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SALINITY STUDY, COOK INLET BASIN, ALASKA

By
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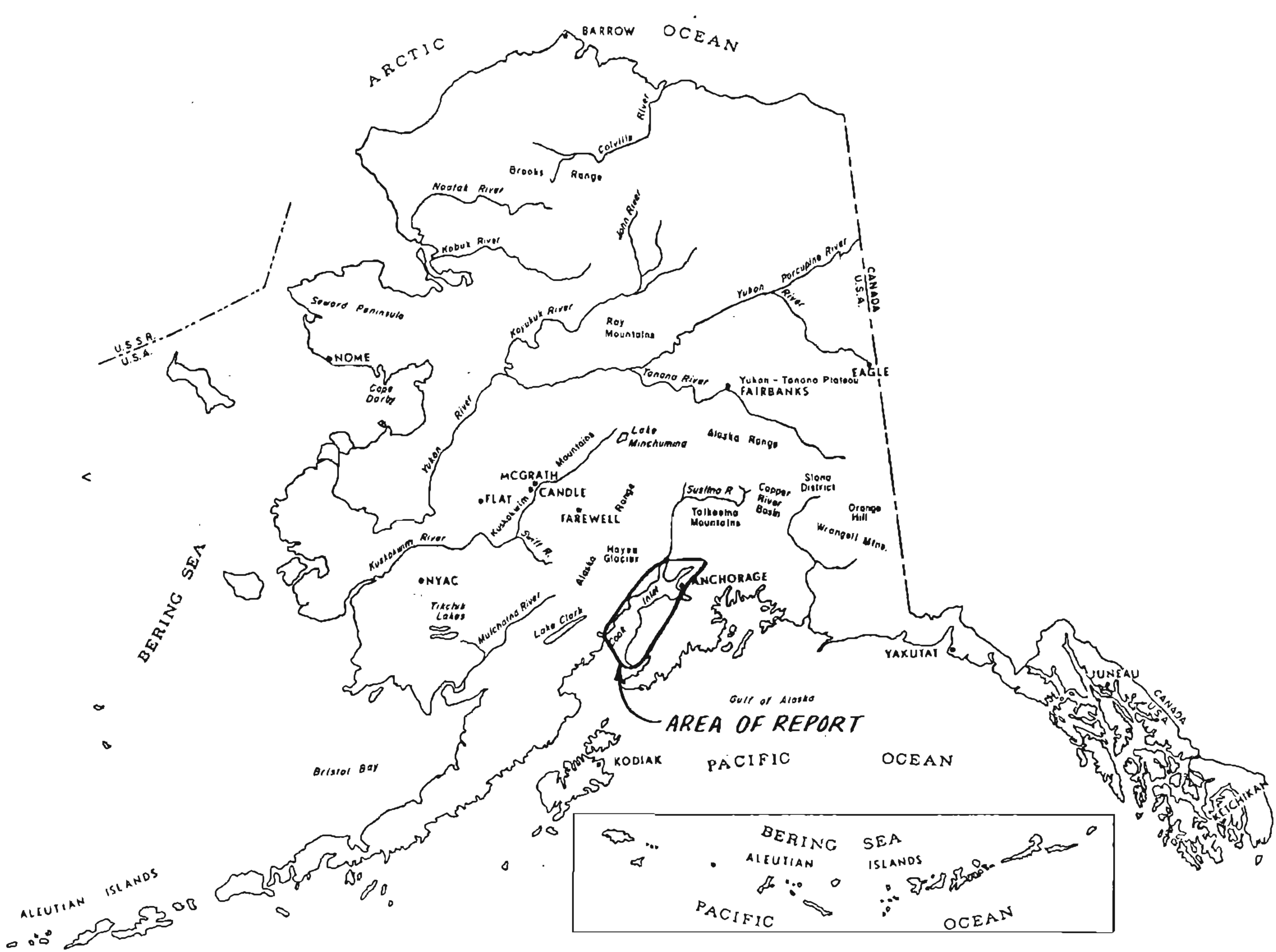
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ABSTRACT

Exploratory boreholes drilled in the Cook Inlet basin for oil and gas yield data that can be applied to the study of subsurface waters. Tentative conclusions relating to oil and gas include the following: 1) the commercial dry gas is associated with intermediate salinities and probably had a source in Tertiary sediments, 2) the oil migrated simultaneously with relatively salty water that probably originated from marine Mesozoic sediments underlying the Tertiary sediments either below or to the south of the presently producing oil fields, and 3) the depth to the high salinity horizon (1,000+ grains/gallon NaCl) is increasingly shallow to the south and suggests that oil may be encountered at relatively shallow depths in the south Cook Inlet.

The sedimentary section containing fresh water is thickest along the edges of the Cook Inlet basin, which suggests rapid entry of water in the recharge areas near the mountains, and is thinnest or nonexistent under the waters of the Cook Inlet, where the sedimentary section has not been exposed to fresh water. The Homer-Anchor Point area is an example of an area with a relatively thin fresh-water section that may have salt-water invasion if the fresh water is extracted too rapidly. The Matanuska Valley and the west side of the Cook Inlet are examples of areas underlain by thick fresh-water intervals that should provide adequate water for community needs from deep-drilled wells.

INTRODUCTION

The availability and quantity of fresh water is basic to the growth of any community. In particular, the subunits of the Cook Inlet basin, including the Kenai Peninsula, Matanuska Valley, Susitna basin, and the west side of the Cook Inlet are expected to grow at a rate exceeding the average growth rate for the entire state. Part of this report will examine, within the bounds of available data, the geographic areas of the Cook Inlet basin that have thick stratigraphic sections containing fresh water. The predominant data source is the large number of exploratory and production wells drilled for oil and gas, many of which penetrate nearly the entire Tertiary sequence of sedimentary rocks.

Although plate 1 is not a valid map for locating water wells, it nevertheless delineates those areas where adequate fresh water may be available for community needs if reservoir rocks are present. Conversely, the map points out areas where brackish water is relatively near the ground surface and where it may be difficult to sustain large flow rates of fresh water.

A second reason for examining the subsurface waters of the Cook Inlet basin is to relate the oil and gas accumulations with the salinity of the waters in which they occur. This part of the report is related to questions that arise as to the source of the oil and gas in the Cook Inlet basin. There are several theories that have been proposed. Generally accepted is the theory that the "dry" gas, or natural gas containing very few liquid hydrocarbons, is from Kenai sediments rich in organic material.

The source of the oil is generally more controversial but basically may be separated into the following theories: 1) oil migrated vertically from marine Mesozoic sediments known to underlie the producing areas, 2) oil migrated from a marine source south of the present producing areas, 3) oil migrated from both of these, and 4) oil migrated from Tertiary sediments; this is the least likely source, and is based on the separation of the water salinities associated with the dry gas and oil accumulations. The conclusions listed in this report are presented as tentative ideas, not concrete conclusions.

INTERPRETATION TECHNIQUES

Formationwater resistivity, directly related to the quantity of dissolved salts in the formation water, may be determined by several methods, depending on the basic information available. In an area where considerable exploration and development drilling has occurred, water resistivities have often been compiled from analyses of formation waters collected from different fields and different producing horizons. Values from this source are sometimes listed as chemical analyses and may be converted to resistivities or NaCl-equivalent concentrations. In many cases, however, water produced from initial production and exploratory tests is diluted with filtrate (water) from the drilling fluid and the values are incorrect.

If there are no available data or if the data are restricted, accurate values of water resistivity can often be calculated from spontaneous potential curves on electric logs. Water resistivity values are then converted to salinities and reported in grains per gallon NaCl.

DEFINITIONS AND WATER RESISTIVITIES CALCULATED FROM THE SSP CURVES

Most of the water resistivities were calculated using the format and charts of Schlumberger (1973). To understand the basic calculations, a number of definitions are listed below.

Definitions

a. SSP (static spontaneous potential) - A curve on an electric log that shows the spontaneous potentials at different depths of the borehole. It represents small electromotive forces caused by either infiltration (by the mud filtrate) of the reservoir rocks or possibly by an electrochemical reaction between mud and reservoir fluid (AGI Glossary of Geology).

b. Rmf (resistivity of the mud filtrate) - The resistivity of the fluid portion of the mud system, which represents a mixture of the make-up water (water derived from a surface or shallow subsurface source and mixed with the required solids and chemicals to form a mud system), of ions from chemicals added to the mud system, and of contaminants from the drilled formation.

c. Rw (resistivity of the formation water) - A measure of the conductivity of the water present in subsurface rocks: the lower the resistivity or the higher the conductivity, the more ions present and the saltier the water. The end result of the calculations described in this report is a specific resistivity of water from one subsurface interval at a known temperature. This value may be converted to grains per gallon NaCl. A general assumption is that the deeper waters can be treated as predominantly NaCl solutions. In fresh water, salts of calcium and magnesium become important, bicarbonate water is common, and a direct Rw approach becomes difficult.

d. Temperature - Determined by establishing a temperature gradient based on the maximum temperature measured during the logging run and extrapolating it to the depth where the Rw calculations are being made.

e. Connate Water - Water entrapped in the interstices of a sedimentary rock at the time of its deposition (AGI Glossary of Geology). By this definition, much of the formation water is not connate water, because migration of fluids within a basin and subsequent intermixing by fresh surface water changes the primary character of the water. In this report, the term "connate water" is not used and would be represented only in impermeable rocks that have prevented migration of the original fluids.

Water Resistivities Calculated from the SSP Curve

The basic formula, $SSP = \frac{-K\ (Rmf)e}{(Rw)E}$, which yields the amplitude of the SSP, was used. The water resistivity, Rw, can be calculated from this formula since K (related to formation temperature) and Rmf (resistivity of the mud filtrate) are known and the SSP can be read directly from the log.

The procedure is as follows:

1. Pick the sand with the least amount of shale (cleanest sand) in or near the interval of interest.

2. Calculate the temperature at this depth using the maximum temperature for the logging run (recorded on the log heading) and extrapolating uphole temperatures to the required depth (Schlumberger chart A-2, 1973).

3. Determine the resistivity of the mud filtrate at the calculated temperature. This is done by obtaining the Rmf value measured at the surface usually at a lower temperature (log heading) and determining the resistivity for the formation temperature with Schlumberger chart A-6.

4. Determine the value of SSP from the log curve by establishing a baseline and measuring the excursion of the curve to the left of the baseline.

5. Solve the SSP equation for Rmf/Rw by using Schlumberger chart A-10.

6. Determine the value of Rw by using the value of Rmf and converting Rw at a known temperature to grains per gallon NaCl with Schlumberger chart A-6.

VERTICAL DISTRIBUTION OF SALINITIES IN THE COOK INLET BASIN

Water salinities in the Cook Inlet basin may be essentially grouped into the following four concentrations, each with a particular salinity range.

1. Fresh Water - "Fresh water" as used in this report is water that is usable for community needs. Nearly all of Alaska's fresh water contains varying amounts of salts other than NaCl. In many of the wells in the Cook Inlet basin, a salt water—fresh water gradient is present; the base of this interval has been chosen as the base of the fresh-water interval. These waters are limited to the upper part of the section and largely represent the water that percolates into the reservoir rocks from rain, stream, and snow accumulations. As might be expected, the depths to the base of

the salt water—fresh water gradient are deep along the marginal edges of the basin, where porous and permeable rocks are exposed to streams and other sources of fresh water, and are shallow or nonexistent under the waters of the Cook Inlet, where they have not been exposed to fresh water systems.

2. Slightly Salty to Moderately Salty Water - The salinities for these waters range from slightly saltier than fresh water to less than 200 grains per gallon NaCl. This is the zone in which intermixing of fresh and salt water would be expected.

3. Moderately Salty Formation Waters - These waters have a salinity in an intermediate range between brackish and salty water, from 200 to 1,000 grains per gallon NaCl. They represent water of about the same salinity range as the water present when the original sediments were deposited. They are not considered connate waters because of the probability of migration in the more permeable sediments.

4. Very Salty Formation Waters - The term "very salty" is used here in a relative sense---none of the very salty formation waters in the Cook Inlet approach the high salinities often measured in other basins. These waters have salinities in excess of 1,000 grains per gallon. Because of their non-marine environment (probably deposited in brackish water) they may represent either vertical migration of salty waters into stratigraphically higher reservoirs from an older source or migration of salt water and oil from a source south of the present productive areas. Because nearly all the oil accumulations in the Cook Inlet are associated with formation waters with salinities in this range, a correlation may exist between the liquid hydrocarbons and the relatively salty formation waters.

MAP PRESENTATION OF THE CALCULATED WATER SALINITIES

Logs from selected boreholes drilled for hydrocarbons within the limits of the Cook Inlet basin were analyzed and values of water resistivities calculated. These values were then transferred to cross sections (pl. 1-5) and maps were constructed. Plate 6 is a thickness map contoured from the base of the fresh water—salt water gradient and represents the interval from the ground surface to the approximate top of salt water. Plate 7 is contoured on the subsea depth of the 1,000-plus NaCl grains-per-gallon water; it represents a surface below which the waters are all relatively salty and is also the top of the section in which nearly all the liquid hydrocarbons (oil) occur in the Cook Inlet.

INTERPRETATION RESTRAINTS

There are several problems inherent in determining the water resistivity from the SSP curve. In the shallow intervals, salts other than NaCl are commonly present. In the deeper intervals, analyses of formation waters obtained from tests in the Cook Inlet demonstrate that nearly all the salt present is NaCl and that other contributors to conductivity may be ignored. SSP baseline shifts, or the tendency of the curve to drift because of mechanical or electrical functions (common for logs run in the Cook Inlet), sometime makes it difficult to measure the SSP departure. Sometimes an electrokinetic potential affects the SSP. However, this component of SSP can generally be considered negligible in the Cook Inlet because the sands have adequate permeabilities, the deeper waters are salty and the drilling fluids are generally in a normal pH range. Probably the greatest introduced error is in determining the depth where salinity changes occur. There are thick intervals of silt, clay, and clayey sands that do not contain sands that are clay-free enough to make salinity determinations. Calculations below and above these intervals often show that a salinity change has occurred, but the depth at which the change occurred is not known.

CONCLUSIONS

Fresh Water, Plate 6

1. Plate 6 indicates geographic areas where thick intervals of fresh water occur. Because adequate fresh-water reservoirs must be present, the map cannot be used to directly determine the quantity of extractable water. However, it can delineate areas where problems may occur if fresh water is extracted too rapidly. The Homer area, for example, is underlain by brackish water at a relatively shallow depth, and the use of fresh water at high rates may cause salt water to enter the wells. Areas such as Anchorage apparently have an adequate interval of fresh water, but thick portions of the section do not contain reservoir rocks. The Matanuska Valley, on the other hand, has a combination of adequate reservoir rocks and a thick fresh-water section, which should present a favorable water source.

2. The thickening of fresh-water intervals near the basin edges is related to proximity to recharge areas and to possible preservation of fresh water originally present during the deposition of the sediments.

3. Large areas on the west side of the Kenai Peninsula have thick fresh-water intervals and should have adequate water from drilled wells.

4. Thick fresh-water intervals are present on the west side of the Cook Inlet and future growth needs could be easily supported---particularly industries requiring large amounts of fresh water.

5. The steep gradient of the base of the fresh water to the west---from none under the waters of the Cook Inlet to thousands of feet in the Beluga area---may be partly related to block faulting but may also represent large areas of surface-water recharge.

Saline Water, Plate 7

1. All the commercial oil accumulations in the Cook Inlet are associated with relatively salty water (1,000-plus grains per gallon).

2. All the commercial dry-gas accumulations in the Cook Inlet are associated with less saline water (200 to 1,000 grains per gallon). Waters in this salinity range are believed similar to those associated with the sediments during deposition.

3. The arcuate salt-water ridge containing the known commercial oil fields in the Cook Inlet may be related to vertical migration of water from older marine sediments. The configuration of this ridge suggests that structure is a modifying but not a controlling physical element for the top of the

high-salinity surface and that a relationship exists between vertical salt-water migration (migration from marine Mesozoic rocks) and the configuration of this surface.

4. A shallow high-salinity belt on the west side of the Cook Inlet extends from the mouth of the Susitna River apparently into the south Cook Inlet. The top of this surface rises rapidly near the south end of the Kenai Peninsula (south of the Pennzoil, Starichkof State 1 and the Occidental, South Diamond Gulch boreholes). Although control is lacking, the configuration suggests that the depth to high-salinity waters in the south Cook Inlet may be shallow. The presence of oil shows in the Standard Oil of California North Fork Unit 11-4 and the Pennzoil, Starichkof State 1, both associated with salty waters, again suggests a relationship between the oil and salt water and the possibility of a similar genetic source.

5. Plate 7 also suggests that oil would be confined to deep horizons in the eastern part of the Kenai Peninsula.

Summary

This report suggests a genetic relationship between oil and associated salt water. The source of the liquid hydrocarbons for the known productive fields is probably from underlying marine Mesozoic sediments. This does not, however, preclude the possibility of migration of oil and saline water along the west side of the Cook Inlet from a marine source south of the oil-productive areas. If the salt water is acting as a transportation medium for the liquid hydrocarbons, there may be shallow Tertiary oil accumulations in the south Cook Inlet (pl. 7). If, as indicated in this report, the gas is associated with less saline waters and probably derived from Tertiary sediments, the section containing dry gas may be relatively thin in the south Cook Inlet.

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