GEOLOGY AND PETROLEUM OF THE MANCOS B FORMATION DOUGLAS CREEK ARCH AREA COLORADO AND UTAH

by
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ABSTRACT

The Mancos B Formation is a complex of intimately interbedded and interlaminated claystone, siltstone, and fine sandstone formed in a marine environment about 100 miles east of the Emery shoreline. The lower Mancos B was deposited as east-west trending, northward prograding fore slope sets built on a sub-horizontal ocean floor; sandy facies are found as far north as Douglas Creek anticline but rapidly change to a shaly facies farther north. Deposition of the upper Mancos B began with an influx of sandy material, probably from the west, that filled an erosional (?) topographic low in the North Douglas Creek area and spread southward; some clastics continued to enter the area from the south or southwest. The formation is "sandiest" at Douglas Creek anticline, where it is about 500 feet thick, and "shaliest" in the southeast, where it can be over 1000 feet thick.

The Mancos B has low porosity (average 10-11%), low permeability (average 0.7 md), and is very sensitive to formation damage by introduced water. Its emergence as a significant producer of natural gas has therefore been largely dependent upon the development and application of air drilling techniques and of massive pseudolimited entry fracture treatments. Over 127 BCF of gas has been produced from the formation in the last ten years, mostly from Douglas Creek anticline. Only a little over 20,000 bbls. of oil have been produced but it now appears that as much as 1,400 feet of oil column may be present beneath the gas cap. Increased drilling activity is extending the known producing area southward on the Douglas Creek arch. As yet no productive limits are known other than those dictated by economics.

INTRODUCTION

Recent shortages of natural gas in the United States make it apparent to the petroleum explorationist that he must expand his search into new frontiers for natural gas reserves. Many Rocky Mountain basins contain great quantities of gas in tight sandstone reservoirs. Wells completed in such reservoirs produce at low rates, and are increasingly expensive to drill and complete. Compensating increases in gas prices make it now economically feasible to develop some of these deposits. This paper is an attempt to explain the stratigraphy of one such gas-bearing formation, and to give a progress report on drilling and completion techniques being used in its development.

The area of interest here in the Douglas Creek arch of western Colorado, from Rangely field south to the outcrop of the Mancos B in the Grand Valley (Fig. 1). Subsurface control decreases rapidly on the flanks of the northern part of the arch as drill depths become great, but data has been incorporated to the southeast and southwest to add greater dimension to the stratigraphic discussion.

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STRUCTURE

The Douglas Creek arch is a large anticlinal feature that extends northward from the Uncompaghre uplift through Rangely to the eastern end of the Uinta uplift in westernmost Colorado (Fig. 1). It separates the Piceance basin on the east from the Uinta basin on the west, and as such may be considered to have over 12,000 feet of structural relief in its northern part. In detail the arch is broken into a number of separate anticlinal features by northeast- and northwest-trending structural elements (Fig. 2). The northwest structural grain is manifest as moderate to large asymmetrical anticlinal trends that may be faulted at depth on their steeper southwest flanks; example of these are the Rangely and Douglas Creek anticlines and, in the south, smaller anticlines such as Garmesa-South Canyon, San Arroyo, etc.

The northeast structural grain is expressed mainly as normal faults (dip average 75-80°, Kopper, 1962, p. 108) with vertical displacements as great as 1,000 feet but generally less than 500 feet; most of these can be mapped at the surface. All but the largest appear to die out downward in the Mancos Shale; for

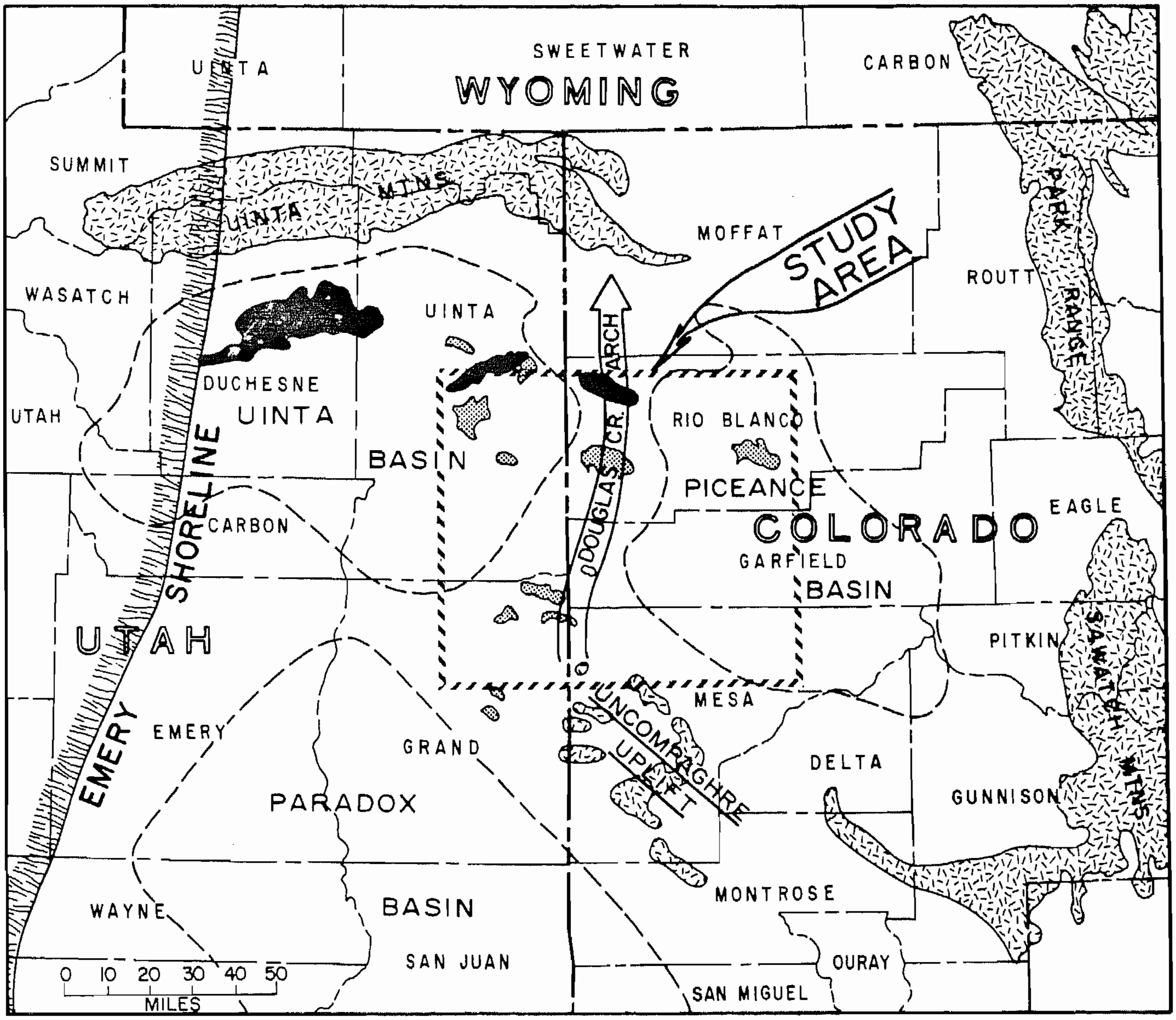

Fig. 1 — Location map showing the Douglas Creek arch as a north-plunging anticlinal uplift between the Piceance basin and the Uinta basin. The Mancos B Formation was deposited in an offshore marine environment a considerable distance east of the Emery shoreline. (Shoreline position from Rocky Mountain Geological Atlas, Mallory, 1972, p. 217).

this reason the faults are most common in the northern part of the arch where post-Mancos rocks are preserved. Many of the faults can be mapped for long distances and some have east-west legs during parts of their traces. Only a portion of the known faults are indicated on the structure contour map.

STRATIGRAPHY

The Mancos B Formation was deposited in an offshore marine environment during a regressive phase of the late Cretaceous. During its deposition the study area lay approximately 100 miles east of the shoreline (in central Utah) where sands of the Emery Formation were being deposited (Fig. 1). It is both underlain and overlain by marine shales of the Mancos Formation.

The name Mancos B is used here because of its common application in the study area and because stratigraphic relationships to the type Emery are still unclear. The name appears to have arisen from subsurface usage in the Douglas Creek area and the type section may be taken as the interval from about 2,445 feet to 2,830 feet depth in the General Petroleum Douglas

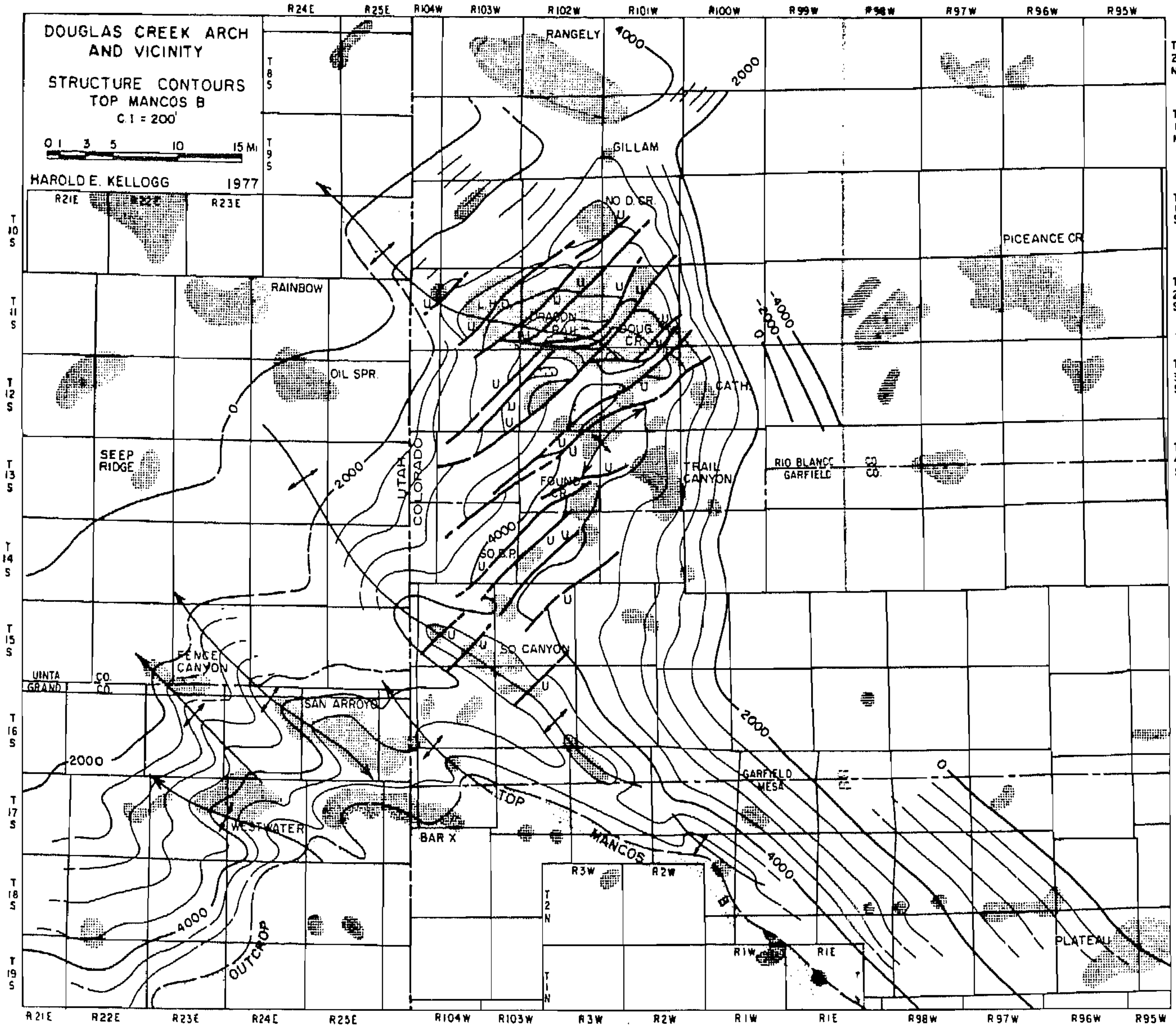

Fig. 2 — Structure contour map on the top of the Mancos B Formation, as used in this paper. Note steep dip into the Piceance basin east of Cathedral field (based on extrapolation from shallower beds). Only the larger faults are shown.

Creek No. 1 (Sec. 24, T. 2 S., R. 103 W., Rio Blanco County, Colorado) after Kopper (1962). However, it is proposed here that the upper boundary of the formation be raised somewhat (to 2,349 feet depth in the type well) to better conform to regional stratigraphy.

LITHOLOGY

The Mancos B consists of intimately interbedded claystone, siltstone, and fine sandstone. In cores at Douglas Creek anticline individual sandstone beds are seldom more than one foot thick and the intercalated claystones range from fractions of an inch to several inches in thickness (Kopper, 1962, p. 109). The sandstone is light gray or brownish gray, very fine to fine-grained (rarely medium grained at Douglas Creek anticline), dolomitic, and poorly sorted. Some carbonaceous material is also present and may appear as dark microlaminae or as carbonized plant (?) fragments. Kopper (1962, p. 109) reports the occasional presence of pelecypods and evidence of small scale cut and fill structures in cores.

Because of the thinly inter-laminated nature of Mancos B rocks, it is apparent that mechanical logs do not acccurately define "beds" but rather varying ratios of sand, silt, and clay.

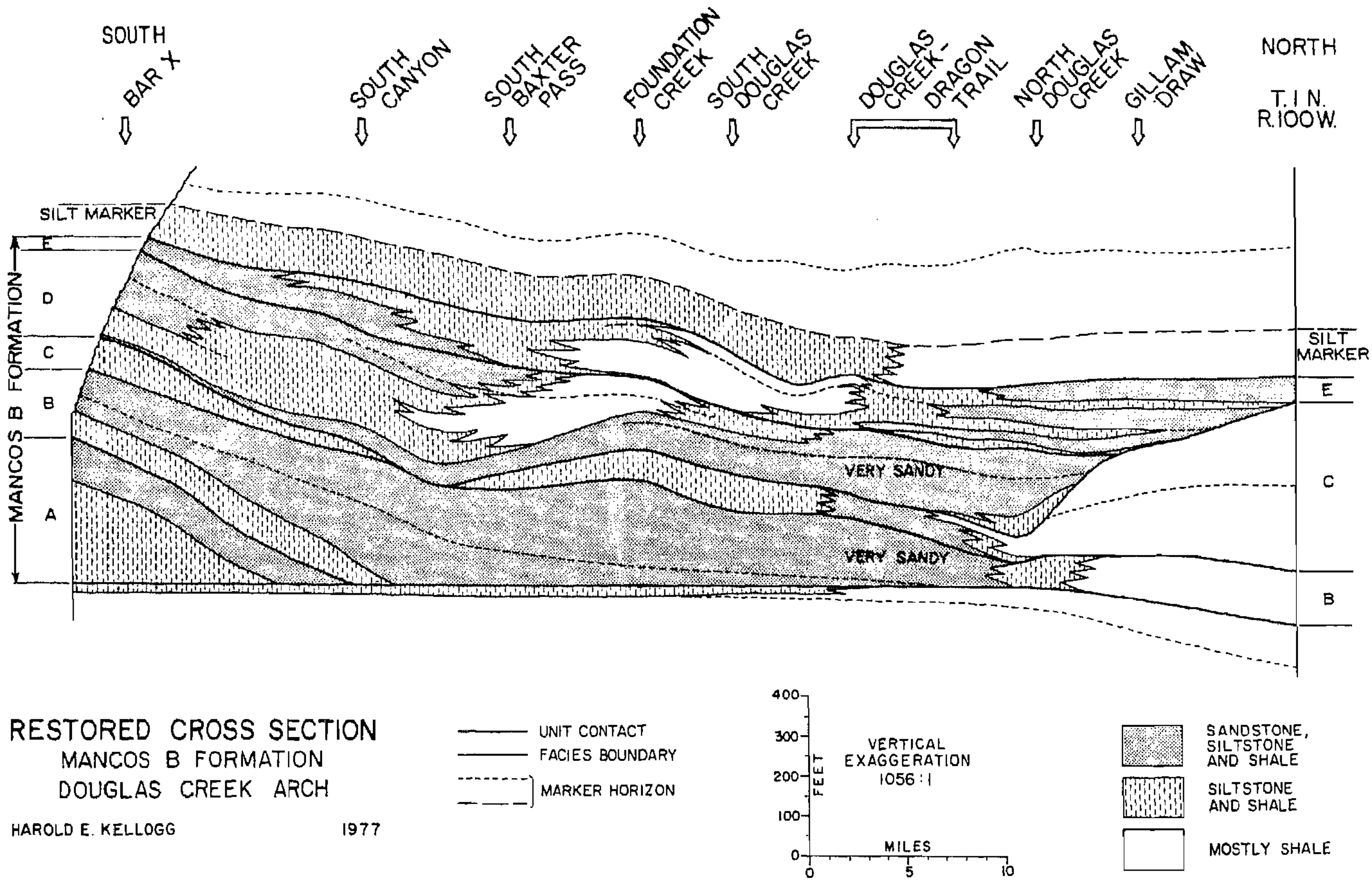

Fig. 3 — Restored cross section of the Mancos B Formation along the Douglas Creek arch. For location of section see Figure 4. The base of the formation is thought to have been nearly horizontal during deposition, except possibly in the northeast. Facies are highly generalized.

To date this has precluded any meaningful detailed lithologic studies based on mechanical logs, and tends to cast doubt on interpretations of porosity logs. Therefore, in illustrating the internal facies changes of the formation, the writer has recognized three qualitative facies (Fig. 3): the "shaly" facies appears to consist largely of claystone with minor amounts of siltstone and little or no sandstone; the "silty" facies may have appreciable siltstone and minor amounts of sandstone; and the "sandy" facies contains moderate to appreciable amounts of sandstone with the siltstone and claystone. There appears to be no massive or even thickly bedded sandstones in the formation.

FACIES DISTRIBUTION

The interval from the top of the Castlegate Formation (Morapos, or Mancos A) to the base of the Mancos B is fairly uniform in thickness (1,500 feet ± 50 feet) over most of the area of study. Only in the extreme northeast (T. 1 N., R. 100-101 W.) does the interval thicken rapidly to over 1,900 feet; the equivalent interval at Piceance Creek field (Mobil Oil Corp., deep test, NW NE Sec. 19, T. 2 S., R. 96 W.) is nearly 2,100 feet. This suggests that the surface on which the Mancos B was initially deposited was a sub-horizontal submarine shelf, possibly with a northwest-trending margin passing just south of Rangely field (Fig. 4). It is not clear, however, to what extent any such shelf margin existed prior to deposition of the Mancos B and how much of the thickening is due to post-Mancos B and pre-Castlegate events.

For convenience of presentation the Mancos B has been divided into five units, with Unit A at the base and Unit E at the top. It is realized, however, that the internal stratigraphy of the formation is very complex, comprising a multitude of depositional episodes. Other subdivisions are equally reasonable and might be more appropriate if the study encompassed a larger area.

Basal Contact: The Mancos B rests with generally sharp

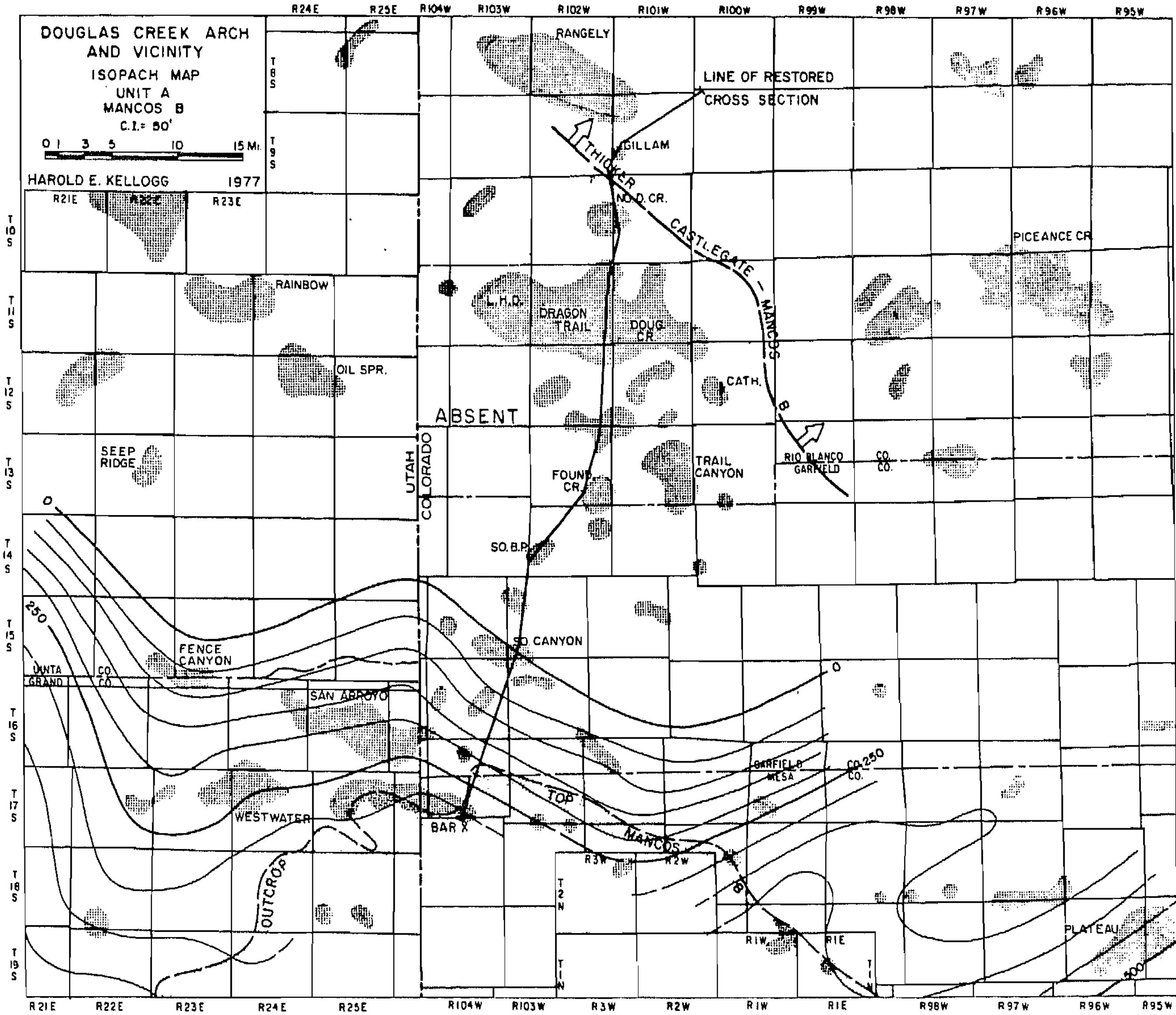

Fig. 4 — Isopach map of Unit A of the Mancos B Formation. North of the zero line the unit was either never deposited or is so thin as to be unrecognizable. The interval from the top of the Castlegate (Morapos?) Formation to the base of the Mancos B is a rather uniform 1500± 50 feet in thickness over most of the area, but thickens rapidly to over 2000 feet northeast of the line trending southeast from Rangely oil field.

contact on shale or siltstone of the lower Mancos Formation and may be placed at a marked reduction (above) in the gamma ray count rate. Niobrara-equivalent (?) calcareous beds are present a short interval below the base. Immediately below the base in the south is a 20-30 foot thick silty interval which can be traced continuously northward to Douglas Creek anticline, where it loses its silt content and thickens to over 100 feet (Fig. 3). Notwithstanding the sharpness of the contact and the continuity of underlying beds, it is apparent that the basal beds are progressively younger northward. This is a result of rapid northward progradation of the lower units of the formation.

Unit A: The basal unit of the Mancos B is present only in the south, where it comprises a southward thickening wedge of siltstone and shale capped by 50-100 feet of the sandy facies. It reaches a maximum thickness of over 500 feet in the southeast (Plateau Creek area) and is about 300 feet thick on the outcrop at the Utah-Colorado border (Fig. 4). The unit thins rapidly northward and is entirely absent (or so thin as to be unrecognizable) north of the South Canyon area. The upper sandy interval maintains its thickness northward and makes up the entire unit where this is less than 100 feet thick.

The geometry and internal features of Unit A indicate that it was deposited as a northwardly prograding fore slope oriented nearly east-west (except possibly in the far west of the area, Fig. 4). The fine clastic material was probably transported eastward from the source area and then northward into deeper water.

Unit B: The next younger unit of the Mancos B continued the northward construction of the fore slope, initially with the deposition of siltstone and shale but rapidly grading upward into the sandy facies characteristic of Unit B. During the latter part of this period the dip of the fore slope decreased and deposition of the sandy facies took place over a much larger area. The sandy facies extends to just north of the Douglas Creek anticline before rapidly changing to a shale facies (Fig. 3); the approximate northern limit of the sandy facies of Unit B closely coincides with an isopach thin of the lower Mancos B (Fig. 5). It is of interest to note that the sandiest part of Unit B exists at Douglas Creek anticline.

Unit C: The overlying unit is again characterized by siltstone and shale deposits over most of the area. Thicknesses range from zero to less than 100 feet, except in the extreme north where Unit C is represented by a thick (over 400 feet) shaly facies. Again the facies at Douglas anticline is anomalous in its higher sand content. The tracing of marker beds within the northern shaly facies of Unit C suggests that the unit may originally have been thicker to the south, and that erosion occurred prior to deposition of the overlying beds (Fig. 3). Evidence for erosion of this unit is also present between South Baxter Pass and South Canyon, where Unit D rests directly on Unit B. Any such erosion probably occurred on the sea floor, possibly as the result of submarine channelling as there is no evidence to suggest emergence.

The isopach map of Units A-C combined (Fig. 5) shows two pronounced thins: an east-trending thin passing through the North Douglas Creek area, and a southeast-trending thin in Utah that turns easterly and passes north of South Canyon. The southern thin area corresponds generally with the area of absence of Unit C.

Unit D: Facies distribution within Unit D gives the first indication of Mancos B sediment transport in a direction other than northward. Sedimentation began with deposition of a silty facies in the North Douglas Creek low and was followed by a sandy facies that spread southward, thinning to near absence at the outcrop (Fig. 3). This lower part of Unit D is one of the sandiest parts of the Mancos B, and is very sandy at Douglas Creek anticline. North of the North Douglas Creek low the deposits pinch out as they onlap the topographic high formed by Unit C, but the sandy facies is also present to the west in Utah and to the east at Piceance Creek anticline.

The upper part of Unit D is also in a sandy facies at North Douglas Creek but this grades southward into a silty facies and, at Foundation Creek, into a shaly facies. South of South Baxter Pass an upper D sandy facies derived from the south or southwest is present; this sandy facies continues upward into Unit E and the boundary between the two units is difficult to place in the south.

Unit D is thickest (over 400 feet) and the least sandy where it filled the pre-existing southern low. It thins gradually southward (to less than 350 feet) and thins rapidly northward (to absence) between North Douglas Creek and Gillam Draw (Fig. 6). The lower sandy beds appear to have been carried into the area from the west; the interval is very sandy in adjacent Utah, and only moderately sandy at Piceance Creek anticline.

Unit E: The uppermost unit of the Mancos B is more uniform in thickness than any of the older units, being between 100 and 200 feet thick over most of the area. It is found in a shaly facies in the central part of the arch, but southward it thins and becomes sandy, reflecting the persistance of a southern "source"; it is thinnest (in places less than 40 feet) in the southwest. North of Douglas Creek anticline a moderately sandy facies, in three benches, thins as it continues to onlap the pre-existing Unit C high (Fig. 3). At Piceance Creek anticline the unit is thin (100 feet) but includes all three sandy benches present at North Douglas Creek.

Overlying beds: The interval above the Mancos B and below the Castlegate is found mostly in a shaly facies. A prominent marker horizon (Silt Marker of Kopper, 1962, Geologic Map) can be traced over most of the area (Fig. 3). On the west flank of the Douglas Creek arch some thin, usually discontinuous sandstone beds are present immediately beneath the marker; the interval between the marker and the Mancos B may become sandy farther to the west.

DEPOSITIONAL SUMMARY

The lower Mancos B (Units A-C) was deposited on an east-west trending, northerly prograding submarine slope or fore slope; a top slope or submarine terrace may have existed to the south during this time, but there is only slight evidence for this in the isopach maps (Figs. 4 and 5). Sediment transport was apparently from south to north during lower Mancos B deposition, although the ultimate source area may have been to the west or southwest. A comparatively steep fore slope (24-40 feet per mile dip) was maintained through deposition of the lower part of Unit B, but then decreased markedly. The prograding sediments were deposited initially on a sub-horizontal submarine terrace that may have had an edge in the northeast part of the area. Following, or during the late stages of deposition of Unit C, an erosional submarine topography was developed whose main features were two east- or southeast-trending lows.

Deposition of the upper Mancos B (Units D-E) began with

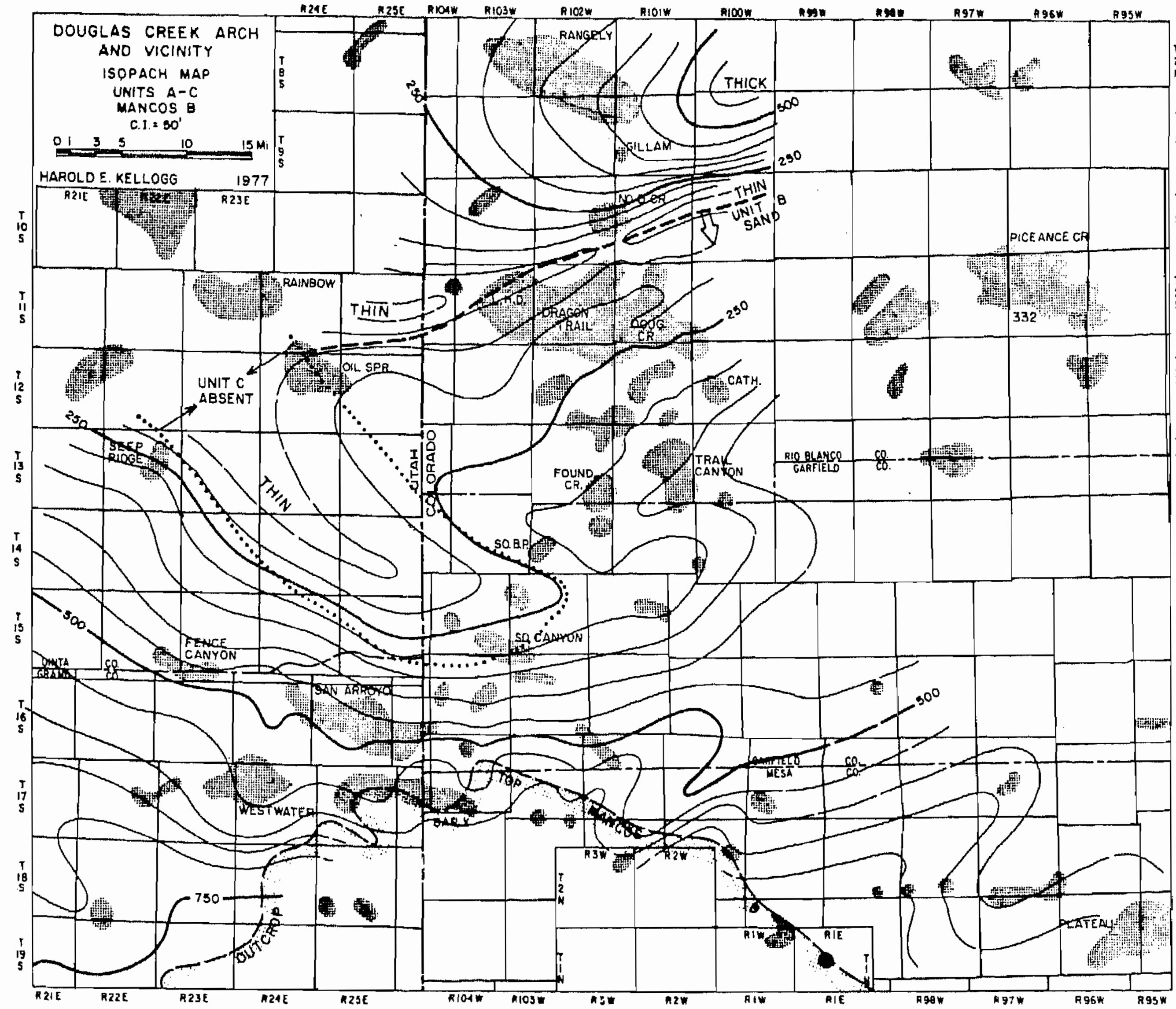

Fig. 5 — Isopach map of the lower Mancos B Formation (Units A-C). Note the pronounced thin north of Douglas Creek anticline which is coincident with the facies change from sandy (south) to shaly (north) of Unit B. The thickness at the Mobil Oil Corporation deep test in Piceance Creek gas field is shown but not contoured.

an influx of sandy material, probably from the west, that filled the North Douglas Creek low and spread southward. During late D and early E deposition, sandy material again entered the southern or southwestern part of the area. Onlap of the northern topographic high was not completed until the end of Mancos B deposition, if then.

By the end of Mancos B deposition the dip of the southern fore slope had been greatly reduced, and the two low areas had been largely filled. The total Mancos B interval is over 1,000 feet thick in the southeast, but a fairly uniform 500 feet thick in the vicinity of Douglas Creek anticline (Fig. 7).

Because of facies changes in the upper Mancos B the "top of the sand" varies through a considerable stratigraphic interval over the area, and may be placed as high as the Silt Marker (west of the arch) or as low as the lower part of Unit D (at Foundation Creek). A lithologically based top of the Mancos B formation is therefore of little value in mapping time stratigraphic units.

It will be apparent from the foregoing discussion and from Fig. 3 that the immediate area of Douglas Creek anticline experienced the greatest concentration of sands throughout deposition of Units B, C, and D. This may be the result of a

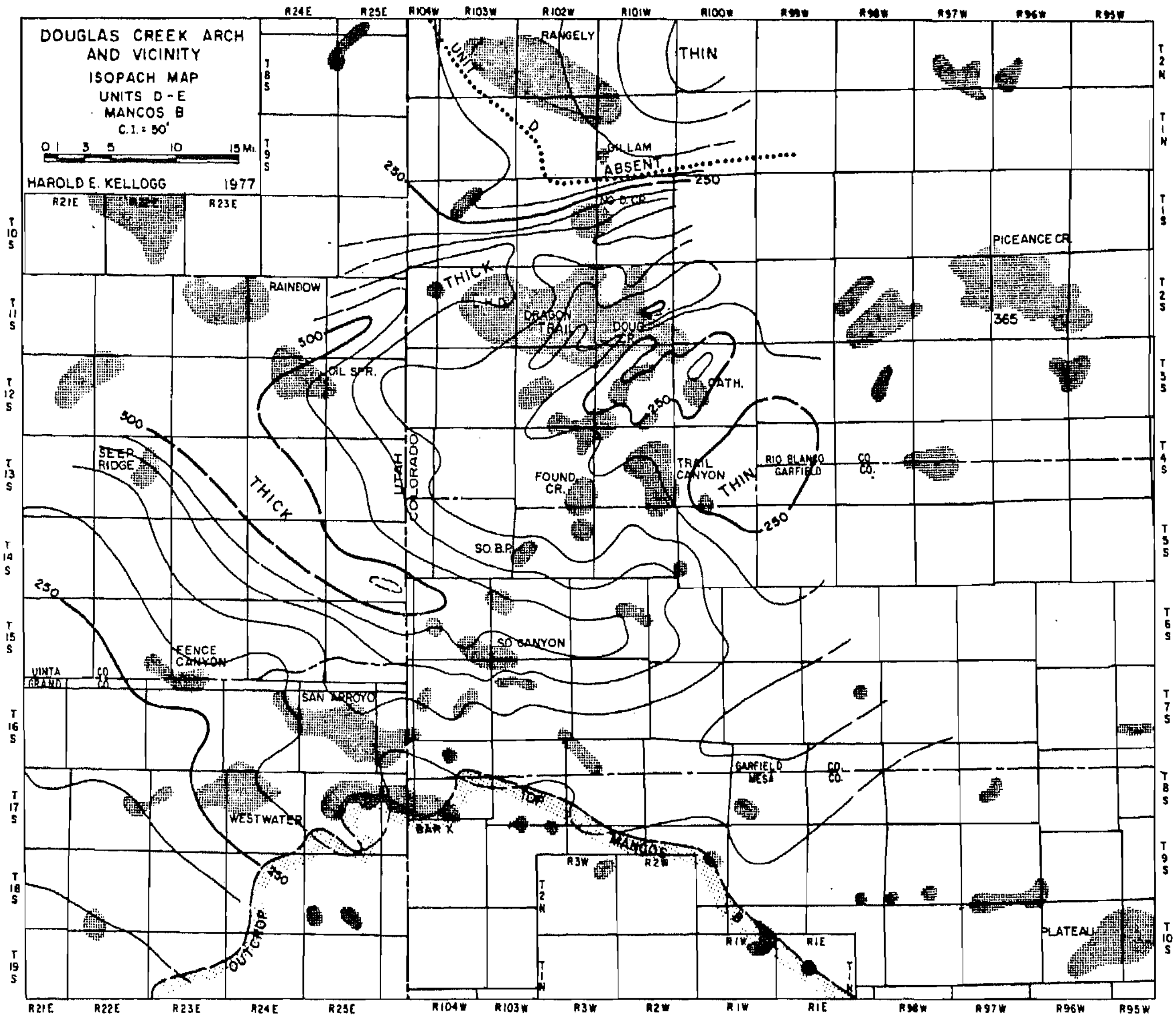

Fig. 6 — Isopach map of the upper Mancos B Formation (Units D-E). Thick areas are apparently the result of infilling of pre-existing submarine topographic lows developed on the lower Mancos B (compare with isopach thins of Figure 5). Unit D is absent, due to depositional onlap, at Rangely oil field.

winnowing effect, due to differential compaction or insipient growth of the Douglas Creek anticline, but it seems more likely that the high degree of sandiness there is the result of more or less fortuitous "stacking" of facies.

RESERVOIR CHARACTERISTICS

Core analyses of the Mancos B have been reported upon by Kopper (1962) and by Mathias (1971). These indicate porosities of 10-11%, average permeabilities of about 0.7 md, and 50% water saturation in the sandy facies at Douglas Creek anticline. Uncorrected density log porosity values range as high as 14% but are more commonly around 10%. The measured carbonate (mostly dolomite) content is 10-20%. The silty and shaley facies contain little or no reservoir rock although they may contribute to production through fractures.

There is as yet no evidence that the Mancos B is differentiated into separate pools by stratigraphic variations. This is not likely considering the high degree of faulting present. Undisturbed reservoir pressures are difficult to obtain because of the very long pressure buildup times (measured in months) required to approach static conditions following drilling or testing. Nevertheless, it is clear that the reservoir is "underpressured" having a gradient of 0.17 to 0.22 psi/ft. depth. The rocks are

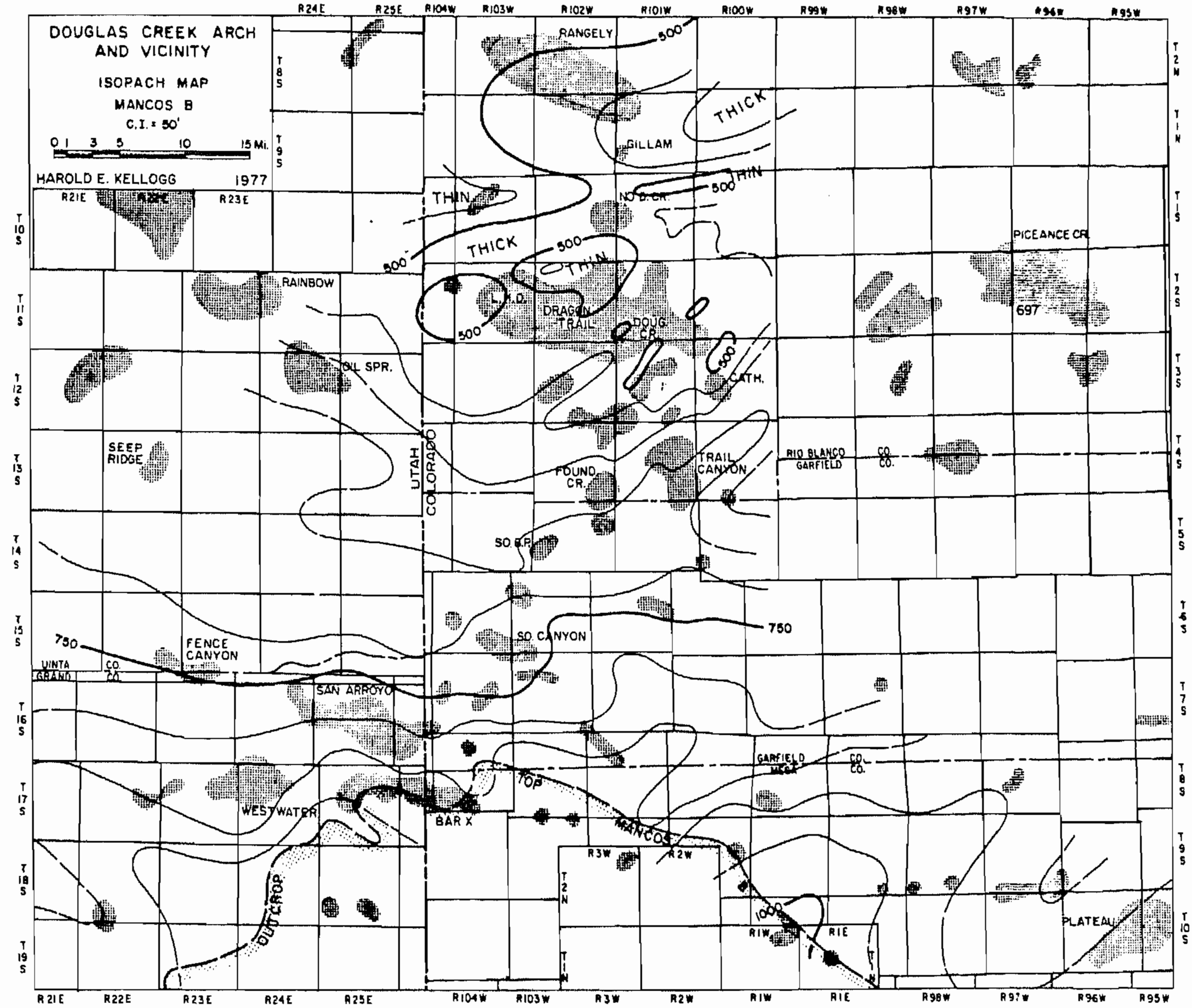

Fig. 7 — Isopach map of the Mancos B Formation (Units A-E). A north-facing depositional slope was still present in the south at the end of Mancos B deposition, but the northern area had been filled to a rather uniform thickness. The thick at Rangely Oil Field consists largely of shaly facies (Units B and C) with a thin capping of sandy or silty upper Mancos B (Unit E).

extensively fractured in some areas. Cores show the fractures to be oriented predominantly in a horizontal plane but also vertically (Mathias, 1971, p. 186).

The Mancos B Formation is extremely susceptible to damage by fresh water. This may in part be due to alteration of interspersed clay minerals, as use of saline (KCl) drilling and fracturing fluids appears to reduce formation damage. But it may also be the result of absorption of water into minute pore spaces around the well bore; permeability damage due to water absorption is a function of the time that fluid is on the formation and apparently is an irreversible process.

PETROLEUM DEVELOPMENT

Early drilling on the central portion of the Douglas Creek arch (south of Rangely) was directed toward deep objectives — the Pennsylvanian Weber Formation, the Jurassic Entrada Sandstone, and the Lower Cretaceous Dakota Formation. Gas was discovered in the Dakota Formation in 1943 at Douglas Creek anticline, and in 1956 both oil (Weber) and gas (Castlegate-Morapos) was discovered at North Douglas Creek. Gas shows in the Mancos B had been tested but with little or no recovery.

By 1959 the advent of air drilling had provided a better method of drilling wells in tight, water sensitive formations, and in July of that year the Continental Oil Company tested the first commercial gas well at their No. 31-5 Douglas Creek Unit (SW SW Sec. 31, T. 2 S., R. 101 W.). Active development began in the summer of 1960 and by March 1, 1962, 42 Mancos B gas wells had been completed (Kopper, 1962, p. 109). The wells were drilled with cable tool or air-rotary rigs and mostly completed open hole.

It soon became apparent, however, that the low producing rates obtained (generally less than 300 MCFPD) would not supply the gas needed for an expanding market, and in 1966 the Continental Oil Company began casing Mancos B wells, perforating, and fracturing these with newly developed pseudo-limited entry techniques (Mathias, 1971, p. 186). The resulting large increases in producing rates spawned a new period of development; new wells were drilled and a number of existing wells cased and fractured. Soon the Douglas Creek anticline had become one large field, comprising the Douglas Creek, Dragon Trail, Lower Horse Draw, North Dragon Trail, and West Douglas Creek Units, and satellite fields existed at North Douglas Creek, Hells Hole Canyon, and Cathedral (shut in). Drilling slowed in the late 60's as demand was met.

By the mid 70's increasing demand and higher gas prices led to yet another round of activity. The Dakota Formation has continued to be a primary drilling objective, but a large proportion of the new wells are being directed towards extending Mancos B production. No actual limits to production had been established by previous drilling, other than that dictated by economics. Inside locations are now being drilled and the field limits extended, particularly to the east and to the northwest.

In addition, it has been recognized that the Mancos B is productive elsewhere than Douglas Creek anticline, and exploration has been extended into adjacent areas. In 1975 the Norris Oil Company completed a Mancos B producer at Foundation Creek, and in 1976 Mancos B production was established at South Douglas Creek. It now appears that an essentially continuous producing area will be established along the crest of the arch, at least as far as T. 5 S.

GAS PRODUCTION

Table 1 summarizes Mancos B production in the study area by field or unit, as of the end of February 1977. It will be noted that the bulk of the production has come from and continues to come from the Douglas Creek anticline (February 1977 production: 1,175,269 MCF, cumulative production: 126,694,291 MCF. This situation is expected to prevail for some time because (1) the best producing wells are found on the structure, (2) a large number of extension wells are being drilled and will be connected soon, and (3) the field has been on full scale production for only about 10 years and is estimated to have a 50-year life.

Initial producing rates of over 10,000 MCFPD have been reported in the best part of the field, but reported potentials commonly do not reflect stabilized producing rates. The average per well production for 127 gas wells on the anticline is currently about 330 MCFPD in the winter (February 1977 figures). Historically, reduced demand has dropped average production to about half this figure during the summer months. Decline rates for Mancos B wells appear to be averaging about 6% per year once the producing rate has stabilized. Early figures for wells southward on the arch suggest that average producing rates may be somewhat lower there. Mancos B gas has appreciable condensate and a heating value of about 1,200 BTU per MCF.

Marketing outlets are via three established pipelines. The Western Slope Gas Company takes the bulk of the gas from Douglas Creek anticline for the intrastate market, but increasing amounts are going interstate via the Cascade Natural Gas line into Utah, and the large diameter Northwest Pipeline Corporation line. Gathering system pressures are low (50-75 psi) and compression is required for injection into the pipelines. The sales price is currently controlled by or closely related to the FPC national rate; however the high heating value of Mancos B gas results in an approximately 20% increase in price, due to BTU adjustments.

OIL PRODUCTION

The existence of producible oil in the Mancos B has been known since 1960, when the Continental Oil Co. drilled its No. 36-4 Dragon Trail Unit well (SE SW Sec. 36, T. 2 S., R. 103 W.). This well was located on the down-thrown side of a large fault, encountering the Mancos B at a low structural position, and was completed pumping 12 BOPD. Again in 1967 the Continental Oil Co. found oil in a well drilled on the north flank of the structure (Sec. 2, T. 2 S., R. 102 W.; I. P. 40 BOPD and 8 BWPD.). Several wells have since been completed in the area producing variable amounts of oil, sometimes in association with gas — notably along the north margin of Lower Horse Draw (Sec. 2; 10 and 11, T. 2 S., R. 103 W.), in the Philadelphia Creek area (Secs. 2-4, T. 2 S., R. 101 W.), at Rocky Point (Sec. 17, T. 2 S., R. 100 W.), and at Trail Canyon (NW SE Sec. 23, T. 4 S., R. 101 W.). The produced oil is about 40° API gravity, green, and with a moderately high pour point; it appears to be similar to that produced from the fractured Mancos Shale (Niobrara) at Rangely anticline. Producing rates are generally only a few barrels per day.

The factor common to all of the oil producing wells is their low structural position relative to gas wells in the area. Although data is still sketchy, it now appears that there may be an oil ring around Douglas Creek anticline with a transitional gas-oil contact at about + 3300 ± 100 feet elevation. Whether or not an oil-water contact exists at some lower elevation has not yet been established. It is of interest that the Rocky Point oil well apparently has no oil-water contact in the Mancos B, which is 500 feet thick there and whose base is at an elevation of +1930 feet. This suggests that there may be over 1400 feet of oil column present.

Perhaps the most significant well in the area from the point of future oil production is the Tipperary Corporation test in Trail Canyon field. This well was completed open hole pumping 107 BOPD, but was shut in due to mechanical problems after producing only 1688 BO. This shows that oil production is not restricted to Douglas Creek anticline and that higher producing rates may be obtained. The well is located structurally low on the arch (top at + 3675 feet, base at + 3024 feet) and might be taken as evidence of a southward extension of a tilted (?) Douglas Creek oil column were it not for the fact that Cathedral field, which is 300-700 feet structurally lower than the Trail Canyon well, apparently produces only gas from the Mancos B.

DRILLING AND COMPLETION

As noted in the discussion of reservoir characteristics, the Mancos B Formation has low porosity, low permeability, and is very sensitive to formation damage by introduced water. The emergence of the formation as a significant producer of natural gas has therefore been largely dependent upon the development and application of special drilling and completion techniques.

DRILLING PRACTICES

The main objective in designing a drilling program for Mancos B wells is to avoid introducing fresh water into the formation. It was proven early in the history of Mancos B production that wells drilled with natural mud had significantly lower productive capacity than adjacent wells drilled with air (Mathias, 1971, p. 186). A few wells are still being drilled with mud, perhaps with the rationalization that fracture treatments will overcome any formation damage around the well bore, but results continue to bear out the earlier conclusions.

Most wells drilled to the Mancos B utilize air as the circulating medium and are either drilled dry (dusting) or wet (misting). In order to drill dry it is necessary to set an intermediate string of casing (usually 7 inch) through shallow water-bearing formations (including the Castlegate Sandstone). This method is particularly preferred for wells programmed to test deeper formations (Dakota, etc.) while retaining the option of a Mancos B completion, and provides the additional advantage of permitting quantitative open hole flow tests of the formation. At least one operator has used natural gas as a drilling medium, but at today's prices the cost appears to out-weigh any advantages.

Mancos B tests in known producing areas are also commonly drilled without shutting off shallower water sands (i.e., without an intermediate string of casing). If good, high pressure compressors are available, a considerable amount of water influx can be tolerated without hampering operations unduly. It should be noted that because of the altitude (5000-9000 feet above sea level) larger compressor engines must be used.

Drilling with air also provides considerable savings in drilling costs over mud-drilled holes because of high penetration

Table 1: Gas and oil production from the Mancos B Formation on the Douglas Creek arch.

FIELD or UNIT	YEAR DISC.	PROD.[1] WELLS	GAS PROD. (MCF) FEB. 1977	GAS PROD. (MCF) CUMM.	OIL PROD. (Bbls) FEB. 1977	OIL PROD. (Bbls) CUMM.
Douglas Creek	1959	16	112,881	10,797,283	0	0
Dragon Trail	1959	74	601,775	71,703,863	0	1,711
Lower Horse Draw	1960	28	305,245	29,452,160	72	1,977
Dragon Trail North	1961	1	96	53,720	44	14,448
Hells Hole Canyon	1963	0	0	306,087	0	0
Douglas Creek North	1963	7	2,244	158,872	0	0
Cathedral[2]	1967	4	9,442	20,693	0	0
Douglas Creek West	1968	8	155,272	14,687,265	0	337
Foundation Creek	1975	7	22,204	192,897	0	0
Trail Canyon[3]	1975	0	0	3,718	0	1,688
Rocky Point	1976	1	0	0	335	557
TOTALS		146	1,209,159	127,376,558	451	20,718

[1] Number of wells that produced during the month of February, 1977. Does not include shut in or depleted wells.

[2] Shut in until 1976.

[3] One well, shut in due to mechanical problems.

rates (1000 feet per day is common) and low mud costs. Also eliminated are lost-circulation and caving problems in the Tertiary and Mesa Verde formations, which can be severe in mud-drilled holes.

The standard open-hole logging device is the Density log, and many development wells have no other logs run. Also common are the Neutron-Density combination and the Induction log, although these require loading the hole with KCl water, or low water loss mud, which may cause hole problems. Special logging devices, such as the Dual Spacing Thermal Decay Log, and the Fracture Finder Micro-Seismogram Log, have been tried recently in attempts to better locate zones for perforation.

A production string, usually 4-½'' casing, is run through the Mancos B Formation and cemented with low water loss cement. Some operators are making open hole completions, setting production casing at the top of the Mancos B and foregoing fracture treatment. However, because the formation is so shaly, open hole completions over such a thick interval run a high risk of later caving and resultant workover problems.

COMPLETION PRACTICES

The great majority of Mancos B wells completed in the last ten years have received some sort of fracture treatment. The development by the Continental Oil Company of a pseudo-limited entry fracturing technique for the Douglas Creek area has been described by Mathias (1971). The technique was designed to provide better vertical fracture control over a thick interval by assuring that the fracturing fluid entered essentially all of the perforations. To accomplish this, injection rates are kept high enough to cause sufficient pressure drop across the perforations to theoretically assure that all are penetrated.

For economic reasons the carrying media in the pseudo-limited entry fracture treatment is water, rather than condensate. Experiments have shown that the addition of 2% KCl to the water greatly reduces permeability loss due to water invasion, particularly if the fluid is not left in the formation for an extended period. To facilitate flow-back of the fracture fluid considerable inert gas (nitrogen or carbon dioxide) is added in liquid form and the well is opened to the atmosphere as soon after fluid injection ceases as is possible. The propping agent is 10/20 mesh sand which is added at a concentration of 2-4 pounds per gallon.

Early fracture treatments involved the displacement of 40,000-60,000 pounds of sand into the formation, but larger treatments are now becoming standard. The average well has 25 half-inch perforations over a 300-400 foot interval at 2200-3500 foot depths. Operators and service companies are still experimenting with fracturing techniques (''foam frac'', addition of acid to fracturing fluid, etc.), but a typical two-stage fracture treatment is probably about as follows (all fracture fluids contain 500-900 SCF/bbl CO_2; injection pressures are 2500-4000 psi; average injection rate 30-40 bbl/min., or about 1-½ bbl/min/perforation):

A. Spot 1500-3000 gal. 15% HCl mud acid, dropping balls at regular intervals.
B. Inject 3500-5000 gal. 2% KCl water pad. Continue dropping balls until there is no more ball action (total of 30-40 balls, steps A and B). Shut down and rig up for fracture treatment.
C. Inject 1500 gal 2% KCl water with 2 lb/gal 100 mesh sand and 40 lb/1000 gal gelling agent. Follow with 1500 gal KCl water spacer (no sand).
D. Inject 3000 gal KCl water with 4 lb/gal 100 mesh and gelling agent. Follow with 1500 gal spacer.
E. Inject 1500 gal KCl water with 2 lb/gal 10/20 sand and gelling agent. Follow with 1500 gal spacer.
F. Inject 4000 gal KCl water with 3 lb/gal 10/20 sand and gelling agent. Follow with 1500 gal spacer.
G. Inject 4000 gal KCl water with 3.5 lb/gal 10/20 sand and gelling agent. Follow with 1500 gal spacer.
H. Inject 6000 gal KCl water with 3.5 lb/gal 10/20 sand and gelling agent.
I. Inject 500 gal. KCl water spacer with 200 lbs. Benzoic Acid Flakes and 14 ball sealers.
J. Repeat step C through H.
K. Displace to perforations with KCl water.
L. Rig down and open to atmosphere through tubing.
Total materials used: 65,000-70,000 gal (1500-1600 bbls) 2% KCl water; 30,000 lbs. 100 mesh sand; 80,000 (to 100,000) lbs. 10/20 mesh sand; 90 tons CO_2; plus acid, surfactant, and gelling agent.
Total Cost: About $50,000.00.

The injected carbon dioxide or nitrogen provides additional temporary reservoir energy to help flush fracturing fluids from the formation until natural pressures become effective, and eliminates or minimizes the need for swabbing. A gas well will normally flow completely dry gas and condensate after 3-7 days of open flow using this procedure. However, even under ideal conditions only about 30% of the fracturing fluid is recovered, the rest staying in the formation. The pseudolimited entry fracturing technique has been observed to increase flow rates (over natural flows) as much as tenfold in ''good'' areas and by considerably larger ratios in ''poor'' areas; some gas wells have no measurable natural flows before treatment.

LOOKING AHEAD

Development of Mancos B gas will undoubtedly continue for at least the next few years. The number of new locations on the arch announced during the first part of 1977 is up about 35% over the comparable period in 1976, which was up significantly from 1975. A number of wells have been connected to the pipeline since the end of February, 1977, the cutoff date for compilation of Table 1, and an even larger number of wells are currently awaiting connection.

Drilling will eventually establish some limits to Mancos B gas production, but until the trapping mechanism is better understood it cannot be stated whether this limit will be physical or economic. There now appears to be physical limits to gas production at Douglas Creek anticline (i.e., the probable existence of a gas/oil contact combined with northward pinch out of the sandy facies on the arch). Activity there will probably soon focus on developing means of extracting oil from the formation at economic rates, although at 160-acre spacing there remains a number of undrilled gas well locations, particularly on the east end of the anticline.

Although Mancos B producing rates are generally lower south of Douglas Creek anticline on the arch, this appears to be the result of poorer facies there rather than to any structural limit. Anticlinal or fault closures are generally small in this southern part of the arch, and petroleum production is obtained far lower structurally than any possible limit of closure. Also, there are virtually no tests of the Mancos B south of T. 5 S., or on the flanks of the arch.

A drillstem test of the upper part of Unit D (stratigraphically equivalent to South Baxter Pass area on Fig. 3) flowed gas at rates up to 300 MCFPD in the Marathon No. 1. Two Waters well in adjacent Utah (Sec. 8, T. 14 S., R. 25 E.), and at least two wells apparently produced minor amounts of oil from the formation farther to the southwest (Sar Arroya field, and at Segundo Canyon, Sec. 9, T. 17 S., R. 21 E.). Also Mancos B oil shows have been encountered in some air drilled holes on the southern part of the Arch.

This suggests that production may eventually extend over a very large area. Development of the Mancos B reserves in areas with poor facies may, however, require further breakthroughs in drilling and completion techniques, or significantly increased product prices, to be economic.

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