Wattenberg Field, Denver Basin, Colorado[1]

R. A. MATUSZCZAK[2]

Abstract Wattenberg field produces from a large gas accumulation (1.1 Tcf estimated recoverable reserves) in the "J" sandstone of Cretaceous age. The trap was formed in the delta-front environment of a northwesterly prograding delta.

The gas is contained in a stratigraphic trap straddling the axis of the Denver basin. Reservoir characteristics are poor, and fracturing by artificial means is necessary to test a well.

Large extensions to the field may be made in the future by following the trend of the delta-front environment. Industry exploration efforts will be dependent on gas-price economics.

INTRODUCTION

Wattenberg gas field is located in the Colorado portion of the Denver basin. Its present area comprises 978 sq mi (2,530 km^2) lying between Denver and Greeley, Colorado (Fig. 1). The Denver basin is a Laramide feature oriented north-south and paralleling the east flank of the Rocky Mountain Front Range uplift. The basin is asymmetric, with a steep (10° dip) west flank and a gentle (½° dip) east flank. Wattenberg field straddles the basin axis. It produces from an accumulation of gas stratigraphically trapped in the "J," or Muddy, sandstone of Cretaceous age (Fig. 2). Estimated recoverable reserves from the "J" sandstone of Wattenberg field are estimated to be 1.1 Tcf of gas. In addition, the shallow Upper Cretaceous Hygiene sandstone is oil- and gas-productive in local areas within the field.

The purpose of this paper is to present the history of Wattenberg field from exploration conception to date, tracing both evolution of geologic thought and working procedures used to develop the field.

EXPLORATION CONCEPT, "J" SANDSTONE

A regional and isolith map (Fig. 3) shows that a large lobe of the Cretaceous "J" sandstone was deposited in the Denver-Greeley area by a westerly to northwesterly prograding delta complex. A smaller lobe of sand was deposited in the area south of Denver by a northeasterly prograding delta. Study of outcrops on the west flank of the basin provides further evidence of these two lobes, inasmuch as the "J" sandstone is thin and exhibits characteristics of shallow-marine deposition from the city of Boulder northward to a few miles south of Fort Collins. Haun (1963), Weimer (1970), and MacKenzie (1971) have provided excellent studies that substantiate the presence of these delta lobes. A marine embayment crosses the outcrop northwest of Denver, as indicated on Figure 3.

Examination and evaluation of available data from old wells drilled on the Union Pacific Railroad land (later optioned by Amoco Production Company) revealed the presence of a large area where all drill-stem tests or cores taken in the "J" sandstone had shows of gas. Core analyses of the "J" sandstone were compared with those of the Dakota Formation of the San Juan basin, which produces gas from very low-permeability sandstones of Cretaceous age. The "J" sandstone in the Wattenberg area is similar to the Lower Cretaceous Dakota Sandstone reservoir of the San Juan basin (Table 1).

Supporting data were provided by an earlier discovery at Roundup field, in T2N, R60W, northeast of Denver (Fig. 3). This small gas field, discovered in August 1967, has several unusual qualities. It produces from a stratigraphically lower part of the "J" sandstone than is productive in the D-J basin "trend" area. The prospect also was located on the basis of minor shows of gas recovered from drill-stem tests made in subsequently abandoned wildcat wells. The major risk involved was the uncertainty of achieving a commercial completion by fracturing techniques. Reservoir characteristics of the "J" sandstone are similar to those of the Dakota Sandstone in the San Juan basin. The discovery well in Roundup field was completed for 2,700 Mcf of gas per day after a fracture treatment.

In the Wattenberg field area, gas shows suggest the presence of a sandstone of marine origin on the northeast edge of the marine reentrant. The

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[2]Amoco Production Company, Denver, Colorado 80219.

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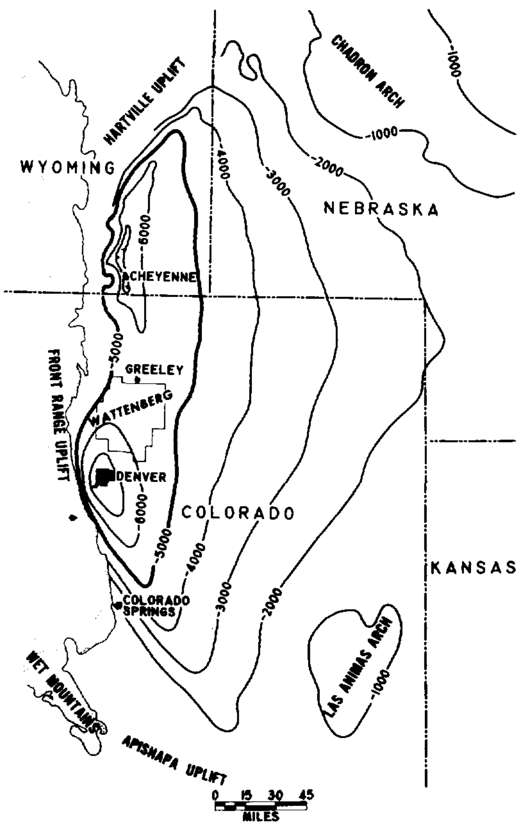


FIG. 1—Structural contour map, Denver basin. Datum is top of Precambrian. C.I. = 1,000 ft.

transition from marine shale at the base of the "J" to sandstone at the top, as seen on electrical logs and in cores, implies the presence of a delta-front sandstone of a regressive marine sequence. The electrical logs run on several old wells in the area are remarkably alike, indicating a similar environment of deposition. As a result of this subsurface evaluation, it was concluded that a delta-front sandstone was present in this area. Because delta-front sandstones tend to be sheet sandstones of possibly large areal extent, a preliminary prospect map was prepared (Fig. 4).

FIRST STAGE OF DEVELOPMENT

The initial step was to outline the possible maximum areal extent of the "J" sandstone reservoir in the Wattenberg area. Of equal importance was

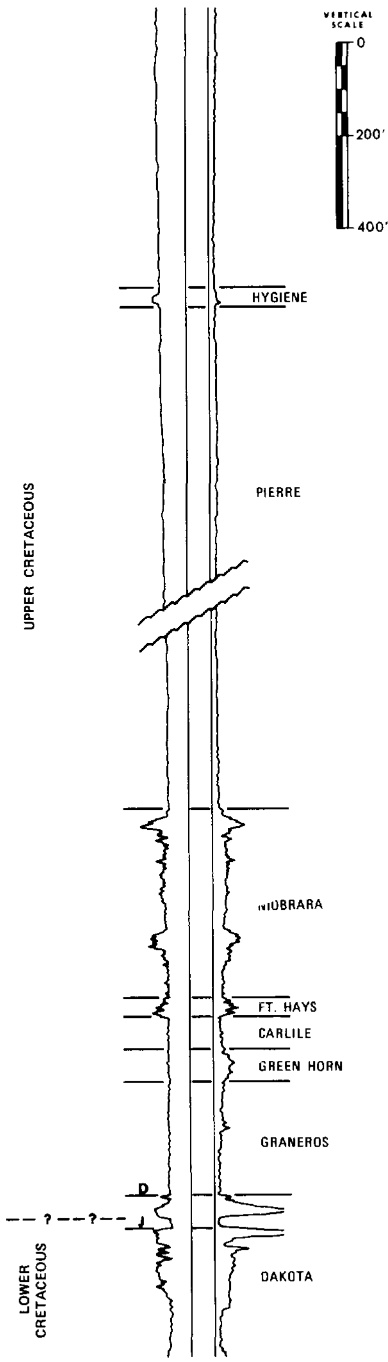


FIG. 2—Type log, Denver basin.

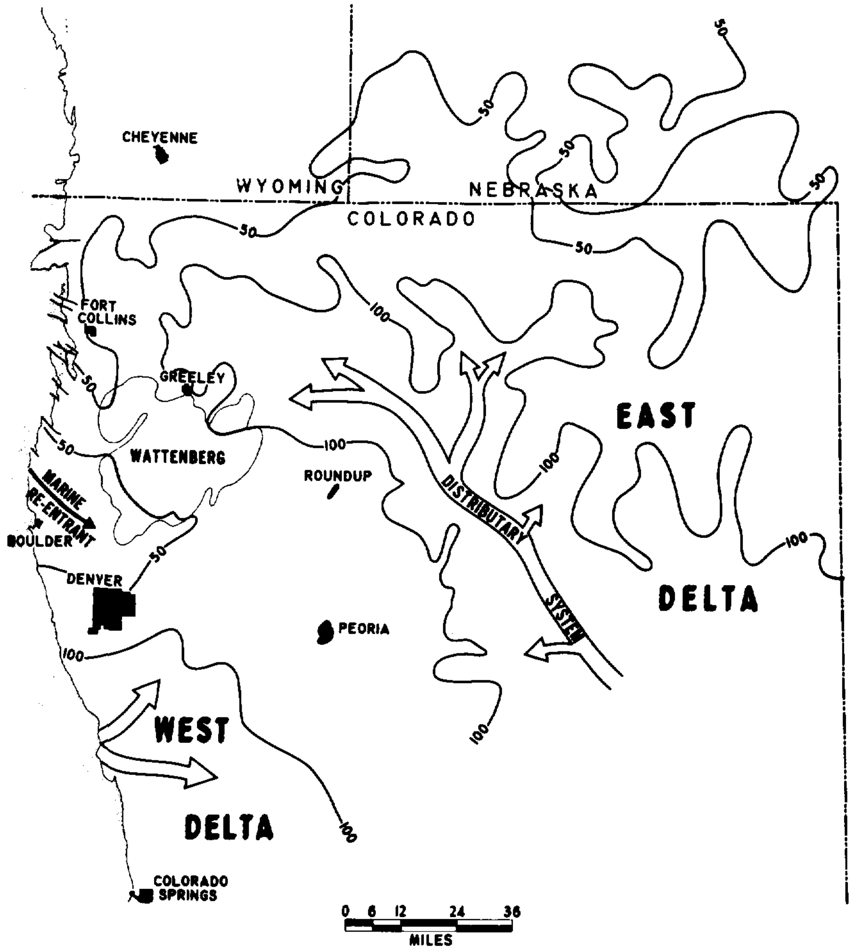


FIG. 3—Delta-sand isolith, "J" sandstone, Denver basin (modified from Haun, 1963).

the need to prove that commercial completion was possible. To test these concepts, six wells were drilled close to the original control wells. Five were completed as small gas wells, and acquisition of additional leases began.

Subsequent to the acquisition of acreage by Amoco, a drilling program was undertaken in partnership with Panhandle Western, a subsidiary of Panhandle Eastern Pipeline Company. Initial plans were to drill 100 test wells spaced to outline the limits of the "J" sandstone prospect as envisioned at that time.

The evaluation of prospective shallow zones also was considered desirable, inasmuch as minor production and shows in these intervals were present in nearby wells. However, to evaluate the Upper Cretaceous Hygiene sandstone (Parkman, Sussex, Shannon sandstone equivalents?) properly by means of samples, cores, and drill-stem tests would have been very costly and would have considerably slowed down the program for the deeper "J" sandstone objective. Denver basin wells normally are drilled with native mud and water to at least the Niobrara Formation. This technique facilitates rapid drilling; penetration rates of 2–3 ft/min (0.6–0.9 m/min) are not uncommon through the shallow formations. Under such conditions, sample quality is poor, and proper core

Table 1. Comparison of Productive Sandstones in San Juan and Denver-Julesburg Basins

Well Name and Location	*Status*	*Interval Analyzed*[a] *(ft)*	*Formation*	*Range of Permeability (md)*	*Water Sat. (%)*	*Porosity Range (%)*	*DST Data*
			San Juan Basin, New Mexico				
Pan American Duff Gas Unit C-1 Sec. 27, T30N, R12W San Juan County	IP 2,502 Mcf gas/day from Dakota	6,152-6,162	Dakota	0.01-0.07	ND	2.8-9.6	
		6,228-6,248	Dakota	<0.01-3.7[b]	ND	4.7-8.9	
Pan American Gallegos Can. Unit No. 195 Sec. 33, T29N, R12W San Juan County	IP 9,516 Mcf gas/day from Dakota	5,850-5,864	Dakota	<0.1-1.3	23.2-90[c]	4.1-8.8	
		5,932-5,939	Dakota	<0.1-0.2	17.7-31.9	6.4-8.0	
		5,952-5,962	Dakota	<0.1-0.1	38.9-74[d]	6.2-9.6	
			Denver-Julesburg Basin, Colorado				
Round Rouse Monaghan No. 1 Sec. 8, T3S, R65W Adams County	"D" sandstone oil production[e]	8,363	"J"	0.99	52.7	5.5	DST 8,308-8,453 ft. Open 1½ hr; SI 30 min. GTS 15 min. No gas. Rec. 550 ft oil and 60 ft oil-cut mud. SIP 3,500 lb.
		8,367-8,399	"J"	0.94-7.1	11.7-43[f]	5.7-12.3	
California No. 1 Hayes Sec. 20, T5N, R66W Weld County	Abandoned[e]	7,856-7,905	"J"	0.0-0.07[g]	7.4-69[h]	5.5-11.8	

[a] Water saturation, porosity, and permeability from core analysis.
[b] 1 ft. Mostly 0.02 md or less.
[c] Mostly 30.0± percent.
[d] Mostly 45-50 percent.
[e] "J" sandstone probably productive.
[f] Mostly 15-25 percent.
[g] Accuracy of lower permeability determinations questionable.
[h] Mostly 30-45 percent.

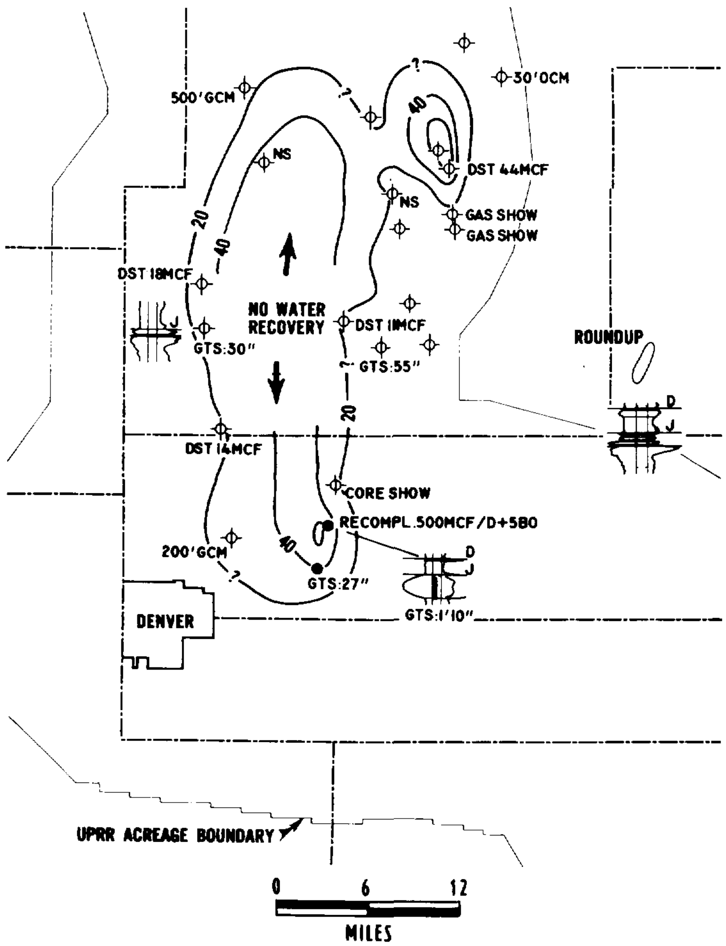


FIG. 4—Isopach map of lower "J" sandstone. Preliminary prospect map, Wattenberg field. C.I. = 20 ft.

points and drill-stem-test intervals are difficult to estimate. Therefore, it was decided to use mud-gas detecting units as an exploration method for the shallow formations above the "J" sandstone. It was believed that gas-detection equipment, combined with a suitable mechanical logging program, would provide sufficient data to make possible the subsequent location of a series of shallow wells to test the most prospective areas. Discoveries to December 1972 are shown on Figure 5.

Cumulative production to the end of 1973 was 10 Bcf of gas and 260,000 bbl of oil. Most of the wells are shut in. Gas plants, gathering system, and other facilities are under construction. Development drilling is continuing so that production will be ready when equipment is installed.

Present Status of "J" Sandstone Exploration

The discovery well for the field was the Tom Vessels No. 1 Grenemeyer, SW ¼, SW ¼, Sec. 26, T1N, R67W, Adams County, Colorado. Initial potential, flowing, was 485 Mcf of gas plus 10 bbl of oil per day through a 20/64-in. choke. The well was completed in July 1970 at a total depth of 8,315 ft (2,537 m).

The drilling of 100 "J" sandstone wells by Amoco Production Company and Panhandle Western resulted in the completion of 72 wells capable of gas production from the "J" sandstone. Other companies and individuals have drilled and completed over 30 additional wells in the field. The present configuration is shown on Figure 6, which is a net-"pay" isopach map based on mechanical log analyses.

During the drilling program, 26 cores of the "J" sandstone were obtained from the Wattenberg field area, and several were obtained outside the area. Interpretation of the cores by Tohill (1972) verified the original concept of the delta-front sheet sand.

Trapping Mechanism in Wattenberg Field

Data from cores and mechanical logs provided insight into the trap responsible for the gas accumulation in Wattenberg field. The trap on the west and south sides is formed by the pinchout of the reservoir sandstone into a thin, "tight" siltstone and silty sandstone. The trap on the northeast side is formed by a loss of permeability caused by an increase in siliceous cement.

A total-sand isolith map shows that the "J" sandstone in Wattenberg field thickens in a northeast direction (Fig. 7). It is presumed that the main source of sand was in that direction; however, this portion of the sandstone body is

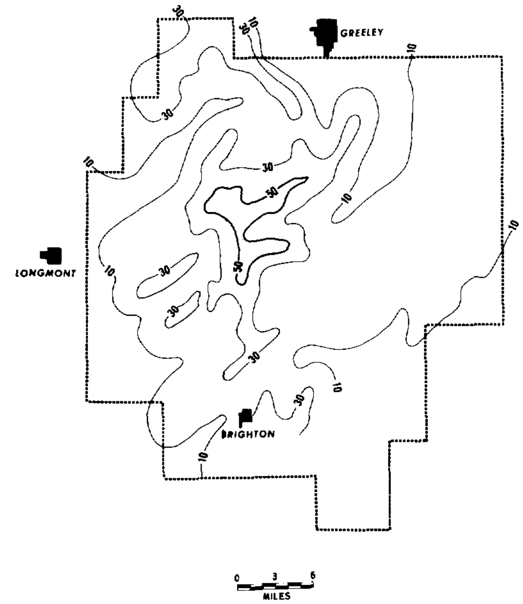


FIG. 6—Wattenberg field, net-"pay" isopach map, based on log calculations; 8 percent or more porosity, 60 percent or less water saturation. Contours are in feet.

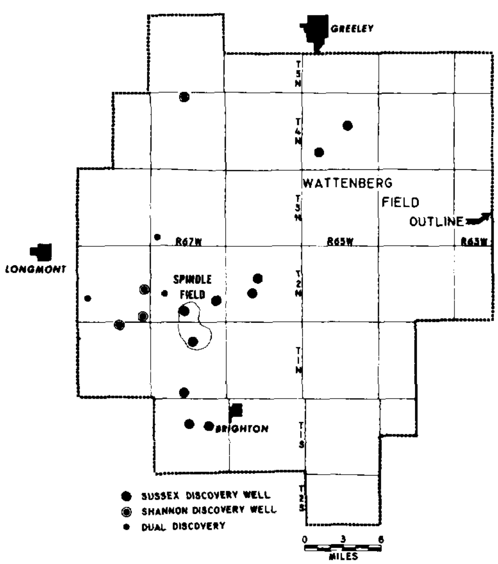


FIG. 5—Sussex-Shannon (Hygiene) discovery wells to December 1972, Wattenberg field.

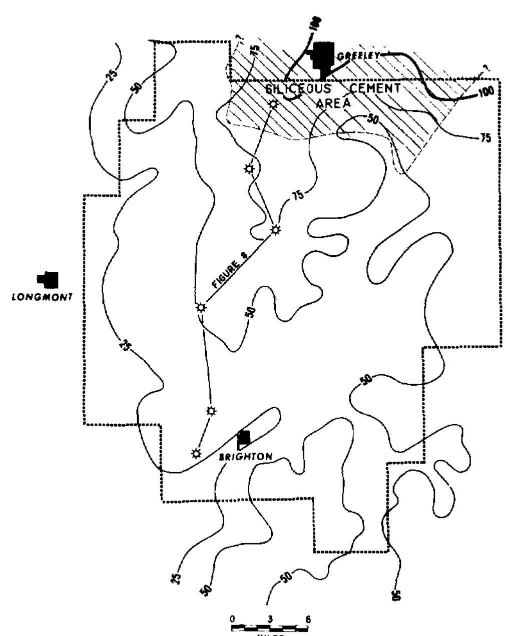
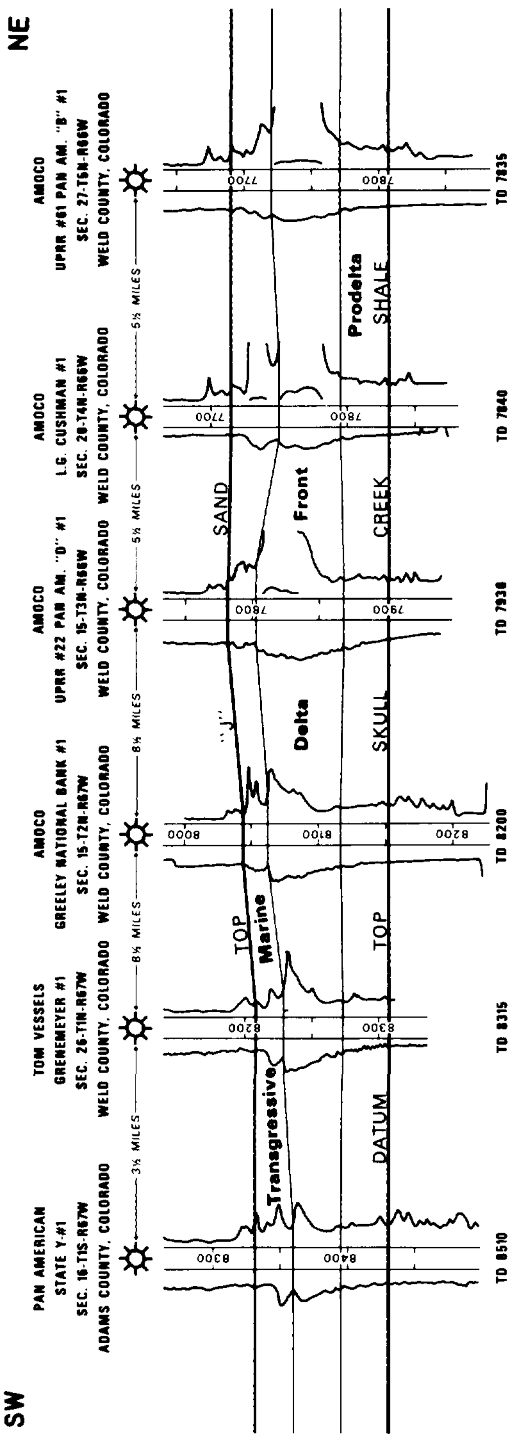


FIG. 7—"J" sandstone isolith, Wattenberg field. C. I. = 25 ft. Location of cross section (Fig. 8) is shown.



now tightly cemented in what originally was the thickest and coarsest grained reservoir rock. A possible explanation is that secondary silica cementation was caused by a pH contrast resulting from expulsion of alkaline marine waters into acidic fresh distributary waters during postdepositional compaction (Fisher et al, 1969, Fig. 118). The trap on the east side of Wattenberg field is formed by loss in permeability caused by the presence of both siliceous cement and clay.

Mechanical logs indicate that the "J" sandstone can be divided into two distinct members over most of the field area. Locally, these two parts merge into a single unit. Figure 8 displays this two-part division. Examination of cores indicates that this division is caused by an increase in dispersed-clay content, presence of clay balls, and increase in number of scattered thin shale laminae found in the "J" sandstone. The division is made at the contact between delta-front and transgressive-marine sediments. The contrast on mechanical logs is more apparent than real, because the low-resistivity, low-SP zone, which resembles shale in log character, is usually a sandstone. Figure 9 is a display of electric-log and core data. It also includes the environmental interpretation.

Table 2 presents some statistical data for the "J" sandstone reservoir. Hydraulic fracturing of the "pay" zone with sand, glass beads, and water is a standard procedure. The "J" sandstone in this field has such low permeability that evaluation of a well is conclusive only after fracturing and testing through casing. A well in Sec. 33, T1N, R67W, was gas-drilled into the "J" sandstone. An open-hole test of the reservoir flowed gas at a rate too small to measure, indicating a decided lack of natural permeability. The initial potential of the well after fracture treatment was 573 Mcf/day of gas and 22 bbl/day of condensate.

Future Possibilities

The geologic conditions responsible for the trap in Wattenberg field, particularly the east and northeast permeability barrier, may extend throughout the area covered by delta-front deposition. Thus, a trend can be delineated within estimated limits (Fig. 10). It is possible that

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Fig. 8—Southwest-northeast cross section, Wattenberg field, showing division of "J" sandstone into two members. Location is shown on Figure 7.

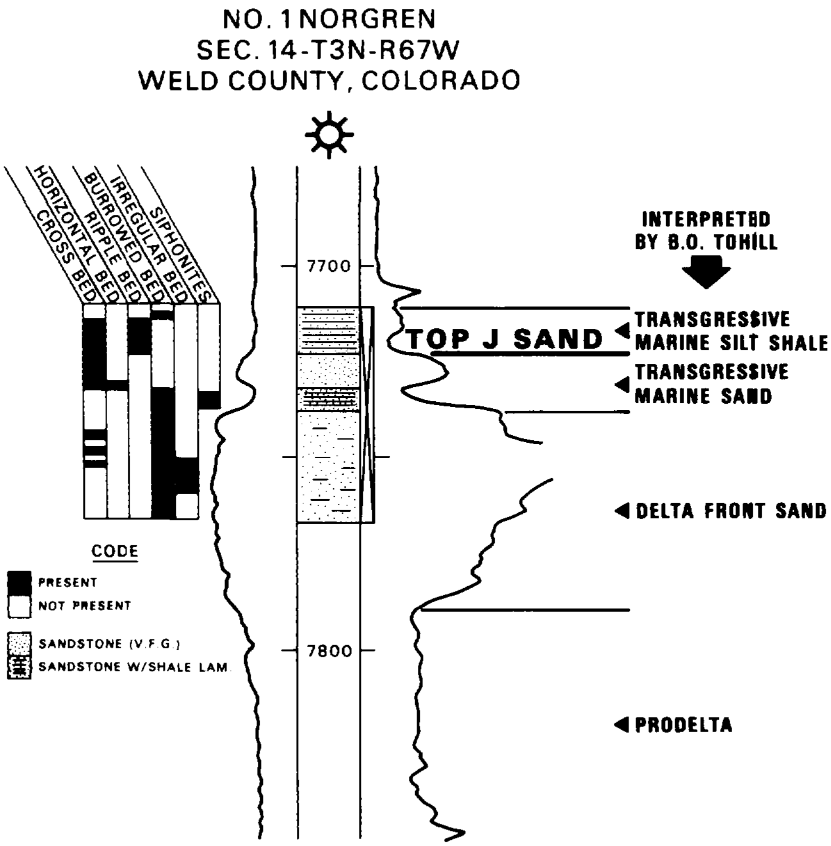

FIG. 9—Environmental interpretation of electric log and core data (Tohill, 1972).

Table 2. Basic Reservoir Data, "J" Sandstone

Parameter	
Average porosity	9.5 percent
Average permeability	0.1–0.2 md
Connate water saturation	44 percent (?)
Recoverable reserves	1.1 Tcf
Field size	283,000 acres
Average pay thickness	25+ ft
Original reservoir pressure	2,750 psi
Depth range	7,350–8,500 ft
Initial potentials	100–3,575 Mcf/day

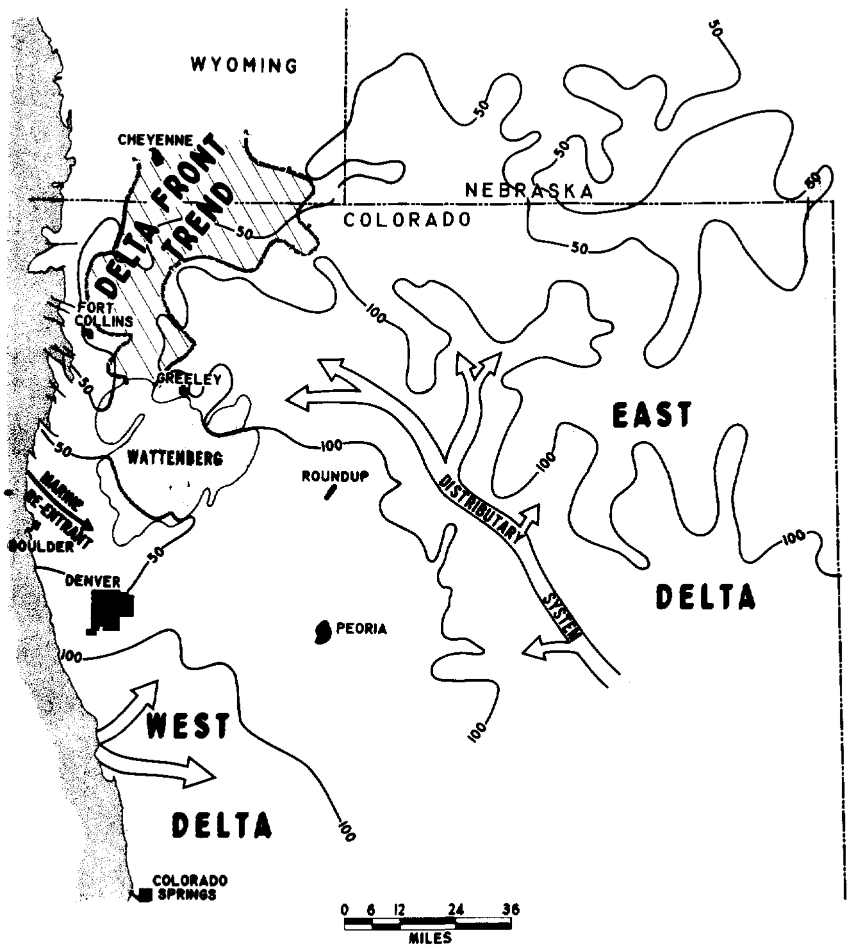

FIG. 10—Denver basin, showing area of delta-front deposition.

considerable extensions to the gas-productive area will be made.

Extension of commercial production is dependent only in part on sufficient geologic evaluation. It must be assumed that future discoveries will be similar to existing wells and, therefore, will be of low to moderate deliverability. Gas prices necessarily will affect the timing and extent of further industry exploratory efforts.

REFERENCES CITED

Fisher, W. L., et al, 1969, Delta systems in the exploration for oil and gas: Texas Univ. Bur. Econ. Geology, 78 p.

Haun, J. D., 1963, Stratigraphy of Dakota Group and relationship to petroleum occurrence, northern Denver basin: Rocky Mtn. Assoc. Geologists Guidebook, 14th Ann. Field Conf., p. 119-134.

MacKenzie, D. B., 1971, Post-Lytle Dakota Group on west flank of Denver basin, Colorado: Mtn. Geologist, v. 8, no. 2, p. 91-131.

Tohill, B. O., 1972, Depositional environments and hydrocarbon traps in "J" sandstone (Lower Cretaceous), Denver basin, Colorado (abs.): Denver, Colorado, AAPG-SEPM Ann. Mtg. Prog., p. 658-659; 1972, AAPG Bull., v. 56, no. 3, p. 658-659.

Weimer, R. J., 1970, Dakota Group stratigraphy, southern Front Range, South and Middle Parks, Colorado: Mtn. Geologist, v. 4, no. 3, p. 157-184.