A REFINED INTERPRETATION OF THE DEPOSITIONAL ENVIRONMENTS OF WATTENBERG FIELD, COLORADO

WAYNE L. PETERSON[1] and STEPHEN D. JANES[1]

ABSTRACT

Wattenberg field is a large gas reservoir producing from the Lower Cretaceous Muddy "J" sandstone. A detailed analysis of the Muddy "J" using trace fossil assemblages, cores, and subsurface mapping has led to a refined interpretation of the depositional environments. Previous work (Tohill, 1972, Matuszczak 1973, 1976) recognized the Muddy "J" of Wattenberg as a southwesterly prograding delta and described some of the depositional environments found in Muddy "J" cores. This study delineates three distinct lithofacies intervals in the Muddy "J" that occur and can be mapped throughout the field. These three intervals are the delta front, delta plain and transgressive facies. Additional subenvironments (distributory mouth bars, marshes, bays, levees, channels, and crevasse splays) can be recognized in some cores. This interpretation is part of a continuing research program aimed at improving field exploitation.

INTRODUCTION

Wattenberg field is located north of Denver, Colorado in Adams and Weld Counties (Fig. 1). The field straddles the present day axis of the Denver basin. Production is from the Lower Cretaceous Muddy "J" sandstone at depths ranging from 7600 ft in the northeast portion of the field to 8400 ft in the southwest. The Muddy "J" is a fine to very-fine grained sandstone with permeabilities varying from 1 to 40 microdarcies. Because of the poor reservoir quality of these rocks, massive hydraulic fracturing is required to achieve economic producing rates. The Muddy "J" sandstones overlie the marine Skull Creek Shale and are overlain by the marine Huntsman Shale. The total Muddy "J" interval varies in thickness from 100 ft in the southwest part of the field to 150 ft in the northeast. Earlier work (Tohill, 1972, Matuszczak, 1973, 1976) classified Wattenberg as a secondary delta of a northwesterly trending distributary system, with the primary delta located somewhere to the north of the field.

REGIONAL GEOLOGIC SETTING:

Regional maps of the total Muddy "J" sand thickness for the western Denver basin delineate a large northwest-southeast trending lobe of sand in the Greeley and Fort Collins areas (Fig. 2). This lobe has been interpreted as the westernmost extent of an early Cretaceous northwesterly prograding delta complex. Cores from wells in the Greeley lobe reveal a thick sequence of stacked delta front and delta plain deposits having relatively high permeabilities and porosities (1.0-3.0md permeability, 12-13% porosity). No production has been discovered in these potential reservoir rocks. Instead a large number of gas and oil fields (including Wattenberg) have been discovered in the areas peripheral to the Greeley lobe.

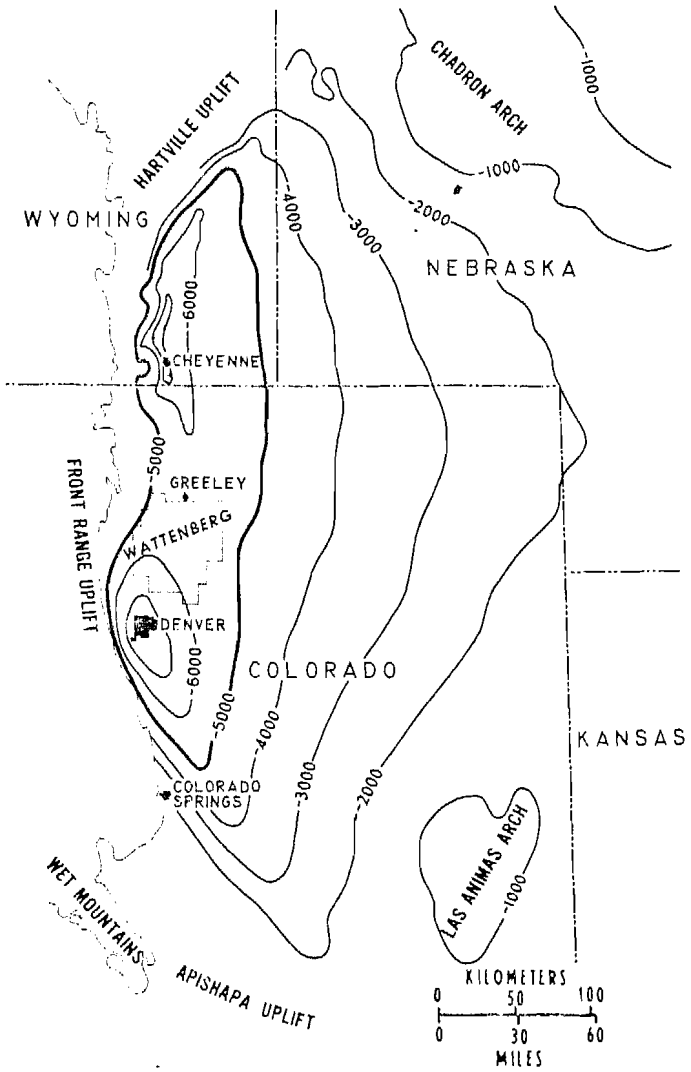
In the productive areas surrounding the Greeley lobe the Muddy "J" has considerably poorer reservoir characteristics (0.1-0.4md permeability, 9-11% porosity). Clay content in these sands is much higher than sands of the Greeley lobe, resulting in decreased permeability. This characteristic in association with the lenticular nature of most of these deposits has resulted in the formation of several stratigraphically trapped hydrocarbon reservoirs. North of the Greeley lobe (southeast Wyoming's Borie and Horsecreek fields) the Muddy "J" is composed of several stacked lenticular sand bodies inferred to have been deposited in various environments of both fluvial and marginal marine origin (Cronoble, 1977). South of the Greeley lobe two distinct depositional regimes can be recognized. To the southeast the formation was deposited in a complex of delta plain environments dominated by distributary channels as represented in Third Creek, Jamboree, and Peoria fields. Southwest of Greeley the J sands have been interpreted as a series of secondary delta front lobes of the northwesterly trending distributary system (Greeley lobe). By far the largest lobe of delta front sands is found in the Wattenberg field area. While delta plain deposits are represented in most wells in Wattenberg, it is the thick, low permeability delta front sands which produce the majority of Wattenberg gas.

The Greeley lobe and the areas peripheral to it are part of the same regional delta system having its source somewhere to the east (Tohill, 1972). Depositional patterns adjacent to the Front Range outcrop belt are exceedingly difficult to unravel. Outcrop evidence indicates the presence of several small northeasterly prograding deltas with sources to the west (Haun, 1963; Mackenzie, 1971; Weimer, 1970; Clark, 1978). Whether these deposits merge with Wattenberg and other eastern source lobes in the subsurface has yet to be revealed by drilling.

DEPOSITIONAL ENVIRONMENTS

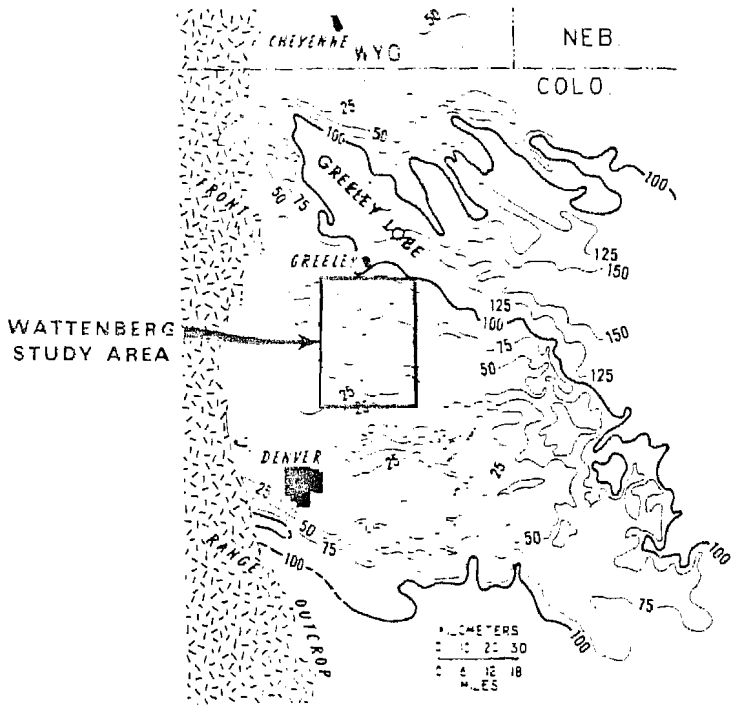
Figure 3 is a typical electric log of the Muddy "J" sandstone in Wattenberg. Using biogenic and physical sedimen-

[1]Amoco Production Company, Denver, Colorado.



DENVER BASIN
TOP PRE-CAMBRIAN STRUCTURE
C.I.=1000'
R.A. Matuszczak 1973

Fig. 1



WESTERN DENVER BASIN
ISOLITH "J" SANDSTONE
C.I.=25'
R.A. Matuszczak 1973

Fig. 2

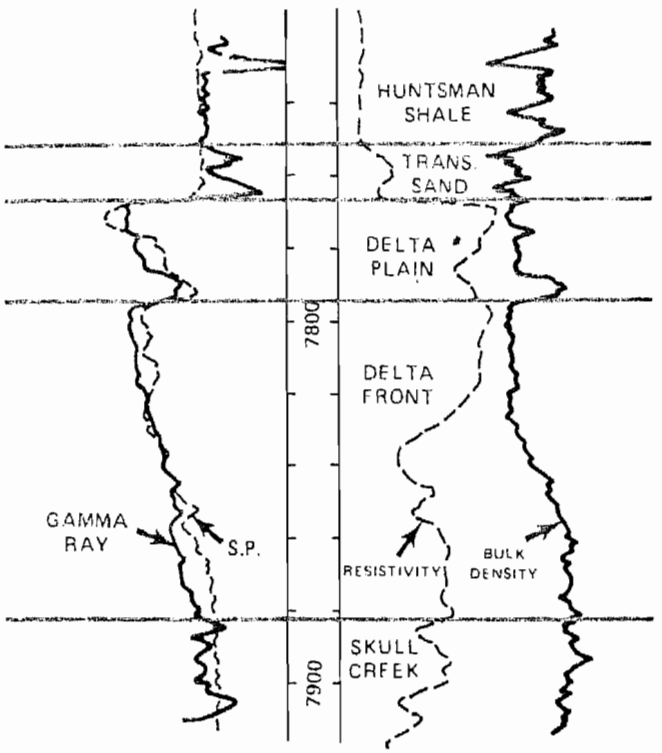
tary structures, the formation was divided into three intervals which are present throughout the field. In ascending order, these intervals are the delta front (subaqueous delta), the delta plain (subareal delta) and a transgressive facies. A prodelta facies, also part of the subaqueous delta, should be expected to underlie the delta front facies. Unfortunately, none of the cores examined went deep enough to penetrate the prodelta. However, the Skull Creek Shale underlying the Muddy "J" in Wattenberg has been described previously by Matuszczak (1976) as being the prodelta portion of a prograding deltaic sequence. A description of a Muddy "J" outcrop 15 miles west of Wattenberg by Clark (1978) also categorized the Skull Creek Shale as prodelta.

Delta Front

In the lower interval grain size increases upwards from coarse silt to fine sand (60u to 150u). The lower part of this interval is highly bioturbated, suggesting low energy conditions and a low rate of sedimentation. The trace fossils *Zoophycos, Terebellina, Teichichnus, Ophiomorpha,* and *Asterosoma* are the most common biogenic structures in this portion of the lower zone. This assemblage of trace fossils, plus the upwardly increasing grain size, is indicative of the delta front facies in the subaqueous portion of a deltaic sequence (Basan and Peterson, 1978).

A distributary mouth bar facies is commonly found in the upper part of the lower interval. It can be distinguished in cores from the delta front facies by: (1) a lesser degree of bioturbation, (2) horizontal laminations, and (3) the presence of the trace fossil, *Ophiomorpha,* which generally is a vertical form and more robust than those found lower in the interval. Grain size also increases upwards in this portion of the lower interval.

Although the delta front and the distributary mouth bar can be distinguished in cores, the difference in log response between the two facies is very subtle and, consequently, logs are not a reliable means of differentiation. Therefore, in this paper, the entire lower interval is referred to as the delta front and is mapped as one unit.



WATTENBERG TYPE LOG

Fig. 3

The sands of the delta front form a unit that is consistent lithologically across the field. Log response in this interval is similar throughout the field and can be correlated easily from well to well. Figures 4 and 5 are log cross sections from north to south and west to east across the field which illustrate the continuity of the delta front sands. Figure 6 is an isopach of the delta front. Slight thinning of the delta front to the southwest suggests southwestward progradation.

Although the delta front interval does contain small amounts of what seems to be organic detritus, source rock analysis on samples from this interval in the Kunzman well, SW5-2N-66W, indicate the rock is not a hydrocarbon source.

Delta Plain

The unit immediately overlying the delta front is characterized by extreme variability of both grain size and sedimentary structures. The trace fossils, *Terebellina, Thalassinoides, Planolites,* and *Skolithos,* are commonly found in this interval, as well as crab burrows and root bioturbation. Carbonaceous material also commonly is found in this interval. The association of these trace fossils in conjunction with the variability of sediment and sedimentary structures suggests that this interval is the delta plain. The upward sequence of prodelta to delta front, which suggests a prograding delta, normally would have a delta plain on top of the delta front.

Environments associated with the delta plain are channels, natural levees, interdistributary bays, marshes, and crevasse splays. These facies are of limited areal extent and generally are difficult to correlate over wide areas. Capillary pressure in the finer grained units, such as marsh and interdistributary bay deposits, will probably be too great to allow the development of gas saturation. However, these facies do contain organic material and have been determined to be gas sources at peak generation. Facies in the delta plain containing coarse-grained sediments such as channel deposits and crevasse splays will develop gas saturations and therefore must be considered as prospective reservoir quality rock. Figure 7 illustrates the relationship of the delta front facies to the delta plain facies. The delta front will be laterally continuous, whereas the facies in the delta plain will be of limited areal extent. The variable nature of the delta plain is also visible on the cross sections, Figures 4 and 5.

Figure 8 is an isopach of the delta plain. As can be seen on this map, the delta plain interval thins to the southwest suggesting a southwesterly progradation, which is also the direction of progradation indicated by the delta front isopach (Fig. 6).

Transgressive Facies

The uppermost interval in the Muddy "J" formation (Fig. 3) is a parallel-laminated silt and shale that is continuous across the field. Trace fossils are rare in this interval. The parallel laminae and fine-grained nature of these sediments suggest that this interval was deposited in a progressively deepening environment and thus this interval is interpreted as being the beginning of a transgressive marine sequence which marked the end of deltaic deposition.

The capillary pressures associated with these fine-grained sediments will preclude development of a gas saturation. Consequently, sediment in this interval is not considered to be reservoir quality rock.

CONCLUSIONS

Detailed biogenic and physical sedimentary structure analysis demonstrates that the Muddy "J" formation in Wattenberg can be divided into the regressive and transgressive phases of a deltaic complex. The regressive phase contains the subaqueous and subareal deltaic environments which can be readily differentiated from each other both in the cores and on the logs. Mapping of these environments indicates that the delta prograded from the northeast. The transgressive phase can also be readily identified in cores and logs. It is of nearly uniform thickness across the field and marks the cessation of deltaic deposition in the Wattenberg field.

ACKNOWLEDGEMENTS

Amoco Production Company is gratefully acknowledged for permission to publish this study. Particular thanks are given to Paul Basan of Amoco's Research Center whose work on trace fossils led to the geological model of the Wattenberg depositional environments.

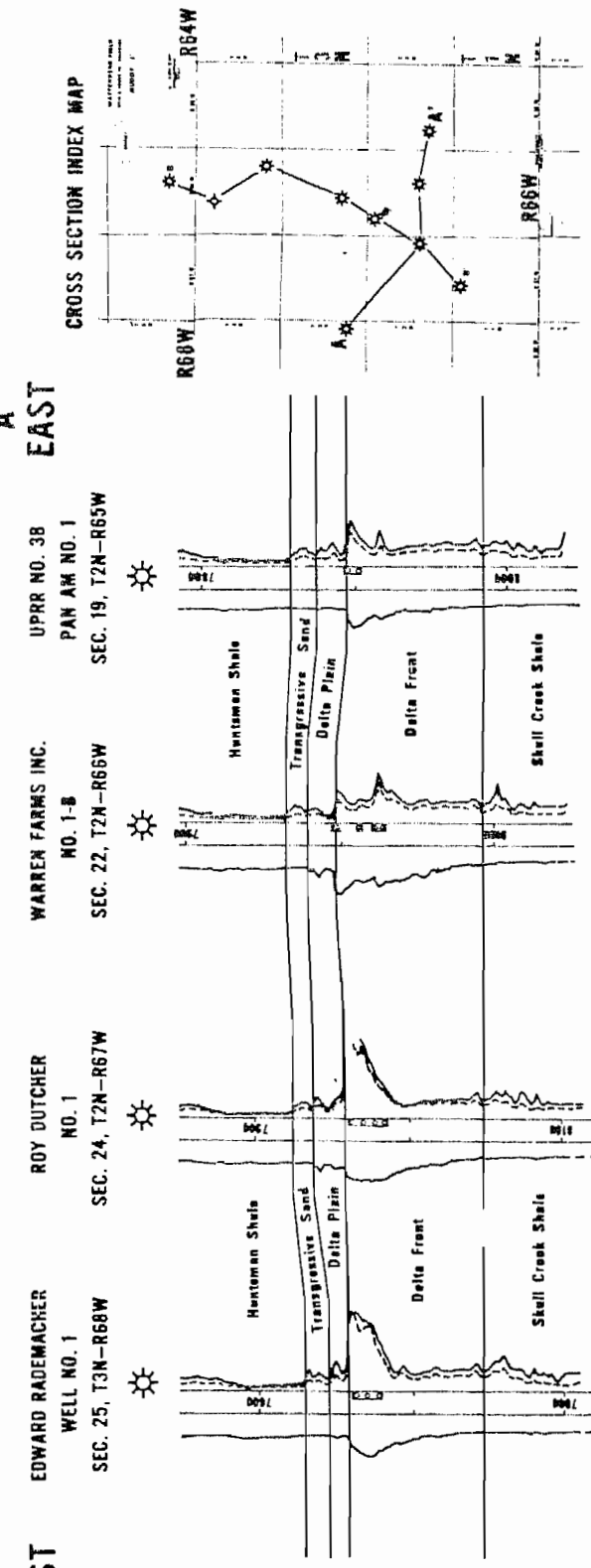

A
WEST
EDWARD RADEMACKER WELL NO. 1
SEC. 25, T3N–R68W
ROY DUTCHER NO. 1
SEC. 24, T2N–R67W
WARREN FARMS INC. NO. 1-B
SEC. 22, T2N–R66W
UPRR NO. 38 PAN AM NO. 1
SEC. 19, T2N–R65W
A'
EAST
CROSS SECTION INDEX MAP
R68W
R64W
R66W
Huntsman Shale
Transgressive Sand
Delta Plain
Delta Front
Skull Creek Shale

Fig. 4

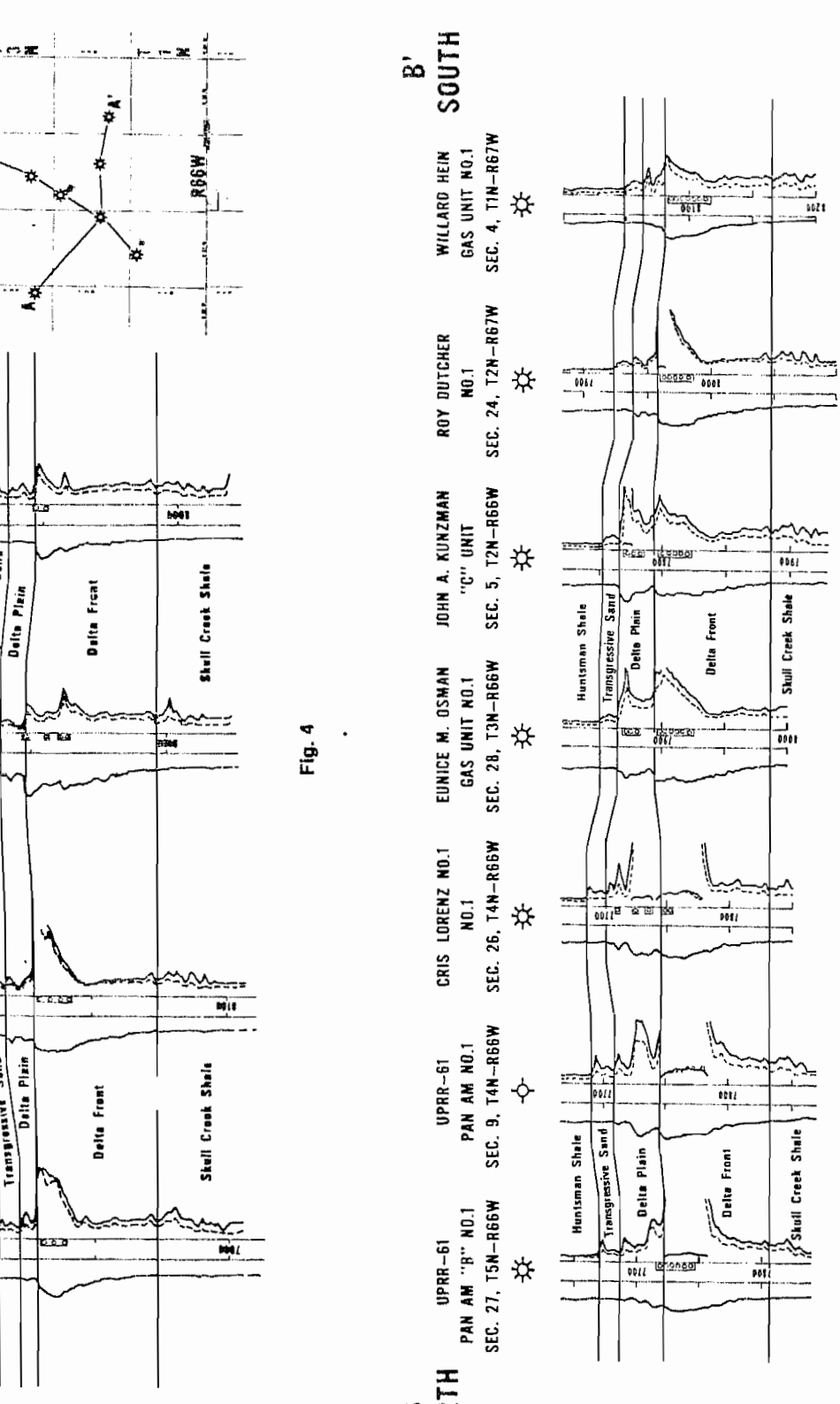

B
NORTH
UPRR–61 PAN AM "B" NO.1
SEC. 27, T5N–R66W
UPRR–61 PAN AM NO.1
SEC. 9, T4N–R66W
CRIS LORENZ NO.1
SEC. 26, T4N–R66W
EUNICE M. OSMAN GAS UNIT NO.1
SEC. 28, T3N–R66W
JOHN A. KUNZMAN "C" UNIT
SEC. 5, T2N–R66W
ROY DUTCHER NO.1
SEC. 24, T2N–R67W
WILLARD HEIN GAS UNIT NO.1
SEC. 4, T1N–R67W
B'
SOUTH
Huntsman Shale
Transgressive Sand
Delta Plain
Delta Front
Skull Creek Shale

Fig. 5

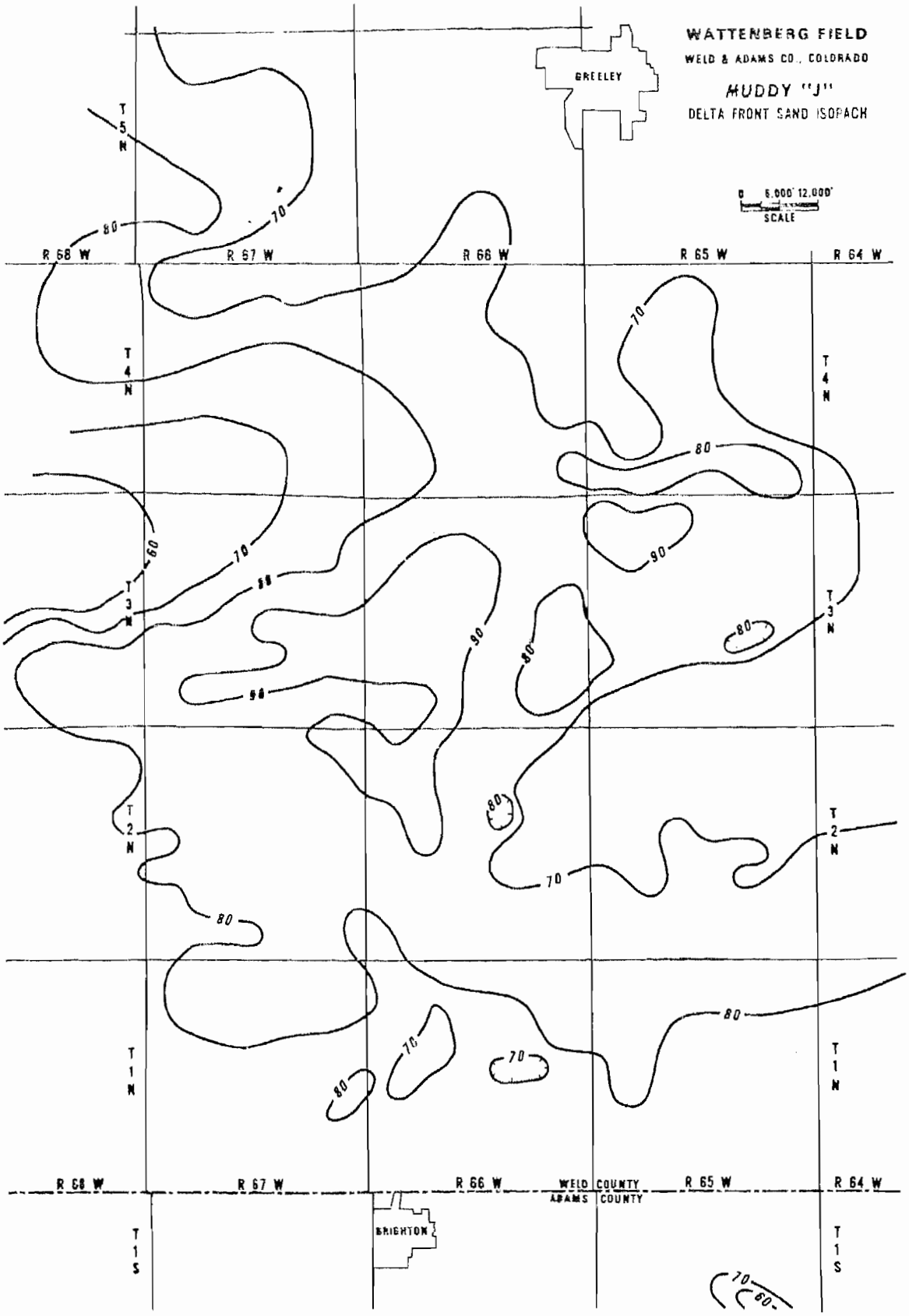

WATTENBERG FIELD
WELD & ADAMS CO., COLORADO
MUDDY "J"
DELTA FRONT SAND ISOPACH
0 6,000' 12,000'
SCALE
GREELEY
BRIGHTON
WELD COUNTY
ADAMS COUNTY
R 68 W
R 67 W
R 66 W
R 65 W
R 64 W
T 5 N
T 4 N
T 3 N
T 2 N
T 1 N
T 1 S
60
70
80
90

Fig. 6

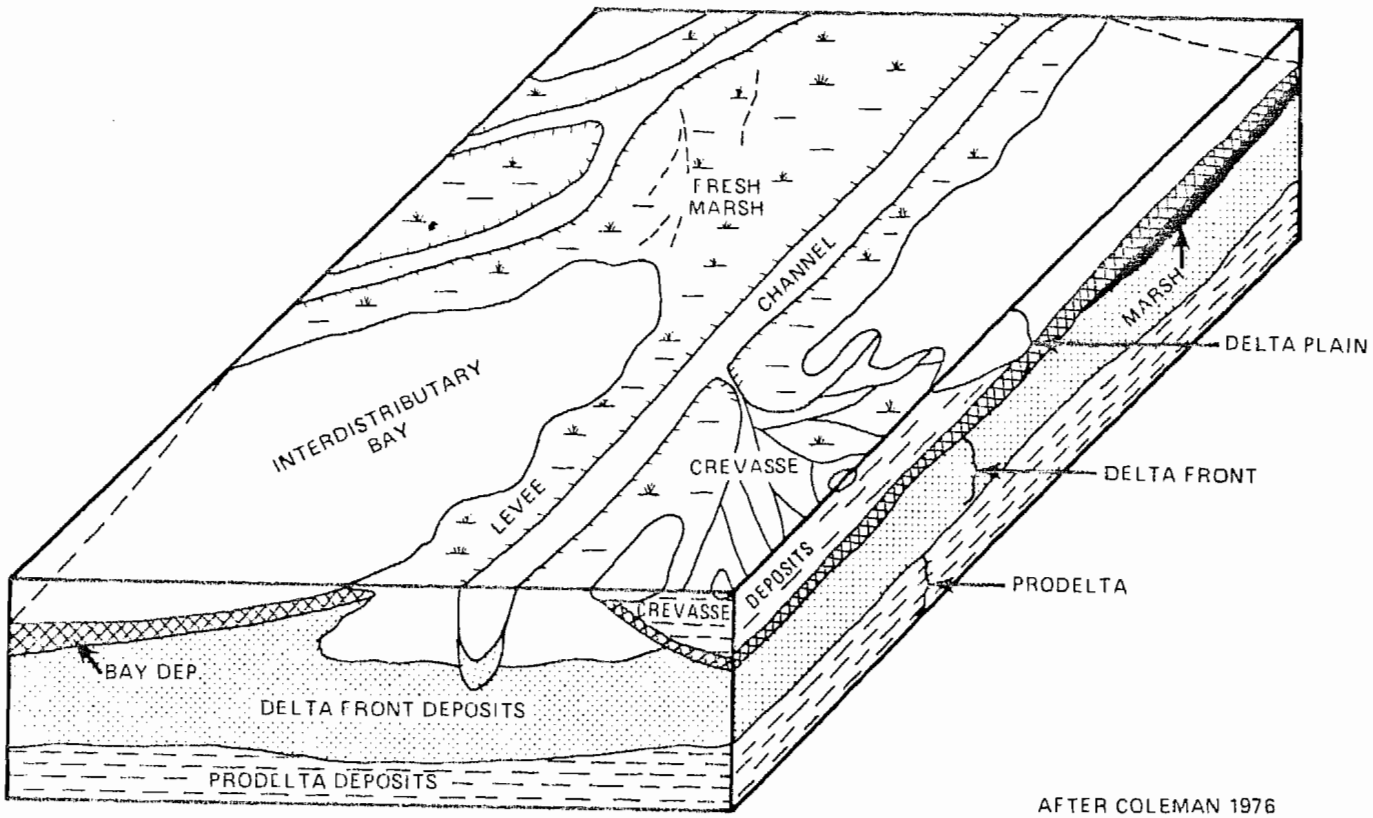


Fig. 7—Block diagram schematically showing deltaic depositional environments.

REFERENCES

Basan, P.B., and Peterson, W.L., 1978, Trace fossil associations and depositional history, Peoria, Third Creek, and Wattenberg fields, northeastern Colorado (abs.): Geol. Soc. America Abs. with Programs v. 4, no. 1, p. 1.

Clark, B.R., 1978, Stratigraphy of the J sandstone (Lower Cretaceous) Boulder County and southwest Weld County, Colorado: unpub. Master's Thesis, Colorado School of Mines, 190 p.

Cronoble, J.M., 1977, Stratigraphy and petroleum potential of Dakota Group, North Park, Laramie, and northwest Denver basins, Wyoming and Colorado: unpub. Ph.D. Thesis, Colorado School of Mines, 358 p.

Fast, C.R., Holman, G.B., and Covlin, R.J., 1977, The application of MHF to the tight Muddy "J" formation, Wattenberg field, Colorado: Bull. Canadian Pet. Geol., v. 25, no. 2, p. 419-433.

Haun, J.D., 1963, Stratigraphy of Dakota Group and relationship to petroelum occurrence, northern Denver basin: Rocky Mtn. Assoc. Geol. 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. 3, p. 92-131.

Matuszczak, R.A., 1973, Wattenberg field, Denver basin: Mtn. Geologist, v. 19, no. 3, p. 99-105.

_____, 1976, Wattenberg field, a review, Prof. Contr. Colorado School of Mines, no. 8, p. 275-279.

Tohill, B.O., 1972, Depositional environments and hydrocarbon traps in "J" sandstone (Lower Cretaceous), Denver basin (abs.): A.A.P.G. 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. 7, no. 3, p. 157-184.

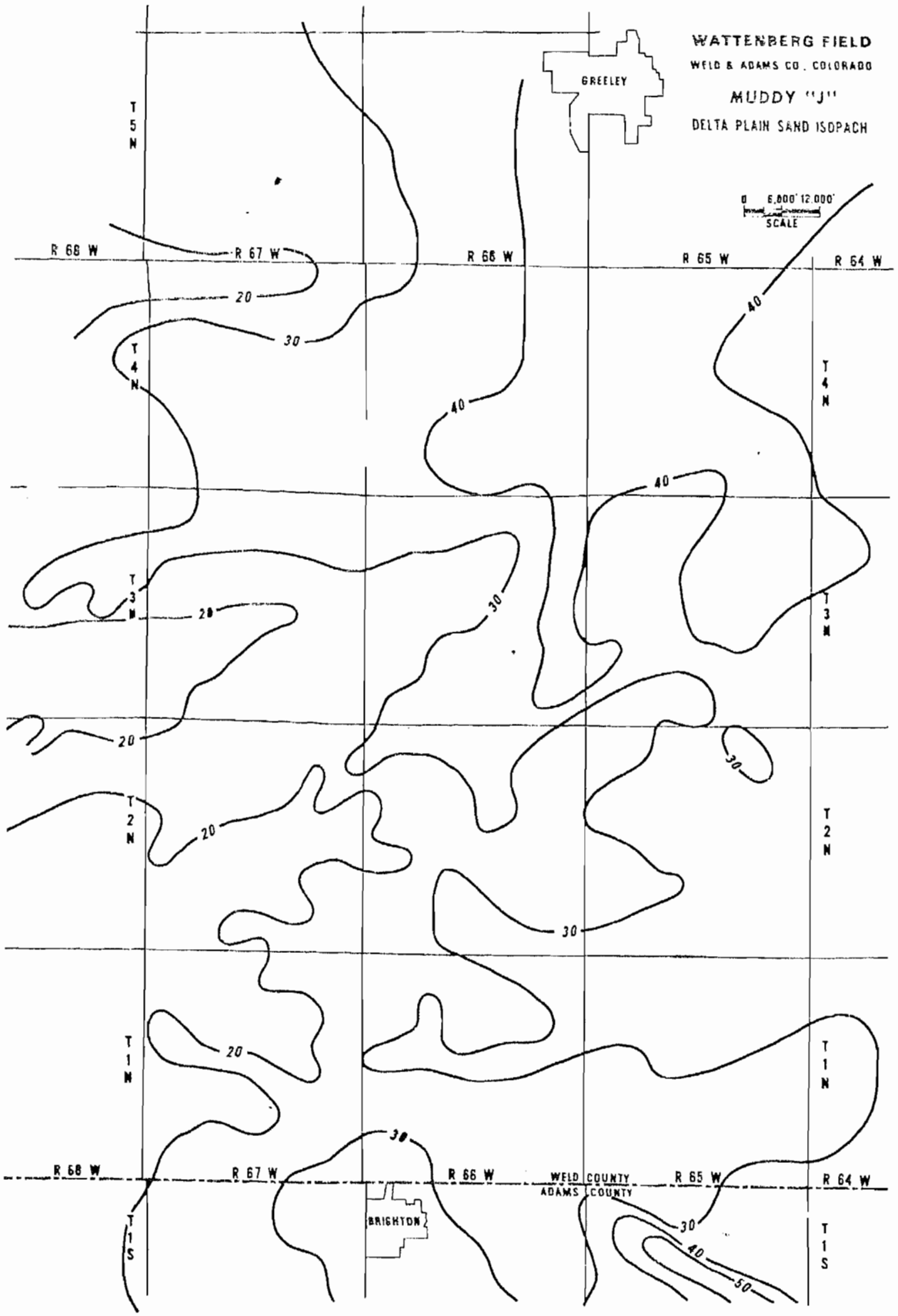

WATTENBERG FIELD
WELD & ADAMS CO., COLORADO
MUDDY "J"
DELTA PLAIN SAND ISOPACH
0 6,000' 12,000'
SCALE
GREELEY
BRIGHTON
WELD COUNTY
ADAMS COUNTY
R 68 W
R 67 W
R 66 W
R 65 W
R 64 W
T 5 N
T 4 N
T 3 N
T 2 N
T 1 N
T 1 S
20
30
40
50

Fig. 8