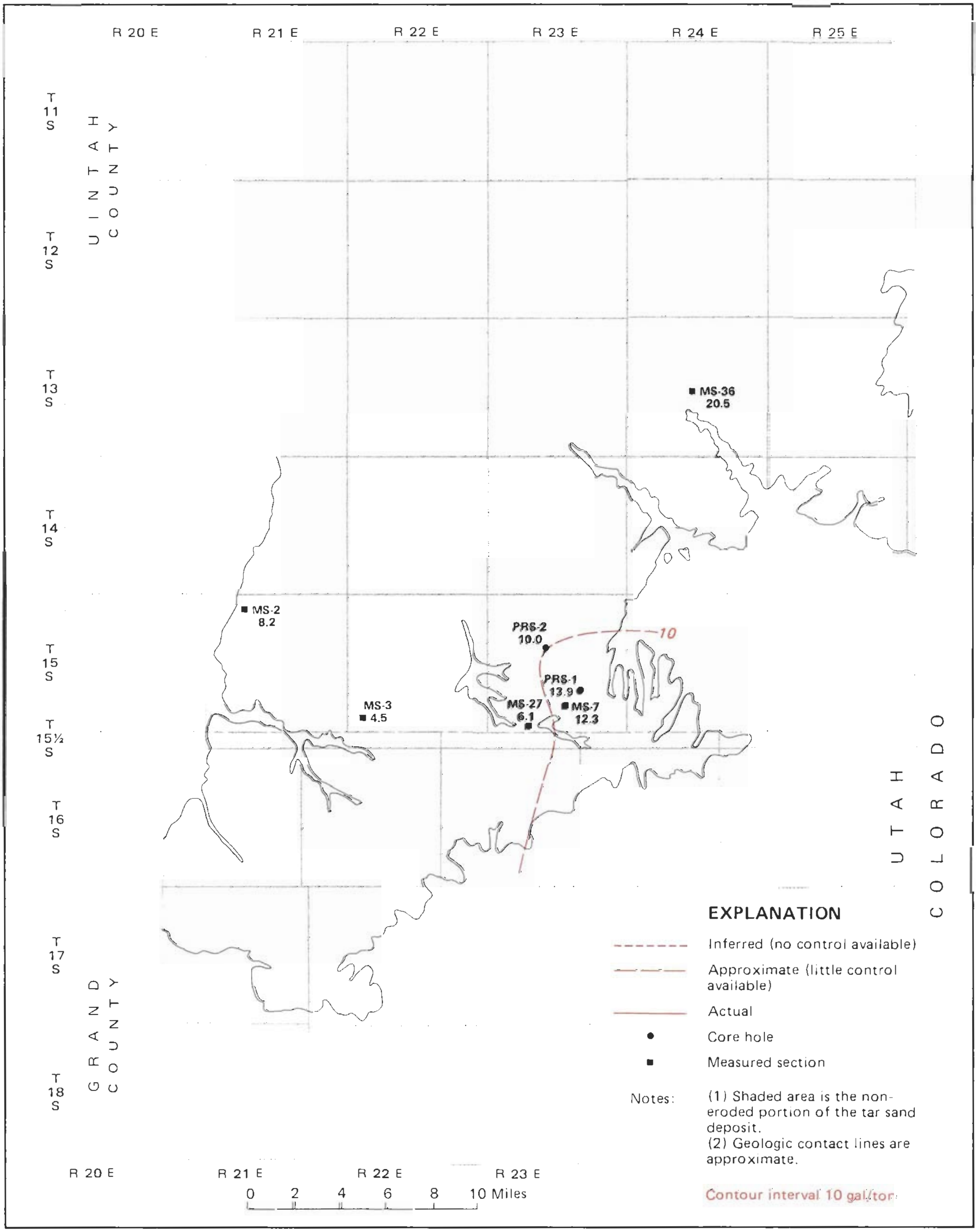


FIGURE 17. Zone "A" saturation map (gallons per ton).

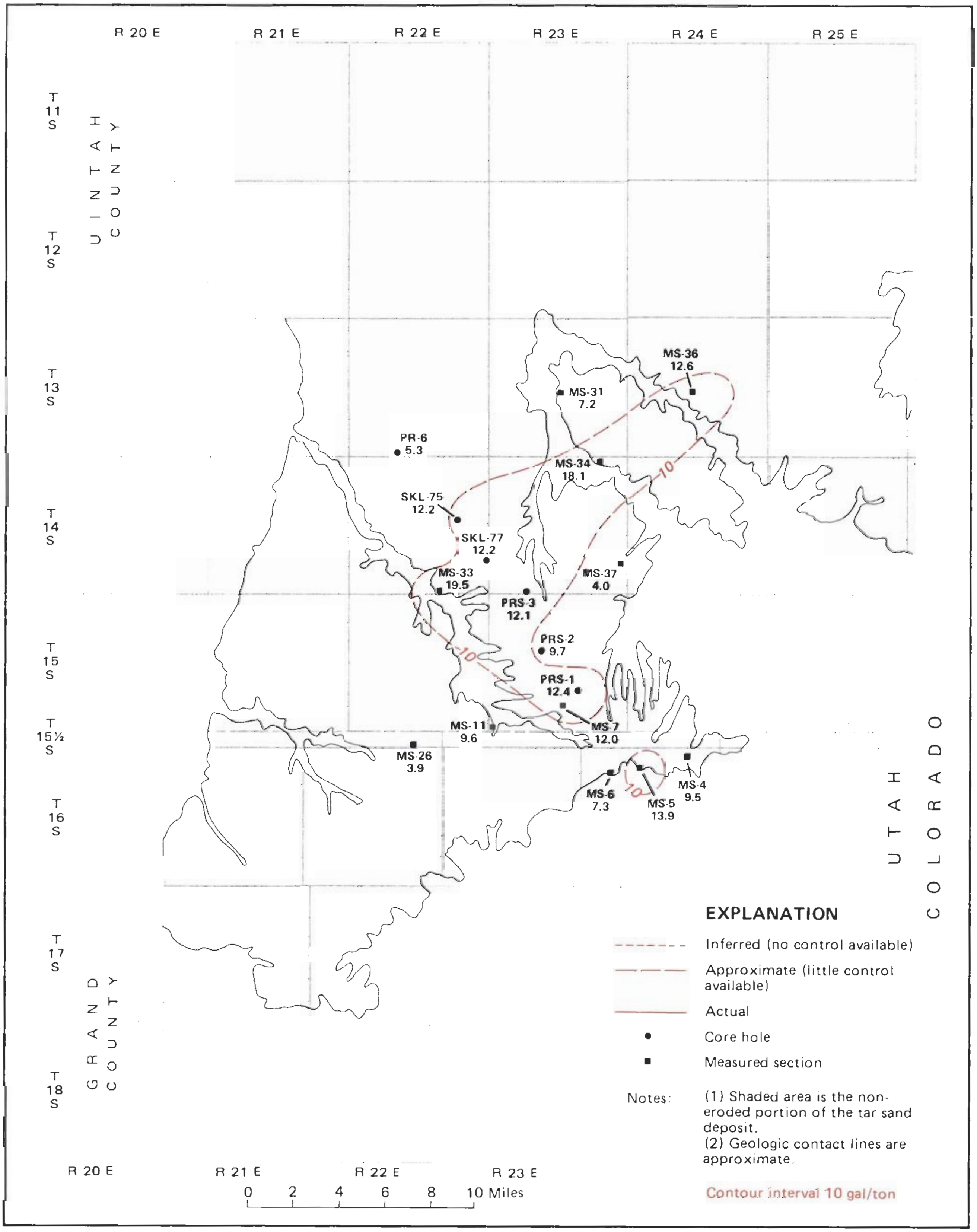


FIGURE 18. Zone "B" saturation map (gallons per ton).

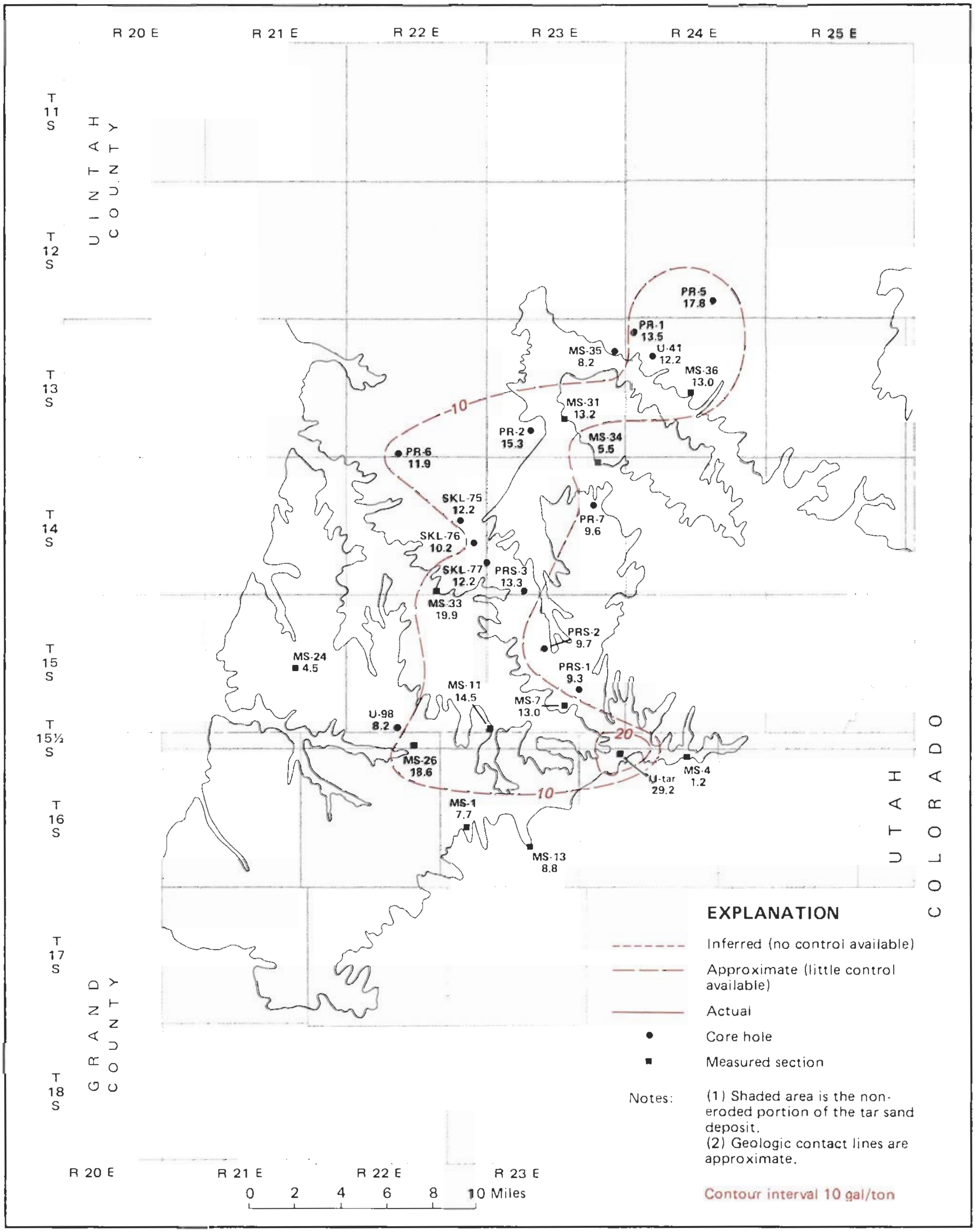


FIGURE 19. Zone "C" saturation map (gallons per ton).

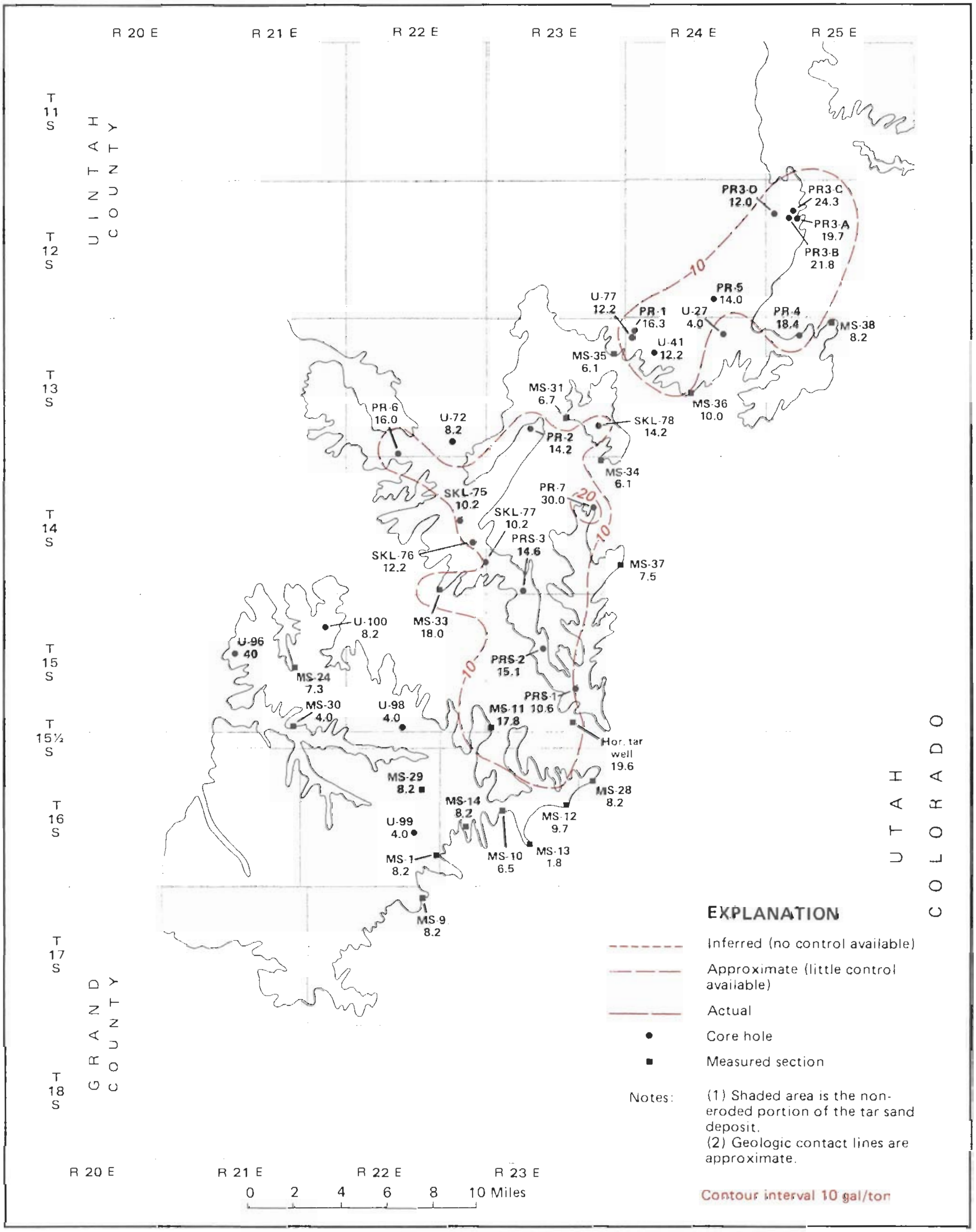


FIGURE 20. Zone "D" saturation map (gallons per ton).

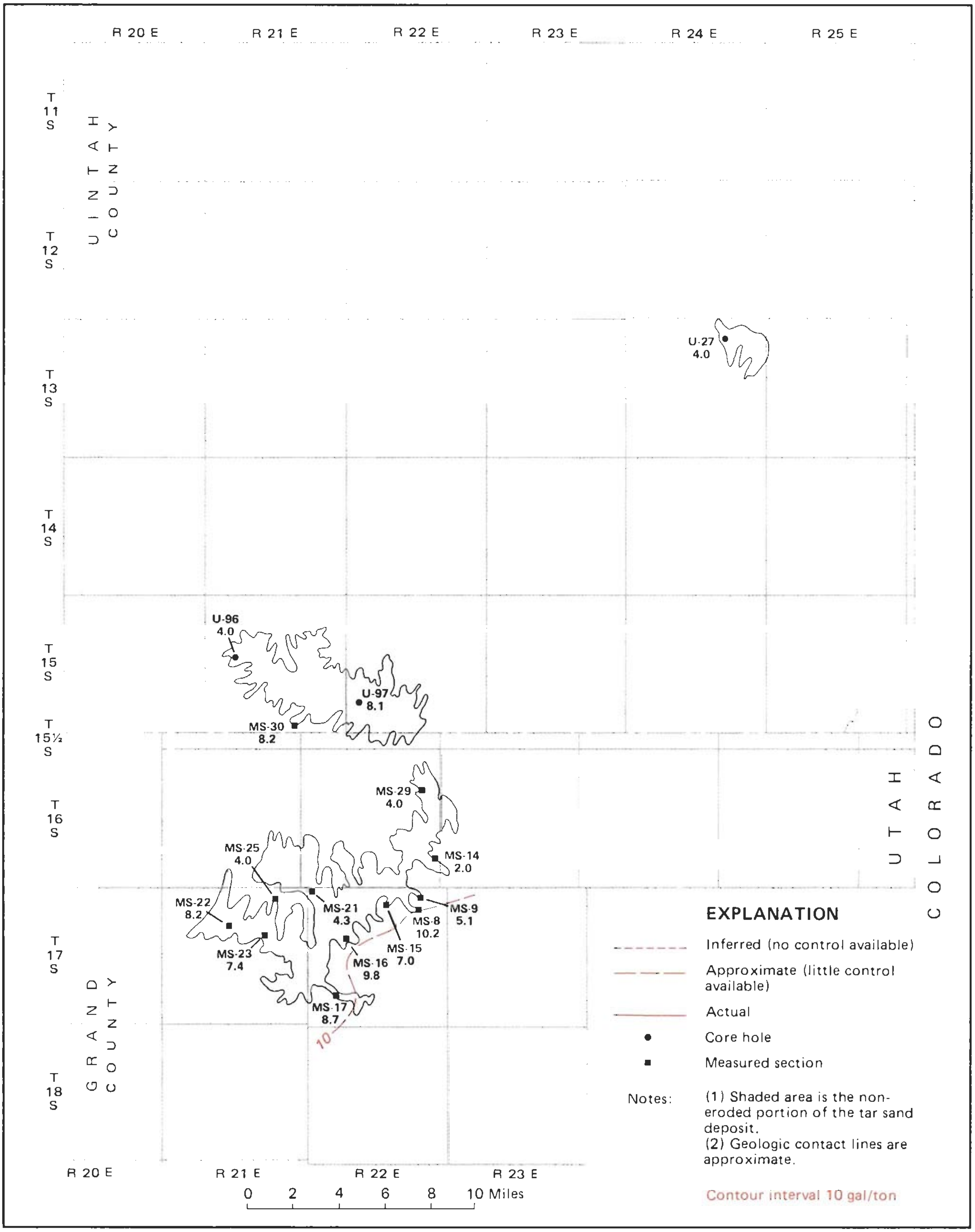


FIGURE 21. Zone "E" saturation map (gallons per ton).

Resource calculations were made under a number of considerations and assumptions. Three maxims were employed to minimize the risk involved in the calculation: The smaller the block, the larger the estimation error; smaller blocks tend to appear alike; and smaller blocks appear more alike than larger blocks. In calculation, the saturation was assumed to be uniform and relatively constant in a particular zone even though it is known to be erratic. The uniform saturation was calculated to represent a conservative expected average for the area. For this reason, and due to the lack of sufficient control points, the isopach lines are dashed rather than solid (figures 12 through 16). The bulk of the resource is therefore classified as inferred or approximate.

Mining and Oil Recovery

There are several processes on the market for the recovery of oil from tar sands. At present, the only active operation in the P.R. Spring area is a 200-barrels-per-day extraction by UTAR Division of Bighorn Oil, Salt Lake City, Utah. Their operations consist of an open-pit mine and an extraction plant, both located in the southeastern part of the P.R. Spring area. Their process utilizes a solvent solution which separates the oil from the sand. The process requires approximately 5.5 to 6 gallons of water and approximately 0.5 gallons of solvent per barrel of oil extracted. The UTAR operation at P.R. Spring consists of 160 acres of private land, is privately funded, and employs approximately five people.

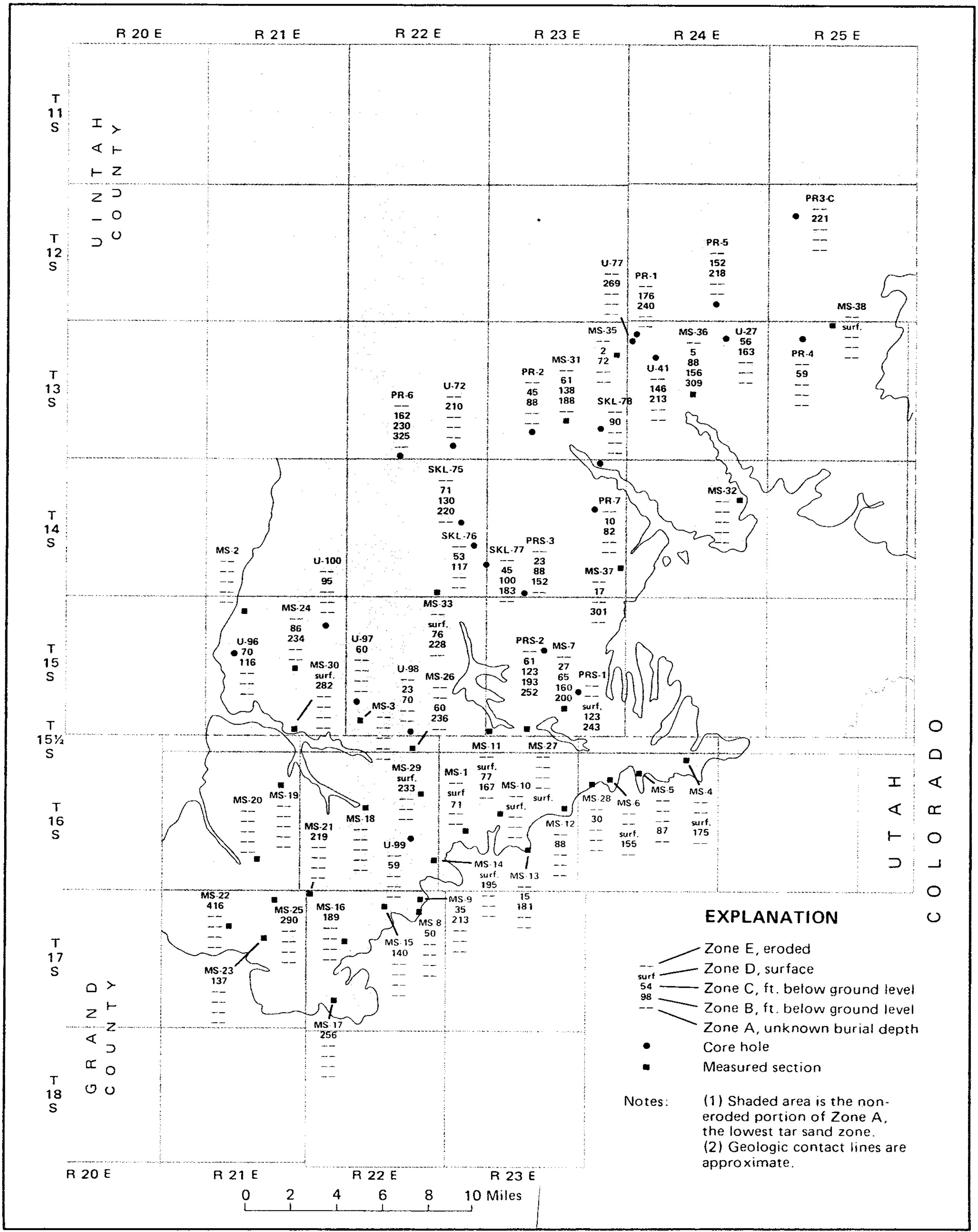
The earliest known operation for petroleum recovery from the P.R. Spring area was an oil test well drilled in sec. 35, T. 15 S., R. 23 E., by John Pope in 1900. It was also the first well drilled for petroleum in the Uinta Basin (Ritzma and Campbell, 1981). Another venture consisted of an adit of more than 50 feet and was used to produce tar and is located in section 34, T. 15 S., R. 23 E. A steel pipe runs from the adit on the ground and hangs over a metal trough which collected the tar. The date and other information concerning this venture is unknown. As of 1980, most of P. R. Spring area was under lease to Anschutz and Kerr-McGee. There is no known exploration or development activity by these companies at present.

The economic problems of recovering oil from the P.R. Spring deposit are complex. Numerous factors suggest that the P. R. Spring area is unsuitable for a large scale surface-mining operation. These include the remoteness and relative inaccessability, lack of water for processing and land reclamation, heavy overburden except near the southeastern end of the deposit, and the wide separation of the tar zones by barren material. The in-place 3.3 billion barrel resource translates into 14.7 million barrels per square mile (Appendix 3), which is assumed by the experts to be a relatively low figure for a large scale operation. However, a small scale, selective surface mining operation might be feasible for the southeast part of the deposit. In situ mining methods will have to be employed to recover oil in the rest of the area.

Several American companies consider that a small volume plant can operate profitably. Arizona Fuels and Fairbrim expect to spend $450,000 to $700,000 for a 5,000 barrel-per-day plant to produce oil at costs of $6 to $8 per barrel or from $90 to $140 per barrel capacity. Enercor's estimates, on the other hand, are for a 2,000 barrel-per-day plant, with startup costs at $34 million and production cost of $27 per barrel. Ford, Bacon and Davis' cost estimates are $0.80 to $1 per ton for open pit mining and $1 to $2 per ton for underground mining while extraction cost would be $8 to $9 per barrel. These cost estimates were derived from computer models, developed in cooperation with U.S. Bureau of Mines (Glassett and Glassett, 1976).

Extraction processes that have been or are being tested or utilized for tar extraction are: 1) alkali assisted hot water process of Enercor, 2) hot water high temperature process of GNC Energy and Standard Oil of California, 3) high-pressure steam in situ process of Laramie Energy Technology Center, 4) heat-gasifer process of Ramex Synfuels, 5) reverse burn/fire flood process of Laramie Energy Technology Center, 6) warm water-oleophilic belt separator process of Kruyer Tar Sands Development, and 7) ultrasonic-solvent process of Western Tar Sands. Little information is available concerning production volume versus water and solvent consumption for any of these various known processes.

In situ recovery methods generate pressures within the oil reservoir or tar-sand bed, making a closed system between injection and producing wells necessary. The shallow depth of some of the tar-sand pay zones at P.R. Spring, coupled with the presence of fractures and nearby outcrops, may cause leakage in recovery systems (fig. 22). For economical in situ secondary recovery in oil fields, it is suggested the pay zone contain at least 1,000 barrels per acre-foot of saturation. Averages for most areas of the P.R. Spring deposit are below this minimum. However, the average subsurface porosity of the P.R. Spring tar sands is 26.4 percent, which is above the required 18 to 20 percent and may offset the low saturation problem. Another problem involves the lithologic variations within the strata, which would make planning



Notes: (1) Shaded area is the non-eroded portion of Zone A, the lowest tar sand zone.
(2) Geologic contact lines are approximate.

FIGURE 22. Composite depth of burial of individual zones.

of in situ closed systems very difficult.

Numerous "in situ" operations are presently being carried out in the Uinta Basin. These are more commonly referred to as oil fields, with the majority of the fields located in the Green River Formation and with the oil quality similar to P. R. Spring tar. One example of this in situ production is the Monument Butte field, located primarily in T. 9 S., R. 17 E. of Duchesne County. The stratigraphy is very similar to P.R. Spring, with production from the Douglas Creek Member. Oil analysis calculates gravity 33° API and pour point of 90° Fahrenheit. It must be noted that with an increase in temperature and/or pressure, an increase in API gravity and a decrease in pour point will follow. An average bottom-hole temperature of 140° Fahrenheit, bottom-hole pressure of 2800 PSI, and average production interval of 4,800 to 5,300 feet does not compare with any locality at P. R. Spring but does exemplify present technology in a related field.

Water availability, necessary for oil recovery, is limited in the area. The Willow Creek and Upper Willow Creek system is used for irrigation (Resnick et al., 1981). The annual drainage of Willow Creek and Upper Willow Creek contribute 17,500 and 13,000 acre-feet respectively to the Upper Colorado River Basin system. Only 11,500 acre-feet are used for cropland and wet-land depletion. The flow of P.R. Spring, located in section 36, T. 15 S., R. 23 E., is 0.033 acre foot per day. Resnick et al. (1981) consider the water supply for resource development sufficient, especially if storage and reuse are considered. Annual precipitation ranges from 12 to 16 inches, mostly as snowfall, with the northern part receiving less than the southern part. Ground-water distribution is poorly understood, although fresh to saline water is encountered at depths ranging to thousands of feet. Numerous springs have been mapped at the heads of the canyons where water seeps to the surface from the oil-impregnated sandstones.

Oil recovery methods require a supply of fuel for the production of in situ medium or for the extraction process. Coke and other by-product fuels derived from the tar-refining process itself could provide a self-sufficient fuel source. Nearby natural gas and coal deposits could be exploited (Gwynn, 1970).

SUMMARY AND RECOMMENDATION

The P.R. Spring deposit is located in the southeastern portion of the Uinta Basin, approximately 50 miles northwest of Grand Junction, Colorado. The oil-impregnated sandstones are located in the Green River Formation and five zones have been identified. These zones consist of one or more lenticular beds of lacustrine sandstone, separated by intervals of barren lithologies. The impregnation of individual beds within the five zones is controlled by the lateral extent of the bed, its porosity and permeability, and the distance the oil has migrated within the bed. The degree of saturation varies both laterally and vertically.

The oil extracted from the P.R. Spring tar sands is a naturally occurring, brown to black, highly viscous or solid mixture of hydrocarbons. Its composition indicates that the oil was formed in situ or migrated only a short distance. The author has calculated the total barrels of oil in place for the area to be approximately 3.3 billion barrels. This is lower than other published calculations of 3.7 and 4.0 to 4.5 billion barrels (Byrd, 1967, and Ritzma, 1974).

Problems associated with the economic recovery of the oil remain to be solved. Only the southeastern corner of the field is strip minable. Other areas will probably have to be exploited by in situ recovery methods and several are being tested. The only known operation actively being pursued in P.R. Spring is by Bighorn Oil, located in the southeastern part of the deposit. Their operation consists of an open-pit mine and extraction plant utilizing a solvent solution process. Surface water availability in the area is limited, but may be sufficient if storage, reuse and ground-water potential are considered. Oil extraction will require a fuel supply; this may possibly be provided by generated coke and other byproduct fuels from the tar refining process or by local natural gas or coal production.

Further work is needed in the area, specifically more core holes and associated analyses. Strategic drilling in T. 11 S., R. 22 and 24. E, and T. 12 S., R. 22 E., could be used to verify assumed saturation.

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APPENDIX

Appendix No. 1 - Laboratory Procedure For Tar Sand Mass Fraction Analysis.

I Sample Preparation

a) Select approximately 100 gram sample of preserved native core
b) Crush sample into 1/4 inch pieces
c) Sieve crushed sample through -100 mesh screen to remove the individual grains

II Water Extraction - Dean-Stark Method Using Toluene

a) Place clean, dried extraction thimble on balance, record weight to nearest 0.01 gram
b) Pour crushed, sieved sample into extraction thimble, record weight to nearest 0.01 gram
c) Place extraction thimble with crushed sample into clean 250 milliliter Dean-Stark plug extraction unit containing approximately 150 to 175 milliliter of clean distilled toluene
d) Dean-Stark unit is then heated to 230° Fahrenheit (boiling point of toluene). The sample is also brought up to the 230° Fahrenheit by means of convection heating by solvent vapors. Once the boiling point of water (212° Fahrenheit) has been reached, water will begin to vaporize in Dean-Stark unit, condense and drop into calibrated receiving chamber. The time required for the water extraction process is from 5 to 12 hours
e) Monitor water readings hourly until constant reading is achieved and maintained for 4 hours
f) Allow Dean-Stark unit to cool to room temperature
g) Record water reading to nearest 0.01 milliliter

III Bitumen Extraction - Vapor Phase Method (*)

a) Remove extraction thimble containing crushed sample from Dean-Stark unit, place in vapor phase cleaner. Sample will be monitored for fluoresence daily by use of an ultra violet lamp. The removal of the bitumen takes approximately 5 to 7 days, dependent on gravity of bitumen
b) Remove cleaned sample - allow toluene vapors to vent under exhaust fume hood
c) Place extraction thimble with sample into a forced convection oven at a 110° Centigrade for a minimum of 24 hours
d) Remove sample and weigh to nearest 0.01 gram
e) Place sample back in oven at 110° Centigrade for 4 hours. Remove and reweigh to nearest 0.01 gram. If weight is within 0.015 grams of weight taken in step III-d, remove and place in dessicator. Dessicator will contain $CaSO_4$ absorbent with less than 10 percent relative humidity
f) Allow sample to cool to room temperature
g) Reweigh extraction thimble and sample, record weight to nearest 0.01 gram

IV Calculations

a) Initial sample weight initial sample weight = thimble and sample weight - thimble weight
b) Sample dry weight (after all hydrocarbons and water has been extracted) dry weight = thimble and sample dry weight - thimble weight
c) Water weight = milliliter as recorded from Dean-Stark extraction
d) Oil weight = total weight loss - water weight
e) Oil (mass fraction) oil weight divided by initial sample weight, then multiplied by 100
f) Water (mass fraction) water weight divided by initial sample weight, then multiplied by 100
g) Gallons per ton gal/ton = 907,200 divided by initial weight, then multiplied by cc oil, then divided by 3784
h) Barrels per acre foot bbl/acre-ft = 32.373 multiplied by 0.990, then multiplied by gal/ton

(*) The vapor phase cleaner is an insulated tank containing toluene solvent in the bottom with electrical heating elements submerged in the solvent. The samples to be cleaned are placed on a rank slightly above the solvent level. As the heating elements bring the toluene to its boiling point, hot solvent vapors fill the tank above the liquid level. The toluene vapors are condensed as clean distilled solvent by means of a cooling coil in the lid. Hydrocarbon removal from the samples is accomplished by means of the hot toluene vapor environment in conjunction with clean distilled toluene dripping from the lid onto the samples.

Appendix No. 2 - Mass Fraction Analyses from TerraTek
(Sample locations are indicated in figure 3.)

Sample number	Mass fraction oil (%)	Mass fraction water (%)	Grain density (sm/cc)	Natural bulk density (sm/cc)	Gallons per ton	Barrels per acre foot
Samples taken from operations.						
Tar Pit 1	6.3	10.6	2.68	2.06	15.1	484
U Tar 1	10.0	0.0		1.89	24.1	772
U Tar 2	14.2	3.2		1.95	34.4	1102
Hor Tar Well 1	8.1	0.3		1.88	19.6	628
12-25-8	6.7	0.6	2.67	1.88	16.3	522
Samples taken from measured sections. First number refers to section number.						
1-D	3.2	0.3		1.87	7.7	247
6-B	0.9	0.4		1.91	2.1	67
6-E	11.0	6.0		1.91	26.6	853
7-A1	4.1	0.0		1.89	10.0	320
7-A2	6.7	0.6	2.63	2.00	16.2	519
7-B1	6.1	0.0		1.85	14.8	474
7-B2	13.0	0.0		2.12	31.4	1006
7-C3	3.5	1.0	2.64	1.87	8.4	269
7-E	6.4	0.0		1.92	5.6	500
11-A	6.3	0.0		1.87	15.3	490
11-B	4.5	7.9	2.66	2.10	11.0	353
11-C	7.8	0.8		1.87	19.0	609
11-E1	4.3	0.8		1.86	10.5	337
11-E2	12.0	0.3		2.13	29.2	936
13-B	3.6	0.7		1.89	8.8	282
13-C	0.7	1.8	2.64	1.82	1.8	58
15-E	6.1	0.4		1.96	14.8	474
15-E2	0.4	1.7		1.94	4.1	131
15-E3	0.4	1.6		1.81	1.0	32
23-E	2.5	0.9		1.85	6.0	192
24-C	2.4	1.5	2.64	1.89	5.9	189
24-E	2.6	0.7		1.82	6.4	205
26-A	2.0	1.8		1.80	5.0	160
26-B	1.2	2.1		1.87	2.8	90
26-C	1.6	1.0		1.92	3.9	125
26-D	7.8	0.4	2.64	1.92	18.6	596
31-C1	1.8	2.6		1.85	4.4	141
31-C2	4.2	0.6		1.95	10.1	324
31-D1	5.5	0.2		1.82	13.2	423

(Continued)

Appendix No. 2 - Mass Fraction Analyses from TerraTek - Continued.
(Sample locations are indicated in figure 3.)

Sample number	Mass fraction		Grain density (sm/cc)	Natural bulk density (sm/cc)	Gallons per ton	Barrels per acre foot
	oil(%)	water(%)				
Samples taken from measured sections. First number refers to section number.						
31-D2	2.1	1.0	2.64	1.87	5.1	163
31-D3	3.4	2.4		1.87	8.3	266
31-E	2.8	0.5		1.94	6.7	215
33-C1	8.3	1.9		1.96	20.0	641
33-C2	13.5	2.2	2.64	1.92	32.6	1045
33-C3	2.4	3.1		1.89	5.7	183
33-D1	8.4	0.6		1.91	20.4	654
33-D2	8.0	0.6		1.92	19.5	625
33-E	7.5	0.8		1.87	18.0	577
34-C	7.5	1.0	2.64	1.97	18.1	580
34-D1	2.9	0.2		1.82	7.0	224
34-D2	1.7	0.2		1.86	4.0	128
34-E	2.5	0.6		1.97	6.1	195
36-B	8.5	1.6		1.84	20.5	657
36-C1	5.4	1.3	2.64	1.90	13.2	423
36-C2	5.0	0.2		1.88	12.1	388
36-D	5.4	0.0		1.85	13.0	417
36-E	4.1	0.0		1.81	10.0	320

Appendix No. 3 - Saturation by Townships.
(All tar sand zones included.)

Location	Saturation (barrels)	Area (square miles)
T11S, R21E	61,440,000	30
R22E	73,728,000	36
R23E	73,728,000	36
R24E	73,232,000	36
R25E	64,464,000	30
T12S, R21E	55,872,000	28
R22E	73,728,000	36
R23E	71,888,000	36
R24E	98,944,000	36
R25E	77,168,000	30.5
T13S, R21E	24,176,000	18
R22E	90,672,000	36
R23E	62,937,000	35.5
R24E	97,888,000	34
R25E	58,441,000	32.5
R26E	720,000	0.5
T14S, R21E	87,701,000	21
R22E	217,794,000	36
R23E	103,456,000	34.5
R24E	22,000,000	19
R25E	19,216,000	13
R26E	1,536,000	1
T15S, R21E	237,664,000	27
R22E	170,512,000	34
R23E	180,864,000	31
R24E	30,160,000	5
T15-1/2S, R21E	18,048,000	2.5
R22E	34,448,000	2.5
R23E	24,768,000	2
R24E	22,528,000	3
R25E	1,232,000	0.5
T16S, R21E	226,392,000	26
R22E	307,552,000	33
R23E	178,704,000	19
R24E	43,328,000	5
T17S, R21E	171,136,000	19.5
R22E	128,088,000	13
TOTAL	3,286,153,000	223