Sedimentology and Sequence Stratigraphy of the Cretaceous Nanushuk, Seabee, and Tuluvak Formations Exposed on Umiat Mountain, North-Central Alaska

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Abstract

Upper Cretaceous strata of the upper part of the Nanushuk Formation, the Seabee Formation, and the lower part of the Tuluvak Formation are exposed along the Colville River on the east flank of Umiat Mountain in north-central Alaska. The Ninuluk sandstone, which is the uppermost unit of the Nanushuk Formation, displays a vertical succession of facies indicative of deposition in an upward-deepening estuarine through shoreface setting. A marine-flooding surface lies between the Ninuluk sandstone and organic-rich shale of the basal part of the Seabee Formation. The Ninuluk sandstone and the lower part of the Seabee Formation are interpreted as components of a transgressive-systems tract.

The lowest, well-exposed strata in the Seabee Formation are a succession of shoreface sandstone beds in the middle of the formation. Integration of outcrop information and the Umiat No. 11 well log suggests that this sandstone succession rests on a sequence boundary and is capped by a marine-flooding surface. The sandstone succession is interpreted as a lowstand-systems tract.

The upper part of the Seabee Formation includes a thick interval of organic-rich shale deposited in a dysaerobic offshore environment, and the gradational Seabee-Tuluvak contact is a coarsening-upward shale-to-sandstone succession deposited in a prodelta/delta-front environment. The observation that the upper part of the Seabee Formation correlates with seismic clinoforms suggests that dysaerobic conditions extended well up onto the prodelta slope during intervals of transgression and highstand.

Correlation of the Umiat Mountain outcrop section with well logs and seismic data suggests that sequence boundaries and lowstand shoreface deposits may be common in the Seabee Formation and that wave action may have been important in transporting sand to the paleoshelf margin. These conclusions may contribute to an enhanced understanding of sand distribution in prospective lowstand turbidite deposits in the subsurface of the central North Slope of Alaska.

Introduction

Oil exploration on the North Slope of Alaska has focused increasingly on stratigraphic objectives, including turbidites and topset strata in the Cretaceous through Tertiary Brookian Sequence (fig. 1). Exploration targets in turbidite facies have included lowstand-systems tracts (LSTs) along a series of ancient shelf margins that formed during the progressive southwest-to-northeast filling of the Colville Basin, a foreland basin that formed across northern Alaska during Cretaceous through Tertiary time (Bird and Molenaar, 1992; Houseknecht and Schenk, 2001).

An Upper Cretaceous (Cenomanian through Turonian), north-south-oriented, east-facing shelf margin about 20 mi east of the Colville River (fig. 2) has been a particular focus of exploration activity. Two oil fields, the Tarn and Meltwater (126 million and 44 million barrels of oil, respectively; Alaska Division of Oil and Gas, 2004), have been developed in lowstand turbidite deposits along this paleoshelf margin (fig. 2). Although general stratigraphic relations are known, many aspects of sedimentation and sequence stratigraphy across this paleoshelf margin remain poorly constrained.

Cenomanian through Turonian strata of the uppermost part of the Nanushuk Formation, the Seabee Formation, and the lowermost part of the Tuluvak Formation are well exposed at an easily accessible outcrop on Umiat Mountain along the Colville River a few miles east of Umiat and about 35 mi west of the paleoshelf margin described above (fig. 2). The objectives of this chapter are to describe and interpret the succession of Cenomanian through Turonian facies exposed on Umiat Mountain, to correlated these facies with subsurface data (Umiat No. 11 well log and seismic data), to interpret the sequence-stratigraphic framework of these facies, and to infer the significance of this interpretation to the regional sequence stratigraphy of north-central Alaska.

Geologic Setting

Regional Stratigraphic Framework

The stratigraphic nomenclature used in this chapter follows the revisions suggested by Mull and others (2003) and shown in figure 1. Regional stratigraphic relations are illustrated in the seismic profile in figure 3. The strata exposed on Umiat Mountain are part of two major depositional sequences, the Torok-Nanushuk sequence and the Seabee-Tuluvak sequence.

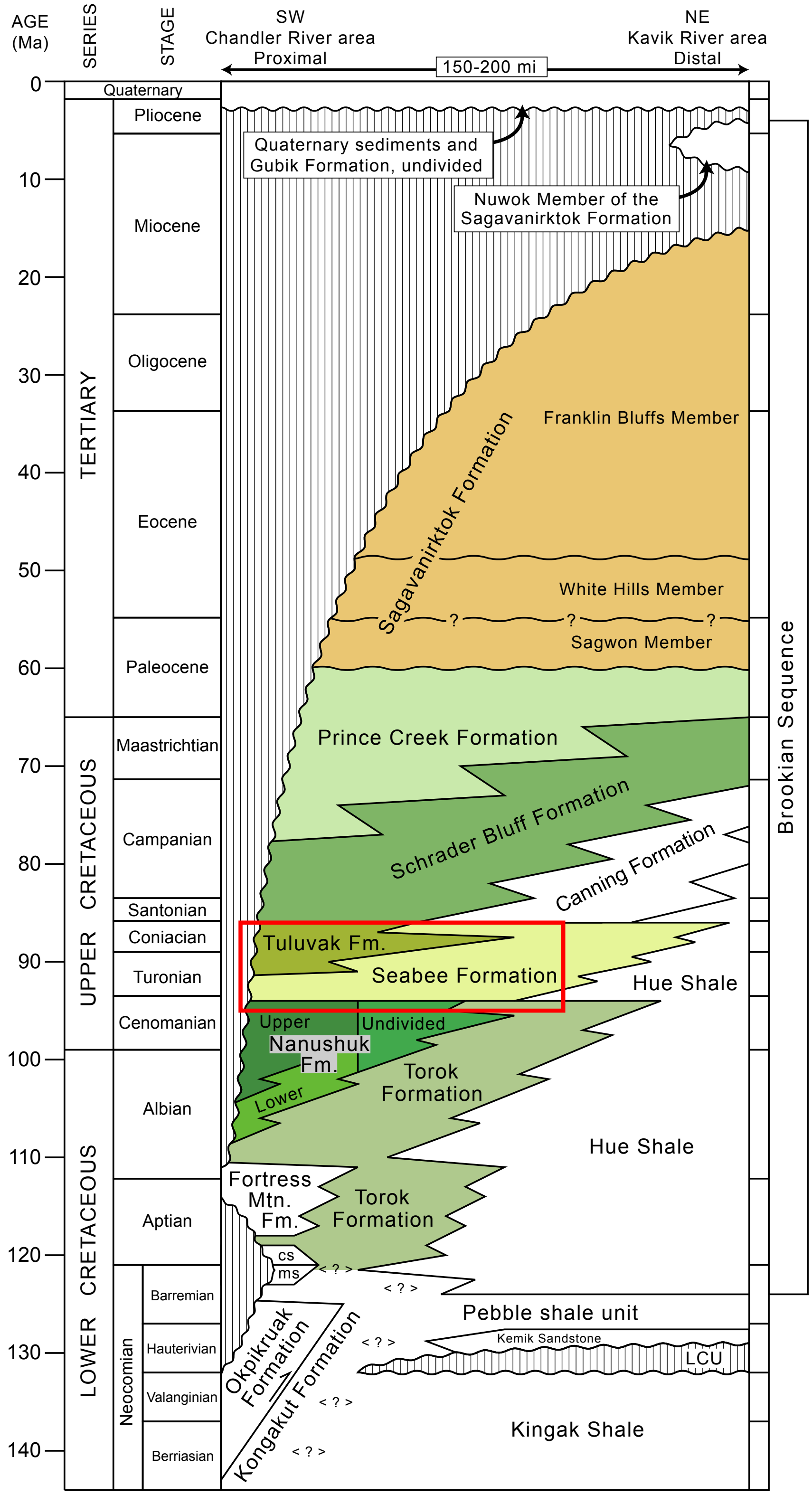

Figure 1. Chronostratigraphic column for the Colville Basin, northern Alaska, showing nomenclature and ages of strata of the Brookian Sequence. Strata highlighted by red rectangle are the subject of this chapter. cs, Cobblestone sandstone of the Fortress Mountain Formation; LCU, Lower Cretaceous unconformity; ms, manganiferous shale (informal term). Stratigraphic column modified from Mull and others (2003); geologic time scale from Gradstein and Ogg (1996). Query, relation uncertain.

Previous work has demonstrated that the Torok and Nanushuk Formations, both of mostly Albian through Cenomanian age in the study area (fig. 1), together display the overall seismic geometry of bottomset-clinoform-topset strata, indicating eastward to northeastward progradation of a depositional system that included deep-marine through nonmarine environments (for example, Molenaar, 1988; Bird and Molenaar, 1992; Houseknecht and Schenk, 2001). The Torok Formation, which is defined by seismic bottomset and clinoform reflections, comprises mudstone and sandstone deposits of deep-marine-basin, marine-slope, and outer-shelf environments (Molenaar, 1985, 1988; Houseknecht and Schenk, 2001). The Torok Formation downlaps onto and grades basinward into a distal condensed section of the Hue Shale (fig. 1). The Nanushuk Formation, which is defined by seismic topset reflections, comprises sandstone and mudstone deposits of marine-shelf and shoreface, deltaic, and nonmarine environments (Ahlbrandt and others, 1979; Huffman and others, 1985, 1988; LePain and Kirkham, 2001). Within the overall progradational geometry of the Torok-Nanushuk depositional sequence, seismic and other data indicate the presence of numerous higher-order depositional sequences, which add complexity to the internal stratigraphy of the succession (Houseknecht and Schenk, 2001).

The Torok-Nanushuk depositional system prograded eastward to an ultimate (farthest basinward) shelf margin east of the Colville River (fig. 2). A subsequent lowstand in relative sea level apparently resulted in at least minor erosion, as suggested by truncated seismic reflections in the upper part of Torok clinoforms of the ultimate slope wedge (east of the Nanushuk Formation pinchout). Although the top of the Nanushuk shelf probably was broadly eroded or at least locally incised by fluvial systems during this lowstand, evidence of erosion is meager in both two-dimensional seismic profiles and outcrops. At least part of the LST that contains the reservoir intervals in the Tarn and Meltwater oil fields likely was deposited during this time (fig. 2).

The Nanushuk shelf subsequently was drowned by a significant rise in relative sea level, resulting in marine flooding that extended hundreds of miles westward into the area of the Chukchi Sea. Widespread deposition of a condensed mudstone facies during this flooding and ensuing maximum transgression resulted in an accumulation of organic-rich shale (Shale Wall facies) in the lower part of the Seabee Formation (Mull and others, 2003). The onset of distant volcanism is indicated by numerous bentonite interbeds in the Shale Wall facies.

Progradational facies of the second major depositional sequence were deposited above the Shale Wall facies. Progradational strata are defined by clinoform seismic reflections in the upper part of the Seabee Formation and by topset seismic reflections in the overlying Tuluvak Formation (fig. 3). West of the ultimate Torok-Nanushuk shelf margin, clinoforms of the Seabee Formation are relatively thin (300–700 ft thick), and they downlap onto and grade basinward into the Shale Wall facies. East of the ultimate Torok-Nanushuk shelf margin, clinoforms of the Seabee Formation thicken significantly (2,000–3,000 ft thick) and are commonly deformed by rotational faults and slumps. The Tuluvak Formation is defined by seismic topset reflections that include evidence of conspicuous growth faulting in an area extending from ~5 mi west of the Torok-Nanushuk ultimate shelf margin eastward to the basinward limits of the Tuluvak Formation (fig. 3). The lower part of the Tuluvak Formation displays tens to hundreds of feet of growth across most of the faults, which become listric with depth and sole into the lower parts of Seabee clinoforms (fig. 3). Although relatively little research has been done on the sedimentology of the Seabee-Tuluvak depositional sequence, Mull and others (2003) inferred that the sequence includes facies of a dysaerobic offshore marine shelf and basin (Shale Wall facies of the Seabee Formation), the marine slope (clinoforms of the Seabee Formation), and shallow marine, deltaic, and nonmarine environments (Tuluvak Formation).

Umiat Mountain

Umiat Mountain is situated on the east flank of the Umiat anticline (fig. 4). A structure map based on well logs and seismic data (fig. 4) illustrates the northward vergence and asymmetry of the anticline at depth. In addition, Mull and others (2004) inferred the presence of a southward-vergent backthrust along the crest of the anticline, on the basis of surface geology and topographic expression. Oil seeps at Umiat Mountain led to delineation of the anticline by surface mapping and seismic surveys, and to subsequent exploration drilling by the U.S. Navy in the 1940s. That exploration program resulted in the discovery of the Umiat oil field, which contains ~70 million

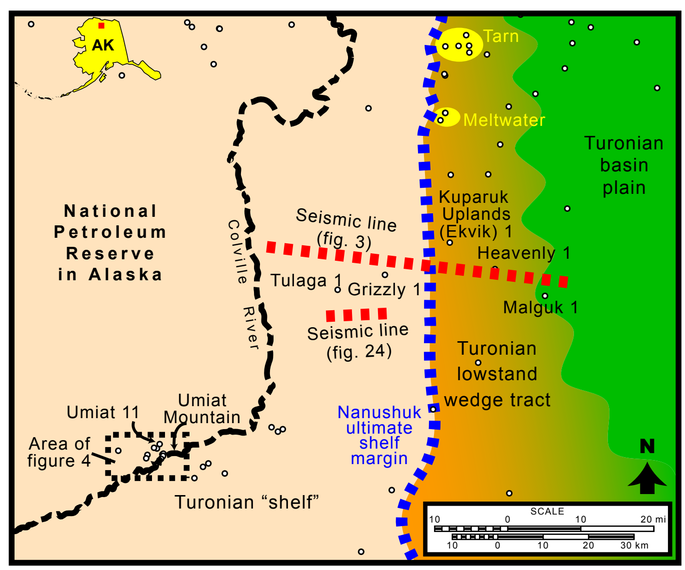

Figure 2. Part of the west-central North Slope, Alaska, showing locations of the Nanushuk ultimate shelf margin, main facies tracts in Turonian strata, the Tarn and Meltwater oil fields, seismic lines illustrated in figures 3 and 23, and area of figure 4. Circles, exploration wells, named if mentioned in text or figures.

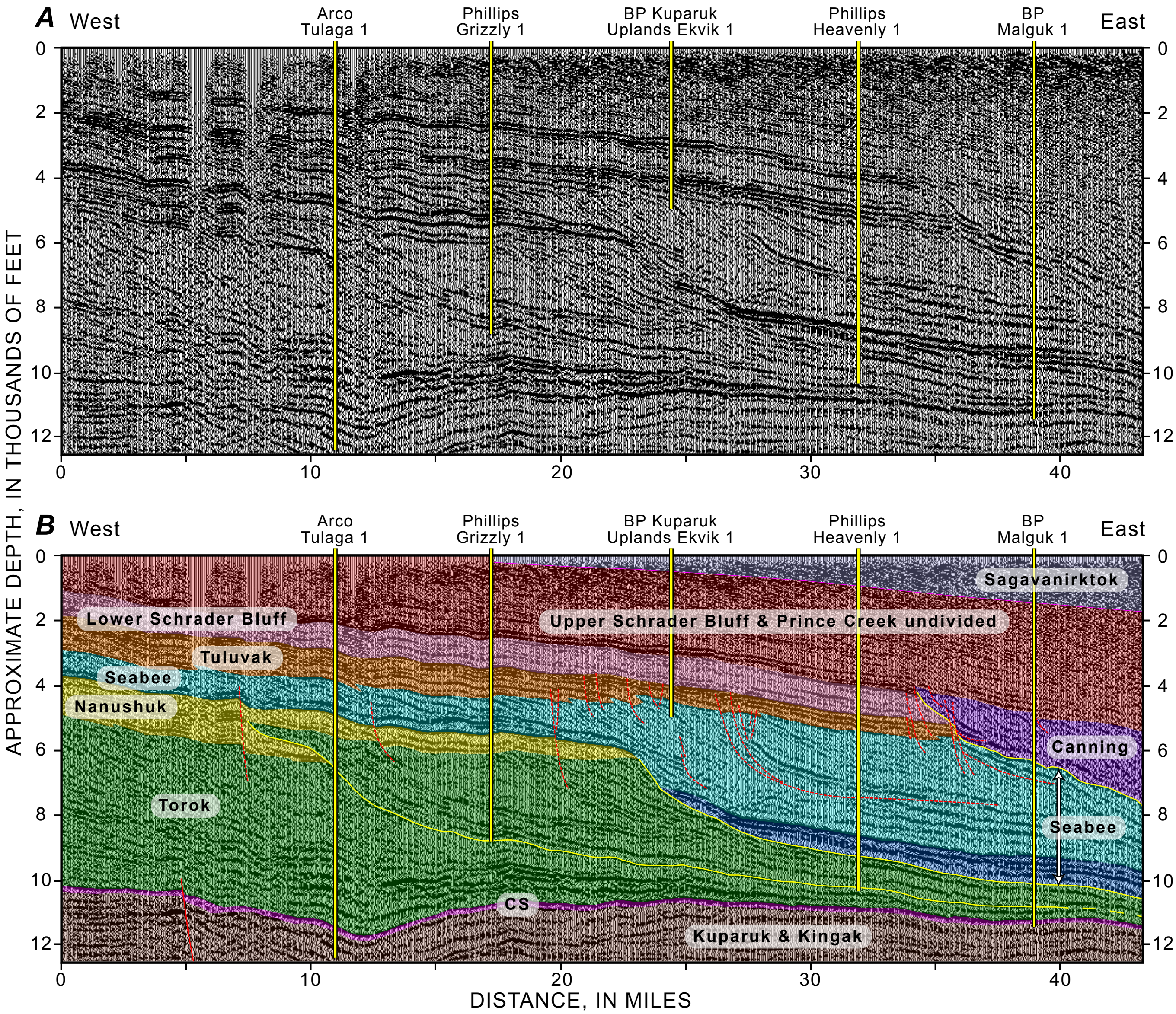

Figure 3. Segment of west-east seismic line across the Nanushuk ultimate shelf margin (fig. 2), illustrating stratal geometry of Torok-Nanushuk and Seabee-Tuluvak depositional sequences. Wells are projected onto seismic section along lines perpendicular to line of section. *A*, Noninterpreted image. *B*, Interpreted image, with colors keyed to labeled formations. Seabee dark blue, lower Seabee basinal-lowstand systems tract; Seabee light blue, rest of formation. Red lines, inferred faults; yellow lines, inferred sequence boundaries. CS, condensed section at based of the Brookian Sequence.

barrels of recoverable oil (Molenaar, 1982) in sandstone of the Nanushuk Formation.

The exposures on Umiat Mountain occur where the Colville River has cut into the east-plunging anticlinal axis (fig. 4). Strata exposed along the river include the uppermost part of the Nanushuk Formation, the middle and upper parts of the Seabee Formation, and the lower part of the Tuluvak Formation (Brosgé and Whittington, 1966; Mull and others, 2003, 2004). The Ninuluk sandstone, the uppermost part of the Nanushuk Formation, is exposed in a low bluff at river level at the west end of the mountain (fig. 4). The Seabee and Tuluvak Formations are exposed on a prominent bluff along the eastern part of the mountain (fig. 4). Relief on this bluff, the top of which is formed by sandstone of the Tuluvak Formation, decreases eastward from ~300 to ~40 ft, following the eastward plunge of the Umiat anticline. The highest, central part of Umiat Mountain (dotted line, fig. 4) is formed by sandstone of the Tuluvak Formation, but most of the underlying slope is covered by bentonitic mud weathering from the Seabee Formation, and virtually no bedrock is exposed. The striking decrease in elevation from the Tuluvak Formation that caps the highest, central part of Umiat Mountain eastward to the Tuluvak Formation at the west end of the prominent bluff correlates with an east-dipping normal fault (dashed line, fig. 4; see fig. 8).

The age of the strata exposed on Umiat Mountain can be inferred from previously published work. Regionally, the uppermost part of the Nanushuk Formation (Ninuluk sandstone) has been dated as Cenomanian, the Seabee Formation has been dated as Cenomanian through Turonian, and the Tuluvak Formation has been dated as mostly Turonian, on the basis of megafaunas, microfaunas, plant fossils, and radiometric dating of bentonites, as summarized by Mull and others (2003). Locally, the Ninuluk sandstone has been dated as Cenomanian, and the Seabee Formation on the Umiat Mountain outcrop and in Umiat wells has been dated as Turonian (Collins, 1958; Brosgé and Whittington, 1966; Mull and others, 2003), on the basis of megafossils (for example, ammonites and bivalves), microfossils (especially foraminifers), and plant fossils.

The exposed section on Umiat Mountain spans the stratigraphic interval within which an influx of volcanic material has been documented regionally. Sandstone of the Nanushuk Formation, including the Ninuluk sandstone at the top of the formation, is typically lithic arenite, with low-grade metamorphic and sedimentary lithic fragments predominant in the lithic component. Bentonite interbeds are absent throughout most of the formation, although a few of them have been documented in the Ninuluk sandstone at other sites. In contrast, the Seabee Formation includes a significant volcanic component throughout its vertical extent. All rock types are commonly tuffaceous, bentonite interbeds are common (Mull and others, 2003), and the sandstone contains abundant volcanic lithic fragments (Fox and others, 1979).

Sedimentology of Strata Exposed on Umiat Mountain

The strata exposed along the Colville River at Umiat Mountain were measured and described in 2001, and a gamma-ray profile of the section was collected in 2003. Spectral measurements were collected with a gamma-ray spectrometer equipped with an internal stabilization source (Cs),

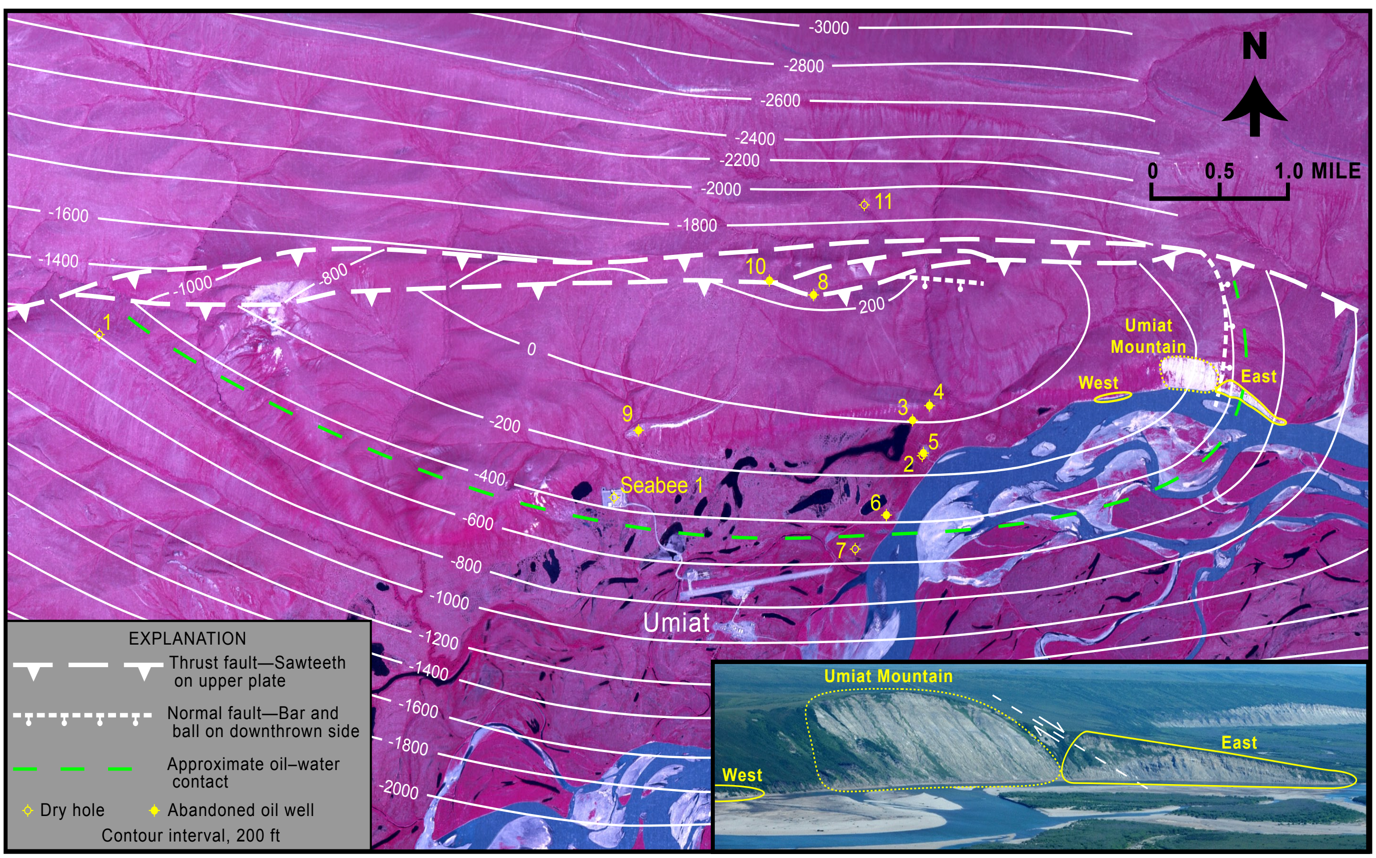

Figure 4. False-color infrared aerial photomosaic of Umiat area, northern Alaska (fig. 2), with superimposed structure-contour map of the former Grandstand Formation (now part of the Nanushuk Formation) defining the Umiat anticline (modified from Brosgé and Whittington, 1966, and Molenaar, 1982). Yellow symbols, Umiat wells (numbered), Seabee No. 1 well, and outcrops along the Colville River cut through Umiat Mountain. Key to exposures: west, Ninuluk sandstone; east, Seabee and Tuluvak Formations (pl. 1). Note location of landing strip at Umiat in lower center. Inset, Umiat Mountain, showing outcrop areas discussed in text. Dashed white line, normal fault. Bluff in distance at upper right is western part of Shivugak Bluff. View northeastward.

and output included estimates of K, U, and Th contents, which were converted to total gamma-ray exposure by using the relation of Grasty and others (1984). The average stratigraphic distance between sample points was 3 ft, and the collection time for each spectrum was 3 minutes. The following sections summarize pertinent observations and provide interpretations of the depositional environments for each unit.

Nanushuk Formation (Ninuluk Sandstone)

Description

A section totaling 40 ft in thickness was measured at the west end of the Colville River cut at Umiat Mountain (pl. 1); the base of the section was covered by river water. Two main units were recognized. The lower unit (A, pl. 1), 18 ft thick, is fine- to medium-grained sandstone. Although the sandstone contains abundant dark-colored lithic grains, it appears to be distinctly more quartzose than is typical of sandstone of the Nanushuk Formation. Porosity is visible in most beds, and the unit is oil stained. The sandstone displays crossbedding throughout. Sets of tabular-planar and tabular-tangential crossbedding (fig. 5) are present in nearly equal proportions, and sets of trough crossbedding are less common. Predominant paleocurrent directions are to the west, as indicated by the dip direction of crossbedding foresets (fig. 5). A few paleocurrent directions are to the east and northeast. Locally, the opposing dip directions of crossbedding foresets appear to define herringbone crossbedding. The trace fossil *Diplocraterion* is present in the uppermost few feet of this unit.

Figure 5. Tabular and trough crossbedding in unit A (pl. 1) of the Ninuluk sandstone (Nanushuk Formation) at Umiat Mountain, northern Alaska (figs. 2, 4). Crossbedding foreset dip directions indicate westward paleocurrents. Apparent westward dip of bedding is inaccurate because sandstone block has broken off main outcrop. View northward.

Figure 6. Upper part of unit B (pl. 1) of the Ninuluk sandstone (Nanushuk Formation) at Umiat Mountain, northern Alaska (figs. 2, 4). Interval displays subtle hummocky cross-stratification.

The upper unit (B, pl. 1), 22 ft thick, is fine-grained sandstone that is locally porous and locally oil stained. A lens of solid hydrocarbon, as much as 0.5 in. thick and extending approximately 5 ft parallel to bedding, is present near the middle of the unit. The lower 8 ft of unit B is fine-grained sandstone that appears massive (no visible sedimentary structures), and no distinct trace fossils were observed. Small-scale swaly cross-stratification is predominant in the middle part of the unit, and small-scale hummocky cross-stratification (1–3-ft-wide sets) is predominate in the upper 10 ft of the unit (fig. 6). Wave ripples also are common in the upper 10 ft of the unit. The top of unit B is covered by bentonitic mud and soil; however, above the 22-ft measured thickness of unit B, the outcrop weathers recessively, and the presence of an abrupt contact with overlying shale or mudstone near that level is inferred.

A gamma-ray profile of the Ninuluk sandstone section is plotted on plate 1. Most of unit A is characterized by low gamma-ray values and a relatively blocky response. The upper part of unit A, continuing upward to the lower part of unit B, is characterized by an upward increase in gamma-ray values. This trend is reversed toward the top of the section, and most of unit B is characterized by an upward decrease in gamma-ray values.

Interpretation

The suite of sedimentary structures throughout unit A (pl. 1) and the presence of *Diplocraterion* near the top of the unit indicate deposition in a shallow-water coastal environment characterized by moderately high energy. The abundance of tabular crossbedding (fig. 5), the predominance of westward-directed paleocurrent indicators (fig. 5) in a regional context of mostly eastward or northeastward deltaic progradation (Molenaar, 1985; Houseknecht and Schenk, 2001), and the local occurrence of possible herringbone crossbedding suggests deposition in an estuary or flood-tidal inlet.

Unit B (pl. 1) is characterized by a vertical gradation from massive sandstone at the base to swaly cross-stratification upward to hummocky cross-stratification (fig. 6) and wave ripples, suggesting deposition on an upward-deepening, wave-influenced shoreface. If the inference of an abrupt contact with an overlying shale or mudstone is correct, then this contact likely represents a flooding surface separating the Ninuluk sandstone below from the basal part of the Seabee Formation above.

Seabee Formation—Footwall of Normal Fault

Description

Above the Ninuluk sandstone, the stratigraphic interval is covered by extensive bentonitic mudslides, and the next bedrock exposure occurs at river level approximately 0.7 mi east of the east end of the Ninuluk exposure (fig. 4). Field relations and correlation of the section to the Umiat No. 11 well log (discussed below) suggest that approximately 600 ft of the lower part of the Seabee Formation is obscured by bentonitic mudslides.

Starting at river level at the west end of the prominent bluff that forms the east flank of Umiat Mountain (fig. 4), a section totaling 125 ft in thickness was measured on the footwall (west) side of the normal fault mentioned previously (fig. 7). Four main units were distinguished. The lowest unit (C, pl. 1), 37 ft thick, is mostly very fine grained, nonporous sandstone. Unit C is generally thin bedded and displays various sedimentary structures. Thin (<3 in. thick) graded beds and thin (<3 in. thick) irregularly stratified beds are common throughout the unit (fig. 8). The graded beds display sharp bases and undulatory tops, and the irregularly stratified beds commonly display a mottled fabric and locally display subtle, discontinuous laminae parallel to bedding surfaces. Beds displaying small-scale hummocky cross-stratification and wave-rippled tops are present 10 ft above the base of the unit and also at the top of the unit. An interval of small-scale swaly cross-stratification is present a few feet below the top of unit C. Distinct examples of the trace fossil *Planolites* are present in the lowermost several feet of the unit.

The overlying unit (D, pl. 1), 48 ft thick, is very fine grained sandstone and siltstone. One 3-ft-thick bed near the base of unit D has a low porosity and is oil stained, whereas the other sandstone and siltstone beds in unit D appear to be nonporous. Graded beds and irregularly stratified beds (fig. 9) are predominant in unit D, but the beds are generally thicker than in the underlying unit C. In the upper half of unit D, pelecy-

Figure 8. Unit C (pl. 1) of sandstone within the Seabee Formation at Umiat Mountain, northern Alaska (figs. 2, 4). Note succession of thin, graded beds (lighter and more resistant) and thin, irregularly stratified beds (darker and more recessive).

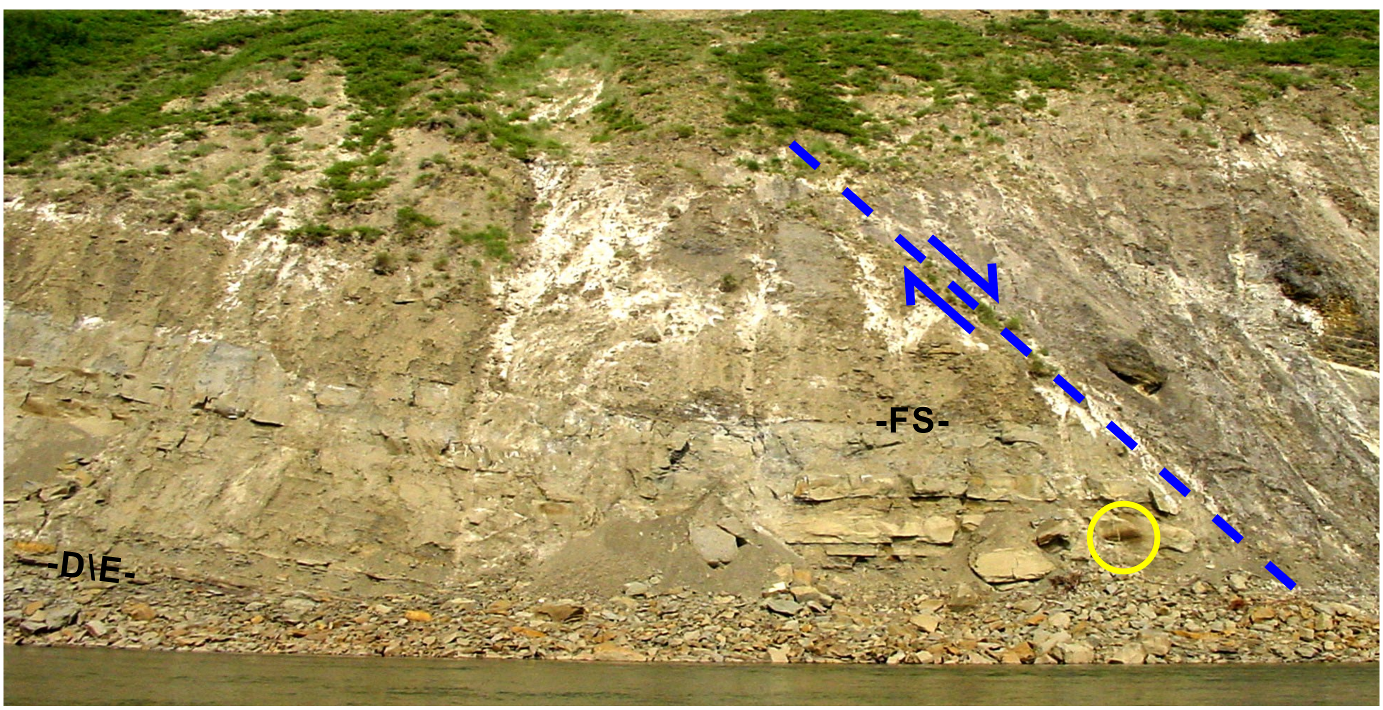

Figure 7. Normal fault (blue dashed line) and upper part of footwall section near west end of outcrop on east flank of Umiat Mountain, northern Alaska (figs. 2, 4). FS, flooding surface at top of unit E; D\E, contact between units D and E. Dark stain inside yellow circle is oil seeping from sandstone in unit E. Vertical extent of exposure is about 50 ft. The Colville River is in foreground. View northward.

Figure 9. Unit D (pl. 1) of sandstone within the Seabee Formation at Umiat Mountain, northern Alaska (figs. 2, 4), showing succession of thin, graded beds (lighter beds at and below hammerhead), thin, irregularly stratified beds (darker beds between graded beds), and one swaly cross-stratified bed (thickest bed, beside hammer handle).

Figure 10. Unit E (pl. 1) of sandstone within the Seabee Formation at Umiat Mountain, northern Alaska (figs. 2, 4), showing succession of irregularly stratified beds (darker and more recessive), graded beds (lighter and more resistant in lower part of photograph), and swaly cross-stratified beds (thickest beds in upper part of photograph).

pod-shell hash is concentrated at the base of many graded beds. The pelecypod shells are mostly whole and randomly oriented (with regard to concave up and concave down); some shells are articulated and open. Planar stratification also is common throughout unit D. Swaly cross-stratification (fig. 9) is locally present but is less common than in the underlying unit C.

Unit E (pl. 1), 35 ft thick, is almost entirely very fine grained to fine-grained sandstone that is porous and heavily oil stained throughout. Oil commonly seeps from freshly exposed surfaces of some beds in the upper third of the unit (fig. 7). Unit E is slightly coarser grained and thicker bedded overall than units C and D, resulting in the appearance from a distance of a more nearly massive, blocky sandstone that is distinctively exposed along the face of the outcrop (fig. 7). The coarsest grained beds in unit E range from 0.7 to 5 ft in thickness and display mostly swaly cross-stratification (figs. 10, 11). The bases of these beds are sharp (fig. 10), and some of the beds contain mud ripup clasts and pelecypod-shell hash at the base, particularly in the lower third of the unit. One block of this facies, displaced from the outcrop face, contains an *Inoceramus* shell, 15 in. across (fig. 12); similar shells probably are scattered through the thicker beds. Wave ripples are present on the upper surfaces of some swaly cross-stratified beds. In the lower half of unit E, the thicker beds are separated by thin (<3 in. thick) graded beds and thin (<3 in. thick), irregularly stratified beds (fig. 10), similar to those that are predominant in unit C. The upper 10 ft of unit E is mostly a composite of relatively thin (3–8 in. thick) graded beds with swaly cross-stratified interbeds.

At the top of unit E is an abrupt contact with the overlying shale of unit F (fig. 7). Only about 5 ft of this shale is accessible on the footwall of the normal fault (fig. 7). The shale is dark gray (organic rich?) and contains a few scattered ironstone concretionary layers.

A gamma-ray profile was collected from the middle of unit D upward through unit F (pl. 1). The sandstone beds in units D and E display a moderately blocky response, with gamma-ray values distinctly higher than those in the Ninuluk sandstone. The siltstone beds and thin beds of irregularly stratified sand-

Figure 11. Swaly cross-stratification in upper half of unit E (pl. 1) of sandstone within the Seabee Formation at Umiat Mountain, northern Alaska (figs. 2, 4).

Figure 12. Large *Inoceramus* shell in talus block from upper half of unit E (pl. 1) of sandstone of the Seabee Formation at Umiat Mountain, northern Alaska (figs. 2, 4). Pen is 5 in long.

stone generally have higher gamma-ray values than the slightly coarser grained, swaly and hummocky cross-stratified sandstone beds (pl. 1). The gamma-ray values of the shale bed near the base of unit F are only slightly higher than those of the underlying sandstone beds.

Interpretation

The suite of sedimentary structures and the local presence of whole, but transported, pelecypod shells in units C through E (pl. 1) suggest deposition on a wave-influenced shoreface. Unit C, which displays mostly thin graded beds and irregularly stratified beds, probably was deposited in a lower shoreface environment. The graded beds may represent storm events, during which sand eroded from the shoreface was transported offshore and deposited as “event beds” below fairweather wave base. The irregularly stratified beds likely represent fairweather conditions, during which the substrate was mottled by burrowing organisms. The local presence of *Planolites* is consistent with this interpretation. At the top of unit C, swaly and hummocky cross-stratification capped by wave ripples may indicate shallower, higher energy conditions near fairweather wave base.

Unit D displays a range of sedimentary structures similar to that in unit C but is generally finer grained and contains numerous concentrations of transported pelecypod shells at the base of beds. These characteristics probably represent deposition in a lower-shoreface environment, possibly in somewhat deeper water than that proposed for unit C. Deposition evidently occurred in proximity to pelecypod-shell concentrations that were eroded and transported a relatively short distance before deposition.

Unit E, somewhat coarser grained and thicker bedded than the underlying units, probably was deposited in a shallower and (or) higher-energy shoreface environment, possibly near the transition from lower to middle shoreface. The presence of graded beds and irregularly stratified beds suggest a lower-shoreface setting, similar to that proposed for unit C. However, the thicker beds that display swaly cross-stratification and wave ripples likely represent deposition in an environment of higher energy and probably shallower water.

The abrupt contact between units E and F is interpreted as a flooding surface (fig. 7). The organic-rich shale of unit F probably was deposited in a dysaerobic, offshore environment. This shale is interpreted as a condensed section that probably is a tongue of the Shale Wall facies of the Seabee Formation.

Seabee and Tuluvak Formations—Hanging Wall of Normal Fault

Description

Above the normal fault, an additional 245 ft of section was measured (fig. 13). This section, starting at the normal fault (125 ft, pl. 1), extends upward through the lowest prominent sandstone bench of the Tuluvak Formation (370 ft, pl. 1) but does not extend through the sandstone bluff at the top of Umiat Mountain (fig. 13).

Three main units were distinguished in this additional section. The lowest unit (G, pl. 1) is dark-gray to black shale, typical of the Shale Wall facies of the Seabee Formation (fig. 14). Although its measured thickness is 100 ft, this unit extends below river level on the east side (hanging wall) of the normal fault, and so a true thickness cannot be measured in outcrop. The shale is fissile with paper-thin laminae and contains abundant *Inoceramus* prisms concentrated on bedding planes (fig. 15). The dark color suggests a high organic content, and organic-geochemical analysis of two samples

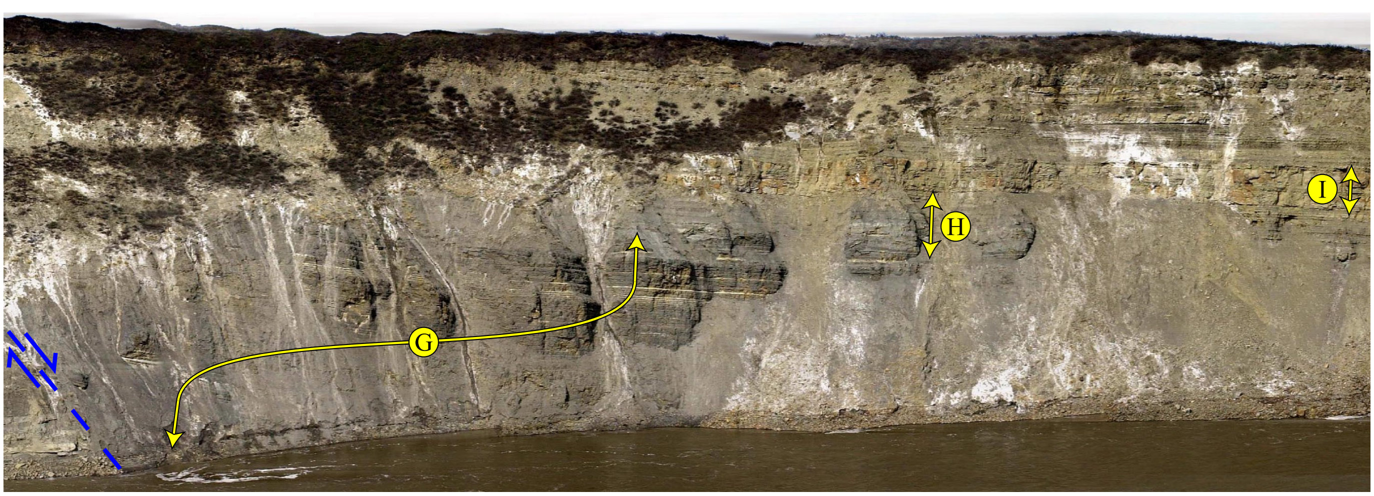

Figure 13. Photomosaic of normal fault (blue dashed line) and hanging-wall section on east flank of Umiat Mountain, northern Alaska (figs. 2, 4), showing outcrop intervals (pl. 1): unit G, upper part of the Seabee Formation; unit H, including gradational contact between the Seabee and Tuluvak Formations; unit I, lower part of the Tuluvak Formation. Note additional mudstone and sandstone units in the Tuluvak Formation at top of bluff (omitted from measured section). Bluff is about 300 ft high. The Colville River is in foreground. View northward.

(see pl. 1 for locations) from this unit yielded total organic-carbon contents of 2.88 and 4.99 weight percent and hydrogen indexes of 347 and 412. The mean vitrinite reflectances of these samples are 0.64 and 0.58 percent. Bentonite beds, ranging from a fraction of an inch to about 8 in. in thickness, are common throughout the unit (fig. 14). Calcareous concretions, ranging from 2 to 18 in. across, also are common (fig. 14). Weathering blocks of this facies exhibit dark-gray, papery sheets of shale covered by white-weathering *Inoceramus* shells, with yellow, popcorn-weathering mud at bentonite interbeds.

The overlying unit (H, pl. 1), 48 ft thick, includes silty shale, mudstone, and sandstone. The contact between units G and H is gradational. The lower 28 ft of unit H grades upward from dark-gray, slightly silty shale to medium-gray mudstone. Organic-geochemical analysis of one sample (see pl. 1 for location) from this unit yielded a total organic-carbon content of 1.80 weight percent and a hydrogen index of 31. The mean vitrinite reflectance of this sample is 0.81 percent. A few thin (<6 in. thick) interbeds of very fine grained sandstone occur throughout this interval (fig. 16). The upper 20 ft of unit H is sandstone (fig. 17) that generally coarsens upward from very fine to fine grained. The lower 10 ft of sandstone consists mostly of thin (<1 in. thick) graded beds that commonly contain abundant fragments of plant material on the upper bedding surfaces; the upper 10 ft of the sandstone includes similar graded beds and thicker (0.5–3 ft thick), massive and graded beds. Macerated plant fragments are common throughout, and subtle convoluted laminae are locally present.

Figure 14. Typical outcrop of unit G (pl. 1) of the Shale Wall facies of the Seabee Formation at Umiat Mountain, northern Alaska (figs. 2, 4). Unit consists mostly of dark-gray, fissile, organic-rich shale. Thin, light-colored interbeds are bentonite, and round to discoid, light-colored blobs are calcareous concretions. Hammer is 1 ft long.

Figure 15. *Inoceramus* shells from unit G (pl. 1) of the Seabee Formation at Umiat Mountain, northern Alaska (figs. 2, 4). Shells are concentrated on bedding plane (right) and collected on a sample bag. Pen is 5 in. long. Photograph by Gil Mull.

The top unit (I, pl. 1), 52 ft thick, is a generally coarsening upward succession that includes mudstone and sandstone. A sharp contact separates sandstone at the top of unit H from mudstone at the base of unit I. The lower 11 ft of unit I is mostly medium-gray silty mudstone, with thin interbeds of silty, very fine grained sandstone. The thin sandstone interbeds display current ripples. The upper 41 ft of unit I is mostly sandstone, with thin interbeds of mudstone and bentonite. The lower 18 ft of the sandstone consists of thin (<6 in. thick) graded beds (fig. 18) of very fine grained sandstone and a few thicker (0.5–2 ft) beds of fine-grained, massive sandstone. Subtle crossbedding is visible in some beds (fig. 18). Macerated plant fragments are common on bedding planes (fig. 19). The upper 23 ft of sandstone consists of thick (max 14 ft), massive sandstone beds (fig. 20) that contain mud ripup clasts (fig. 21) and macerated plant fragments. Subtle convoluted laminae are locally visible. Traversing eastward in a downplunge direction along the bluff formed by this sandstone, the thick, massive sandstone beds grade laterally into thin graded and rippled sandstone beds, which predominate in the upper part of unit I at river level at the easternmost end of Umiat Mountain (fig. 4).

Above unit I, another succession that coarsens upward from mudstone to sandstone is visible from a distance near the top of the east bluff of Umiat Mountain (fig. 4). The lower part of this section was measured (top, pl. 1), but most of the bluff was inaccessible for measuring the entire succession.

A gamma-ray profile was collected through units G, H, and I (pl. 1). The gamma-ray values of unit G are generally moderate and just slightly higher than those of the underlying sandstone of units C, D, and E (pl. 1). A few very high gamma-ray values correlate with relatively thick bentonite beds. The gamma-ray responses of units H and I vary and are generally higher than those of unit G (pl. 1). Overall, the gamma-ray profile through the entire section measured on the hanging-wall side of the normal fault displays a generally increasing-upward trend from the Seabee Formation into the Tuluvak Formation, except for the very high gamma-ray values that correlate with bentonite beds (pl. 1).

Interpretation

The dark, organic-rich, fissile shale of unit G (pl. 1) was deposited in a dysaerobic, distal offshore setting characterized by occasional volcanic-ash falls. Evidence collected in the Umiat Mountain outcrop is insufficient to determine whether unit G represents a single depositional sequence or a con-

Figure 16. Medium-gray silty shale with thin bentonite interbeds (yellow-orange weathering) and one bed of very fine grained sandstone in lower half of unit H (pl. 1) of the Seabee Formation at Umiat Mountain, northern Alaska (figs. 2, 4). Hammer is 1 ft long.

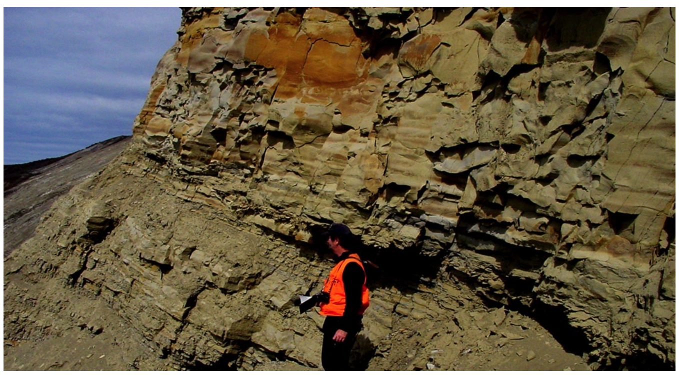

Figure 17. Contact (253-ft level of measured section, pl. 1) between mostly shale and mudstone of the Seabee Formation below and mostly sandstone of the Tuluvak Formation above near middle of unit H at Umiat Mountain, northern Alaska (figs. 2, 4). Strata below geologist's head are upper part of interval, coarsening upward from silty shale to mudstone with sandstone interbeds; strata above geologist's head are lower part of interval consisting mostly of sandstone.

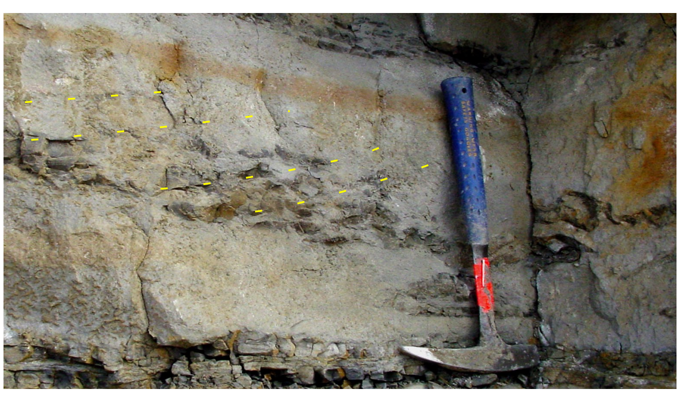

Figure 18. Sandstone beds near middle of unit I (pl. 1) of the Tuluvak Formation at Umiat Mountain, northern Alaska (figs. 2, 4). Beds are graded and contain mud ripup clasts. Note subtle crossbedding (yellow dashed lines) in upper bed. Hammer is 1 ft long.

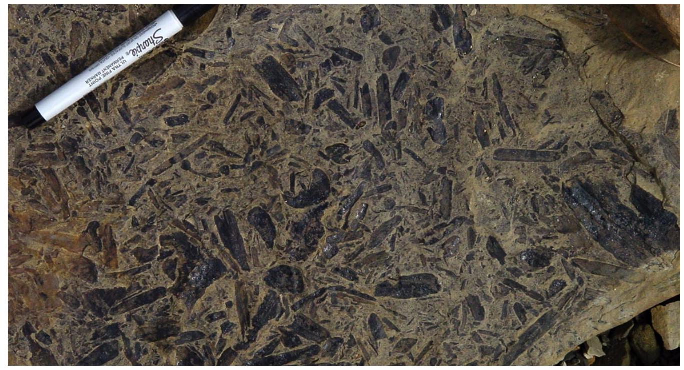

Figure 19. Macerated plant fragments on bedding plane of sandstone in unit I (pl. 1) of the Tuluvak Formation at Umiat Mountain, northern Alaska (figs. 2, 4). Pen is 5 in. long

Figure 20. Massive sandstone bed interbedded with thinner, graded sandstone beds in upper part of unit I (pl. 1) of the Tuluvak Formation near the east end of bluff on east flank of Umiat Mountain, northern Alaska (figs. 2, 4). Massive sandstone beds here are thinner and finer grained than farther west along bluff.

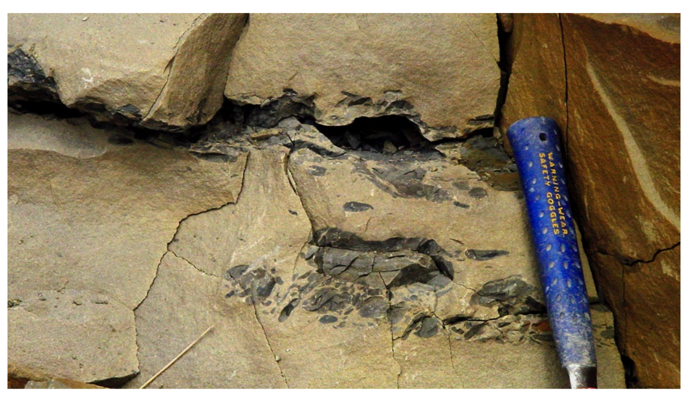

Figure 21. Mud ripup clasts in sandstone beds in upper half of unit I (pl. 1) of the Tuluvak Formation at Umiat Mountain, northern Alaska (figs. 2, 4). Hammer handle is 8 in. long.

densed section that includes the distal facies associated with multiple sequences deposited in more proximal parts of the depositional system.

Unit H (pl. 1) is interpreted as the deposits of a prograding delta. At the base of this unit, the upward gradation from silty shale to mudstone with interbedded sandstone beds probably represents deposition on the muddy slope of a prodelta. The overlying sandstone beds, which subtly coarsen upward and mostly display grading, are interpreted as delta-front deposits. The abrupt top of the sandstone in unit H may represent abandonment of the delta lobe before more proximal facies were deposited at this site.

Unit I (pl. 1) also is interpreted as the deposits of a prograding delta. The mudstone with interbedded sandstone at the base of unit I may represent prodelta deposits on an accommodation platform built by the underlying deltaic deposits of unit H. The overlying sandstone was likely deposited in delta-front (thin graded beds) and either channel-mouth-bar or distributary-channel (thicker massive beds) environments. The lateral variation observed in grain size, bed thickness, and sedimentary structures in traversing from the west to the east end of the bluff on the east flank of Umiat Mountain (fig. 4) suggests deposition near a prograding-channel or channel-mouth-bar system. The facies on the west end of the bluff probably were deposited in a relatively axial position to a channel-mouth bar, whereas those on the east end of the bluff were deposited in a relatively lateral position.

On the basis of limited observations, the uppermost sandstone bluff on the east flank of Umiat Mountain (fig. 4) appears to be a deltaic succession similar to units H and I (pl. 1). Additional interpretations would require more detailed examination of that part of the section.

Surface-Subsurface Correlations

Correlation with the Umiat No. 11 Well

One goal of this study was to correlate the outcrop section with the wireline log from the Umiat No. 11 well (fig. 22). This well, which was drilled on the north flank of the anticline in the footwall of the inferred northward-vergent thrust system (fig. 4), is the only well on the Umiat anticline with a complete wireline log through the stratigraphic section of interest (Collins, 1958).

The outcrop section of the Ninuluk sandstone is correlated with the uppermost sandstone of the Nanushuk Formation in the Umiat No. 11 well (fig. 22). The outcrop gamma-ray profile and the spontaneous-potential (SP) log from the well match reasonably well across the depth interval of the upper part of the Ninuluk sandstone (fig. 22), suggesting that the Nanushuk-Seabee contact just above the Ninuluk measured section is interpreted correctly as a flooding surface. The very low gamma-ray response of the Ninuluk sandstone is attributable to its generally clean, well-winnowed texture and to the absence of volcanic lithic grains and matrix, as documented by Fox and others (1979).

The measured outcrop units C through E (pl. 1) are correlated with the upper part of a sandstone succession that occurs in the middle of the Seabee Formation between 1,315- and 1,480-ft depth in the Umiat No. 11 well (fig. 22). This correlation is based primarily on the estimated thickness of the stratigraphic interval covered by bentonitic mudslides and the overall lithologic succession described on Umiat Mountain. This succession is the only interval comprising predominantly sandstone near the middle of the Seabee Formation in the Umiat No. 11 well, and the top of this interval is a sharp contact between sandstone and an overlying condensed shale facies (upper “paper shale” of Whittington, 1956). Together, these characteristics from the well log uniquely match the outcrop section. The outcrop gamma-ray profile through this interval only moderately correlates with rock types described on the outcrop (pl. 1) and provides only a fair match with the SP log through the inferred correlative succession in the Umiat No. 11 well (fig. 22). This result is attributable to the high volcanic-lithic content of the sandstone, as documented by Fox and others (1979). This inferred correlation differs from that suggested by Brosgé and Whittington (1966), who correlated the interval between 1,315- and 1,480-ft depth in the Umiat No. 11 well with the sandstone forming the bluff at the top of Umiat Mountain.

The measured outcrop units G through I (pl. 1) are correlated with the interval between 680- and 920-ft depth in the Umiat No. 11 well (fig. 22), primarily on the basis of correlating the coarsening-upward succession described on Umiat Mountain (units H, I) with the lowermost occurrence of a distinct coarsening-upward log response at the top of the Seabee Formation in the Umiat No. 11 well (fig. 22). This outcrop interval is interpreted as the gradational contact between the Seabee and Tuluvak Formations, an interpretation consistent with that by Mull and others (2003). The outcrop gamma-ray profile through this interval poorly matches the rock types described on the outcrop (pl. 1) and similarly provides a poor match to the SP log from the Umiat No. 11 well. In fact, the outcrop gamma-ray profile generally displays the opposite trend to that expected. (Gamma-ray values generally increase upward through a section that grades from organic-rich shale, through silty shale and mudstone, to sandstone.) This poor correlation is attributable to the volcanic-rock content of the entire section, especially to the volcanic components in the sandstone (Fox and others, 1979). A similar absence of correlation between gamma-ray response and lithology is observed in the Tarn oil field, where gamma-ray profiles in the main reservoir interval cannot be used as accurate indicators of sandstone, which contains volcanic components (Helmold and others, 2001) in abundances similar to those documented in sandstone of the Seabee and Tuluvak Formations in the Umiat No. 11 well (Fox and others, 1979). This conclusion is supported by correlation of the highest gamma-ray values in the Umiat Mountain outcrop section with bentonite beds (pl. 1).

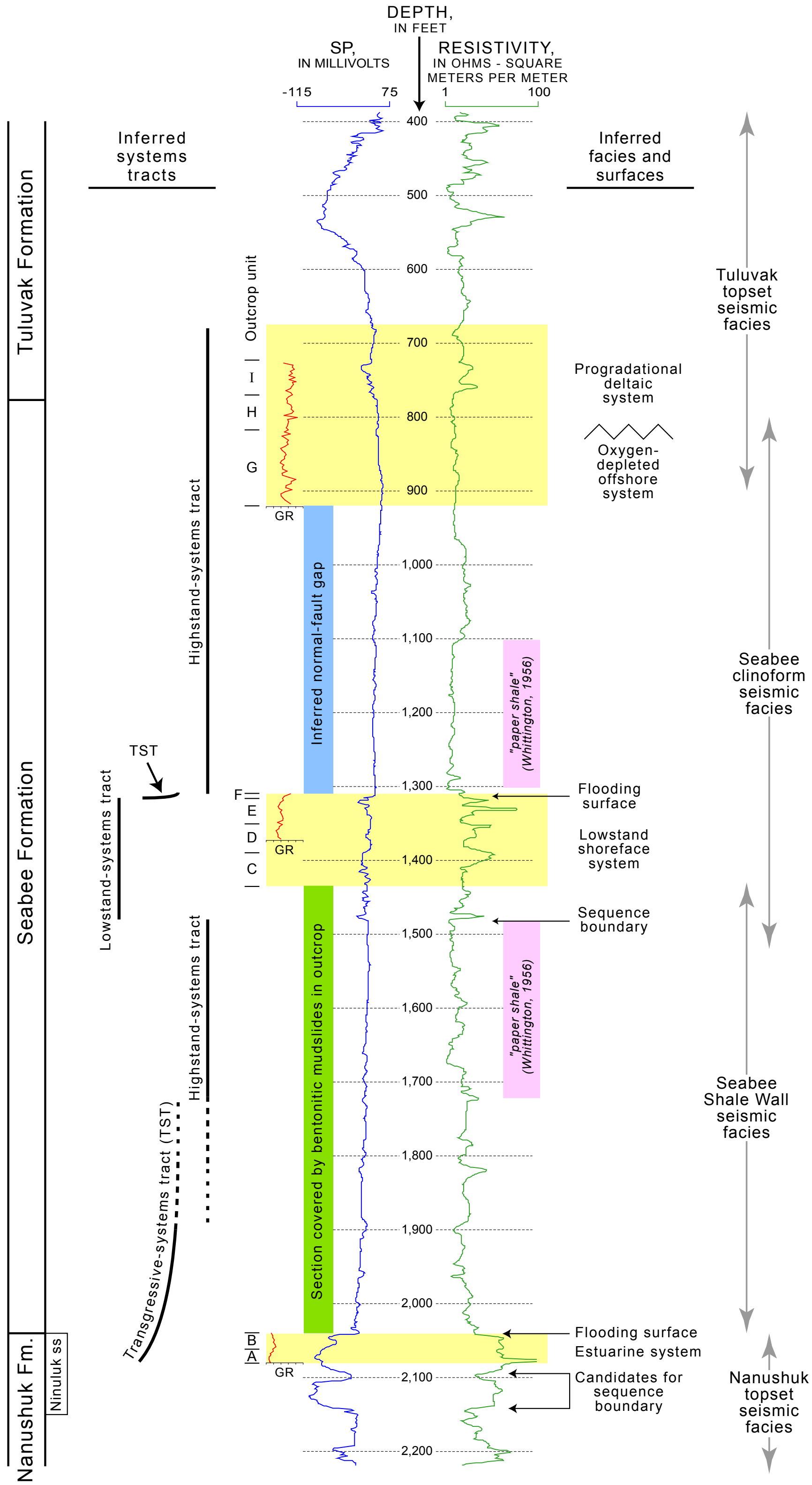

Figure 22. Wireline log from the Umiat No. 11 well, gamma-ray profiles collected from Umiat Mountain outcrop section, and summary of interpretations (see figs. 2 and 4 for locations). Intervals highlighted in yellow are inferred correlations between outcrop and well log. Curves: blue, spontaneous potential (SP); green, resistivity; red, outcrop gamma-ray (GR) profile. TST, transgressive-systems tract.

Sequence Stratigraphy

An interpretation of the sequence stratigraphy of the Umiat Mountain outcrop section and of the correlative succession in the Umiat No. 11 well is summarized in figure 22. The succession that includes the Ninuluk sandstone in outcrop (units A, B, pl. 1), the flooding surface at the top of the Ninuluk sandstone, and the lower part of the overlying Seabee Formation is interpreted as a transgressive-systems tract (TST, fig. 22). The lowest part of this succession (unit A) is interpreted as estuarine facies, suggesting deposition under the predominant influence of tidal processes in an incised accommodation space. Logically, the incision (candidate depths of sequence boundary, fig. 22) would have occurred during a lowstand, possibly at the culmination of progradation of the Torok-Nanushuk sequence, and the estuarine facies that fill the incision would represent initial phases of a subsequent transgression. The facies in unit A are inferred to have been deposited as rising base level permitted aggradation of estuarine beds. The rest of the succession (unit B and above) displays the overall characteristics of upward-deepening depositional facies, consistent with continued transgression.

The overlying succession of shale, which is covered by bentonitic mudslides in outcrop and part of which was described in the Umiat No. 11 well as “paper shale” (Whittington, 1956), is interpreted as a highstand-systems tract (HST, fig. 22). The thick, organic-rich shale is interpreted to have been deposited in a dysaerobic, distal offshore setting while relative sea level was high. As implied by the dashed and dotted parts of the TST and HST lines in figure 22, the contact between the TST and HST is gradational.

The sharp contact at the base of the sandstone at 1,480-ft depth in the Umiat No. 11 well (fig. 22) is interpreted as a sequence-bounding unconformity, and the overlying sandstone succession, the upper 120 ft of which is inferred to be exposed in the Umiat Mountain outcrop, is interpreted as an LST. The sedimentary structures and fossil content of the outcrop section suggest deposition in a wave-dominated shoreface system, spatially removed from any obvious influence of deltaic influx. Within this context, the sharp contact at the base of the sandstone in the Umiat No. 11 well is interpreted as a sequence boundary between distal offshore facies (below the boundary) and shoreface deposits (above the boundary). The multistoried SP log profile in the Umiat No. 11 well and the contrasting depositional units identified in outcrop suggest the presence of multiple, higher-order depositional sequences (that is, parasequences) within the LST.

The flooding surface at the top of the LST and the abrupt gradation into overlying organic-rich shale suggest the presence of a thin TST (fig. 22). The thick organic-rich shale and the overlying succession that coarsens upward into deltaic sandstone are together interpreted as an HST (fig. 22). The organic-rich shale, which was deposited in a dysaerobic, distal offshore setting, basically represents a return to the conditions that prevailed before lowstand shoreface sedimentation. The coarsening-upward deltaic successions at the top of the section are interpreted as the initial progradations of highstand deltaic systems into the Umiat area (fig. 4).

Seismic Analog

Seismic data in the vicinity of Umiat Mountain (fig. 2) display generally poor resolution within the stratigraphic interval of interest, probably because of the shallow depth of this interval and the presence of permafrost across the area. Nevertheless, local seismic data reveal that the lower half of the study interval is characterized by bed-parallel, high-amplitude reflections and the upper half of the study interval by clinoforms that downlap basinward and toplap landward into topset reflections. A candidate analog seismic profile that clearly displays the reflection characteristics of the study interval is shown in figure 23. This seismic profile is located approximately 30 mi northeast of the Umiat Mountain outcrop section and the Umiat No. 11 well (fig. 2). The stratigraphic intervals illustrated in figure 23 are constrained by correlation with synthetic seismograms from nearby wells (especially the Tulaga No. 1 well, fig. 2).

The upper part of the Nanushuk Formation is characterized by moderate- to high-amplitude, parallel reflections (red area, fig. 23). The lower part of the Seabee Formation (dark-blue area, fig. 23) is characterized by high-amplitude to very high amplitude, parallel reflections in which the troughs (negative amplitudes) appear to be slightly thicker than in the underlying Nanushuk Formation. The upper part of the Seabee Formation (light-blue area, fig. 23) displays clinoforms that downlap onto the lower part of the Seabee Formation and toplap the basal part of the Tuluvak Formation (orange area, fig. 23). The Tuluvak Formation generally displays parallel reflections defined by varyingly spaced, moderate- to high-amplitude reflections (orange area, fig. 23).

The seismic characteristics of the upper part of the Nanushuk Formation and the Seabee Formation are consistent with the facies and sequence-stratigraphic interpretations presented earlier, except that the Seabee clinoform seismic facies is much thicker than would be expected, considering the modest thickness of the lowermost coarsening-upward parasequence at the Seabee-Tuluvak gradational contact and the great thickness of dark-gray, organic-rich shale in the upper part of the Seabee Formation (pl. 1; fig. 22). In other words, the extent of the dark-gray, organic-rich shale—from the top of the lowstand shoreface sandstone upward to within 50 ft of the deltaic facies (on the Umiat Mountain outcrop, pl. 1, and in the Umiat No. 11 well, fig. 22) that probably display topset seismic-reflection characteristics—suggests that the clinoforms in the upper part of the Seabee Formation include significant proportions of organic-rich shale (fig. 22). This observation implies that the dysaerobic conditions in which the organic-rich shale was deposited extended well up onto the prodelta slope during deposition of the upper part of the Seabee Formation.

The interval of clinoforms in the upper part of the Seabee Formation is interpreted to be a composite of higher-order

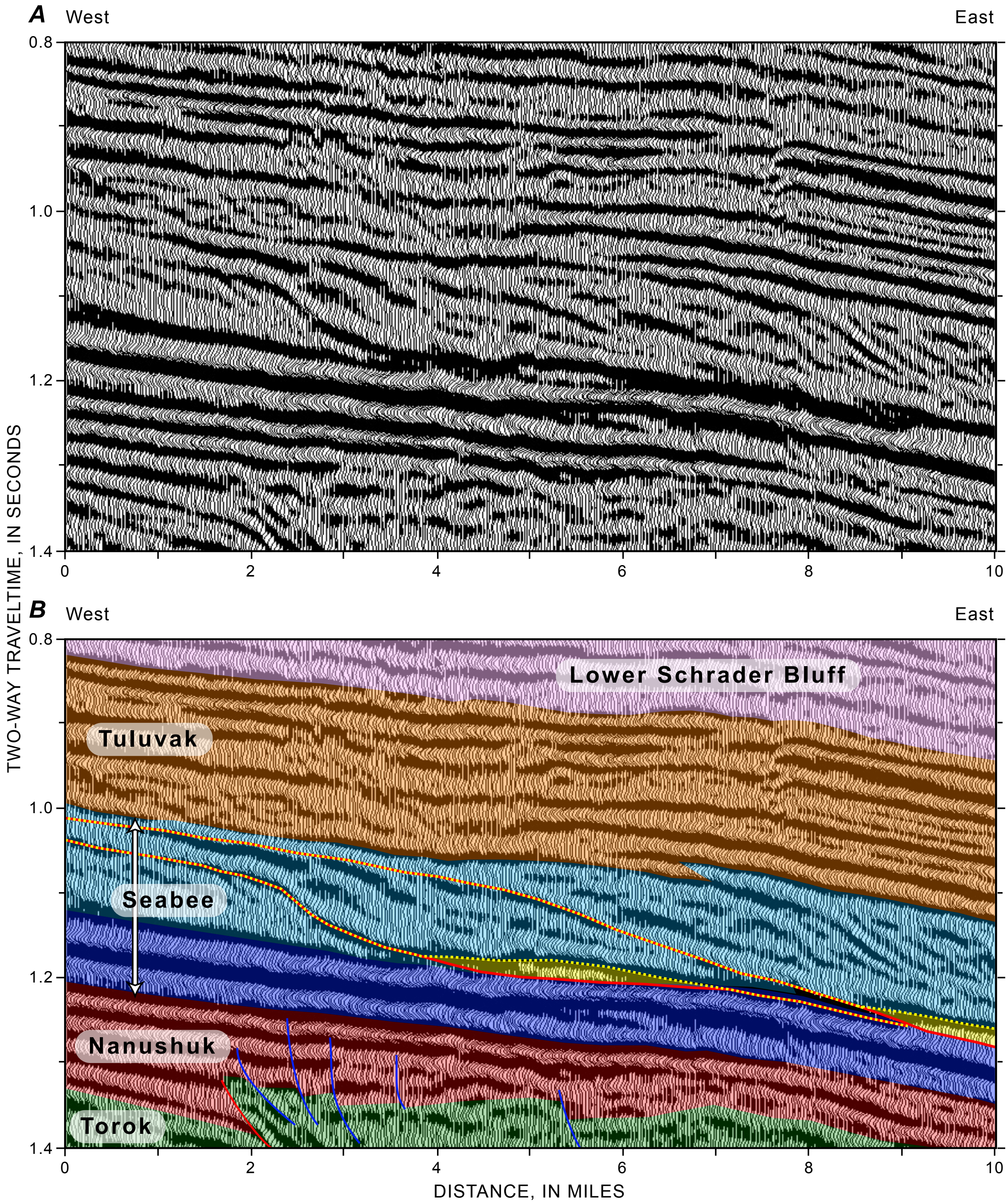

Figure 23. Segment of west-east seismic line west of Cenomanian-Turonian paleoshelf margin (see fig. 2 for location), illustrating stratal geometry of the Nanushuk, Seabee, and Tuluvak Formations (pl. 1). *A*, Noninterpreted image. *B*, Interpreted image, with colors keyed to labeled formations. Within the Seabee Formation, darker blue strata are lower organic-rich shale (Shale Wall facies), yellow strata are inferred sandstone-prone lowstand-systems tract, and lighter blue strata are clinoform seismic facies consisting of organic-rich shale in lower and distal parts and coarsening-upward prodelta facies in upper and proximal parts. In the Seabee Formation, red lines are inferred higher-order-sequence boundaries, and yellow dotted lines are inferred flooding surfaces. In the Torok-Nanushuk sequence, blue lines are growth faults, and red line is sequence boundary.

depositional sequences (fig. 23), on the basis of the presence of slug-shaped packages of reflections that display subtle contrasts in amplitude, dip-angle, and lapout geometries. The surfaces that separate these contrasting packages of reflections are interpreted as higher-order-sequence boundaries (fig. 23). At the places where the inferred sequence boundaries downlap onto parallel reflections of the lower part of the Seabee Formation, the lower parts of some of the higher-order sequences display reflections that define lenticular, convex-upward stratal geometries (yellow areas, fig. 23), which are interpreted as sandstone-prone LSTs that may be analogs for the lowstand shoreface deposits documented in the middle of the Seabee Formation on the Umiat Mountain outcrop and in the Umiat No. 11 well. As interpreted, these lowstand deposits rest on a higher-order-sequence boundary and are capped by a flooding surface. In both downdip (basinward) and updip (landward) directions, the lowstand deposits pinch out, and the flooding surface rests directly on the sequence boundary (fig. 23). In those areas where LST deposits are absent, sequence boundaries may be difficult or impossible to recognize because the facies above and below are similar.

Regional Implications

Analysis of regional seismic data suggests that the entire thickness of the Seabee Formation deposited west of the Cenomanian-Turonian shelf margin correlates with only the lower quarter to third of the formation east of that shelf margin (fig. 3). Only limited information is available, however, regarding the age of the “basinal” Seabee Formation (that part of the formation deposited east of the shelf margin). The age of the reservoir interval in the Tarn oil field (fig. 2) has been reported as Cenomanian (Morris and others, 2000, 2002; Helmold and others, 2001), and the age of the reservoir interval in both the Tarn and Meltwater oil fields has been reported as Cenomanian through Turonian in testimony submitted to the State of Alaska by the field operator (Alaska Oil and Gas Conservation Commission, 1998, 2001). The Tarn reservoir interval includes multiple sandstone “complexes” that display contrasting architectures interpreted to represent temporally distinct “slope-apron systems” fed by incised slope gullies (Morris and others, 2000, 2002; Hastings and others, 2001). On the basis of this meager evidence, at least part of the stratigraphic interval studied on Umiat Mountain may correlate with part of the basinal LST in which the Tarn and Meltwater reservoirs occur (fig. 3). The abundance of volcanic detritus in the Tarn and Meltwater reservoir sandstone (Alaska Oil and Gas Conservation Commission, 2001; Helmold and others, 2001) supports the conclusion that the basinal LST is at least younger than the Ninuluk sandstone (uppermost part of the Nanushuk Formation), which contains little or no volcanic detritus.

The sequence-stratigraphic interpretation of the Umiat Mountain section may influence the inferred origin of the prospective basinal LST, which includes the Tarn and Meltwater reservoir intervals. The sequence-stratigraphic interpretation suggests that nearly the entire Seabee Formation, the interval from the flooding surface at the top of the Ninuluk sandstone to the base of the coarsening-upward deltaic succession at the base of the Tuluvak Formation, comprises thick intervals of organic-rich shale (deposited during transgressions and highstands) separated by relatively thin, sandstone-prone LSTs or by merged sequence boundaries/flooding surfaces. A basinal section coeval with the Umiat Mountain section similarly might be expected to comprise a predominantly organic-rich shale succession punctuated by sandstone-prone lowstand deposits.

The Umiat Mountain section also may provide insights regarding the depositional processes by which sand bypassed the shelf to accumulate as basinal turbidite deposits, such as the Tarn and Meltwater reservoirs. The Umiat Mountain LST is interpreted to have been deposited on a wave-dominated shoreface, suggesting that transport of sand to the shelf margin by wave action (possibly during storm events) may account for sand bypass to deeper-water environments. Phillips and others (1990) inferred that, in addition to shoreface deposits, Seabee lowstand deposits in the Umiat area (fig. 4) include fluvial and coastal-plain facies, suggesting additional processes by which lowstand-shelf bypass may have occurred.

In addition to regional implications regarding coeval basinal sedimentation, the Umiat Mountain section may indicate the potential for small stratigraphic traps along a broad north-south fairway west of the paleoshelf margin. The presence of apparently lenticular, lowstand shoreface sandstone in direct contact both below and above with organic-rich shale, which has seal potential, suggests a favorable stratigraphic-trap geometry. The organic-rich shale also may have significant source-rock potential in deeper parts of the basin where thermal maturity is higher.

Conclusions

Exposures of Cretaceous strata along the Colville River on the east flank of Umiat Mountain, north-central Alaska, include the Ninuluk sandstone of the Nanushuk Formation, the Seabee Formation, and the lower part of the Tuluvak Formation. The Ninuluk sandstone was deposited in estuarine and successively deepening shoreface environments. An abrupt contact between the Ninuluk sandstone and overlying shale of the Seabee Formation is inferred to represent a flooding surface. Together, the exposed Ninuluk sandstone and lower part of the Seabee Formation are interpreted as a TST.

Above the Ninuluk sandstone, more than 600 ft of the lower part of the Seabee Formation is covered by bentonitic mudslides. Correlation to the Umiat No. 11 well (fig. 22) indicates that the covered interval is mostly organic-rich shale, interpreted as an HST that may represent a distal composite of multiple depositional sequences.

A succession of sandstone beds exposed in the middle of the Seabee Formation was deposited in a wave-dominated shoreface environment. A sequence boundary is inferred at the base of this succession, and a flooding surface is exposed at the top of this succession, which is interpreted as an LST. A normal fault, representing a gap of approximately 400 ft of section, occurs a short distance above the shoreface sandstone in the middle of the Seabee Formation. This fault-gap section in outcrop correlates to mostly organic-rich shale in the Umiat No. 11 well. Above the normal fault, the outcrop section includes an additional 100 ft of dark-gray, organic-rich shale. This entire shale section was deposited in a dysaerobic offshore environment and is interpreted as an HST. Seismic analogs of this interval suggest that the shale section may contain unrecognized sequence boundaries and may be a composite of multiple depositional sequences.

At the top of the Umiat Mountain section, a succession that coarsens upward from shale to sandstone represents the gradational contact between the Seabee and Tuluvak Formations. The basal coarsening-upward succession, as well as a second, similar succession above the first, are deltaic deposits interpreted as part of an HST.

These interpretations, together with inferred seismic analogs, suggest that sequence boundaries and lowstand shoreface deposits may be common in the Seabee Formation. Wave action, possibly during storm events, may have been important in transporting sand to the shelf margin during deposition of the Seabee Formation. These interpretations also suggest the potential for small stratigraphic traps in the paleoshelf part of the Seabee Formation. Such traps may involve LST shoreface sandstone beds encased in organic-rich shale of the TST and HST.

A gamma-ray profile collected through the Umiat Mountain outcrop section correlates well with described lithofacies and with the SP log from the Umiat No. 11 well in the lower part of the section (Ninuluk sandstone) but poorly with described lithofacies and with the SP log from the Umiat No. 11 well in the upper part of the section. The poor correlation in the Seabee Formation and lower part of the Tuluvak Formation is attributable to the abundance of volcanic detritus in both sandstone and shale, and is consistent with the poor correlations of gamma-ray logs with lithofacies in the Tarn and Meltwater oil fields.

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