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North Dakota has rapid Mesozoic facies changes

Jurassic-Cretaceous boundary now thought to be gradational, not marked by unconformity; prospective stratigraphic traps indicated

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THE RE-INTERPRETATION of the Upper Jurassic-Lower Cretaceous stratigraphy in the North Dakota portion of the Williston Basin suggests the possibilities of oil production in a section previously of little economic interest.

The boundary between the lithologic units of the Upper Jurassic-Lower Cretaceous interval in the North Dakota portion of the Williston Basin and adjacent areas heretofore has generally been interpreted to be at a major unconformity. This interpretation as applied in the subsurface of North Dakota is herewith substantially refuted. Instead, the Jurassic-Cretaceous contact is postulated to be gradational. The concept of a gradational contact originated during the study of the stratigraphic positions and lithologies of the units of a limited stratigraphic section immediate to the boundary.

Prior interpretation. Previously the author used the fine-to very coarse-grained quartzose sandstones (assigned to a Lower Cretaceous age and thought to indicate a transgressing Cretaceous sea) as the criteria to identify the postulated unconformity between the Jurassic and Cretaceous.[2] The boundary was then placed at a change in lithology from the greenish gray shales and fine-grained sandstones of the Jurassic to the fine- to very coarse-grained quartzose sandstones of the basal Lower Cretaceous. The very basal Cretaceous sandstone was then correlated as the Lakota sandstone equivalent, except in northeastern North Dakota where it was correlated as the Fall River equivalent.

Placing the boundary as just described resulted, however, in relatively abrupt changes in its stratigraphic position in northeastern North Dakota. These changes were first interpreted to be an indication of pre-Cretaceous erosion upon the Jurassic surface. After further study, it was decided that the Jurassic-Cretaceous boundary was not necessarily below a quartzose sandstone in northeast North Dakota, but could underlie a mostly non-marine section that would be interpreted as the lateral equivalents of the Lakota sandstone and, in part, the Fall River sandstone. Non-marine sediments were deposited in northeastern North Dakota—possibly the entire extreme east part—while the very Lower Cretaceous sands (probably mostly littoral) were deposited immediately to the southwest. The non-marine Cretaceous lithologies, as interpreted, are greenish gray, red-brown and gray shales, and calcareous, silty, fine-grained sandstones generally thought heretofore to be Jurassic. Stratigraphic position was the sole means of correlating the dissimilar lithologies, as paleontological evidence is rarely found in well cuttings from the Jurassic-Cretaceous section.

Present interpretation. The Jurassic-Cretaceous stratigraphic section chosen is bounded by probable time lines. The lower limit of the stratigraphic section studied is the boundary between the Rierdon and Swift formations of eastern Montana.[1] The lower limit is parallel to, but often times placed *20 to 30 feet below the top of the Rierdon "A."*[4] The upper limit is the "marker horizon" used as the boundary between the Upper and Lower Cretaceous.[2]

The arbitrary boundary and the experimental stage-like units are used to demonstrate the gradational nature of the contact.

The experimental stage-like units are:

1. *The XB unit* is equivalent to the Swift formation of eastern Montana

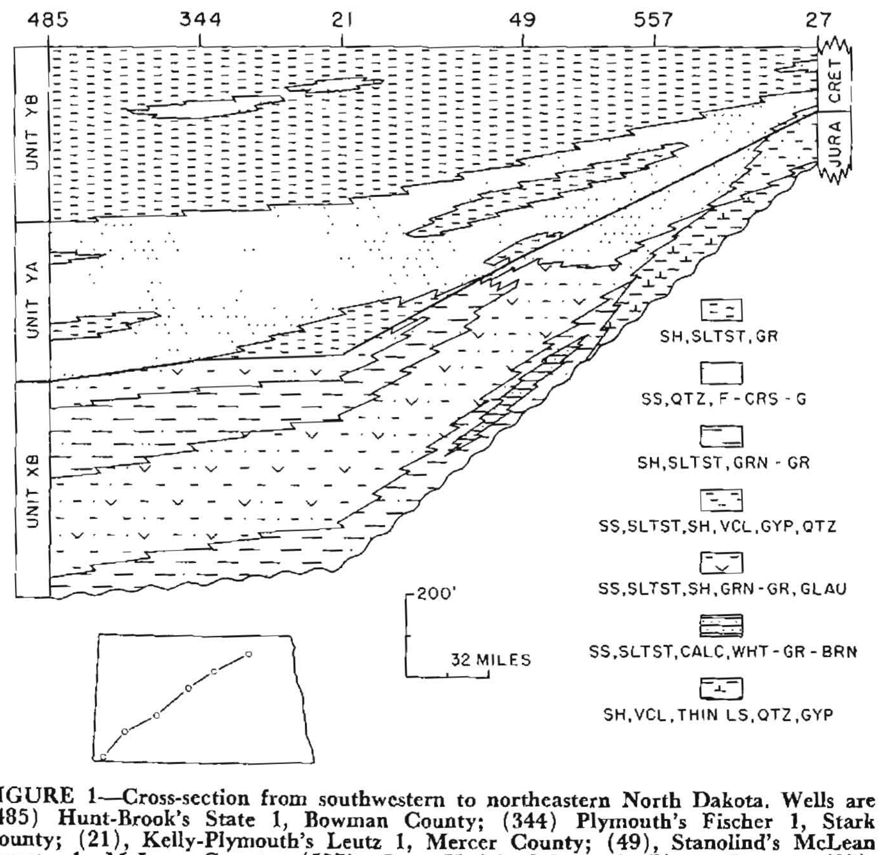

FIGURE 1—Cross-section from southwestern to northeastern North Dakota. Wells are (485) Hunt-Brook's State 1, Bowman County; (344) Plymouth's Fischer 1, Stark County; (21), Kelly-Plymouth's Leutz 1, Mercer County; (49), Stanolind's McLean County 1, McLean County; (557), Owen-Hyde's Schaan 1, Pierce County; (27), Union's Skjervheim 1, Cavalier County. Extensive facies changes, and arbitrary placement of Jurassic-Cretaceous boundary are shown.

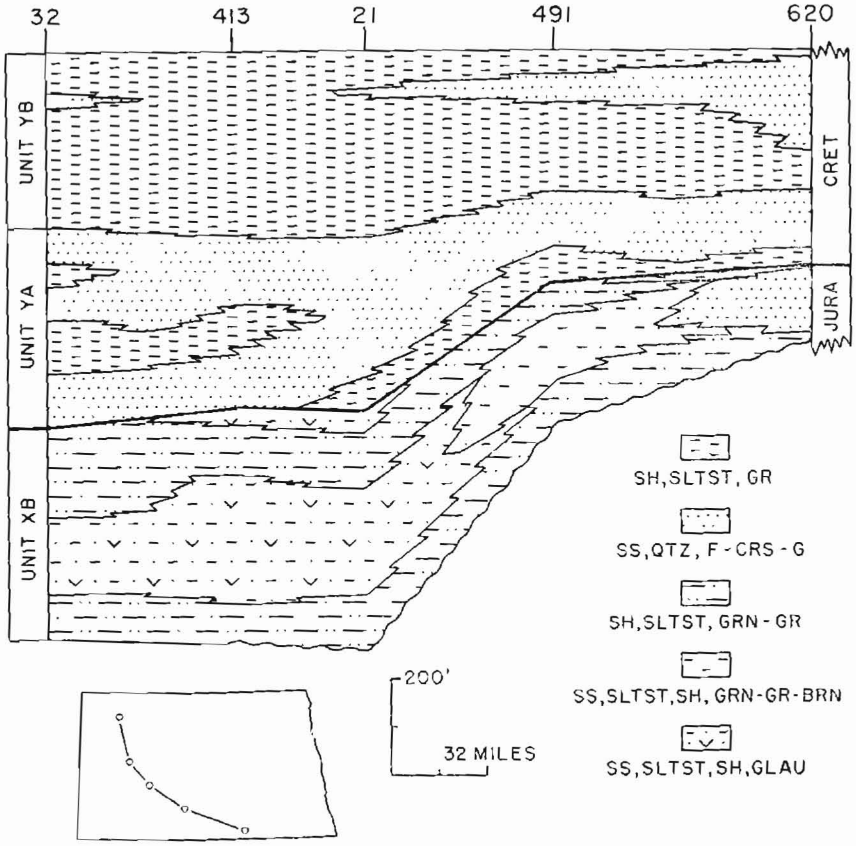

FIGURE 2—Cross-section from northwestern to southeastern North Dakota. Wells are (32) Amerada's Bakken 1, Williams County; (413) Carter's Lockwood 1, Dunn County; (21) Kelly-Plymouth's Leutz 1, Mercer County; (491) National Bulk Carriers' Miller 1, Morton County; (620) Calvert's Nitschke 1, McIntosh County.

TABLE 1—XB Unit

The stage-like arbitrary time rock XB unit of Jurassic age varies in lithology. This variance of lithology is described in the following table:

	GEOGRAPHIC AREAS OF NORTH DAKOTA		
	Western	**North-central**	**Northeastern**
XB Unit	A basal marine, greenish gray, gray shale unit; a middle marine, glauconitic, fine-grained quartzose sandstone and greenish gray, gray shale unit; and an upper marine, greenish gray, gray silty shale unit that, in many of the wells studied, is overlain by a marine, glauconitic, fine-grained quartzose sandstone unit. More arenaceous in southwestern North Dakota and gradually changes to the characteristics of the marine Sundance formation of the northern Black Hills. Up to 560 feet thick.	A basal marine greenish gray, brown, gray shale and light gray, calcareous sandstone and siltstone unit; and an upper marine to non-marine fine-to very coarse-grained quartzose sandstone unit. Up to 350 feet thick.	Consists for the most part of non-marine gray, greenish gray and vari-colored shales; light gray siltstones; thin limestones; very fine-grained, calcareous sandstones; and traces of coarse quartz grains and gypsum Up to 200 feet thick.
		South-central	**Southeastern**
		A basal marine greenish gray, gray and brown silty shale unit; a middle marine brownish gray to light gray sandstone and siltstone unit; and an overlying marine, light gray and greenish gray, silty shale unit. Up to 400 feet thick.	Consists of marine to non-marine fine- to very coarse-grained quartzose sandstone and gray, red-brown shales. Up to 200 feet thick.

and to the Sundance formation of the northern Black Hills.[3]

2. *The YA unit* consists of equivalents of the Jurassic Morrison formation[4] and the equivalents of the Cretaceous Lakota, Fuson and Fall River formations of the northern Black Hills.[2]

3. *The YB unit* is composed of equivalents of the Cretaceous Skull Creek, Newcastle and Mowry formations of the northern Black Hills.[2]

The arbitrary Jurassic-Cretaceous boundary is the upper limit of the XB unit.

Stratigraphy. The time rock XB unit of Jurassic age varies in lithology. (See Table 1 and Figures 1 and 2.)

The pre-XB unit paleogeological map (Figure 3) illustrates the areal extent of the Jurassic Rierdon. The XB unit overlaps onto the Rierdon and both have a similar areal extent. The paleolithologic map of the middle of the XB unit (Figure 4) is an arbitrary horizontal slice to show the variance from a marine, fine-grained sandstone (glauconitic for the most part) in western and south-central North Dakota to a marine and non-marine fine-to coarse-grained quartzose sandstone in north-central and southeastern North Dakota. This in turn, varies to non-marine shales, siltstones and sandstones in the northeast.

The paleolithologic map of the top of the XB unit (Figure 5) illustrates a variance from a marine, glauconitic, fine-grained sandstone in the west to a marine green and gray shale unit that extends from the extreme northwestern to the south-central portion of the state. East of the marine sediments, one small area of quartzose sandstone, marine to non-marine, appears in central North Dakota and occurs because of the westward regression of the marine units. East of the quartzose sandstone and marine sediments, gray, silty shales (mostly non-marine) are shown. In northeastern North Dakota non-marine sediments are shown.

The Rierdon-XB unit contact is gradational in the northwest and the boundary is placed at a prominent point on electric and/or gamma ray logs. In the remainder of the state, the Rierdon-XB unit boundary lies at an unconformity. The unconformable contact of the XB unit and the underlying Rierdon formation in southeastern North Dakota is below a unit in which lithology varies from a calcareous siltstone and sandstone to an arenaceous limestone. Where the Rierdon is absent in southeastern North Dakota, the unconformity is below reddish shale overlying the Jurassic Piper limestone or Paleozoic limestones where the Middle Jurassic is absent. In southwestern North Dakota the boundary (indicated to be at an unconformity) is either below a thin calcareous siltstone and sandstone or an extremely thin arenaceous limestone. In northeastern North Dakota, the unconformable contact is below a unit of varicolored shales, thin limestones, and siltstones.

The Rierdon-XB unit boundary is thought to be a time line, because it is delimited by an unconformity of very low angularity in the east and south and an equivalent "marker horizon" in northwestern North Dakota.

YA Unit. The Cretaceous YA unit, overlying the Jurassic XB unit, reaches a thickness of 460 feet in western

North Dakota. (See Table 2 for a description of the YA facies.)

The lower boundary of the YA unit is the arbitrary Jurassic-Cretaceous boundary. In western North Dakota, the boundary is placed arbitrarily below a quartzose sandstone of the YA unit and above the glauconitic, fine-grained sandstone of the XB unit, or, where the glauconitic sandstone does not occur, above the greenish gray, silty shale of the XB unit. The boundary could be placed higher in the section; or it could be placed within or at the top of the very basal quartzose sandstone, identified at times as a lithologic unit in northwestern North Dakota and as an equivalent unit containing Jurassic Morrison (?) in the southwest. It then would be at a stratigraphic position more in accord with the position of the boundary farther east. The author, however, could not solve the problem satisfactorily and placed the lower boundary of the YA unit below the series of fine-to-coarse-grained quartzose sandstones. The lower YA unit boundary in southeastern North Dakota is placed arbitrarily below or within a gray, silty shale that separates two quartzose sandstones of similar texture.

In north-central North Dakota the boundary is placed at the bottom of a thin gray shale within the lower part of a series of fine-to-coarse-grained quartzose sandstones. If the gray shale is not present, it is placed at the first convenient "break" within the quartzose sandstones that corresponds to the stratigraphic position of the gray shale. In the northeast, placing the arbitrary lower YA unit boundary is difficult. The lower YA boundary is placed by a combination of stratigraphic position and the last occurrence of coarse quartz grains in the gray, brown and green-gray shales and gray siltstones immediately below the thin quartzose sandstone of the YA unit.

In summary, the lower YA unit boundary, the Jurassic-Cretaceous boundary, is placed by stratigraphic position. The strata immediately above and below the boundary are very similar in texture and composition in eastern North Dakota. The similarities of the strata (marine to non-marine) of the XB and YA units as interpreted in the east and the gradational nature of the marine to non-marine strata of the XB unit are used to indicate that the Jurassic-Cretaceous contact is gradational and not at an unconformity.

YB Unit. The YB unit, overlying the YA unit, reaches a thickness of 470 feet in western North Dakota. The lithology of the units is relatively simple and is illustrative of sandstone and shale facies relationships that were the result of transgressive and regressive movements of the Cretaceous sea. The subdivisions of the YB unit in ascending order are: a marine medium gray to dark gray shale termed the Skull Creek shale; a non-marine to marine, discontinuous, fine-to very coarse-grained sandstone termed the Newcastle sandstone; and a marine, dark gray shale termed the Mowry shale.

The lower boundary of the YB unit is placed with some difficulty because of the slight time transgressive nature of the contact of the underlying uppermost sandstone of the YA unit and the overlying Skull Creek shale of the YB unit. The lower boundary of the YB unit in eastern North Dakota is for the most part arbitarily placed at the top of the uppermost sandstone of the YA unit, a sandstone previously

PALEOGEOLOGIC MAP PRE-UNIT XB

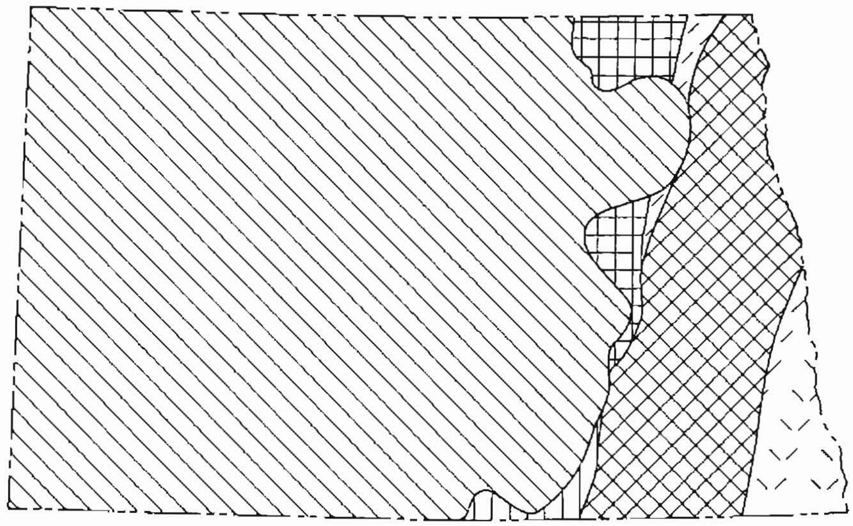

FIGURE 3—Pre-XB unit paleogeological map shows the areal extent of the Jurassic Rierdon. Piper-Rierdon beds are present over the entire state of North Dakota with the exception of the extreme east portion. There it unconformably overlaps existing Paleozoic formations.

TABLE 2—YA Unit

The Cretaceous YA unit, overlying the Jurassic XB unit, is described as to lithology in the following table:

	GEOGRAPHIC AREAS OF NORTH DAKOTA		
	Northwestern	**Southwestern**	**Northeastern**
YA Unit	In some of the wells studied the unit can be separated into three lesser units consisting of a very basal fine- to coarse-grained quartzose sandstone containing gray shales; a gray shale; and an overlying fine- to medium-grained quartzose sandstone, gray shale, and siltstone unit. For the most part the shales thicken and thin rapidly to make separation into units difficult. Up to 460 feet thick.	In some of the wells studied the unit is separable into three lesser units of quartzose sandstone and gray shale, but the equivalent of the very basal fine- to coarse-grained quartzose sandstone of northwestern North Dakota also consists, at times, of quartzose sandstone, varicolored shale, and siltstone that could be equivalent to the Jurassic Morrison. This relationship needs more study. Up to 460 feet thick.	Consists of a silty, medium-grained quartzose sandstone that grades, in a northeast direction, into a unit of varicolored shales and light gray siltstones overlain by a thin, primarily coarse-grained sandstone. Up to 125 feet thick.
	North-central	**South-central**	**Southeastern**
	Consists of a fine- to coarse-grained sandstone with interbedded gray shales. Up to 250 feet thick.	Consists of basal light gray silty shale and an overlying fine- to very coarse-grained quartzose sandstone. Up to 330 feet thick.	Consists of fine- to very coarse-grained quartzose sandstone with interbedded gray shales. Up to 250 feet thick.

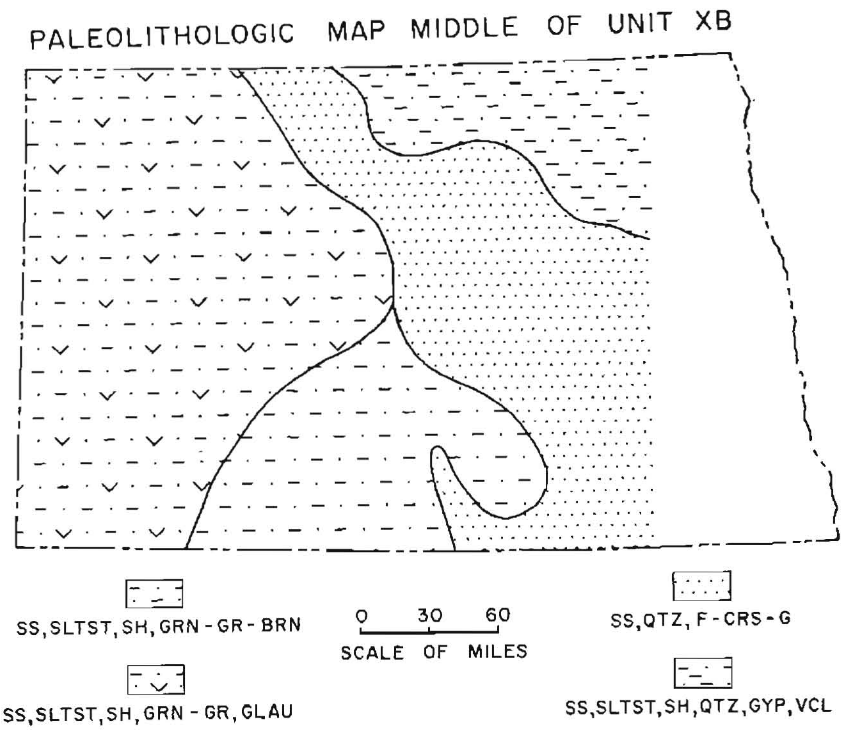

FIGURE 4—Paleolithologic map of the middle of the XB unit. This map is an arbitrary horizontal slice to show variance from a marine, fine-grained, mostly glauconitic sandstone in western and south-central North Dakota to a fine to coarse grained quartzose sandstone, both marine and non-marine, in north central and southeastern parts of the state. This in turn varies to non-marine shales, siltstones, and sandstones in the northeast. Middle marine XB sandstones could contain petroleum if deposits in permeable sandstones pinching out updip into impermeable strata could be found.

termed the Fall River by the author.[2] In western North Dakota a "marker horizon," a prominent point on the gamma ray log and coincident with the top of the uppermost sandstone of the YA unit, is used to place the lower boundary of the YB unit. However, the writer is unsure of the continuation of the "marker horizon" throughout the state. Furthermore, since the interface of the Skull Creek shale and the uppermost sandstone of the YA unit apparently transgresses time at such a low angle the top of the sandstone is used as the lower boundary of the YB unit. The upper boundary of the YB unit appears easy to identify as it is a prominent point on the gamma ray and electric logs. This prominent point, a "marker horizon," is below a thin, bentonitic, silty and arenaceous shale unit and is used to indicate the boundary between the Upper and Lower Cretaceous.

Tectonism and sedimentation. The regional tectonism that controlled the deposition of the Jurassic sediments in North Dakota caused an unconformity to be developed during the change from the Jurassic Rierdon to the XB unit depositional environments. However, in northwestern North Dakota the Jurassic Rierdon-XB unit contact is conformable and the change was gradual. Following the development of the unconformity between the Rierdon and the XB unit, uplift tendencies ceased for a time and subsidence was dominant during the deposition of the lower marine shale of the XB unit. After deposition of the lower shale of the XB unit regional uplift was the dominant tectonic process and areas to the southwest, south and east were probably the most effective as source areas for the sediments deposited. During this uplift the middle marine sandstones and shales of the XB unit were deposited in western North Dakota. Marine and non-marine strata (quartzose sandstone and light gray shales for the most part) were deposited in eastern North Dakota during deposition to the west of the middle marine sediments of the XB unit. A temporary tectonic balance was sustained and the non-marine to marine sediments continued to be deposited in eastern North Dakota while the upper marine shale of the XB unit was deposited in western North Dakota. However, regional uplift became effective again—probably an uplift southwest of the state was the most effective—and the uppermost marine, glauconitic sandstone of the XB unit was deposited in western North Dakota. The uppermost marine glauconitic sandstone is gradational into the overlying marine to non-marine strata of the Cretaceous YA unit in western North Dakota. During this time marine to non-marine sediments continued to be deposited in eastern North Dakota. Following the deposition of the uppermost marine, glauconitic sandstone the environments characteristics of the marine Jurassic disappeared in the state.

The facies changes characteristic of the Lower Cretaceous were widespread in North Dakota following the last deposition of the Jurassic marine sediments in western North Dakota. The marine to non-marine environments had spread over the state mostly from the eastern half. In addition, uplift of source areas to the southwest and south continued to contribute sediments to the same area. A relaxation of the uplift tendencies followed and the marine portion of the uppermost sandstone of the YA unit and the overlying marine Skull Creek shale were deposited in North Dakota. However, one more regional uplift occurred that resulted in the deposition of the marine to non-marine, quartzose, and discontinuous equivalent to the Newcastle sandstone. The effect of the uplift was greatest in southeastern North Dakota where thicker deltaic (?) sediments of the Newcastle were deposited. This is the last evidence of extensive uplift in the state until the close of the Cretaceous.

The "marker horizons" (top of unit YB and bottom of unit XB) are useful as datum points for subsurface structure maps because of their near parallelism to time lines. The "marker horizons" and the arbitrary Jurassic-Cretaceous boundary are probably the precise limits of the stratigraphic intervals that should be used when applying mathematical methods of stratigraphic analysis, such as lithofacies and sand-shale ratio maps.

The accumulation of petroleum in the interval studied of the North Dakota portion of the Williston Basin appears to depend more on the successful development of stratigraphic traps (localized development of porosity and permeability) rather than those of structure. This is emphasized while discussing various units.

The lower shale of XB unit appears to contain no possibilities of petroleum accumulation. The middle marine sandstones and shales of the XB unit could contain petroleum if accumulations in permeable and porous sandstones pinching out updip into impermeable sandstones and shales could be found. For example, offshore bars and/or channel sandstones could have been developed in central and southern North Dakota where the middle XB unit marine sandstones and shales grade into non-marine sandstones and shales (see Figure 4). The uppermost marine sandstone of the XB unit (see Figure 5) could also be locally developed in porosity and permeability to form stratigraphic traps for petroleum accumulation. Examples in an equivalent interval to the XB unit are found in the Saskatchewan portion of the Williston Basin in the Cantuar, Fosterton, Gull Lake, Success, North Premier, Battrum, Verlo and Wapella fields.

The very basal sandstones (considered Lower Cretaceous in age for this discussion) of the YA unit are very discontinuous and may be marine, at least in part, in the deeper parts of the Williston Basin of western North Dakota. Hence, there are possibilities of stratigraphic traps in these sandstones. The nearest production in sandstones equivalent to those of the basal part of the YA unit is in the Cat Creek field of central Montana, a field not in the Williston Basin. The uppermost sandstone of the YA unit is mostly marine, but because the sandstone is continuous throughout the greater part of North Dakota there appears to be little likelihood of stratigraphic trap accumulations except in the upper interval of western North Dakota, and that too appears very remote.

The YB unit contains equivalents of the Newcastle sandstone, a prolific producer on the west flank of the Black Hills in the Powder River Basin of Wyoming. These equivalents are discontinuous, marine to non-marine, channel and deltaic (?) sandstones that could well be potential petroleum reservoirs in southwestern North Dakota where they thicken and thin rapidly in this area and stratigraphic traps in this unit are quite probable. There is, of course, no petroleum production from this interval and preceding intervals discussed in the Williston Basin portion of North Dakota. So far this sandstone and underlying Jurassic-Cretaceous sandstones are known only as producers of artesian water in North Dakota.

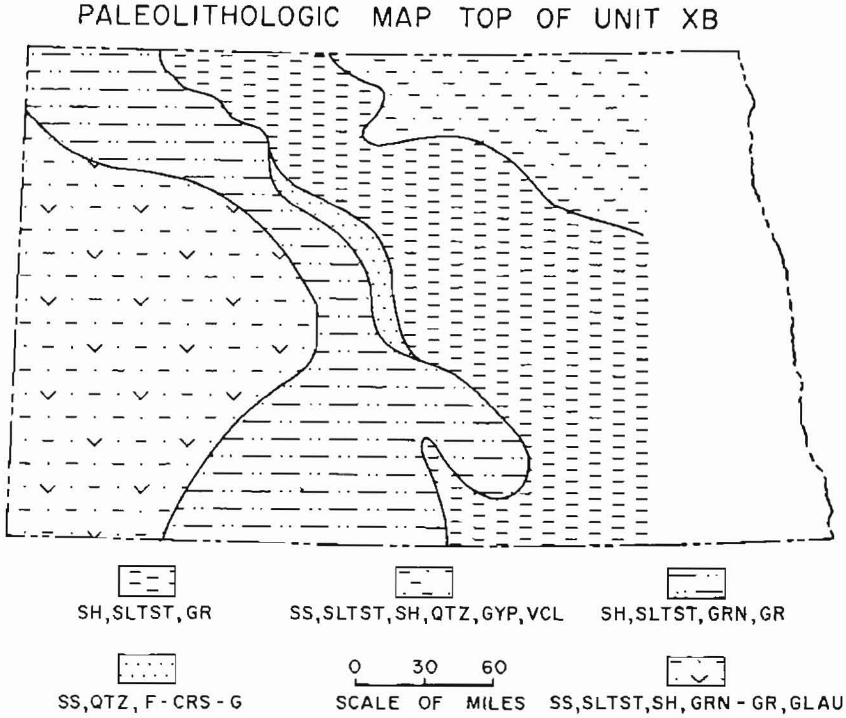

FIGURE 5—Paleolithologic map of top of XB Unit. Uppermost marine sandstone of XB unit may be locally prospective for oil in stratigraphic traps.

In summary, the regional tectonism, epeirogenic movement that controlled the deposition of the subject Jurassic and Cretaceous sediments primarily caused a "silting in" of the marine Jurassic Basin and the later development of a marine basin of a different environment during the Lower Cretaceous. The epeirogenic movement that controlled the deposition of the Jurassic sediments can be described as a gradual uplift with intermittent subsidence. Conversely, the epeirogenic movement that controlled the deposition of the Cretaceous sediments can be described as a gradual subsidence with intermittent uplift.

The lithologies and environments discussed are time transgressive. The Jurassic lithologies and environments mostly appear to be time transgressive in a western direction in North Dakota. The overlying gross Cretaceous lithologies appear to be primarily time transgressive in an eastern direction. The Jurassic-Cretaceous boundary is then wrapped in a history of regional tectonics. The boundary appears to be primarily gradational in North Dakota.

(The writer thanks the State Geologist, North Dakota Geological Survey for permission to publish this article. The article is a modified and condensed version of a paper presented at the Second International Williston Basin Symposium, Regina, Saskatchewan, 1958.)

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About the Author

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