United States

Department of the Interior

Geological Survey

Washington

Geological Investigations

Naval Petroleum Reserve No. 4

Alaska

Special Report No. 25

THE SUBSURFACE STRATIGRAPHY AND STRUCTURE OF THE SIMPSON AREA

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By

Thomas G. Roberts

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INTRODUCTION

During the summer of 1949, 12 core tests were drilled in the vicinity of Simpson Seep No. 2 on the east side of the Simpson peninsula. These tests were drilled in an attempt to determine the origin of the Simpson oil seeps and to evaluate the petroleum possibilities of the area. These holes failed to satisfy the objective for which they were drilled, but did define a nearly north-south linear ridge of essentially unconsolidated sand enclosed by a monotonous sequence of clay shale. A gas-bearing horizon and good oil shows were encountered on the crest of the ridge in the vicinity of Seep No. 2 during the 1949 drilling season. In November 1949 the Operating Committee approved the drilling of additional core holes in this area to resolve the complex geologic problems encountered by the shallow drilling of the previous season. Four additional tests had been completed by November 1, 1950, and a fifth is now in progress. Drilling completed thus far in 1950 has resulted in more accurate delineation of the sand ridge, and a flowing oil well has been discovered on the west edge of the ridge near Seep No. 3.

STRATIGRAPHY AND GEOLOGIC SETTING

The stratigraphic section penetrated by the drill in the Simpson Seeps area is as follows:

Pleistocene and Recent Gubik formation	Tundra, yellowish gray clay, sand, and gravel. Sand is poorly sorted, grains subangular to well rounded, mostly clear, white and yellow quartz and dark chert plus a small admixture of vari-colored grains. Gravel is primarily rounded black chert with a small amount of rock fragments including quartzite, mafic and silicic igneous rock, schist, and limestone. Excellent calcareous microfauna, also some pelecypods and gastropods.
UNCONFORMITY Cretaceous Nanushuk group Zone G	Clay shale, light gray to medium light gray, medium soft, good cleavage, silty partings, some finely disseminated pyrite, rare thin laminae of limestone and very calcareous siltstone. Nearly barren of microfossils except the rare radiolarian <u>Zonodiscus</u>.

Zone F	Clay shale, light gray to medium gray, similar to zone G but contains bentonite in varying amounts. Some sand, possibly reworked zone E, but "dirtier." Inoceramus labiatus, Borissjakoceras and abundant fish remains. Radiolaria and very few foraminifera. Identification of the macrofossils led to the discovery that the shale section overlying the sands was not Tertiary as previously supposed, but Upper Cretaceous.
UNCONFORMITY Upper zone E	Sand, medium light gray, usually very soft and clean, primarily white and clear quartz with dark chert, subangular, very fine to medium grained. Clay and claystone, medium light gray to medium gray, slightly harder and darker in color than Upper Cretaceous clays, silty partings less prominent. Hard, yellowish clay ironstone concretions and a small amount of coal and carbonaceous material present. The scaphopod Laevidentalium abundant, also some Inoceramus sp. and a very good foraminiferal fauna. The sands contain oil.

The Gubik formation covers the entire region as a thin (70 to 110 feet) mantle. The thickness of Cretaceous sediments varies because of the pre-zone F unconformity. During the progress of drilling it became increasingly apparent that the oil seeps are located along the crest of the north-south sandy ridge composed of upper zone E sediments buried by zone F and G (and possibly younger) shales. Both geologic and geophysical evidence indicate a regional north strike in the Seeps area. Dips in upper zone E sands as measured in core samples are never more than 3°. Dips in excess of 1°, however, are probably due to cross-bedding because correlation of recognizable horizons in core holes aligned at right angles to the regional strike consistently indicate regional dips to the east of less than 1°. For example, a correlative horizon recognized in Lake Minga Velocity Test No. 1 and Simpson Core Test No. 28 has a measured dip of two thirds of one degree. The base of the upper zone E sands has not been penetrated in the Simpson Seeps area. Attitudes in the overlying clay shales range from flat-lying beds to strata dipping erratically as steeply as 15°. Steepness in dip diminishes with distance from the sand ridge.

Unmistakable evidence of faulting has been found in Simpson Core Tests Nos. 13, 17, 21, 22, and 25. All of these tests are located near the edges of the sand ridge. Faults in these tests are indicated by slickensides, fault breccia, steep dips (as high as 70°), and loss of section.

The following table summarizes the geologic location of each of the core tests in the Simpson Seeps area (see index map).

Number and location of test	Depth to upper E sands	T. D.
On or near crest of ridge		
Near Seep No. 1		
23	570	1,035
24	580	901
Near Seep No. 2		
13	710	1,438
14	~~310~~ 480	1,270
15	~~300~~ 475	900
16	~~290~~ 475	800
17	565	1,100
Near Seep No. 3		
26	170	1,171
West of ridge		
18	does not penetrate sands	1,460
19	does not penetrate sands	1,061
25	830	1,510
Minga V.T. No. 1	740	1,233
East of ridge		
20	does not penetrate sands	1,001
21	1,270	1,502
22	does not penetrate sands	903
28	1,030	2,505

PREVIOUS INTERPRETATIONS OF STRUCTURE

In November 1949 the Navy Oil Unit presented a tentative explanation for the origin of the sand ridge.[1] The simplest, most logical explanation based upon data then available was that the sand ridge is a horst with normal faults on both sides. A minimum total displacement of 800 feet is required. Geophysicists of the United Geophysical Company have maintained that faulting of sufficient magnitude to produce the horst is conclusively disproved by seismograph reflection data. Several alternative hypotheses were considered and discarded as untenable, i.e., the sand ridge seems too persistent vertically to be an offshore bar, and the disappearance of the sand laterally seems too rapid to be the result of facies changes.

Mr. C. A. Everett, Arctic Contractors geologist on the 1949 Simpson Seeps Core Hole Project, suggested that the sand ridge is an erosional remnant produced after extensive uplift of the region.[2] The erratic dips and observed faults in the cores were explained by block slumpage along the sides of the ridge. It seems unlikely to the geologists of the Navy Oil Unit that sands as poorly consolidated as are those of upper zone E in the Simpson Seeps area could have been preserved in such a steep ridge

1/ Roberts, T. G., and Robinson, Florence M., Suggested correlation in Simpson Seeps area, U.S.G.S., Navy Oil Unit, Special Report No. 13, November 1949.

2/ Everett, C. A., Discussion of geology, pp. 16-25, in Arctic Contractors, Simpson Seeps Core Hole Project, Completion Report, March 1950.

under conditions of subaerial erosion. The failure of a distinctive sequence of zone F sediments to overlie the sands in two of the tests, as it does in all others, is also not readily explained by ordinary mechanics of erosion and resumption of sedimentation. The development of the unconformity by subaerial erosion would have required nearly 4,000 feet of uplift and an equivalent amount of subsequent subsidence. Crustal movements of such magnitude are not indicated by geologic evidence elsewhere on the Alaskan Coastal Plain. Mr. Everett's theory nonetheless fits the available data better than other theories previously presented. However, when drilling was resumed in 1950 an adequate explanation of the complex local geology still was lacking.

SUBMARINE EROSION THEORY OF SIMPSON SEEPS STRUCTURE

The combination of two quite unrelated developments prompted the application of a theory involving unique geologic mechanics to explain the geology of the Simpson Seeps area. First, a regional pre-zone F unconformity was suggested by Harlan R. Bergquist and Helen N. Loeblich during paleontologic study of the section in North Simpson Test Well No. 1 and subsequent review of microfaunas from surface collections. Secondly, Thomas G. Payne was impressed by the possible applicability of submarine erosion to explain the origin of the sand ridge. He suggested that an unconformity might have been developed under submarine conditions by erosion of the unconsolidated zone E sands by high density turbidity or gravity currents subsequent to a slight elevation of the marine shelf at the close of zone E time. Following this suggestion, Miss Florence Robinson and Mr. Payne prepared an isopach map of upper zone E sands (essentially a contour map of the unconformity). The map was compiled from both geological and geophysical data. The map outlined the shelf area, the thinning of zone E sands northward, and the sandy ridge in the vicinity of the seeps. This map was presented to the Operating Committee at the September meeting in Fairbanks. The United Geophysical Company subsequently has conducted a detailed restudy of shallow reflections from the Simpson peninsula seismic profiles, and has completed a similar map contoured on the pre-F unconformity.[3]

The geologic history of the Simpson Seeps area is best described in three stages. (See infolded block diagram illustration drawn by Helen N. Loeblich.)

Stage 1. Flat-lying winnowed sands of upper zone E were deposited on a shallow marine shelf. Southward, coals accumulated in a marshy coastal plain area. The strandline shifted north and south in a northwest trending belt south of Simpson Test Well No. 1

Stage 2. The marine shelf in the area of the Simpson peninsula was slightly elevated at the close of zone E time, which marked the beginning of a period of erosion of the shelf by waves and of the slope by turbidity

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3/ Exhibit L, Report of 1950 Operations and Proposed Integrated 1951 Program, by Fairbanks combined staff, November 1950.

GENERALIZED BLOCK DIAGRAMS SHOWING INTERPRETATIONS OF GEOLOGIC CONDITIONS IN SIMPSON PENINSULA
(based on information from drill holes and seismic profiles)

Stage 1. Deposition of flat-lying winnowed sands of upper Zone E on a shallow marine shelf. To the south, deposition of coals in a marshy coastal plain area. Strandline shifted north and south between Simpson and the site of Middle Meade T. W. No. 1.

Stage 2. Slight elevation of marine shelf at the close of E time in the Simpson area results in erosion of the shelf by waves and of the slope by turbidity currents, which cut shelf-edge canyons in upper E sands and in older sediments. Submarine hill (?) was left at site of N. Simpson T. W. No. 1. The E-F unconformity involves marked loss of section north of shelf edge (as at N. Simpson), slight loss of section in most of the coastal plain (as at Fish Creek, Topagoruk, and Middle Meade), and large loss of section in the uplifted Foothills.

Stage 3. Resumption of sedimentation in the Simpson area. Deposition of thin flat-lying marine beds of Zones F-I on the shelf area of Stage 2. Infilling of canyons and northward rebuilding of shelf by deposition, in topographically low area, of thick marine F-I sediments having dips of 5-15° (probably initial dips). Lithology and predominantly north dips suggest advancing foreset deposition below wave base, probably by turbidity currents.

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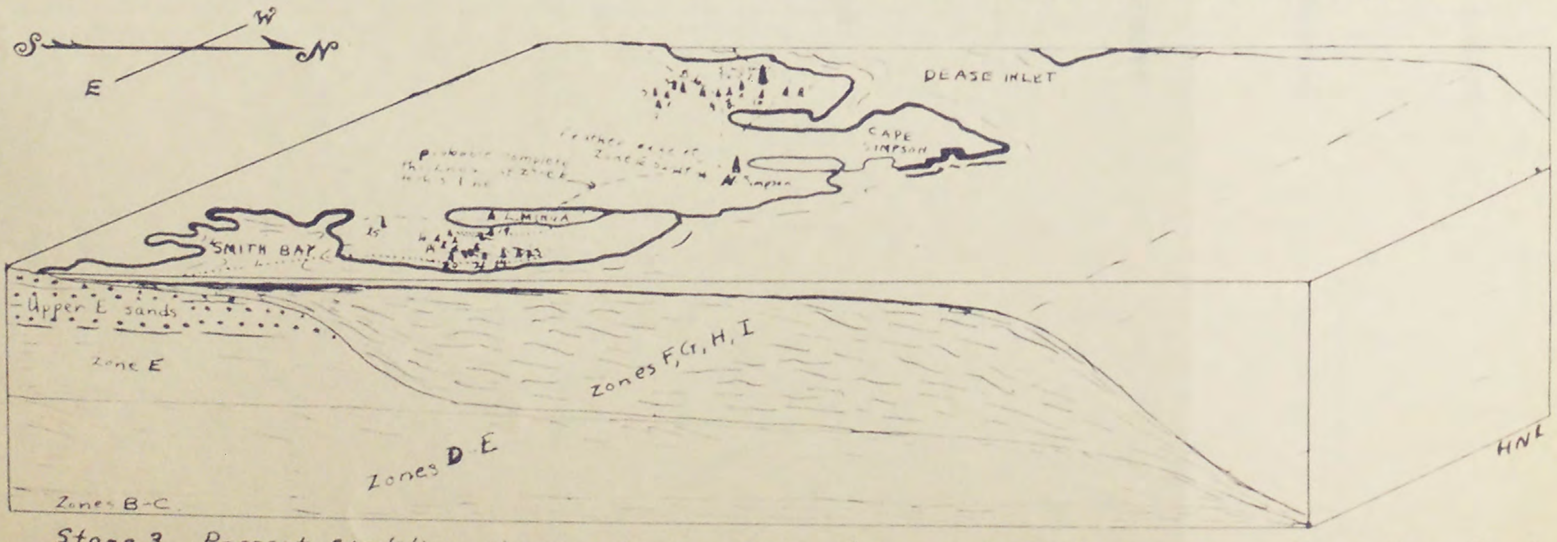
Stage 1. Inferred condition at close of Zone E deposition.

Stage 2. Post Zone E - pre Zone F erosional surface, showing result of submarine dissection of Upper Zone E sands



Stage 3. Present condition, showing dipping shales of Zones F-I resting unconformably on Upper Zone E sands and older sediments.

currents. Shelf-edge canyons were cut in the unconsolidated sands and clays. A submarine hill (of D-E clay shales) was preserved as an erosion remnant at the location of North Simpson Test Well No. 1. North of the area where upper zone E sands have been preserved, as much as 4,000 feet of sediments were removed by submarine erosion.

Stage 3. At the beginning of zone F time sedimentation was resumed in the Simpson area. Thin flat-lying marine beds of zones F to H were deposited on the shelf area of stage 2. Thick marine sediments with initial dips of 5° to 15° were accumulated in the topographically low areas by infilling of submarine canyons and northward rebuilding of the shelf. Deltaic types of lithology and predominant north dips suggest advancing foreset type of deposition below wave base, probably by turbidity currents which have been shown in the laboratory to be capable of both erosion and deposition.[4] At the beginning of zone F time the relatively quiet environment on top of the ridge favored the growth and fossilization of an abundant marine fauna, and the preservation of thin, almost varve-like laminae of bentonite. In the canyons, where deposition took place rapidly and quite possibly under unstable conditions, only traces of the diagnostic criteria by which zone F sediments are recognized were preserved.

The three stages in the geologic history of the Simpson peninsula are not believed to have been sharply defined times of completely dissimilar geologic processes. Rather it is assumed that stage 1 (stable marine deposition) was followed by a gradual change to a time when submarine erosion by turbidity currents became the dominant geologic process, and finally by another gradual change to a time when deposition of sediments, probably also by turbidity currents, became the primary geologic mechanism.

Faulting, evidenced by the data from five of the core tests, is believed to be large-scale slumping caused by slippage on the steep slopes of the ridge and by compaction of soft clays. All of the faults occur at or near the contact of the upper E sands and the overlying clay shales. The fault found in Simpson Core Test No. 13 may have cut upper zone E sands. Part of the apparent displacement of 435 feet along this fault may be caused by the slope of the surface of the unconformity. Displacement on the other faults cannot be measured because it is impossible to distinguish the loss of section by slumpage from that by submarine erosion.

The theory that submarine erosion has produced the geologic phenomena found in the Simpson Seeps area was developed early during the 1950 drilling season. Subsequent drilling of Simpson Core Tests Nos. 25, 26, and 28 has furnished additional support for this thesis and has required no revision of original maps except for thickness estimates of the upper zone E sands. The failure of Simpson Core Test No. 28 to encounter, at depth, the same sands found at shallow horizons near Seep No. 2 disproves that the east boundary of the sand ridge is a buried scarp of a normal fault. Simpson

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4/ Kuenen, P. H., and Migliorini, C. I., Turbidity currents as a cause of graded bedding: Jour. Geol. vol. 58, no. 2, pp. 91-107, 1950.

Core Test No. 25 is located well down the west flank of the sand ridge, and Simpson Core Test No. 26 is located at the west edge of the ridge. Local topographic highs on the sandy ridge, preserved beneath the unconformity, seem to account for the accumulation of oil and its escape at the seeps. A small oil seep, No. 2A, the precise location of which is not known at present, is approximately midway on a line between Seeps 2 and 3. The presence of this seep suggests that the ridge is continuous between Seeps 2 and 3. Geologic evidence is inconclusive to prove whether or not a saddle in the ridge exists between Seeps 1 and 2. Along the crest of the ridge the sands are as shallow as 200 feet.

For convenience of reference the deep north-south cut developed in upper zone E sediments between Lake Minga and the seeps is named Eureka Canyon, and the ridge along which the seeps are located is named Seep Ridge.

The fence diagram, enclosure 1, is a graphic representation of the area from Seep No. 1 to Seep No. 3. All holes shown are located with respect to triangulation station "East." No attempt has been made at this scale to illustrate sand-to-sand correlation, detailed lithology, or the slump faults. The uppermost occurrence of Laevidentalium, a good horizon marker, has been shown. Enclosure 2 is an index map showing the location of the Simpson Seeps Core Tests, Eureka Canyon, and Seeps Ridge. Contours on the pre-zone F unconformity also are illustrated.

The faunal and lithologic differences between Simpson Core Tests 10 and 12, located on the west side of the peninsula near Simpson Test Well No. 1, almost certainly have the same explanation as similar differences between core tests in the Seeps area. The sand and upper zone E fauna of Core Test No. 10 is located on the edge of the shelf, while the younger Cretaceous clay shales of Core Test No. 12 belong to the seaward sequence beyond the break in slope. This relationship is substantiated by geophysical evidence, and by dip measurements from cores.

OTHER CURRENT STUDIES IN SIMPSON SEEPS AREA

Study of heavy-mineral samples from cores in the Simpson Seeps area has revealed interesting data which complements the conclusion derived from lithologic, paleontologic, and electric log correlation. No data are in conflict. Robert H. Morris is presenting the results of his studies in a separate report.

The United Geophysical Company contour map of the pre-zone F unconformity (see page 4) generally is in close agreement with the interpretation to which the Navy Oil Unit subscribes. The only point of possibly important disagreement is the amount of eastward dip shown by the contours on the three different shallow horizons in zone E. Correlations based on lithologic and paleontologic data indicate that the easterly dip in the shallow zone E horizons is only about half as steep as they appear to be on the United Geophysical map if it is assumed that the dips shown in their three different contoured areas are representative of the regional dips in the zone E sands across the entire peninsula. The reflecting horizons from which these dips are calculated might be initial depositional dips below the thick sand beds but which cannot be projected upward and assumed to represent dips in overlying sediments.