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OIL AND GAS POTENTIAL OF THE SAN JUAN BASIN

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INTRODUCTION

AAPG—Prep Study

Sixty-seven years after the discovery of oil and gas in the San Juan Basin we know a great deal about the potential of the major producing areas, and we know little about the potential of the less explored plays. The American Association of Petroleum Geologists (AAPG) included the San Juan Basin as part of a pilot study in their Petroleum Resources Estimation Project (PREP). This project covered five Rocky Mountain basins: the Big Horn, Wind River, greater Green River (including Sand Wash basin and excluding the overthrust belt), the Paradox and the San Juan. (The outline of the PREP San Juan-Paradox basin study area is shown on Figure 1.) The AAPG-PREP used a play analysis approach wherein each basin was subdivided into known or potential producing horizons or groups of horizons that constitute a play. For the purpose of this study a play was defined as follows:

> A play has *geographic limits* and is confined to a basin or part of a basin, an uplift or part of an uplift, an overthrust belt, or some other geologically determined area. It may be subdivided arbitrarily by state or county lines. There may be similar plays in several basins or on several uplifts, but they should be considered as separate plays.
>
> A play has *stratigraphic limits* and is confined to a formation, or a group of closely related formations, on the basis of lithology, depositional environment, or structural history.
>
> *Traps* within a play may be entirely structural, entirely stratigraphic or combinations of structural and stratigraphic elements. Early in the play, structural traps may have been the dominant objective, but present exploration may be concentrating on stratigraphic traps.
>
> A "play" is a practical, meaningful planning unit around which an integrated exploration program can be developed. It is based on geological concepts and embraces all the area under which a particular combination of reservoirs, traps, and hydrocarbons has been mapped or is postulated. When active, a play involves exploratory effort, with a view to locating exploitable accumulations of oil and/or gas. Exploration ventures based on a particular play can be aimed at more than one reservoir and at more than one type of trap, as long as the integrated exploratory effort involved is designed to locate attractive anomalies (prospects) within the suite of geological principles which define the concept of that play.

AAPG estimates of recoverable oil and gas are based on present price and present technology. If undiscovered but postulated oil and gas accumulations were considered to be non-economic under present price and technology, those hypothetical accumulations were not included in the estimates of resources.

Since undiscovered oil and gas is both unknown and unknowable to even an imprecise estimate, the AAPG-PREP made estimates of four probability categories; these have 4 different values ranging from a lowest value with the most probability, to a highest value with the least probability. These four categories are:

1. There is a 95% chance that there will be at least this amount of petroleum.
2. There is a most likely probability that there will be at least this amount of petroleum.
3. There is a 5% probability that there will be at least this amount of petroleum.
4. There is a .01% probability that this amount of petroleum might be found.

The AAPG undertook this study at the request of the United States Department of the Interior. The United States and state governments have long felt the need for well-based estimates of undiscovered resources. The AAPG study was a pilot study to determine the feasibility of new methods and definitions and to determine the practicality of obtaining the very detailed data required.

The AAPG project is a landmark. It is the first time that experienced petroleum geologists with a variety of professional associations have ever undertaken such a study. The "play" analysis approach is a rigorous one and the credentials of the project workers are excellent.

Prior estimates of undiscovered oil and gas are numerous. None of them used such a scientific approach as the current study, and none had the benefit of a large group of experienced petroleum geologists who had actively engaged in petroleum exploration over a long time period in the area studied. A prior AAPG study using data as of 1968 estimated thirteen times as much oil might be found as that listed under this study's "most likely" category. A USGS study using 1974 data came up with almost three times as much oil in the "most likely" category as this 1977 AAPG study. The current AAPG study estimated three times more gas might be found in the "most likely" category than the USGS estimated in 1975. The USGS considered a much larger potentially productive area in their San Juan-Paradox basin province, thus all of their numbers should have been larger if considerations other than area were equal.

The above comparisons point out three things that should be obvious, but unfortunately are not to those outside the field of petroleum geology. First, the unknown cannot be estimated by anybody to a precise number; second, explora-

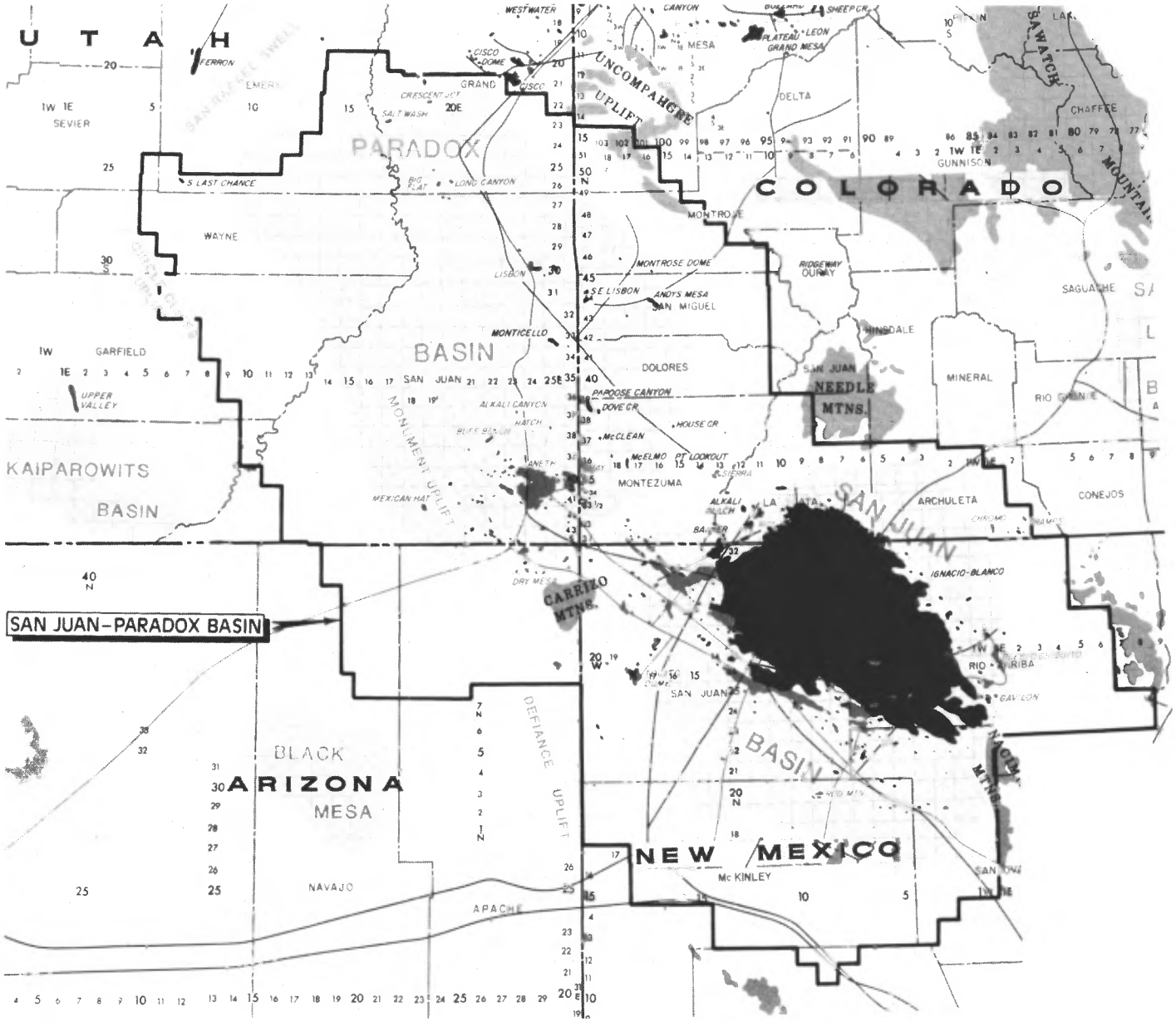

Figure 1. Index map showing the location of the San Juan-Paradox basin area. Dark gray area is San Juan Basin gas field, black areas are oil fields; major oil and gas pipelines are also shown.

tion costs and oil and gas prices are critical items in a study that estimates what might be found with a stated price and under known technology. Nobody will look for something that will not pay for the cost of finding it; and third, science is a useful tool, particularly when applied by experienced people with diverse backgrounds and professional associations.

A tabulation of the AAPG-PREP estimates for the San Juan and Paradox basins follows (Tables 1 and 2). Since the AAPG study combined the Paradox and San Juan basins, we have not attempted to make a separate study of the San Juan Basin. However, the Paleozoic potential is believed to be much greater in the Paradox basin and the Mesozoic potential is much greater in the San Juan Basin.

Probability estimates such as those listed for each play in Table 2 are best combined or summed using probability distributions. The simplest approach is to use a lognormal distribution. Allen N. Quick and P. Terry Pope, Cities Service Oil Company, worked out a computer program that used the "most" likely" and 5% values to determine the lognormal curve for each play. Once that fit was determined, the modal and .01% values were used to define a lognormal distribution for summation. The process of Monte Carlo simulation was used to find the total distribution of all of the plays considered in a basin. In the simulation 500 passes were used. The calculated mean is simply the arithmetic average of the points that the simulation model calculated. This program, in addition to determining the mean, also determines the "mode," or the probability with the greatest chance of occurring. The "total" figures on Table 2 were obtained from this Cities Service program. The total estimate listed under the undis-

Table 1. AAPG-PREP Basin Total Tabulation

PARADOX-SAN JUAN BASIN CUMULATIVE PRODUCTION 12/31/75 (Oil in 10^6 bbls, Gas in Bcf)					PARADOX-SAN JUAN BASIN PROVED RESERVES 12/31/75			
PLAY	Oil	Assoc. Gas	Non-Assoc. Gas	NGL	Oil	Assoc. Gas	Non-Assoc. Gas	NGL[1]
Nacimiento	possibly mostly charged from leaking gas wells in older rocks		.007	—	—	—	5.0	—
Farmington	.07	?	.95	—	.04	—	1.2	—
Fruitland	.02	—	62.3	—	.02	—	25	—
Pictured Cliffs	.13	?	2,009	—	.07	—	2,200	—
Chacra	.01	—	75.4	—	.02	—	210	—
Mesaverde	17.4	?	4,542	—	20	—	6,750	—
Gallup (Niobrara)	123.88	—	2	7.2	20	—	2	—
Dakota-Morrison	47	—	2,795	—	15	—	3,200	—
Entrada	1	—	—	—	9	—	—	—
Pennsylvanian (includes Cutler upper Hermosa)	325.75	362	254	.084	203	225.5	50	—
Miss.-Devonian	40.73	298[2]	—	—	14.02	457.3	(includes 298 reinjected)	
Cambrian	—	—	—	—	—	—	—	—
TOTALS	555.99	660	9,740.657	7.284	281.17	682.8	12,443.2	—

[1] NGL estimates were not made in the Paradox-San Juan basin
[2] reinjected

covered "most likely" category is the statistical mode. The totals listed under the other three undiscovered categories are as defined, namely 95%, 5% and .01%.

The decision to use the "most likely" and 5% values to determine the lognormal curve for each play was made for two reasons; those two estimates were judged to be the most reliable by the men making the original play analyses, and had the best statistical fit and range.

Figures 2, 3, 4 and 5 (courtesy of Cities Service Oil Company) illustrate the statistical summation of the individual "play" estimates for non-associated gas in the Paradox-San Juan basin.

SAN JUAN BASIN GAS PRODUCTION FUTURE

The influence of gas and oil prices on exploration and development in the San Juan Basin has had a much more significant effect on exploration and development in the basin than the geology has. The change in Mesaverde spacing rules in 1975, allowing a second (infill) well to be drilled on a 320-acre tract, did not change the amount of gas present in this formation, but it did change the rate at which the gas could be withdrawn and marketed. The decline curves, Figure 6, vividly portray the uniqueness of Mesaverde production from the Cretaceous sandstones in the San Juan Basin (decline curves of the major Pictured Cliffs and Basin-Dakota fields are similar).

The new $1.44 per Mcf price allowed by the Federal Power Commission has stimulated additional exploration and development drilling in the San Juan Basin, both for deep and relatively unknown Pennsylvanian and older objectives and for the shallower Cretaceous objectives. Pennsylvanian exploration is in its infancy in the basin. The biggest recent change in development plans has occurred in the Mesaverde reservoir in the main San Juan Basin gas producing area (Blanco-Mesaverde gas field). The following comments concerning Mesaverde infill drilling are from an *Oil and Gas Journal* article (March 21, 1977) on this field.

Operators, according to rough estimates, will drill about 200 infill wells this year in the 850,000-acre Blanco-Mesaverde gas field. Operators already have drilled 275-300 wells since 1975, including 209 completions. El Paso holds an interest in 340,000 of the approximately 860,000 acres that lie within the field's productive limits. El Paso holds gas-purchase contracts on another 150,000 acres. About half the rigs running in the infill program this year will be contracted to El Paso. Although economics will determine the extent of drilling beyond 1977, El Paso is expected to have a leasehold or contract interest in 1,500 of the approximately 2,000 infill wells that ultimately could be drilled.

Aztec Oil and Gas, an affiliate of Southland Royalty Co., says it plans to drill 34 infill wells this year and will have an interest in another seven wells. It currently is operating two rigs. The company over the life of the project could drill about 100 net wells. It has drilled 28 and participated in seven others to date. Aztec's net-acreage interest totals about 50,000 acres. Gross acreage is about 188,000. Tenneco, with an interest in about 40,000 acres, will use one rig this year to drill about 13 wells. It has drilled 127 as operator and had an interest in 186. It plans to drill about 75 more beyond 1977.

Northwest Pipeline will operate two rigs in the field this year, with one drilling infill wells. Northwest as operator plans 150-160 wells over the life of its project. It has drilled 41 and participated in four or five others.

Amoco will have one rig drilling some of the 40 gross wells in which it has an interest in 1977. The operator has drilled eight wells for itself and has participated in 15. It has an interest in about 25,000 acres.

Wells currently cost about $180,000 each, including $50,000 in completion costs. Those costs were estimated at about $110,000 in 1974 when El Paso sought a reduced-spacing order from the New Mexico Oil Conservation Commission (OGJ, Dec. 16, 1974, p. 17). At that time, El Paso says, the project was considered economically feasible at 44 cents/Mcf. El Paso says it ultimately could invest nearly $200 million. Northwest Pipeline estimates it could spend $75 million and Aztec $17.5 million. Without the higher price, operators say drilling could decrease markedly.

Northwest Pipeline says it estimates infill drilling already has boosted its production by about 32.8 MMcfd. Its current production from the entire San Juan Basin is about 270 MMcfd. The operator estimates its production ultimately could be boosted by 80 MMcfd. Tenneco's production of 75 MMcfd is up by 25 MMcfd since infill drilling began. It estimates a 40-MMcfd increase by the end of the program. Amoco says its production in November 1976 totaled 40 MMcfd from wells it operates. By the end of 1977, it expects to be producing about 63 MMcfd. El

Table 2. AAPG-PREP Basin Total Tabulation of Undiscovered Recoverable Oil & Gas

PARADOX-SAN JUAN BASIN — *Oil in 10^6 bbls, Gas in Bcf* — *Estimates as of 12/31/75* — *PARADOX-SAN JUAN BASIN*

PLAY	UNDISCOVERED[1] 95% PROBABILITY				UNDISCOVERED[1] 5% PROBABILITY				UNDISCOVERED[1] THE MOST THAT MIGHT BE FOUND (assumed to be a probability of .01%)				UNDISCOVERED[1] MOST LIKELY			
	Oil	Assoc. Gas	Non-Assoc. Gas	NGL[2]	Oil	Assoc. Gas	Non-Assoc. Gas	NGL[2]	Oil	Assoc. Gas	Non-Assoc. Gas	NGL[2]	Oil	Assoc. Gas	Non-Assoc. Gas	NGL[2]
Nacimiento	—	—	—	—	—	—	—	—	—	—	considered to be insignificant					—
Farmington	unexploited but essentially proven so no undiscovered numbers listed															
Fruitland	—	—	180	—	—	—	500	—	—	—	700	—	—	—	250	—
Pictured Cliffs	—	—	1,250	—	—	—	4,000	—	—	—	5,000	—	—	—	2,500	—
Chacra	—	—	670	—	—	—	2,000	—	—	—	2,700	—	—	—	1,300	—
Mesaverde	33.6	—	1,870	—	70	—	10,000	—	125	—	15,000	—	40	—	7,500	
Gallup (Niobrara)	3	10	.5	—	50	50	2	—	60	60	75	—	24	25	1	—
Dakota-Morrison	16	—	2,000	—	26	—	3,200	—	30	—	3,800	—	20	—	2,500	—
Entrada	4	—	—	—	20	—	—	—	30	—	—	—	6	—	—	—
Pennsylvanian (includes Cutler upper Hermosa)	75	84	100	—	375	417	1,052	—	400	440	2,060	—	100	90	160	—
Miss.-Devonian	22.4	164	—	—	370	2,710	290	—	600	4,390	350	—	44	322	5	—
Cambrian	0	0	0	—	30	150	9	—	75	375	40	—	.15	1	1	—
TOTALS[3]	209	373	12,892	—	573	3,055	17,989	—	1,071	12,354	20,269	—	252	333	14,666	—

[1] Because of the nature of the Cretaceous gas fields in the San Juan Basin, the values listed under "undiscovered" are actually "undeveloped" estimates for the most part.
[2] NGL estimates were not made in the Paradox-San Juan basin.
[3] The *undiscovered* column do not total arithmetically because individual probability curves for each play were summed using a statistical technique described in the report.

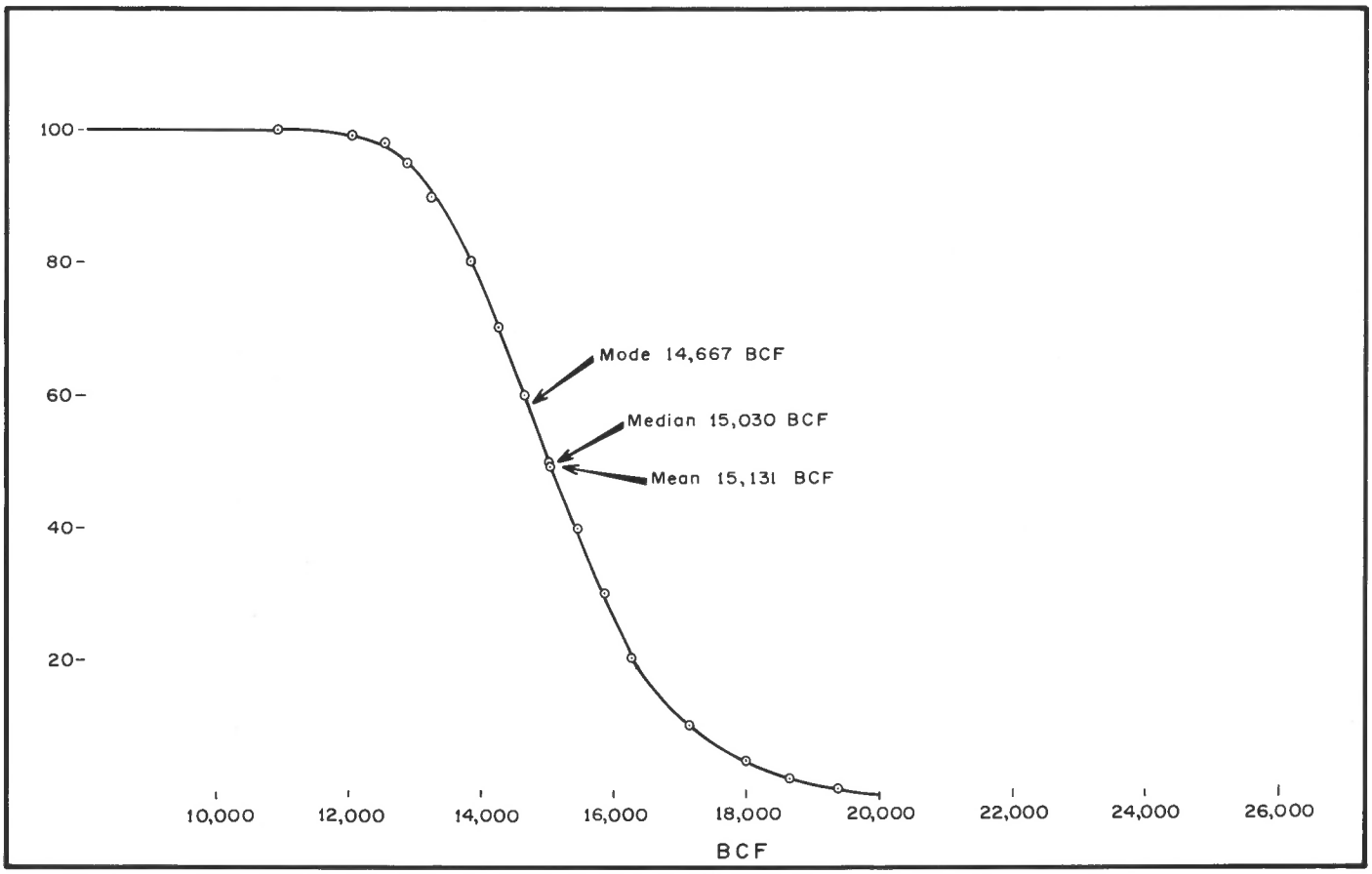

Figure 2. Cumulative probability curve for Paradox-San Juan basin non-associated gas (BCF=billion cubic feet).

Paso says its dedicated production from infill wells in 1976 averaged 70 MMcfd. Continuation of the program is expected to ultimately increase production to El Paso by 300 MMcfd over what could have been produced without infill drilling.

El Paso says the average Blanco-Mesaverde well is estimated to have original gas reserves of about 4.2 billion cu ft; infill drilling could increase those reserves by as much as 70%. Aztec says it calculated 1.5-2 billion cu ft of additional recoverable reserves from some of its better infill of the new infill wells completed to date. The estimated average productive life of the new infill wells is 25-30 years. Aztec's production decline from older wells hasn't yet been offset by new production from infill wells, however, it expects to arrest the current decline and increase daily production as the program progresses. Aztec's current production in the San Juan Basin is about 90 MMcfd.

With more than 2,000 wells completed in the field before the infill program began, operators had encountered and solved about all the dirlling problems they were going to find. However, higher gas costs have forced some operators to switch from gas to air drilling. A typical drilling program, El Paso says, calls for a 13¾-in. surface hole drilled to 200 ft. where 9 5/8-in. casing is set and cemented to the surface. Drilling then continues to about 2,000 ft in the Lewis shale where 7-in. intermediate string is set. El Paso replaces mud with gas when drilling below 2,000 ft. Drilling resumes with 6¼-in. bits through the Lewis shale and Mesaverde formation to an average depth of 5,600 ft where 4½-in. linear is set. Mesaverde zones later are perforated for limited-entry fracturing through the 4½-in. liner, and 2 3/8-in. tubing is run for completion.

Aztec sets 7-in. casing through the Pictured Cliffs formation at 2,900 ft and drills to total depth with air. It says the higher cost of gas has forced it to switch from gas to air.

Northwest Pipeline drills with mud and water to about 3,000 ft, then drills with gas to total depth. The company adds that it has encountered a few pressured gas zones in shallower horizons that probably have been caused by casing leaks from older wells.

Fracture treatments generally call for use of 125,000-175,000 gal of water with 250,000-300,000 lb of sand, according to Amoco. Aztec shoots the Mesaverde with one hole/foot and treats the formation with 1,000 gal (1.5 lb sand/gal) of water/frac per foot of perforated interval.

Separation equipment, according to Aztec, generally recovers about 4 bbl of condensate/MMcfd of gas from the Mesaverde. Aztec produces the liquids into small storage tanks and trucks it to local refineries for processing.

The infill program began after the New Mexico Oil Conservation Commission in December, 1974, granted El Paso's request for reduced well spacing. The order allowed operators at their discretion to drill a second well on a 320-acre unit. El Paso estimated ultimate recovery at 15 trillion cu ft under the reduced-spacing rule, compared with 8.7 trillion with only one well drilled on each 320-acre unit. The field was established in 1949.

SUMMARY

San Juan-Paradox Basin

The San Juan-Paradox basin area of the AAPG-PREP study differed significantly in outline and area from previous resource appraisals of the general Four Corners region. The two previous studies, the USGS-RAG and AAPG Memoir 15, included approximately 68,000 sq. miles as compared to 40,000 sq. miles for the AAPG-PREP appraisal. The two earlier studies included part of all of the following geologic elements not included in the AAPG-PREP San Juan-Paradox area: the San Luis basin, Albuquerque trough, Kaiparowits

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PROGRAM STP AT 200
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READY
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Figure 3. Computer print-out showing the various calculated probability numbers.

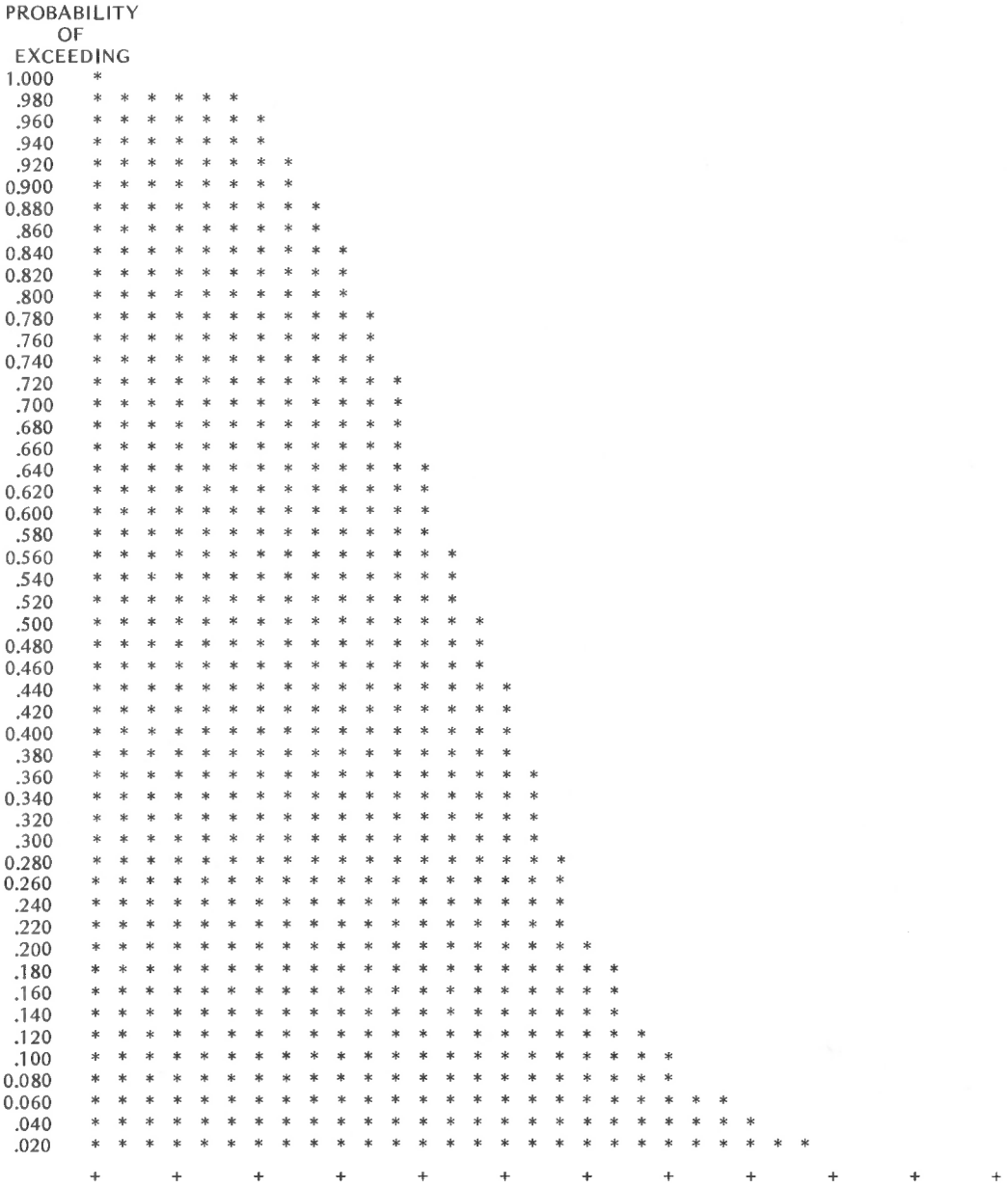

Figure 4. Computer cumulative probability plot.

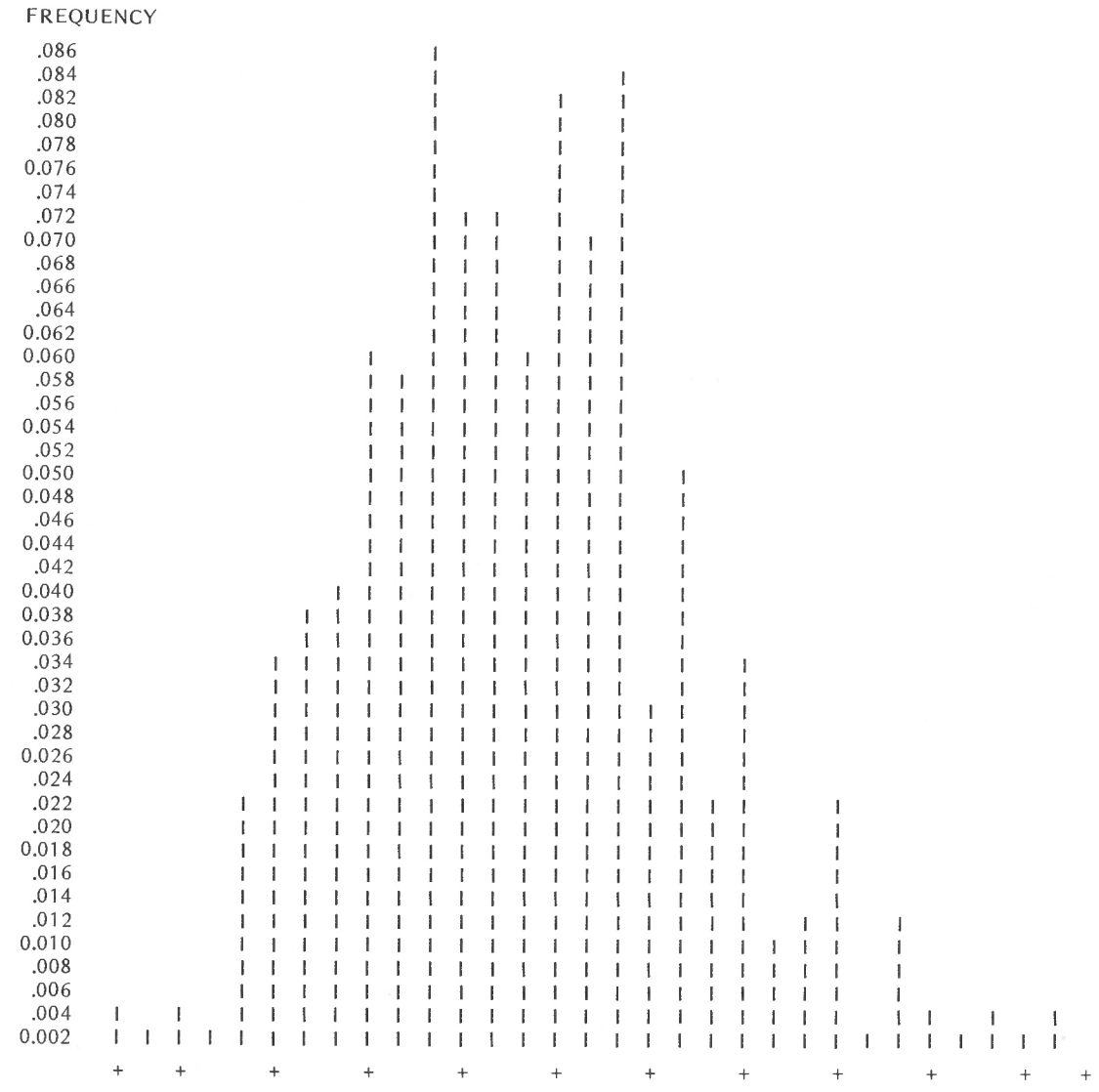

Figure 5. Computer plotted frequency distribution.

basin, Circle Cliffs uplift, San Rafael swell, Wasatch Plateau, Kaibab uplift and Cordilleran hingeline. These differences in area should be taken into account when comparing PREP hydrocarbon resource numbers with those of the RAG or Memoir 15 studies.

The play analysis method is another feature of the AAPG-PREP study which makes comparison with the earlier appraisal studies difficult. The play analysis method better accounts for many of the geologic vagaries associated wity oil and gas exploration than the volumetric and discovery rate projection techniques utilized in earlier studies. Such things as reservoir heterogeneity and the interplay between source rock, carrier bed, reservoir and trapping situation can be considered in the play analysis method.

In the San Juan-Paradox area the Mesozoic potential is limited to the San Juan Basin. The Mesozoic section has been stripped by past erosion or crops out through much of the Paradox basin. So little of this section is preserved in the subsurface that its resource potential is considered negligible. Within the San Juan Basin most of the resource potential in the Mesozoic section is essentially proven, but undeveloped, and falls within known field areas. As concluded in the previous AAPG study (Memoir 15), the best potential for developing future reserves falls within the Middle and Upper Paleozoic carbonate section. The Mississippian-Devonian is prospective in all but about the eastern half of the San Juan Basin. The Pennsylvanian is probably prospective throughout the entire area. Discovery of two fields, one about half the size of Lisbon and one a quarter the size of Aneth, would account for all of the PREP "most likely" undiscovered potential in the Mississippian-Devonian and Pennsylvanian. The explorationist is urged to keep in mind the figures under "the most that might be found" category.

In the Four Corners region roughly 16.5 million acres are controlled by Indian tribes. Some of the prospective acreage on tribal lands is currently leased or in HBP (Held by Production) status. Recently the tribes concerned have shown reluctance toward further leasing to industry and for practical purposes have stymied new exploration efforts. As much as 25% of the oil and gas potential in the Pennsylvanian and 10%

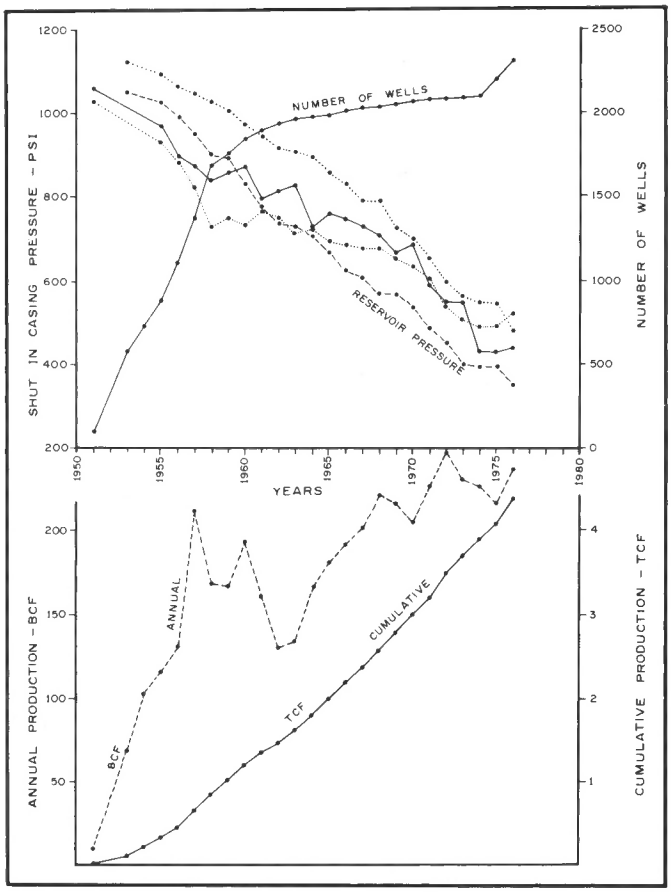

Figure 6. General historical data of Blanco-Mesaverde gas field, San Juan Basin, northwest New Mexico. Reservoir pressure decline taken from Pc value (shut-in casing or tubing pressure, whichever is greater) on annual New Mexico Oil and Gas Conservation Commission. Top curve: EPNG no. 48 SJU 30-6 well, (L) sec. 27, T. 30 N., R. 6 W., 1976 production: 211,835 Mcf + 239 BO; cumulative to 1-1-77: 5,690,491 Mcf + 7,568 BO. Second curve: Amoco no. 1 Shaw GC well, (B) sec. 14, T. 30 N., R. 9 W., 1976 production: 453,746 Mcf + 79 BO; cumulative to 1-1-77: 12,118,428 Mcf + 9,324 BO. Third curve: Aztec O&G no. 4 Grenier well, (D) sec. 7, T. 31 N., R. 11 W., 1976 production: 192,441 Mcf + 762 BO; cumulative to 1-1-77: 4,153,319 Mcf + 10,853 BO. Bottom curve: Amoco no. 1 A. L. Elliott C well, (B) sec. 15, T. 29 N., R. 9 W., 1976 production: 40,674 Mcf + 89 BO; cumulative to 1-1-77: 2,304,758 Mcf + 8,347 BO.

of the potential in the Mississippian-Devonian is, or could be, excluded by the tribes involved (Navajo, Jicarilla Apaches, Southern Utes and Mountain Utes).

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