STRATIGRAPHY OF THE LOWER CRETACEOUS J SANDSTONE, BOULDER COUNTY, COLORADO: A DELTAIC MODEL

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ABSTRACT

The J Sandstone is the uppermost formation of the Lower Cretaceous Dakota Group. In the Denver basin it is composed of a regressive sequence of deltaic sediments which entered the Cretaceous seaway from both the east and west. The J Sandstone exposed on the western flank of the Denver basin in Boulder County in the Dakota hogback was derived from a western source.

Prodelta shales of the upper Skull Creek Shale are overlain by delta front deposits of J Sandstone which in turn are covered by delta plain deposits. A transgressive sandstone caps the J Sandstone sequence underlying the marine shales of the Upper Cretaceous Benton Formation.

The J Sandstone unit within the study area is divided into two delta lobes, one prograding from the southwest and another prograding from the northwest. Differences in depositional environments and thickness of equivalent units in these delta lobes are attributed to salinity changes from fresh water influx and basement block movements.

Subsurface correlations provide a direct relationship between surface and subsurface terminology in the Denver basin and demonstrate the existence of a similar delta system entering the seaway from the east.

INTRODUCTION

The Early Cretaceous (Albian) J Sandstone (Kauffman, 1977) is the uppermost formation of the Dakota Group which crops out in the Dakota hogback on the western flank of the Denver basin. Underlain by the Skull Creek Shale and overlain by the Benton Formation, the J Sandstone is the midpoint in a depositional cycle which grades upward from marine shale to deltaic sandstone and shale and back again to marine shale.

The purpose of this study is to describe and interpret the environments of deposition within the J Sandstone and to identify the depositional processes which controlled the type and distribution of sediment. This was done by adding greater detail in Boulder County to past regional studies of the J Sandstone. Interpretations are based on stratigraphic measured sections; names for trace fossil assemblages follow the identification and terminology of Chamberlain (1976).

LOCATION

The study area is located on the west flank of the Denver basin in the northern Front Range foothills of Colorado (Fig. 1). Except where absent because of faulting, the J sandstone crops out in the hogback which extends within the study area northward from Boulder to a point about a mile east of Lyons, roughly paralleling U.S. Route 36. About 12 mi (19 km) east of the hogback, gas is produced from the J Sandstone in the Wattenberg gas field. Table I lists locations of measured sections used in this study.

TERMINOLOGY AND PREVIOUS WORK

The first detailed study of the Dakota Group in the northern Front Range foothills was published in 1955 by Waage, who studied Dakota Group outcrops from Rainbow Creek in Douglas County to Boxelder Creek in northern Larimer County. Waage divided the Dakota Group into the lower Lytle Formation and upper South Platte Formation. The latter was divided into seven members. This division of the South Platte Formation is useful south of Boulder. However, from Boulder northward, facies changes make it impossible to adequately distinguish the seven members.

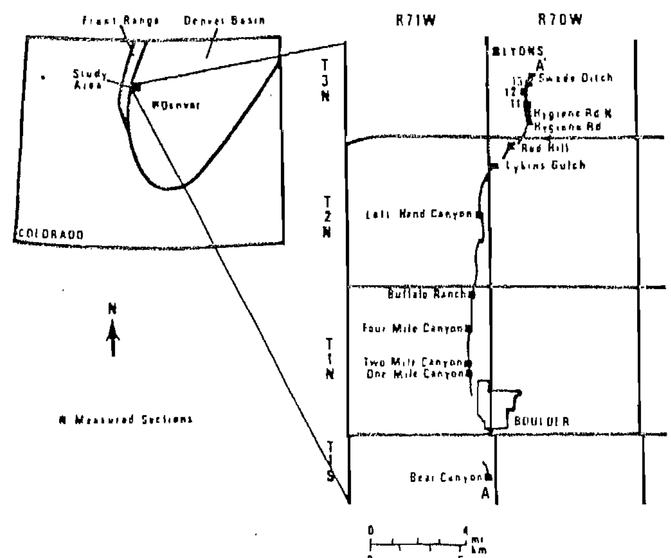

Fig. 1—Location of Study Area.

Waage (1955) recognized that the sediments he grouped in the South Platte Formation were deposited in "deltaic, estuarine, littoral and neritic environments around the spreading Cretaceous Sea," and divided the observed facies into a southern nonmarine phase, an intermediate phase (which occurs in Boulder County) and a northern

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Table 1—Location of Measured Sections

1. Bear Canyon	SE Sec. 12, T1S, R71W
2. One Mile Canyon (Hawthorn Ave.)	W1/2 Sec. 24, T1N, R71W
3. Two Mile Canyon (Linden Ave.)	NW Sec. 24, T1N, R71W
4. Four Mile Canyon (Lee Hill Rd.)	W1/2 Sec. 12, T1N, R71W
5. Buffalo Ranch	NW Sec. 1, T1N, R71W
6. Left Hand Canyon	NE Sec. 24, T2N, R71W
7. Lykins Gulch	NW Sec. 7, T2N, R70W
8. Red Hill	NE Sec. 6, T2N, R70W
9. Hygiene Road	N1/2 Sec. 32, T3N, R70W
10. Hygiene Road -- North	SE Sec. 29, T3N, R70W
11. No. 11	SW Sec. 29, T3N, R70W
12. No. 12	SW Sec. 29, T3N, R70W
13. No. 13	NW Sec. 29, T3N, R70W
14. Swede Ditch	SE Sec. 20, T3N, R70W

marine phase. This paper is an attempt to improve upon the detail in which Waage presented the intermediate phase.

MacKenzie (1971) studied the stratigraphy and depositional environments of the post-Lytle Dakota Group from Deer Creek south of Morrison, Colorado, to Boxelder Creek near the Wyoming border. In Boulder County he retained the term South Platte Formation but subdivided it into the Plainview member, Skull Creek Shale and northern tongue of the South Platte Formation (Fig. 2). North of Boulder County, he replaced the term South Platte Formation with the Plainview Formation, the Skull Creek Shale and the Muddy Sandstone which he correlated southward from equivalent beds in Wyoming. MacKenzie studied seven surface sections within the study area and incorporated descriptions of these sections into a generalized surface stratigraphic cross section which correlates the various formations and members of the Dakota Group from Deer Creek to Boxelder Creek (MacKenzie, 1971, Fig. 2, p. 94).

Instead of the term South Platte Formation the following three formations will be used in this paper as northern equivalents: the Plainview Formation, the Skull Creek Shale and the J Sandstone (Fig. 2). The term J Sandstone is employed to maintain consistency with equivalent rocks nearby in the subsurface of the Denver basin. Regional correlation of the J Sandstone with equivalent units is discussed in detail by Haun (1963).

GEOLOGIC SETTING

The J Sandstone was deposited in deltaic environments marginal to the Early Cretaceous Western Interior seaway. Deltas prograded northwestward into Colorado from northwestern Kansas, and eastward from an area west of the present day outcrop (Haun, 1963). Provenance studies of constituent minerals in J Sandstone (MacKenzie and Poole, 1962) distinguished sediments of an eastern source from these of a western source. Sediments in the J Sandstone Front Range outcrops were derived from the west whereas J Sandstone sediments in the subsurface about 15 miles (24 km) east of the outcrop were derived from the eastern source area.

Structure in the outcrop belt is largely the result of Laramide tectonic events. High angle reverse and normal faults frequently cut the outcrop. Dips are predominantly to the east, ranging upward from 15°, but some overturning of beds as a result of faulting has been ovserved. Maximum overturning is 80° west near a thrust fault northwest of Boulder (Boos and Boos, 1957).

STRATIGRAPHY

The Skull Creek Shale in Boulder County is usually covered because it weathers easily and commonly forms small valleys between more resistant hogback-forming sandstones of the Plainview Formation and the J Sandstone, but where exposed consists of graded laminations of silt and clay. Beds of siltstone and very fine-grained, very thinly-bedded sandstone increase in frequency upward and are overlain by sandy siltstone. Although gradational in the northern part of the study area, the Skull Creek Shale-J Sandstone contact is placed between this uppermost sandy siltstone and the overlying sandstone. In the southern part of the study area the contact is picked where black shale of the Skull Creek Shale changes to the silty sandstone of the J Sandstone.

The J Sandstone is composed of very fine- to fine-grained, poorly- to well-sorted sandstone with lesser amounts of siltstone and shale. The sandstones vary from quartzwackes to quartz arenites (Pettijohn, Potter and Siever, 1973). Feldspar, when present, constitutes less than 3 percent of the mineral composition of the sandstone.

Thickness of the J Sandstone along the outcrop ranges from 55 to 91 feet (16 to 28 m) and thins eastward to about 40 feet (12 m) a few miles to the east where the eastern and western source sediments probably interfinger. Farther east the J Sandstone thickness, reflecting deposition from the eastern delta system (Fig. 3) increases to approximately 80 feet (25.8 m) at the northeast corner of the study area.

The contact between the J Sandstone and overlying laminated light gray silts and dark gray clays of the Benton Formation is sharp. Siliceous marine shales of the Benton have been referred to as Mowry Shale in the subsurface (Haun, 1963).

DELTAIC ENVIRONMENTS AND ASSOCIATED GENETIC UNITS

Prodelta-Marine Shelf

The prodelta siltstones and shales of the upper Skull Creek Shale are transitional with underlying marine shelf deposits. Stratification consists of graded laminations of silt and clay with siltstones increasing in frequency and thickness upward. Gradation into the overlying delta front deposits is marked by upward increase of very fine-grained, very thin, wavy-bedded sandstone containing silty laminae (Fig. 4). In outcrop, about 50 feet (15 m) of prodelta and marine shelf deposits are exposed.

Body fossils are rare with only one poorly preserved *Inoceramus* observed. Only a few trails and fecal pellets are found on bedding planes. The lack of fossils may be the result of low salinity in the Cretaceous sea (Waage, 1961, p. 100), overly turbid water, or an unfavorable substrate.

The depositional environment postulated for the prodelta portion of the Skull Creek Shale is one of low energy with intermittent sediment influx. Wave and current energy was low, but occasionally of sufficient strength to

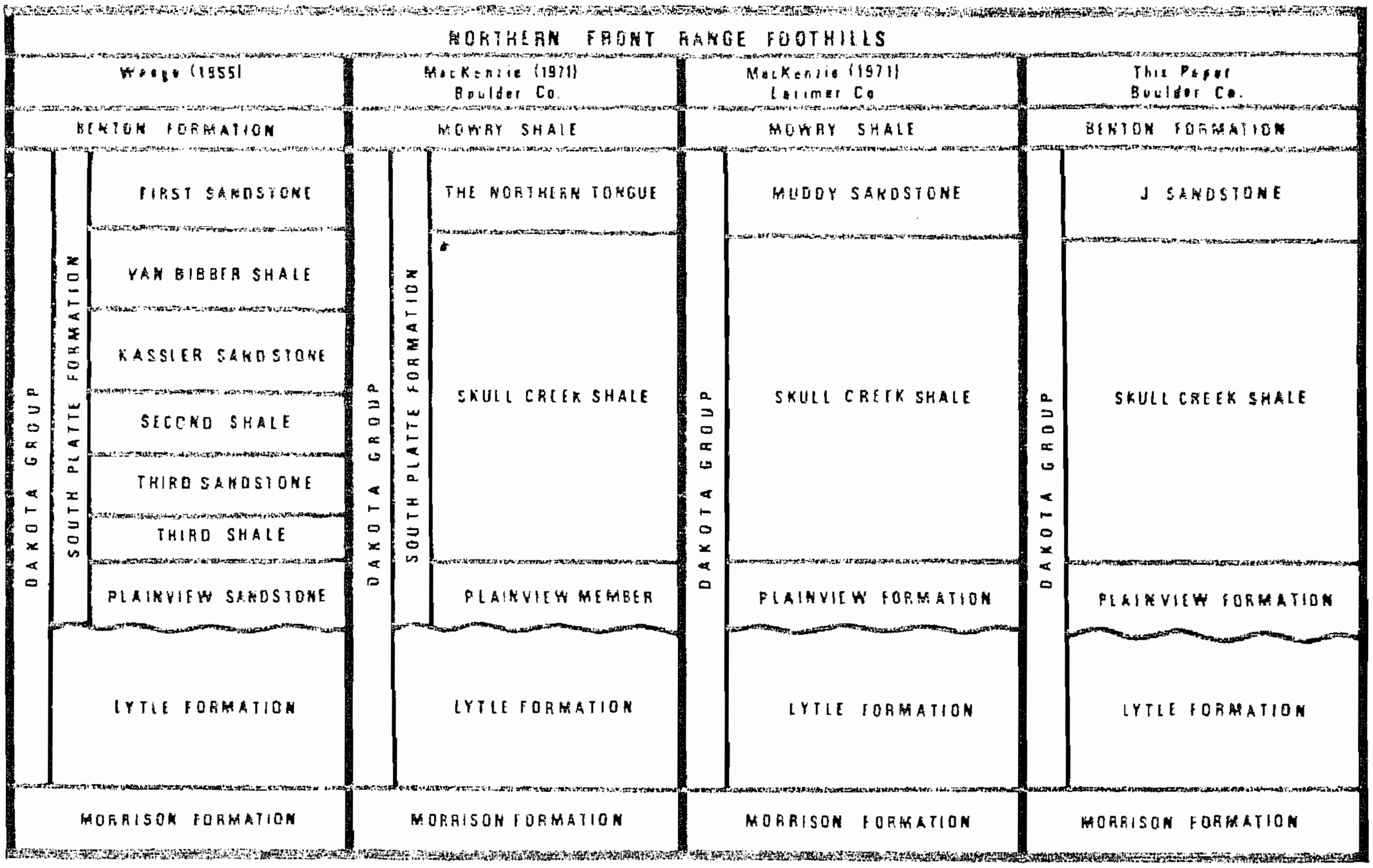

Fig. 2—Nomenclature Chart

produce ripple laminations. Coleman and Gagliano (1964) described the depositonal process for similar prodelta sediments in the modern Mississippi delta as fallout sedimentation.

Delta Front

Very fine-grained delta front sands (Fig. 5) overlie the prodelta deposits. In the northern part of the study area where the contact is gradational, the transitional unit consists of very silty, very fine-grained sandstone and sandy siltstone. The siltstone and sandstone of this unit are bioturbated, with bioturbation increasing upward. Few distinct trace fossils can be identified, but some very thin, wavy sandstone beds contain the trace fossil *Arenicolites*. Only one body fossil, a poorly preserved *Lingula* was found in these rocks. The top of this transitional unit is considered the top of the Skull Creek Shale.

The base of the delta front environment is the lower limit of J sandstone deposition. In the northern part of the study area delta front deposits of the lower J Sandstone are marine deposits 30-40 feet thick (9-12 m) and are characterized by structureless, dark-gray, very fine-grained, poorly-sorted, well indurated, intensely bioturbated sandstone with abundant clay matrix and low porosity. Lack of physical structure and intense bioturbation suggest a low energy depositional environment with slow rates of sedimentation which gave deposit-feeding organisms adequate time to rework the organic rich sediments which supported them. Traces produced by these organisms include *Teichichnus, Asterosoma, Terebellina* (white-walled burrows) and unoriented sand-filled burrows, some of which are clay lined.

South of a covered lateral transition zone, delta front deposits in the southern part of the study area lack the intense bioturbation and deposit-feeder trace fossil

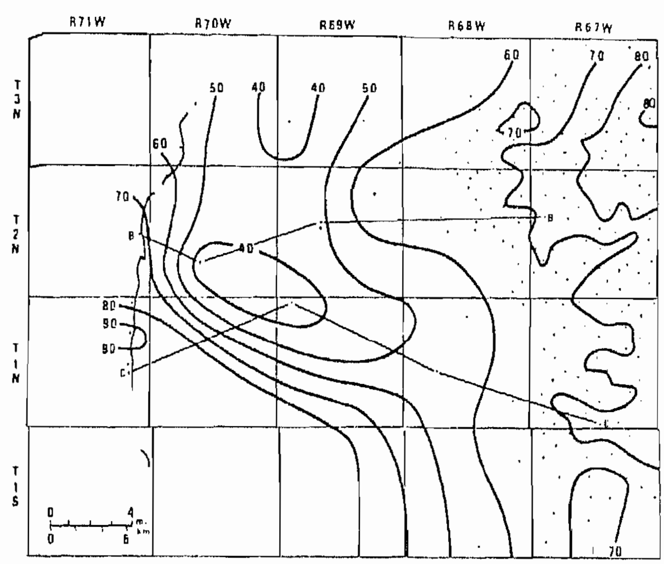

Fig. 3—Isopach Map of the J Sandstone. Contour interval—10 feet. Dots indicate data points.

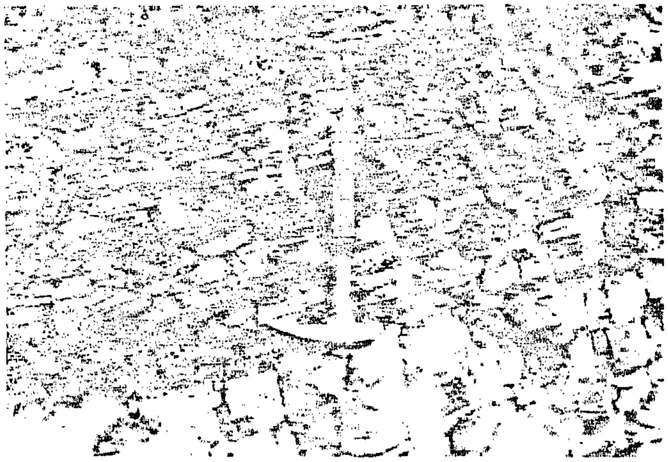

Fig. 4—Prodelta deposits in the upper Skull Creek Shale (Swede Ditch).

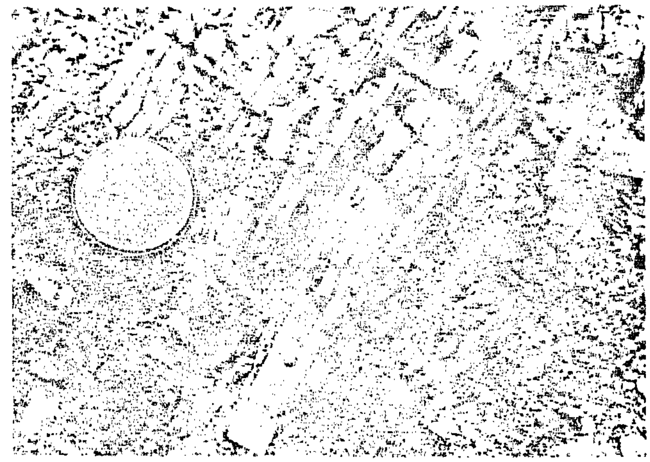

Fig. 6—Brackish-water delta front deposits in the J Sandstone (One Mile Canyon). Lens cap is 2.4 inches (6 cm) in diameter. Beds are overturned.

assemblage that characterize the delta front in the northern area. Southern delta front deposits reach a maximum of 22 feet (6.7 m). They consist of very fine-grained, very thin-bedded to laminated and cross-laminated sandstones with wavy bedding planes and occasional silt laminae. The presence of the suspension feeder trace fossil *Arenicolites,* the general lack of bioturbation, and the occurence of cross-lamination in some beds suggest a shallow, brackish water depositional environment (Fig. 6).

Delta Plain

The majority of the upper J Sandstone was deposited in the subaerially exposed delta plain which can be subdivided into many smaller, interrelated subenvironments including distributary channels with associated levees, crevasse splay deltas, marshes and fresh-water to marine bays. In the study area, the delta plain deposits vary in thickness from about 20 feet (6 m) east of Lyons to a maximum of about 90 ft (27 m) at Four Mile Canyon.

Distributary Channels

Distributary channels are the major conduits for supplying sediment to the entire delta and fill within them reflects a complete depositional sequence (Meckel, 1972). This sequence consists from the base upwards, of active channel fill deposited during full channel flow; a partial-abandonment fill as flow was reduced; and the final abandoned-channel fill which was deposited in a quiet body of water when the channel was abandoned. This model has been applied to the outcrop of the Dakota Group in the Turkey Creek area of Jefferson County, 30 miles (48 km) to the south of this study (MacMillan and Weimer, 1976).

Active-channel fill in the J Sandstone of Boulder County consists of 8 to 13 feet (2.4 to 4.0 m) of predominantly very fine- to fine-grained sandstone. These sandstones which are characterized by planar and trough cross-bedded units (Fig. 7), are commonly interstratified with thinner ripple-laminated zones which document fluctuating energy levels within the channel. Bioturbation or other biogenic structures are rare in these deposits.

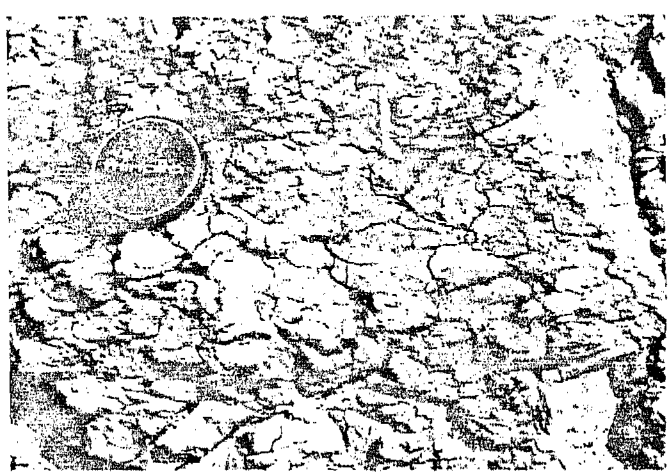

Fig. 5—Marine delta front deposits in the J Sandstone (Hygiene Road). Photographed perpendicular to bedding. Lens cap is 2.4 inches (6 cm) in diameter.

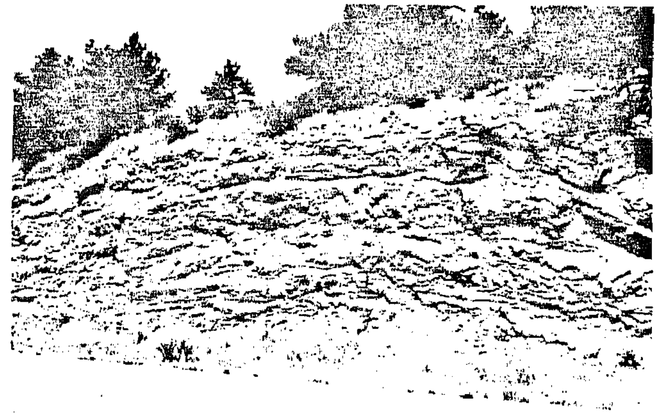

Fig. 7—Active-channel fill in the J Sandstone (Lykins Gulch).

Partial-abandonment fill may be as much as 12 feet (3.6 m) thick and is characterized by lenticular beds of very fine- to fine-grained sandstone overlain by siltstones (Fig. 8). These sandstones contain low-angle to planar cross-beds with root casts and zones indicating shallow water deposition or periodic subaerial exposure.

Fig. 8—Partial-abandonment fill (P-A), the lenticular beds, were deposited as sand bars in a channel. These beds are overlain by abandoned-channel fill (A). (Four Mile Canyon). Stick is 5 feet (1.5 m) long.

As flow through the channel was further reduced, final filling of the channel took place. Abandoned-channel fill does not exceed 3 feet (0.9 m) of very fine-grained silty sandstone or black shale. Bedding in this unit is generally laminar and contains abundant wood fragments and carbonaceous material.

Natural levees are commonly associated with recent examples of distributary channels and serve to separate the channel from the bays and marshes of the interdistributary area (Fisk, et al, 1954). However, natural levee deposits were not observed in the study area, possibly due to lack of preservation or lack of exposure.

Crevasse Splay Deltas

Beyond the natural levees, the influence of the channel is seen in crevasse splay delta sandstones which interfinger with bay deposits (Fig. 9). These splay deposits are characterized by thin, light-gray- to buff fine- to very fine-grained sandstone. Individual beds may be laminated, ripple laminated, planar cross-bedded or massive. They may contain root zones or be capped with a marsh deposit of carbonaceous shale. Evidence of shallow water deposition can be inferred from desiccation cracks, the root zones and a three-toed dinosaur foot print cast found in J Sandstone float at the One Mile Canyon outcrop. The footprint was similar to those observed in the J Sandstone at the Alameda Avenue outcrop west of Denver (MacKenzie, 1972).

In three southern outcrops in the study area, Bear Canyon, One Mile Canyon and Two Mile Canyon, the J Sandstone is composed of alternating splay delta and fresh-water bay deposits. These deposits are observed along 5 miles (8 km) of outcrop. The nearly 70 feet (21 m) of stacked shallow water deposits suggests subsidence.

Fig. 9—Crevasse splay delta deposits in the J Sandstone (Left Hand Canyon).

Marsh

Marsh deposits consisting of thin carbonaceous shales are preserved above some splays. In Four Mile Canyon, a white kaolinitic claystone is evidence for a well-drained marsh in which carbonaceous material was completely oxidized.

Bays

Between distributary channels interdistributary bays receive predominantly fine-grained sediment. Fresh-water bay deposits are characterized by dark-gray- to black, laminated, unbioturbated fissile shale. Brackish bay deposits are similar to those of a fresh-water bay except that the shale in these deposits is slightly bioturbated. Marine bay deposits are characterized by medium-gray, very fine-grained, very poorly-sorted, clayey sandstone which is intensely bioturbated. Trace fossils include *Asterosoma*, *Teichichnus*, and smooth, unoriented sand-filled burrows.

Transgressive Deposits

The uppermost portion of the J sandstone in many of the outcrop sections was the result of the reworking of the deltaic deposits as the sea transgressed the delta. The transgressive deposit consists of a thin, 2 foot (0.6 m) or less, sandstone. This sandstone is thin-bedded, commonly quartzitic, fine- to medium-grained, black to dark-gray or brown and usually very well-sorted and rounded. In outcrop the sandstone weathers orange-brown and shows a wide variation in degree of cementation.

Above the transgressive sandstone, a lag deposit at the Hygiene Road outcrop contains granules and pebbles of quartz and chert with an imprint of bone material. MacKenzie (1971) reported a similar lag deposit from Red Hill, Boulder County, to west of Fort Collins in Larimer County, and explained the zone as the result of "stratigraphic condensation during a period of very slow deposition immediately following the post-Muddy (post-J Sandstone) transgression."

DEPOSITIONAL MODEL

Within the study area the nature of the deltaic sediments of the J Sandstone changes from north to south. These changes are lithologic and environmental with the approximate boundary separating the north and south areas between Left Hand Canyon and Four Mile Canyon. These changes are:

1. The marine prodelta and delta front deposits of the Skull Creek Shale and the J Sandstone in the northern area are not present to the south (Fig. 10). Instead, in the southern sections at One Mile Canyon and Bear Canyon, brackish-water delta front deposits underlie the delta plain deposits.
2. The southern delta plain deposits are predominatly fresh-water bay and splay delta shallow water sediments 68 to 91 feet (21 to 27 m) thick. In contrast, the delta plain sediments of the northern area consist of a comparatively thin sequence of distributary channels and splay delta sediments alternating with bay and marsh deposits varying in thickness from 15 to 35 feet (4.6 to 10.7 m).
3. Channel flow direction in the northern area was to the southeast while in the southern area the flow direction was to the east (Fig. 11).

MacKenzie (1971) proposed that the intensely bioturbated marine sandstones noted in the northern area were originally deposited across both the northern and southern portions of the study area. During a lowering of sea level, these sands were eroded from the southern area and with a subsequent rise in sea level, the sediments now present in the southern area were deposited. This explanation presents several difficulties. An erosion surface attributable to the lowering of sea level was not observed in the study area. In addition, there is no other evidence for a fluctuating sea level during that time. The absence of *Terebellina* (white-walled burrows) south of Left Hand Canyon is attributed to "truncation of spoor zones" by erosion although an alternate explanation could be found in changes of environmental conditions.

An alternate model is proposed employing subsidence and salinity variations to explain the lateral changes in the J Sandstone observed in Boulder County. To the north the marine influence is stronger where an abundance of trace

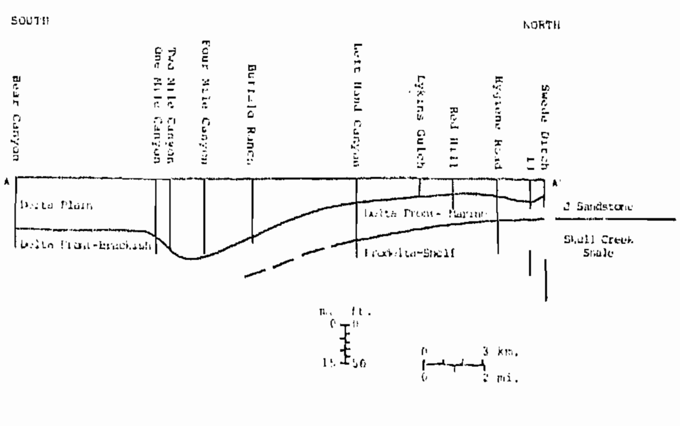

Fig. 10—Surface cross section A-A' showing basic genetic units.

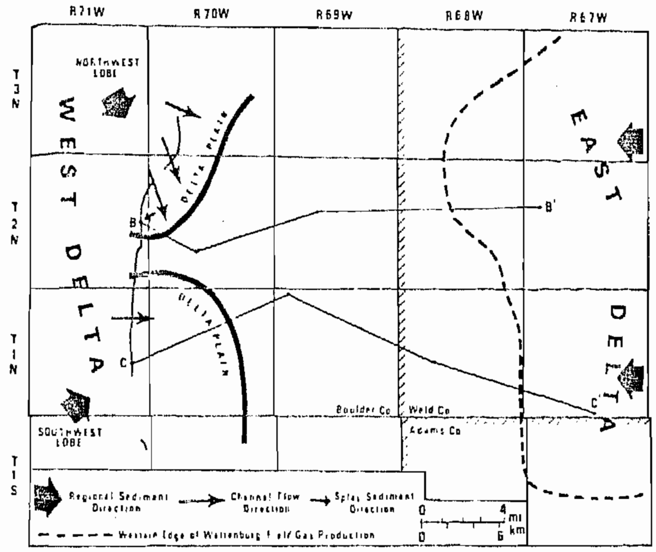

Fig. 11—Pattern of sediment transport during deposition of the J Sandstone.

fossils in the delta front deposits indicates more saline conditions. The lower salinity present to the south was the result of dilution of marine water by fresh water from distributary and splay channels of a delta lobe to the southwest.

Sedimentation in the study area may have been tectonically controlled as thick delta plain deposits from the southwest are present at Four Mile Canyon but do not appear at Left Hand Canyon. These anomalously thick, shallow-water sediments suggest penecontemporaneous growth faulting. Sediment loading by the prograding delta lobe may have reactivated a zone of weakness in the basement, with downward movement of the associated basement block controlling subsidence and sedimentation in the southern area.

The sediments preserved in the outcrops form a continuous record of depositional events. However, no time surfaces, such as a bentonitic clays, could be traced across the area. Thus, the sequence of events suggested here is an interpretation to account for the assemblage of process-controlled genetic units observed in outcrop.

The J Sandstone was first deposited in the study area in a delta front environment. In the southern portion of the area the delta front sediments were deposited in shallow brackish water near a delta plain prograding toward the northeast. To the north, where conditions were more saline, the delta front deposits take on a more marine aspect. Clay and silt carried further offshore and deposited to the north and east form the prodelta sediments of the Skull Creek Shale.

As the delta plain prograded over the southern outcrop area from the southwest, subsidence accommodated a thick sequence of fresh-water bay and splay sediments. Simultaneously, to the north, marine delta front sediments continued to be deposited.

The delta front sediments from the southwest were later supplemented by sediments from a delta lobe that was prograding toward the southeast. This lobe was part of the same delta system as the lobe from the southwest. A shift

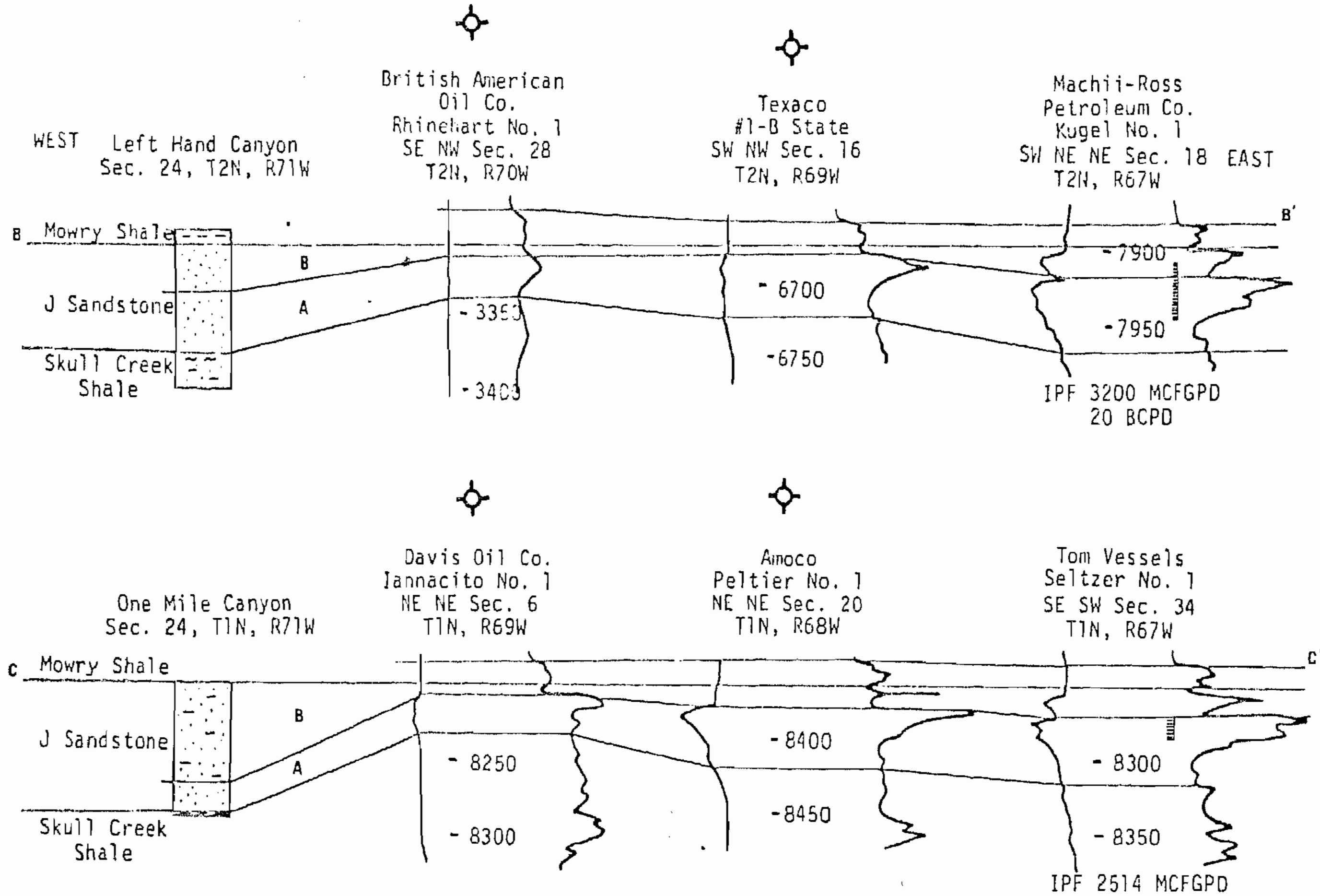

Fig. 12—Cross Sections B-B' and C-C'. No horizontal scale.

in the sedimentation pattern in the delta resulted in later progradation of the northwestern delta lobe into the northern outcrop area (Fig. 11).

The delta plain in the northwest lobe is thin because of a smaller sediment supply, a shorter depositional interval or possibly tectonic stability in the northern area.

With cessation of deltaic progradation the delta plain deposits of both the northern and southern area subsided and the sea began to transgress and rework the uppermost sediments. This process left a thin transgressive sand across the delta deposits. A period of slow deposition followed which is recorded by the lag deposit of granules and pebbles (MacKenzie, 1971). The neritic siltstones and shales of the Benton Formation record the total inundation of the area by the Cretaceous sea.

As shown on Figure 11, an eastern delta system developed simultaneously along the eastern side of the Cretaceous sea. In Figure 12, the lower part of the J Sandstone labeled "A" consists of delta front deposits with the delta plain part of the J Sandstone labeled "B" at Left Hand Canyon (B) and at One Mile Canyon (C). From these outcrop sections, the J Sandstone can be correlated into the subsurface and into the Kugel No. 1 well (SW NE NE, Section 18-T2N-R67W) and the Seltzer No. 1 well (C, SE SW, Sec. 34-T1N-R67W), where delta plain deposits overlie delta front deposits of the eastern delta. As marked on the easternmost logs of Figure 12, gas is produced from these delta front deposits of the eastern delta (Matuszczak, 1976).

CONCLUSIONS

1. The J Sandstone outcrops in Boulder County are composed of prograding delta front and delta plain deposits capped by a transgressive sandstone.

2. The sediments in the delta deposits were derived from the west as shown in provenance studies of constituent minerals (MacKenzie and Poole, 1962) and paleocurrent indicators.

3. The different nature of the delta front deposits, from north to south, is attributed to a local salinity decrease of the sea as a result of fresh water influx from distributary and splay channels to the southwest.

4. Subsidence of the basement as a result of deltaic sediment loading may explain thick delta plain deposits in the southern part of the area.

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Raspberry Butte Photo by Rathbone