STRATIGRAPHY, SEDIMENTOLOGY, AND PETROLEUM POTENTIAL OF DAKOTA FORMATION, NORTHEASTERN UTAH

by

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ABSTRACT

The Lower Cretaceous Dakota Formation in northeastern Utah is a fluvial deposit containing channel and overbank facies. The channel facies consist of multistoried sandstone bodies deposited as point-bars in sinuous streams and rivers. Each point-bar displays an upward fining sequence of grain sizes and sedimentary structures that indicate an upward decrease in flow density.

Through time the fluvial system changed from relatively large streams to smaller, more numerous streams that underwent repeated channel avulsions. Deposits of both stream types display a distinctive outcrop morphology. This stream system flowed across a low-lying coastal plain not far from the advancing shoreline of the Mowry sea.

The lower contact of the Dakota with the Cedar Mountain Formation is a scoured erosional surface. The upper contact of the floodplain facies with the overlying Mowry Formation is also an unconformity marking the common boundary between a continental and a transgressive marine deposit. Above the channel facies the contact is conformable. Deposition was probably continuous within the channel facies during late Dakota and early Mowry time.

Paleocurrent measurements of individual channel sandstones are strongly unimodal. However, successive channel deposits at a particular location show a wide scatter of transport directions through time. Based on 349 measurements, the net regional dispersal direction was N 3° E.

Sedimentary rocks of the Dakota Formation predominantly consist of grains recycled from pre-existing sandstone and limestone beds. Sandstone and siltstone of the Dakota are quartzarenite or quartz-rich varieties of sublitharenite and subarkose. The source area probably was the Mesocordilleran Geanticline of west-central Utah and adjacent parts of Nevada.

INTRODUCTION

The Dakota Formation of the Western Interior has long been of interest to geologists because of its important record of Cretaceous history, and because it is a frequent objective in the exploration for oil and gas. This paper extends the collective knowledge of the Dakota in both of these areas.

The Dakota Formation is well exposed on the north and south flanks of the Uinta Mountains where 11 Dakota sections were measured in detail (Fig. 1). In each section detailed descriptions were made of the beds and sedimentary structures. Special attention was given to the identification and characteristics of the cyclicity of fluvial channels. A total of 349 paleocurrent azimuths were taken, and evaluated at different interpretative levels. Thin sections of 50 rock samples were studied in detail, 35 of which were analyzed by modal analysis. One hundred-fifty rock samples were examined under a binocular microscope to determine modal grain size, frosting, sorting, color, and roundness. Sixteen rock samples were selected for X-ray analysis.

Information from these observations is used here to briefly discuss the following topics: 1) stratigraphy, 2) types of outcrops, 3) formational contacts, 4) internal sedimentary structures, 5) petrography, 6) paleocurrents, and 7) provenance.

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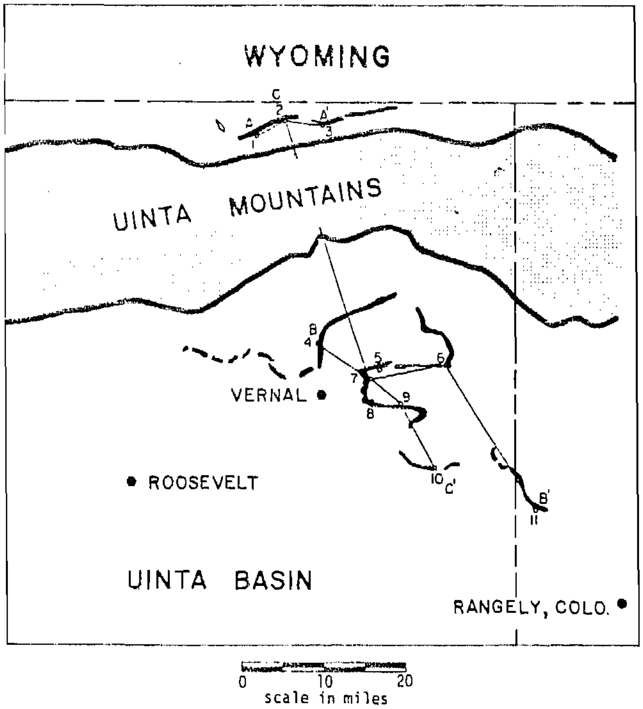
In addition, oil and gas possibilities of the Dakota Formation are discussed briefly.



1 - Manila, Utah area, (M)
2 - Finch Draw (F)
3 - Chokecherry Draw (C)
4 - Steinaker Draw (S)
5 - Split Mountain area, (SM-A)
6 - Split Mountain area, (SM-D)
7 - Split Mountain area, (SM-B)
8 - Split Mountain area, (SM-C)
9 - Quarry area, (QA)
10 - Green Mountain area, (GM)
11 - Dinosaur, Colorado area, (DC)

Fig. 1 — Index map showing location of cross-sections in study area.

PREVIOUS WORK

Meek and Hayden (1861) were the first to study the Dakota Formation from exposures near the town of Dakota, Nebraska. Since then the Dakota has been the subject of many papers and theses whose study areas ranged from the western Great Plains to the western slope of the Rocky Mountains. Depending on the geographic location, the Dakota has been reported to represent several marine and nonmarine depositional environments that are usually closely associated with shoreline conditions. Some of the more recent contributions dealing with Dakota stratigraphy are those of Kinney (1955), Haun (1959, 1963), Young (1960, 1973, 1975), Haun and Barlow (1962), MacKenzie and Poole (1962), Weimer (1962, 1970), Lane (1963), Hale and Van De Graff (1964), Suttner (1969), Haverfield (1970), and Furer (1970).

STRATIGRAPHY

General

The Dakota Formation, as here described, is bounded below and above by the Cedar Mountain and Mowry formations respectively. The Cedar Mountain Formation is continental in origin, and is recognized by its slope-forming habit and variegated colors of red, purple, and gray. Claystone, siltstone, and sandstone lenses are dominant in the Cedar Mountain. The Mowry is a dark gray to black, siliceous marine shale, easily identified in the field by its color, fissility, diagnostic fish scales, and slope-forming topography.

Dakota Stratigraphy

The Dakota Formation in northeastern Utah (Fig. 1) is a fluvial deposit consisting of channel and overbank facies. The channel facies consist of locally thick deposits of sandstone, pebbly sandstone, and conglomerate. The overbank facies are mainly siltstone, mudstone, and thin beds of sandstone. Exposures of the channel facies are common, and form prominent sandstone cliffs. Thickness of the channel deposits is variable, reaching a maximum of about 100 feet (30m) on the south flank of the Uintas and thickening to about 240 feet (72m) on the north flank. Two east-west cross-sections (Figs. 2 and 3) and a north-south cross-section (Fig. 4) summarize the stratigraphy and the various sedimentary structures of the channel facies.

Figures 2 and 3 are oriented generally perpendicular to the paleoslope and are situated across ancient Dakota fluvial valleys. The substantial thinning and thickening of the channel deposits is a reflection of the paleotopography as well as the erosive nature of the Dakota streams. Within the thicker channel deposits, it is evident that the Stage I and Stage II deposits (Figs. 2 - 4) represent deposition in a dynamic fluvial system. Beds of Stage I can be correlated surprisingly well although they were deposited in relatively large streams and are typical point-bar deposits. This was a degrading stream system, as shown by its erosional base. The energy level was relatively high compared to later streams. The banks were cohesive enough to minimize lateral migration and allow a substantial thickness of overbank material to accumulate and be preserved. The ease of correlation suggests that the fluvial system was operating under stable geomorphic conditions, and sedimentary processes were controlling deposition uniformly across northeastern Utah.

Subsequent to Stage I, the fluvial system evolved into smaller streams in which the thinner channel deposits of Stage II were deposited. The lower boundary surfaces of Stage II channels are smooth (not undulatory), indicating that the streams approached "grade" and that downward erosion was negligible. In contrast to Stage I deposits, a general lack of floodplain material suggests that the banks of the streams were not resistant to erosion, which in turn allowed rapid lateral migration across the floodplain and frequent reworking of sediments.

The coarse-grained unit contains pebbly sandstone and conglomerate and minor amounts of sandstone.Its internal texture is generally massive. In some places, however, it is crudely graded and contains unusually large ripple marks. The north-south cross-section (Fig. 4) indicates that the coarse-grained unit thickens and becomes finer grained northward.

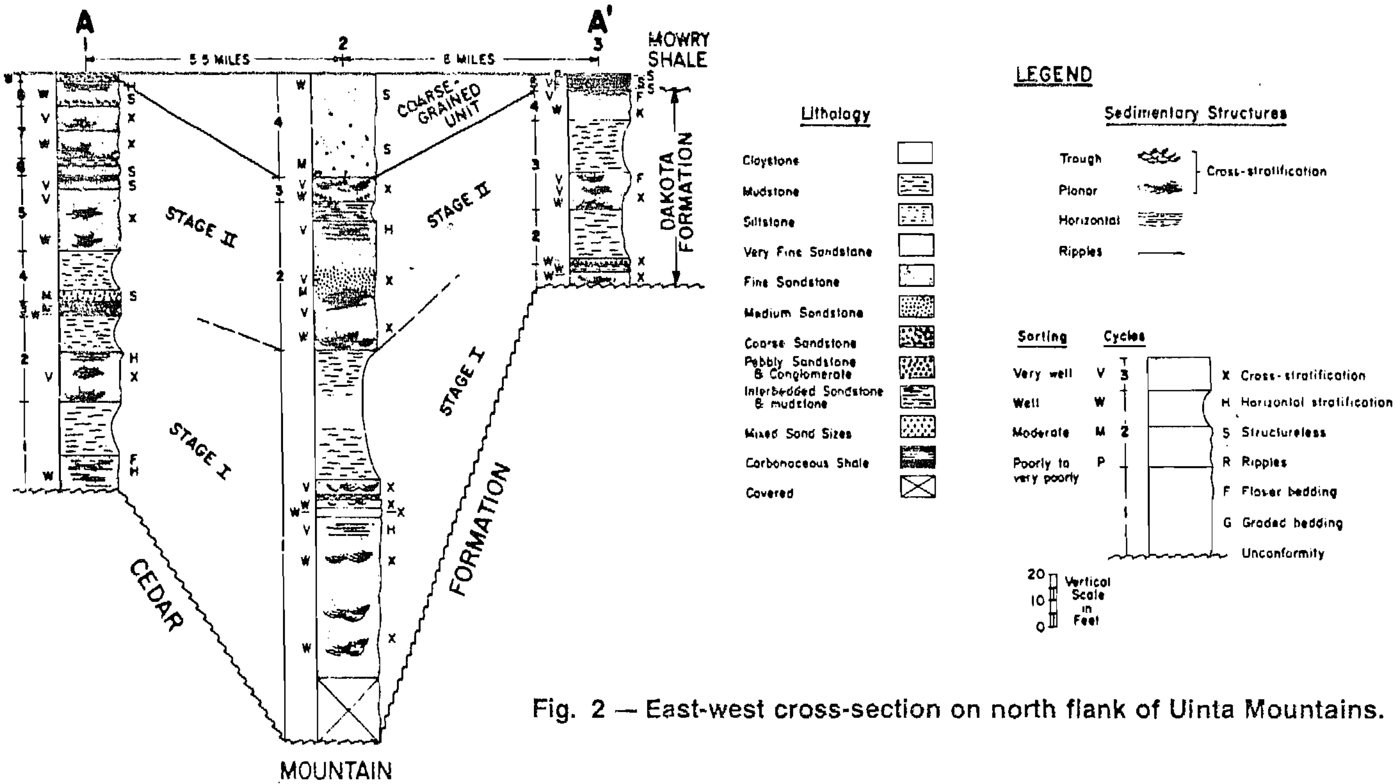


Fig. 2 — East-west cross-section on north flank of Uinta Mountains.

The north-south cross-section (Fig. 4) is oriented approximately parallel to the paleoslope and shows an over-all thickening of the Dakota north of section 9, which is the seaward direction.

Types of outcrops. — Outcrop morphologies of the Dakota channel facies are of two types and are useful in analyzing the nature of this ancient fluvial system. The change in outcrop morphology indicates that the fluvial system changed substantially through time. The two types of outcrops vary in gross thickness, thickness of individual channels, sand/shale ratios, lateral continuity of individual channels, and width of outcrops. Figures 5 and 6 are photographs of the two types of outcrops.

The first type (Fig. 5) is a thick cliff-forming outcrop that contains point-bar deposits formed in the large meandering streams (Stages I and II). Outcrops of this type range in thickness from approximately 100 feet (30m) on the south side of

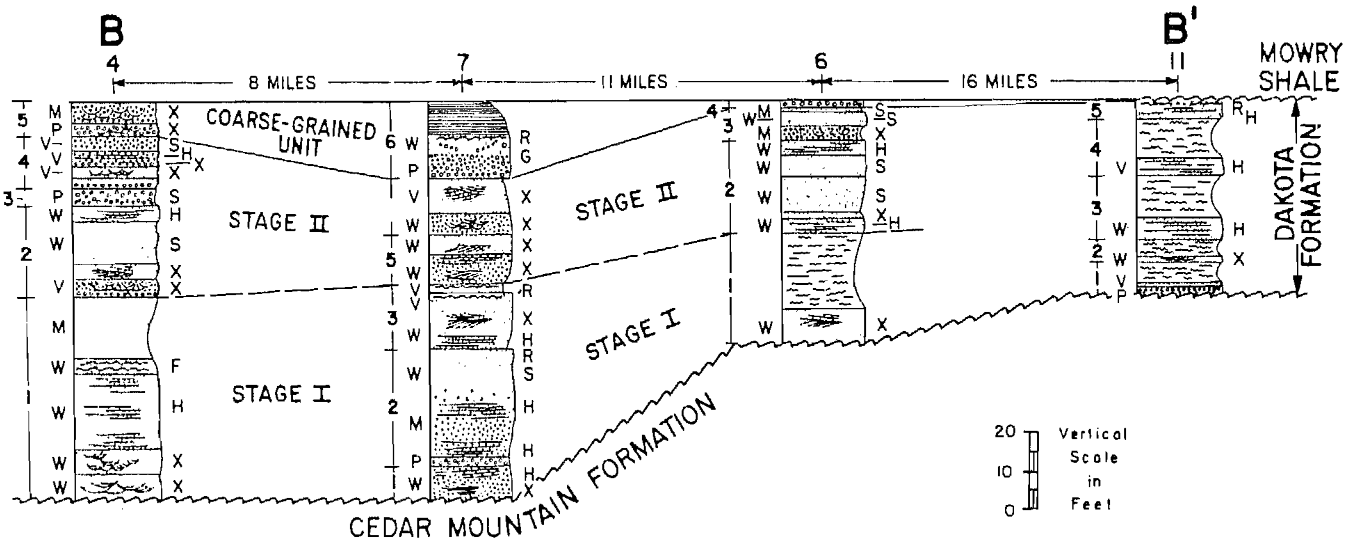


Fig. 3 — East-west cross-section on south flank of Uinta Mountains.

the Uintas to approximately 240 feet (72m) on the north side. They have high sand/shale ratios, ranging from 2.3 to 13.0. These are cyclic or multistoried sands, with the basal erosional surface of a sandstone commonly resting directly on the underlying channel deposit with no intervening floodplain shale. Individual channels of the larger outcrops may have lateral dimensions of over 1000 feet (300m).

The second type of channel outcrop (Fig. 6) contains deposits of the smaller, more numerous, meandering streams. These deposits are thinner than those of type one, ranging in outcrop thickness from 50 to 80 feet (15 to 24m). The sand/shale ratio varies only slightly, and is about 1. Individual channels are less extensive laterally than those of type one, commonly pinching out within the outcrop. These channel sandstones are often enclosed by fine-grained overbank beds.

Type two outcrops contain a cluster of isolated channel deposits at various stratigraphic levels, and have lateral dimensions of approximately 200 to 400 feet (60 to 120m). This outcrop pattern probably resulted from deposition in aggrading streams where repeated avulsions formed new channels in nearby low areas. A few deposits that probably represent crevasse-splay deposition were noted.

Contacts. — The basal contact of the Dakota with the Cedar Mountain Formation is unconformable. Dakota streams incised channels into the underlying Cedar Mountain Formation, as indicated by undulating, erosional, channel bottoms. Local relief on this erosional surface is as much as 50 feet (15m) according to Hansen (1965). The magnitude of the hiatus or the thickness of beds removed was not determined. The basal Dakota contact is a regional disconformity.

The upper contact of the Dakota with the Mowry Formation is probably unconformable over the floodplain facies and conformable over the channels. The upper contact marks a common boundary between a continental deposit and an overlying marine deposit. However, complications arise when the nature of the marine transgression is considered in detail.

As the Mowry sea transgressed over the Dakota, it failed to deposit a beach or nearshore sand along its leading edge. This is probably one reason why the Dakota has been called a transitional deposit between the Cedar Mountain and Mowry formations.

However, during this investigation, it became increasingly apparent that the coarse-grained unit, which is present above the channel facies, is genetically related to the transgression of the Mowry sea and represents, at least in part, the "missing link" in the geologic record. The coarse-grained unit was deposited in channel bottoms near the mouths of streams and rivers as they entered into the advancing Mowry sea. These topographically low entry points along the shoreline were subjected to very strong currents, probably alternating tidal currents.

Summary. — The stratigraphic information indicates that the Dakota fluvial system consisted of meandering streams that probably flowed sluggishly across a low-relief coastal plain not far from the advancing shoreline of the Mowry sea. The system was a dynamic one, and the streams changed in size and character in order to reach equilibrium as the sea transgressed.

FEATURES OF DAKOTA FLUVIAL CHANNELS

The basic element of a fluvial facies is the channel deposit. Knowledge of the physical parameters of a fluvial facies is useful in petroleum exploration, especially in terms of predicting sandstone geometry. Some of the salient features of channels analyzed in this study are rock types, thicknesses, internal structures, vertical profiles, and flow regimes.

Each channel deposit of the Dakota Formation consists of a coarse, poorly-sorted basal lag deposit that is overlain by finer grained sandstone. The lag consists of pebbly sandstone and/or conglomerate. Large clasts of bank material are rare. The sandstone portion, which constitutes as much as 95 percent of the channel deposits, is dominated by fine-grained sand.

Channel thicknesses, which are indicative of stream size, were compared. In the larger, meandering, stream channels of Stages I and II, 73 percent are 20 feet (6m) thick or less. The remaining 27 percent ranges from just over 20 feet (6m) to more than 40 feet (12m). In the smaller stream system, the majority of channels are less than 10 feet (3m) thick. Only about 30 percent are over 10 feet (3m), and none exceed 20 feet (6m).

Sedimentary structures are abundant in the Dakota and are useful for interpreting the environments of deposition. Based on the terminology of McKee and Weir (1953), the most common types of cross-stratification are trough and planar. Horizontal stratification is also common. Many bedding plane features were noted, including current lineation marks, sole marks, and rib-and-furrow structures. Ripple marks, ripple stratification, and flaser bedding are present in the uppermost parts of some channels.

One of the most conclusive indicators of the fluvial origin of the Dakota sandstone is the vertical sedimentary structure profile. From base to top, the sequence of sedimentary structures is: 1) cross-stratified channel lag deposit (conglomeratic sandstone), 2) trough cross-stratification, 3) planar cross-stratification, 4) horizontal stratification, and 5) ripple stratification. These structures indicate an upward decrease in flow intensity and are a sequence of primary sedimentary structures

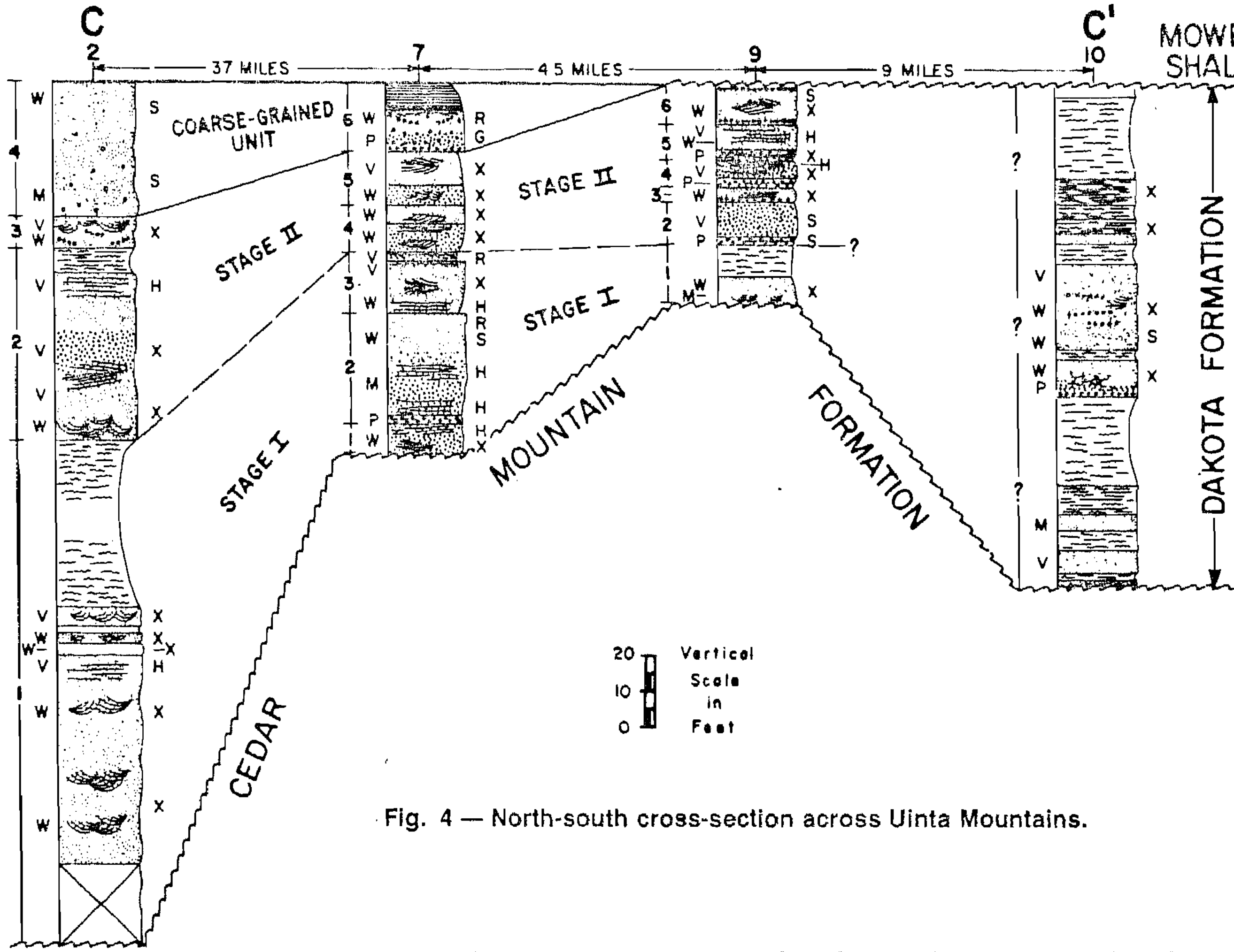


Fig. 4 — North-south cross-section across Uinta Mountains.

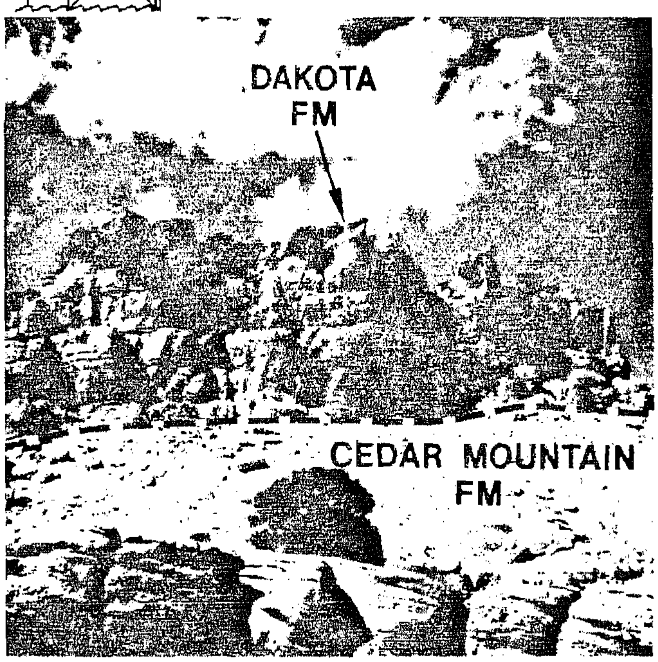


Fig. 5 — Outcrop of large meandering stream deposit (section SM-B) showing cyclic deposition of fluvial channels. Outcrop thickness about 112 feet.

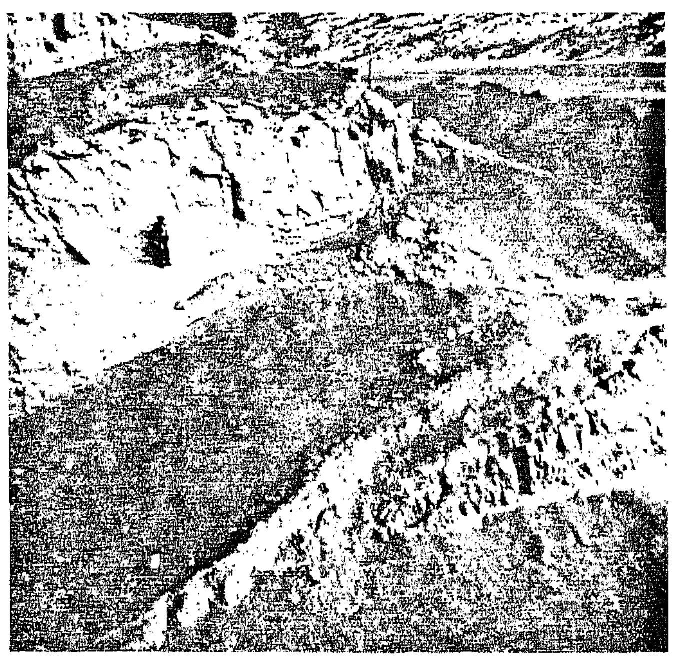


Fig. 6 — Outcrop of alluvial plain stream deposit (section M) showing low sand/shale ratio, pinching out of channels and crevasse-splay deposits.

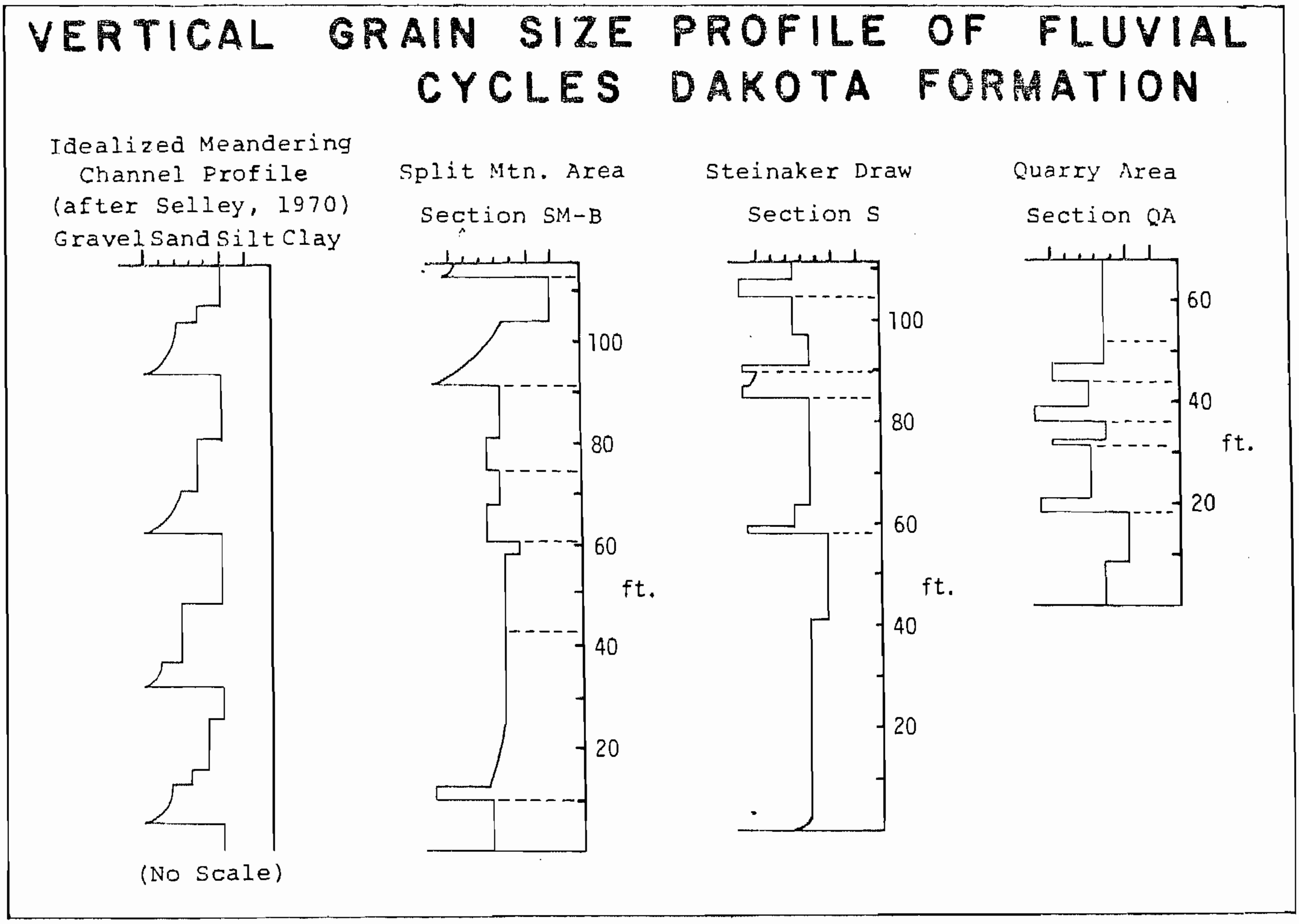


Fig. 7 — Shows vertical repetition of channels by grain size.

commonly found in point-bar deposits (Allen, 1970; Bernard and Major, 1963; and Harms, *et al.*, 1963).

A distinctive feature of the channel facies is the vertical repetition of channels, each channel resulting from a new episode of fluvial deposition. This pattern imparts a cyclicity to the outcrops, which is also shown in a vertical grain-size profile chart (Fig. 7). The upward fining sequence of grain sizes within each cycle is indicative of point-bar deposits in which lateral accretion was the mode of deposition (Allen, 1965 and 1970).

PETROGRAPHY

Pebbly Sandstone and Conglomerate

The pebbly sandstones and conglomerates that constitute the channel lag deposits (Folk, 1968) are litharenites (Fig. 8). Rock fragments consist of chert plus metamorphic and sedimentary rock fragments. The matrix is composed primarily of authigenic clays. X-ray analyses indicate that kaolinite is the dominant clay mineral. Montmorillonite is also present, but in lesser amounts.

Feldspar grains are rare, generally forming less than one percent of the rocks. These beds have a characteristic reddish-brown color because of hematite stain emanating from sedimentary rock fragments. Porosity values range from less than 1 to 13 percent and average 4.7 percent. The principal bonding agent is the clay matrix. Silica is also present as a bonding agent, but is insignificant compared with the clay. Carbonate cement is rare. However, this may be partly a weathering phenomenon and could change substantially in the subsurface.

Sandstone and Siltstone

Based on modal analyses, the sandstone and siltstone is quartzarenite and sublitharenite. The quartz grains are mainly monocrystalline and have straight extinction. Silica overgrowths are present on many quartz grains and are of two types, post-depositional and reworked. The first type is recognized by straight crystal faces that occasionally form an interlocking network of grains. Reworked silica overgrowths are recognized by nuclei of rounded grains whose overgrowths are very irregular in outline and have been "chipped" away in places down

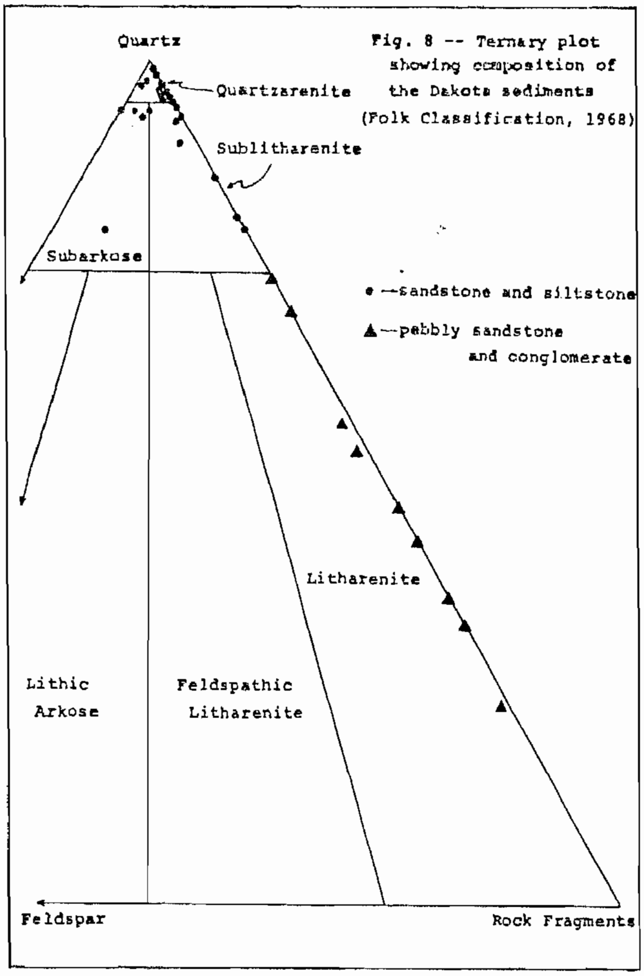


Fig. 8 — Ternary plot showing composition of the Dakota sediments (Folk Classification, 1968).

to the surface of the original grain. In some grains, the "chipped" surfaces penetrate through the overgrowth and into the original grain.

Feldspar grains are rare, ranging from 0 to a maximum of 9 percent. The relative abundance of feldspar varieties is orthoclase>Na-plagioclase>microcline. The rock fragments consist of chert and metamorphic rock fragments that average 2 percent and 1.5 percent respectively. Sedimentary rock fragments are virtually absent.

The matrix of the sandstone and siltstone is almost exclusively authigenic kaolinite with lesser amounts of montmorillonite and illite. The clay matrix is the primary bonding agent. Silica cement is also present, but only in small amounts. Porosity values for the sandstone and siltstone range from less than 1 to 22 percent, averaging 10.6 percent.

Textural parameters indicate that 83 percent of the sandstone and siltstone is unimodal in grain size. Furthermore, 96 percent of the unimodal samples range from very fine to medium-grained, with the fine-grained sandstone most common. Eighty-one percent of the sandstone and siltstone ranges from well- to very well sorted. Well-sorted samples are the largest group, accounting for 40 percent of all samples. Plots of grain roundness values show a strong grouping of grains in the subangular and subrounded classes.

Diagenesis

Thin section examination suggests that the clay matrix did not form from the alteration of original grains. Silica overgrowths are commonly coated by the matrix showing that silica was precipitated first. The presence of matrix within the pore spaces, its absence at grain contacts, and the lack of feldspar grains that could alter into clays indicate that the matrix formed from formation waters. Complete alteration of the feldspar grains is not likely because the existing grains show almost no deterioration.

PALEOCURRENT PATTERN

A total of 349 paleocurrent measurements were made from small- and medium-scale trough and planar cross-stratification. The number of measurements per locality ranged from 10 to 64 and averaged 35. Measurements were corrected for tectonic tilt where necessary. The information was evaluated quantitatively according to the methods described in Potter and Pettijohn (1963, p. 264), and was grouped at different interpretative levels to determine: 1) paleocurrent patterns for individual cycles, 2) variation of dispersal direction through time by comparing results of all the cycles at each location, 3) the net dispersal direction at each location, and 4) the net regional dispersal direction.

Results. — Paleocurrent azimuths for individual cycles are strongly unimodal. The larger meandering stream deposits have a slightly greater concentration of azimuths than the smaller channel deposits. When paleocurrent information from all the cycles at a particular outcrop is compared, it is seen that the streams transported sediment in widely scattered directions through time (Fig. 9). This variation in the dispersal direction is indicative of the meandering nature of the streams. The net paleocurrent direction at each location is shown in figure 10, and the net regional paleocurrent direction is shown in figure 11.

PROVENANCE

As seen from the paleocurrent analysis, the general direction of sediment dispersal was to the north. Source areas were therefore on the south. The most likely source areas were in west-central and southern Utah (MacKenzie and Ryan, 1962; Young, 1970). This region was occupied by the Mesocordilleran Geanticline, a highland area from which the dispersal system transported sediment north and east into Colorado and Wyoming.

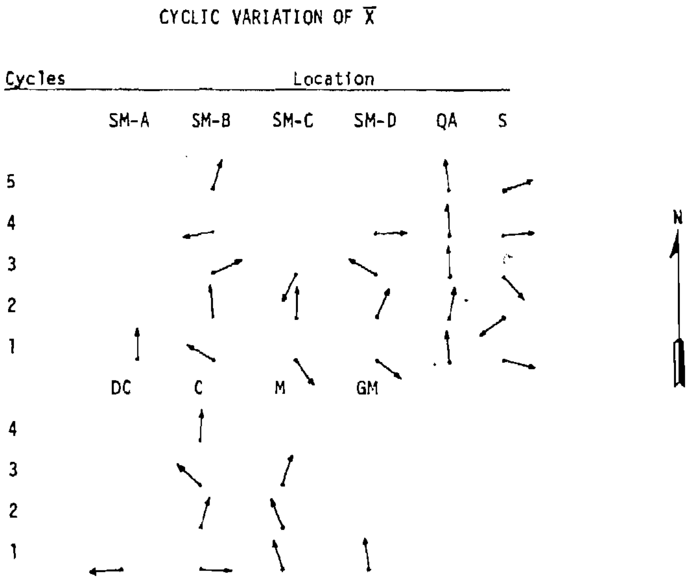


Fig. 9 — Shows the cyclic variation of transport direction at each section.

Petrographic analysis indicates that pre-existing sandstone and limestone were the source rocks for most of the Dakota sediment. Metamorphic rocks contributed minor amounts of material. Recycling of pre-existing sedimentary rocks is suggested by the predominance of quartzarenite or quartz-rich varieties of sublitharenite or subarkose in the Dakota (Fig. 8).

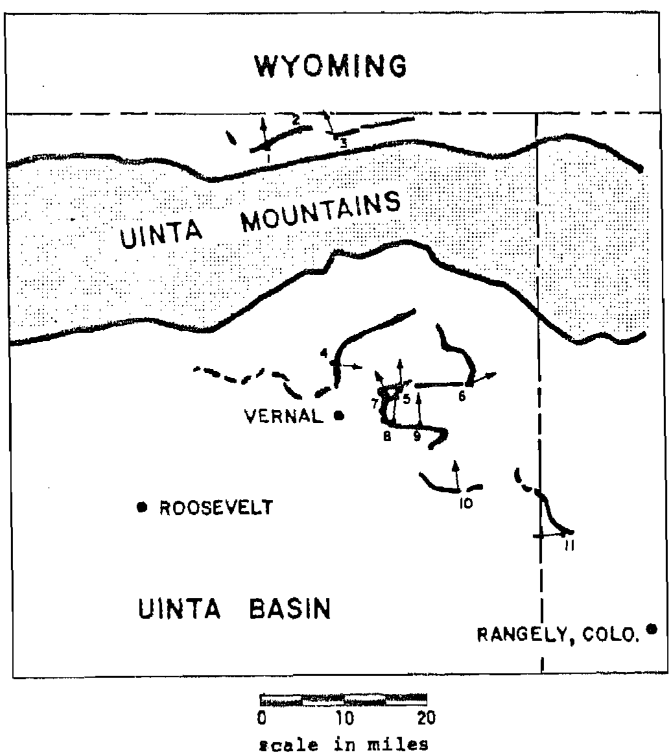


Fig. 10 — Shows net direction of sediment movement at each locality.

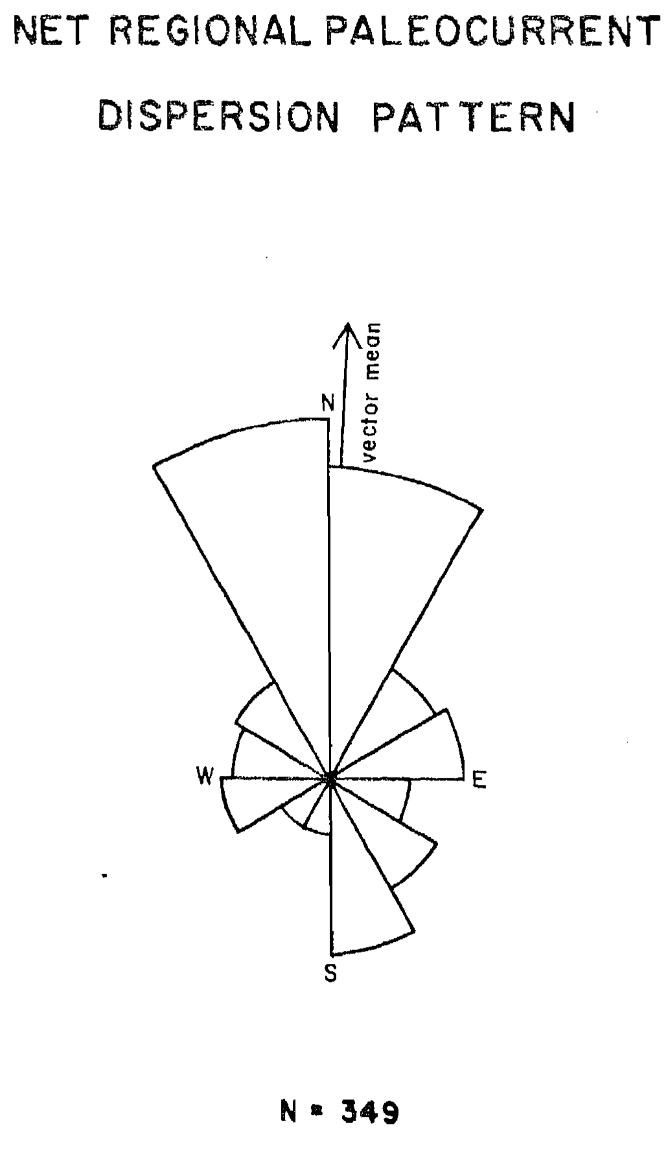


Fig. 11 — Shows the net regional direction of sediment movement in northeast Utah.

Easily decomposed particles are rare in rocks of the Dakota Formation. Some scattered quartz grains have silica overgrowths but others do not. Chert is ubiquitous in the Dakota, and is a good diagnostic indicator of carbonate source terranes. Pebbly sandstone and conglomerate are common, and rock fragments in them are also indicative of sedimentary sources.

Sedimentary sources are further indicated by textural features. The Dakota is characterized by fairly well-rounded quartz grains, which suggests that they have been recycled at least once and possibly several times. Although textural inversions are not abundant, they were observed, and consist of fairly well-rounded grains that are not well-sorted, and well-sorted bimodal grains. Both of these inversion types probably represent multiple sedimentary source rocks (Folk, 1968, p. 106).

PETROLEUM POTENTIAL

Oil and gas production from the Dakota Formation in northeastern Utah is limited. However, there has been sufficient production at Bridger Lake, Clay Basin, and other fields in Emery and Grand counties of eastern Utah (Fig. 12) to sustain interest in the formation.

The following sections briefly discuss the geology of some important Dakota producing fields. Some ideas concerning the origin of the hydrocarbons are outlined. Information summarized on the composition of oil and gas in the Morrison, Cedar Mountain, and Dakota formations (Tables 2 - 6) is from the Symposium on Oil and Gas Fields of Utah (1961), Bureau of Mines Information Circulars, and Stowe (1972).

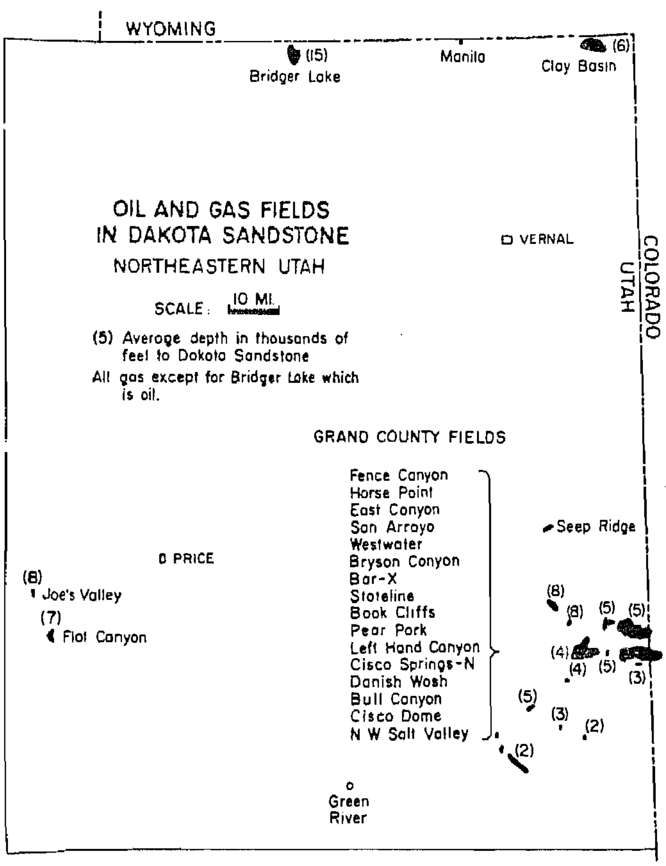


Fig. 12 — Index map showing location of Dakota oil and gas fields.

Oil and Gas Fields

Bridger Lake field. — Significant production of oil from the Dakota Formation has come from the Bridger Lake field immediately north of the Uinta Mountain uplift. The geology of this field is discussed in papers by Garvin (1969) and Peterson (1973).

Production at Bridger Lake is from lower sandstone beds of the Dakota on a south-plunging, faulted, anticlinal nose near the south end of the Church Buttes-Moxa arch. South of the field, the anticlinal trend is cut by the Uinta Mountain fault that separates the Uinta Mountain uplift from the Green River Basin. Lithologic studies indicate that the field is mainly a stratigraphic trap. Two dry holes on the north side of the field are structurally higher than several producers, but do not contain adequate reservoir beds.

According to Peterson (1973), the wells at Bridger Lake are the deepest producers in Utah, and the deepest Cretaceous oil producers in the Rocky Mountains. Estimated original oil in place is 63 million barrels (9 million metric tons), of which 40 million barrels (5.7 million metric tons) are expected to be recovered. The estimated original gas in solution is 54,000 million cubic feet (14,600 million cubic meters).

Clay Basin field. — Gas was first discovered in the Dakota Formation at Clay Basin in 1935. Structure contour maps drawn at the top of the Dakota show an asymmetric anticlinal axis trending west with about 450 feet (135m) of structural closure.

The Clay Basin anticline closely parallels the Uinta Mountain fault, which is immediately south of the field. A tightly folded to slightly overturned syncline separates the Clay Basin anticline from the fault zone. Structural closure on the south flank of the field is believed (Hummel, 1969) to be formed by the lowest closing contour rather than by faulting.

The Dakota sandstones at Clay Basin are considered by Hummel (1969) to be mainly fluvial deposits that were partially reworked by an advancing marine transgression. The average sandstone thickness per well is 40 feet (12m), ranging from 15 feet (4.5m) to 60 feet (18m). Reservoir properties vary considerably, but generally deteriorate northward across the field.

Flat Canyon and Joe's Valley fields. — The Flat Canyon gas field is on the Flat Canyon anticline midway across the north-south trending Wasatch Plateau. The anticline is a closed structure (75m of closure at the Ferron Sandstone) trending northeast. It is bounded and partly truncated on the west by the steeply-dipping Joe's Valley graben (Seeley, 1961). The structure apparently is terminated on the east by a north-south fault complex that is downthrown to the east.

Gas in both the Ferron and Dakota formations is very similar. Seeley (1961) suggested that a common source for both accumulations is possible. His preference is for Lower Cretaceous source beds, probably marine beds below the Ferron Sandstone.

Joe's Valley gas field, northwest of Flat Canyon and southwest of the Clear Creek gas field, also contains gas in both

Table 1. Summary of geology of oil and gas fields in Dakota Formation, northeastern Utah (Information from Oil and Gas Fields of Utah, 1961; Garvin, 1969; and Hummel, 1969)

Field Name	Location	Year of Discovery	Average Depth (ft.)	Net Pay (ft.)	Porosity (%)	Permeability (MD)	Initial Pressure (psi)	Btu (ft.³)	Trap
Bridger Lake	3N-14E	1966	15,500	32	13	80	7,230		faulted anticlinal nose
Clay Basin	3N-24E	1935	5,760	40	16	24	2,100	1080	faulted anticline
Joe's Valley	15S-6E	1956	7,700						faulted anticline
Flat Canyon	16S-6E	1953	7,020	44	4		1,514	1151	faulted anticline
Bar-X (Colorado)	8S-104W	1953	2,844	29	13.5		925	1045	stratigraphic
Fence Canyon	15S-22E	1960	8,126	9			1,600	1067	stratigraphic
Horse Point	16S-23E	1962	7,958	9					stratigraphic
East Canyon	16S-24,25E	1962	5,500						stratigraphic
San Arroyo	16S-25,26E		4,500	35	15	50	1,100	1085	stratigraphic-structural
Westwater	17S-23,24E	1957	4,400	24	19		1,140	1085	stratigraphic
Bryson Canyon	17S-24E	1960	4,600					983	stratigraphic
Stateline	17S-25,26E	1963							stratigraphic
Book Cliffs	18S-22E	1961	5,350					1075	stratigraphic
Pear Park	18S-23E	1961							
Cisco Springs-N	19S-23E	1954	2,820	20					stratigraphic
Danish Wash	19S-24E	1955	1,965	15	17.5		770	1013	stratigraphic
Cisco Dome	20S-21,22E	1925	2,000	30	16.5		880	1083	stratigraphic-structural
NW Salt Valley	21S-19E	1956	3,166						

Table 2. Characteristics of oil in Dakota and Morrison formations, northeastern Utah

	Bridger Lake (Dakota)	Bar-X (Morrison)	Seiber Nose (20S-24E) (Morrison)	Cisco Townsite (21S-23E) (Morrison)	Agate (20S-24E) (Morrison)
Gravity (°API)	40	40.9	34.8	33.8	40.4
Gravity (specific)	0.826	0.821	0.851	0.856	0.823
Pour point	50°F	55°F	30°F	< 5°F	< 5°F
Color	brn-grn	brn-grn	brn-blk	brn-blk	grn-blk
Gas-oil ratio	859 to 1				
Base	paraffin				
Viscosity	100°F, 40 sec.	100°F, 40 sec.	100°F, 44 sec.	100°F, 48 sec.	100°F, 38 sec.
Sulfur (%)	0.05	0.12	0.96	1.07	0.61
Nitrogen (%)	0.047	0.013	0.055	0.070	0.034

the Dakota and Ferron formations. The trap at Joe's Valley is a faulted anticline in an area of complex normal faulting. Johnson (1961) suggested that the gas in both reservoirs originated in the Mancos Shale.

The wells at Flat Canyon and Joe's Valley are now plugged and abandoned.

Grand County fields. — All 16 Dakota discoveries (Fig. 12) in Grand County, Utah are closely related to lithologic and stratigraphic variables. Although well defined structural features are present, few accumulations are without stratigraphic components.

Most of the Dakota discoveries in Grand County have been abandoned or are shut-in. Calculation of reserves, based on present production information, is speculative because many of the wells are completed in several reservoirs (Entrada, Morrison, Cedar Mountain, and Dakota).

Characteristics of Oil

At Bridger Lake, oil in the Dakota is high gravity, low in sulfur and nitrogen, and characterized by a paraffin base (Table 2). Oil with similar characteristics was found at the Bar-X field in the Morrison Formation of northeastern Utah. Three other fields in the Morrison (Table 2) contain oil that has lower gravities and pore points, higher nitrogen and sulfur contents, and no paraffin base.

Characteristics of Gas

Gas of the Dakota Formation is of good quality. The amounts of noncombustible gases are generally low (Table 3). Gas in the Cedar Mountain and Morrison formations (Table 4) has characteristics similar to gas in the Dakota (Table 5). Gas found in the Morrison contains more nitrogen and helium than gas from the Dakota and Cedar Mountain formations, but the differences are small (Table 6). Morrison gas has a lower

Table 3. Composition of gas in Dakota Formation, northeastern Utah

	Methane	Ethane	Higher Fractions	Nitrogen	Carbon Dioxide	Helium	Btu (ft.^{3})
Bridger Lake	71.3	11.4	12.6	2.0	0.8		1357
Clay Basin	99.3						1080
	92.4	3.9	3.2		0.3	trace	1074
Joe's Valley	86.0	4.6	5.6		0.1	trace	1129
Flat Canyon	86.5	6.4		0.6	0.2		1151
Bar-X (Colorado)	90.3	4.1	1.8	2.8	0.4		1045
	91.6	4.1	1.9		0.3	0.10	1060
Fence Canyon	95.1	2.4	0.6	0.7	1.0	trace	1024
	92.7	4.1	1.8	0.4	1.1	0.10	1067
San Arroyo	89.9	5.1	1.9		0.8	0.10	1059
	91.1	4.4	1.8	0.8	0.9	0.10	1064
	90.2	5.4	2.5		0.9	0.10	1089
	78.6	5.1	2.3	10.3	1.2	0.10	969
Westwater	94.5	2.2					1086
	91.1	5.2	2.3	0.7	0.5	0.08	1089
	94.0	3.1	1.0	0.5	1.2	0.06	1041
Bryson Canyon	87.1	3.7	1.1	5.7	1.0	0.10	983
Book Cliffs	88.9	5.7	2.5		0.2	0.20	1081
	87.7	5.5	2.6	3.4	0.7	0.20	1070
	89.4	5.5	2.3	2.4	0.2	0.20	1077
Harley Dome	84.2	0.7	0.3	11.4	0.5	0.20	877
Cisco Dome	92.4	3.6	2.3		0.1	0.10	1074
Mean	89.2	4.4	2.7	3.2	0.6	0.12	1070

Table 4. Composition of gas in Cedar Mountain Formation, northeastern Utah

Field Name	Methane	Ethane	Higher Fractions	Nitrogen	Carbon Dioxide	Helium	Btu (ft.^{3})
Evacuation Creek (12S-25E)	90.2	5.3	2.9	0.6	1.0	trace	1100
East Canyon	89.0	5.9	3.2	0.4	1.4	0.1	1107
Bar-X (Buckhorn Cgl.)	88.8	4.7	2.1		0.5	0.3	1049
Segundo Canyon (16,17S-21E)	96.6	1.4	0.4	0.6	0.8	trace	1017
	89.5	6.1	2.3	0.6	1.3	trace	1083
Book Cliffs	86.9	6.7	4.3		1.0	0.1	1132
Gravel Pile (20S-24E)	92.4	1.8	1.0	3.6	0.7	0.3	1001
Cisco Townsite (Buckhorn Cgl.)	82.1	2.5	1.4	13.1	trace	0.7	922
Mean	89.4	4.3	2.2	2.4	0.8	0.2	1051

Table 5. Composition of gas in Morrison Formation, northeastern Utah

Field Name	Methane	Ethane	Higher Fractions	Nitrogen	Carbon Dioxide	Helium	Btu (ft.^{3})
10-10S-24E	73.4	1.1	0.9	23.2		1.3	795
Fence Canyon	92.8	3.9	1.1		1.1	0.1	1045
San Arroyo	92.7	3.6	1.7	0.9	1.0	0.1	1058
Westwater	77.9	4.3	4.7		0.5	0.2	1027
	93.4	3.3	1.9		0.8	0.1	1073
Bryson Canyon	82.4	3.6	1.7	9.3	0.5	0.7	958
Cisco Dome	89.5	2.1	0.6		3.0	0.1	967
	89.9	4.0	2.5		0.1	0.2	1063
Agate (20S-24E)	88.7	1.0	1.3	8.4	trace	0.5	958
	76.7	2.9	2.8	16.7	0.1	0.7	913
Harley Dome (19S-25E)	83.2	1.4	0.5	14.9			
Mean	85.5	2.8	1.8		0.6	0.8	986

Table 6. Comparison of average compositions of gas in Morrison, Cedar Mountain, and Dakota formations (Number of analyses in average)

	Dakota Ss. (22)	Cedar Mountain Fm. (8)	Morrison Fm. (11)
Methane	89.2	89.4	85.5
Ethane	4.4	4.3	2.8
Higher Fractions	2.7	2.2	1.8
Nitrogen	3.2	2.4	
Carbon Dioxide	0.6	0.8	0.6
Helium	0.12	0.2	0.8
Btu (ft.^{3})	1070	1051	986

Btu value because of slightly larger contents of noncombustible gases.

Picard (1962) found a general increase in the percentage of nitrogen and helium with depth in the Pennsylvanian and Mississippian rocks of the Four Corners region. He attributed their origin to degassing of Precambrian basement rocks. A similar origin for inert gases in the Jurassic and Cretaceous seems likely.

Origin of Oil and Gas

Young (1975) stressed that Lower Cretaceous beds of northeastern Utah and northwestern Colorado have not been prolific producers of oil and gas, yielding only 14.6 million barrels (2.1 million metric tons) of oil and 164.8 billion cubic feet (44.5 billion cubic meters) of gas by the end of 1974. However, Lower Cretaceous beds in Wyoming and eastern Colorado are highly productive. Young (1975) suggested several reasons for this difference: 1) the predominantly nonmarine Lower Cretaceous beds in this area, 2) thinner Mowry Shale, which is probably a source bed, and 3) drilling confined to basin margins near existing pipelines.

In addition to Young's suggestions, another possibility for the origin of oil and gas in the Dakota, Morrison, and Cedar Mountain formations in northeastern Utah is that hydrocarbons originated in predominantly nonmarine environments and migrated short distances from local source beds into lenticular sandstone reservoirs. Organic material was not as abundant in these depositional settings as in the marine conditions of Wyoming and eastern Colorado. This organic deficiency may be responsible for the generally small accumulations of hydrocarbons in this area. Although the Mancos and Mowry shales contain possible source beds, migration of hydrocarbons from these beds into nonmarine reservoirs is believed to be minimal.

Petroleum Potential of the Dakota

Through January 1976, the Bridger Lake Field has produced 8,675,608 barrels of oil (1,239,372 metric tons) and 50,369,948 MCF of gas (about 13.6 billion cubic meters) from the Dakota. Such quantities of production are very encouraging even at deep drilling depths (Table 1).

Recently, the American Quasar Petroleum No. 35-1, UPRR, in section 31, T. 2 N., R. 6 E. tested 2 million cubic feet (0.54 million cubic meters) of gas per day from the Dakota at depths of almost 17,000 feet (5,000m).

In contrast to deep production, the Clay Basin field has produced 129,910,099 MCF of gas (about 35 billion cubic meters) and 299,125 barrels of oil (42,732 metric tons) through January 1976 (including Frontier production) from moderate depths. This field is nearing its economic limit and may be used as a gas storage reservoir.

Except for Grand County, the Dakota has not been fully tested because of drilling depths and complex structural conditions. Much of the drilling has been confined to locations close to present pipelines.

In view of the production records of the Bridger Lake and Clay Basin fields, recent discoveries, and the generally sparse testing of the Dakota, we feel that the full potential of the formation has not been realized. Further stratigraphic and sedimentologic studies coupled with aggressive exploration programs could very possibly locate significant reservoirs in the future.

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