2/19/77

ORNL/SUB-74/38284

EVALUATION OF
HYDROCARBON POTENTIAL
AEC STUDY AREA, SOUTHEAST NEW MEXICO

Netherland, Sewell & Associates

May, 1974

This report was prepared by Netherland, Sewell & Associates under Purchase Order Subcontract 78X-38284V with Union Carbide Corporation, Nuclear Division. The subcontract was administered by Oak Ridge National Laboratory

**UNION
CARBIDE**

OFFICE OF WASTE ISOLATION
OAK RIDGE, TENNESSEE

*prepared for the U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
under U.S. GOVERNMENT Contract W-7405 eng 26*

The assumptions, views, and conclusions expressed in this document are those of the author and are not to be interpreted as those of Union Carbide Corporation, Nuclear Division, or USERDA

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

NETHERLAND, SEWELL & ASSOCIATES

CONSULTING PETROLEUM ENGINEERS AND GEOLOGISTS

2000 REPUBLIC NATIONAL BANK BUILDING

DALLAS, TEXAS 75201

CLARENCE M. NETHERLAND

FREDERIC D. SEWELL

June 11, 1974

(214) 741-4881

Dr. William C. McClain, Director
Geologic Disposal Evaluations Project
Oak Ridge National Laboratory
Building 9104-3
Post Office Box Y
Oak Ridge, Tennessee 37830

Dear Dr. McClain:

This report, based on our comprehensive geological and engineering studies as of May, 1974, sets forth the results of our evaluation of the hydrocarbon potential of a three-square-mile Study Area located in the northern portion of the Delaware Basin of Southeast New Mexico, encompassing the SE/4 of Section 35, the S/2 of Section 36, T21S-R31E, all of Section 1, the E/2 of Section 2, T22S-R31E, Eddy County, New Mexico; the SW/4 of Section 31, T21S-R32E, and the W/2 of Section 6, T22S-R32E, Lea County, New Mexico. This report was prepared for the Oak Ridge National Laboratory (ORNL) operated by Union Carbide Corporation, Nuclear Division, for the Atomic Energy Commission, under Purchase Order Number ORNL 78X-38284V of Union Carbide Corporation, dated January 17, 1974.

As a result of this study, we conclude that no economically recoverable oil and gas exist within the limits of the ORNL Study Area or under the acreage immediately adjoining the Study Area. Comprehensive analyses of the available geological and engineering data have been made for the upper portion of the Delaware Basin in which the Study Area is located, and the thorough study and analysis of these data lead us firmly to this conclusion.

Also, concerning the value of minerals, as pertains to oil and gas rights within the Study Area, we reach a three-part conclusion as follows: (1) The option to lease the minerals, as they pertain to oil and gas, has no value for an oil and gas operator with full knowledge of the geology of the Study Area because we believe he, too, would conclude that no economically recoverable oil and gas exist within the limits of the Study Area; (2) An oil and gas operator who does not have available to him

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

a comprehensive analysis of the geology of the Study Area and who drills exploratory wells based on "his interpretation of trends," as some operators do, might pay a cash bonus as much as \$40 to \$50 per acre for the leasing rights of the minerals which would permit him to drill an exploratory well in search for oil and gas (we believe such exploratory well would be a failure); and, therefore, (3) For the owner of the minerals under the Study Area, we estimate the value of these minerals, as they pertain to oil and gas rights only, to be approximately \$100 per acre (which is approximately two and one-half times the estimated cash bonus payment indicated in (2) above) not because of the prospect of finding oil and gas under the Study Area, but because of the occasional payments of bonuses and yearly rentals in consideration for leasing rights by such oil and gas operators described in (2) above. As will be noted, such value of mineral ownership is derived not from the finding and producing of oil and gas, but from some operators' "hoping" to find oil and gas and their willingness to pay a "cash bonus" for the lease or contractual right to conduct exploratory drilling toward that end. Additional discussion on these points will be found in the GENERAL DISCUSSION section of this report.

We believe that the first, most significant factor to be recognized in the evaluation of the hydrocarbon potential of the ORNL Study Area is that the northern, shallower portion of the Delaware Basin, in which the Study Area is located, is vastly different from the central-to-southern, deeper (20,000 to 22,000 feet) portion of the Delaware Basin where large, prolific, and high deliverability Ellenburger and Devonian-Fusselman fields such as Puckett, Gomez, Cayanosa, Toro, Lockridge, Barstow, etc., are found. These are the fields that come to the minds of persons in and outside of the oil and gas industry when the Delaware Basin is mentioned. However, no field of such magnitude is found in the northern, shallower portion of the basin in which the Study Area is located.

It will be noted on Exhibit 1 that the Ellenburger and the Devonian-Fusselman fields are located in the central-to-southern deeper portion of the Delaware Basin whereas we find no Ellenburger field located in the northern portion of the basin in which the ORNL Study Area is located. Furthermore, it will be noted that the three or four Devonian (Siluro-Devonian) fields located in the northern portion of the basin are small, one-to-three-well fields whose small size and, in most cases, whose gas recovery have been disappointing. As illustrated by Exhibits E-7 and E-8, monthly production of gas from these small fields declined rapidly after the first two or three years of sustained production. Thus, from these data and from our detailed geological studies, we conclude that the potential for significant gas production from the Ellenburger and Devonian

NETHERLAND, SEWELL & ASSOCIATES

formations in the northern portion of the Delaware Basin is, at best, only minimal and for the ORNL Study Area is nil.

The current focus of activity in the northern portion of the Delaware Basin is the exploration effort to develop gas production from the Morrow, Atoka, and Strawn formations of the Pennsylvanian series of rocks found at depths of approximately 11,000 to 14,000 feet. Oil and gas operators have been successful in developing Morrow and Atoka gas production along the northwestern edge of the basin in such fields as South Carlsbad, located approximately 35 miles west of the Study Area, Catclaw Draw (Morrow) Field, located approximately 45 miles northwest of the Study Area, and Washington Ranch Field, located approximately 60 miles southwest of the Study Area. However, the difference in the geologic conditions relating to these fields, such as faulting and the environment existing at the time of deposition of the gas-bearing rocks, reduces to a minimum the usefulness of relating the performance of these fields to the smaller fields located in the immediate vicinity of the Study Area. The Indian Basin Field, located still farther west from the South Carlsbad Field, or a distance of approximately 60 miles from the Study Area, has developed significant Morrow and Upper Pennsylvanian gas production; however, this field is on the "Shelf" area in a different geological province and is therefore not pertinent to the geological investigation of the Study Area.

Other and smaller Morrow-Atoka-Strawn fields located nearer the Study Area, such as Cabin Lake, Los Medanos, South Salt Lake, Sand Dunes, etc., have been included in our comprehensive geological and engineering studies and are discussed in more detail in the following sections of this report. The Grama Ridge Field, located approximately 16 miles east of the Study Area, has produced Morrow gas from five wells since its discovery in 1961. The performance of the Grama Ridge Field is shown on Exhibit E-9. As illustrated by this exhibit, the monthly production of gas from the Grama Ridge Field declined rapidly after the first few months of production. We believe the production history of the Grama Ridge (Morrow) Field typifies the production performance that can be expected from the Morrow wells currently being drilled and completed in the northern portion of the Delaware Basin. This exhibit also indicates that the five wells in the Grama Ridge Field will recover approximately 19 to 20 billion cubic feet of gas for an average of approximately 4.0 billion cubic feet per well. Our current geological and engineering studies indicate to us that production from the Morrow-Atoka-Strawn formations in the area of investigation is very elusive and that, even where production is found from these formations, the reservoirs are thin, lenticular, and

NETHERLAND, SEWELL & ASSOCIATES

limited in areal extent. Therefore, it is our opinion that the magnitude of gas recoveries per well from the Morrow-Atoka-Strawn formations will be limited and less than most operators are expecting.

Concerning the shallower Permian formations, records indicate that the northern portion of the Delaware Basin has been extensively drilled without developing any substantial production in the vicinity of the ORNL Study Area. From published maps showing all wells which have been drilled, including dry holes, in the northern portion of the Delaware Basin, we found approximately 245 dry holes that have been drilled within a radius of 15 miles of the ORNL Study Area. While drilling these dry holes, oil and gas operators found a nominal amount of Permian production in such fields as Paduca, Double X, Triste Draw, Salado Draw, and Corral Canyon. However, the drilling of these 245 dry holes within 15 miles of the ORNL Study Area attests to the fact that these shallow zones have been extensively explored.

Plats accompanying this letter show the location of the Ellenburger fields, the Devonian-Fusselman fields, the Morrow-Atoka-Strawn fields, and the Delaware-Permian fields within the Delaware Basin. Another plat, included for orientation purposes only, illustrates the general relationship of the relative magnitude of oil and gas recoveries by area. It will be noted on this plat that the northern portion of the Delaware Basin in which the Study Area is located falls within the lower range of estimated oil and gas recoveries when the northern portion of the Delaware Basin is considered in relation to the entire West Texas-Southeast New Mexico oil and gas producing areas. This further supports our conclusion that no major oil and gas field will be developed within the area of investigation.

In summary, we have thoroughly investigated the hydrocarbon potential of all the formations from surface to the granite basement of the area of investigation located in the northern part of the Delaware Basin, including the formations of the Permian, Pennsylvanian, Devonian-Silurian Age as well as the Ellenburger formation of Ordovician Age. Based on our geological study and supported by our engineering analysis of reservoir performance including ultimate recoveries of oil and gas from formations found productive in the northern portion of the Delaware Basin, it is our conclusion that no major field with substantial oil and gas reserves will be developed within the area of investigation. It is our further conclusion, based on the geological trends summarized on Exhibit 2 which depicts the results of our comprehensive geological study, that no economically recoverable oil or gas exists within the limits of the ORNL Study Area or under the acreage immediately surrounding this Study Area.

NETHERLAND, SEWELL & ASSOCIATES

Detailed discussion and exhibits relating to our geological and engineering studies are presented in the following sections of this report. Basic geological and performance data, together with our engineering work sheets are maintained on file in our office. Certain geological data, such as logs, completion cards, well location maps, etc., were obtained from commercial and private log libraries, map companies, and drilling activity reporting companies. Certain engineering data such as pressure data, oil and gas production, etc., were obtained from published reports of data filed with the state regulatory bodies, such as the Railroad Commission of Texas and the New Mexico Oil Conservation Commission. We believe these data to be accurate; however, we do not certify as to the authenticity of all such data used.

We appreciate the opportunity of performing these studies for you.

Yours very truly,

A handwritten signature in cursive script that reads "Clarence Netherland". The signature is written in dark ink and is positioned below the typed name "Clarence Netherland".

LEGEND

This illustration is for orientation purposes to depict the general range of oil and gas recoveries by area. It is not intended to be and should not be construed to be a precise measure of oil and gas recoveries. The numbers on the contours, 1 through 5, indicate the range from low to higher oil and gas recoveries. This illustrates the lower range of oil and gas recoveries estimated for the northern portion of the Delaware Basin where the study area is located.

FOR ORIENTATION PURPOSES ONLY
GENERALIZED RELATIONSHIP
ILLUSTRATING
RELATIVE MAGNITUDE OF OIL AND GAS
RECOVERIES BY AREA

NETHERLAND SEWELL

&
ASSOCIATES, INC.

DALLAS, TEXAS

MAY, 1974

SCALE IN MILES
10 0 10 20 30 40 50

NETHERLAND, SEWELL
&
ASSOCIATES, INC.

DALLAS, TEXAS

MAY, 1974

DELAWARE (PERMIAN) FIELDS

PRODUCING ZONE MAP
DELAWARE BASIN
WEST TEXAS - SOUTHEAST NEW MEXICO
DELAWARE (PERMIAN) FIELDS

NETHERLAND, SEWELL
&
ASSOCIATES, INC.

DALLAS, TEXAS

MAY, 1974

GENERAL DISCUSSION

The purpose of this report is twofold: (1) To evaluate the hydrocarbon potential of the ORNL Study Area located in the northern portion of the Delaware Basin of Southeast New Mexico (defined in the first paragraph of the accompanying summary letter) based on our comprehensive geological and engineering studies and (2) to evaluate the hydrocarbon mineral interest in the Study Area based on the results of these geological and engineering studies. The major portion of this report presents the technical studies upon which our evaluation of the hydrocarbon potential of the area is based. In this GENERAL DISCUSSION section of the report, we should like to discuss some of the fundamental factors of the oil and gas industry that influence the level of exploration effort for any particular area and thereby indirectly influences the value of the hydrocarbon mineral interests in that area.

We believe it is important to note that the ownership of the minerals contained in or associated with the surface land, or real estate, is considered separate and apart from the ownership of such lands with which these minerals are associated. Under these conditions, the minerals can be sold, traded, leased, or otherwise contracted for separately from the surface land. The ownership or transfer of ownership of minerals is recorded in the county courthouses in the same manner that ownership of the surface land is recorded. While the owner of minerals may also own the surface land, the minerals may also be owned by someone other than the owner of the surface land. Because of this severance in the ownership of minerals from the ownership of surface lands, the owner of minerals has a number of options available to him, some of which are noted as follows:

- (1) The owner of the minerals may sell them outright, thereby relinquishing all further ownership in such minerals;
- (2) The owner of the minerals, if he has sufficient resources, can extract them, as they pertain to oil and gas, by drilling exploratory wells himself and, if successful, he would then own the entire oil and gas production from the well drilled.
- (3) If the owner of the minerals does not desire to drill oil and gas wells himself, he generally can lease the minerals to an oil and gas operator for a specified interval of time or term, usually five years. As an incentive for the

mineral owner to enter into a leasing contract, operators usually agree (a) to permit the mineral owner to retain a "royalty" of $1/8$ or $1/6$ of any monies received from the production and sale of all future oil and gas and (b) to pay the mineral owner a cash bonus which may be as high as several hundred dollars per acre, similar to the bonus paid by oil operators to the state and federal government for offshore leases.

- (4) If the oil and gas operator does not drill a well during the term of the lease or if he drills and abandons a well during this time, the lease expires at the end of its term. Following the expiration of such lease, the mineral owner is then in position to lease the minerals again to another oil and gas operator who wishes to conduct additional oil and gas exploration. In this manner, the minerals associated with one parcel of land may be leased several times to different operators, and each time the minerals are leased the mineral owner receives the "negotiated" cash bonus for entering into such lease contract as well as the annual rental set forth in such lease. As a result of this possible repeated leasing of the same minerals over a period of years, the ownership of such minerals has a value, whether or not oil and gas is ever produced from such property.

The magnitude of the cash bonus which operators are willing to pay the owner of oil and gas minerals for the right to explore for oil and gas is influenced by the expectations of the amount of oil and gas which operators believe to be recoverable by the drilling of such wells. Of course, different operators have different beliefs about the magnitude of recoverable oil and gas for any given lease. Therefore, different operators will agree to pay different prices for the same minerals at any given time. The operator with benefit of favorable geologic, geophysical, and other data helpful in locating possible oil and gas fields may be willing to pay a high cash bonus for such lease. On the other hand, if his findings are not favorable, that operator may not be willing to pay anything for such lease. However, some oil and gas operators who drill exploratory wells based on their interpretation of "trends," but without benefit of geological or other scientific studies, may be willing to pay a certain cash bonus for a lease which the operator mentioned above would have no interest in acquiring. It is because of the different view points and the possession of different scientific data and knowledge by the various operators relative to the po-

NETHERLAND, SEWELL & ASSOCIATES

tential recovery of oil and gas from a particular area that the minerals in that area may have a value, even though we may believe that probabilities of economically recovering oil and gas for this area to be nil.

We present the above discussion in order to point out that the ownership of minerals within the ORNL Study Area can have a value even though it is our conclusion from comprehensive geological and engineering studies that no economically recoverable oil and gas exist within the limits of the Study Area or under the acreage immediately adjoining this Study Area. The bases of our conclusions concerning the hydrocarbon potential of the Study Area are presented in more detail in the geological and engineering sections of this report.

For the minerals pertaining to oil and gas, the value at any given time is influenced by many factors which also affect the economics of the oil and gas industry at that particular time. One of the most obvious of these factors is, of course, the price received from the sale of oil and gas. In this regard, the value of minerals in all areas of the United States has moved upward in the last year along with the upward trend in price of oil and gas. While we expect the present gas price to hold firm or to move upward in this general area, we do not expect it to move substantially higher so long as the interstate sale of gas is regulated by the Federal Power Commission. Generally, we expect the price of oil to either hold firm at current levels or to decrease during the next two- or three-year period, if the world price of oil recedes from its current high level. After that, however, we expect oil prices in this area and the world oil price to continue to increase, but at a lower rate than experienced during the past year. Therefore, we believe any increase in the value of minerals resulting from the increased oil and gas prices to date has reached a plateau, and we would anticipate only modest additional increases in the value of minerals as a result of anticipated future increases in oil and gas prices.

Another factor which affects the value of minerals in an area is the cost of exploring for oil and gas and of operating oil and gas wells, if production is found. In this regard, the cost of seismic surveys and geologic studies to locate suitable drilling prospects have increased sharply during the past two years, and we expect such increases in cost to continue. The cost of drilling and completing oil and gas wells has increased substantially during the past year as a result of a severe shortage of drilling rigs, drilling personnel, and increased cost of equipment such as drill pipe, casing, tubing, separators, and other production facilities. The effect of these increased costs is to reduce the value of oil and gas minerals.

The cost of operating producing wells, once oil and gas is found, has also increased throughout the oil and gas industry because of the shortage of well tenders and operating personnel as well as increased cost of equipment and supplies. The remoteness of the operating area also accentuates and compounds the problem.

Of particular influence on the value of minerals, as pertains to oil and gas, is the hydrocarbon potential of the geologic basin or province in which the minerals are located. As appraisal engineers and geologists, we have observed that oil and gas basins exhibit a discernible life cycle covering a generally definable time span and also that they follow a reasonably predictable performance pattern. Both the life cycle and the performance pattern combine to control the economics of a company's operation in a particular basin and, therefore, the cash bonus which such operator is willing to pay for mineral leases within the basin. We include in the discernible life cycle of oil and gas basins such characteristics as the stages of development from discovery through youth, maturity, old age, and then decline, followed by possible secondary recovery programs for the fields found in the basin. We include in the predictable performance pattern such characteristics as recoverable reserves (influenced by numerous factors, all subject to reasonable analysis), reservoir fluid and pressure performance, and producing capabilities. Each significant producing formation in a basin will have its own performance pattern as exhibited in the Delaware Basin by the Ellenburger fields, the Devonian-Fusselman fields, the Morrow-Atoka fields, and the Permian fields found in this basin, all of which are discussed in more detail in the engineering section of this report. Other economic factors being reasonably comparable, we believe that the cash bonus that a company will pay for the leasing of the minerals in a particular basin is determined by (1) the magnitude of recoverable reserves and producing capabilities associated with the different producing formations in the basin and (2) the point of the basin's life cycle at which a company commences acquiring leases of mineral interests in the basin. In summary, the value of minerals will, of course, be greater where the recoverable reserves are greater, and we believe the value of minerals is higher during the youth stage of the basin's life cycle.

When considering the producing formations in the Delaware Basin in which the ORNL Study Area is located, we believe it important to note that the northern portion of the Delaware Basin is vastly different from the central-to-southern portion of the basin. It is in the central and southern portions of the Delaware Basin that the large, prolific, and high deliverability Ellenburger and Devonian-Fusselman fields such as Puckett,

NETHERLAND, SEWELL & ASSOCIATES

Gomez, Cuyanosa, Toro, Lockridge, Barstow, etc., are located. These are the fields that come to the minds of persons both in and outside of the oil industry when the Delaware Basin is mentioned. However, no such fields as these are found in the northern, shallower portion of the basin where the Study Area is located.

As will be noted from the engineering discussion and the engineering exhibits of this report, as well as the geologic data, there is no significant Ellenburger field within the Southeast New Mexico portion of the Delaware Basin in which the Study Area is located. Also, there are no Devonian-Fusselman fields in the Southeast New Mexico portion of the Delaware Basin comparable to the Cuyanosa, Barstow, and Greasewood fields which are located in the southern portion of the basin. The few Devonian fields found in the northern portion of the basin appear to be small in size and limited in recoverable reserves. Therefore, we have concluded that the northern portion of the Delaware Basin located in Southeast New Mexico simply does not possess the same type of highly prolific, large Ellenburger and Devonian-Fusselman fields for which the southern portion of the basin is noted. Furthermore, we do not believe, based on our comprehensive engineering and geologic studies, that any such large, prolific field will be found in the northern portion of this basin.

The particular producing formation of interest in the Southeast New Mexico portion of the Delaware Basin at the present time is the Morrow-Atoka of Pennsylvanian age. The fields currently producing from these formations are discussed in more detail in the engineering and geological sections of this report. However, it is our opinion that the level of drilling activity for the Morrow-Atoka formation is nearing or has reached its peak, and we do not believe that large, prolific fields will be found in the Morrow-Atoka formation that will compare in any way favorably with the Ellenburger and Devonian-Fusselman fields found in the southern portion of the basin.

The combined evidence resulting from our comprehensive geologic and engineering investigation of the Study Area and of the particular performance pattern of the formations present in and near the Study Area leads us firmly to the conclusion that no economically recoverable oil and gas reserves exist within the limits of the ORNL Study Area or under the acreage immediately adjoining the Study Area.

ENGINEERING DISCUSSION

Based on our comprehensive geological and engineering analysis of the ORNL Study Area located in the northern portion of the Delaware Basin of Southeast New Mexico, we find that both the geology and the engineering aspects of field performance in the northern, shallower portion of the Delaware Basin, in which the Study Area is located, is vastly different from the central-to-southern, deeper (20,000 to 22,000 feet) portion of the basin. We find that it is in the central-to-southern, deeper portion of the basin that the large, prolific and high deliverability Ellenburger and Devonian-Fusselman fields, such as Puckett, Gomez, Cayanosa, Toro, Lockridge, Barstow, etc. are located. These are the fields that come to the minds of persons both in and outside the oil and gas industry when the Delaware Basin is mentioned; however, no such fields as these are found in the northern, shallower portion of the basin where the Study Area is located. Furthermore, based on our comprehensive geological and engineering studies, we do not believe that any such large, prolific field will be found in the northern portion of this basin. To determine the nature and extent to which the northern, shallower portion of the Delaware Basin is different from the southern, deeper portion of the basin, we approached our engineering and geological analyses in the manner described below.

We obtained records of oil and gas production for the fields located in Texas and New Mexico within the limits of the Delaware Basin for the purpose of determining the size of the fields, the magnitude of recoverable oil and gas reserves expected from these fields, and the producing capabilities, particularly of the gas wells, for the fields located throughout the basin. From these data, it became apparent that the large, prolific and high deliverability Ellenburger and Devonian-Fusselman fields were located in the southern, deeper portion of the Delaware Basin. As our investigation moved northward through Reeves, western Ward, and Loving Counties, Texas, into Lea and Eddy Counties, New Mexico, it became further apparent that no comparable Ellenburger and Devonian-Fusselman fields were present in the Lea and Eddy Counties area of the northern, shallower portion of the Delaware Basin. The size and producing characteristics of the smaller fields located in the northern, shallower portion of the basin will be discussed in a later section of this engineering discussion. In the meantime, we should like to spotlight the nature of the more prolific Ellenburger and Devonian-Fusselman fields found in the southern, deeper portion of the basin.

The mention of the Delaware Basin brings to the minds of most people the presence of such Ellenburger and Devonian-Fusselman fields as

NETHERLAND, SEWELL & ASSOCIATES

the Puckett, Gomez, and Coyanosa Fields, located in the southern, deeper portion of the basin, in which very substantial gas recoveries are to be found. The Puckett Field, located in Pecos County, Texas, at the very southern end of the Delaware Basin, covers approximately 31,000 acres and produces Devonian gas from 18 wells and Ellenburger gas from 48 wells. These wells have produced a total of approximately 2.42 trillion cubic feet of gas to January 1, 1974. We estimate that this field will produce an additional 1.86 trillion cubic feet, for an ultimate recovery of 4.28 trillion cubic feet of gas. This field was discovered in 1952 and several of the wells in the field will recover as much as 30 to 40 billion cubic feet of Devonian gas and as much as 100 billion cubic feet of Ellenburger gas, as illustrated by the plot of pressure history versus cumulative gas production for two wells shown on Exhibit E-14. Many of these wells have produced for years at an average rate of 12,000 to 15,000 MCF of gas per day. Puckett has indeed been a field that has attracted the attention of gas explorationists to the Delaware Basin in search of additional fields of this nature.

The Gomez Field, also located in Pecos County, Texas, in the southern portion of the Delaware Basin, covers approximately 70,000 acres and produces Ellenburger gas from depths of approximately 20,000 to 22,000 feet. There are 108 wells in the field which have produced approximately 1.60 trillion cubic feet of gas to January 1, 1974, and we estimate a remaining recoverable reserve of 2.04 trillion cubic feet, for an ultimate recovery of approximately 3.64 trillion cubic feet of gas. Many of the wells in this field will recover 60 to 75 billion cubic feet of gas with some wells estimated to recover in excess of 100 billion cubic feet. The wells in this field are high deliverability wells with many of them producing in excess of 20,000 MCF of gas per day and some of the wells having recorded sustained production between 25,000 and 30,000 MCF per day. The plot of "closed in pressures versus cumulative production" for two rather typical wells in this field are shown on Exhibit E-13. The Gomez Field also merits its distinction as a "giant" gas field in the southern portion of the Delaware Basin.

The Coyanosa Field, approximately 10 to 15 miles north of the Gomez Field, is also located in Pecos County, Texas. The field has produced approximately 550 billion cubic feet of Devonian gas from 22 wells and 315 billion cubic feet of Ellenburger gas from 21 wells, for a total cumulative production of approximately 865 billion cubic feet of gas to January 1, 1974. We estimate a remaining recoverable reserve of 374 billion cubic feet of Devonian gas and 191 billion cubic feet of Ellenburger gas, for a total remaining recoverable reserve of 565 billion cubic feet.

This, when added to the cumulative production of 865 billion cubic feet of gas results in an estimated ultimate recovery from this field of approximately 1.43 trillion cubic feet of gas. Many of the wells in the Cayanosa Field will recover 40 to 50 billion cubic feet of gas with some wells indicated to recover as much as 50 to 60 billion cubic feet, as illustrated on Exhibit E-12. Also, delivery rates in the range of 12,000 to 15,000 MCF per day have been recorded for a number of the wells in this field.

In addition to these three large, prolific and high deliverability fields, we find, as we continue our study northward into the central portion of the Delaware Basin, additional substantial Ellenburger and Devonian-Fusselman fields such as Grey Ranch, Toro, Block 16, Oates, Lockridge, Barstow, Waha, and Mi Vida. We find the Evetts Field of western Winkler County, Texas, located along the eastern edge of the Delaware Basin, as it approaches the New Mexico line, to be the most northern field with any significant Ellenburger production. We find no significant Ellenburger field within the northern portion of the Delaware Basin that extends into Lea and Eddy Counties, New Mexico, where the ORNL Study Area is located. A similar situation exists relative to the large, prolific and high deliverability Devonian fields. Although we find three or four small one-to-three-well Devonian fields in the northern portion of the Delaware Basin of Lea and Eddy Counties, New Mexico, the size of these fields is limited and the performance and recoveries from these smaller fields can in no manner be compared favorably with the quality of the reserves and the deliverabilities of the Devonian-Fusselman fields located in the central-to-southern, deeper portion of the Delaware Basin.

In addition to studying the fields of the central and southern portion of the Delaware Basin as described above, we studied in depth the production and pressure performance of the fields located in the northern, shallower portion of the Delaware Basin as it extends into Lea and Eddy Counties, New Mexico, where the ORNL Study Area is located. This study reveals that the only significant oil and gas development taking place in this portion of the Delaware Basin is the exploration effort to develop production from the Morrow, Atoka, and Strawn formations of the Pennsylvanian series of rocks, found at depths of approximately 11,000 to 14,000 feet. While we find isolated areas or fields where profitable wells are being drilled and favorable gas reserves developed, we believe that the exploration effort to develop production from the Morrow, Atoka, and Strawn formations is approaching or has reached its peak and we would expect that the exploration drilling for the Morrow, Atoka, and Strawn formations will begin to decline during the next one to two years because of what we believe to be rather marginal economics based on exploration costs in drilling

to these formations and the recovery of gas from the wells drilled because of the erratic occurrence of hydrocarbons in these formations, thin lenses of porosity scattered through a thick gross section suggesting any reservoirs found may not be of major importance as such reservoirs likely will be small and probably not connected. These factors, lead us to the conclusion that the economics of drilling to the 11,000 to 14,000 foot depths for these erratic occurrences of thin Morrow, Atoka, and Strawn production is not attractive in this area.

Oil and gas operators have been successful in developing Morrow, Atoka, and Pennsylvanian gas production along the northwestern edge of the Delaware Basin in such fields as South Carlsbad, located approximately 35 miles west of the Study Area, and Washington Ranch Field, located approximately 60 miles southwest of the Study Area. We believe the remoteness of these fields from the Study Area and the difference in the geologic conditions relating to these fields, such as faulting and the environment at the time of deposition of the hydrocarbon bearing rocks, reduces to a minimum the usefulness of relating the performance of these fields to the smaller fields located in the immediate vicinity of the Study Area. The Indian Basin Field, located still farther west from the South Carlsbad Field, or a distance of approximately 60 miles from the Study Area, has developed significant Morrow and Upper Pennsylvanian gas production. However, this field is on the "Shelf" area in a different geological province and is therefore not pertinent to the geological investigation of the Study Area.

Concentrating our study in the immediate vicinity of the ORNL Study Area, we find the fields which produced gas from the Morrow, Atoka, and Strawn formations to be small in size and disappointing in gas production and pressure performance. As will be noted on Exhibit E-1, the production in the Cabin Lake Field, located approximately five miles west of the Study Area, experienced a sharp decline from 1968 through 1970, during which time one well produced approximately 820,000 MCF of gas from the Strawn formation before the well was recompleted to produce from the Morrow formation in the early part of 1973. The plot of monthly gas production indicates that production from the Morrow had begun to decline by the end of 1973, by which time two additional wells had been drilled and completed to produce gas from the Morrow formation. Currently, these three wells appear to be producing approximately 100,000 MCF per month, for an average rate of slightly over 1,000 MCF per well per day. As shown on Exhibit 2, our geologic study indicates the Cabin Lake Field and the Zonne wells to be on the West to East "Cabin Lake Trend" which is located approximately two miles south and outside of the Study Area. We believe

the size of the producing reservoirs from which the wells in this trend are producing is limited in areal extent and therefore the recoverable gas from these reservoirs will be limited.

The Los Medanos (Atoka) Field (the New Mexico Oil & Gas Engineering Committee information indicates "Atoka" production; our geology indicates the production is from the Lower Strawn zone) is located approximately six miles south of the Cabin Lake Field. The monthly production and pressure history of the Shell Oil Company-James Ranch Unit No. 1-0 well (36SE1 T22S-R30E), shown on Exhibit E-4, indicates that it produced rather erratically during the years 1961 through 1967 and that it reached a peak producing rate of approximately 180,000 MCF per month, or approximately 6,000 MCF per day during 1969, after which the monthly production declined at approximately ten percent per year during the last three years. The pressure history of this well indicates that the reservoir from which it is producing likely will recover approximately 26 billion cubic feet of gas (offset wells drilled in the south-southeast portion of this field failed to find this reservoir and the limits of the reservoir in the other directions have not been defined). Immediately offsetting the Shell Oil Company-James Ranch Unit No. 1-0 well is the Belco Petroleum Corporation-James Ranch No. 3-J well, completed to produce gas from the Morrow zone in August of 1972; records now indicate that the No. 3-J well currently is producing from an Upper Strawn zone not present in the two offset wells. In September of 1973 the Belco Petroleum Corporation-James Ranch Unit No. 4-L well was completed to produce gas from the Morrow formation. We believe it very pertinent in the study of this area that neither of these three wells produces from the same reservoir as either of the other wells; in fact, each well produces from a zone that is not present in either of the other two wells. From an engineering viewpoint, this indicates small, lenticular reservoirs of unknown but likely very limited size. See pages G-14 and G-15 of the geologic discussion for additional comments concerning the geological conditions existing in the Los Medanos Field area. We believe it highly unlikely that significant gas reserves can be developed where such geologic conditions exist.

As shown on the Hydrocarbon Distribution Map, Exhibit 2, the Sand Dunes trend of gas production is approximately six miles southeast of the Los Medanos Field. History of monthly gas production and of the pressure performance of the Todd 26 Federal No. 1-G well (26NE2 T23S-R31E), producing gas from the Atoka zone of the Sand Dunes Field, is shown on Exhibit E-5. This exhibit indicates a rapid decline in producing rate for this well, as well as a substantial decline in reservoir pressure to date. The data on Exhibit E-5 indicates that the recovery from the

reservoir from which this well is producing will be approximately 20.5 billion cubic feet of gas.

A similar situation exists for the Morrow production from the Paduca Field, located approximately 10 miles southeast of the Sand Dunes Field. Exhibit E-6 shows a rapid decline in monthly production for three wells producing from the Morrow formation in the Paduca (Morrow) Field and the pressure history indicates that the closed-in wellhead pressure has declined from an original of approximately 6,000 pounds to a current closed-in pressure of approximately 2,000 pounds. This pressure history indicates that the recovery from this reservoir will be approximately 41 billion cubic feet of gas, and, while this represents an average of approximately 14 billion cubic feet of gas per well, the absence of additional development in this field indicates that the field is limited in size.

We believe it is significant that Devonian (Siluro-Devonian) gas production from the Paduca Field and Mid Bell Lake Field, as shown on Exhibit E-7, has been disappointing, with one well in each area having produced less than one billion cubic foot of gas with current producing rates in the range of 6,000 to 7,000 MCF per month.

The Devonian production from three wells located in the Bell Lake Field was approximately 18 billion cubic feet of gas to May of 1973, for an average recovery of approximately 6 billion cubic feet of gas per well. Last production from these wells was recorded in May, 1973. Exhibit E-8 also shows the Devonian production from the North Bell Lake Field. Records since 1962 for one well located in this field indicate the well has produced approximately 19 billion cubic feet of gas to date and a plot of monthly gas production indicates that the producing rate has declined at approximately twelve percent per year during the last six years. Geological data show that the Devonian reservoirs of the Bell Lake and the North Bell Lake Fields occupy anticlines having considerable vertical closures. Such vertical closure is not present in the Devonian formation in the vicinity of the ORNL Study Area; therefore, we conclude that the Devonian formation is not an attractive exploration objective in the ORNL Study Area.

Also shown on the Hydrocarbon Distribution Map, Exhibit 2, is the South Salt Lake Field and our interpretation of the trend of production on which this field is found. The trend is indicated to be from northwest to southeast, with the southeast end of the trend pointing in the direction of the Grama Ridge Field, located approximately 16 miles east of the ORNL Study Area (while the Grama Ridge Field is indicated to be

immediately outside of the Delaware Basin at the current time, we believe that geologically the Grama Ridge Field was inside the limits and part of the Delaware Basin during the geologic time when the gas producing rocks found in the Grama Ridge Field were deposited). In the South Salt Lake Field, Morrow gas wells have been drilled approximately six miles north-east of the ORNL Study Area. The plot of monthly gas production, shown on the lower portion of Exhibit E-1, for the Hat Mesa (Morrow) Field, which we include within the geologic limits of the South Salt Lake Field, shows that the well drilled during the last half of 1972 experienced a very sharp decline in production until mid-year 1973, at which time the second well in this field was completed. Even with the second well included in this plot of monthly gas production, the producing rate has declined from approximately 100,000 MCF per month during October and December of 1973 to approximately 85,000 MCF per month during March of 1974. We believe this decline in producing rate will continue and that the ultimate recovery from these wells likely will not exceed 4 to 5 billion cubic feet of gas per well. Exhibit E-2 shows a plot of monthly gas production as well as the pressure history versus cumulative production for one of the earliest wells, the Little Eddy Unit "CM" State No. 1-0, that was drilled in the South Salt Lake (Morrow) Field; as shown by the pressure history, we estimate this well will ultimately recover approximately 7 billion cubic feet of gas. The production from the South Salt Lake Field has been increased sharply during the last six months by drilling and completing of additional new wells in the field. These wells are too new to have meaningful pressure histories sufficient to indicate the magnitude of recoverable gas, but we do not expect them to recover any more than, and possibly less than, the first well drilled in the field (the Little Eddy Unit "CM" State No. 1-0) described above. Exhibit E-3 shows the monthly gas production and pressure history versus cumulative production for the Little Eddy "CH" State Unit No. 1-H well which has produced approximately 4.27 billion cubic feet of gas from the Atoka formation. Current production from this well averages approximately 15,000 MCF per month, or approximately 500 MCF of gas per day. This is the only well in the South Salt Lake Field producing gas from the Atoka formation.

Wells in the South Salt Lake Field are estimated to cost approximately \$1,000,000 to drill and complete and the cost of a dry hole is estimated at approximately \$750,000. We believe these costs for drilling to depths of 11,000 to 14,000 feet for thin and scattered zones of Morrow porosity, as shown on Exhibit E-10, from which the gas is produced, together with the cost of drilling one and perhaps several dry holes in the process of defining the limits of the field, will render this field less profitable than expected and will thereby reduce the level of drilling activity

in this area. Furthermore, it is our conclusion that the field will not extend south-southwest to any point nearer than approximately 3.5 to 4.0 miles from the northeast corner of the ORNL Study Area.

The production history of the Grama Ridge (Morrow) Field, located in Lea County, New Mexico, approximately 16 miles east of the ORNL Study Area, we believe typifies the type of production performance that can be expected from the Morrow wells currently being drilled and completed in the northern, shallower portion of the Delaware Basin. The plot of monthly gas production and the pressure history versus cumulative production for the five wells located in the Grama Ridge (Morrow) Field are shown on Exhibit E-9. This field commenced production in early 1966, reached a peak production of approximately 22,000 MCF per day from five wells during early 1967 and immediately started a decline of approximately forty percent per year, which has persisted through the end of 1973, at which time total production from the three remaining wells in the field was approximately 750 MCF per day. The pressure history from the field indicates an ultimate recovery of 19 billion cubic feet of gas, for an average recovery of approximately 4.0 billion cubic feet of gas per well.

In summary, our comprehensive geologic studies indicate to us that production from the Morrow-Atoka-Strawn formations, which is currently the focus of the major activity in the northern portion of the Delaware Basin, is very elusive and that even where production is found from these formations, the reservoirs in the area of investigation are thin, lenticular and limited in areal extent; therefore, it is our opinion that the magnitude of gas recoveries per well will be limited and less than most operators are expecting. We believe the pressure history and monthly production shown on the accompanying engineering exhibits support the fact that reservoirs are limited in size and that the recoverable gas is limited in magnitude. These data lead us to the conclusion that the general exploration effort to develop gas reserves from the Morrow-Atoka-Strawn formations in the northern portion of the Delaware Basin will prove to be less profitable than most operators believe and likely will be no more than marginally profitable when all exploration and operating costs are considered together with the revenue received from the production and sales of gas obtained from the Morrow-Atoka-Strawn fields in this area. We believe, therefore, that the Morrow-Atoka-Strawn exploration effort is approaching or has reached its peak and will commence a decline during the next one to two years.

Relative to the probabilities of developing substantial reserves from the Devonian formation in the northern portion of the Delaware Basin,

we believe the performance of the three or four one-to-three-well fields found to date demonstrate that the potential of developing such substantial reserves are at best minimal. And concerning the probabilities of Ellenburger production in the area of investigation, we find no significant production from the Ellenburger zone and we consider the possibilities of developing significant production from the Ellenburger to be nil.

Records indicate that the shallower Permian formations in the northern part of the Delaware Basin have been extensively drilled without developing any substantial production in the vicinity of the ORNL Study Area. From published maps showing all wells, including dry holes, which have been drilled in the northern portion of the Delaware Basin, we count approximately 245 dry holes that have been drilled within a radius of 15 miles of the ORNL Study Area in search for production from the shallow Permian zones, and while drilling these dry holes, oil and gas operators did find a nominal amount of Permian production in such fields as Paduca, Double X, Triste Draw, Salado Draw, and Corral Canyon Fields; the drilling of these 245 dry holes within a 15-mile radius of the Study Area attest to the fact that these shallow zones have been extensively explored.

In summary, we have thoroughly investigated the hydrocarbon potential of all the formations from surface to the granite basement of the Delaware Basin, including the formations of the Permian, Pennsylvanian, and Devonian-Silurian Age, as well as the Ellenburger formation of Ordovician Age. Based on this comprehensive geological study within the area of investigation, supported by our engineering analysis of reservoir performance and ultimate recoveries of hydrocarbons from the formations which have been found productive in the northern portion of the Delaware Basin, it is our conclusion that no major field with substantial oil and gas reserves will be developed within the area of our investigation. It is our further conclusion based on the geological trends summarized on Exhibit 2 which depicts the results of our comprehensive geological study, that no economically recoverable oil and gas exist within the limits of the ORNL Study Area or under the acreage immediately surrounding this Study Area.

TABLE OF CONTENTS

<u>GEOLOGICAL DISCUSSION</u>	<u>Page No.</u>
INTRODUCTION	G- 1
HYDROCARBON DISTRIBUTION MAP AND OVERLAY	G- 3
SUMMARY OF DELAWARE BASIN GEOLOGY	G- 4
AREA OF INVESTIGATION	G- 6
STRATIGRAPHY	
General	G- 7
Precambrian	G- 7
Cambrian and Ordovician	G- 7
Silurian and Devonian	G- 8
Mississippian	G- 8
Pennsylvanian	G- 8
Permian	G- 9
STRUCTURE	G-12
HYDROCARBON ANALYSIS	
General	G-13
Mississippian Lime, Siluro-Devonian, Ellenburger Analysis Map	G-13
Morrow Analysis Map	G-14
Atoka Analysis Map	G-14
Strawn Analysis Map	G-15
Bone Springs-Wolfcamp Analysis Map	G-15
Delaware Analysis Map	G-16
CONCLUSIONS	G-17
TABULATION OF KEY WELLS	G-18
SELECTED REFERENCES	G-21

INTRODUCTION

The area of investigation encompassed by this report covers a segment of the northern end of the Delaware Basin in southeastern New Mexico as depicted on Exhibit G-1. This sixteen-township investigation is centered around the ORNL PROJECT 78X-38284V Study Area which covers three square miles. These 1,920 acres are shaded on all maps in this report and are described as follows: The southeast quarter of Section 35, the south half of Section 36, T21S-R31E, all of Section 1, the east half of Section 2, T22S-R31E, Eddy County, New Mexico; the southwest quarter of Section 31, T21S-R32E and the west half of Section 6, T22S-R32E, Lea County, New Mexico.

The assignment to determine the probability of commercial hydrocarbons present under the ORNL Study Area acreage necessitated a complete review of the oil and gas distribution in the area of investigation together with a study of the structural and rock conditions responsible for such accumulations. Literature appertaining to the geological history of the entire Delaware Basin and contiguous elements was studied to form a basis for setting the geological environment for potential hydrocarbon accumulations in the ORNL Study Area. A list of selected references is included with this report.

Exhibit G-1 is the Key Well Map showing the area of investigation and all of the essential wells examined for this geological work. A list of these key wells is included at the end of this report. These wells afforded both the geological and production data necessary to formulate the eventual conclusions. Each formation in approximately 310 wells was investigated to determine the subsurface depth of critical formations above basement rocks in the stratigraphic column (Exhibit G-2). These data were incorporated on the 22 maps accompanying this report. Ten cross-sections were prepared, of which two are included as Exhibits G-17 and G-18, which depict the subsurface conditions under the ORNL Study Area.

The structural configurations of each significant rock unit was determined and the hydrocarbon production from each such unit was delineated. The producing section of each well was also examined to ascertain the rock characteristic which composed the porous section. The relationship of production to structure was noted and the trends of production established.

An analysis map was made of each producing or potentially productive formation, trends depicted, and findings in each case were related to the three-square-mile ORNL Study Area.

NETHERLAND, SEWELL & ASSOCIATES

All production from all producing rock units was incorporated on the hydrocarbon distribution map (Exhibit 2) and the overall relationship of the hydrocarbon accumulations to the ORNL Study Area was investigated to form the basis for the conclusions.

HYDROCARBON DISTRIBUTION MAP AND OVERLAY

Exhibit 2 with overlay depicts all of the hydrocarbon producing wells in the area of investigation and the estimated present limits of such production. It will be noted that practically all of the production is on the axes of structural anticlines with the Morrow gas accumulations being the most outstanding. Some isolated wells have produced off of the structural highs, but their production has been insignificant.

The production situation in the three-well offset cluster on the west side of the Los Medanos trend presents an interesting reservoir complex as each well produces from a zone not present in the other two wells.

The Strawn reef field in T20S-R30E is the only reef production in the area of investigation and the one Wolfcamp and two Bone Springs wells north of the ORNL Study Area are the only producers from these formations. There is no Mississippian, Devonian, Silurian, or Ellenburger production although these units have been tested along the crests of the structural trends. A small Ellenburger gas show was tested through casing in the South Salt Lake field, but it was not commercial.

The ORNL Study Area lies on the south flank of a synclinal trough, 3.2 miles south of the South Salt Lake field, 4.1 miles east of the Cabin Lake field, and 1.8 miles northwest of the Zonne pool. It is also less than two miles northeast of a deep dry hole (15SW1 in T22S-R31E) which failed to find commercial hydrocarbon production in any formation.

Based on the results of drilling to date, the only commercial production in the area of investigation has been found along the anticlinal trends as depicted on Exhibit 2.

SUMMARY OF DELAWARE BASIN GEOLOGY

Prior to Pennsylvanian time, the area now encompassed by the Delaware Basin was part of a broad depression, called the Tobosa Basin, that extended across southeastern New Mexico and West Texas.

During Cambrian time, the area was emergent and Cambrian sediments are missing due to erosion or non-deposition over most of the basin.

Transgression of the sea began in Ordovician time and thick carbonate shelf deposits of the Ellenburger formation accumulated on the eroded Precambrian surface.

As the Tobosa Basin subsided in Middle and Late Ordovician time, the clastics and carbonates of the Simpson formation and the carbonates of the Montoya formation were deposited.

During Silurian and Devonian time, shelf carbonates were deposited along the margins of the basin and dense limestones, cherts, and black shales accumulated in the deeper waters.

In Late Devonian time, the area was uplifted, eroded, and again invaded by a transgressing sea which deposited the Woodford shale unconformably over the eroded surface.

Shelf carbonate and basinal shale deposits of Mississippian age accumulated conformably above the Woodford. In the northern part of what is now the Delaware Basin, the Mississippian deposits are represented by a thick limestone overlain by the Barnett shale.

In Early Pennsylvanian time, the Tobosa Basin was divided into the Midland Basin, on the east, and the Delaware Basin, on the west, by the emergence of the Central Basin platform.

Early Pennsylvanian deposits in the Delaware Basin are represented by the Morrow sands and shales. These clastics were followed by the limestones and shales of the Atoka and Strawn formations. A northeast-southwest trending line of Strawn reefs formed along the northwest margin of the basin. At the close of Pennsylvanian time, the predominantly shale deposits of the Cisco and Canyon formations were laid down.

In Early Permian time, renewed tectonic activity resulted in rapid sinking of the Delaware Basin and growth of many local structural features. The thick Wolfcamp formation, mostly clastics, was deposited in the basin, while shelf limestones and reefs accumulated along the northern margin. Following the Wolfcamp, subsidence resumed and was accompanied by a thick accumulation, in the northern part of the basin, of the alternating fine-grained clastics and carbonates of the Bone Springs formation. Reefs continued to grow along the northern shelf margin. In Late Permian time, reefs built up around the margins of the basin and acted as barriers which segregated the back-reef shelf deposits from the basin proper. Within the basin, the thick clastics of the Brushy Canyon and Cherry Canyon were deposited and, at the close of this phase, the Bell Canyon clastics and carbonates accumulated basin-ward from the encircling Capitan reef. Growth of the Capitan reef sealed off the basin from sources of clastic material, and the thick Permian evaporite section, represented by the Castile, Salado, and Rustler formations was laid down. At the end of Permian time, the seas had retreated and deposits of redbeds had begun. The Delaware Basin and surrounding elements had achieved the shapes essentially as shown on Exhibit 1.

AREA OF INVESTIGATION

Exhibit G-1 is the Key Well Map showing the essential wells which formed the basis for preparing the 21 structural, isopachous, and analysis maps included in this report, being Exhibits 2, G-3 through G-16, and G-19 through G-23. Additional well data were examined in this sixteen-township area of investigation, but the key wells shown are the ones most critical to the ORNL assignment.

Each key well has a proper symbol designation, as set out in the legend, showing whether it is a producing oil or gas well, abandoned oil or gas well, or a dry hole. The particular formation or formations from which the wells produce is shown on the appropriate formation map. The Triste Draw and the Cruz fields contain some 12 and 5 oil wells, respectively, which are surrounded by dry holes. The dotted outlines of these fields show the productive limits. The wells in these fields are not shown.

Cross-sections A-A' and B-B' traverse the ORNL Study Area and are shown in detail on Exhibits G-17 and G-18.

STRATIGRAPHY

GENERAL

Rocks in the area of investigation range in age from Precambrian to Quaternary. This report is concerned only with those sedimentary deposits which occur below the base of the Castile evaporites of Late Permian age in the central and southern portions of the area and below the Capitan Reef of Late Permian age in the northern portion of the area. Exhibit G-2 shows the stratigraphic column for the area. The geology of the Castile and younger deposits in this area is extensively described in a recent report published by the United States Geological Survey (Jones, 1973).

Various published and private sources were consulted in an attempt to identify the rock units present in the area of investigation. While some units can be easily picked from wireline logs of wells in the area, other units are more difficult to correlate and previous workers have disagreed about the positions of some unit boundaries. In this investigation, disputed unit boundaries have been arbitrarily fixed by selecting wireline log markers that are a compromise of earlier picks and that can be correlated throughout the area.

PRECAMBRIAN

Only one well in the area of investigation penetrated the base of the sedimentary section. This well, 23SW1, T20S-R31E, bottomed in granitic basement rocks that are assumed to be Precambrian in age.

Regional magnetic maps do not indicate any radical changes in basement rock type or structure in the area of investigation.

CAMBRIAN AND ORDOVICIAN

Sediments of these systems are represented in the area of investigation by the Ellenburger, Simpson, and Montoya formations.

Three wells in the area reached the Ellenburger formation, and the only well to penetrate the entire section found the formation to consist of 445 feet of carbonate (probably dolomite) rocks. Tests and cores show portions of the Ellenburger to be porous and permeable.

The Simpson formation, which overlies the Ellenburger, is represented in the area by about 300 feet of dense clastics.

NETHERLAND, SEWELL & ASSOCIATES

Above the Simpson is the Montoya formation which is about 450 feet in thickness and is composed of dense carbonates with interbeds of shale.

SILURIAN AND DEVONIAN

In the area of investigation, these systems are represented by a thick (935 to 1,240 feet) section of carbonates overlain by 140 to 210 feet of Woodford shale.

The carbonates are undifferentiated but, for the most part, are probably Silurian shelf deposits. It is doubtful that much, if any, Devonian carbonates are preserved in the area of investigation. Tests and cores indicate these carbonates to have zones of good porosity and permeability.

Regional studies (McGlasson, 1973) indicate the Woodford shale to have been deposited unconformably over the older carbonates during an invasion of the sea in Late Devonian time.

MISSISSIPPIAN

In the area of investigation, this system is represented by the massive Mississippian Lime and the overlying Barnett shale. Total thickness of the Mississippian is 825 to 1,100 feet. Tests indicate the Mississippian Lime to be porous and permeable at some localities.

PENNSYLVANIAN

Major rock units of the Pennsylvanian system in the area of investigation are the Morrow, Atoka, Strawn, Cisco, and Canyon formations. The geology of these units in southeast New Mexico has been extensively described by Meyer (1966).

Morrow Formation

In the area of investigation, the Morrow formation ranges in thickness from 500 feet in the north to 1,000 feet in the south. It is composed of interbedded sandstone and shale units with occasional limestone beds. Distribution of porosity in the sandstones is erratic, both vertically and horizontally, making it difficult (1) to predict which beds will be porous prior to drilling and (2) to estimate the lateral extent of known individual porous beds. In general, Morrow sandstone porosity appears to be concentrated along the anticlinal trends. This could indicate either

winnowing of sands over gentle positive areas during deposition or preservation of porosity by early hydrocarbon accumulations. Either case would be affirmation that growth of present structural trends began during, or prior to, Pennsylvanian time. However, the Morrow isopachous map does not indicate any strong variations in thickness due to local structures.

Atoka Formation

The Atoka formation is primarily limestones with interbedded shales in its lower portion and primarily shale with occasional limestone beds in its upper portion. The basal contact appears to be gradational with the Morrow, and limey sands and sandy limes occur in the Atoka near the contact. In the area of investigation, the Atoka thickens from 400 feet in the northwest to 700 feet in the southwest and does not show any pronounced local thickness variations. The Atoka limestones are dense except for small local pockets of porosity.

Strawn Formation

The Strawn formation is dominantly a massive limestone with alternating lime and shale stringers in the upper part of the formation. In the northwest part of the area of investigation, there is a local porous reef buildup in the Strawn. This buildup is along a regional northeast-southwest reef trend and there is no evidence of Strawn reefing in the area southeast of this trend. Where reefing is absent, the Strawn limestones are dense except for small local developments of porosity in the southwestern part of the area. The Strawn ranges from 300 to 400 feet in thickness over most of the area, but thickens to more than 700 feet in the vicinity of the reef to the northwest.

Cisco and Canyon Formations

These formations are predominantly shale with thin interbeds of dense carbonates and coarser clastics. The upper contact of the Cisco with the Wolfcamp is difficult to determine in the area of investigation. Therefore, no attempt was made to map the thickness of these individual units.

PERMIAN

Over most of the area of investigation, the Permian formations that occur below the Castile evaporites are the Wolfcamp, Bone Springs, Brushy Canyon, Cherry Canyon, and Bell Canyon. The last three formations make up the Delaware Mountain Group and are commonly referred to

as the "Delaware." Post-Delaware deposits that are older than the Castile are limited to the northern part of the area and are not significant to this investigation. Meyer (1966) and Silver and Todd (1969) have described the Wolfcamp, Bone Springs, and Delaware in considerable detail.

Wolfcamp Formation

In the area of investigation, the Wolfcamp formation is composed of dense limestones and shales with occasional sandy units. Porosity is lacking except for small patches in the north part of the area. The Wolfcamp appears to have been affected by local tectonic activity in the area. An isopachous map (Exhibit G-3) shows that the interval from the top of the Wolfcamp to the top of the Strawn thins over structural highs and thickens in the troughs. Thickness of the total Wolfcamp-Cisco-Canyon interval ranges from 800 feet to 1,800 feet.

Bone Springs Formation

This formation consists of a thick sequence of alternating clastics and dense limestones. Significant occurrences of porosity in the Bone Springs formation have not been found in the area. In thickness, the Bone Springs ranges from 2,700 feet in the north to 3,400 feet in the south. There is some evidence of thinning over local highs, but not of the magnitude exhibited in the Wolfcamp.

Brushy Canyon and Cherry Canyon Formations

In the area of investigation, these formations are represented by a sequence of interbedded sands, silts, and shales. The sands are commonly fine-grained and tight except for local developments of porosity that are usually associated with structural highs. An isopachous map (Exhibit G-4) shows the thickness of these units to range from 2,500 feet to 2,900 feet. The map also shows thinning over the highs and thickening in the troughs, indicating rejuvenation of local folding during deposition of these formations.

Bell Canyon Formation

In the central and southern portion of the area of investigation, the Bell Canyon formation is similar to the underlying Cherry Canyon formation except for the occurrence of limestone interbeds, particularly in the upper portion. Porous zones in the Bell Canyon appear to be related to accumulation of clean sands in depressions on an undulating topographic

NETHERLAND, SEWELL & ASSOCIATES

surface (Nottingham, 1960). Across the northern part of the area, the Capitan reef interfingers with, and replaces, all except the lower portion of the Bell Canyon deposits described above. The reef marks the boundary of the Delaware Basin at the close of Bell Canyon deposition. South of the reef, the Bell Canyon is overlain by the Castile evaporites.

STRUCTURE

The area of investigation is located at the north end of the Delaware Basin. Most of the area is on the west flank of the basin, near the central axis, and regional dip is generally to the southeast. Several local folds which trend more or less east-west are present in the area.

Preliminary mapping of the area indicated, where deep control was available, that deep structures were reflected as gentle folds in the shallow (Bell Canyon and Cherry Canyon) formations. Inasmuch as subsurface control from wells is greatest for the shallow formations, structural features in those formations were honored in preparing maps of the deeper horizons. Exhibit G-5 is an isopachous map that shows how the overall interval, from the top of the Cherry Canyon to the top of the Siluro-Devonian Lime, thins over the local structural highs and thickens in the troughs. Growth of the structural highs probably was initiated in pre-Pennsylvanian time and was accelerated during time of deposition of the Wolfcamp, Brushy Canyon, and Cherry Canyon formations. Exhibits G-6 through G-16 show the structure of various formations and Exhibits G-17 and G-18 are structure sections that cross the area of investigation.

Three prominent anticlines and two less pronounced structural highs cross the area of investigation. To the northeast, a strong anticline plunges east-southeast across T20S-R32E, T20S-R33E, and T21S-R32E. This feature is referred to in this report as the South Salt Lake Trend. A broad gentle anticline trends east-west across T22S-R30E, T22S-R31E, and T22S-R32E in the central part of the area. The western portion of this feature plunges to the east and is referred to in this report as the Cabin Lake Trend. Near the west edge of T22S-R32E, the anticline crosses a saddle and the resulting closure on the eastern part of this feature is referred to as the Zonne Trend. In the southern part of the area, a broad irregular anticlinal nose plunges eastward across T23S-R30E, T23S-R31E, and T23S-R32E. This feature is referred to in this report as the Sand Dunes Trend. The two less pronounced anticlinal features are the Big Eddy Trend in the northwestern part of the area and the Los Medanos Trend located between the Cabin Lake and Sand Dunes Trends. Both of these features plunge in an easterly direction and die out, particularly in the older formations, near the center of the area.

The three-square-mile ORNL Study Area (in the center of the area of investigation) is located low on the northeast flank of the Cabin Lake Trend.

HYDROCARBON ANALYSIS

GENERAL

Oil activity in the investigation area started in the Nineteen Forties, and hundreds of Delaware sand wells were drilled. Several small Delaware sand fields were found in the area, including South Hackberry, Maroon Cliffs, Parallel, Quahada Ridge, Sand Dunes, Triste Draw, and Cruz (Exhibit G-24). Deeper exploration for the Devonian and Ellenburger formations was touched off by success in these formations in the southern part of the Delaware Basin (Exhibit 1), but no commercial production has been found in these beds in the area of investigation. However, the deep tests disclosed that thin Morrow sands and thin Atoka and Strawn limestone porosities were often productive on small structures with the most significant being the Morrow gas accumulation in the South Salt Lake field (Exhibit G-20). These thin porosities scattered through a large gross section suggest the fields may not be of major importance as the reservoirs may be small and probably not connected. In all events, the economics of drilling to great depths for these erratic occurrences of thin Strawn, Atoka, and Morrow production are not as attractive in this area as elsewhere in the basin.

The geological findings are portrayed on analysis maps, Exhibits G-19 through G-24.

MISSISSIPPIAN LIME, SILURO-DEVONIAN, AND ELLENBURGER ANALYSIS MAP,
EXHIBIT G-19

No commercial production has been found in the Mississippian Lime, Devonian-Silurian Lime, and Ellenburger formations in the area of investigation. One well in the South Salt Lake field (25SE1, T20-R32E) tested non-commercial gas from the Ellenburger through casing.

Most of the tests of these formations were drilled on the anticlinal highs except in Ranges 32E and 33E of Township 20S. Exploration for these formations included 20 Mississippian Lime tests and 19 Devonian-Silurian tests. Of the 20 Mississippian Lime tests, only two had a gas show. Of the 19 Devonian-Silurian tests, two wells were not tested, one had a gas show, 13 yielded salt water, and three resulted in salt water with a show of gas.

The tests of these deep Mississippian, Devonian-Silurian, and Ordovician formations indicate that exploration for hydrocarbons in these

rock units in the area of investigation is not attractive, even on the indicated structural highs.

MORROW SAND ANALYSIS MAP,
EXHIBIT G-20

Morrow gas production has been found in the area of investigation on structural highs in thin sands erratically scattered through the Morrow formation. It appears that most of the sands lose porosity on the flanks although edge water has been encountered in the South Salt Lake field and on the Cabin Lake and Sand Dunes Trends. No production has been found in the tight sands in the synclinal areas between the established trends, and often tight sections are encountered along the anticlinal axes. Furthermore, the thin, porous sands do not always appear to be connected and are often absent in offset wells. For example, the Belco well in the southwest quarter of Section 6, T23S-R31E, is producing gas from a porous Morrow sand section not present in the offset wells. The production is associated with the anticlinal trends, and the three-square-mile ORNL Study Area, which is in a synclinal trough between the South Salt Lake and Cabin Lake-Zonne Trends, does not appear to be favorably located for Morrow sand exploration.

ATOKA ANALYSIS MAP,
EXHIBIT G-21

Atoka production in the area of investigation is associated with porosity in the limes on structural highs. One well is producing from six feet of porosity on the crest of the South Salt Lake field; one well produced to depletion from six feet of porosity in the Los Medanos field; and three wells currently are producing from four, eleven, and twenty feet of porosity, respectively, in the Sand Dunes field. The twenty feet of porosity in the latter wells is from two zones of twelve and eight feet, respectively. No water has been reported for any of these wells.

The Atoka has been penetrated and found to be non-porous in twelve wells other than the gas well (36NE1) in the South Salt Lake field and in four wells on the Cabin Lake Trend; one well had eleven feet of wet porosity (20NE1) and one well (36NW1) was tight on the Zonne Trend; one well (1SE1) produced gas to depletion in the Los Medanos field and two wells east of, and on trend with, the Sand Dunes field penetrated the Atoka and found no porosity.

NETHERLAND, SEWELL & ASSOCIATES

Based upon the foregoing, it does not appear that the Atoka formation is an attractive hydrocarbon objective in the vicinity of the ORNL Study Area acreage.

STRAWN ANALYSIS MAP, EXHIBIT G-22

Strawn production is limited to the western side of the area of investigation, South Hackberry and Big Eddy oil fields in the north and Cabin Lake and Los Medanos gas fields in the south. The accumulations in the northern wells are due to reef porosity, and limestone porosity harbors the gas in the south. All of the fields appear to be related to structure. The reef production is floored by water, and the gas-bearing limestone porosity appears to be erratic in nature.

The Shell well (36SE1, T22S-R30E) and the offset Belco well (1SE1, T23S-R30E) are not producing from the same reservoirs, as comparable porous intervals in one well are not present in the other. Also, the offset Belco Morrow gas well (6SW1, T23S-R31E) does not have comparable porosity in either of the offset wells.

The Strawn formation has been penetrated and found tight by some 13 wells in the South Salt Lake field, two wells on the Cabin Lake Trend, two wells on the Zonne Trend, and seven wells on the Sand Dunes Trend.

Thus it appears the Strawn is not an attractive objective reservoir in the synclinal area where the ORNL Study Area acreage is located (Exhibit G-11).

BONE SPRINGS-WOLFCAMP ANALYSIS MAP, Exhibit G-23

Forty-nine wells have been drilled in the area of investigation through the Bone Springs-Wolfcamp formations and only three resulted in producers. These three wells, 3SE1 and 21NW1 in T20S-R31E and 14NW4 in T20S-R33E, are all in the extreme northern portion of the area of investigation and far removed from the ORNL Study Area.

Sixteen wells in the South Salt Lake field penetrated these formations without finding commercial accumulations. Several wells had oil and gas shows, but the majority found the entire section non-porous.

Five wells penetrated the formations on the Cabin Lake and Zonne Trends and all found the Bone Springs-Wolfcamp formations tight.

These formations were penetrated by four wells on the Los Medanos Trend and by seven wells on the Sand Dunes Trend and, in all cases, no zones were encountered that warranted testing.

Based upon the dry-hole results of the wells drilled on the axes of the four structural trends in the area of investigation, it is believed that the Bone Springs-Wolfcamp formations do not constitute attractive hydrocarbon objectives under the ORNL Study Area.

DELAWARE ANALYSIS MAP,
EXHIBIT G-24

Delaware sand production has been found to the north and south of the ORNL Study Area. These fields include South Hackberry, Maroon Cliffs, and Parallel fields in the north and Sand Dunes, Triste Draw, and Cruz in the south. One well produced to depletion in the Quahada Ridge field in the western portion. All of these fields are on structurally high trends, and no production has been established within a six-mile radius of any of the ORNL Study Area.

Based upon the results of wells drilled to date, it is not felt that the Delaware sands offer an attractive objective in the synclinal area of the ORNL Study Area acreage.

CONCLUSIONS

Three prominent structural highs cross the central portion of the area of investigation: the South Salt Lake Trend in the northeast; the Cabin Lake-Zonne Trend south of the ORNL Study Area; and the Sand Dunes Trend in the southern part of the area. These structural highs carry through from shallow Permian beds to the deeper Siluro-Devonian beds as reflected by the structure and isopachous maps (Exhibits G-3 through G-16).

The three-square-mile ORNL Study Area, shaded on all maps, is located in a synclinal trough on the north flank of the Cabin Lake-Zonne Trend.

Hydrocarbon production near the central portion of the area of investigation is limited to the Delaware, Strawn, Atoka, and Morrow formations where porosity exists on the crests of the structural highs. No production in any formation has been found in the synclinal troughs, such as the one traversing the central portion of the area (Exhibits 2 and G-19 through G-24).

This study indicates that no hydrocarbon accumulations of significance can be expected in the trough area under the lands comprising the ORNL Study Area in any formation from the Permian to the Precambrian.

Respectfully submitted,

Chas. C. Bankhead, Jr.

AAPG Certified Petroleum Geologist 257

William A. Huckaba

AAPG Certified Petroleum Geologist 1592

TABULATION OF KEY WELLS

AREA OF GEOLOGIC INVESTIGATION FOR ORNL STUDY

DELAWARE BASIN, EDDY AND LEA COUNTIES, NEW MEXICO

MAP KEY	Operator	Lease	Production
<u>T20 - R31E</u>			
2SW1	Shell Oil Company and Texas Crude	#1-2 Big Eddy Unit	
3SE1	Pan American Petroleum Corporation	#1 Big Eddy Unit	Wolfcamp Gas Well
4SE2	Champlin Petroleum Co.	#33 Big Eddy Unit	Strawn Oil Well
5SE1	Monsanto Company	#34 Big Eddy Unit	
6SE1	Pan American Petroleum Corporation	#3 Big Eddy Unit	Strawn Oil Well
7SE1	Pan American Petroleum Corporation	#11 Big Eddy Unit	Delaware Sand Oil Well
10NW1	Perry R. Bass	#37 Big Eddy Unit	
19NE1	Pan American Petroleum Corporation	#9 Big Eddy Unit	
19SW1	Pan American Petroleum Corporation	#10 Big Eddy Unit	Strawn Oil Well
19SE1	Pan American Petroleum Corporation	#7 Big Eddy Unit	Strawn Oil Well
20SE1	Richardson & Bass	#1 Federal Welch	
21NW1	Pennzoil United	#12 Big Eddy Unit	Bone Springs Oil Well
23SW1	Richardson & Bass	#1 Cobb Federal	Delaware Sand Oil Well
25NW1	Shell Oil Company	#1-25 Big Eddy Unit	
27SE1	Richardson & Bass	#1 Federal Baxendale	
27NE1	Richardson & Bass	#1 Federal Rodke	Delaware Sand Oil Well
29NW1	Union Texas Petroleum	#14 Big Eddy Unit	
30NE1	Perry R. Bass	#15 Big Eddy Unit	Abandoned Strawn Oil Well
30SE1	Shell Oil Company and Texas Crude	#1-30 Big Eddy Unit	Abandoned Delaware Oil Well
30NW1	Perry R. Bass	#8 Big Eddy Unit	Strawn Oil Well
<u>T20S - R32E</u>			
10NW1	Shell Oil Company	#1 Perry Federal	
15SW1	Phillips Petroleum Company	#1 Plata Deep Unit	
21SW1	Shell Oil Company and Texas Crude	#1-21 Big Eddy Unit	
25SE1	Texas Company	#1 Richards	Morrow Gas Well
36NE1	Texaco, Inc.	#1 CH State	Dual - Atoka Gas, Morrow Gas
<u>T20S - R33E</u>			
5SW1	Pan American Petroleum Corporation	#1 Little Eddy Unit	
7SW3	The Texas Company	#1 Muse Federal	
14NW4	Sinclair Oil & Gas Co.	#1 Mahaffey Federal	Dual - Bone Springs Oil, Morrow Gas
30NW2	Belco Petroleum Corp.	#1 Bass Federal	Morrow Gas Well
31SE1	Texaco, Inc.	#1 CM State	Morrow Gas Well
32SW1	Amini Oil Co.	#1 SL State	Morrow Gas Well
33SW1	Amini Oil Co.	#1 Aztec State	Morrow Gas Well
<u>T21 - R30E</u>			
26SW1	Phillips Petroleum Company	#1 James "D"	Atoka Gas Well
35SW1	Stanolind Oil & Gas Co.	#1 Duncan	Morrow Gas Well
<u>T21S - R32E</u>			
1NE1	Phillips Petroleum Company	#1 Etz Federal	
1SW1	Kimball Production Co.	#1 Federal	Morrow Gas Well
2NW1	Amini Oil Co.	#1 Pubco Federal	Morrow Gas Well
4NW1	Amini Oil Co.	#1 New Mexico Federal	Morrow Gas Well
6NW1	Fred Turner	#1 AID Federal	
10NE1	Superior Oil Company	#1 Govt. "H" Com.	Morrow Gas Well
11NE1	Phillips Petroleum Co.	#1 Hat Mesa	Morrow Gas Well
14NE1	Brunson & McKnight	#1 Hat Mesa	Morrow Gas Well
26NE1	Gulf Oil Company	#1 San Simon Federal	

NETHERLAND, SEWELL & ASSOCIATES

TABULATION OF KEY WELLS

AREA OF GEOLOGIC INVESTIGATION FOR ORNL STUDY DELAWARE BASIN, EDDY AND LEA COUNTIES, NEW MEXICO

MAP KEY	Operator	Lease	Production
<u>T22 - R30E</u>			
2SE1	Phillips Petroleum Company	#1 James "A"	Strawn Gas Well
11NE1	Phillips Petroleum Company	#1 James "E"	Strawn Gas Well and Morrow Gas Well
27NE1	Richardson-Bass	#1 Legg	Delaware Oil Well
36SE1	Shell Oil Company	#1 James Ranch Unit	Strawn Gas Well (Called Atoka by Operator)
<u>T22 - R31E</u>			
15SW1	C. W. Williams	#1 Badger Unit Federal	
23SE1	Texas Crude	#1 Wright Federal	
<u>T22S - R32E</u>			
9SE1	Culbertson & Irwin	#1 Murray	
13SE1	Ray Smith	#1 Texas Weaver Federal	
14SW1	Carper Driller	#2 Red Tank Unit	
18SE1	John Trigg	#1-18 Federal Jennings	
19SE1	Ralph Lowe	#1 Bass Federal	
20NE1	R. J. Zonne	#1 Federal	Morrow Gas Well
21NW1	Culbertson & Irwin	#1 Gilmore	
21SE1	Union of California	#1 Gilmore Federal	
22NW1	John Trigg	#1-22 Federal Red Tank Unit	
31NE1	Tidewater Oil Company	#1 Richardson-Bass Estate	
36NW1	Shell Oil Company	#1 Bootleg Ridge Unit	
<u>T22S - R33E</u>			
7SW1	Cabot Corp.	#1 K State	
20NW1	Davis & Collins	#1 Continental Federal	
32SW1	S. B. Helbing	#1 B Shell SL	
33NE1	Kirklin & Farris	#1 Phillips State	
34SE1	C. P. Miller	#1 Humble State	
<u>T23 - R30E</u>			
1SE1	Belco Petroleum Corp.	#3 James Ranch	Strawn Gas Well (Atoka Gas Depleted)
16SE1	Skelly Oil Co.	#1 Forty-Niner Ridge Unit	Morrow Gas Well
<u>T23S - R31E</u>			
2NE1	Continental Oil Company	#1 State "AA-2"	
6SW1	Belco Petroleum Corp.	#4 James Ranch Unit	
11SE1	M. Wilson	#1 Bauerdorf Federal	
14SW1	Texas American Oil Corp.	#14-1 Todd Federal	Atoka Gas Well
16SW1	El Paso Natural Gas Co.	#1 Arco State	Atoka Gas Well
21SE1	Patoll Corp.	#1 Muse Federal	
23SE1	Texas American Oil Corp.	#1 Todd "23" Federal	Cherry Canyon Oil Well
26NE1	Texas American Oil Corp.	#4 "26" Federal	Cherry Canyon Oil Well
26NE2	Texas American Oil Corp.	#1 Todd Federal	Atoka Gas Well
26NE3	Texas American Oil Corp.	#2 Todd Federal	Cherry Canyon Oil Well
27SW1	Patoll Corp.	#1 Wright	
29SE1	El Paso Natural Gas Co.	#1 Mobil Federal	Morrow Gas Well
36NW1	Texas American Oil Corp.	#1 Todd "36" Federal	Morrow Gas Well

TABULATION OF KEY WELLS

AREA OF GEOLOGIC INVESTIGATION FOR ORNL STUDY
DELAWARE BASIN, EDDY AND LEA COUNTIES, NEW MEXICO

<u>MAP KEY</u>	<u>Operator</u>	<u>Lease</u>	<u>Production</u>
<u>T23S - R32E</u>			
3NE1	O. B. Kell, Jr.	#1	Federal
7NE1	J. H. Trigg	#5-7	Federal "WL"
9SE1	McBee Oil	#1-9	Continental Federal
11NE1	Hill, Meeker & Ambassador	#1-11	Mathews
15NE1	J. H. Trigg	#1-15	Continental Federal
20SE1	Kirklin Drig.	#1-AE	Federal Estill
21NW1	C. Hankamer	#1-AA	Gulf Federal
28NW1	M. M. Wilson	#1	Continental Federal
31SW1	C. Hankamer	#1	Continental Federal
33NE1	C. Hankamer	#1	Holder Federal
36SE1	Pure Oil Company	#1	Brinninstool Deep Unit

SELECTED REFERENCES

- Adams, J. E., 1965, Stratigraphic-Tectonic Development of Delaware Basin: AAPG Bull, Vol. 49, No. 11, p. 2140-48.
- Barnes, V. E., et al., 1953, Stratigraphy of Pre-Simpson Paleozoic Rocks of Texas and New Mexico: Texas Univ., Bureau of Eco. Geology Publ. No. 5924.
- Berg, J. W., Jr., et al., 1960, Seismic Investigations-Eastern Part of Basin and Range Province: Seis. Soc. America Bull., Vol. 50, p. 511-35.
- Daly, J. and Page, C. N., 1953, Velocity Conditions in W. Texas and New Mexico: AAPG Bull. Vol. 36, No. 4, p. 658-76.
- Dobrin, M. B., et al., 1954, Surface and Near-Surface Waves in the Delaware Basin: Geophysics, Vol. 19, No. 4, p. 695-715.
- Elam, J. G., 1973, Tectonic Evolution of Val Verde - Delaware Basin (Abstract): AAPG Bull. Vol. 57, No. 2, p. 420.
- Flawn, P. T., 1961, The Ouachita System: Texas Univ. Pub. 6120, p. 49-58 and 65-81.
- Flower, R. H., 1958, Cambrian - Mississippian Beds in Southern New Mexico: Roswell Geol. Soc. 11th Field Conference Guidebook, p. 61-78.
- Hills, J. M., 1963, Late Paleozoic Tectonics - Western Texas to Southern Colorado: AAPG Bull. Vol. 47, No. 9, p. 1709-25.
- Hills, J. M., 1970, Late Paleozoic Structural Directions in Southern Permian Basin: AAPG Bull., Vol. 54, No. 10, p. 1809-27.
- Hills, J. M., 1968, Gas in Delaware and Val Verde Basins, Natural Gases of North Americas: AAPG Mem. G, p. 1394-1432.
- Hills, J. M., et al., 1949, Pre-Permian Rocks of Trans-Pecos Area and Southern New Mexico: W. Texas Geol. Soc. Guidebook, Field Trip No. 5.

SELECTED REFERENCES

- Holmgren, H. J., 1965, Deep Pays in Delaware and Val Verde Basins: AAPG Mem. 4 (Fluids in Subsurface Environments), p. 257-279.
- Huffington, Roy M., et al., 1951, Petroleum Geology of Permian Basin of West Texas and Southeastern New Mexico: W. Texas Geol. Soc. Publ.
- Jacka, A. D., 1967, Guadalupian Depositional Cycles of Delaware Basin: W. Texas Geol. Soc. Pub. 69-56 (Cyclic Sedimentation in the Permian Basin) p. 152-196.
- Jones, C. L., 1973, Salt Deposits of Los Medanos Area, Eddy and Lea Counties, New Mexico: U.S. Geol. Sur. Open-File Report USGS-4339-7.
- Kinney, E. E., et al., 1967, Oil and Gas Fields of Southeastern New Mexico: Roswell Geol. Soc. Symposium.
- LeMay, W. J., 1973, Oil and Gas Energy and its Impact on New Mexico: Energy Crisis Symposium, Albuquerque, New Mexico.
- McGlasson, E. H., 1973, Silurian-Devonian of W. Texas and E. New Mexico (Abstract): AAPG Bull. Vol. 57, No. 2, p. 421-22.
- Meyer, R. F., 1966, Geology of Pennsylvanian and Wolfcampian Rocks in S.E. New Mexico: New Mexico Bur. Mines and Minerals Resources, Mem. 17, p. 123.
- Nettleton, L. L., 1971, Elementary Gravity and Magnetics (Puckett Field, Delaware and Midland Basins, Hobbs Field): SEG Monograph No. 1, p. 86, 95-96, and 101-114.
- Nottingham, M., 1960, Recent Upper Bell Canyon Exploration in the North Delaware Basin, Oil and Gas Fields of Southeastern New Mexico: Roswell Geol. Soc. Symposium.
- Podpechan, F., 1960, Lower Pennsylvanian Gas Exploration, S.E. New Mexico: Roswell Geol. Soc. Symposium of Oil and Gas Fields of S.W. New Mexico.

SELECTED REFERENCES

- Silver, B. A., and Todd, R. G., 1969, Permian Strata, Midland and Delaware Basins: AAPG Bull. Vol. 53, No. 11, p. 2223-51.
- Sweeny, H. N., et al., 1960, Oil and Gas Fields of Southeastern New Mexico: Roswell Geol. Soc. Symposium.
- Stipp, T. F., et al., 1956, Oil and Gas Fields of Southeastern New Mexico, a Symposium: Roswell Geol. Soc. p. 376.
- Thomton, D. E., and Gaston, H. H., Jr., 1968, Lusk Strawn Field, Eddy, and Lea Counties, New Mexico: AAPG Bull. Vol. 52, No. 1, p. 66-81.
- Vertrees, C. D., et al., 1963, Cross-Section Axis of Val Verde and Delaware Basins: West Texas Geol. Soc. Pub. 64-49.
- Vertrees, C. D., et al., 1960, Paleozoic Geology of the Delaware and Val Verde Basins, Corpus Christi Geol. Soc. 10th Annual Field Trip Guidebook, p. 32-41. (Also in Geology of the Val Verde Basin Guidebook: West Texas Geol. Soc. p. 64-73).
- Young, Addison, et al., 1960, Geology of the Delaware Basin: W. Texas Geol. Soc. Guidebook.

TABLE OF CONTENTS

ENGINEERING EXHIBITS

HISTORY OF MONTHLY GAS PRODUCTION and/or PLOT
OF PRESSURE VERSUS CUMULATIVE GAS PRODUCTION

<u>Field</u>	<u>County, State</u>	<u>No.</u>
Cabin Lake (Morrow)	Eddy County, New Mexico	E- 1
Hat Mesa (Morrow)	Lea County, New Mexico	E- 1
South Salt Lake (Morrow)	Lea County, New Mexico	E- 2
South Salt Lake (Atoka)	Lea County, New Mexico	E- 3
Los Medanos (Atoka)	Eddy County, New Mexico	E- 4
Sand Dunes (Atoka)	Eddy County, New Mexico	E- 5
Paduca (Morrow)	Eddy County, New Mexico	E- 6
Paduca (Devonian)	Lea County, New Mexico	E- 7
Mid Bell Lake (Devonian)	Lea County, New Mexico	E- 7
Bell Lake (Devonian)	Lea County, New Mexico	E- 8
North Bell Lake (Devonian)	Lea County, New Mexico	E- 8
Grama Ridge (Morrow)	Lea County, New Mexico	E- 9
Antelope Ridge (Devonian)	Lea County, New Mexico	E-11
Antelope Ridge (Morrow)	Lea County, New Mexico	E-11
Coyanosa (Ellenburger)	Pecos County, Texas	E-12
Coyanosa (Devonian)	Pecos County, Texas	E-12
Gomez (Ellenburger)	Pecos County, Texas	E-13
Puckett (Ellenburger)	Pecos County, Texas	E-14
Puckett (Devonian)	Pecos County, Texas	E-14

CORRELATION SECTION

South Salt Lake-Grama Ridge	Lea County, New Mexico	E-10
-----------------------------	------------------------	------

CORRELATION SECTION

ORNL PROJECT 78X 382 84V	
EDDY AND LEA COUNTIES, NEW MEXICO	
NETHERLAND, SEWELL & ASSOCIATES, INC.	
DALLAS, TEXAS	MAY, 1974

NETHERLAND, SEWELL & ASSOCIATES

TABLE OF CONTENTS

<u>GEOLOGICAL EXHIBITS</u>	<u>No.</u>
KEY WELL MAP SHOWING CROSS-SECTIONS	G- 1
STRATIGRAPHIC COLUMN	G- 2
ISOPACHOUS MAPS	
Wolfcamp and Cisco-Canyon	G- 3
Cherry Canyon to Bone Springs	G- 4
Cherry Canyon to Siluro-Devonian Lime	G- 5
STRUCTURE MAPS	
Ellenburger	G- 6
Top Siluro-Devonian Lime	G- 7
Mississippian Lime	G- 8
Top Barnett	G- 9
Top Morrow	G-10
Atoka	G-11
Strawn	G-12
Wolfcamp	G-13
Top Bone Springs	G-14
Top Cherry Canyon	G-15
Top Bell Canyon	G-16
CROSS-SECTIONS	
A-A'	G-17
B-B'	G-18
ANALYSIS MAPS	
Mississippian Lime, Siluro-Devonian, Ellenburger	G-19
Morrow Sand	G-20
Atoka	G-21
Strawn	G-22
Bone Springs-Wolfcamp	G-23
Delaware	G-24

NORTHERN DELAWARE BASIN
PALEOZOIC STRATIGRAPHIC COLUMN

SYSTEM	EPOCH	ROCK UNITS
PERMIAN	OCHOAN	RUSTLER ANHYDRITE SALADO SALT CASTILE EVAPORITES TANSIL
		DELAWARE GROUP BELL CANYON CAPITAN REEF BELL CANYON CLASTICS CHERRY CANYON BRUSHY CANYON
		BONE SPRINGS FORMATION
		WOLFCAMP FORMATION

SYSTEM	EPOCH	ROCK UNITS
PENNSYLVANIAN	MISSOURIAN AND VIRGILIAN	CISCO CANYON FORMATION
	DESMOINESIAN	STRAWN FORMATION
	DERRIAN	ATOKA FORMATION
	MORROWAN	MORROW FORMATION
MISSISSIPPIAN	CHESTER - MERAMEC	BARNETT SHALE
	OSAGE - KENDERHOOK	MISSISSIPPI LIME
SILURO - DEVONIAN		WOODFORD SHALE SILURO - DEVONIAN LIME
ORDOVICIAN		MONTOYA SIMPSON ELLENBURGER
PRECAMBRIAN	BASEMENT	

ORNL PROJECT 78X 382 84V
EDDY AND LEA COUNTIES, NEW MEXICO

NETHERLAND, SEWELL
&
ASSOCIATES, INC.
DALLAS, TEXAS MAY, 1974

L E G E N D

WELLS THAT PENETRATED
SILURO-DEVONIAN LIME

ORNL PROJECT 78X 382 84V
EDDY AND LEA COUNTIES, NEW MEXICO

TOP SILURO-DEVONIAN LIME STRUCTURE MAP

SCALE IN FEET
4000 0 4000 8000 12000 16000 20000 24000 28000

NETHERLAND, SEWELL
&

ASSOCIATES, INC.

DALLAS, TEXAS

MAY, 1974

L E G E N D

- STRAWN OIL WELL
- ⊗ STRAWN GAS WELL
- WELLS THAT PENETRATED STRAWN
- ⊘ ABANDONED OIL WELL

ORNL PROJECT 78X 382 84V
EDDY AND LEA COUNTIES, NEW MEXICO

STRAWN STRUCTURE MAP

SCALE IN FEET
4000 0 4000 8000 12000 16000 20000 24000 28000

**NETHERLAND, SEWELL
&
ASSOCIATES, INC.**
DALLAS, TEXAS MAY, 1974

ORNL PROJECT 78X 382 84V
EDDY AND LEA COUNTIES, NEW MEXICO

CROSS SECTION A-A'

HORIZONTAL SCALE IN FEET
5000 0 5000 10,000 15,000 20,000 25,000
VERTICAL EXAGGERATION: 8X

NETHERLAND, SEWELL & ASSOCIATES, INC.
DALLAS, TEXAS

MAY, 1974

ORNL PROJECT 78X 382 84V
EDDY AND LEA COUNTIES, NEW MEXICO

CROSS SECTION B-B'

HORIZONTAL SCALE IN FEET
5000 0 5000 10,000 15,000 20,000 25,000
VERTICAL EXAGGERATION: 8X

NETHERLAND, SEWELL
&
ASSOCIATES, INC.

DALLAS, TEXAS

MAY, 1974

L E G E N D

BE	BELL CANYON	●	DELAWARE OIL WELL
CH	CHERRY CANYON	⦿	ABANDONED OIL WELL
BR	BRUSHY CANYON		
SG	SHOW OF GAS		
SO	SHOW OF OIL		
SOG	SHOW OF OIL-GAS		
SOGSW	SHOW OF OIL-GAS-SALT WATER		

ORNL PROJECT 78X 382 84V
EDDY AND LEA COUNTIES, NEW MEXICO

DELAWARE ANALYSIS MAP

SCALE IN FEET
4000 0 4000 8000 12000 16000 20000 24000 28000

**NETHERLAND, SEWELL
&
ASSOCIATES, INC.**
DALLAS, TEXAS
MAY, 1974