Chapter TK (Thomson and Kemik Sandstones)

SEDIMENTOLOGY OF KEMIK AND THOMSON SANDSTONES IN THE WESTERN PART OF THE ARCTIC NATIONAL WILDLIFE REFUGE 1002 AREA, ALASKA

by Christopher J. Schenk[1] and David W. Houseknecht[2]

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[1] U.S. Geological Survey, MS 939, Denver, Colorado 80225
[2] U.S. Geological Survey, MS 956, Reston, Virginia 20192

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ABSTRACT

Assessing the potential for undiscovered hydrocarbon resources of the Lower Cretaceous Kemik Sandstone and the Thomson sandstone (local usage) is largely a function of defining the uncertainty associated with the existence of adequate reservoir facies of these sandstones in the ANWR 1002 area. The presence of Kemik Sandstone and the presence of adequate reservoir properties in postulated Kemik sandstones are highly uncertain in the 1002 area. The Thomson sandstone is known to be present and have good to excellent reservoir properties immediately adjacent to the western margin of the 1002 area, so the uncertainty associated with the presence of a potential Thomson reservoir is less than the Kemik. Both the Kemik and Thomson may be present in the 1002 area as graben-fill deposits, as incised valley deposits, or as shallow marine sandstones deposited as parts of backstepping parasequence sets formed during overall transgression. We postulate that grabens on the crest and flanks of the Mikkelsen High hold the best potential for undiscovered resources in both the Kemik and Thomson sandstones.

INTRODUCTION

The Kemik Play and the Thomson Play were developed as part of the assessment of the ANWR 1002 area to account for potential undiscovered resources in these sandstones (Figs. AO10, AO9). At present the Kemik and Thomson sandstones are known to exist outside of the ANWR 1002 area. We postulate that both sandstones may also be present as reservoirs in the undeformed part of the 1002 area northwest of the Marsh Creek Anticline. The thickness of the Kemik and Thomson are generally below the resolution of seismic data available to us, so play attributes developed for this assessment were extrapolated from these sandstones just outside the 1002 area, such as in the Thomson sandstone at Point Thomson Field, the Kuparuk “C” zone at the Kuparuk River Field west of Prudhoe Bay field, and, in the case of the Kemik, from published field observations and our own field observations.

The purpose of this paper is to present hypotheses regarding the sedimentology and possible types of Kemik and Thomson reservoirs that may be present in the area we assessed for undiscovered resources (Figs. AO10, AO9). The presence of Kemik and Thomson sandstones was not mutually exclusive in the area of 1002, such that the two sandstones, separated largely on the basis of detrital composition, can be intercalated (Figs. AO10, AO9). Understanding the potential distribution of the Kemik and Thomson sandstones requires not only an evaluation of the sedimentology of these sandstones outside the 1002 area, but also an evaluation of the tectonic evolution of the northern margin of Alaska during the Early Cretaceous.

LATE JURASSIC-EARLY CRETACEOUS EVOLUTION OF THE NORTHERN ALASKA CONTINENTAL MARGIN

Deposition of the Kemik, Thomson, and coeval units such as the Kuparuk "C" sandstone and the Put River Sandstone is closely linked to the tectonic evolution of the margin of northern Alaska in Late Jurassic and Early Cretaceous time (Carman and Hardwick, 1983; Noonan, 1987). The northern margin of Alaska was a stable platform through much of the Paleozoic and until the Late Jurassic, at which time crustal doming related to a presumed thermal anomaly in the mantle resulted in the formation of a pre-rift uplift called the Barrow Arch complex (Carman and Hardwick, 1983). With uplift in the Early Cretaceous came widespread erosion of the Ellesmerian sedimentary section, beginning with the Kingak Shale and extending down to the Lisburne Group and even to basement in some areas. Axial metamorphism within the uplifted area resulted in a tensional regime, which caused partial collapse of the central part of the uplift, and the formation of a wide zone of horst and graben structures that trended along the same northwest-southeast direction of the uplift (Carman and Hardwick, 1983; Hubbard and others, 1987). The horsts were local sources of sediment, primarily Ellesmerian sediments and pre-Mississippian sediments, and the grabens and half grabens were sediment traps. The sediments that accumulated in these structures were considered to be in a sequence termed the "Barrovian" by Carmen and Hardwick (1983) after the Barrow Arch, and the "Kup River" sequence by Noonan (1987), rather than being included with the underlying Ellesmerian sequence. Studies of similar-age rift-related sediments in the offshore resulted in the naming of the "Beaufortian" sequence (Fig. AO5). Subaerial erosion may have resulted in a system of incised valleys or drainages along the flanks of the Barrow Arch. As rifting progressed to the breakup and sea-floor spreading, the uplifted area subsided, and a widespread transgression occurred on the Barrow Arch. Parts of the Kuparuk "C" Sandstone and possibly the Kemik and Thomson sandstones were deposited during this transgressive event. The Pebble Shale unit was deposited at the culmination of this transgression. These rift-related sediments were then onlapped from the southwest by prograding units in the Brookian sequence (Fig. AO5).

STRATIGRAPHY

Several coeval Lower Cretaceous sandstones were deposited on the Lower Cretaceous Unconformity (LCU) along the North Slope (Fig. AO5); the Kemik Sandstone, Thomson sandstone, Kuparuk “C” Sandstone, and the Put River Sandstone are the most well-known. The Kemik interval in particular has been examined since the first geological studies on the North Slope (Leffingwell, 1919; Keller and others, 1961; Detterman and others, 1975). The source of these sandstones is generally considered to be from a landmass that existed to the north. These sandstones were deposited as either graben fill or incised valley fill deposits, or as sandstones redistributed during transgression from south to north.

THE KEMIK SANDSTONE

General Discussion

The Kemik Sandstone is differentiated from the Thomson sandstone (local usage) for this assessment on the basis of composition. The Kemik Sandstone is generally a very fine to fine grained lithic arenite to quartz arenite, with varying percentages of chert and metamorphics as lithic grains (Fig. TK1; Reifenstuhl, 1995). The Thomson, in contrast, is characterized by a significant percentage of carbonate lithic grains (Gautier, 1987), and is classified as a lithic arenite (Reifenstuhl, 1995). The compositional differences are related to provenance; the Kemik was most likely sourced by siliciclastic rocks of the Sadlerochit Group and cherts of the Lisburne Group, whereas the Thomson was most likely sourced by carbonates of the pre-Mississippian basement. Thus, the presence of Thomson sandstone depends upon the presence of basement carbonates, and for that reason the Thomson may be more areally restricted as compared to the Kemik with its Ellesmerian provenance (Fig. TK2).

Sedimentology

The sedimentology of the Kemik Sandstone has been interpreted from outcrops along the Sadlerochit Mountains and the Ignek Valley of ANWR (Molenaar and others, 1987; Mull, 1987; Melvin, 1987; Knock, 1987;

Reifenstuhl, 1995; Schenk and Houseknecht, unpub. data). These outcrops extend south and east from a few kilometers to tens of kilometers from the southern boundary of the 1002 area. What is unknown is the relationship between the sedimentology of the sandstones in outcrop to potential coeval Kemik Sandstone to the north in the 1002 area, if any. Outlined below are several possibilities for potential Kemik reservoirs in the undeformed part of 1002, based on the interpretations of the sedimentology of the Kemik sandstone in outcrop and the evolution of the northern margin of Alaska.

Case 1: Structural traps containing Kemik Sandstone

Noonan (1987) argued that the Barrow Arch was the location for many axial-aligned grabens formed during thermal-contraction-induced (extensional) collapse of the Barrow Arch in Late Jurassic to Early Cretaceous time. The grabens trend onshore in the 1002 area with a northwest-southeast orientation (Fig. TK3). If indeed these grabens are present in the 1002 area, we postulate that Kemik-type sandstones with adequate reservoir quality may be present as part of the graben fill. The proximity to the sediment source may mean that the Kemik Sandstone in these structures may be coarser grained than Kemik typically observed in outcrop. The potential for adequate reservoir quality of the Kemik would be greatly enhanced if a coarser grained facies were present, as is described from a similar structural setting in the Kuparuk "C' sandstone (Fig. TK4; Carman and Hardwick, 1983; Masterson and Paris, 1987; Halgedahl and Jarrard, 1987). If there is Kemik in the grabens, and if the Kemik is as fine-grained as the outcrop sandstones, then the possibility for reservoir quality Kemik in the 1002 area is uncertain. However, if the coeval Kuparuk "C" Sandstone in the Kuparuk River Field can be used as an analog, then the reservoir quality may be good to excellent, as the Kuparuk "C" is reported to have an average porosity of 21%, and average permeability of 90 mD (Carman and Hardwick, 1983).

Interpretation of the 1002 area seismic data available to the USGS indicates that in several areas the LCU is offset by normal faults, forming what may be, in these limited views, graben structures. The presence of grabens, the possibility of reservoir quality sandstone, and the sealing by the overlying Pebble Shale unit were considered to be positive factors in the assessment of the Kemik Sandstone.

Case 2. Stratigraphic traps associated with barrier island model of Mull (1987) and Reifenstuhl (1995)

Working with sections measured in the Ignek Valley and around the margin of the Sadlerochit Mountains, Mull (1987) divided the Kemik Sandstone into two members. The Ignek Valley Member is a cross-stratified sandstone facies that crops out prominently in the Ignek Valley, whereas the Marsh Creek Member is a mudstone and siltstone facies. Using vertical and lateral facies associations, Mull interpreted the Ignek Valley Member as a barrier-island sandstone (Fig. TK5), and the Marsh Creek Member, measured north of the Sadlerochit Mountains, was postulated to be the result of deposition in a back-barrier lagoon, with typical fine-grained deposits including burrowed siltstones and mudstones. Thus, the Ignek Valley Member and the Marsh Creek Member were interpreted in this study as coeval facies. Reifenstuhl (1995) measured two sections of the Kemik and arrived at an interpretation of an inner-shelf to barrier-island sandstone for the Ignek Valley Member. In addition to the shoreface-related barrier sandstones, Reifenstuhl interpreted a tidal-inlet sandstone facies, which is significant in that if tidal inlet deposits are present, it suggests that tidal-delta reservoir sandstones may also be present in the Kemik. Reifenstuhl also reported paleosols in the Kemik, suggesting two phases of subaerial weathering during deposition of the Ignek Valley Member. These lines of evidence suggest that the Kemik is a composite sandstone made up of at least two depositional sequences.

This interpretation of a fairly narrow band of barrier-island sandstone precludes much of the 1002 area from having potential reservoir sandstones, as the Kemik facies in the 1002 area would be mainly the fine-grained lagoonal deposits of the back barrier. Although some barrier island sandstones have been reported to be up to 2 km wide (Willis and Moslow, 1994), even this width would not extend this single Kemik barrier north into the 1002 area. This interpretation leads to a low probability of adequate Kemik reservoir in the 1002 area.

One possibility for reservoirs according to the barrier-island model is that a genetically related fluvial-deltaic system is present to the north somewhere in the 1002 area. The presence of such a system at this point is purely hypothetical, and has not been observed on seismic lines. Another possibility for reservoirs is the presence of tidal deltas, but the extent of the deltas given the location of the Kemik barrier may mean that any potential tidal delta sandstones may not extend as far north as the 1002 area.

A further possibility for reservoirs in the 1002 area is that the Kemik barrier island in outcrop may represent one of several such sandstones that formed as a series of backstepping parasequences as the sea transgressed to the north episodically over the LCU in the Early Cretaceous. In this scenario, other Kemik sandstones similar to the one exposed in the Ignek Valley are present in the 1002 area, and these sandstones formed as minor regressive events during the overall transgressive episode. Such backstepping parasequences have been documented from the Almond Sandstone in Wyoming (Van Wagoner and others, 1990), which encompasses a series of shallow marine sandstones. In this analog, backstepping parasequences represent an overall transgressive event, and the sandstones are generally porous, shallow marine sandstones that can have updip pinch-outs into coastal plain mudstones that serve as seals. Again, the problem with this possibility is that the reservoir quality of the Kemik in similar shallow marine parasequences to the north would be predicted to be as poor as the Kemik in outcrop.

Case 3. Stratigraphic traps associated with shelf sandstone model of Knock (1987a, b), Melvin (1987), and Molenaar and others (1987)

The Kemik as exposed in and around the Ignek Valley has been interpreted as a shelf sandstone by Knock (1986, 1987a, b), Melvin (1987), and Molenaar and others (1987). Melvin (1987) concluded that the Kemik "…represents a storm-dominated inner shelf sandstone with regressive characteristics, deposited in an overall transgressive setting". Molenaar and others (1987) presented a similar interpretation in that the Kemik represents sand "…deposition on a broad shelf associated with a transgressing sea-probably as large offshore bars during a stillstand of the transgression." Implicit in this interpretation is that the Kemik was deposited some distance from the shoreline as a shelf sand (Figs. TK6, TK7), with the shoreline some unspecified distance to the north in the 1002 area. The Marsh Creek Member of the Kemik in this interpretation is not a back-barrier lagoonal mudstone but rather a transgressive mudstone.

As in the case of the barrier-island interpretation, the shelf sandstone interpretation leaves one with the problem of postulating a scenario for adequate Kemik reservoir to the north in the 1002 area. The best possibility resides in the idea that potential reservoir-quality shoreline sandstones may be present north of the Kemik outcrop in the 1002 area. However, given the poor reservoir properties of the Kemik in outcrop, any shoreline sandstone would have to be coarser grained in order to predict adequate reservoir properties.

Kemik shelf sandstone may also represent one of a series of sandstones deposited in backstepping parasequences that formed during the northward transgression. The Kemik in outcrop may only be one of several such sandstones, but again, reservoir quality is predicted to be a significant detriment to the viability of this play.

Reservoir Quality

Most of the information on reservoir quality of the Kemik comes from outcrop samples, in which the Kemik has poor reservoir quality (Knock, 1987; Reifenstuhl, 1995). Outcrop samples range in porosity from 0.8 to 14.1%, averaging 5.3%, and the few subsurface samples analyzed ranged from 3.9-8.4%, averaging 6.2% (Reifenstuhl, 1995). Permeability was low, ranging from 0.00012 to 0.0157 mD. Slightly higher porosity values were reported by Bird (1987), with porosity ranging from 3-10%, averaging 8%. All of these samples, however, are essentially from the fine-grained sandstones of the Kemik. If similar sandstones exist in the 1002 area, then the prediction is for similarly poor reservoir quality in the assessment area. If a coarser grained facies is present to the north of the outcrop belt in the1002 area, then there is a chance for improved porosity and permeability from both preserved primary and secondary porosity.

The most optimistic analog for reservoir quality in the Kemik comes from the Kuparuk "C" Sandstone, where average porosity is about 21%, and permeability averages 90 mD (Carman and Hardwick, 1983). We considered this analog as a possibility when arriving at the risk structure for the Kemik Play (Chap. P5).

Play Concept

The northerly source for the Kemik Sandstone figures strongly in the development of the Kemik Play concept. A landmass to the north of the present day coastal plain provided sediment for the Kemik Sandstone. Given what we know of the Kemik in outcrop, the probability of finding adequate reservoir quality in the 1002 area is poor, unless we use the coarser grained Kuparuk "C" sandstone as a direct analog. Thus, the Kemik Play was risked based on the presence of adequate reservoir to produce a minimum field size of 50 mmboe. The probability that one of the scenarios outlined above actually leads to reservoir quality sandstone being deposited in the 1002 area was estimated to be low, especially in any of the scenarios involving stratigraphic traps. More likely, however, the Kemik is present in one of the grabens that offset the LCU (Figure TK3). The key to the viability of the play is that a coarser grained facies of the Kemik (as compared to what is observed in outcrop) would have to be present in a graben to provide the porosity, either preserved intergranular or secondary, that would enable a field of the minimum size to be formed in the 1002 area. In the assessment we considered the possibility of a number of graben traps in the Kemik, and included the possibility, however unlikely, for a large stratigraphic trap in the Kemik Sandstone.

THOMSON SANDSTONE

General Discussion

The Thomson sandstone (local usage) was deposited on the LCU along the flanks and crest of the Mikkelsen High (Fig. TK3, Fig. AO9). The Thomson sandstone is known to contain significant quantities of hydrocarbons, reportedly up to 5 tcf gas and 350 million barrels of condensate in the Point Thomson area (Bird and others, 1987), which is immediately adjacent to the 1002 area. The presence of hydrocarbons and the obvious trend of the Point Thomson Field into the 1002 area led to the development of the Thomson Play. What is uncertain is the extent of the play into the 1002 area.

Stratigraphy

The stratigraphy of the Thomson sandstone is known from the interpretation of a few well logs in the Point Thomson area, and the regional distribution of the Thomson is unknown. The well logs show a blocky sandstone immediately above the LCU, but the Thomson is not present in every well at the eastern end of the Barrow Arch, suggesting that the Thomson does not have a blanket distribution. An important observation is that the Thomson is present where basement carbonates have been eroded by the LCU (Fig. TK8, well Alaska State F-1).

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Sedimentology

Little is known of the sedimentology of the Thomson sandstone due to the fact that the unit does not crop out, and cores known to exist from the Point Thomson area were not made available to us for examination. Thus the possible reservoirs outlined below are less constrained than those outlined for the Kemik Sandstone. The Thomson is present in several wells from the Point Thomson area, but not all, suggesting that the Thomson does not have a blanket distribution. The blocky log character suggests a relatively uniform set of physical properties. Gautier (1987) stated that the Thomson displayed several fining up sequences on the well logs from the Point Thomson area, but our work did not corroborate this claim.

Case 1. Structural traps in grabens

The hypothesis is, like the Kemik, that the Thomson sandstone was deposited in a series of northwest-southeast trending grabens formed on the flanks and crest of the Mikkelsen High during the extensional regime associated with rifting, and these served as accommodation sites for the accumulation of coarse-grained Thomson carbonate detritus shed from higher areas flanking the grabens. The grabens would have acted as natural traps for coarser grained sediment, and with continued transgression mudstones of the Pebble Shale Unit would have covered the sandstones, serving as a seal and a source.

The regional distribution of the basement carbonates that are the source for the Thomson is not known, so the extent of the Thomson Play is uncertain. The trend of known hydrocarbons in the Thomson suggests that the trend continues into the 1002 area (Fig. AO9).

Case 2. Stratigraphic traps as incised valley fills

In this hypothesis, Thomson sands would have been deposited in valleys incised into the Mikkelsen High during erosion associated with the LCU. The Mikkelsen High would have been the focus of subaerial erosion, and some of the material would have been regolith formed and deposited in the valleys, the regolith being detritus eroded from pre-Mississippian carbonates of the basement rocks. Following base level rise, the valleys would have back-filled with sands, including quartz sands that are also part of the Thomson interval. Valley fill deposits are complex, and can include sediments deposited in non-marine and marine environments (Van Wagoner and others, 1990).

The pattern of erosion leading to incised valleys on the Mikkelsen High may lead to channels largely oriented downdip, which is not optimum for trapping of hydrocarbons. Fluids moving updip from the generative areas in the Hue Shale and others would migrate up and through the valley-fill sandstones, and possibly leak or be degraded before significant trapping occurred. However, there are cases from the Cretaceous Tuscaloosa Formation of the Gulf Coast where bends in sinuous fluvial paleochannels serve as significant hydrocarbon traps. Such a trapping situation could be present in Thomson sandstones.

The deposits within incised valleys form significant hydrocarbon reservoirs in many areas, and such valleys are difficult to resolve on older vintage seismic data that was available for this area. Incised valleys are below the resolution of the existing 2-D seismic data, and few logs are available, making regional maps of incised surfaces impossible to construct at this point.

Case 3. Stratigraphic traps with transgressive sandstone

As transgression proceeded to the north across the LCU, it is possible that Thomson-type sands were periodically deposited to form stratigraphic traps, such as that described for the Kemik Sandstone. The main line of reasoning against this case is that the composition of the Thomson argues for a very local source (Reifenstuhl, 1995), rather than being a sand that was redeposited during a transgressive event. Like the Kemik, a series of Thomson sandstones can be envisioned as having been deposited as a series of backstepping parasequences (Van Wagoner and others, 1990), during the overall transgression of the LCU, although this was considered an unlikely scenario.

Reservoir Quality

The Thomson contains two major facies, a conglomeratic facies and a sandstone facies. The dominant facies is very fine to fine grained, well-sorted, sandstone consisting mainly of detrital monocrystalline dolomite, with quartz and argillaceous rock fragments as a minor component. The conglomeratic facies consists of boulder to pebbles size fragments of coarsely crystalline dolomite. Although data are limited and appear to be mainly from the conglomeratic facies, the Thomson sandstone reportedly has good to excellent reservoir properties, including porosity up to 25%, with an average of 16%, and permeability up to a darcy or more (Bird and others, 1987; Gautier, 1987). Well logs and core data from individual wells in the Point Thomson area yield median porosity values ranging from 8% to 20% (Fig. PP1g). Where wells penetrate the Thomson, the reservoir properties are remarkably uniform (Plate WL40).

Examination of several hundred core chips from wells in the Point Thomson area has shown that visual porosity of the conglomeratic facies commonly is 12% or less, with a few samples as high as 25%. These conglomeratic samples are comprised of granule to pebble size carbonate clasts that are rounded to sub-rounded, and exhibit poor to fair sorting. The matrix is typically fine-grained carbonate cement, and commonly the cement does not completely fill the pores, leaving interconnections between pores. Some secondary porosity was noted, as the remains of cement shells could be seen around dissolved framework grains. Slight dissolution at framework grain point-contacts demonstrates that the conglomerate facies has not undergone significant compaction. Many samples from the Exxon Pt. Thomson 1 well exhibited a tarry residue in the pore spaces. Intercalated with the conglomerates were fine grained carbonate lithic sandstones, and quartz and lithic Kemik-like sandstones. Visual porosity in most of these sandstones was less than 10%, and a few samples had visual porosity estimated to be about 15%. Sorting was typically poor to fair, and the grains mainly subrounded. Many samples had significant percentages of metamorphic lithic fragments. Several of the sandstones in thin section exhibited significant replacement of quartz by carbonate.

Play Concept

For the assessment, the Thomson was considered to have significant potential if, as in the Point Thomson area, other graben-type structures, or, alternatively but less likely, incised valley fill deposits, are present containing similar coarse-grained Thomson sediment with good to excellent reservoir properties. The limiting factor may be the relatively small area within the 1002 area that potentially has either the graben-type structures or valley fills with Thomson-type sediment. In the assessment, the play concept ranged from a number of graben traps to a large stratigraphic trap, to a simple extension of the known field at Point Thomson into the 1002 area (Chap. P4).

SUMMARY

Several possibilities were outlined for potential Kemik and Thomson reservoirs in the ANWR 1002 area, given the limited knowledge of these sandstones in the subsurface. The most optimistic case for both the Kemik and Thomson is that a coarse-grained facies of each of the sandstones was preserved in graben-type structures developed during rifting of the crest and flanks of the Mikkelsen High. The coarse sediment size would have the potential to either preserve reservoir quality or have the potential for secondary porosity. Improvements in the processing of existing seismic or the acquisition of new 3-D seismic may serve to interpret the other types of trapping elements described here.

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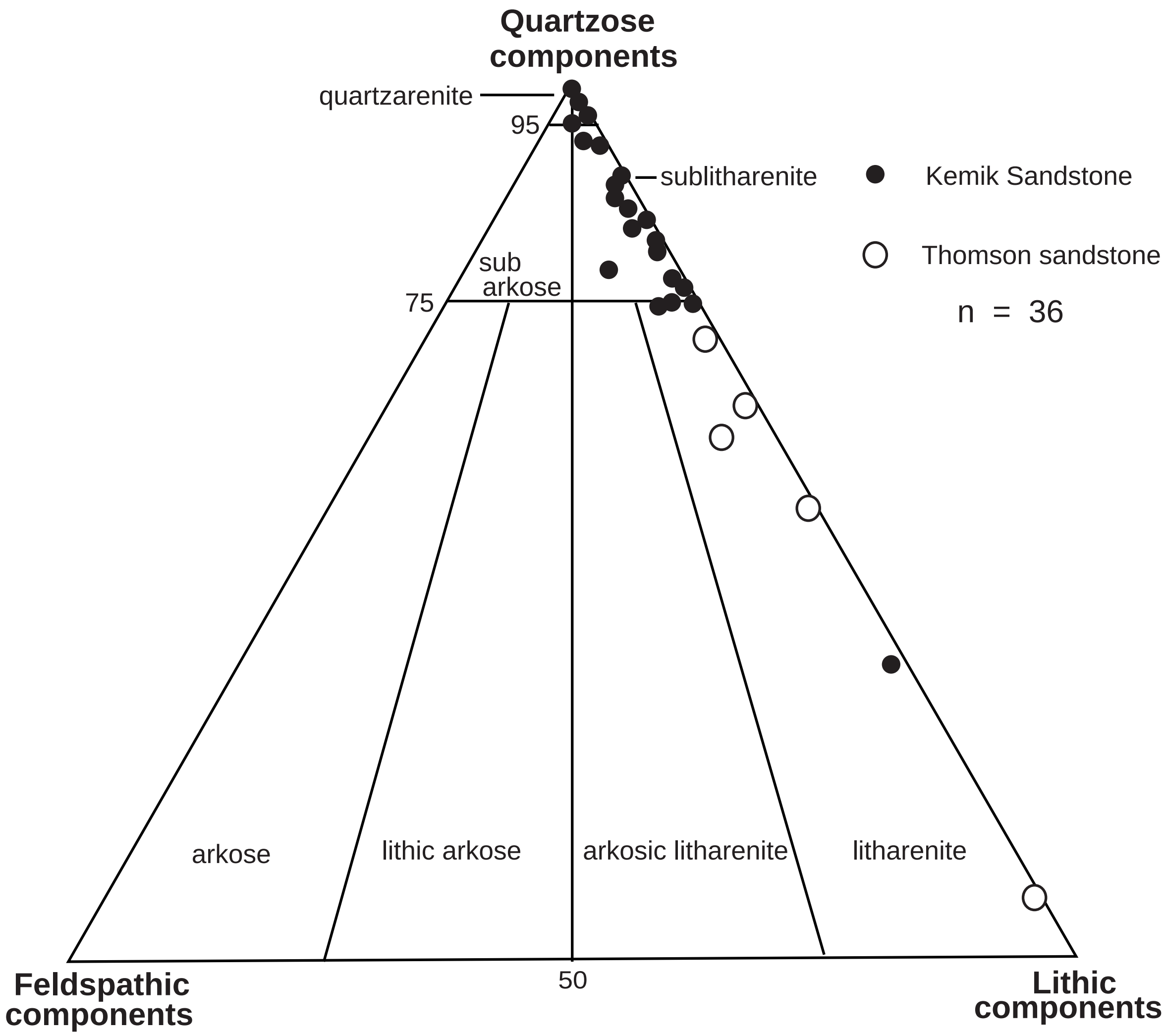

Figure TK1. Composition of the Kemik (solid circles) and Thomson sandstones (open circles) shows that the Thomson sandstone is lithic arenite, whereas much of the Kemik Sandstone is quartz arenite to sublithic arenite (after Reifenstuhl, 1995). The Thomson sandstones contain high percentages of carbonate lithics.

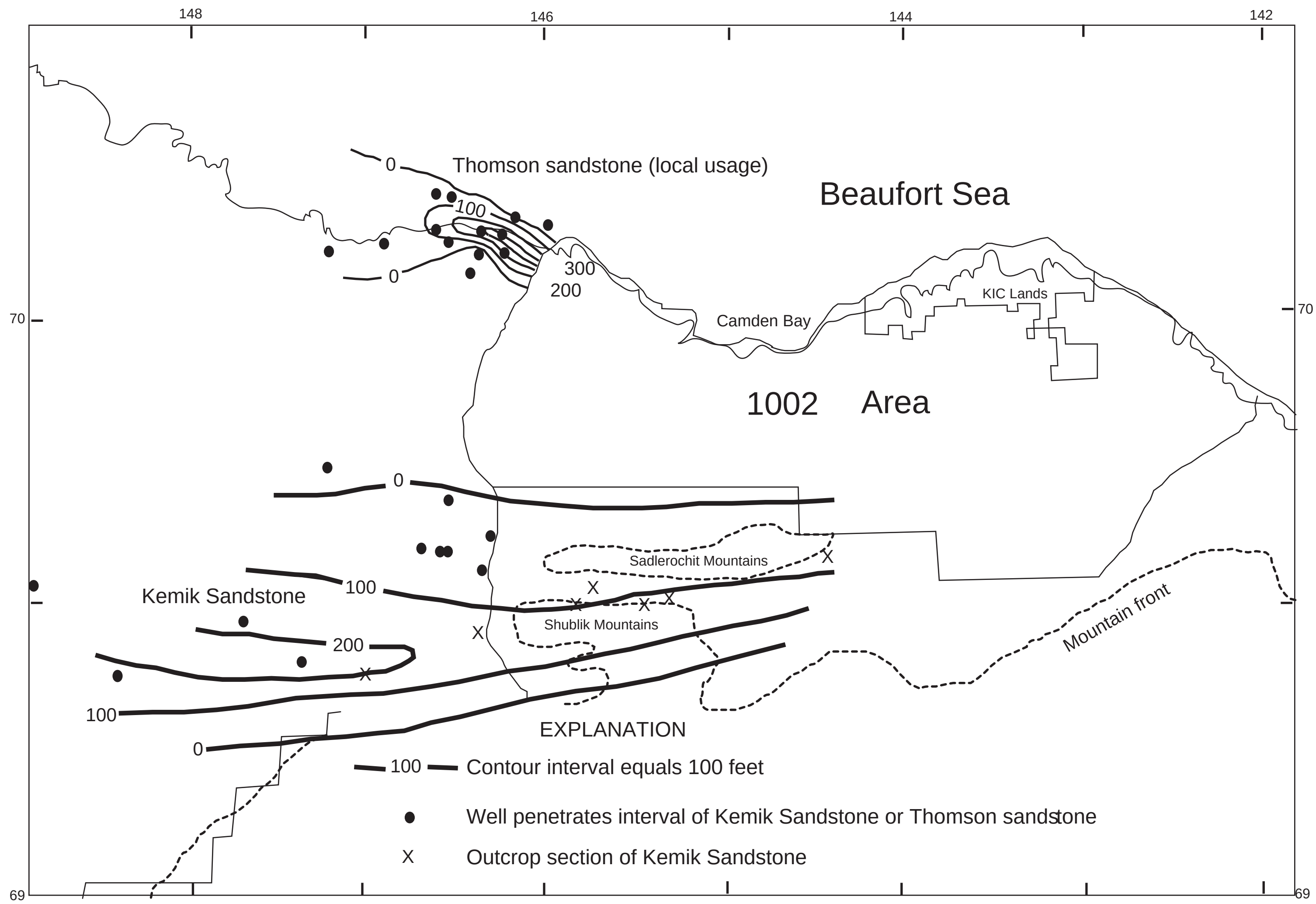

Figure TK2. Isopach maps of the Kemik Sandstone and the Thomson sandstone illustrate the limited distribution of the Thomson in the Point Thomson area, and the wider distribution of the Kemik Sandstone. The map illustrates the lack of information on the Kemik Sandstone and the Thomson sandstone in the 1002 Area (from Reifenstuhl, 1995).

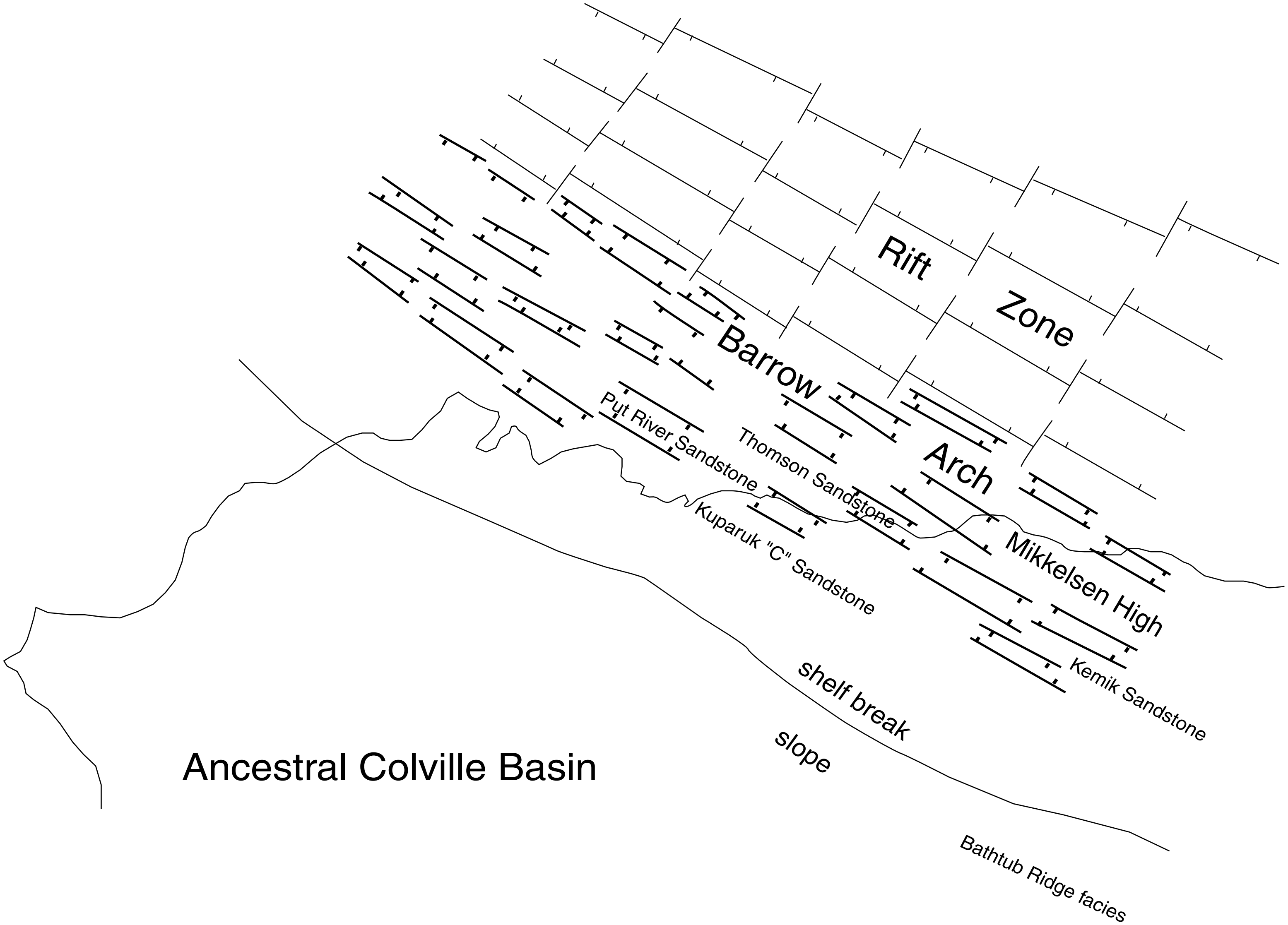

Figure TK3. The crest and flanks of the Barrow Arch (and its eastern extension the Mikkelsen High) are interpreted to have a series of northwest-southeast trending graben structures formed during rifting of the continental margin. The grabens trend onto the present coast of Alaska in the ANWR 1002 Area. North of the grabens is a zone of transforms related to sea-floor spreading (modified from Noonan, 1987).

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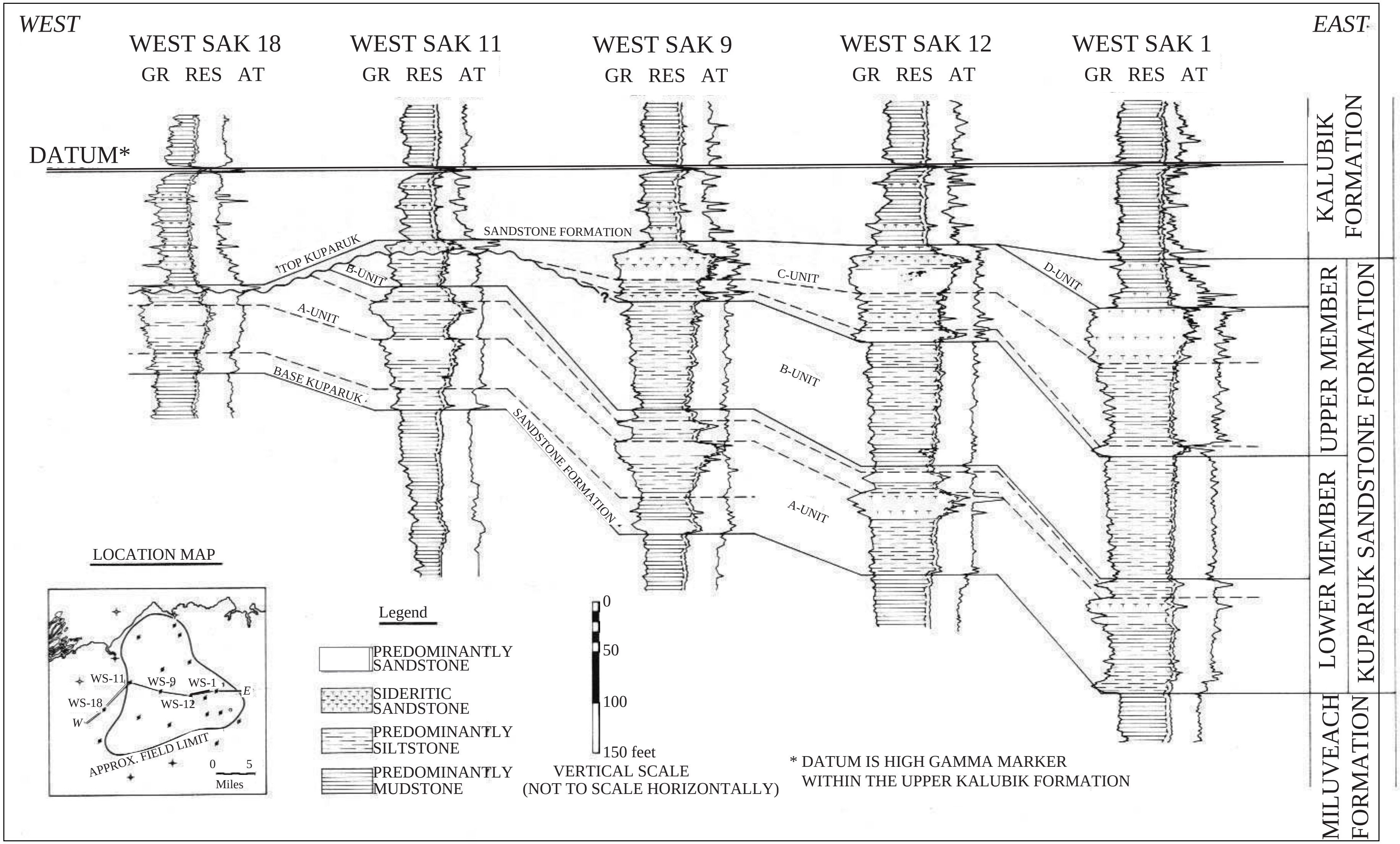

Figure TK4. The Kuparuk "C" sandstone in the Kuparuk River Field in the area of Prudhoe Bay may serve as an analog for some of the Kemik Sandstone. The Kuparuk "C" is interpreted as a shallow marine sandstone that was deposited in a narrow graben structure on the southwest flank of the Barrow Arch (after Carman and Hardwick, 1983).

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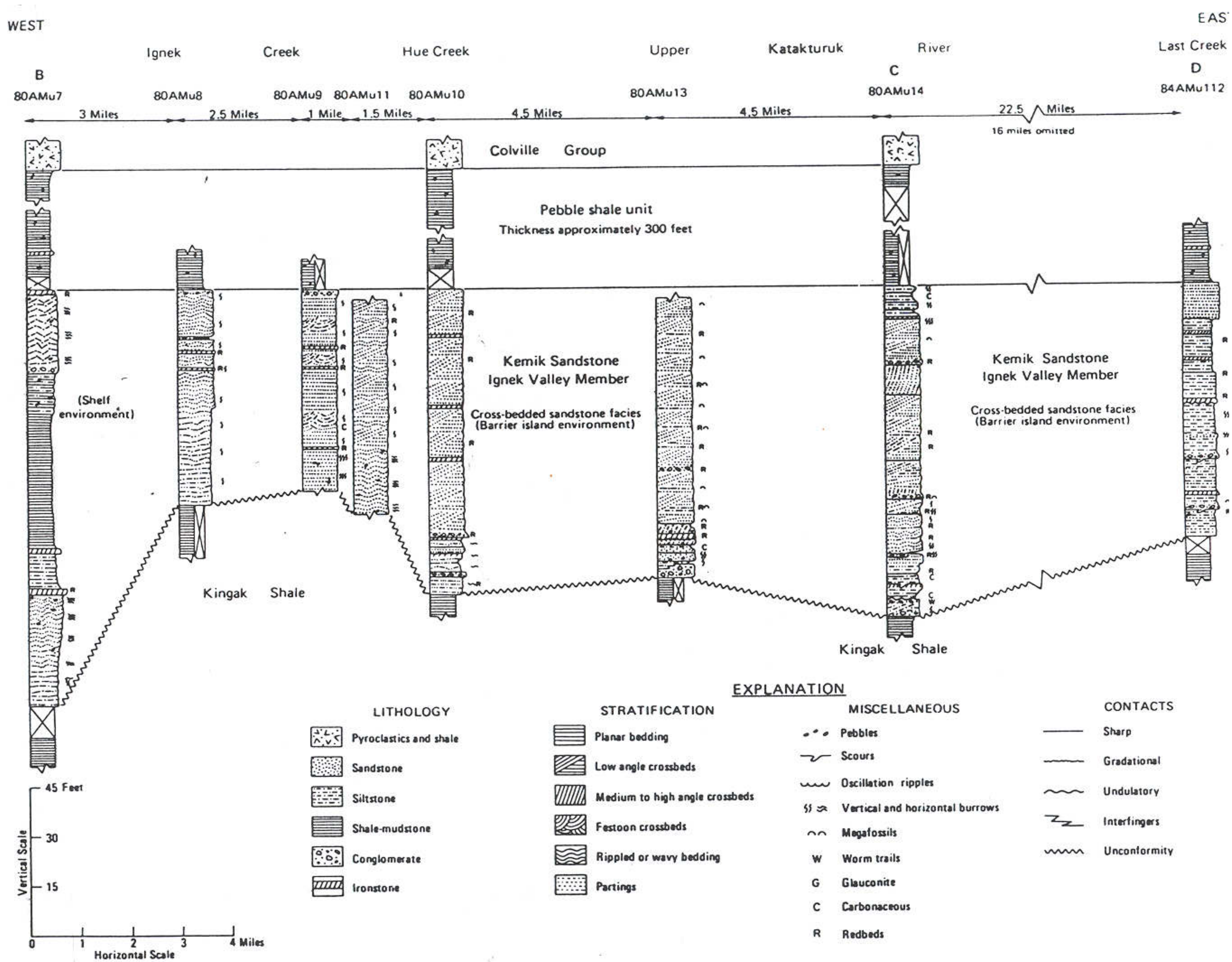

Figure TK5. The Kemik Sandstone was interpreted as barrier-island sandstone by Mull (1987) and Reifenstuhl (1995). The Ignek Valley Member of the Kemik was correlated through the exposures in the Ignek Valley south of the 1002 Area (after Mull,1987).

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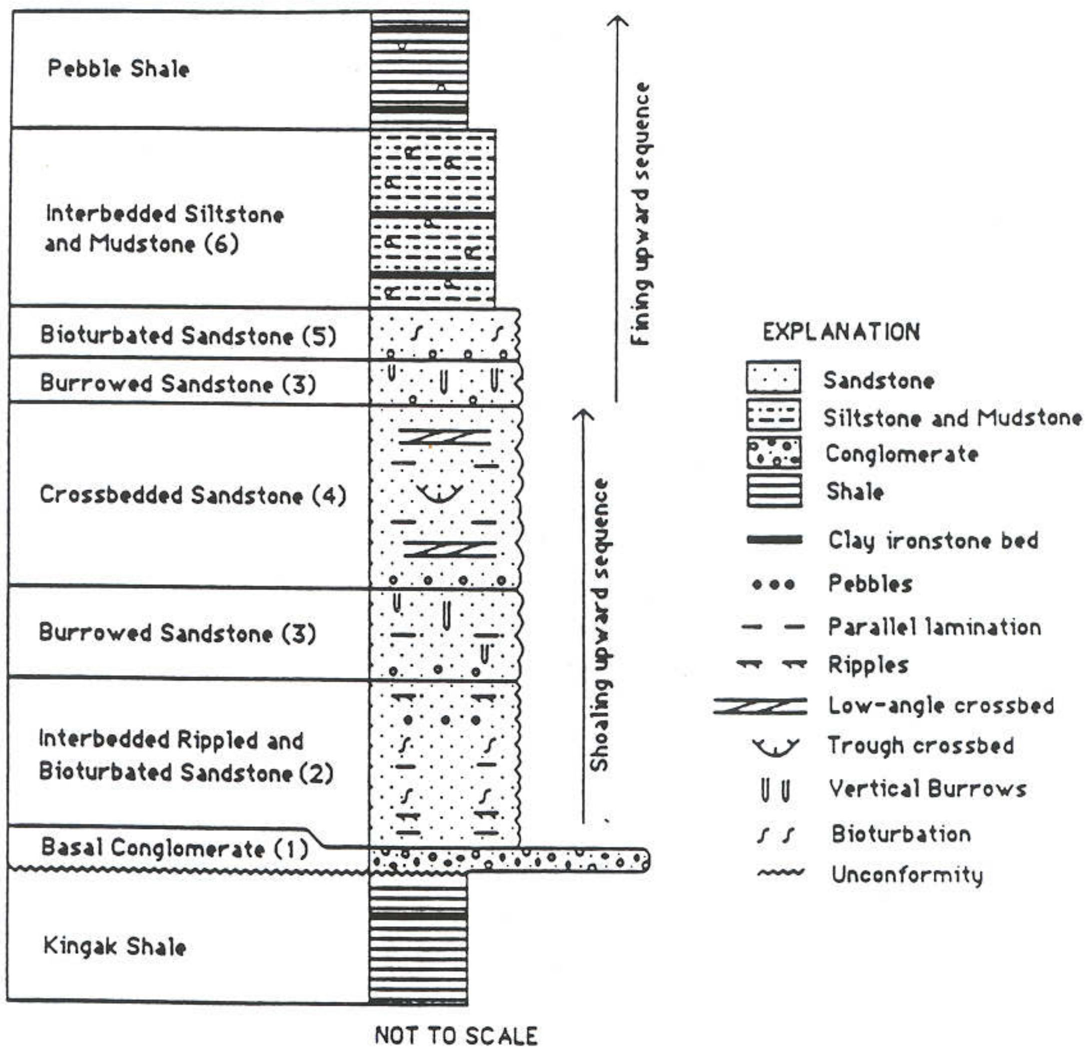

Figure TK6. Typical vertical succession of facies as seen in outcrops of the Kemik Sandstone. The Kemik was interpreted as a shallow marine sandstone (after Knock, 1987a).

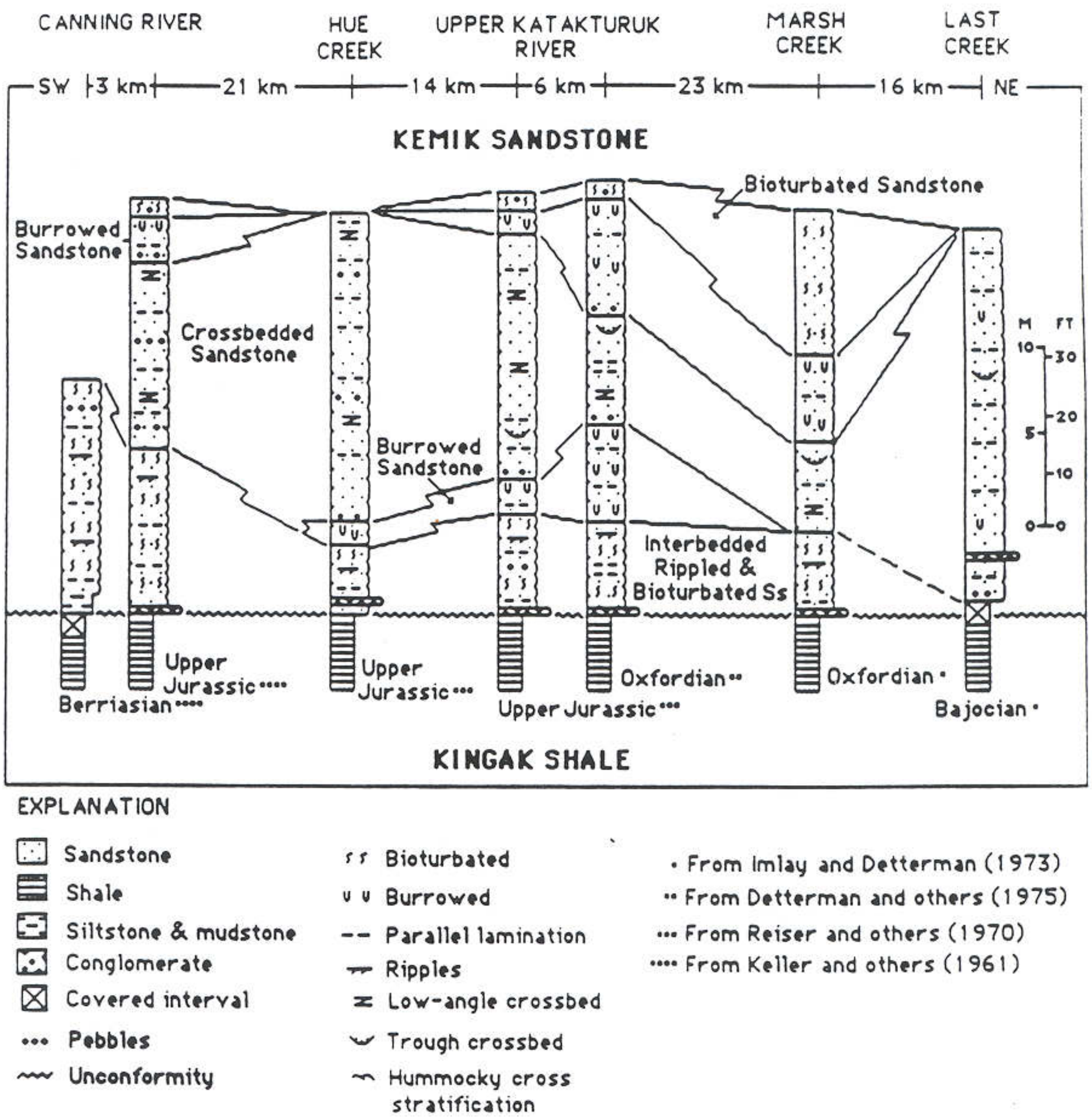

Figure TK7. Cross section of Kemik Sandstone from outcrops in the Ignek Valley and the Sadlerochit Mountains (after Knock, 1987a). Note similarity of facies to barrier island cross-section of Mull (Fig. TK5).

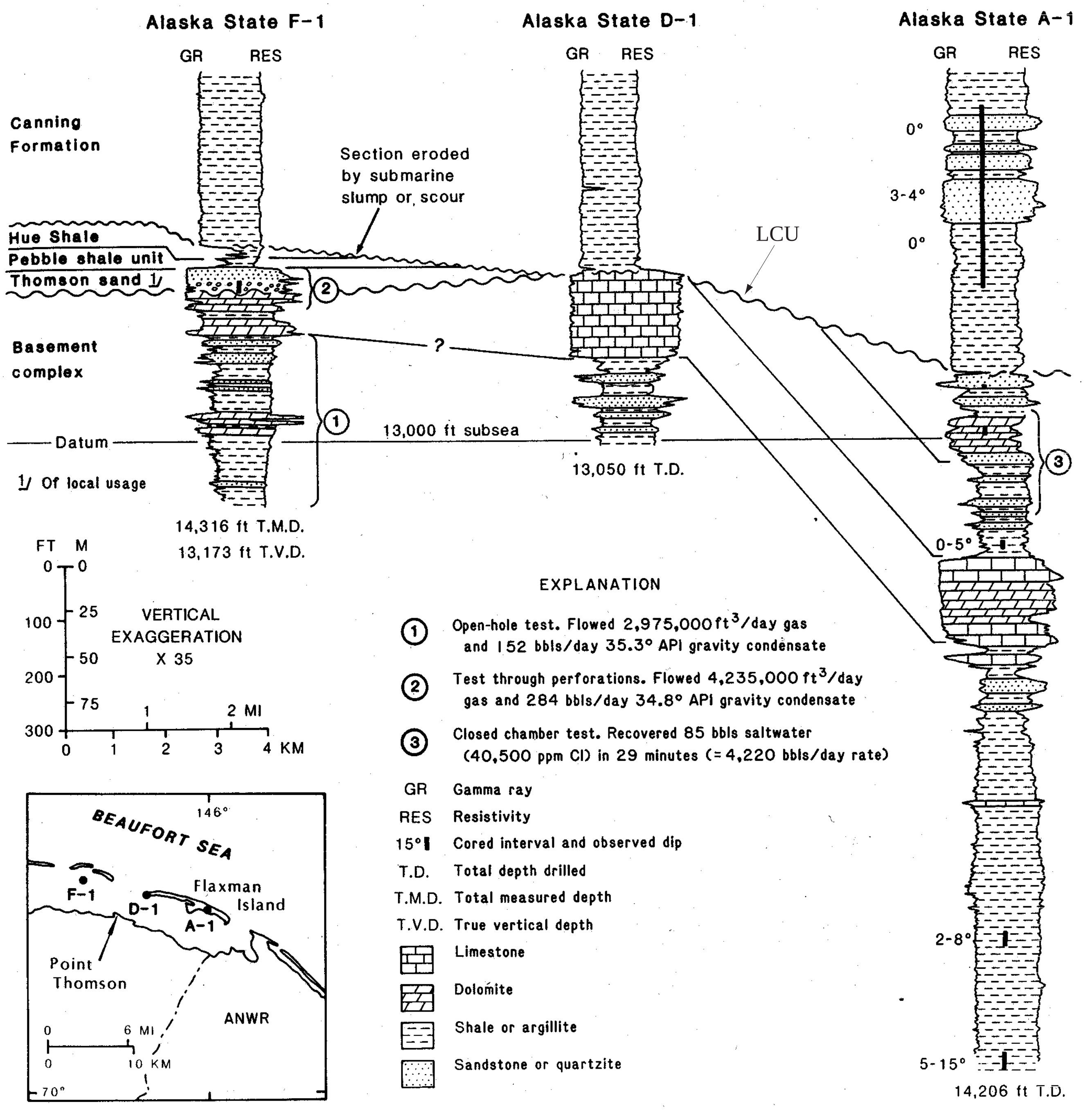

Figure TK8. Borehole log cross section of three wells north of Point Thomson illustrates the Thomson sandstone above the Lower Cretaceous Unconformity (LCU), with erosion of the LCU into pre-Mississippian basement carbonates, which are considered the source of Thomson detritus (after Bird and others, 1987).