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GEOLOGIC FRAMEWORK OF THE "NORTH SLOPE" PETROLEUM PROVINCE

By

George Gryc, Irvin L. Tailleur, and William P. Brosgé

Open-file report

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By George Gryc[1], Irvin L. Tailleur, and William P. Brosgé

That the Prudhoe Bay field and adjoining areas constitute one of the major oil provinces, certainly of North America and possibly of the world, is now widely accepted. Most experts agree on reserves in terms of billions of barrels. Some speak of 40, 50, and even 100-150 billion barrels of oil in all of Arctic Alaska and like amounts in the Canadian Arctic Islands. The lower figures appear to be probable, the upper possible. These possibilities added to the known reserves of Cook Inlet, the prospects in the Gulf of Alaska, the Alaska Peninsula, Bristol Bay, the Bering Sea, and elsewhere have fixed worldwide attention on Alaska.

To those of us who have been active in accumulating the geologic data that generally precedes such discoveries and who have been continuously evaluating the potential mineral resources of Alaska, these recent discoveries are not unexpected. However, the magnitude of the possible reserves at Prudhoe Bay has surprised even the most optimistic oil searcher.

Although there is no need to introduce this audience to the geography of northern Alaska, (slide 1 - part of Tectonic Map of North America, P. B. King, U.S. Geol. Survey, 1969) this tectonic map illustrates rather well the Arctic setting of the North Slope and the close geologic relationship to the Arctic Basin and the nearby areas of

[1] Speaker George Gryc, presented August 26, 1969 at 20th Alaska Science Conference, College, Alaska.

Canada and the U.S.S.R. Note, also, the large continental shelf area about equal to the land area of Alaska.

This map (slide 2 - modified from U.S. Geol. Survey Prof. Paper 482, pl. 1) illustrates the major physiographic features of the North Slope that we will discuss: the Brooks Range which cuts off the slope from the rest of Alaska; a belt of foothills generally divided into a northern and southern section; and a coastal plain, treeless and dotted with literally thousands of lakes and marshes; and the Arctic Coast with low relief, shallow water, and prominent offshore bars.

The initial discovery at Prudhoe Bay in 1967 was the immediate result of a forward-looking, fiscally courageous effort by the Atlantic Richfield Oil Company. But the story of oil on the North Slope of Alaska begins at least 50 years ago and includes several chapters of geographic and geologic exploration and an earlier petroleum exploration program that showed the way to the great strike at Prudhoe Bay. It is important to the broad purpose of this conference to review the more significant steps in this build-up of geologic knowledge and exploration "know how" and to review the general geologic framework and environment of the North Slope. This will provide a historical perspective for viewing the present activity and a geologic basis for a view to the future.

Oil seepages and oil shales in northern Alaska probably were known to the Eskimos long before recorded history. The early traders reported seepages along the Arctic Coast and these were investigated and reported by "Sandy" Smith and E. deK. Leffingwell in about 1916. In 1901, Schrader, a geologist, and Peters, a topographer, made the first recorded geologic and topographic survey across the Brooks Range and the Arctic Slope and in U.S. Geological Survey Prof. Paper 20 they described the structure and stratigraphy along the Anaktuvuk and Colville Rivers. E. deK. Leffingwell began his classic work along the Arctic Coast and the Canning River in 1906. In U.S. Geological Survey Prof. Paper 109, he named and described the Sadlerochit Sandstone, the main oil-bearing formation at Prudhoe Bay and he described the occurrence and origin of permafrost, a unique geologic feature of polar regions that poses new and difficult problems to engineering development.

In 1921 the Standard Oil Company explored the seepages in the Cape Simpson area and made an effort to stake claims under the old mining laws. However, about this time oil was discovered in Oklahoma and Texas and oil in the remote Arctic was forgotten.

Based on the work of Schrader, Leffingwell, and private geologists, President Harding in 1923 set aside 37,000 square miles of the North Slope as Naval Petroleum Reserve No. 4. The U.S. Navy then asked the Geological Survey to explore the area and in three years several traverses were made across the slope. The results, published in U.S. Geological Survey Bulletin 815 in 1930, describe possible source beds including oil shales, possible reservoir beds, and reported that "structural features favorable for retaining petroleum were widespread."

In 1944, as part of the World War II effort, the U.S. Navy began an exploration program to further evaluate the petroleum possibilities of NPR-4 and again the Geological Survey was asked to participate in the geologic aspects. The program was recessed in 1953 and the results are recorded in a series of U.S. Geological Survey Prof. Papers. Many of you are familiar with these reports and the "Pet-4" effort and I won't take the time to review it in any detail. However, it should be emphasized that the Pet-4 program pointed the way and the feasibility of modern oil exploration in the Arctic using all of the latest oil-finding techniques, including surface and subsurface geology, refraction and reflection seismic surveys, airbourne magnetic and gravity surveys and drilling by experienced oil industry personnel. It should be emphasized, also, that oil and gas deposits were discovered and although not of sufficient size to warrant development because of the remoteness, these discoveries provided positive evidence that there was a major oil province in northern Alaska. The program was suspended with the full knowledge that the exploration was not complete and that all prospects had not been tested within and to the east of NPR-4.

Since 1953 the Geological Survey, as part of its long-range objectives and responsibilities, has been mapping the geology and studying the stratigraphy of the Brooks Range and adjacent foothills and has continued to provide new geologic information and a periodic review of the petroleum possibilities of Arctic Alaska. The latest review, the AAPG report on the potential gas resources of the United States, was prepared in 1964 and finally published in 1968. The potential of Alaska was assessed by U.S. Geological Survey geologists and for northern Alaska east of the Colville, Patton reported "Facies studies of the Triassic and Permian strata in the foothills suggest that these rocks, which are mainly shale and chert in outcrop, may contain fairly clean sandstone beneath the Coastal Plain." Thus he accurately described in 1964 the upper oil horizon discovered at Prudhoe Bay in 1967.

This brief historical review demonstrates how the gradual build-up of geologic information sharpens the focus on exploration targets and also demonstrates the lead-time frequently required for such discoveries.

Turning now to the geologic framework of the North Slope--we have generalized on this map (slide 3,[1] Generalized geologic map - after Brosgé and Tailleur, 1969, fig. 10) the major distribution of rock units as we know them from the published work, largely that of U.S. Geological Survey geologists. In the broadest terms, the geologic framework relevant to the petroleum possibilities of northern Alaska consists of four major structural belts and two major depositional cycles. The structural belts include 1) the Brooks Range geanticline or uplifted belt of faulted structures, mainly involving thick competent Paleozoic rock units; 2) a disturbed belt of shallow thrusts involving incompetent Mesozoic rocks in the Southern Foothills of the Brooks Range and in the De Long Mountains; 3) the deep Colville geosyncline consisting of Cretaceous rocks; and 4) a broad northern regional high comprising the Barrow Arch, the Arctic Platform, and the Romanzof uplift. The first depositional cycle which Tailleur has called the Arctic Alaska Basin began in the Silurian or Devonian about 400 million years ago, and continued to Jurassic, about 150 million years ago. The basin extended across the present Brooks Range well into central Alaska. The northern shoreline oscillated from about the latitude of the present

[1] Slide 3 and 5 through 10 were 35 mm colored modifications of illustrations in "Isopach maps of Upper Paleozoic and Mesozoic rocks, Northern Alaska," by Brosgé, W. P., and Tailleur, I. L., U.S. Geol. Survey open-file report, 1969. Copies of original illustrations here provided for easy reference.

Arctic Coast to the Range. Near this shoreline, sandstone and other well-sorted sediments were deposited creating possible reservoir rocks. Organically rich limestones and shales including phosphatic beds were deposited offshore to form possible source beds of petroleum.

Early Jurassic to Cretaceous uplift, thrusting, and igneous activity disrupted the older Alaska Arctic Basin and formed a fold belt in the area of the present Brooks Range and a new depositional trough, the Colville geosyncline, to the north. Erosion of the fold belt provided a flood, first of flysch or poorly sorted dirty sediments to a foredeep along the south edge of the Colville geosyncline and later molasse or better sorted cleaner sediments to a succession of basins progressively moving and filling north across the subsiding geosyncline. The source of sediments was from the south opposite to the primarily northern source for the late Paleozoic and Triassic sediments.

These structural belts and depositional cycles are portrayed on this generalized map. Other pertinent detail plotted here includes the Meade Arch which separates the Colville geosyncline into two minor basins, the Umiat and Chukchi. The two major anticlinal alinements shown illustrate the continuous nature of these trends; the one to the south is the Carbon Creek-Ayiyak structure which can be readily traced for more than 200 miles and the northern alinement is the Umiat-Oumalik-Meade trend which some geologists believe is the northern limit of the decollement or decoupling in Cretaceous rocks. The Colville geosyncline, as shown in the diagrammatic section, is overthrust in the orogenic belt, interrupted by a sill, then steepens

to at least 20,000 feet in the vicinity of Umiat and gradually rises to within 2,500 feet at Barrow and about 8,000 to 10,000 feet in the area of the Colville Delta.

The "basement" or pre-Cretaceous rocks in the middle of the trough remain somewhat of a mystery. But in the area of the Romanzof uplift or positive tectonic element and on the Barrow Arch, the Jura-Cretaceous rocks overlie Triassic, Carboniferous, and Devonian in sequence and these rocks lie unconformably on schist and phyllites of Devonian and older age shown here in pink.

The Submarine High shown just off the west coast is based on a magnetic anomaly at about 9,000-foot depth and may represent a basement feature or a younger intrusive.

The red line pattern outlines the major granitic masses and the solid red are basic igneous rocks. In general, exposed igneous rocks and metallization are rare on the North Slope. No extensive metal occurrences or deposits are known.

The blue lines, as you have probably already noted, outline withdrawn federal lands, NPR-4, and the Arctic Wildlife Reserve, which make up about two-thirds of the potential petroleum province.

Also plotted are many of the wells drilled or announced to be drilled as of about three months ago. The well symbols are conventional, the more important discoveries include Prudhoe Bay, Gubik and Umiat, Square Lake, Meade, and Barrow. Many, but not all other tests in NPR-4, are shown by the four-rayed dry hole symbol and the open circles are current test wells. Roughly these test wells and discoveries can be grouped into first, the 36 test and 45 core tests drilled by the U.S. Navy within and adjacent to NPR-4 from 1945 through 1952; a second group of seven relatively shallow tests drilled from 1963 to 1965 presumably to explore for other Umiat-Gubik type deposits, and a third group began in 1966 with ARCO's Susie No. 1, followed by two wells near the Colville Delta and climaxed by the discovery of Prudhoe Bay.

This chart (slide 4) summarizes the stratigraphic sequences in the eastern and central area but does not include the far western area where relationships are similar but not identical. The color codes are blue for carbonate, dark green for chert-shale, green for shale-siltstone, yellow for sandstone-conglomerate, and orange for graywacke. All units are shown in proper stratigraphic relationship except the older rocks of the Neruokpuk Formation which is shown in its physical relationship to the Baird Group.

The red dots indicate the horizons in which oil and(or) gas has been discovered. From the top they are the Gubik gas field in the Tuluvak tongue, the prospective Square Lake gas field in the sandstone of the Seabee Formation, the upper horizons in the Gubik and Umiat fields in the Ninuluk Formation, all upper Cretaceous, the deeper Umiat and Meade gas horizons in the Grandstand and Kukpowruk Formations of the lower Cretaceous, the Barrow gas sands in the Jurassic, and finally the Prudhoe Bay oil sands in the Sadlerochit Formation and the lower oil horizon in the Lisburne limestone. This is a good record for any basin and there are other possibilities.

It should be noted that the section of rocks in the Brooks Range and southern foothills differ from that to the north in that:

(1) The Lisburne Group and underlying Kayak shale are older in

the south where they appear to have been deposited on older rocks without interruption. To the north these units are younger and lie unconformably or at angular relationship to argillites and phyllites that were planed by erosion before the sea lapped northward.

(2) Permian through Jurassic rocks are generally chert-shale in the south but normal marine shale, sandstone, or limestone in the north.

(3) Jurassic and Neocomian Cretaceous rocks are graywacke flysch or dirty marine and mafic volcanics in the Range, very thin shale, chert, and coquina in the foothills, and marine shale and sandstone to the north.

(4) Lower Albian Cretaceous rocks are also rapidly deposited graywacke flysch facies composed of mafic and recognizable Paleozoic detritus in the foothills and shale and siltstone to the north.

The stratigraphic chart and cross section depict a history of basin filling beginning with overlap of Mississippian shale and limestone and ending with Upper Cretaceous and Tertiary nonmarine deposits. There is some suggestion that the marine Tertiary deposits exposed at Marsh Creek may extend seaward and westward and possibly thicken offshore.

The next series of slides summarize our knowledge of the thickness, distribution and lithology of these several stratigraphic intervals beginning with the Lisburne Group of carbonates, 300 to 350 m.y. old (slide 5, after Brosgé and Tailleur, 1969, fig. 3). These maps were prepared by W. P. Brosgé for a special study by the National Petroleum Council and are available in the U.S. Geological Survey open-file upon request. I will not discuss these in any detail but I would like you to see the general state of our knowledge on this subject. The isopachs or lines of equal thickness are in hundreds of feet and the thickness of the Lisburne Group ranges from 0 to 3,000. The available subsurface data are shown by the red circles; Lisburne carbonate is reported to be the lower oil horizon at Prudhoe Bay, carbonate at Colville T.W. No. 1, and red beds of about the same age in the Topagoruk test well. The other well shown is Kukpuk No. 1 and it can be assumed that the Lisburne is represented in that test. West of the Colville River in those areas where on the seismic profiles a pre-Triassic interval is indicated, we have inferred the presence of a facies equivalent to the Lisburne Group, but not necessarily carbonate. The blank area to the west is so shown because there are no data. The disturbed belt bounded by thrust faults is left blank for the most part because the belt is not well known, and the rocks are structurally complex.

Phosphatic rocks reminiscent of the Phosphoria formation are common in this Lisburne unit and in the overlying Triassic.

In Canada on the North Slope of the British Mountains, Triassic and Jurassic rocks rest directly on pre-Mississippian argillite and phyllite and the Lisburne carbonate is missing. This, then, is an observed zero line of the Lisburne Group and by using the few scattered data in the subsurface we have extended it along the Arctic Coast to Barrow. It is either an erosional edge or onlap edge extending along an ancient shoreline which follows roughly the Arctic Coast.

The next slide (slide 6, after Brosgé and Tailleur, 1969, fig. 4) depicts the Permian and that part of the lower Triassic that makes up a clastic lithologic unit and the upper oil zone at Prudhoe Bay.

The control points for the thickness and distribution lines are the unconformity in the British Mountains where the Permian is missing, the Prudhoe Bay field, the Colville and Topagoruk tests, and the exposures in the Brooks Range and Arctic Foothills. The subsurface to the west is inferred from seismic profiles within NPR-4 and left blank where we have no data.

The lithology of this interval is fairly constant from west to east but changes greatly from south to north. In the Brooks Range the Permian Siksikpuk Formation is consistently about 500 feet of red, green, and gray silty shale and chert with barite and pyrite. In the Romanzof Mountains the Sadlerochit Formation is dark shale, siltstone, cherty siltstone, and sandstone conglomerate. The Sadlerochit thins to the north and grades into fine-grained pyritic sandstone and quartzite interbedded with shale and conglomerate. Similar fine sandstone, chert, pebble conglomerate, siltstone, and shale are present in the subsurface at the Colville and Topagoruk tests. The sandy petroliferous facies along the north edge of the basin is on the inferred coastal high onto which the upper Triassic and Jurassic rocks overlap and like the Lisburne the Sadlerochit may be truncated or overlapped by upper Triassic and Jurassic all along the coastal high.

No isopach maps were prepared for the upper Triassic Shublik Formation or for the Jurassic. The Shublik forms an almost uniform blanket of dark shale, siltstone, and thin-bedded limestone 200 to 700 feet thick. There is very scanty control for the Jurassic. Jurassic rocks in and just south of the disturbed belt are thin, difficult to recognize, and are of several facies, mixed tectonically. Rocks include intrusives and flows, tuffs, chert, shale, and oil shale.

The oil shales in the Jurassic and lower Cretaceous have been studied extensively by Tailleur and Tourtelot with generous support by the U.S. Navy and Arctic Research Laboratory. Although no extensive tonnage can be identified the richer shales yield up to 145 gallons of oil per ton and some of the shales contain anomalous amounts of metals including zinc, vanadium, molybdenum, mercury, and gold, and larger than ordinary amounts of arsenic, copper, nickel, selenium, and silver.

This map (slide 7, after Brosgé and Tailleur, 1969, fig. 6) shows the thickness, distribution, and general lithology of all of the Lower Cretaceous and Cenomanian rocks--in the orogenic belt these include Okpikruak and Fortress Mountain Formations and in the basin the Okpikruak, and Torok Formations and the Nanushuk Group. The color code is orange for graywacke--conglomerate, dark green for the older shales and siltstone, and a lighter green for the predominantly sandstone and shale facies. The thickness is in thousands of feet.

This slide and those that follow illustrate the gradual filling of the basin that developed north of the Brooks Range during the Late Jurassic-Cretaceous orogeny. Initially, the basin was deepest to the south but as thrusting progressed and the basin was filled the axes of deposition moved northward.

The next two slides separate the Nanushuk Group sandy facies from the rest of the equivalent and older Torok and Okpikruak shaly facies.

This (slide 8, after Brosgé and Tailleur, 1969, fig. 7) is the predominantly shaly facies, Okpikruak, shown in olive green and the

Torok in the lighter green. The Okpikruak underlies the Torok and is shown only where the Torok is absent. The thicknesses represent both formations. Note that in the section and the map, the light area represents a change to a sandy facies and thus a thinning of the Torok and the darker area a more shaly facies and thus an apparent thickening of the Torok lithologic unit. The wells shown on the section are from left to right, the Kaolak, Meade, Oumalik, and east Oumalik test wells. We have plotted the shaling trends in the southwest as determined by mapping and the initial dips as interpreted from the seismic profiles. Near Barrow and probably in the Colville Delta area, the lower Torok thins onto the basement high. The upper Torok overlaps in full thickness onto the high but both upper and lower is then cut out by a pre-Turonian unconformity with a relief of as much as 4,000 feet. Near the Romanzof uplift relations are similar.

The black beds in the cross section are coal which is widely distributed in the west and constitutes about 90 percent of the coal reserve in Alaska.

The next map (slide 9, after Brosgé and Tailleur, 1969, fig. 8) shows the Nanushuk which is the sandy facies of the upper Albian, the time equivalent of the upper Torok, and the sandy rocks of Cenomanian age. The lined overprint indicates the area of interfingering marine and nonmarine and shoreline trends with predominantly nonmarine rocks to the west and south. The yellow indicates the 30-50 percent sandstone facies. The red line is the pre-Turonian unconformity in the Romanzof uplift area and in the Barrow-Simpson area. Note the wells and discoveries in this unit. Note that the Umiat field is in the sandy facies on the marine side of the interfingering zone.

The last isopach map (slide 10, after Brosgé and Tailleur, 1969, fig. 9) shows the Colville including the Seabee Formation. This map again shows the division into two basins by the Meade Arch, the north-south shoreline trends and the apparent thickening to the east with the thickest section just east of the Colville River and NPR-4. This map is different than the other isopach because here we have shown the total thickness by tints of green, each representing 1,000 feet. Because of the limited exposure and the regional dip to the northeast these may represent structure rather than thickness. To get at the thickness distribution we contoured just the Seabee Formation shown here in hundreds of feet. As you can see, these show a thickening to the east and may be representative of the entire group.

This is a very brief and likely a very transient look at the geology of the North Slope. I hope I have left an impression of a large, complex sedimentary basin that includes good source beds for ~~petroleum~~ petroleum-bearing zones in at least five Cretaceous horizons, one in Jurassic, one in Triassic and one in Late Paleozoic. Prudhoe Bay may be the only giant field on the North Slope but there are many other possibilities. Major geologic settings which are favorable targets for petroleum exploration include: 1) the buried "high" or shelf along the north edge of the Colville geosyncline where slightly deformed rocks of both the older and younger cycles of sedimentation may include reservoirs comparable to those drilled near Prudhoe Bay; 2) the eastern uplifted end of the Colville geosyncline and the flanks

of the Romanzof uplift where older rocks may be within drillable depths and extensive unconformities may provide traps; 3) ancient Cretaceous shorelines within the Colville geosyncline where winnowed sandstones form good reservoirs on structural traps such as at Umiat and Gubik; and 4) the structurally complex southern edge of the Colville geosyncline where older rocks are present at or near the surface.

The geology of the North Slope would be incomplete if I didn't at least mention again the word permafrost and its related engineering problems. The subject deserves separate treatment and some aspects of it will or have been discussed by other speakers at this conference. Realizing the tremendous importance of permafrost to North Slope oil development the U.S. Geological Survey prepared a summary report which was published on July 15 of this year as U.S. Geological Survey Prof. Paper 678. The report is written for the layman as well as the engineer and I recommend it to you.

Fig. 10 Generalized geologic map

QUAT.
- Q — Unconsolidated sediments

TERT.
- Ts — Sagavanirktok Fm

CRET.
- Kc — Colville Gp
- Kn — Nanushuk Gp.

CRETACEOUS
- Kt — Torok Fm
- Kf — Fortress Mountain Fm

JURASSIC AND CRET.
- KJ — Jurassic and Neocomian shale units, undiff.

CARBONIFEROUS, PERMIAN AND TRIASSIC
- TRPC — Upper part of Endicott Gp; Lisburne Gp; Shublik Fm, and Sadlerochit Fm in N.E.; Siksikpuk Fm in Endicott and De Long Mtns; Nuka Fm. in De Long Mtns

DEVONIAN
- De — Endicott Gp (lower part)
- Db — Baird Gp

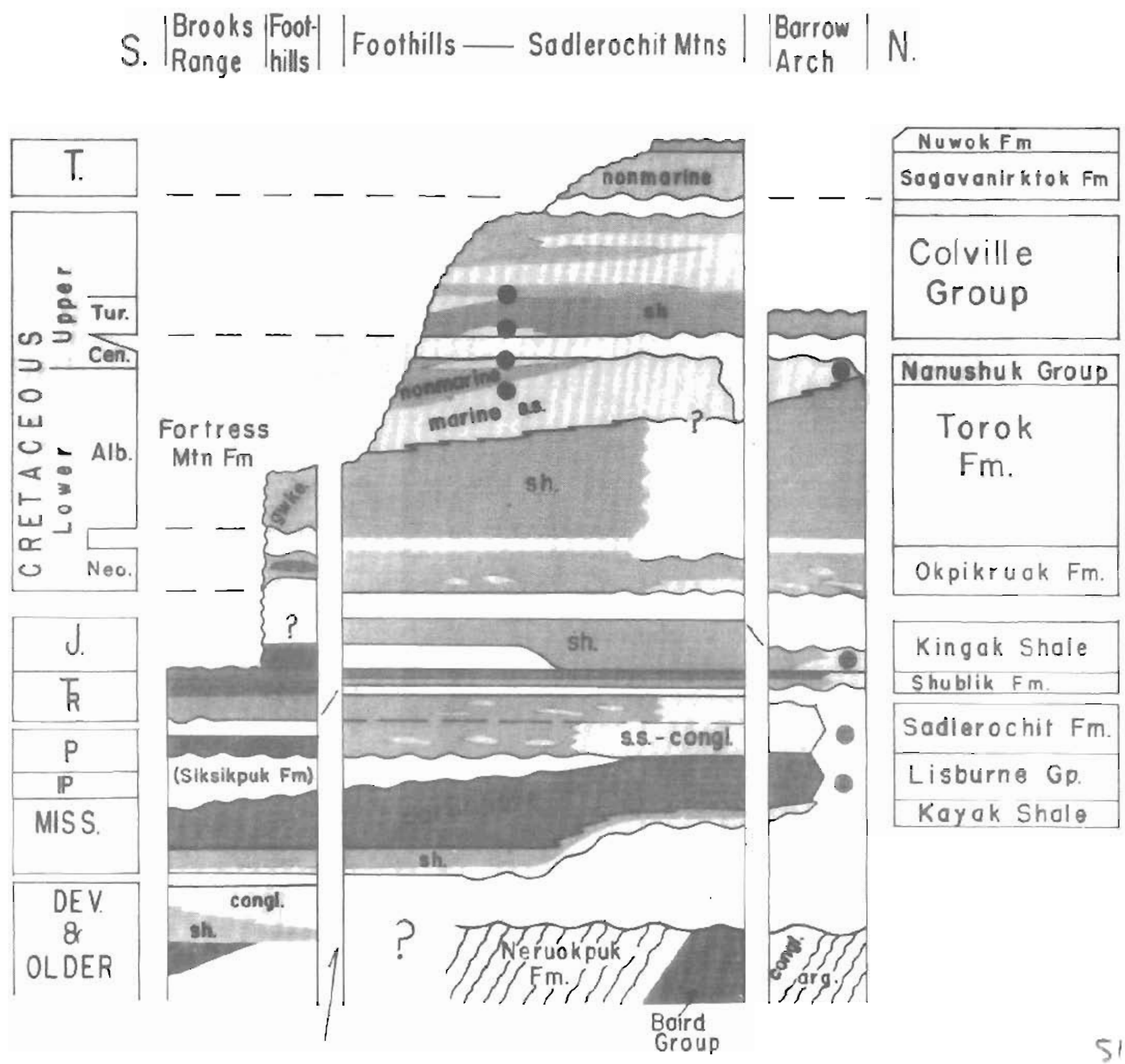
PRE-MISS.
- nK — Neruokpuk Fm.

PALEOZOIC OR MESOZOIC
- Ch — Chert
- g — Granite

JURASSIC(?)
- m — Mafic rocks

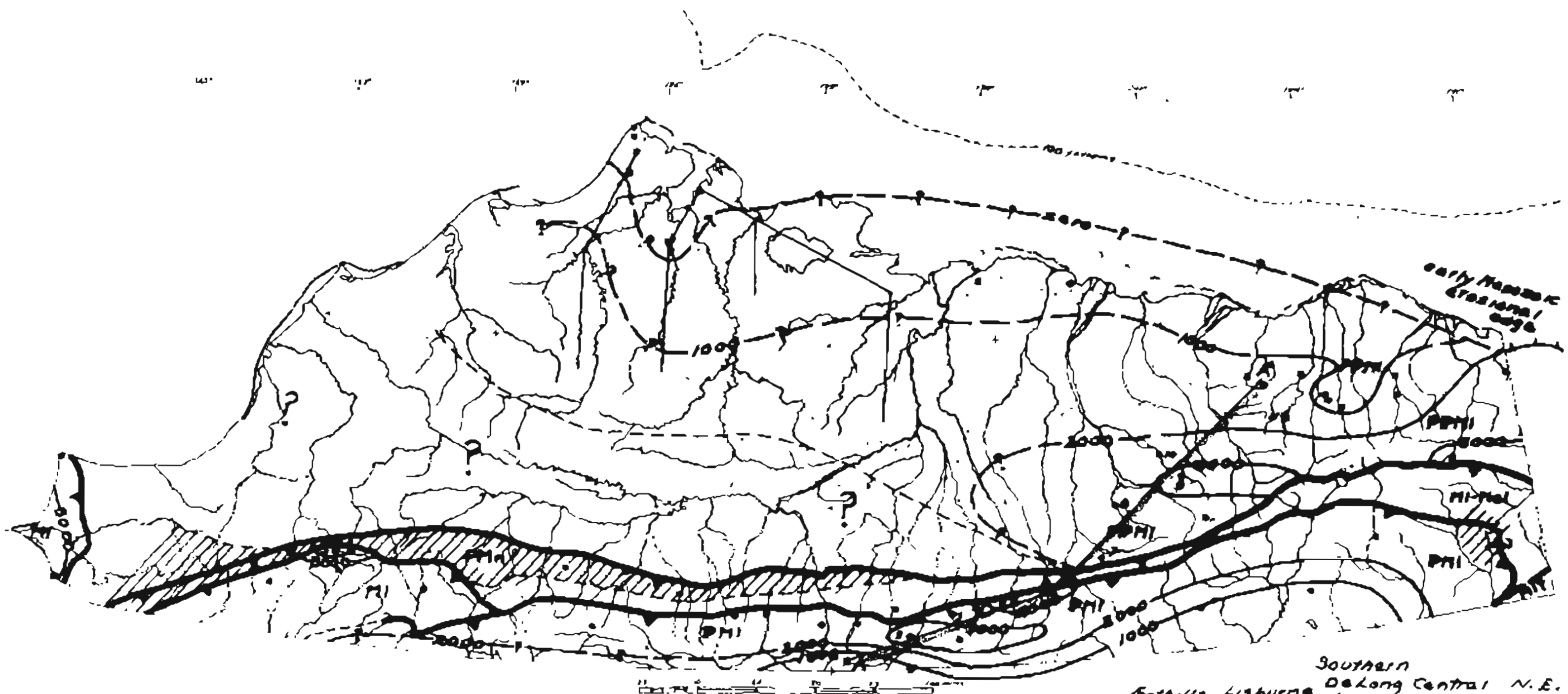
Geologic contact; dashed where concealed

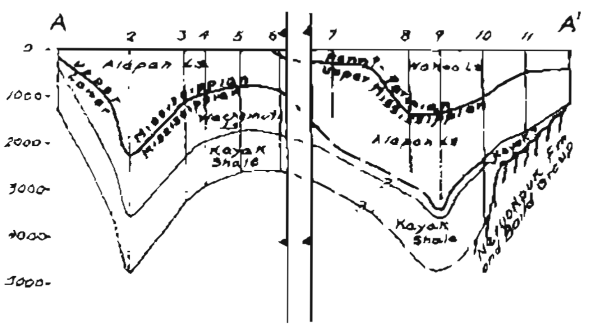
Fault; dashed where approximately located



S.
Brooks Range
Foothills
Foothills — Sadlerochit Mtns
Barrow Arch
N.
T.
CRETACEOUS
Upper
Lower
Tur.
Cen.
Alb.
Neo.
J.
TR
P
IP
MISS.
DEV. & OLDER
Fortress Mtn Fm
gwke.
?
(Siksikpuk Fm)
congl.
sh.
nonmarine
sh
nonmarine
marine s.s.
sh.
sh.
s.s.-congl.
sh.
?
Neruokpuk Fm.
Baird Group
congl.
arg.
Nuwok Fm
Sagavanirktok Fm
Colville Group
Nanushuk Group
Torok Fm.
Okpikruak Fm.
Kingak Shale
Shublik Fm.
Sadlerochit Fm.
Lisburne Gp.
Kayak Shale

Slide 4





Restored section; datum is base of Permian clastic rocks

Fig. 3 Lisburne Group

—1000— Thickness in feet

Ml: Nasorak, Kogruk and Tupik Formations; Lisburne Peninsula

Ml: Utukok, Kogruk and Tupik Formations; De Long Mtns.

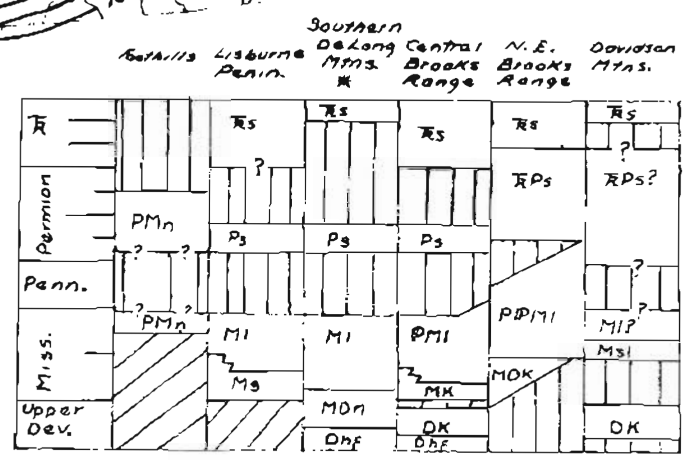
PMl: Wachsmuth, Alapah and locally, lower Wahoo Limestones

PPMl: Alapah and Wahoo Limestones

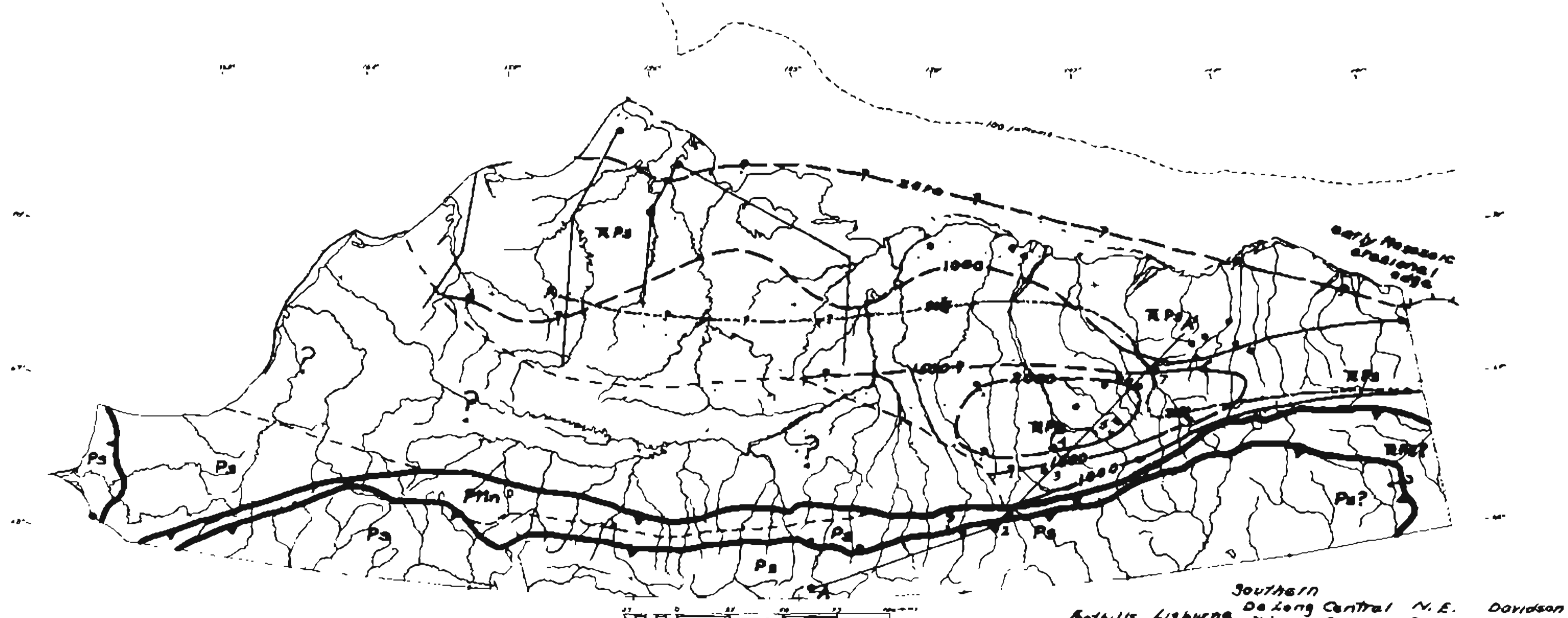
Ml?-Msl: Alapah(?) Limestone and unnamed Upper Mississippian black siltstone-limestone

PMn: Nuka Formation, lower part

///// Mississippian black shale-chert-limestone facies; includes lower Nuka Fm.



* Least allochthonous rocks only



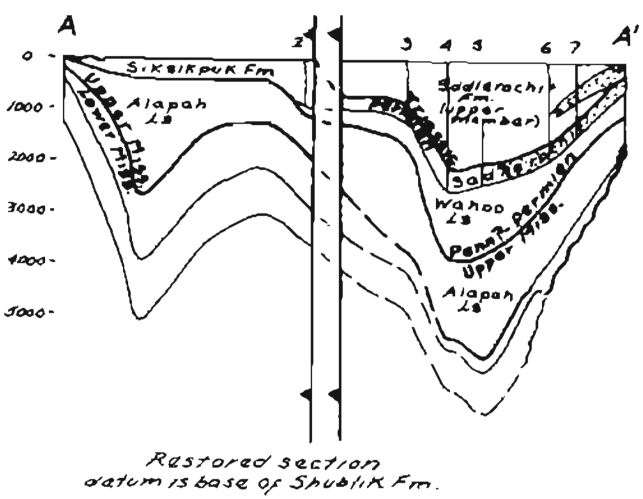


Fig. 4 **Permian and Lower Triassic Sadlerochit Formation**

—1000— Thickness in feet

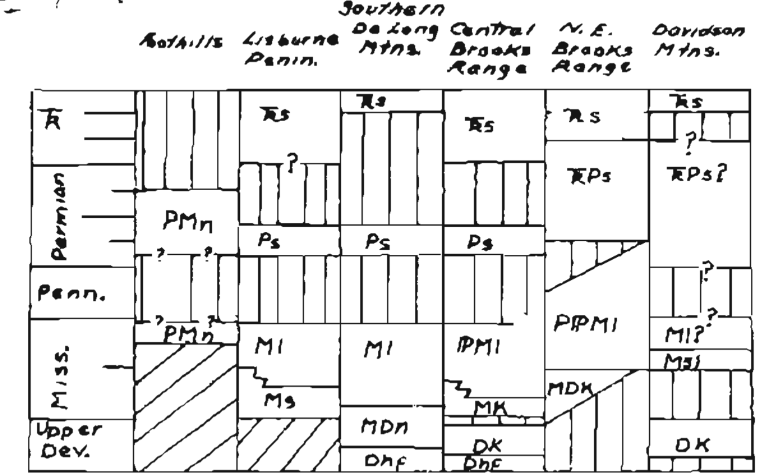
-..-30%-.. Southern limit of area of 30% or more sandstone in Sadlerochit Formation

TRPs: Sadlerochit Formation

Ps: Siksikpuk Formation; 200-1000 feet thick

PMn: Nuka Formation, upper part

TRs: Shublik Formation; not mapped



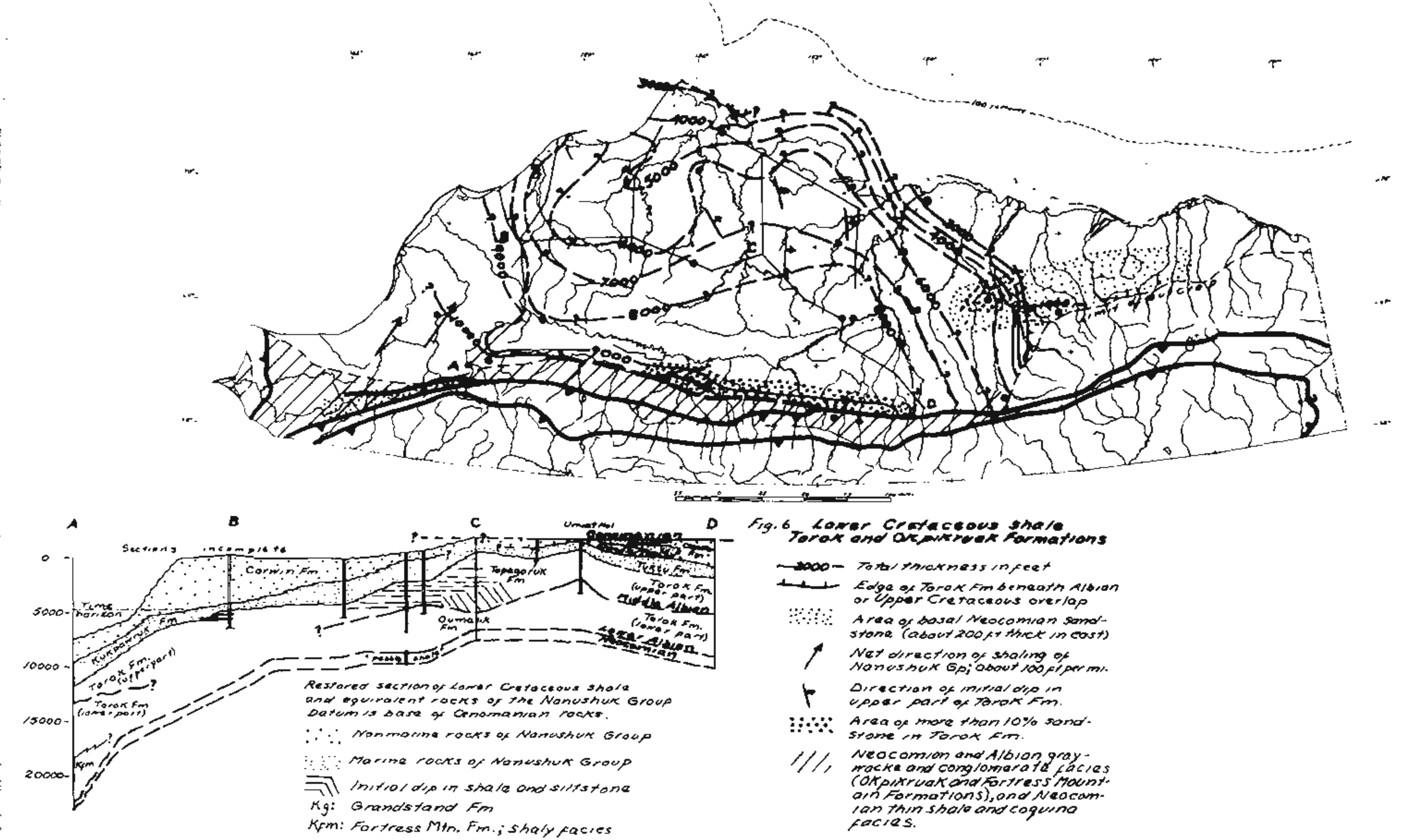


Fig. 6 Lower Cretaceous shale Torok and Okpikruak Formations

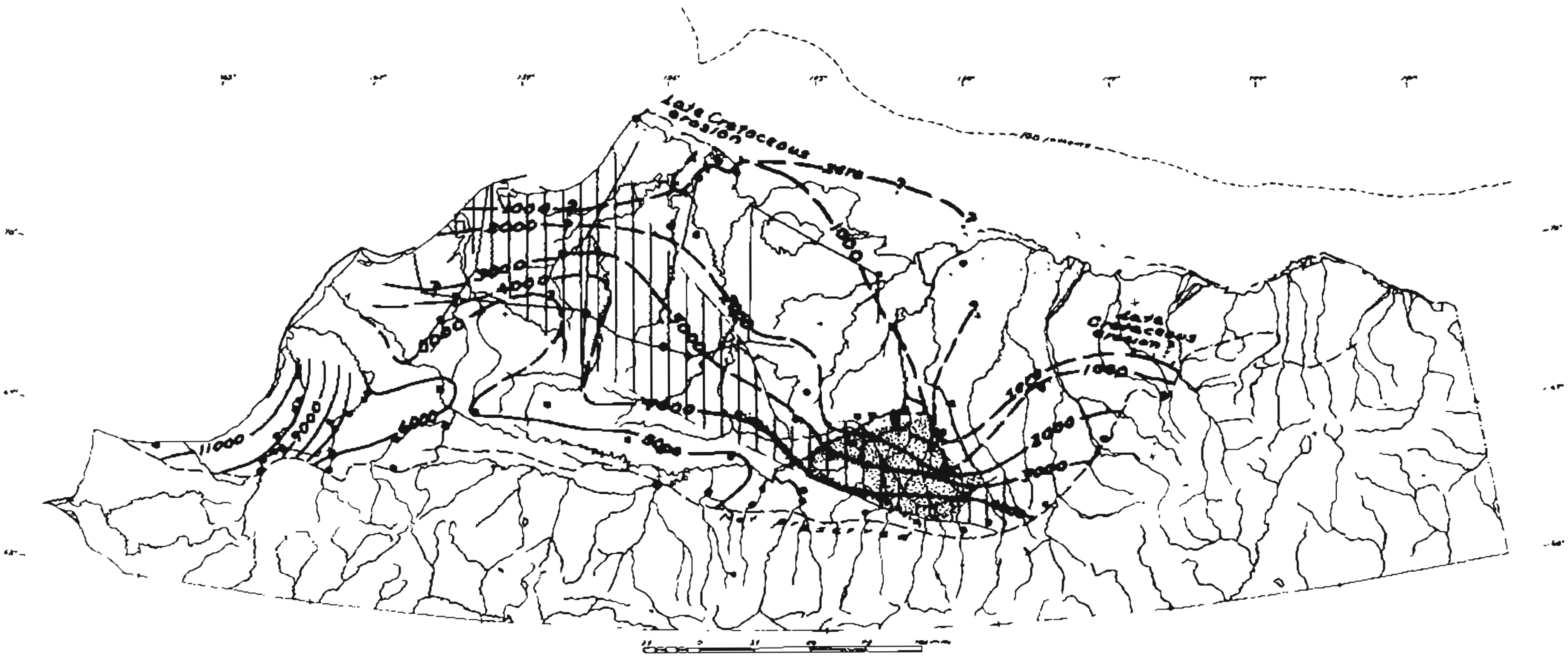


Fig. 7 Nanushuk Group
Albian and Cenomanian
marine and nonmarine sandstone and shale

—1000— Thickness in feet

Average shoreline. Rocks mostly marine to north, mostly nonmarine to south

Axis of greatest thickness of Cenomanian rocks, as much as 1150 ft thick

Area of Albian marine transgression over nonmarine rocks. Youngest Albian rocks are marine Grandstand Fm. (see restored section, Fig 6)

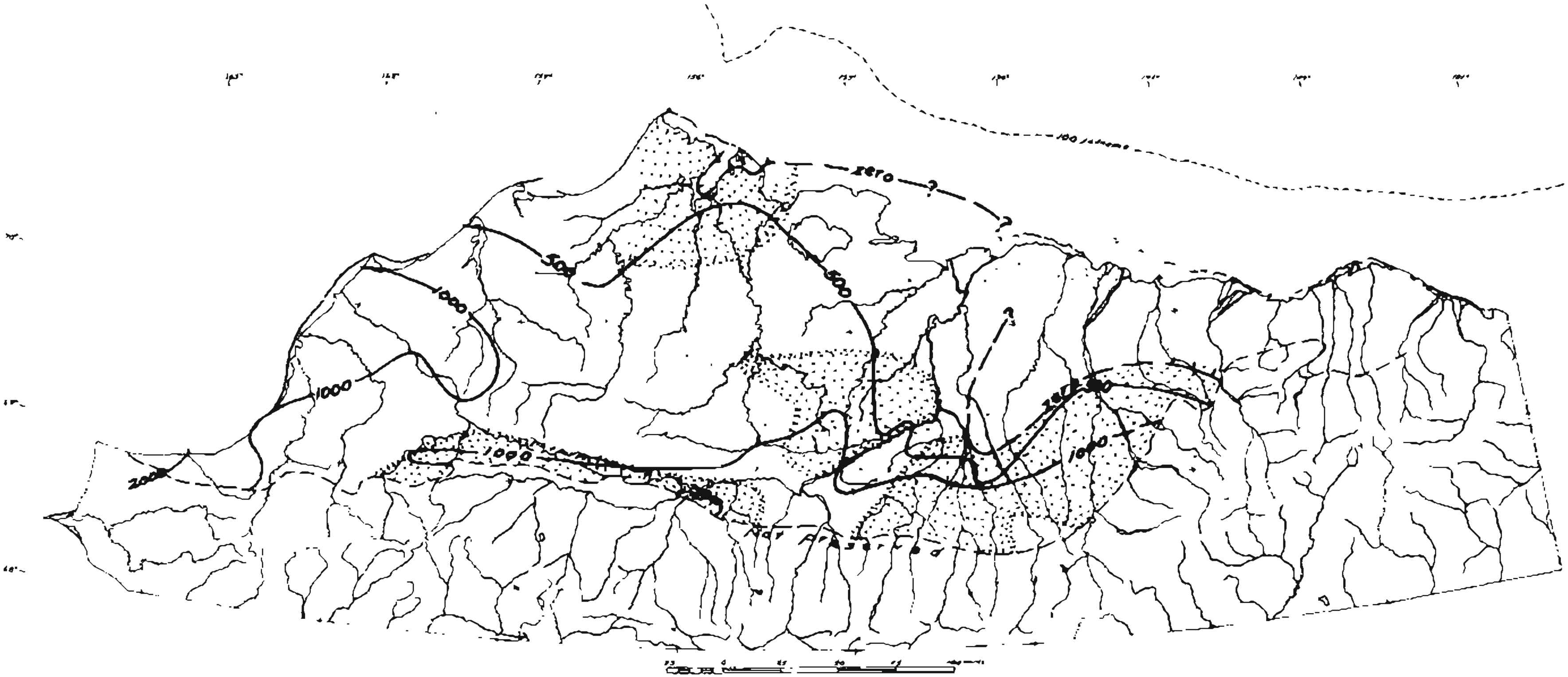


Fig. 8 **Nanushuk Group sandstone**

—500— Total cumulative thickness of preserved sandstone beds in feet; generalized

Nanushuk Group is 30% or more sandstone; area generalized

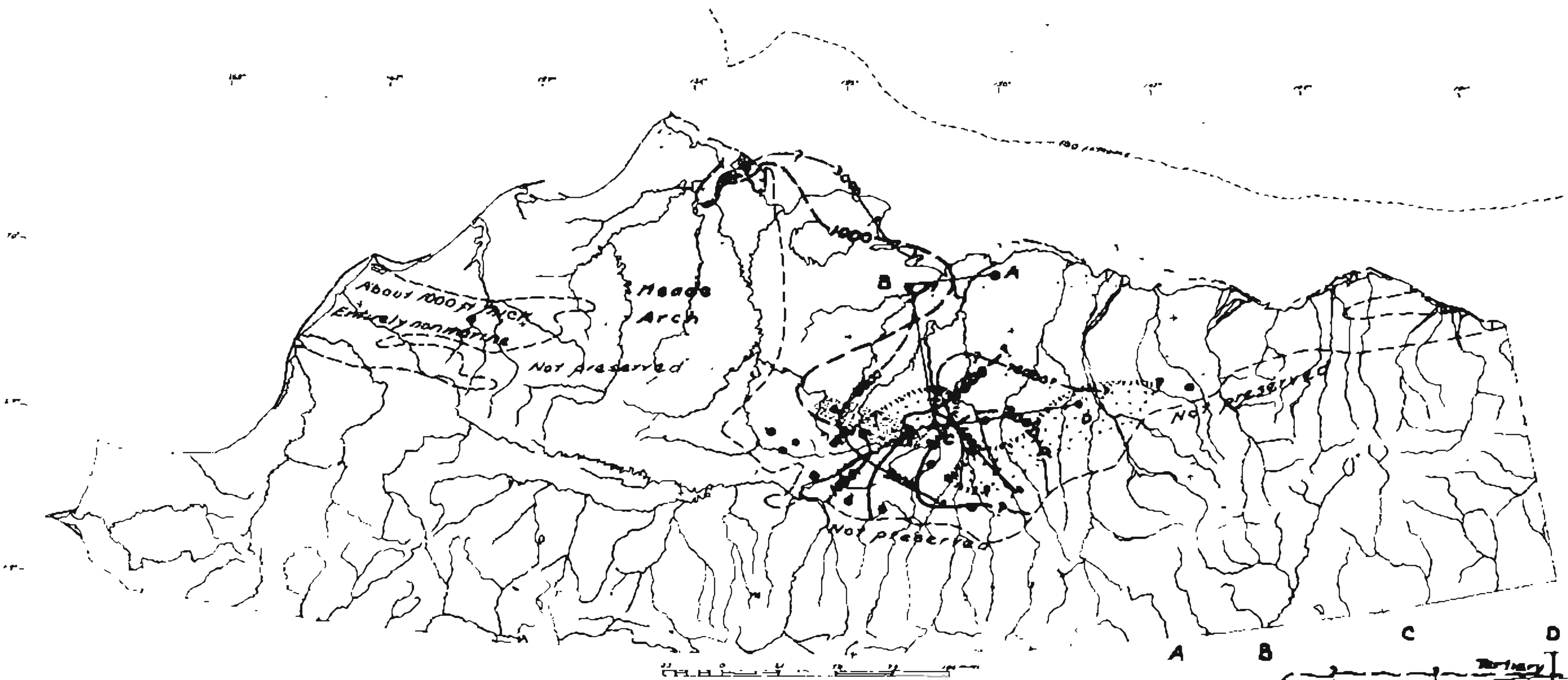


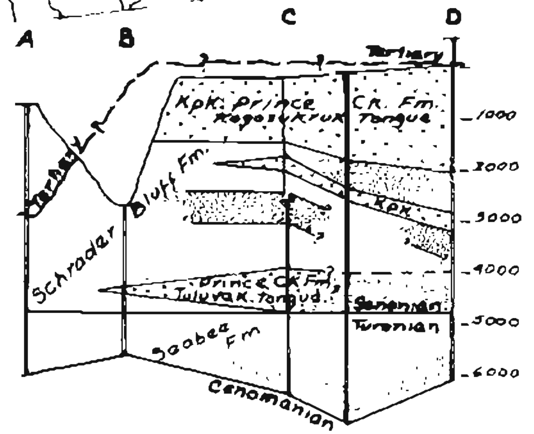
Fig. 9 **Turonian and Senonian Colville Group**

—3000— Thickness in feet of Colville Gp remaining beneath Tertiary and Quaternary unconformity. Most sections are incomplete

—1000— Thickness in feet of Turonian Seabee Fm. Not shown east of long. 150°

Area of 20% or more sandstone in Seabee Fm.

Area of 20% or more sandstone in Senonian rocks below the Kogosukruk tongue



Restored section of Colville Group
Datum is top of Turonian rocks

Nonmarine sandstone and shale

Marine sandstone and shale

Marine shale