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Geologic Characterization of Tight Gas Reservoirs
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FY 1986 USGS ANNUAL REPORT

INTRODUCTION

The objectives of U.S. Geological Survey (USGS) work are to conduct geologic research characterizing tight gas-bearing sequences in the western United States. The USGS research during the last few years has been in the Greater Green River, Piceance Creek, and Uinta basins of Wyoming, Colorado, and Utah (fig. 1). Additional critical objectives are to provide geologic consulting and research support for ongoing Multiwell Experiment (MWX) engineering, petrophysical, log-analysis, and well-testing research.

Within these basins our research efforts have been regional in scope. The Greater Green River basin has high priority because most of the Piceance baasin studies have been completed or are being completed, and because the Greater Green River basin has the greatest areal extent and greatest known thicknesses (>10,000 ft) of strata containing dominantly gas-bearing sandstone reservoirs. The Uinta Basin may have greater thicknesses of tight-gas strata, but there are presently no wells that have been drilled through the Cretaeous Mesaverde Group in the deeper parts of the basin.

As a result of the large area and great thickness of gas-bearing reservoirs, many of our investigations have focused on single wells or small areas containing several wells where a large amount of data is available. The investigations include structure, stratigraphy, petrography, X-ray mineralogy, source-rock evaluation, formation pressure and temperature, borehole geophysics, thermal maturity mapping, fission-track age dating, fluid inclusion thermometry, and isotopic geochemistry. The objectives of these focused investigations are to provide geologic models that can be compared and utilized in tight bas-bearing sequences elsewhere.

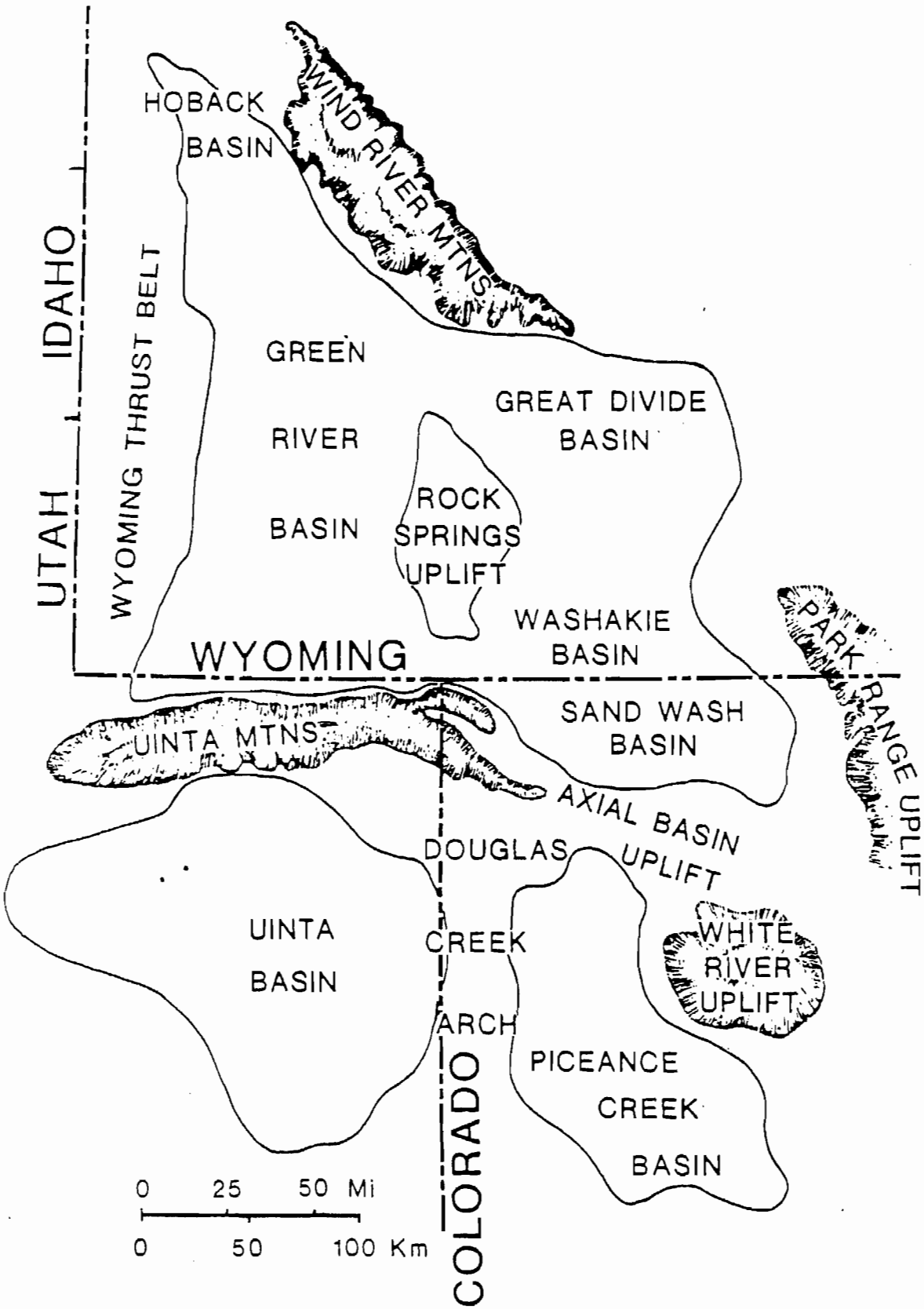

Figure 1.--Index map showing location of basins discussed in this report that contain tight gas-bearing reservoirs in Upper Cretaceous and lower Tertiary rocks.

GREATER GREEN RIVER BASIN ACTIVITIES

Thermal Maturity Mapping

As a result of earlier USGS investigations that have recognized the association of abnormally high pressures and the occurrence of gas-bearing reservoirs, a considerable amount of time has been devoted to gaining an improved understanding of abnormal pressures. One of the more important aspects of abnormal pressures in the Greater Green River basin is that the top of overpressuring commonly occurs at a vitrinite reflectance (R_o) of about 0.8%, ranging from 0.74% to 0.86%.

In an attempt to map the depth of the 0.8% R_o, and thereby the top of overpressured gas-bearing rocks, the USGS has constructed a thermal maturity map for the entire region (Fig. 2). Ideally, this map defines the top of gas-bearing low-permeability rocks. This kind of investigation also provides information concerning the burial and thermal history of the basin and fluid migration pathways which, in turn, can be utilized in diagenetic studies.

During the reporting period, approximately 200 samples were analyzed for vitrinite reflectance and the following observations were made: 1) areas in the Greater Green River basin of unexpectedly high levels of organic maturation may indicate the presence of fluid migration pathways, 2) areas of unusually low thermal maturity may indicate deep circulation of cold meteoric water, and 3) in the absence of pressure data and gas detecting tools, kinks or bends in vitrinite reflectance profiles may provide indirect evidence of the presence of gas and present and (or) past pore pressure.

Thermal maturity mapping in the Greater Green River basin by B.E. Law, M.R. Lickus, and M.J. Pawlewicz has provided evidence that facilitates the

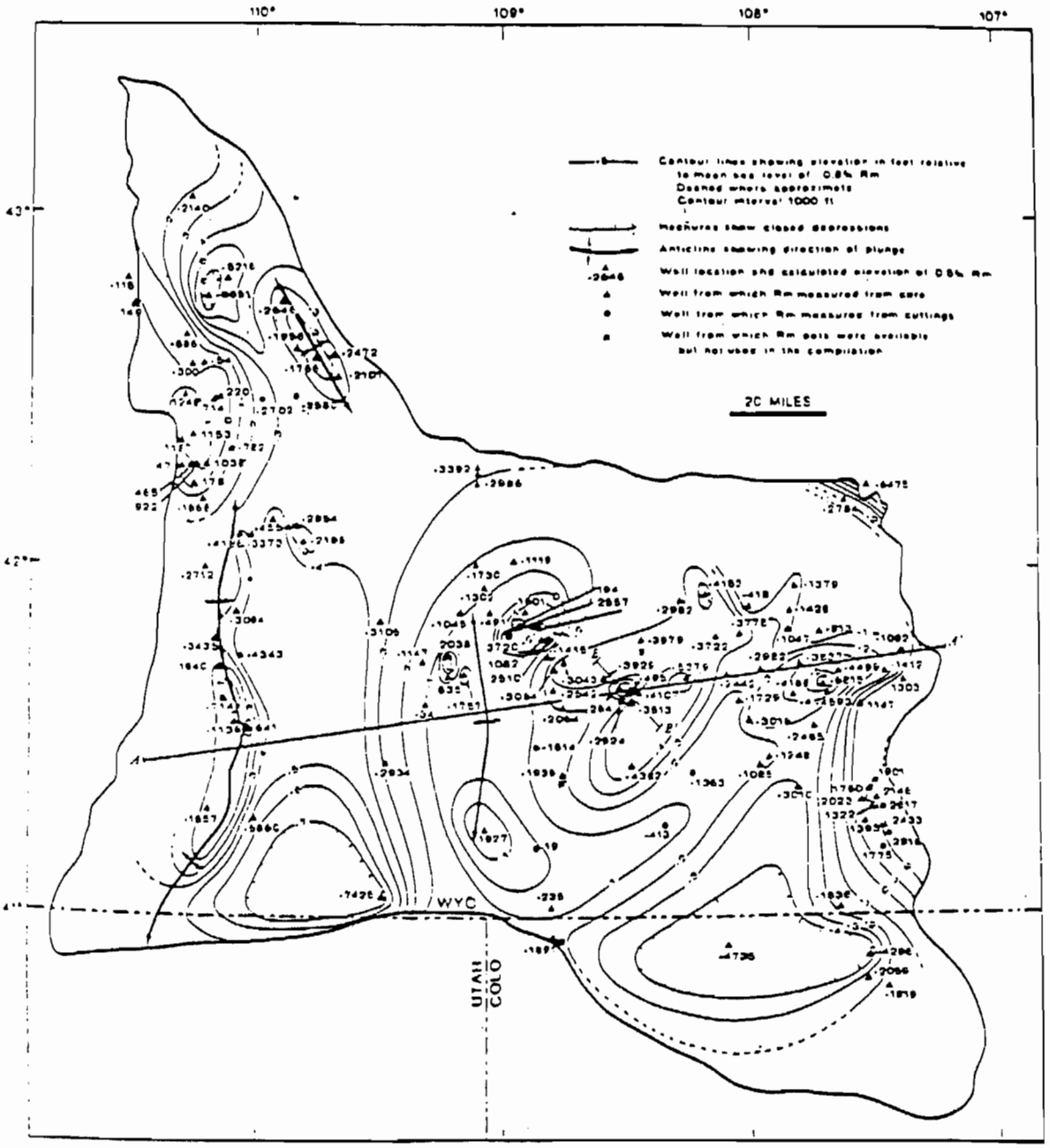

Figure 2.--Map of subsurface elevation of 0.8% vitrinite reflectance. Cross section A-A' shown in figure 4.

identification of fluid migration pathways and specific information bearing on the origin of the Patrick Draw oil and gas field in southwestern Wyoming. The Patrick Draw field, located on the Wamsutter arch east of the Rock Springs uplift, produces from sandstone reservoirs in the Upper Cretaceous Almond Formation. The field is somewhat enigmatic in that it produces oil from a largely gas-producing province.

Vitrinite reflectance (R_o) data from Upper Cretaceous and Tertiary subsurface samples of coal and carbonaceous shale, siltstone, and sandstone in the Greater Green River basin of Wyoming, Colorado, and Utah show several areas of abnormally high levels of organic maturation with respect to regional levels. One of these abnormally high areas is centered over the Patrick Draw field (Fig. 2) and is subparallel to a zone of faults. Figure 3 shows an enlargement of the Patrick Draw area. Figure 4 shows an isoreflectance line superimposed on a structural cross section extending from the Moxa arch in the southwestern part of the Green River basin, east-northeast through the Patrick Draw field to the Rawlins uplift. Along the cross section, the gradient of the isoreflectance line is generally less than, or equal to, the structural dip. However, in the vicinity of the Patrick Draw field, the gradient of the isoreflectance line is greater than the structural dip, indicating that the organic matter in this areas has been subjected to higher temperatures than in adjacent areas. R_o values in the Upper Cretaceous Almond Formation range from 0.48 percent immediately adjacent to the abnormally high area to 0.68 percent within the area.

Law, Lickus, and Pawlewicz have interpreted the occurrence of this and other similar areas of abnormally high levels of thermal maturity in the region to be the result of hot fluids coming into contact with organic matter, elevating the level of thermal maturity above regional levels.

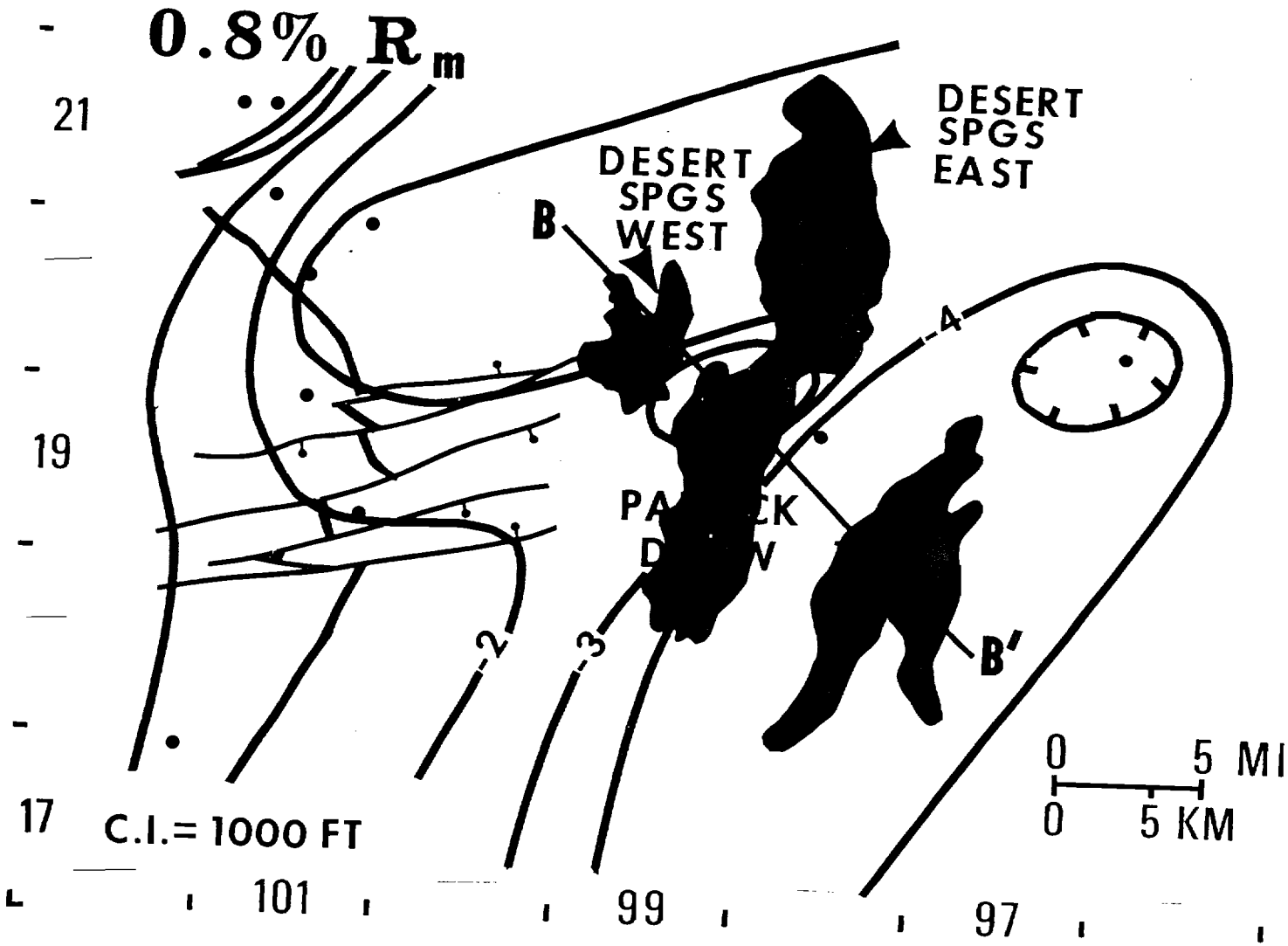

Figure 3.--Enlarged map of Patrick Draw area showing subsurface elevation of 0.8% vitrinite reflectance.

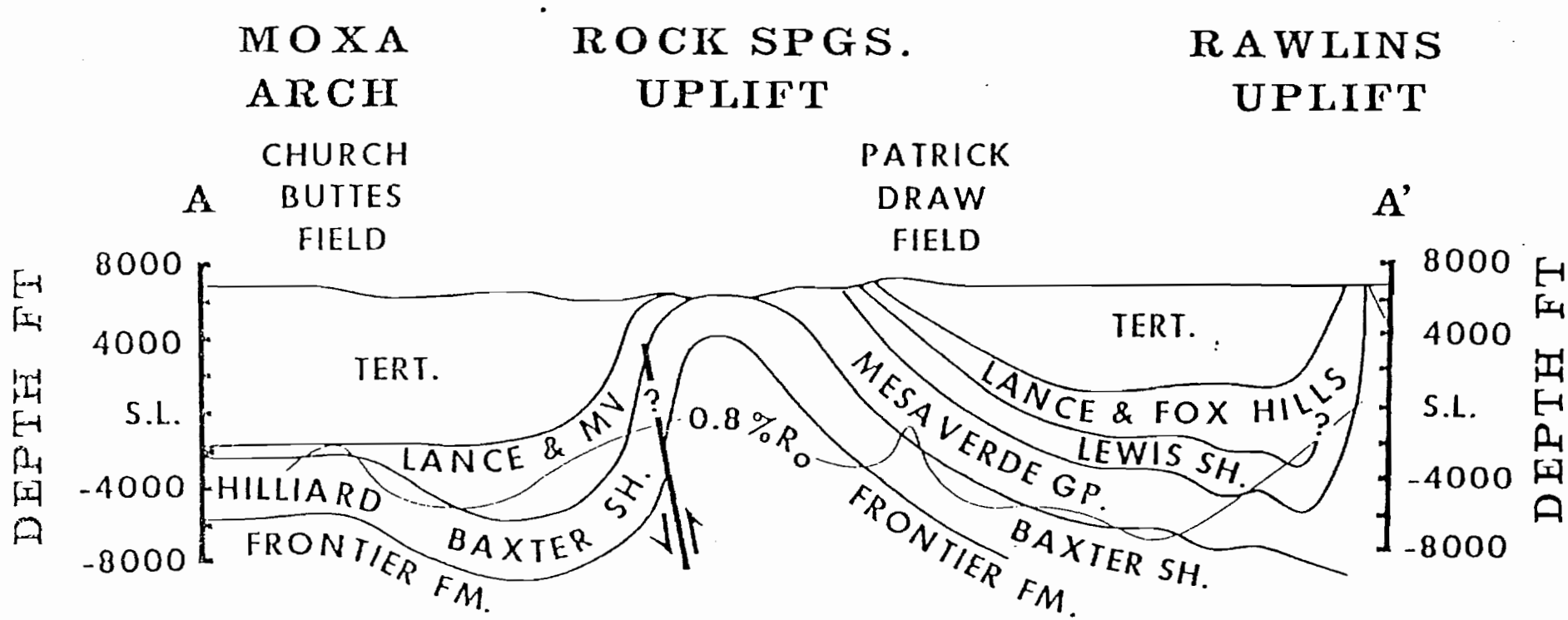

Figure 4.--Structural cross section showing relationship between structure and 0.8% isoreflectance line. Line of section shown on figure 2.

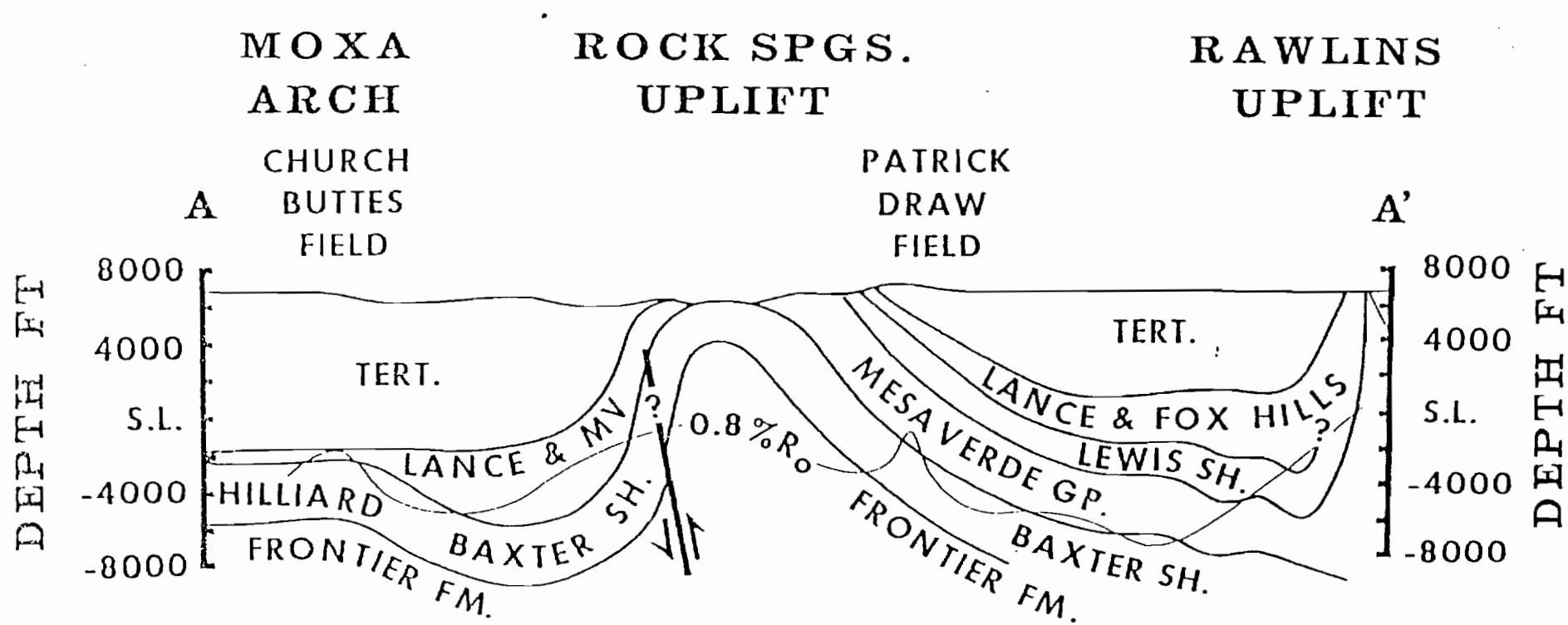

Figure 4.--Structural cross section showing relationship between structure and 0.8% isoreflectance line. Line of section shown on figure 2.

It is probable that one or more of the faults and (or) associated fractures have served as migration pathways for ascending hot fluids. In the specific example of Patrick Draw, they have suggested that the hot fluids were hydrocarbon-bearing, having originated from pre-Almond source rocks located in a more basin-centered position. In response to hydrocarbon generation and expulsion, hot, hydrocarbon-bearing fluids migrated to structurally higher positions along the Wamsutter arch, where faults and fractures provided vertical pathways. Reservoirs with good permeability and porosity, such as those in the Almond Formation, were filled as hydrocarbons flowed upward along fault and fracture surfaces, thereby accounting for the presence of oil in an otherwise gas-producing province.

The study illustrates the applicability of thermal maturity investigations to problems concerning the fluid migration history of a basin, the importance of faults and fractures to fluid migration, and specific information on the origin of the oil accumulation in the Patrick Draw field.

Thermal maturity mapping has also revealed evidence of descending cold meteoric water from outcrops. Unusually low levels of thermal maturity have been identified in a narrow zone parallel to the north flank of the Uinta Mountains in Utah and Wyoming (fig. 2). In this area, Law and Smith (1983) recognized low thermal gradients ($<1.0^{\circ}F/100$ ft). Figure 5 shows the subsurface temperature map of the Greater Green River Basin.

Upper and Lower Cretaceous rocks in this area occur at depths of 13,000 to 16,000 ft. At similar depths elsewhere in the basin, the reservoirs are tight, overpressured, and thermally overmature with respect to hydrocarbon generation and preservation. However, in this area, porosities and permeabilities are high (15% and 100 md), the reservoirs are normally

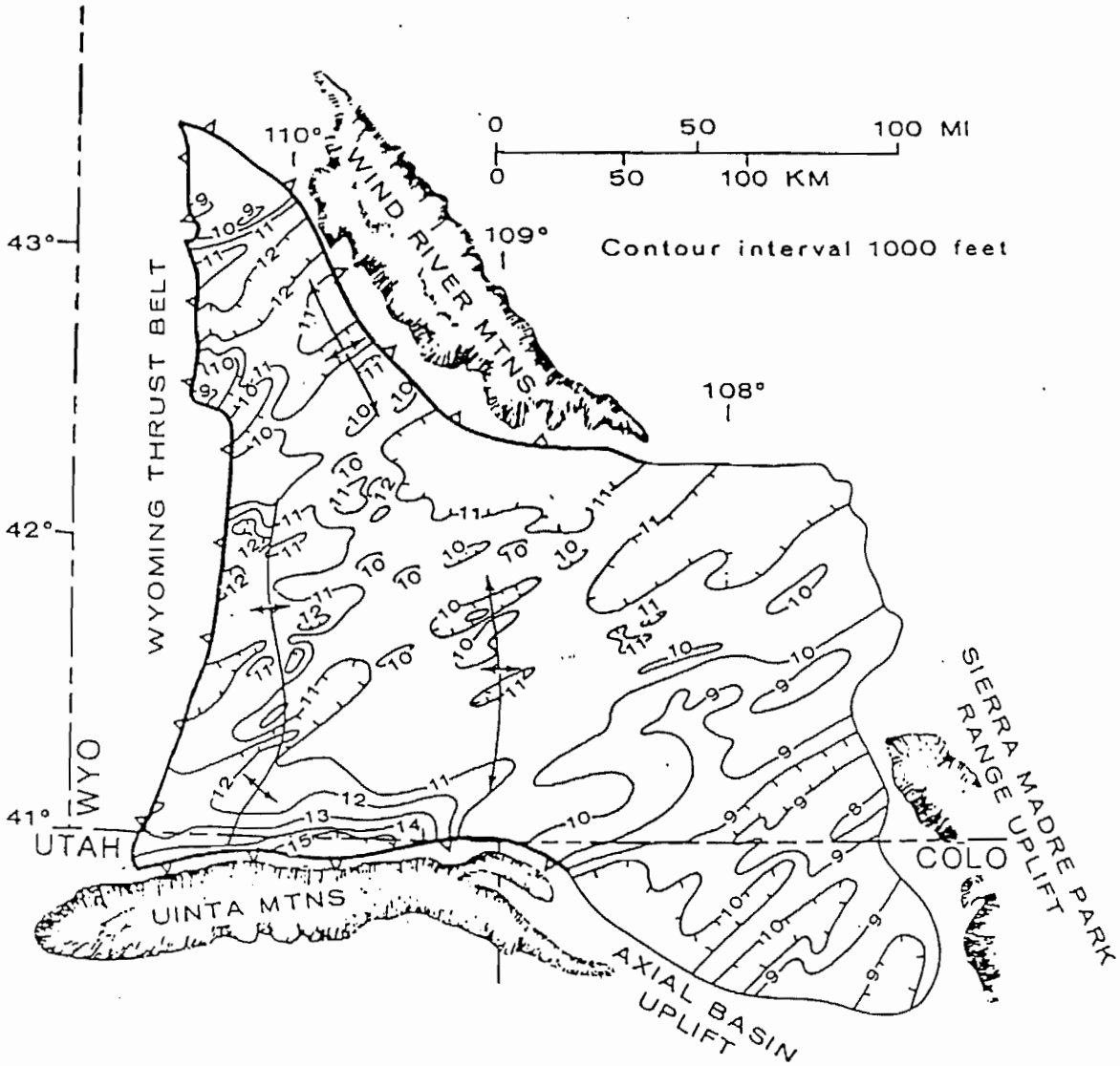

Figure 5.--Depth to uncorrected temperature of 180°F (82°C), Greater Green River Basin (Law and Smith, 1983). Hachures indicate depression contours.

pressured, and the levels of thermal maturity are well within the oil window (vitrinite reflectance values range from 0.5 to 0.8%). Figure 6 shows the vitrinite reflectance profile of one of the wells drilled a few miles north of the Uinta Mountains. The nearly vertical profile down to the Dakota is interpreted to be due to the suppression of thermal maturity by descending cold meteoric water. This is supported by the observations of a low thermal gradient.

Circulation of this water is facilitated by faults and fractures produced by the structural deformation accompanying uplift of the Uinta Mountains during the Laramide Orogeny. Thus, the levels of thermal maturity are low because of the suppression of the thermal gradient by deeply circulating cold meteoric water. Partially as a result of the flux of water through Cretaceous rocks, the reservoir characteristics (porosity and permeability) have been enhanced, and reservoirs, which at similar depths are tight, are conventional high-porosity and high-permeability sandstones.

This is an example of an area where some of our criteria for identifying tight gas-bearing reservoirs do not completely apply, illustrating the need to conduct comprehensive geologic research.

In an effort to gain a better understanding of this area, water samples from the surface and subsurface have been collected and will be analyzed for their chemical and isotopic composition. In addition, samples of gas, oil, and suspected source rocks were collected for analyses.
The interpretation of the analyses in conjunction with structural, thermal, and stratigraphic data will hopefully resolve some of the problems in this area.

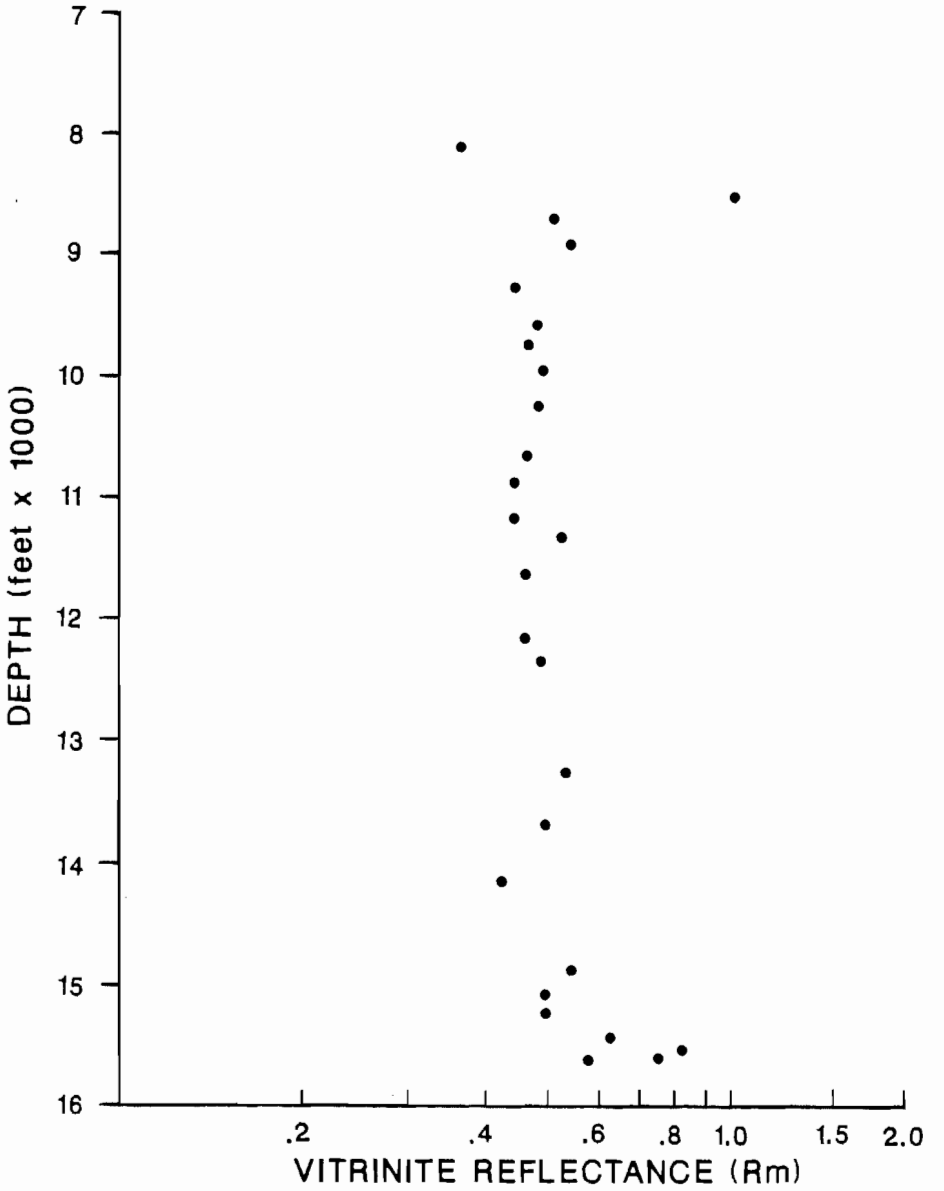

Figure 6.--Vitrinite reflectance profile of Phillips Fork "A" no. 10 well located on south end of Moxa arch immediately north of Uinta Mountains.

Segmented Vitrinite Reflectance Profiles

Several years ago, our attempts to construct vitrinite reflectance profiles for several wells in the Greater Green River basin were frustrated because we commonly observed bends or kinks that were unexplainable. However, in the context of the model proposed by Law and Dickinson (1985) on the origin of abnormal pressures, these segmented profiles provide indirect evidence of paleopore pressure.

Figure 7 is a profile of an abnormally high-pressure well in the northern part of the Green River basin, which is kinked or bends at a depth of about 7,700 ft and 10,750 ft. The intersection of the intermediate steep sloping segment with the lower less steep segment occurs at a vitrinite reflectance of about 0.75%. By analogy with the model of the origin of abnormal pressure proposed by Law and Dickinson (1985), the bend in the profile evolved during the overpressured phase (stage III of Law and Dickinson, fig. 8). The expulsion of relatively hot gas-saturated pore fluids from the top of abnormally high-pressured rocks into the overlying normal-pressured rocks raised the levels of organic maturation and steepened the vitrinite reflectance profile in the normal-pressured rocks. The bend in the profile at about 0.75% R_o represents the top of the overpressured rocks.

The kink at about 7,700 ft is interpreted to be the top of the more intensely altered zone, and the upper linear segment reflects the least altered zone. These three zones are analogous to the description by Masters (1979) of a shallow, water-bearing zone, an intermediate or transition zone that is commonly water and gas-bearing, and a deep gas-bearing zone free of water. Figure 9 shows another example of a segmented vitrinite profile from the Piceance basin. We have also noted similar relationships in

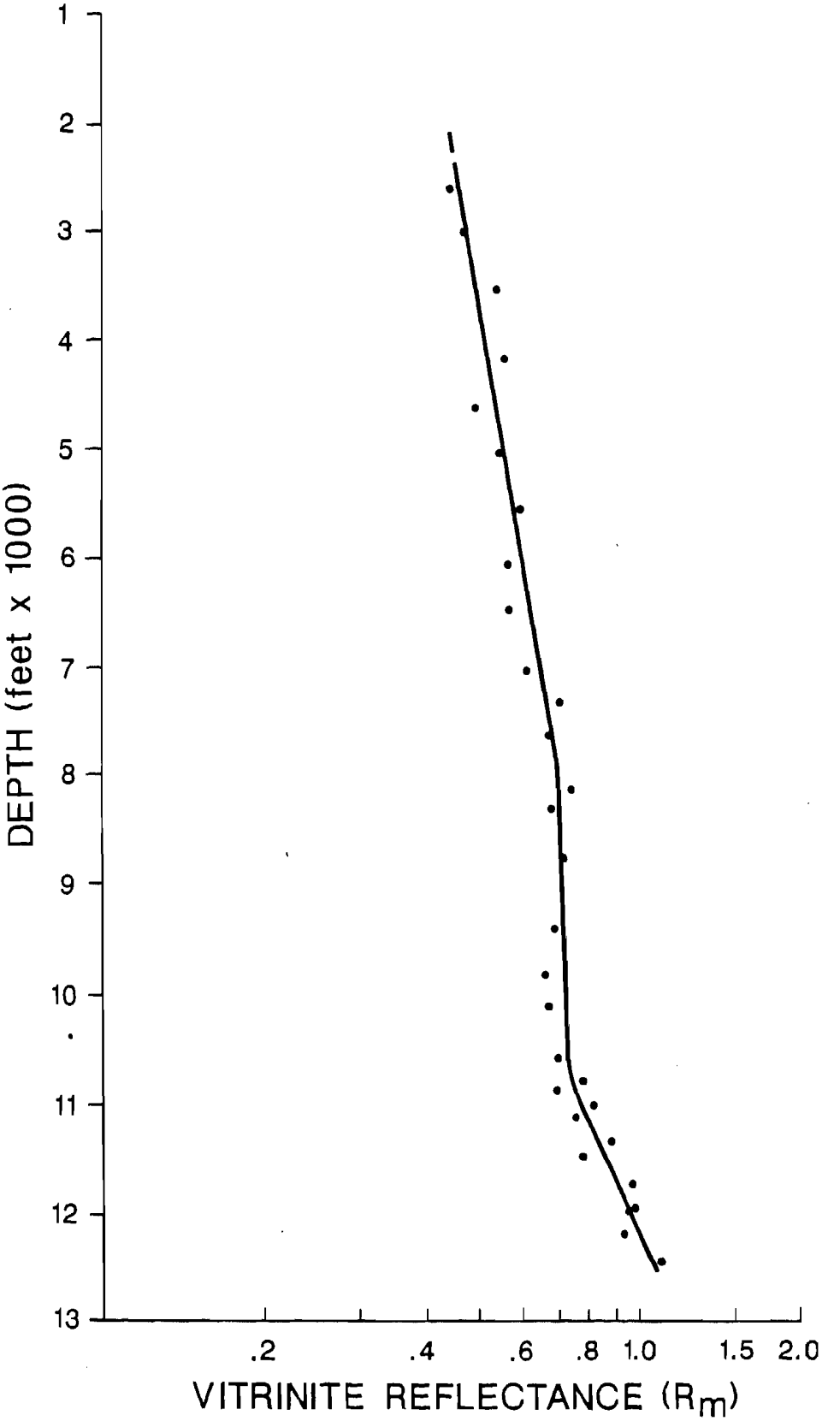

Figure 7.--Vitrinite reflectance profile of Home Petroleum no. 1 Jonah well located in the north-central Green River basin showing 3 segments.

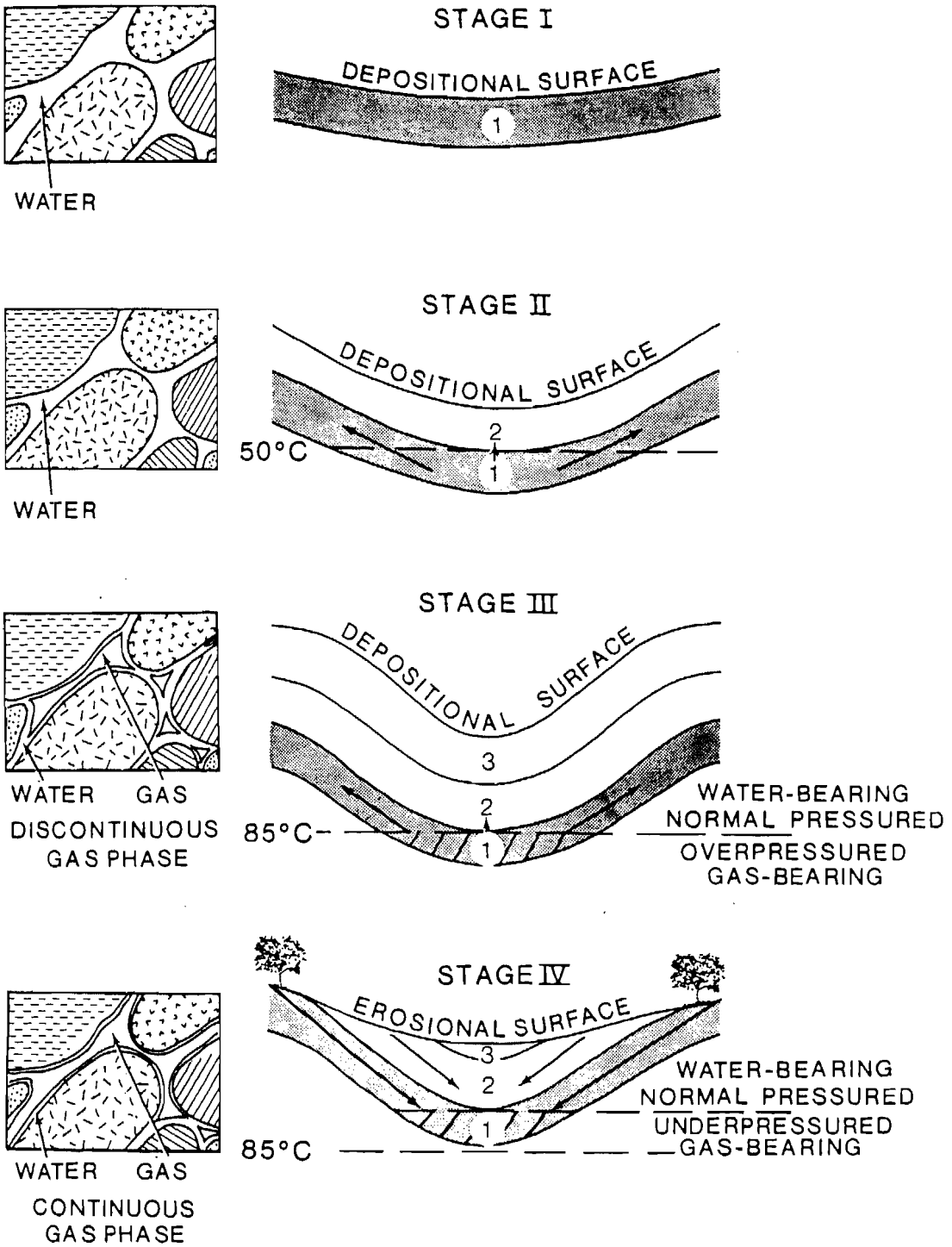

Figure 8.--Gas accumulation model of Law and Dickinson (1985) showing development of abnormal pressure.

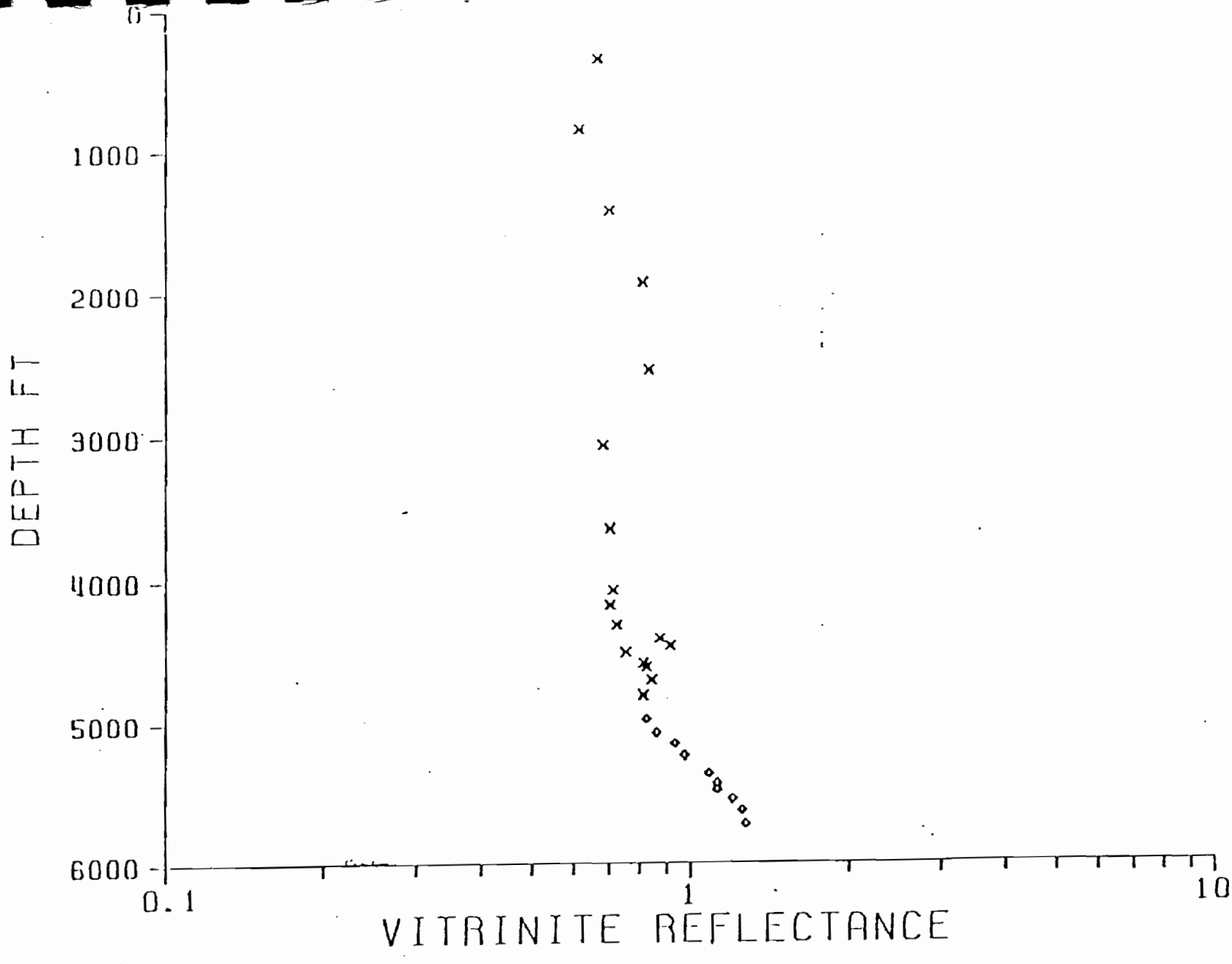

Figure 9.--Segmented vitrinite reflectance profile from well in Piceance basin, Colorado.

low-permeability reservoirs of the Alberta Basin, Canada. This relationship permits the identification of the top of gas-bearing reservoirs in wells where there is no direct indication of gas and in wells which were originally overpressured but are now abnormally underpressured. A paper by Law and Nuccio describing this phenomena was presented in September at the AAPG Annual Rocky Mountain Section Meeting in Casper, Wyoming.

Structure Map

During FY-86, work has proceeded on the structure contour map of the Greater Green River basin. Contour maps of the Washakie and Green River basins have been completed and are shown in figures 10 and 12. The remaining portions of the region will be completed in FY-87.

Existing maps of the region are old and generalized. Published structure maps commonly utilize the top of the Lower Cretaceous Dakota Sandstone as a datum. However, because very few wells penetrate the Dakota, it has been necessary to project downward to the top of the Dakota, thereby introducing errors into the final map.

The approach taken in this effort is to utilize, as much as possible, all the wells in the basin. Since a large number of the wells drilled have penetrated the Mesaverde Group, we decided to choose structural datums that were actually penetrated. However, this requires a frequent change of structural datums. For instance, the structural datum used in the Washakie basin (fig. 10) is a bentonite bed in the Upper Cretaceous Lewis Shale (fig. 11). However, the Lewis Shale is not present throughout the region. It only extends as far west as the west flank of the Rock Springs uplift, where it then undergoes a facies change into sandstone and siltstone that is indistinguishable from rocks above and below (fig. 11). Consequently, at

ASHAKIE BASIN STRUCTURE, LEWIS "A" MARKER, C.I.=500' 1:50

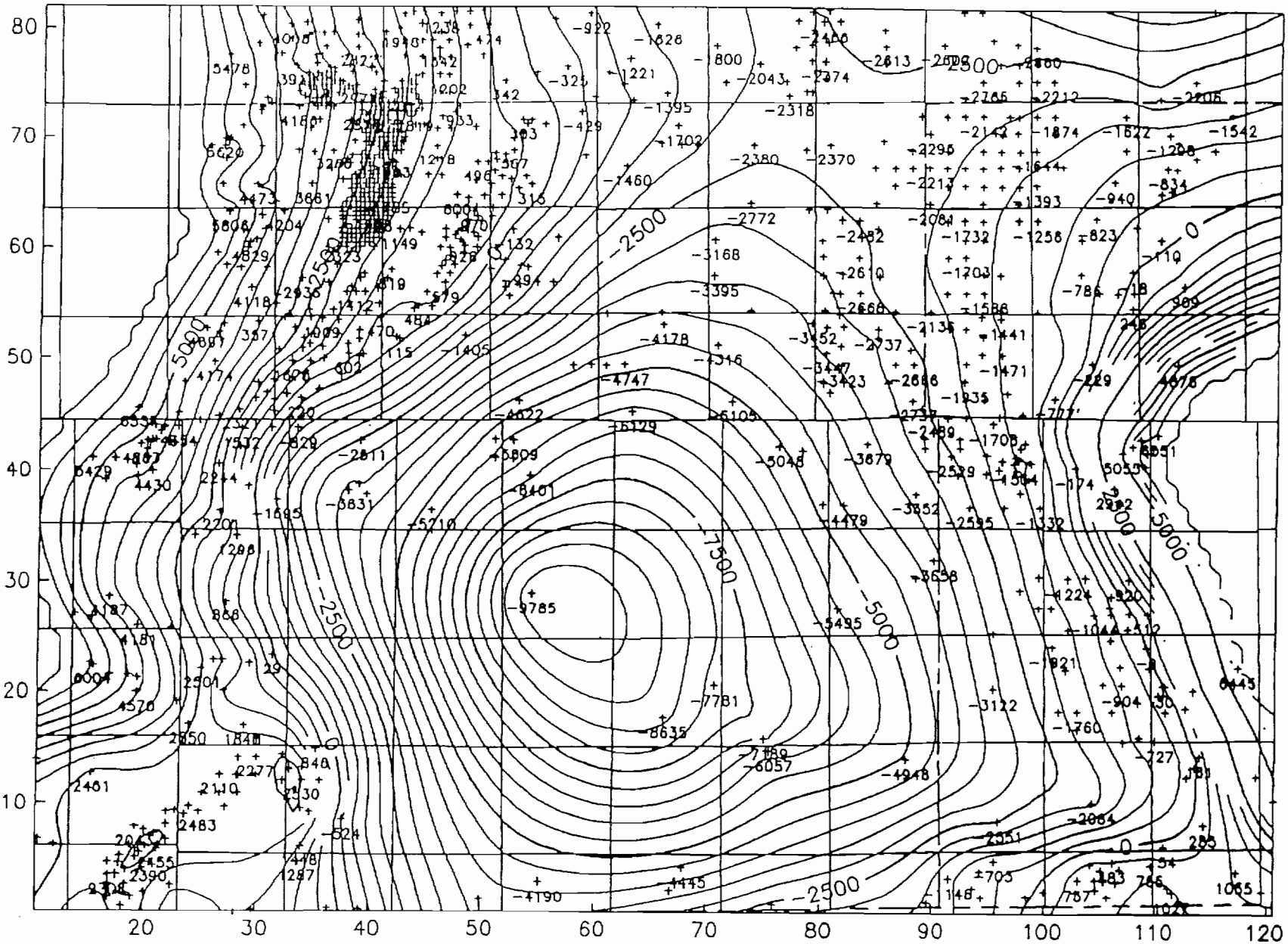

Figure 10.--Structure contour map of Washakie basin. Structure drawn on bentonite marker in Upper Cretaceous Lewis Shale.

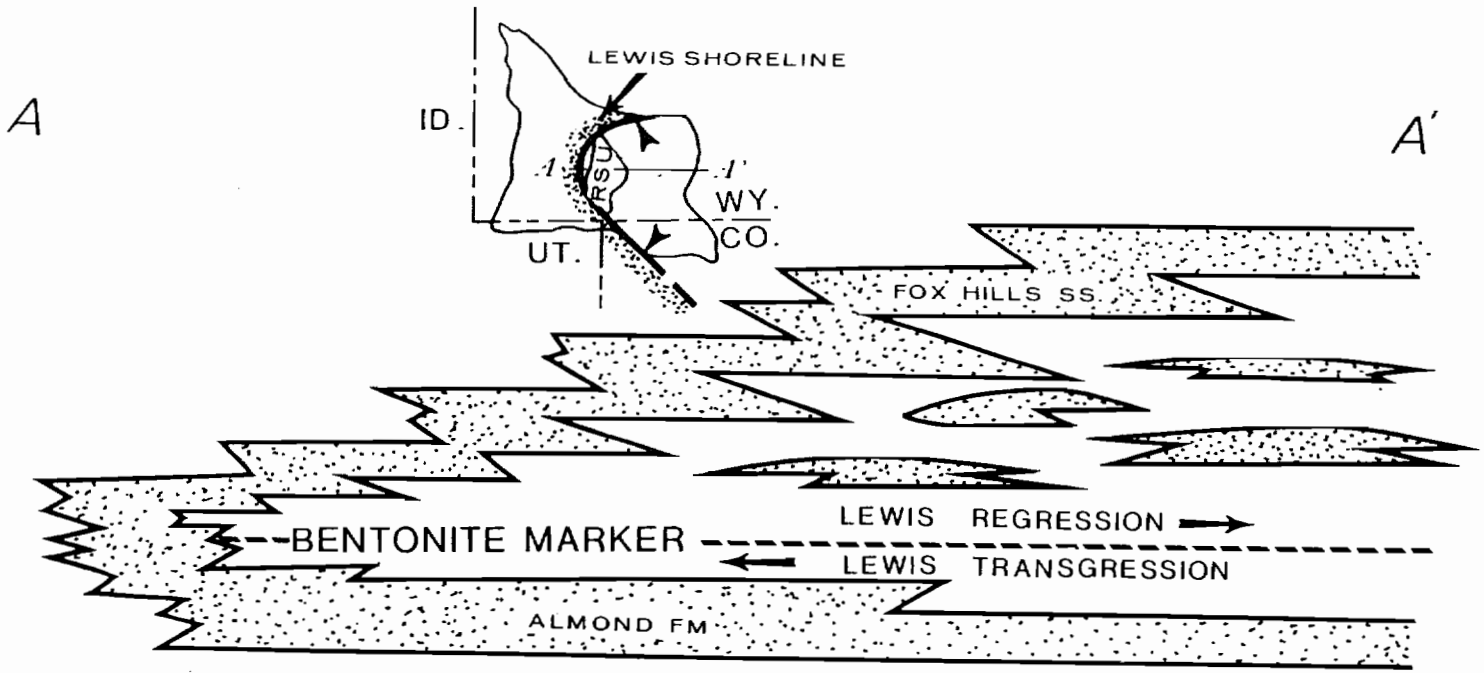

Figure 11.--Diagrammatic illustration showing the depositional limit of the Upper Cretaceous Lewis Shale. The transgressive and regressive depositional phases are shown with respect to the bentonite marker structural datum.

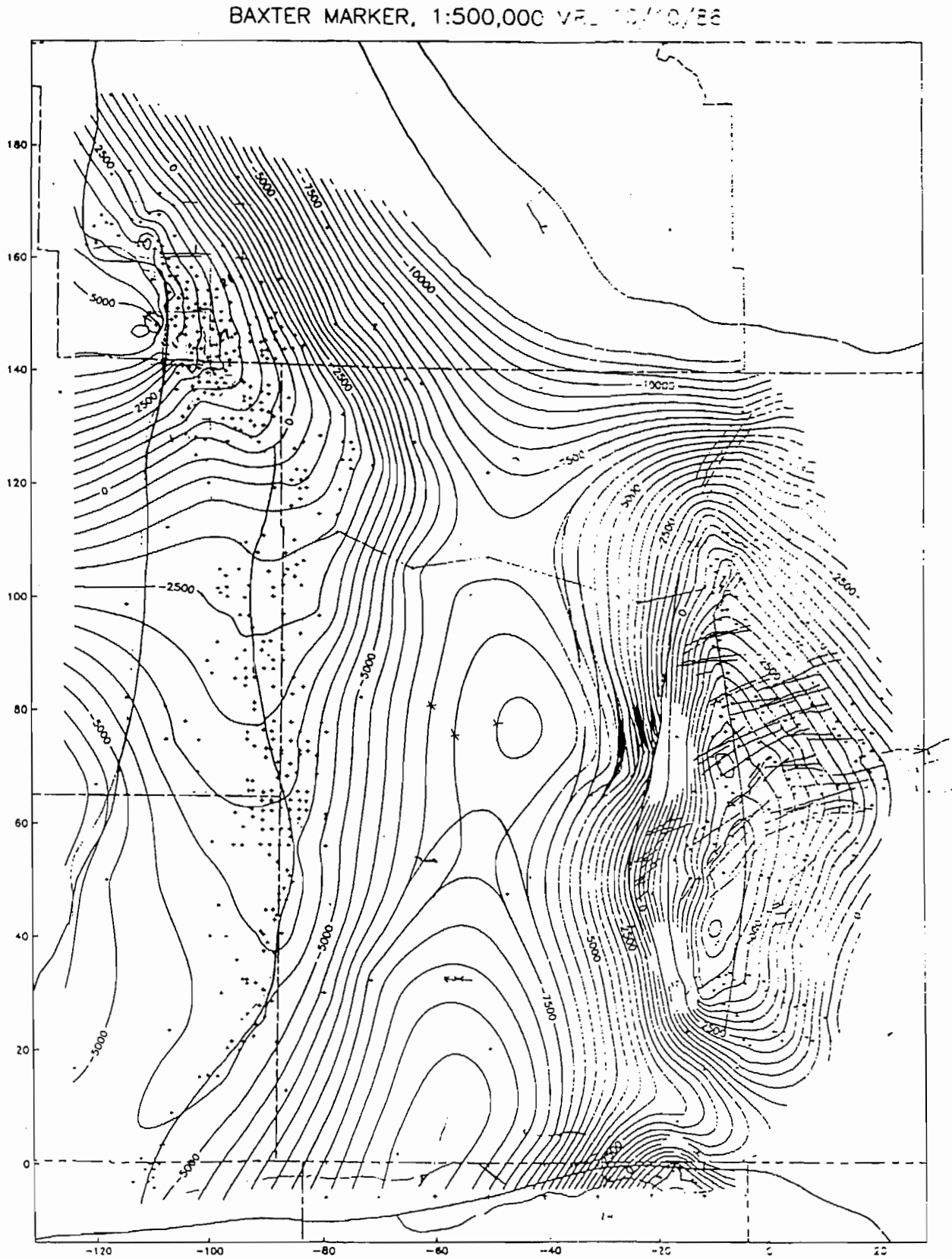

Figure 12.--Structure contour map of Green River basin. Structural datum is bentonite marker in lower part of the Upper Cretaceous Baxter/Hilliard Shale.

that point, a change of datums is necessary, and the new datum is a bentonite bed in the Upper Cretaceous Baxter/Hilliard Shale. Thus, the Green River basin is contoured on a bentonite marker in the Baxter (fig. 12). The advantage of constructing the map in this manner is that it permits greater accuracy, precluding the necessity of projecting to some deeper stratigraphic marker.

Since the well data for this mapping is computerized, the program is flexible enough to produce selected isopach maps in the same region as the structure maps. Figures 13 and 14 show isopach maps in the Washakie and Green River basins. The ability to generate isopach maps allows an investigator to compare the relationships between present structural configuration and thickness variations of various intervals. For example, in the Green River basin, the thickness variations of the interval between the structural datum and the Upper Cretaceous Frontier Formation provide important information concerning the structural evolution of the basins. The thinning relationship over the Moxa arch and Rock Springs uplift indicate that these structural features were present during deposition of the isopach interval. The presence of these major structures implies that they could have provided early-formed structural traps for more conventional oil and gas accumulations, and that sandstone reservoirs deposited on or in close proximity may have good reservoir characteristics because of higher energy depositional processes. Tight-gas reservoirs are more commonly associated with areas of thickening. In these areas, depositional processes were lower energy systems, and the reservoirs are mineralogically heterogeneous. Physical compaction coupled with the heterogeneity in these areas has served to reduce reservoir quality.

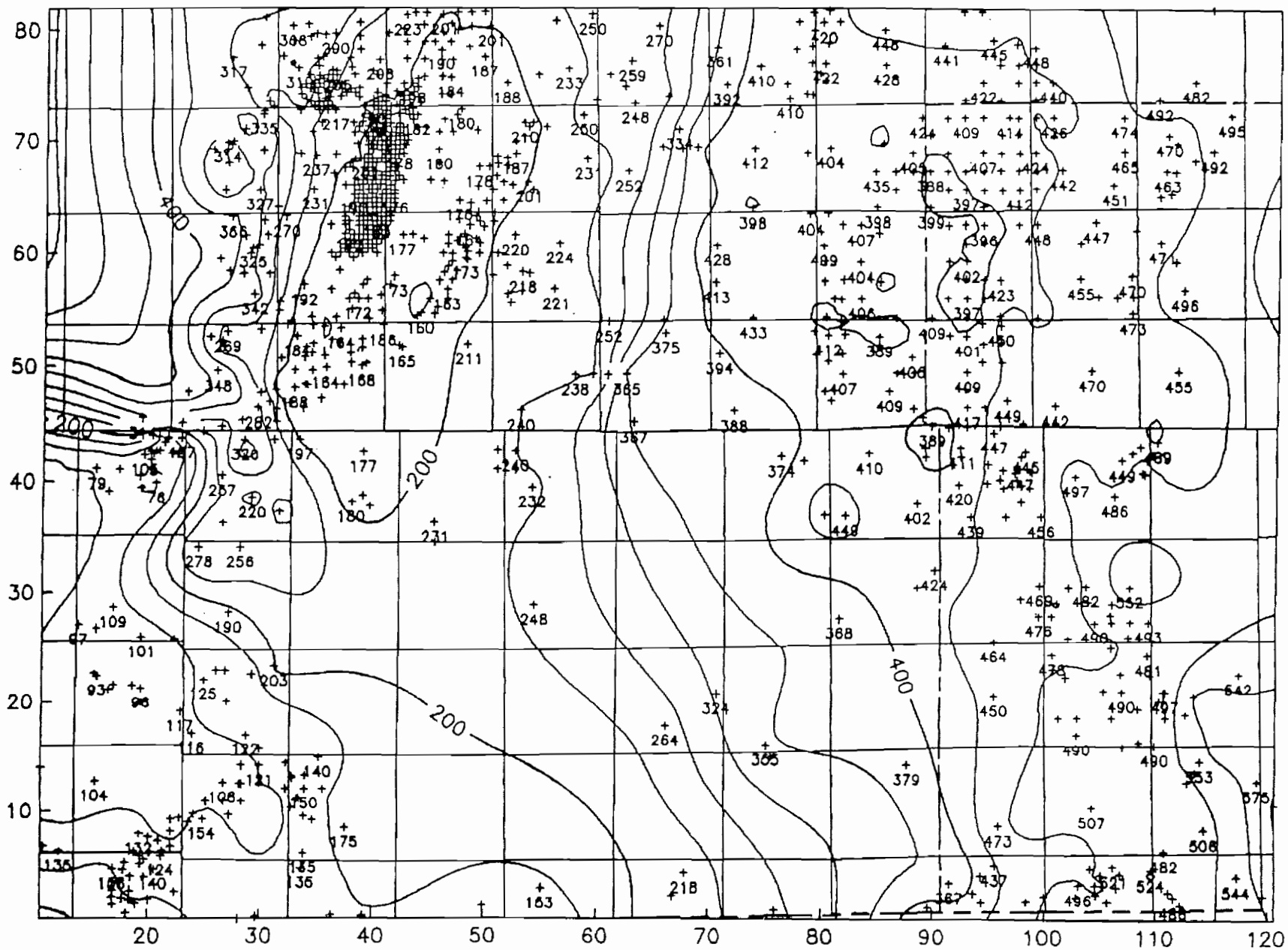

Figure 13.--Isopach map of the interval between bentonite marker in Lewis Shale and top of Almond Formation, Washakie basin.

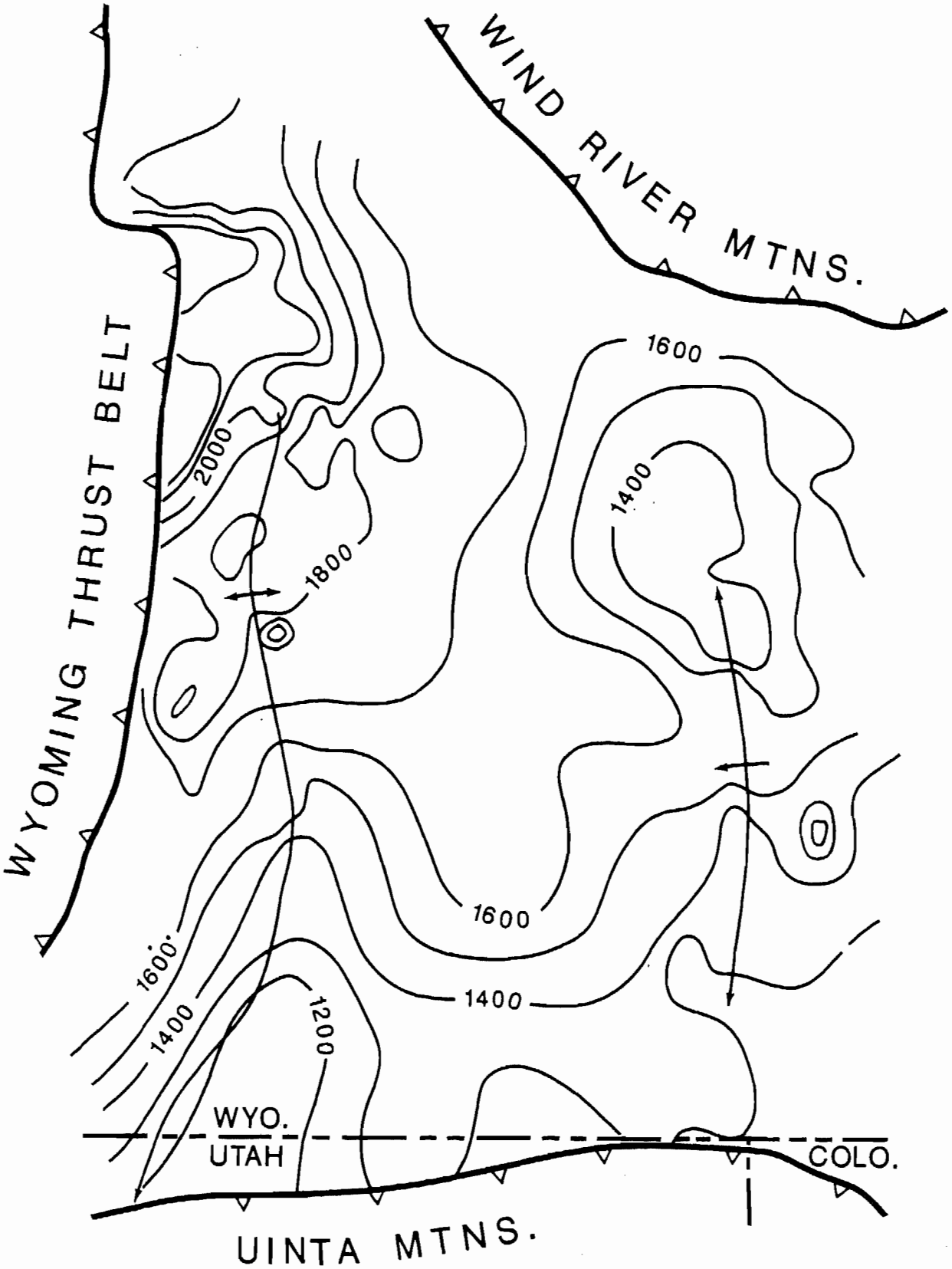

Figure 14.--Isopach map of the interval between bentonite marker in Baxter/Hilliard Shale and top of Frontier Formation, Green River basin.

Pinedale Anticline Gas Resources

The Pinedale anticline, located southwest of the Wind River Mountains in the northern Green River basin, Wyoming (fig. 15), is a large thrust-rooted structure with a thick sequence of Upper Cretaceous overpressured, low-permeability gas reservoirs. A quantitative three-dimensional model of the anticline and its gas reservoirs was constructed in order to better define the occurrence and amount of this large, unconventional resource and to identify a geological rationale applicable to similar accumulations.

The geologic model consists of multiple cells, generally 1 sq mi by 500 ft in thickness. For each cell, geologic parameters such as lithology, porosity, temperature, and pressure are calculated. Lithology and porosity trends with depth are shown in figures 16 and 17. Geologic relationships, most determined by previous studies, are also incorporated in the model. These include: (1) the relationship between structure and the top of overpressuring, (2) the coincidence of gas occurrence and overpressuring, (3) the relationships among overpressuring, temperature, and organic richness, (4) porosity-depth relationships, and (5) the coincidence of irreducible water saturation and overpressuring. The incorporation of these geological relationships to the evaluation of this type of unconventional gas accumulation results in a more accurate and geologically acceptable model.

Most of the data for the model are from the 19,000-ft deep El Paso #1 Wagon Wheel well. Although twenty wells have been drilled on the anticline, the Wagon Wheel well is the only one that has penetrated the entire geologic section of interest (fig. 18). Additional stratigraphic, pressure, and temperature data from the other wells are used in the model. Structural information from a seismic line was also incorporated.

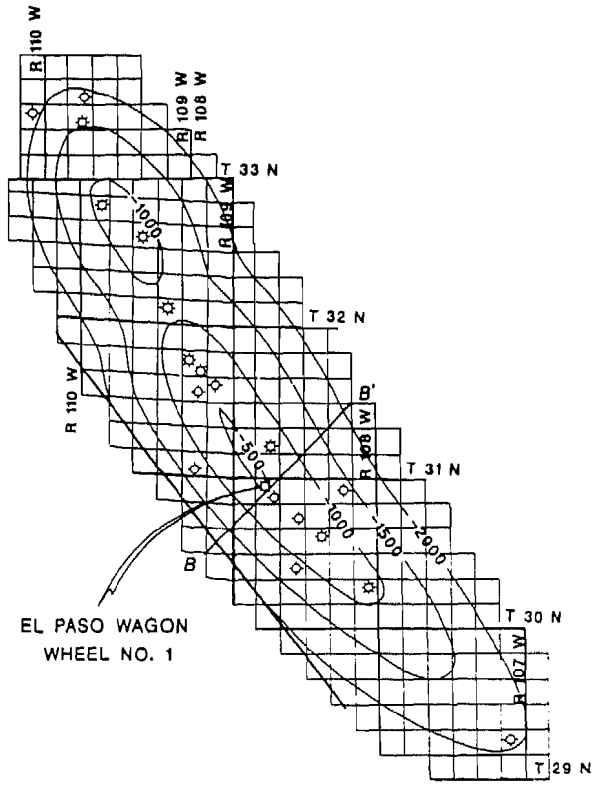

Figure 15.--Computer-generated structure contour map at Pinedale anticline showing approximate area included in resource assessment.

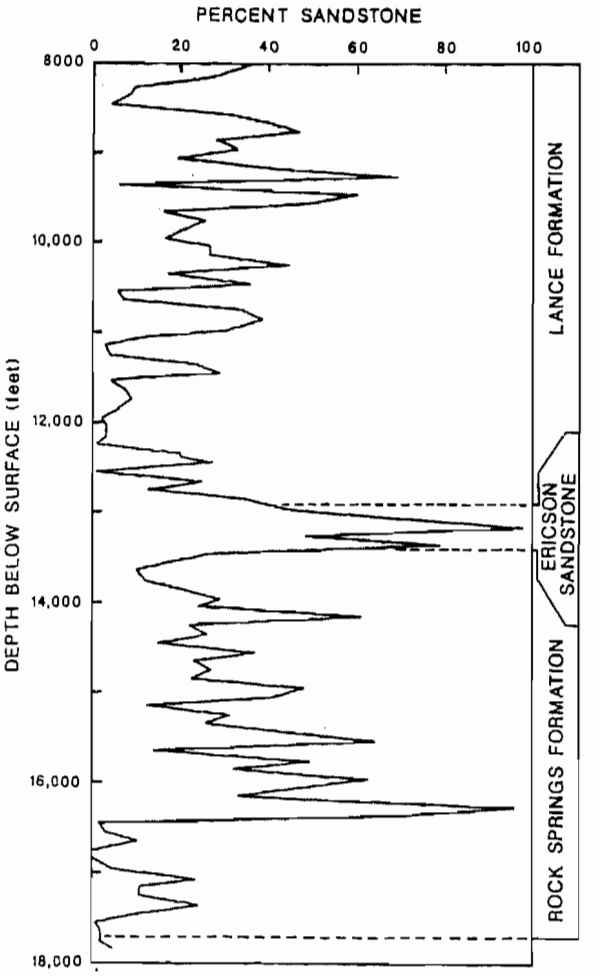

Figure 16.--Proportion of sandstone occurring in gas-saturated interval in the Wagon Wheel no. 1 well.

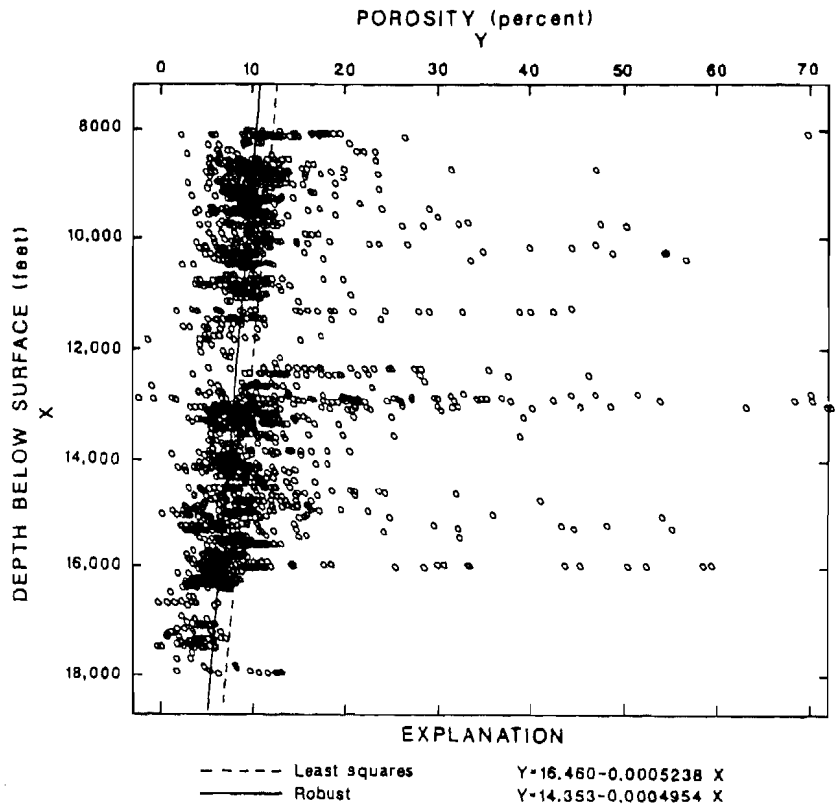

Figure 17.--Porosity versus depth plot in Wagon Wheel no. 1 well showing least squares and robust best-fit line of data.

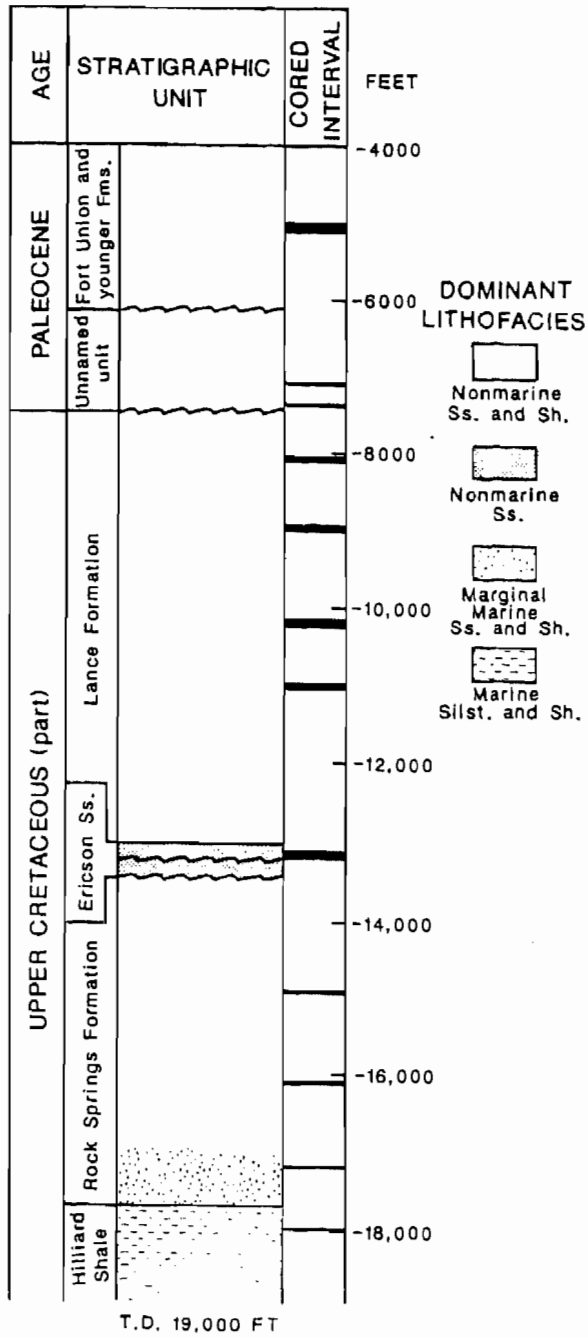

Figure 18.--Stratigraphic sequence penetrated in Wagon Wheel no. 1 well.

The advantages of this approach are that it allows both a more precise estimation of gas resources and an understanding of the spatial distribution of resources within the anticline.

Regional Porosity and Permeability Variations

The objective of this study is to evaluate the effects of temperature, pressure, thermal maturity, depth, and facies on reservoir quality. Our approach has been to collect samples from the same stratigraphic interval (Upper Cretaceous Almond Formation) in the eastern part of the Greater Green River basin. The sampling program has been completed and the samples have been prepared for XRD and petrographic examination. In addition to these studies, we are conducting vitrinite reflectance and fission-track analyses of the same samples. The samples, listed below, are from Almond reservoirs that range from conventional high porosity and permeabiity (20% - 100 md) to tight reservoirs (5% - <0.1 md) and depths from 4,500 to 13,675 ft.

Well	Location	Depth (ft)
Amoco 535 Champlin	sec. 17, T. 16 N., R. 97 W.	13,645-13,674
Forest 1-22-1 Mustang	sec. 22, T. 20 N., R. 97 W.	7,453- 7,503
Forest 63-2-2 Arch	sec. 2, T. 19 N., R. 99 W.	4,475- 4,528
Forest 1-9-6 UPRR	sec. 9, T. 19 N., R. 98 W.	5,744- 5,779
Energy Reserves 2-24 Nickey	sec. 24, T. 24 N., R. 96 W.	11,844-12,037
Amoco Champlin 336A	sec. 21, T. 22 N., R. 94 W.	10,611-10,964
Amoco Champlin 438	sec. 5, T. 22 N., R. 96 W.	9,510- 9,930

Nearly all of the samples have been analyzed by XRD. Thermal maturity of these samples, as measured by vitrinite reflectance, varies from 0.45% (immature with respect to oil generation) for the shallow samples to 2.0% (overmature with respect to oil generation) for the deepest sample.

Preliminary XRD analyses and petrographic studies of some of the samples show that the amount and distribution of porosity and permeability are related to original sediment composition which influences post-depositional alteration. Post-depositional alteration is responsible for both reduction and enhancement of porosity by the precipitation of cements and the dissolution of authigenic minerals and framework grains, respectively.

Quartzose sandstones are cemented by overgrowths of quartz, illite, and minor kaolinite, with lesser amounts of dolomite cement. In general, the porosity of quartzose sandstones decreases with increasing depth. In contrast, feldspathic sandstones contain a smaller volume of quartz cement and show evidence of extensive cementation by calcite or dolomite, precipitation of large amounts of kaolinite, minor amounts of illite, and dissolution of carbonate cement and silicate framework grains.

PICEANCE BASIN RESOURCE ASSESSMENT

The evaluation of gas contained in low-permeability reservoirs in the Piceance basin was initiated during FY-86. A preliminary figure of approximately 500 tcf of gas in-place has been calculated. This figure should be used with caution, however, as the assessment will be re-examined, and each geologic parameter utilized will undergo a careful examination as to degree of certainty.

Based on hydrocarbon-generation thresholds determined in the Piceance and other similar basins, the top of gas-bearing reservoirs is defined on the basis of thermal maturity: a value of 0.73% vitrinite reflectance is the value utilized for the top, and the bottom of the gas-bearing interval is the base of the Upper Cretaceous Mesaverde Group. Within this thick

interval, there is a further breakdown into an interval defined by the 0.73 to 1.1% vitrinite reflectance, referred to as the transition zone, and a deeper >1.1% vitrinite reflectance zone. Each of these two thermal maturity zones have been subdivided into stratigraphic slices and each slice is then evaluated in terms of gas saturation/water saturation, porosity, percentage of sandstone, pressure, temperature, and gas compressibility. Each of these parameters are then evaluated as to their degree of uncertainty. Finally, all of these variables are subjected to a probability program, and a value is determined with upper and lower limits of confidence.

These later steps have yet to be completed; therefore, the preliminary resource figure will most likely change.

OTHER ACTIVITIES

- During the year, field work was conducted in the Greater Green River basin. Most of the field investigations were concerned with the Upper Cretaceous Ericson Sandstone and its relationship to underlying rocks. Despite a considerable amount of work that has been devoted to the Ericson, there still remain significant uncertainties. The main problem concerns the nature of the basal contact of the Ericson and whether it is conformable or unconformable.

  Based on this past season's work and previous investigations, it appears that there are two unconformities associated with the Ericson: one within the unit and one at the base. In the Green River basin proper, both unconformities are probably present. In the vicinity of the Rock Springs uplift, both unconformities appear to be in an area of transition where there is evidence of both erosion and interfingering. Further east and southeast, the contacts change into conformable relationships with underlying rocks.

- A short time was spent in the vicinity of the flank of the Uinta Mountains and northward alaong the Moxa arch. In an effort to gain a better understanding of the thermally cool area along the north flank of the Uinta Mountains, surface and subsurface samples of water were collected in order to attempt a geochemical and isotopic correlation of surface and subsurface waters. In addition, samples of gas, oil, and suspected hydrocarbon source rocks were collected for analyses.
- During February, C.W. Spencer attended an MWX meeting in Albuquerque, New Mexico. Since testing at the MWX site has clearly shown the importance of natural fractures to production, the focus of this meeting was natural fractures.

  Fracture studies by Verbeek and Grout have shown the complexity of fracture systems in the Piceance basin. They have identified two major fracture systems: an older "Hogback System" and a younger "Piceance System." Within each system, there are four or five sets that have distinctive orientation, and some of the fracture sets are more dominant than others.
- Steve Prensky and Warren W. Dickinson published a report during March entitled, "Computer-generated well-log data plots assist in regional subsurface evaluation." They point out that "the use of computers for manipulating well-log data can provide the subsurface geologist with flexibiity for viewing and displaying these data. The use of a greatly compressed depth scale in X-Y trace plots and scatter plots facilitates identification of subtle long-term stratigraphic trends and patterns and can be used in regional stratigraphic correlation. Computer-generated plots have revealed a regional gamma-ray log anomaly in the northern Green River Basin, Wyoming, and have assisted in the evaluation of subsurface porosity and pressure trends in this area."

- A bibliography of the geological applications of well logs by Steve Prensky was published as U.S. Geological Survey Open-File Report 86-170. This report provides a reference on well logging and the geologic applications of well logging.
- Ron Johnson and Tom Finn have completed a report on the Douglas Creek arch which separates the Piceance Creek basin to the east from the Uinta Basin to the west. Although this is not a FY-86 task, it was identified as a FY-85 task and is, therefore, a carry-over. Because the arch separates the two basins, the history of the arch is an important component of the adjacent basins.

  A complex history of uplift, subsidence, and base-level changes is recorded in the sediments and unconformities found on the Douglas Creek arch, a broad, north-south trending structure in western Colorado and eastern Utah that forms a hingeline between two Laramide (Late Cretaceous through Eocene) structural and sedimentary basins, the Uinta Basin to the west and the Piceance Creek basin to the east. The Cretaceous through recent history of the arch was investigated using isopachs, structure contours, and stratigraphic relationships. The arch was previously thought to be one of the first structures to form during the Laramide orogeny or that initial movement on the arch occurred prior to the onset of the orogeny, during Cretaceous Rocky Mountain foreland basin deposition. Isopachs indicate, however, that the arch was not active prior to the onset of the Laramide orogeny. Furthermore, during the early part of the orogeny, the arch did not have its present form. During this period, the arch was part of a much broader area of uplift and beveling. This uplift began sometime between 74 m.y. ago and the end of the Cretaceous. The east flank of this domed area roughly

corresponded to the present-day east flank of the arch, but the west flank was apparently in the western part of the Uinta basin. The unconformity produced during this period of beveling was gradually buried by sediments during the Paleocene as the two adjacent basins began to subside, and by late Paleocene or early Eocene time, the crest of the arch was buried by sediments.

Both beveling trends beneath the Cretaceous-Tertiary unconformity and subsidence trends during deposition of the overlying Paleocene and Eocene section indicate that the two flanks of the arch developed independently of each other. This indicates that the subsidence histories of the adjacent Uinta and Piceance Creek basins differed significantly. An early development of the east flank is indicated. On this flank, the amount of Cretaceous section beveled decreases toward the trough of the Piceance Creek basin. Similarily, the overlying Paleocene section thickens toward the trough of the Piceance Creek basin. Thus, the east flank of the arch is defined by both beveling trends beneath the Cretaceous-Tertiary unconformity and subsidence trends indicated by the overlying Paleocene section. The west flank of the arch was not defined by early Cenozoic subsidence trends until sometime during the Paleocene. This asymmetry in the timing of development of the two flanks of the Douglas Creek arch may have important implications for the history of hydrocarbon maturation and migration in the areas.

- C.W. Spencer and B.E. Law attended and presented papers at the DOE's FY-85 contractors meeting. In preparation for this meeting, two summary reports and USGS FY-85 research activity reports were completed. C.W. Spencer prepared and presented a paper entitled, "Geologic characterization of tight gas reservoirs, Piceance basin," and B.E. Law

prepared and presented a paper entitled, "Geologic characterization of tight gas reservoirs, Greater Green River basin."

- B.E. Law, M.R. Lickus, and M.J. Pawlewicz presented a paper at the 2nd Annual USGS McKelvey Forum, Feb. 5, in Denver. The title was "Fluid migration pathways - evidence from thermal maturity mapping in southwestern Wyoming." A copy of the abstract is included in this report.
- B.E. Law sampled core from El Paso Natural Gas sample facility in Farmington, New Mexico. About 15 samples from wells in the Greater Green River basin were collected and will be prepared for vitrinite reflectance analyses.
- A fracture study in the Piceance Creek basin entitled, "Fracture history of the Plateau Creek and adjacent Colorado River valleys, southern Piceance basin: Implications for predicting joint patterns at depth," by Marilyn A. Grout and Earl R. Verbeek was published as U.S. Geological Survey Open-File Report 85-744.

  They concluded that five episodes of jointing are present in Upper Cretaceous and Eocene rocks. The joint sets are referred to as the "Piceance system" of Verbeek and Grout (1984). Prediction of jointing in drilling operations necessitates a knowledge of the depth to the transition zone between the Piceance and older Hogback systems, and a good understanding of the local fracture network.
- J.K. Pitman, C.W. Spencer, and R.M. Pollastro completed a report on the mineralogy and petrology of MWX site sandstones. The report will include color plates of core thin section photomicrographs and will probably be published as a chapter in a USGS bulletin.

- In late April, Jeff Bader presented a paper at the Rocky Mountain Section of the Geological Society of America, in Flagstaff, Arizona, entitled, "Fault geometry along the Cherokee ridge arch, south-central Wyoming." Based on surface and subsurface investigations along the Cherokee ridge, a structural arch separating the Washakie and Sand Wash basin, Jeff has concluded that the arch may have been present as early as Late Cretaceous time, and that some of the faults in the area have served as fluid migration pathways.
- R.C. Johnson presented a paper at the SPE Unconventional Gas Technology Symposium in Louisville, Kentucky, May 18-21. The paper, authored by R.C. Chancellor and R.C. Johnson, is entitled, "Geologic and engineering implications of production history from five Mesaverde wells in central Piceance Creek basin, north-west Colorado."
- S. Prensky presented a paper entitled, "Geologic implications of large-scale trend in well-log response, northern Green River basin, Wyoming." The paper was presented at the 27th SPWLA Annual Logging Symposium in Houston, Texas.
- At the AAPG 1986 Rocky Mountain Section Meeting in Casper, Wyoming, Ben Law and Vito Nuccio presented a paper entitled, "Segmented vitrinite reflectance profile from the Deep Seam Project, Piceance Creek basin, Colorado--evidence of previous high pore pressure." This work, partially funded by the DOE, provides a means of identifying abnormally pressured gas-bearing reservoirs in wells where there is no pressure data. At the same meeting, Ron Charpentier, Ben Law, and Stephen Prensky presented a poster session entitled, "Quantitative model of overpressured gas resources of the Pinedale anticline, Wyoming." The assessment included sandstone reservoirs in a 10,000 ft abnormally pressured sequence, over

an area of about 200 sq. miles. Their preliminary assessment of in-place gas resources is 143 tcf.

- Two papers were published during August: one by Richard Pollastro and Charles Barker entitled, "Application of clay-mineral vitrinite reflectance and fluid inclusion studies to the thermal and burial history of the Pinedale anticline, Green River basin, Wyoming;" and one by Nancy Naeser entitled, "Neogene thermal history of the northern Green River basin, Wyoming---evidence from fission-track dating."
- A thermal maturity map of the lower part of the Upper Cretaceous Mesaverde Group in the Uinta basin by V.F. Nuccio and R.C. Johnson was published. Although the DOE is no longer funding geological research in the Uinta basin, nearly all of the data analysis was concluded during FY-84 and 85.

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