GEOLOGIC ANALYSIS OF PRIMARY AND SECONDARY TIGHT GAS SAND OBJECTIVES, PHASE C

QUARTERLY REPORT
(May 1, 1984 - July 31, 1984)

prepared by

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DISCLAIMER

RESEARCH SUMMARY

Title	Geologic Analysis of Primary and Secondary Tight Gas Sand Objectives, Phase C
Contractor	Bureau of Economic Geology, The University of Texas at Austin, GRI Contract No. 5082-211-0708
Principal Investigator	R. J. Finley
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Objective	To conduct depositional systems and basin analysis of the Travis Peak Formation and the Corcoran and Cozzette Sandstones as representative blanket-geometry, low-permeability gas sandstones. To integrate studies of sandstone distribution and reservoir geometry with responses to reservoir stimulation and to determine correlation with resource distribution.
Technical Perspective	Previous evaluations of blanket-geometry tight gas sandstones led to the selection of the Travis Peak Formation of the East Texas and North Louisiana Basins and the Corcoran and Cozzette Sandstones of the Piceance Creek Basin as major research objectives. The increased availability of tight gas resources and the development of technology with a high degree of transferability are expected results from the study of these stratigraphic units. Work reported here involves all aspects of the depositional systems and reservoir geology of these units as a basic element of resource characterization. Controls on the distribution of reservoir facies and an interface with engineering aspects of low-permeability reservoir development are emphasized.
Results	Six lithofacies of the Travis Peak (Hosston) Formation in East Texas and North Louisiana have been recognized on electric logs. These facies are: sand-rich fluvial-deltaic facies, silt-rich delta-front facies, clay- and carbonate-rich shelf facies, carbonate reef facies, and clay-rich open marine facies. The best-developed facies in the East Texas area are the fluvial-deltaic and delta-front facies. Travis Peak rocks from the Clayton Williams #1 Sam Hughes well, Panola County, Texas, were deposited mainly in a fluvial environment in a coastal plain setting. The major control of porosity and permeability in the clean sandstones appears to be the volume of quartz overgrowths, chlorite cement, and solid organic matter. The remaining porosity is approximately half secondary, formed by the dissolution of framework grains. Studies of Travis Peak gas production at Pinehill Southeast and Percy-Wheeler fields indicate that the average value of permeability-thickness product is about 10 md-ft in these two fields, and the range is 0.7 to 35 md-ft. Both fields are dry gas reservoirs. Well logs, core, and mud logs from Chapel Hill field in Smith County, Texas were examined in preparation for a complete cooperative

well program in the ARCO #1 Phillips well on the western margin of that field.

Field study of Corcoran-Cozzette Sandstones near Grand Junction, Colorado indicates depositional environments of the Corcoran evolved from marine upper shoreface to non-marine, and the Cozzette sequence evolved from lower to upper shoreface. Porosity and water saturation have been calculated by computer for seven Corcoran and Cozzette depositional units. Comparison of calculated water saturation with core-derived porosity and permeability shows fair to very good correlation of reservoir properties with clay content measured by gamma-ray log.

Technical Approach

All phases of research on the Travis Peak Formation and the Corcoran-Cozzette Sandstones have continued to make extensive use of well log data for geological and engineering interpretations. To evaluate potential sites of cooperative coring and logging operations in the Travis Peak, all available offset well control and completion cards were acquired, cross sections prepared, and recommendations made in coordination with other Gas Research Institute (GRI) contractors.

Travis Peak cores from GRI cooperative wells and other operators are subjected to detailed macroscopic description, then selected samples are examined by petrographic microscope and scanning electron microscope. Initial remote sensing studies are determining which techniques are most effective for defining geologic structures and which data are available for the study areas.

Computer routines have been developed and are now being utilized to define porosity and water saturation distributions in the Corcoran-Cozzette. Initial application of these routines is being made in the Shire Gulch-Plateau-Buzzard field area where dense well control is available; to date, 35 wells have been analyzed.

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PROGRAM OBJECTIVE

Guiding basin analysis research at the Bureau of Economic Geology has been the concept that sandstone bodies are the product of a suite of processes operating within major environments or depositional systems that are active during infilling of a basin. Typically these systems include several major environments of sand deposition; resultant sand bodies are the genetic facies such as meanderbelt, coastal barrier, or crevasse splay facies. Each of these facies has consistent physical attributes within an individual system or major depositional element where processes and available sediment types were relatively uniform. Consequently, interpretive description and mapping of the depositional systems and their component facies are basic steps in the geologic characterization of a tight gas sand or any hydrocarbon reservoir.

Such factors as initial permeability, proximity to source or sealing lithologies, and interconnection with other permeable units are inherent attributes of genetic facies that control or affect migration and distribution of hydrocarbons. Thus, facies analysis may identify preferred reservoir types and provide the basis for improved resource estimation and geographic extrapolation or prediction of tight gas trends. The significance of these attributes is indicated by the fact that typically only limited zones that constitute a small percent of the total sand-bearing interval contain producible gas.

Delineation of the depositional framework has greatest application in providing the basis for characterization of tight gas reservoirs, both on a regional and local basis. Delineation of depositional systems outlines the principal building blocks of the basin fill that may produce gas. Within each of these building blocks, sand bodies of component facies will have similar dimensions, orientation, interconnectedness, and internal permeability variations or compartmentalization. Internal heterogeneity of sand bodies results from the style of sediment accumulation, which may include aggradation, progradation, and lateral accretion. Though similar in geometry, progradation and lateral accretion are characterized by coarsening-upward and fining-upward textures that are typically reflected in permeability trends. Quantification of sand-body geometry in a complex depositional system necessitates initial recognition of differing external and internal geometric elements. Further, extrapolation of detailed sand body studies based on limited areas of dense data is guided by the regional interpretation.

Composition of reservoir sandstones reflects depositional processes, is important in affecting certain petrophysical parameters, and affects the extent and mineralogy of diagenetic mineral phases that occlude pore space and affect reservoir quality. Recognition of mineralogic facies and a full understanding of all aspects of the depositional systems of tight gas reservoirs will vastly improve the ability of the gas industry to effectively delineate and develop the unconventional gas resource in tight sandstones. By studying two stratigraphic units in detail, methodologies and geologic relationships will be developed which can be extrapolated to an understanding of an even broader group of tight gas reservoirs.

SPECIFIC OBJECTIVES FOR THE CURRENT YEAR

Phase C: November 1, 1983 - October 31, 1984

During this time period, derivative geologic mapping and facies interpretation will be completed, having been initiated late in the previous contract year. Emphasis will now shift from framework and areal studies to more specific understanding of reservoir sand package geometry, the diagenetic history of the stratigraphic unit as a whole and of particular reservoirs, and to the correlation of reservoir quality with production data. The degree of success of fracture treatments will be specifically examined in relation to regional tectonic framework, facies, reservoir geometry, and diagenetic characteristics. Correlation will be made between all significant geologic and engineering variables, and a close interface will be maintained with concurrent GRI-funded research on log interpretation, reservoir modeling, fracture design, and development of stimulation treatments including fluids and proppants. Cooperative logging, coring, and testing with well operators will be of particular value during this period because geologic framework and genetic stratigraphic studies will allow more specific targeting of critical facies and reservoir types. A major objective of coring and logging opportunities will be to refine the process of selecting areas for staged field tests. The availability of leases and operator interest in areas of potential field tests will become important in 1985 as selection of possible sites proceeds.

Specific activities during the second contract year (November 1, 1983 - October 31, 1984) will include:

1. Analysis of reservoir dimensions and geometries to determine how to best quantify reservoir continuity and to determine the geologic parameters with the greatest influence on reservoir productivity in specific fields.

2. Specialized mapping of diagenetic characteristics and variability in texture and mineralogy for comparison with primary mapping (isopach, structure contour, etc.) and facies mapping.

3. Areal variation in producibility of tight gas reservoirs and the success of stimulation treatments will be mapped and overlain with maps delineating facies.

4. Overall favorability of different trends within primary and secondary research areas will be assessed as a synthesis of factors needed to locate the most suitable areas for staged field tests.

WORK PLAN FOR THE CURRENT YEAR

The following work plan provides details of the technical approach to be followed:

Phase C. Reservoir Geometry, Diagenesis, Responses to Stimulation and Resource Distribution

Task I. Analysis of Reservoir Geometry

Subtask 1. Complete derivative geologic mapping to complement the primary map suite.

Subtask 2. Continue to recommend coring, logging, and testing operations as part of the description of the component facies elements of principal depositional systems.

Subtask 3. Determine reservoir sand dimensions and geometries through localized detailed studies and determine how best to quantify reservoir continuity.

Subtask 4. Examine extrapolation potential of reservoir geometry studies between primary and secondary objectives and to areas of lower priority.

Subtask 5. Utilize geologic framework and reservoir geometry studies to isolate prospective fairways for staged field tests.

Task II. Studies of Diagenesis

Subtask 1. Summarize mineralogic composition, diagenetic history, and textural features that affect reservoir porosity and permeability.

Subtask 2. Map compositional or diagenetic facies and overlay with genetic facies mapping to characterize tight gas reservoirs.

Subtask 3. Utilize results in selection of coring and logging locations, in evaluation of extrapolation potential between areas, and in definition of prospective fairways for staged field tests.

Task III. Responses to Stimulation

Subtask 1. Analyze production history, extent of productive area, and success of stimulation techniques in relation to the combined factors of genetic facies, reservoir geometry, and composition/diagenesis.

Subtask 2. Illustrate relationships between geologic factors and production or engineering data using cross plots or derivative maps, as appropriate.

Subtask 3. Utilize results in selection of coring and logging locations, in evaluation of extrapolation potential between areas, and in definition of prospective fairways for staged field tests.

Subtask 4. Coordinate with other GRI contractors and provide necessary geologic input into studies of fracture diagnostics, fluids and proppants, and reservoir modeling.

Task IV. Evaluation of Resource Distribution

Subtask 1. Provide geologic data for GRI and its other contractors to utilize in resource analyses of primary and secondary objectives and areas of lower priority.

Subtask 2. Evaluate new formation tests and new trends in operator activity for implications regarding total resources in tight gas units under study.

Task V. Documentation

Subtask 1. Select representative maps, cross sections, cross plots, and photomicrographs for drafting and/or photographic reproduction.

Subtask 2. Prepare report incorporating results of Phase C.

Subtask 3. Recommend actions necessary to screen areas for designation of staged field tests.

RESULTS OF THE PREVIOUS QUARTER

During the previous quarter the first Travis Peak core was obtained and analyzed, a major delta complex in the Travis Peak was defined, and studies of reservoir test data and production history were conducted for four Travis Peak gas fields. Core from the Clayton Williams #1 Sam Hughes well in Panola County, Texas consisted of very fine sandstone, siltstone, and mudstone. Preliminary scanning electron microscope (SEM) studies of the Travis Peak "A" sandstone (6,843.5 to 6,843.7 ft) showed that authigenic quartz had reduced original porosity, and some pores had been completely occluded by the growth of interlocking cement. Further results from study of this core are reported for the current quarter. Additional Travis Peak core located during the previous quarter included two held by Amoco Production Company and two held by Sun Oil Company.

Depositional systems studies of the Travis Peak during the previous quarter defined sandstone-rich intervals characterized by high spontaneous potential (SP) deflection. A percentage map of these intervals outlined a fluvial-deltaic complex that shows a major influx of sand into the East Texas Basin from the northwest across Upshur County. Localized studies of two sandstones in Panola County showed the same northwest to southeast trends. Engineering studies of Travis Peak fields included Whelan, Lansing North, Willow Springs, and Appleby North. These fields were shown to be primarily dry gas reservoirs with average permeability-thickness product of 65 md-ft and with some increase in water/gas ratio during production.

Corcoran-Cozzette studies during the pervious quarter defined three genetic depositional units within the Cozzette. In the producing areas of Shire Gulch and Plateau field a lower and upper strandplain with an intervening regressive barrier sandstone were defined. The distribution of corrected neutron-density crossover in the Shire Gulch-Plateau field area was found to correlate primarily with the distribution of sandstone in individual genetic sand bodies.

WORK PLANNED FOR THE CURRENT QUARTER

Work planned for the current quarter included petrographic studies of Travis Peak core from the Clayton Williams #1 Sam Hughes well, and description of borrowed core from the Amoco #1-"C" Michael Kangerga in Dirgin field, Rusk County, Texas. The Amoco core was sampled for thin section and SEM studies in preparation for its return to Amoco. Evaluation of wells for additional coring and logging continued, one of which, the ARCO #1 Phillips, will be involved in a complete coring, logging and testing program late in the current quarter. Engineering studies of Travis Peak fields were to continue with the addition of Percy Wheeler and Pinehill Southeast fields. Depositional systems studies of the Travis Peak were to continue with facies delineation over a broad area to set the stage for continued, more detailed work.

Porosity and water saturation mapping in the Corcoran and Cozzette Sandstones were planned to help define potential gas productivity of individual genetic sandstones. Field work along the Book Cliffs near Grand Junction, Colorado was carried out to better interpret subsurface mapping and core available from operators. Thin sections were prepared from existing core, and thin section analysis was to begin.

RESULTS OF THE CURRENT QUARTER

Travis Peak Studies

Depositional Systems

The regional synthesis of the Travis Peak (Hosston) Formation in East Texas and North Louisiana is nearing completion. Structure, isopach and various lithofacies maps have been made, and several regional stratigraphic cross sections showing depositional facies are in the process of being completed. The regional sections are being incorporated into a large panel diagram that will show the distribution of the six lithofacies that have been distinguished on the electric logs. These facies are: the sand-rich fluvial-deltaic facies, the silt-rich delta-front facies, the clay- and carbonate-rich shelf facies, the carbonate reef facies, and the clay-rich open marine basin facies.

In general, the fluvial-deltaic facies is best developed over the Sabine and Monroe Uplifts. During Late Jurassic and Early Cretaceous time there were two major river systems draining the continental interior. The ancient Mississippi River of Mann and Thomas (1968) constructed a large Hosston delta in northeastern Louisiana and west-central Mississippi. The large Travis Peak delta that filled the East Texas Basin and covered the Sabine Uplift was constructed by the ancestral Red River, which apparently was a large drainage system in Early Cretaceous time. The area in northern Louisiana between these two large deltas remained a marine embayment, portions of which were rapidly subsiding due to the contemporaneous withdrawal of salt into domes. This subsiding shelf area was bordered on the south by a reef tract in the lower Travis Peak (Hosston). The northern edge of this reef tract extends in an arc from Sabine Parish through Natchitoches and Winn Parishes to southern Caldwell Parish and beyond. The width of this lower Hosston reef trend is unknown. The reefal facies appears to climb stratigraphically to the south in the Hosston Formation. There are few deep wells penetrating this part of the section in central Louisiana, but the available evidence supports the interpretation of McFarlan (1977) that the lower Hosston carbonates climb up section and probably connect with the Sligo reef tract across central Louisiana. The reef trend separates the shallower back-reef shelf area in North Louisiana from the open marine basin to the south.

In East Texas only the fluvial-deltaic and delta-front facies occur at reasonable drill depths. The delta front facies appears to be the most gas productive part of the Travis Peak section, especially where it represents the transition zone with the overlying Pettet (Sligo) Formation. The delta front facies contains a complex assemblage of silt and very fine sand deposits that have been worked by shallow marine processes. The best developed sandstone subfacies in the delta front depositional environment are distributary mouth bars. However, most of the fine sand accumulated in shallow water where it was reworked into extensive, but thin offshore bars and lenticular sheet sands. Because this facies interfingers with the organic-rich source beds of the prodelta shelf deposits, it is the most favorable facies for hydrocarbon accumulations.

The delta front facies is best developed at the downdip margins of the large lower Travis Peak delta system. This major constructive delta complex in East Texas represents the strongest regressive pulse in Lower Cretaceous time. A combination of epeirogenic uplifts in the continental interior and a climatic change to more humid conditions contributed to a rapid and widespread influx of coarse clastics which flooded the broad, shallow, carbonate-supported East Texas shelf in lower Travis Peak time. Following this initial regressive phase, the sea slowly transgressed the East Texas Basin once again, completing the cycle with deposition of the shallow shelf carbonates of the overlying Pettet (Sligo) Formation. The thick buildup of the delta-front facies at the downdip margins of the extensive lower Travis Peak delta offers an attractive exploration target in southern Nacogdoches County which is being drilled at the present time.

The regional study that is nearing completion will supply the necessary framework upon which more detailed field studies can be hung. Future research emphasis will probably focus on the southwest flank of the Sabine Uplift, which is the center of exploration activity for Travis Peak gas in East Texas.

Reservoir Diagenesis

Two intervals of Travis Peak core (6,834.0 to 6,851.7 ft and 7,044.0 to 7,110.4 ft) were recovered from the Clayton W. Williams, Jr. #1 Sam Hughes well, Panola County, Texas. The top of the Travis Peak is at 6,830 ft in this well, so the upper core begins a few feet below the contact with the Sligo Formation.

Macroscopic Core Description

Both cores consist of intervals of fine to very fine sandstone, siltstone, and mudstone (fig. 1). The sandstone units have erosional bases and fine upward; sedimentary structures include planar crossbedding, ripple trough lamination, and contorted beds. Overlying the sandstones are siltstones and mudstones that contain calcareous nodules, wood fragments, and pyrite. The calcareous nodules, which are now calcite and ankerite in composition, also form separate, graded beds 0.1 to 1 ft thick. Mudstone units commonly contain horizontal and vertical burrows. Mudstones at the base of the lower core are red, whereas higher in the core they are medium gray.

Before a final interpretation of the depositional history of these rocks can be made, regional mapping of sand body thickness and extent is necessary. However, preliminary interpretations can be made based on the features observed in the cores. The rocks in the lower core are interpreted as having been deposited in a lower alluvial valley in a coastal plain setting. The calcareous nodules appear to be caliche nodules that formed in floodplain soils in a semiarid environment. Mudstones that contain pyrite and woody organic matter are interpreted to be poorly-drained-swamp deposits. The thicker sandstones were probably deposited in fluvial channels, and thinner sandstones represent natural-levee and crevasse-splay deposits.

The upper core, which occurs only a few feet below the Sligo carbonate, probably represents the transition to a marine environment. Long, well-developed vertical burrows in mudstones at 6,838 ft (fig. 1) suggest a marine setting, perhaps associated with a tidal flat or estuarine environment. Rippled sandstones and siltstones at the top of the core (fig. 1) may have been deposited on an intertidal sand flat.

Petrographic Description

Sandstones from the Clayton Williams #1 Sam Hughes core have been point counted to determine mineralogic composition (table 1). The sandstones are mineralogically mature and are classified as quartz arenites and subarkoses, with quartz comprising 89 to 99% of the essential constituents (quartz, feldspar, rock fragments). Feldspar, which varies from 1 to 11%, is almost entirely plagioclase (table 1). Rock fragments (0 to 4%) are chert, very fine-grained siliceous rock fragments (combined with chert in table 1), and metamorphic rock fragments. Zircon and tourmaline are the most common heavy minerals, and they are another indication of the mineralogic maturity of the Travis Peak sandstones. Detrital matrix, present in about half of the samples, is composed mainly of illite and chlorite.

Authigenic cements constitute between 5 and 36% of the sandstone volume (table 1). Cement volume is lowest in matrix-rich sandstones. Quartz overgrowths, ankerite, and chlorite are the most abundant authigenic minerals, with up to 34% of the sandstone volume consisting of quartz cement (fig. 2). Chlorite cement (up to 7% by volume) occurs as rims of tangentially oriented crystals around detrital grains and as pore-lining cement. Ankerite cement, which commonly has dolomite at the center, fills pore space and may also replace framework grains or earlier cements. Minor amounts of authigenic feldspar, anhydrite, barite, and illite are present in some samples.

Primary porosity is occluded in several samples by the presence of solid organic matter (fig. 3). We speculate that this solid organic matter migrated into the sandstones as liquid hydrocarbons, and later matured further to form pyrobitumen. Secondary pores do not contain solid organic matter.

The amount of porosity in these Travis Peak sandstones is quite variable, ranging from 0 to 22% as measured in thin section (fig. 4). Pre-cement porosity averages 35% in the clean sandstones, which suggests that about 10% porosity was lost by early burial compaction before cementation began. Approximately half of the remaining porosity is primary (figs. 4 and 5). Secondary pores formed by dissolution of framework grains (fig. 5), and some of the secondary pores are now partially filled by chlorite, barite, or authigenic feldspar. The major controls of porosity and permeability in these sandstones appear to be the volume of quartz overgrowths, chlorite cement, and solid organic matter.

Other Core Descriptions

Travis Peak core from the Amoco Production Company #1-"C" Michael Kangerga well, Dirgin field, Rusk County, was available from 8,400 to 8,670 ft. This nearly continuous core starts at about 1,300 ft below the top of the Travis Peak, so it samples the middle aggradational unit of the formation (Seni, 1983). The core consists of fine to very fine sandstones, siltstones, and mudstones. Most of the finer grained units are red beds, although green, reduced areas are common in the mudstones around organic matter and below sandstones. Root traces are abundant. The sandstones are red or light gray in color. Most of the sandstones have erosional bases and fine upward; sedimentary structures include planar crossbedding, horizontal laminations, and ripple trough laminations.

These lower Travis Peak strata were probably deposited in a fluvial environment. The sandstones represent fluvial-channel and crevasse-splay deposits, and the mudstones represent floodplain deposits. Well developed soil zones occur throughout the core in the mudstone units.

Another short Travis Peak core from near the top of the formation (8,161 to 8,220 ft) was available from the Delta Drilling Company #1 E. Williams "A" well, Chapel Hill field, Smith County. Many features of this core are similar to those observed in the Clayton Williams #1 Sam Hughes core, including abundant ripple trough laminations in the sandstones, beds of caliche nodules, and the presence of solid organic matter occluding pore space. The top of the core documents the transition to a brackish or marine environment with abundant pelecypod shells and shell fragments in burrowed mudstone.

Engineering Studies of Production History and Test Data

Field studies of production history and reservoir test data for the Travis Peak Formation in East Texas have been conducted for Pinehill Southeast and Percy-Wheeler field. Cumulative gas production (through June 1983) is 0.94 Bcf from Pinehill Southeast field, and 5.6 Bcf from Percy-Wheeler field. Both fields were developed in 1979-1980. Pinehill Southeast field is a stratigraphic gas trap, and Percy-Wheeler field is a faulted structural gas trap.

Production Mechanism and Original Gas in Place

Because both Pinehill Southeast and Percy-Wheeler fields were developed so recently, few production test data were available to plot P/z versus cumulative gas production, which can be used to estimate initial gas in place and to study the production mechanism. However, by using the P/z plot provided from Dwight's Energydata, original gas in place is roughly estimated to be over 2 Bcf for Pinehill Southeast field. The major production mechanism in the field appears to be gas expansion. Most of the wells in Percy-Wheeler field do not show a linear trend in the P/z plot. Instead, pressures either drop slightly or not at all in the beginning of the production period, and then drop rapidly. Possible reasons for this abnormal P/z plot are the following: 1) the gas/condensate production ratio, which will be discussed later, is relatively low in the field, so that gas and condensate flow at the same time in the formation, or 2) geological complexity in the reservoir. Additional research should be conducted to study this abnormality in the P/z plot.

Reservoir Productivity

Reservoir productivity is directly or indirectly related to selected engineering parameters, such as absolute open-flow potential (initial potential flow), permeability-thickness product, and formation pressure. Thus, these engineering parameters associated with reservoir productivity were reviewed. Initial potential flow ranged from 315 to 2,722 Mcfd with an average of 1,462 Mcfd in Pinehill Southeast field (fig. 6), and from 310 to 6,500 Mcfd with an average of 1,910 Mcfd in Percy-Wheeler field (fig. 7). The productive area with high flow potential is approximately coincident with the structural high in Percy-Wheeler field. In general, high flow potential in Pinehill Southeast field is in the updip part of the productive area, and the distribution of initial potential flow is approximately parallel to the structural contours.

The average value of permeability-thickness product is 11 md-ft (range from 1.7 to 22 md-ft) in Pinehill Southeast field, and 9 md-ft (range from 0.7 to 35 md-ft) in Percy-Wheeler field. In both fields the distribution of permeability-thickness product is similar to the distribution of initial potential flow (figs. 6 and 7), that is, both parameters increase or decrease in the same direction because of the correlation between them.

Initial formation pressure obtained from the back pressure test of each well (at a different depth) was corrected to an arbitrary datum of 8,500 ft by considering the static pressure gradient existing in the fluid column. Average initial formation pressures were 3,447 psi (range from 2,519 to 3,814 psi) in Pinehill Southeast field, and 4,352 psi (range from 2,472 to 4,945 psi) in Percy-Wheeler field.

Water/Gas and Gas/Condensate Production Ratios

In both Pinehill Southeast and Percy-Wheeler fields, initial water/gas production ratios are relatively low, with an average of 27 bbl/MMcf (fig. 8) and 44 bbl/MMcf (fig. 9), respectively (not including one well at the western edge of Percy-Wheeler field with an abnormally high ratio of 6,230 bbl/MMcf). The water/gas ratio in Percy-Wheeler field did not increase much during production, but it increased from 27 bbl/MMcf to 244 bbl/MMcf in Pinehill Southeast field.

Production with gas/condensate ratios greater than 100 Mcf/bbl is commonly called lean or dry gas, although there is no generally recognized cutoff for this ratio. Wet gas reservoirs may be approximately defined as those reservoirs with gas/condensate ratios in the range of 5 to 100 Mcf/bbl. Overall, Pinehill Southeast and Percy-Wheeler fields are dry gas reservoirs because gas/condensate production ratios average 359 and 114 Mcf/bbl, respectively. However, over one-third of the producing wells in Pinehill Southeast field, and over one-half of the producing wells in Percy-Wheeler field have gas/condensate production ratios in the range of wet gas or gas-condensate reservoirs.

Analysis of Cooperative Well Locations

Well logs, core, and mud logs from Chapel Hill field, Smith County, Texas were examined to evaluate the potential for a complete cooperative well program in the ARCO #1 Phillips well on the western margin of that field. The #1 Phillips is projected for a total depth of 8,800 ft, which should be sufficient to test the upper 600 ft of the Travis Peak Formation. A program to collect up to 240 ft of core was outlined based on the distribution of productive intervals in adjacent wells and on the need to evaluate shale barriers surrounding sandstones that may potentially be hydraulically fractured.

Chapel Hill field produces gas and oil from formations ranging in age from the Lower Cretaceous Paluxy Formation to the Upper Jurassic Cotton Valley Group. The field occurs on a north-south trending anticlinal structure that is salt-cored and has a major down-to-the-west normal fault on the west margin of the structure. Two wells were classified as Travis Peak gas wells in Chapel Hill field at the end of 1983, whereas a much greater number of wells produced liquid hydrocarbons from the Travis Peak in Chapel Hill field and its north and northeast extensions. These oil wells have a high gas/oil ratio (GOR) and the gravity of the oil varies from 42 to 50.8 API units (Railroad Commission of Texas, 1983). Four wells recently completed by Stallworth Oil & Gas, Inc. from 1 to 2 mi south of the ARCO #1 Phillips location have GOR's of 1,733:1 to 5,624:1 with an average of 3,808:1. Initial potential flows (IPF) of these wells vary from 218 to 227 bopd with 344 to 850 Mcfd of gas. Hydraulic fracture treatments were required to achieve these producing rates using an average of 361,000 lbs of sand in 100,000 to 130,000 gals of fluid. Although liquid hydrocarbons are produced at Chapel Hill field, the ARCO #1 Phillips is an appropriate well for the GRI cooperative well program because the objective section extends several hundred feet into the Travis Peak, the producing intervals are tight and require hydraulic fracture treatment, and significant quantities of gas are recovered in addition to oil production.

Logs from wells surrounding the #1 Phillips location were used to define an upper Travis Peak coring program (figs. 10 and 11). The uppermost Travis Peak is of particular interest geologically because it represents the transition from fluvial-deltaic sedimentation that predominates lower in the formation to carbonate shelf sedimentation of the overlying Sligo/Pettet. The transition zone in Chapel Hill field varies from approximately 220 to 350 ft thick. Stringers of carbonate 2 to 4 ft thick are especially prevalent in the uppermost 30 ft of the Travis Peak, but may occur up to several hundred feet into the formation. Some of the latter appear to be beds of caliche nodules (Dutton and Finley, 1984) and therefore have a significantly different origin than marine carbonates immediately below the Sligo/Pettet.

Coring in the ARCO #1 Phillips is to begin 5 to 7 ft above the Travis Peak-Sligo/Pettet contact to capture the complete transition zone between the two formations (fig. 11). Up to 180 ft of continuous core is to be obtained. This section is equivalent to intervals perforated in the ARCO #1 Brown well, and in the four Stallworth Oil & Gas, Inc. wells south of the #1 Phillips. Gamma-ray log patterns suggest reasonable correlation in an east-west direction, as illustrated by the highlighted sandstones and siltstones, but variations in bed thickness are evident (fig. 11). The deeper core recommended for the #1 Phillips well should contain a sandstone isolated by shales which would act as effective barriers to hydraulic fracture propagation (deepest sand highlighted by pattern, fig. 11). This sandstone is approximately 11 ft thick in the #1 Brown well, which is 1,400 ft east of the #1 Phillips location. Recovery of this sandstone and surrounding shales (and siltstones?) would provide excellent material for study of mechanical properties of the Travis Peak in relation to effectiveness of fracture barriers. A second sandstone below the lower bounding shale may also be recovered if this sandstone is as well developed as shown on the log of the #1 Lightfoot (fig. 11). The latter sandstone appears to have high water saturation in the #1 Oliver well and would be an excellent candidate for water saturation analysis with respect to log-derived data.

In addition to the cooperation of ARCO Oil and Gas Company, Delta Drilling Company has provided well logs, mud logs, and the loan of a core from Chapel Hill field, and Stallworth Oil & Gas, Inc. has provided well logs. Study of the Delta core confirms the development of an upper Travis Peak transition zone interpreted from well logs; a highly burrowed, probably marine, sandstone occurs approximately 115 ft below the top of the Travis Peak. Chapel Hill appears to be an appropriate area for localized, field-scale studies of depositional environments and sandstone continuity in the uppermost Travis Peak.

Corcoran-Cozzette Studies

Depositional Systems

Outcrops of the Sego, Corcoran, Cozzette, and Rollins Sandstones were examined along the Book Cliffs near Grand Junction, Colorado. The objective of the studies was to define depositional environments of the sandstones based on vertical variation in sedimentary structures and lithology and on variations in sedimentary sequences between localities. The stratigraphic section at Rifle Gap, Colorado was also examined. The Sego Sandstone is present below the Corcoran in depositionally updip localities, and the Rollins overlies the Cozzette throughout the area studied within the southern Piceance Creek Basin.

The stratigraphic sections visited along the Book Cliffs were generally the same as those described in Gill and Hail (1975), and ranged from Big Salt Wash to the north (T8S-R102W) to Watson Creek to the south (3-T11S-R98W). The latter location and the section at Farmers Mine near Palisade, Colorado (25-T11S-R98W) are the localities most directly on depositional strike with Corcoran-Cozzette gas production in Shire Gulch and Plateau fields. A measured section was completed north of Farmers Mine based on outcrops along the Colorado River and is herein termed the Palisade section. A similar measured section will be completed at Watson Creek and the intervening four miles of outcrop examined, where accessible, to define lateral facies relationships of marginal-marine Corcoran-Cozzette sandstones.

Planar bedded to massive and hummocky cross-stratified fine to very fine grained sandstone is present in much of the Corcoran Sandstone of the Palisade section. The shallow marine origin of hummocky cross stratification (Walker, 1979; Hunter and Clifton, 1982), the occurrence of scattered Ophiomorpha plus another, smooth-walled burrow type, and a 1-ft-thick interval of bidirectional trough crossbedding, suggest a lower to upper shoreface origin with some tidal current influence. Above this sequence *Ophiomorpha* becomes much more abundant, and planar to trough cross-stratification is present. The uppermost depositional units within the Corcoran are horizontally stratified to irregularly horizontally stratified and massive, very fine grained sandstone that is capped by siltstone and shale (2 ft) and coal (2.5-3 ft). The nearly horizontal stratification may indicate beach foreshore deposition, but weathering of the outcrop has in part obscured what may be interpreted as swash stratification. The occurrence of the coal, however, clearly indicates a marine to non-marine transition.

The Cozzette Sandstone at the Palisade section shows features similar to those of the Corcoran Sandstone. Within the lower Cozzette a 27-ft-thick, very fine grained sandstone shows massive to gently inclined parallel stratification with very low angle discordances at the base of the unit. This sandstone overlies siltstone containing shale and silty very fine sandstone interbeds up to several inches thick, and is overlain in turn by siltstones and massive to hummocky cross-stratified very fine sandstones. The major unit of the upper Cozzette consists of a 25-ft-thick, highly carbonaceous fine grained sandstone with hummocky cross-stratification. Burrowing increases in sandstones above this major unit, and the uppermost sandstone in the Cozzette is medium-grained and contains asymmetrical ripples and trough cross-stratification. No swash stratification appears to be preserved. The Cozzette sequence may be interpreted as lower to upper shoreface in origin. If foreshore deposition did occur toward the top of this sequence, it may have been reworked during the marine transgression that followed Cozzette and preceded Rollins deposition. Additional field study of the Corcoran and Cozzette Sandstones is warranted between the Palisade section and Watson Creek because these outcrops are on strike with Shire Gulch and Plateau fields 11 mi to the northeast.

Gas Reservoir Analysis

Assessment of the gas productive capacity of individual depositional units within the Corcoran and Cozzette Sandstones cannot be made because most wells contain commingled production from parts of both the Corcoran and Cozzette. Porosity and water saturation have therefore been calculated using a computer routine to define sandstone with more than 7 percent porosity and less than 70 percent water saturation. Computations are made separately for each of the four depositional units defined within the Corcoran and three such units noted within the Cozzette. Thus far 35 wells have been analyzed; all but 5 are within the Shire Gulch-Plateau-Buzzard field area.

Comparison of water saturation (S_w) with core-derived porosity and permeability shows fair to very good correlation of reservoir properties with clay content as measured by gamma-ray log. In the Martin Oil, #1-3 Federal (1-T10S-R97W), for example, upward-improving reservoir quality closely follows upward-decreasing gamma-ray counts in the lower strandplain unit of the Corcoran Sandstone. Porosity increases from 9 to 11 percent to 13 to 15 percent, permeability increases from 0.1 to 1.0 md, and S_w decreases from 70 to 80 percent to approximately 40 percent over a 45 ft interval. Core descriptions show that improved reservoir quality correlates with decreasing mud content, and where an irregular, or "spiky" gamma-ray log pattern occurs, changes in reservoir quality closely follow the same pattern. When a sufficient number of wells have been analyzed, mapping of porosity and water saturation will begin by depositional unit and additional comparisons made with core data.

Remote-Sensing Studies

Initial studies have concentrated on determining the remote-sensing techniques that most effectively define structural geologic features of the Earth's surface and what remote-sensing imagery is available. The remote-sensing study of the East Texas and Piceance basins will include data from two sources: (1) Landsat imagery and (2) airborne synthetic aperture radar (SAR). Landsat imagery, with its synoptic coverage of large areas, will be the basis for regional studies of structural features. Radar data's fine resolution (12 m) will be used to study localized features.

Landsat Data

Three types of Landsat imagery have been investigated: return beam vidicon (RBV), multispectral scanner (MSS), and thematic mapper (TM) data (table 2). The data are available in hard-copy format (black-and-white or false color composite prints) and in digital format on magnetic tape. Each type of imagery has advantages of scale, timely availability, and cost. Because of its higher resolution and greater sensitivity to lithology, Landsat TM data are clearly superior to MSS and RBV data. However, problems with the two TM-carrying Landsat satellites and the TM sensors have made data collection sporadic. In addition, delays in cataloging recently-acquired TM data at Goddard Space Flight Center have slowed the search for TM data for the study areas. Thus far, complete TM coverage of the study areas has not been found.

Methods of manipulating TM and MSS data to enhance geologic features are being investigated. Companies that enhance TM and MSS data have been contacted for descriptions of services and costs, and development of in-house capability to enhance these data is being studied.

Radar Data

Two companies that produce SAR imagery have been contacted and price estimates are forthcoming from MARS Associates and Aero Service. Preliminary estimates indicate that the cost to acquire new imagery will range from \$6 to \$25 per km^2 of area covered, depending on the size of the site. However, for sites smaller than about 1,500 km^2 the cost would be the same (about \$40,000) regardless of size (Bob Norris, Aero Service, personal communication, July 23, 1984). Data can be in hard-copy format (black-and-white prints, transparencies and mosaics) or in digital format on magnetic tape.

SAR data are available for purchase off the shelf from two other sources at a price much lower than that quoted above. However, the quality of data and area covered may not be useful for this project. Investigation of these sources continues.

Technical Problems

No major technical problems were encountered during the contract quarter covered by this report.

WORK PLANNED FOR NEXT QUARTER

1. Core from the ARCO #1 Phillips well will be described and petrographic studies conducted. Results will be integrated with studies of core borrowed from Delta Drilling Company also in Chapel Hill field.
2. A series of cross sections will be prepared and a fence diagram completed illustrating major depositional variations in the Travis Peak across the area of research emphasis in East Texas and adjacent North Louisiana.
3. Thin section petrography will be continued on Travis Peak core borrowed from various operators.
4. An initial synthesis of patterns of diagenesis within the Travis Peak will be defined based on core examined through the completion of the contract year.
5. Engineering field studies of the Travis Peak will continue with analysis of Chapel Hill field and either Danville or Henderson fields, dependent upon the availability of well data.
6. Potential Travis Peak cooperative well locations will continue to be reviewed in coordination with other contractors.
7. Acquisition of remote-sensing data will focus on the East Texas Basin and the availability of Landsat Thematic Mapper imagery and airborne radar imagery over the basin.
8. Porosity and water saturation mapping will be completed in the Shire Gulch-Plateau field area for the Corcoran and Cozzette Sandstones as a method to help define potential gas productivity of individual genetic depositional units.
9. Corcoran-Cozzette field studies will be integrated into an interpretation of depositional systems for the major gas producing area.

10. The Colorado Geological Survey will conduct limited additional field checking and possible sampling for palynologic analyses.

11. A study of Corcoran-Cozzette coal will be completed by the Colorado Geologic Survey.

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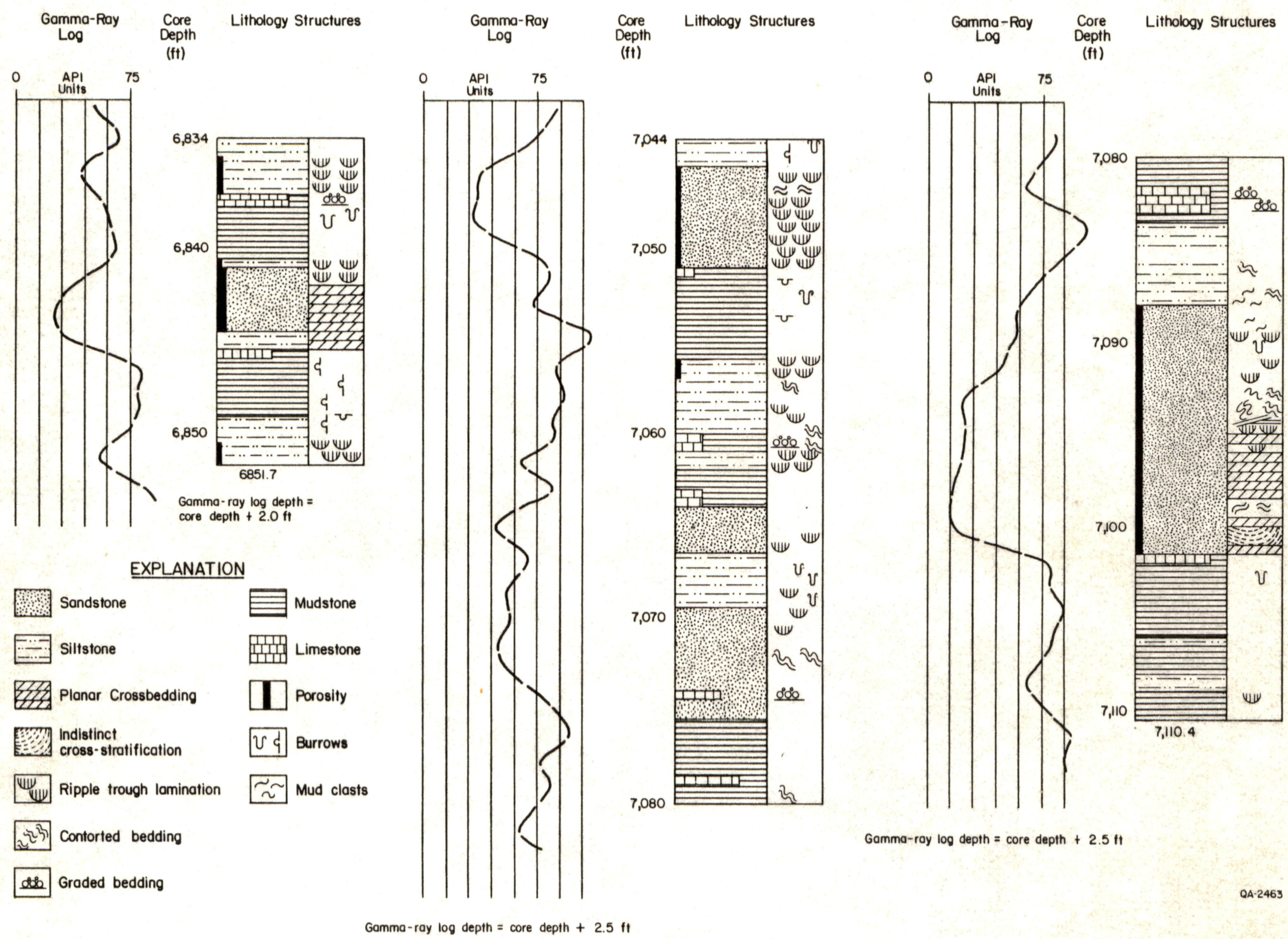

Figure 1. Descriptive log of Travis Peak core from the Clayton W. Williams, Jr. #1 Sam Hughes well, Panola County, Texas.

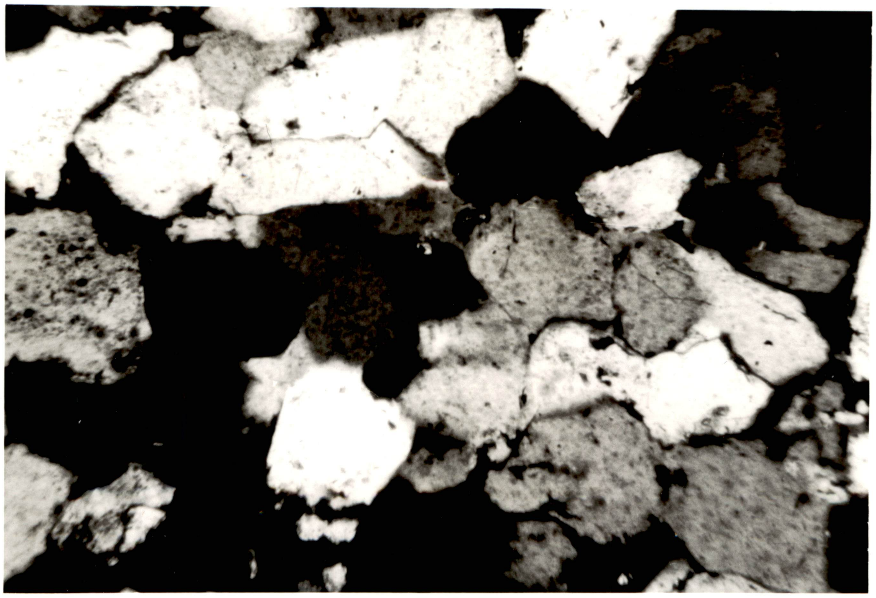

Figure 2. Photomicrograph of Travis Peak sandstone from a depth of 7,093.5 ft in the Clayton Williams #1 Sam Hughes lower core. Primary pores have been completely occluded by interlocking quartz cement. Long dimension of photo = 0.83 mm; polarized light.

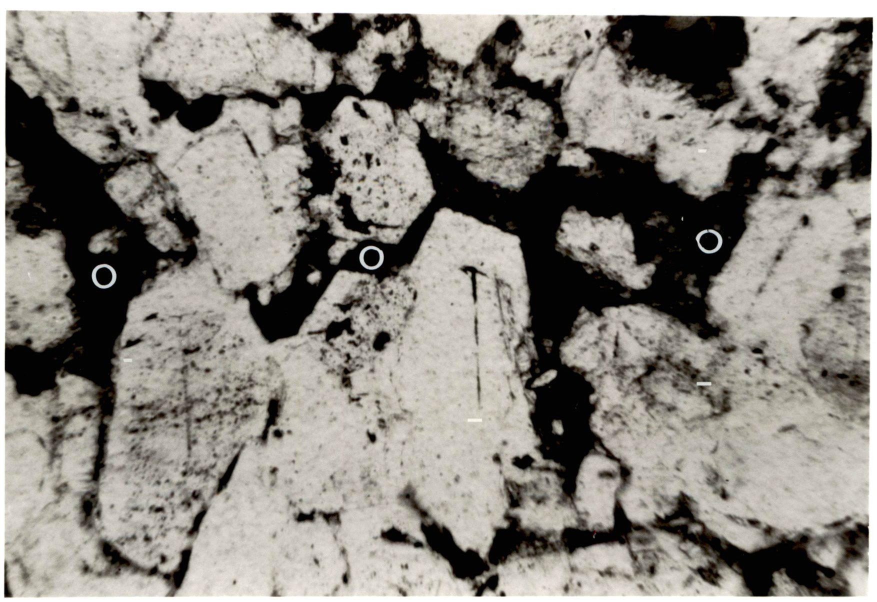

Figure 3. Photomicrograph of Travis Peak sandstone from a depth of 7,100.2 ft in the Clayton Williams #1 Sam Hughes lower core. Solid organic matter (O) lines primary pores. Long dimension of photo = 0.83 mm; plane light.

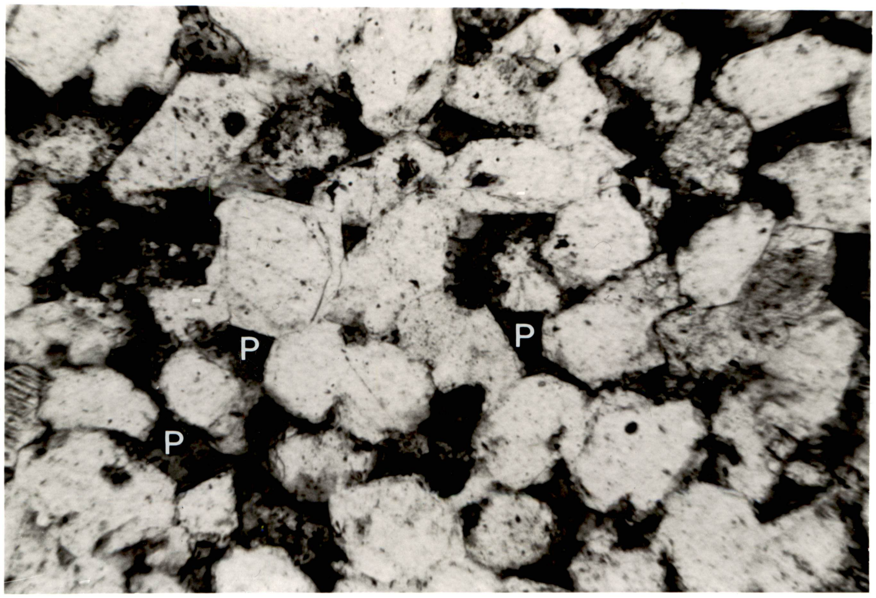

Figure 4. Photomicrograph of Travis Peak "A" sandstone from a depth of 6,843.7 ft in the Clayton Williams #1 Sam Hughes upper core. Abundant primary porosity (P) is bounded by quartz crystal faces. Long dimension of photo = 0.83 mm; plane light.

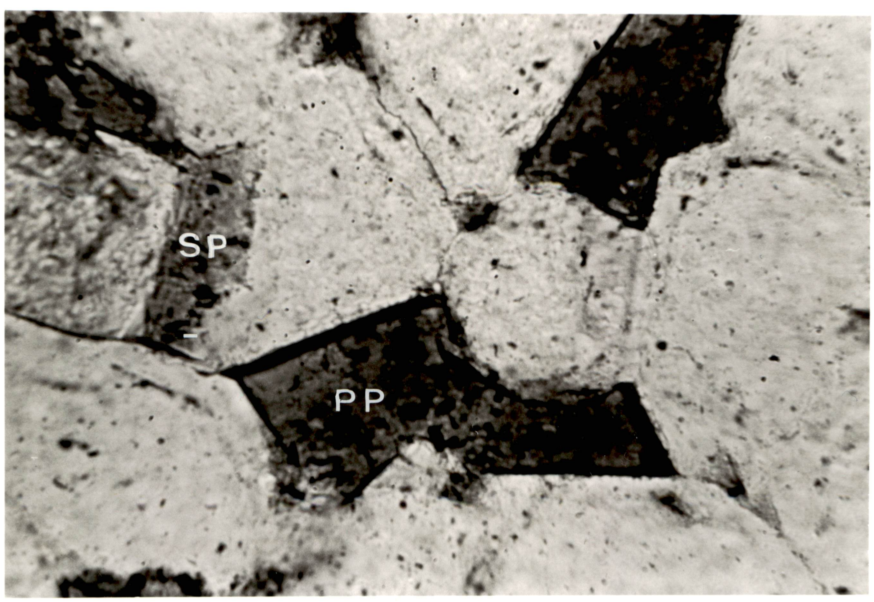

Figure 5. Photomicrograph of Travis Peak "A" sandstone from a depth of 6,843.7 ft in the Clayton Williams #1 Sam Hughes upper core. Both primary (PP) and secondary (SP) pores are shown. Long dimension of photo = 0.33 mm; plane light.

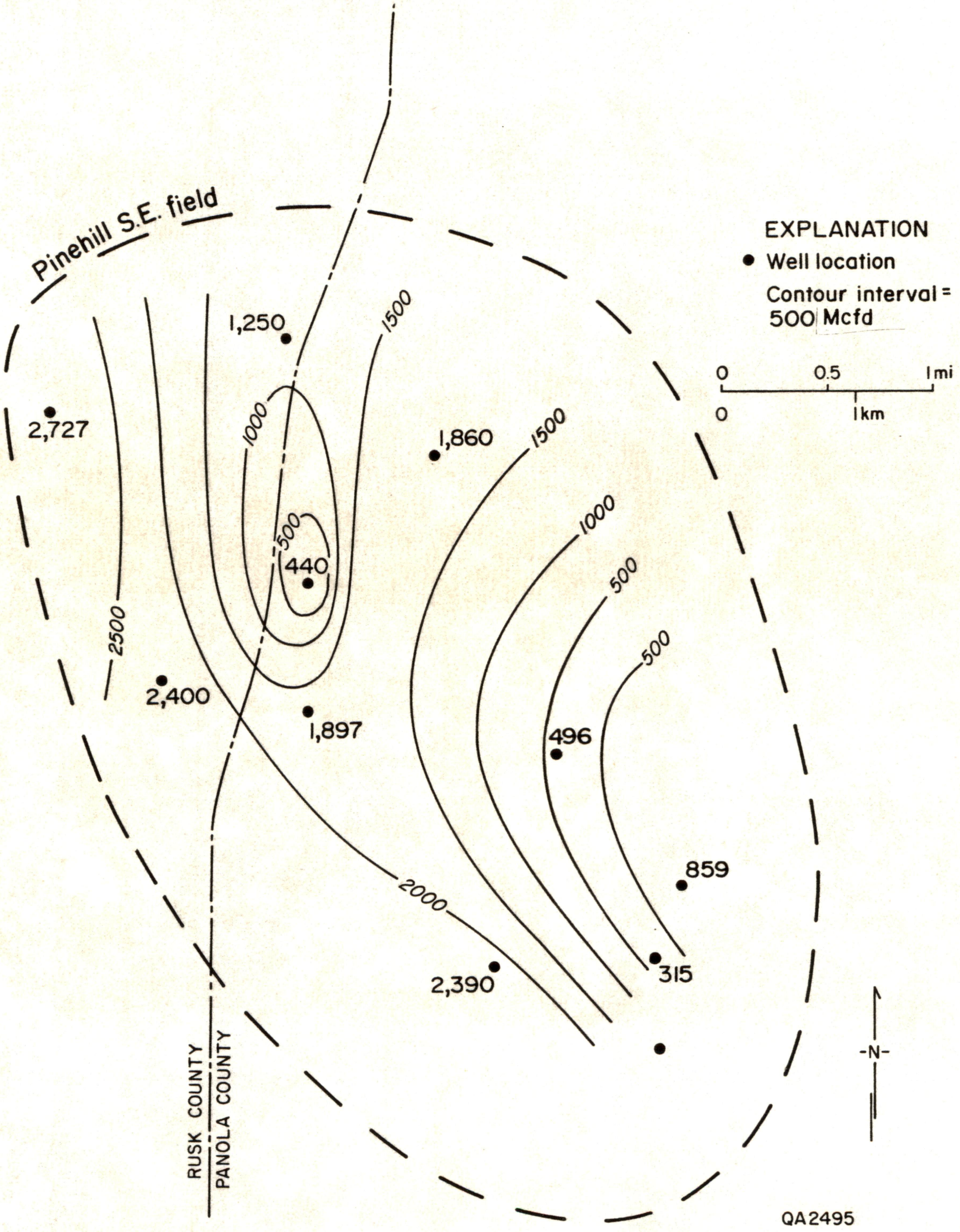

Figure 6. Distribution of absolute open flow potential (or initial potential flow) in the Travis Peak Formation in Pinehill Southeast field.

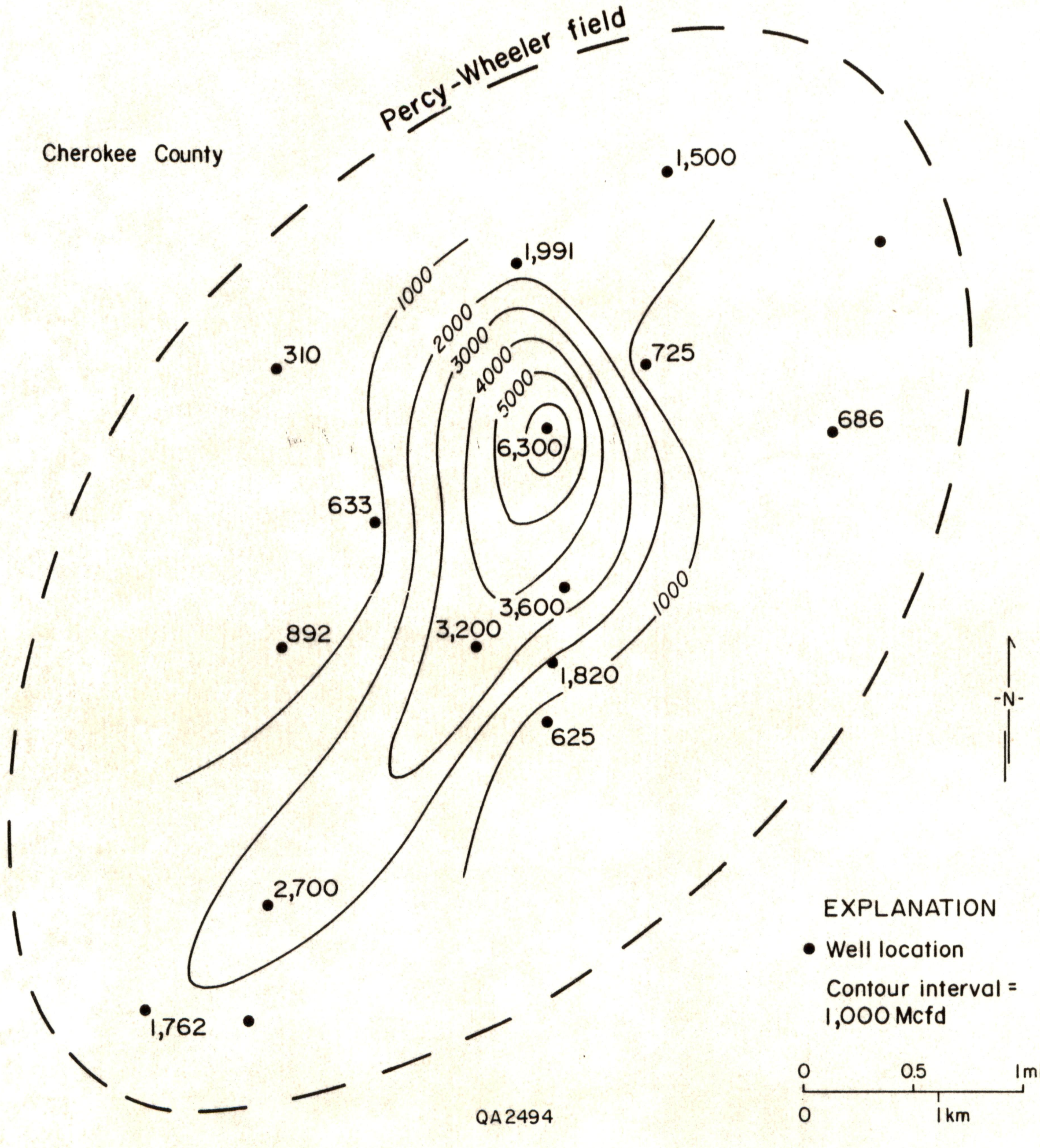

Figure 7. Distribution of absolute open flow potential (or initial potential flow) in the Travis Peak Formation in Percy-Wheeler field.

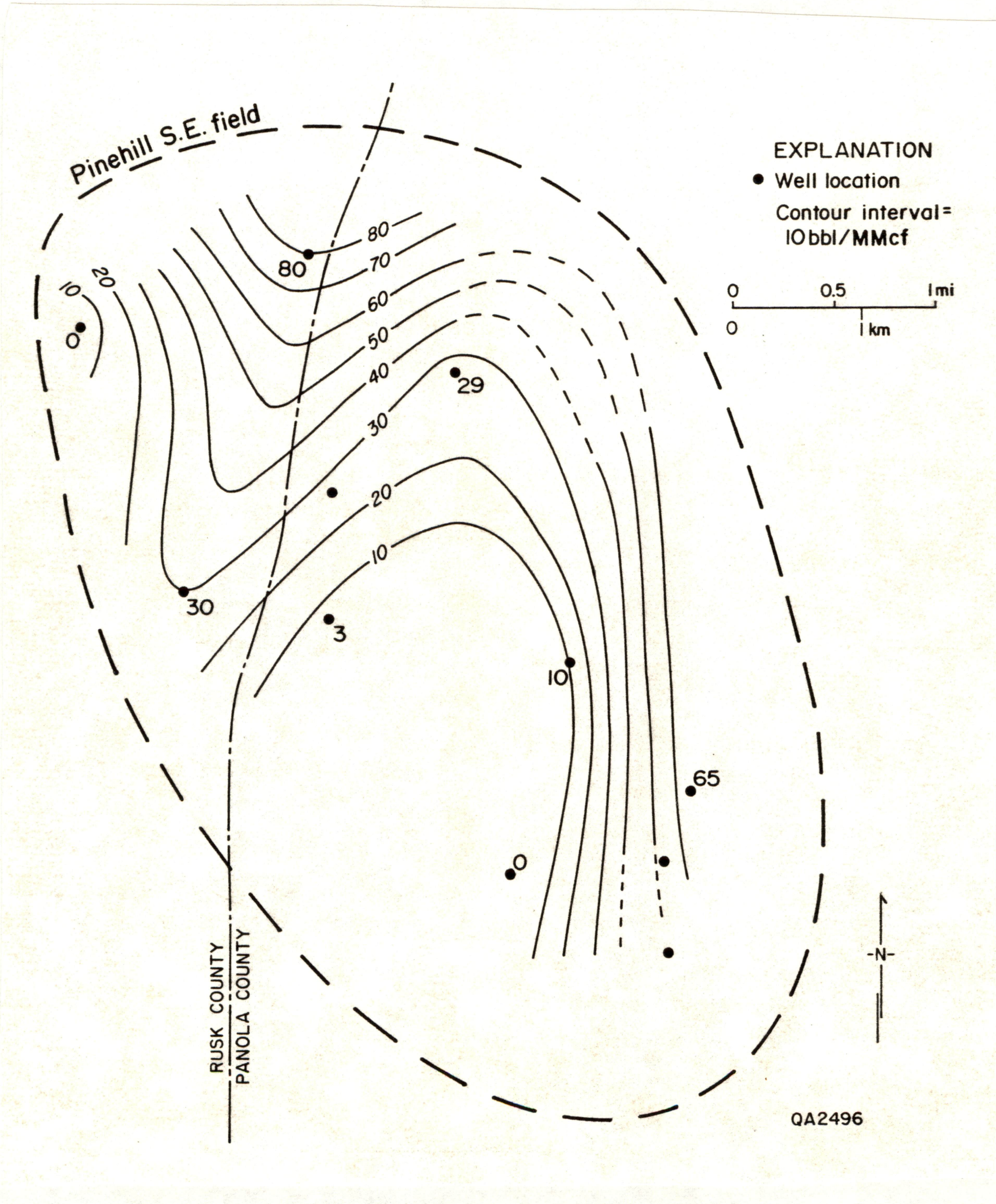

Figure 8. Distribution of initial producing water/gas ratio in the Travis Peak Formation in Pinehill Southeast field.

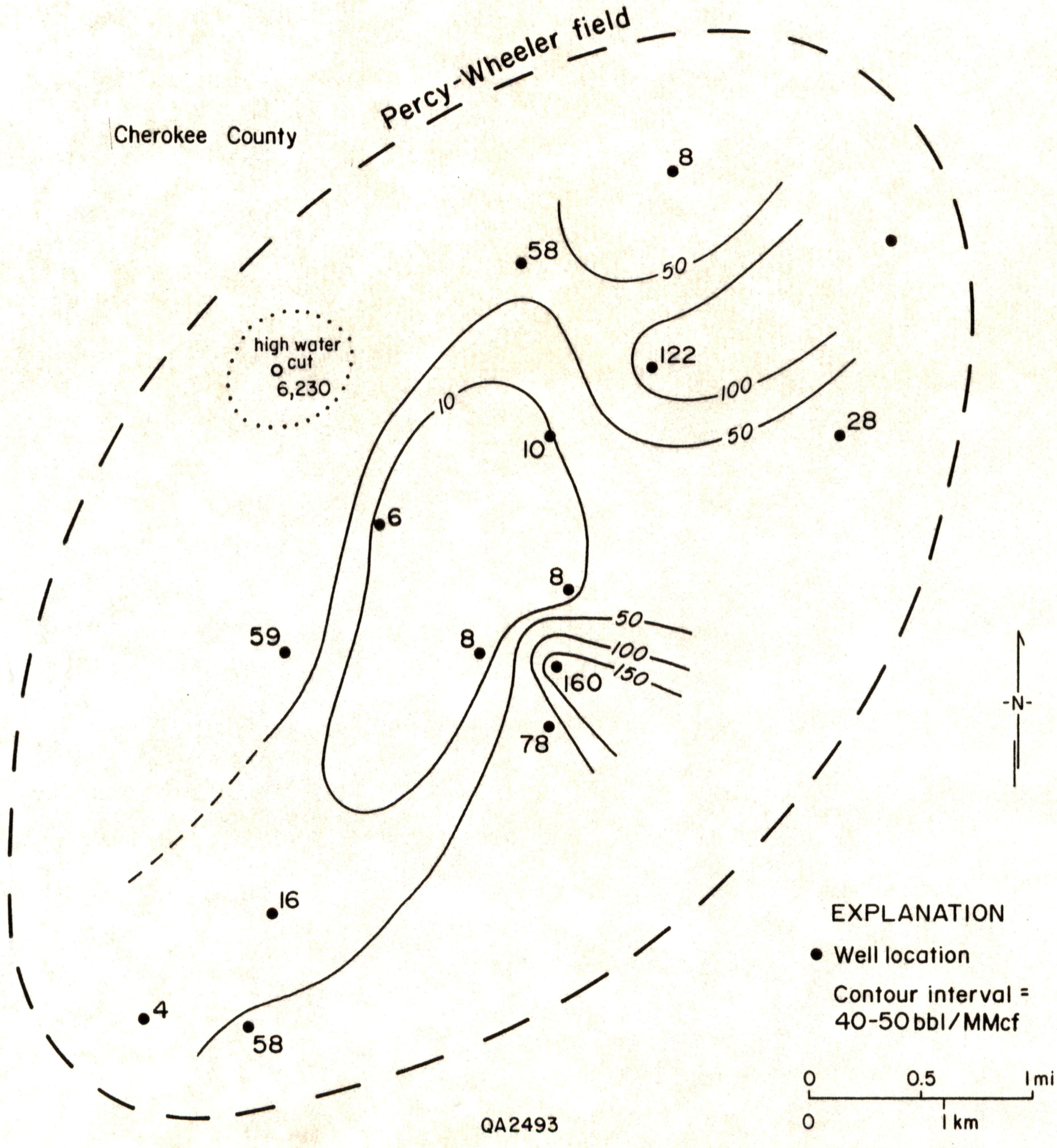

Figure 9. Distribution of initial producing water/gas ratio in the Travis Peak Formation in Percy-Wheeler field.

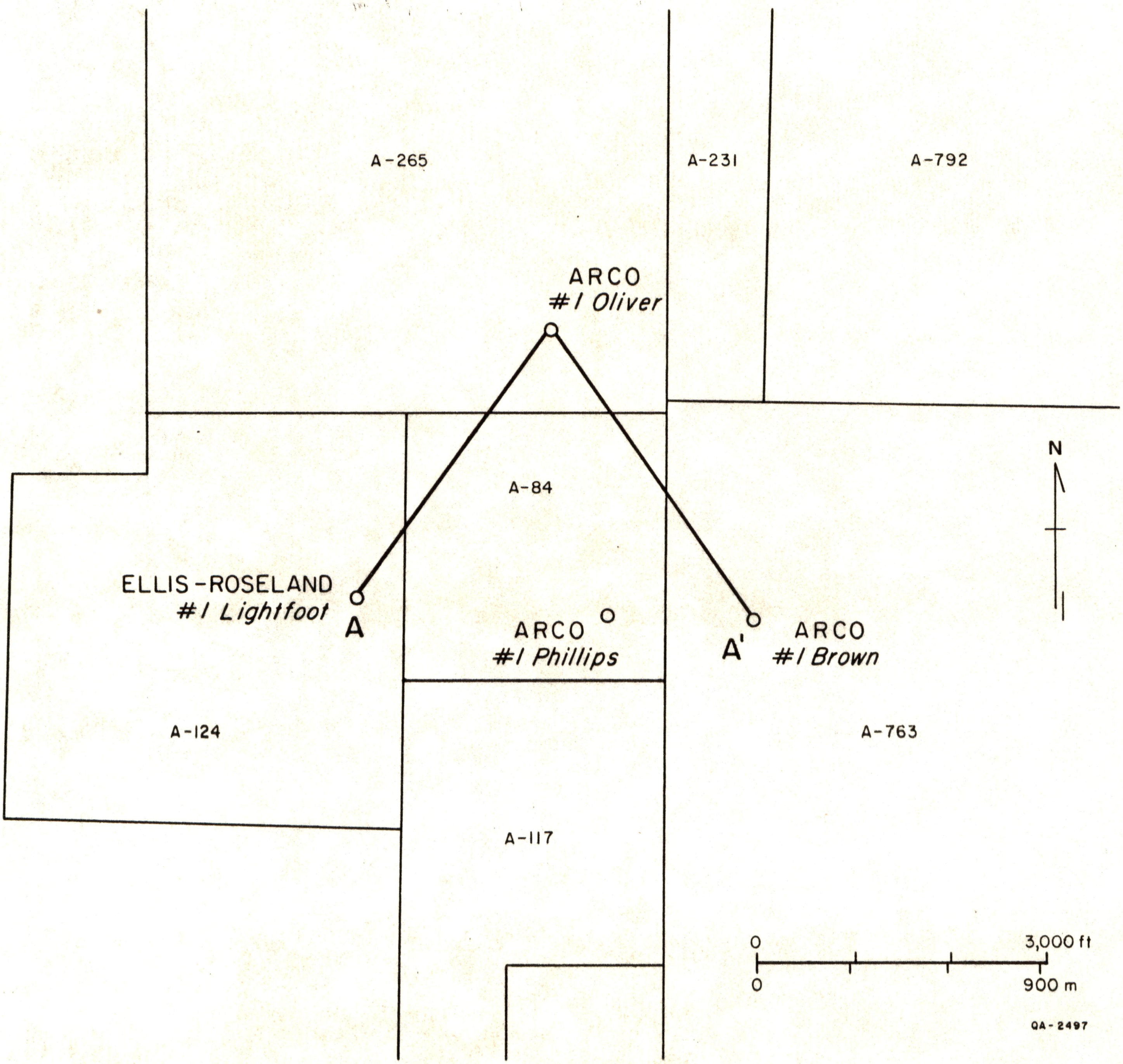

Figure 10. Index map of the area of Chapel Hill field, Smith County, Texas around the ARCO #1 Phillips well. The location of the cross section in figure 11 is shown.

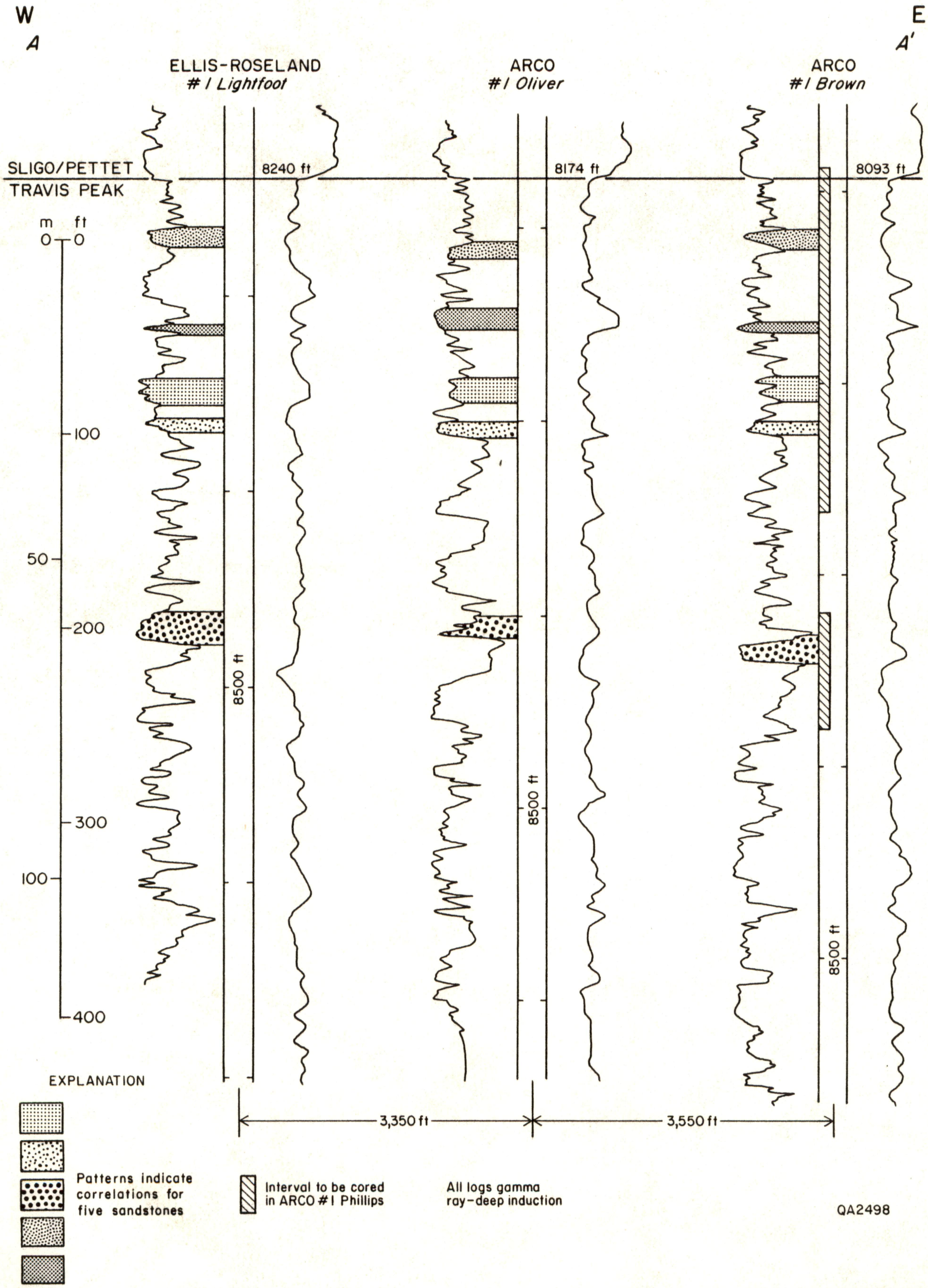

Figure 11. East-west cross section of the Travis Peak Formation in Chapel Hill field, Smith County, Texas near the ARCO #1 Phillips well.

Table 1. Petrographic analyses of Clayton Williams, Jr., No. 1 Sam Hughes core.

	Framework grains										Matrix
Depth (ft)	Quartz	Plagioclase	Orthoclase	MRF*	Chert	Clay clasts	Mica	Heavy minerals	Plant remains	Other	Clay-sized fines
6,835.7	56.0	4.5	0	0	0	0	0	0	0	0	15.0
6,836.3	52.2	2.0	0	0	0.5	0	0	0	0	0	16.4
6,841.5	50.7	6.0	0	0	0	0	0	0	0	0.5	7.0
6,842.5	51.7	2.9	0.5	0	0.5	3.9	0	0	1.0	0	0
6,843.7	50.5	1.9	0	0	0	2.9	0	0.5	0	0	0
6,851.0	66.0	1.5	0	0	0.5	1.0	0	0	0	0	22.2
7,046.3	68.0	3.4	0	0	0	0	0	0	0.5	0	22.7
7,049.4	62.0	1.9	0	0.5	0.5	0	0.5	1.0	0.5	0	25.0
7,061.8	54.0	2.4	0	0	1.4	3.8	0	0	0	0	4.3
7,066.1	65.0	2.0	0	0.5	0.5	0	0	0	0	0	6.4
7,069.5	57.1	2.4	0.9	0	0.5	4.7	0	0	0	0	8.5
7,090.3	66.8	3.9	0	0	0	2.4	0	0	0	0	14.6
7,093.2	61.6	1.5	0	0	0	1.0	0	0	0	0	1.5
7,093.5	58.5	1.4	0	0	1.0	1.4	0	0	0.5	0	0
7,095.3	56.2	2.9	0	0	1.4	0.5	0	0	0.5	0	0
7,097.7	53.6	2.4	0	0.5	0	2.4	0	0	0	0	0
7,099.5	63.2	3.4	0	0	0.5	0	0	0	0	0	0
7,100.2	56.0	2.0	0	1.4	0.5	0.5	0	0	0	0	0
7,101.0	63.8	1.5	0	0	0	0.5	0	0	0.5	0	0
7,101.2	68.5	1.0	0	0	0	0	0	0	0	0	0

*Metamorphic rock fragments

Table 1. (Continued)

	Cements							Porosity	
Depth (ft)	Quartz	Dolomite	Ankerite	Authigenic clay	Feldspar	Anhydrite	Solid organic matter	Primary porosity	Secondary porosity
6,835.7	16.0	0	2.0	0	0	0	5.5	0	1.0
6,836.3	19.4	1.0	4.5	0	0.5	0	3.5	0	0
6,841.5	33.8	0	1.0	1.0	0	0	0	0	0
6,842.5	27.8	0	2.9	4.4	0.5	0	0	2.0	2.0
6,843.7	15.6	0	3.8	1.9	0.9	0.5	0	8.7	13.0
6,851.0	4.4	0	3.0	0	0	0	1.5	0	0
7,046.3	3.9	0.5	0	0.5	0.5	0	0	0	0
7,049.4	6.7	1.0	0	0.5	0	0	0	0	0
7,061.8	28.9	0	5.2	0	0	0	0	0	0
7,066.1	16.3	0	7.4	0	0.5	0	1.5	0	0
7,069.5	25.9	0	0.5	0	0	0	0	0	0
7,090.3	11.2	0	0	1.0	0	0	0	0	0
7,093.2	22.7	0	0	2.5	0.5	0	6.9	1.5	0.5
7,093.5	25.6	0	0	4.3	0	0	5.8	1.0	0.5
7,095.3	24.8	0	0	7.1	0	0	0.5	2.4	2.9
7,097.7	22.3	0	0	7.1	0.5	0	0	6.6	4.7
7,099.5	21.1	0	0	2.0	0.5	0	0	5.4	3.9
7,100.2	24.2	0	0	4.8	0	0	1.0	5.3	4.3
7,101.0	27.1	0	0.5	2.4	1.0	1.0	0	1.4	0.5
7,101.2	20.0	0	4.0	3.5	0	0	0	1.0	2.0

Table 2. Comparison of data types considered for use in remote-sensing study of East Texas and Piceance Creek basins.

Imagery type		Format	Scale initial/working	Resolution (m)	Comment
Landsat:	TM	Photographic print magnetic tape	$1{:}10^6/\leq 1{:}250{,}000$	30	TM data useful for lithologic discrimination.
	MSS	Photographic print magnetic tape	$1{:}10^6/\leq 1{:}250{,}000$	79	
	RBV	Photographic print magnetic tape	$1{:}10^6/\leq 1{:}250{,}000$	20	RBV data products suffer from "shading" problems related to sensor.
Radar:	SAR	Photographic print magnetic tape	$1{:}400{,}000/\leq 1{:}250{,}000$	10-12	

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FRJ 3rd qrt tg84 t-2	WP	8/ 2/84	/ /	1	3
FRJ 3rd qrt tg84 t-1	WP	8/ 2/84	/ /	2	7
FRJ 3rd qrt tg84 tx1	WP	7/27/84	8/ 2/84	21	94
FRJ 3rd qrt tg84 cap	WP	7/27/84	8/ 1/84	1	5
FRJ 3rd qrt tg84 ref	WP	7/27/84	8/ 1/84	1	5
FRJ 3rd qrt tg84 con	WP	7/27/84	8/ 1/84	2	8
FRJ 3rd qrt tg84 sum	WP	7/27/84	8/ 1/84	2	12
FRJ 3rd qrt tg84 ttp	WP	7/27/84	8/ 1/84	2	3
FRJ 3rd qrt tg84 dsc	WP	7/27/84	/ /	1	3

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