Reports

Yukon River: Evidence for Extensive Migration during the Holocene Transgression

Abstract. *The shift of the Yukon River, during the Holocene sea-level transgression, from south of Nunivak Island during the Wisconsin maximum to its present location (a distance greater than 300 kilometers) is indicated by remanent channels, distinct subbottom structures, deltaic sediments, and anomalous rates of sediment accumulation on the continental shelf of the east-central Bering Sea. These features were produced as the ancestral river migrated northward across the easternmost part of this area before 11,000 years ago.*

Recent articles dealing with the geology of the coast and continental shelf of the eastern Bering Sea suggest that the main channel of the Yukon River has shifted considerably since the last maximum lowering of sea level about 20,000 years ago. On the basis of bathymetry, anomalous aeolian deposits on St. Paul Island (south of the map area of Fig. 1), and the location of ancestral channels and distributaries, it is likely that the Yukon River passed south of Nunivak Island (Fig. 1) and breached the shoreline near the Pribilof Islands during the lowest ebb of sea level (*1*, *2*). Indeed, Hoare and Condon (*3*) and Shepard and Wanless (*4*) deduce that there have been major drainage diversions within the area of the Yukon-Kuskokwim deltaic plain since the beginning of the last (Holocene) sea-level transgression. Mineralogic studies in the Northern Bering Sea (*5*) support the hypothesis that the mouth of the Yukon River has only recently attained its present position (Fig. 1).

Because of the possibility of extensive lateral migrations, the position of the Yukon River system during the Holocene transgression is difficult to determine. Yet, if the hypothesis is correct that during this time the drainage shifted from south of Nunivak Island to its present location, then it must have extended at some time onto the subaerially exposed shelf between St. Lawrence and St. Matthew islands (Fig. 1). This study indicates that the ancestral Yukon River flowed onto the easternmost part of this area between 11,000 and 16,000 years ago and, as a result, left its imprint in the bathymetry, sediments, and shallow subbottom structure.

The Yukon River probably did not flow within the zone of isobathic flexure south of St. Lawrence Bank (Fig. 1) despite the fact that this zone was a likely course. This is indicated by the absence of pronounced bathymetric discontinuities, the paucity of subbottom channels, and the lack of acoustic and sedimentary evidence for deltaic deposition. Along the Alaskan mainland, however, the location of subaerial, ancestral channels suggest that the Yukon River created the depression which parallels the coast south of Cape Romanzof (Fig. 1). Consequently, the river, at one time, probably skirted the eastern end of Nunivak Island. In addition, it is likely that the Yukon River during its northward excursion was responsible for an area of sedimentary progradation near the small bathymetric terrace about 120 km northwest of Nunivak Island and for a broad buried channel, both near the site of core 080-184 (Fig. 1). The progradation is discernible in east-west, high-resolution, subbottom records that were obtained along 50 km of track line just south of the terrace, and is taken as an indication of deposition very close to shore. The buried channel was found just north of the core location and (along a north-south line) is as wide as that of the modern Yukon River.

The composition and age of the sediments in core 080-184 indicate not only that the Yukon River flowed onto the easternmost part of the area, but

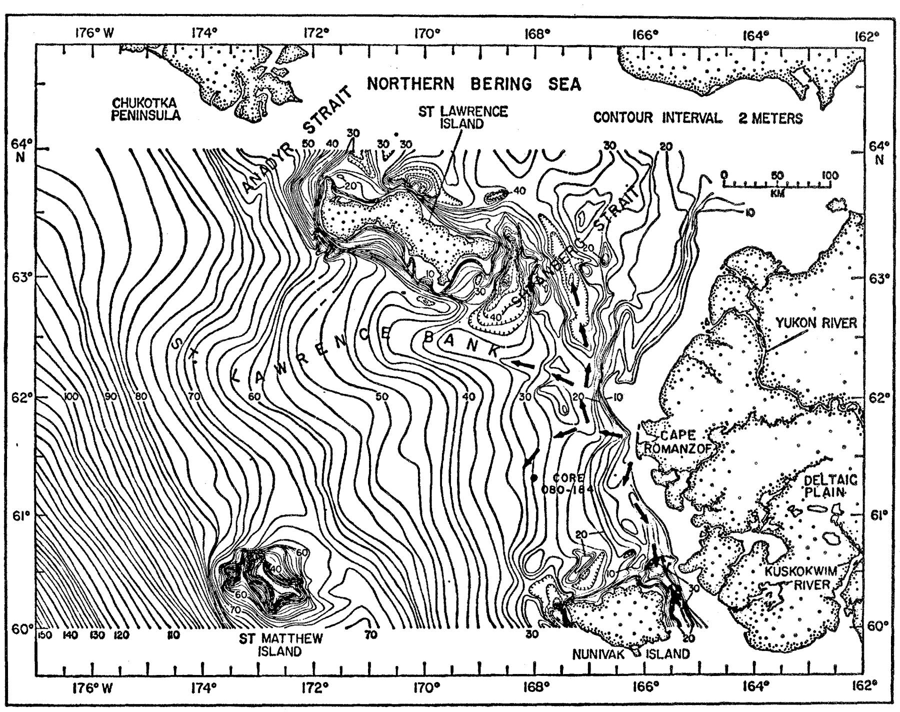

Fig. 1. Index map of the east-central Bering Sea, including bathymetry (*9*) and location of core 080-184. The series of channels which extend across the Yukon-Kuskokwim deltaic plain are flanked by old flood plain deposits and are believed to be former channels of the Yukon River and its distributaries (*3*, *4*). Not all such ancestral channels are shown. The arrows indicate the probable routes of the Yukon River on the former coastal plain.

that it did so about halfway through the transgressive period. Core 080-184 contained only 102 cm of sediment. Within the core, small sandy layers are intercalated with larger silt units. The sandy layers contain foraminiferal remains indicative of deposition under inner shelf conditions (*6*), whereas the silt units contain excessive wood and plant fragments but are devoid of other biogenic components. The radiocarbon age of sediments from the uppermost silt unit, at only 30 cm from the top of the core, is $11{,}800 \pm 190$ years (*7*).

The absence of marine fossils in the finer-grained strata may be the result of nondeposition of tests (due perhaps to nonmarine conditions) or of dilution by terrestrial detritus. Shepard (*8*) has cited the abundance of wood and plant fragments together with a scarcity of foraminiferans as a criterion for the recognition of a marine deltaic facies. The hypothesis that the surface sediments have been largely reworked in the area from which the core was obtained (*9*) is substantiated by the relatively old age of the sediments so near the surface. Thus, in addition to the compositional characteristics of the core, both the presence of reworked sediments along the Alaskan mainland and the age of the sediments relative to the transgressive period are consistent with the suggested migration of the Yukon River.

There is also evidence that the Yukon River debouched on or near the easternmost part of St. Lawrence Bank (Fig. 1). Numerous buried channels occur on its crest at depths less than 38 m. These channels may be remanents of the Yukon River when it crossed the present shoreline near Cape Romanzof (*3, 4*) and flowed toward the northwest (Fig. 1). The channels may have been formed during a widely recognized stillstand of sea level at about -38 m approximately 12,000 years ago (*2, 10*).

Finally, the presence of the Yukon River on or just south of St. Lawrence Bank readily explains the stratigraphic relationship, the characteristics, and the rates of accumulation of sediments north of the western part of St. Lawrence Bank. High-resolution seismic reflection profiles that were obtained normal to the western part of the bank show a thickened lens of acoustically transparent sediment north of the crest (*11*). This lens thins and appears to be draped over the northern flank of the bank, thus creating a more extensive bathymetric feature. Piston cores that were obtained in this area show that the lens is composed primarily of silt (the dominant size group carried by the modern Yukon River) and that the sediments contain abundant plant fragments (*9, 11*). Radiocarbon ages and foraminiferal assemblages indicate that these sediments were deposited between 11,000 and 16,000 years ago, when sea level stood between depths of -30 and -70 m. In the eastern part of this area, sediments accumulated at approximately 62 mg cm^{-2} yr^{-1} (52 cm per 1000 years) (*12*), whereas the rate of accumulation farther west may have been as high as 119 mg cm^{-2} yr^{-1} (102 cm per 1000 years) (*9*).

The stratigraphic relationship of the sedimentary lens, plus the textural and biogenic characteristics of the core sediments, suggest quiet water deposition on the north side of the bank. Because sea level was below -30 m during the time of deposition, Shpanberg Strait (Fig. 1) was closed, and the rudimentary oceanographic circulation was probably directed toward the west. Flow into the Northern Bering Sea was confined to Anadyr Strait. Fine sediments derived from the Yukon River, insular drainage to the south, or former shelf deposits could have been carried over St. Lawrence Bank and deposited on its lee (northern) side. Although several origins for these sediments are possible, a relatively large source (such as the Yukon River) is requisite for the high rates of sediment accumulation north of the bank.

Radiocarbon ages of sediments from cores north of St. Lawrence Bank also indicate that after 11,000 years ago the rates of accumulation decreased greatly. The depositional rates were estimated at two locations and were found to be less than 13 mg cm^{-2} yr^{-1} (12 cm per 1000 years). Moreover, foraminiferal data indicate that modern sediments form only thin layers at the tops of cores; the maximum thickness was 1 m (*9*). The decrease in depositional rates and the thin surface layers may reflect either a change in the sediment source (perhaps the departure of the Yukon River) or a change in the oceanographic regime, or both. Initiation of the present-day northward flow through Shpanberg Strait accompanied the rise of sea level above the Shpanberg Strait sill depth of -28 m. The sedimentary ridge and adjacent trough in the eastern part of Shpanberg Strait (Fig. 1), which are relict features (*5, 13*), as well as the shoal north of Cape Romanzof, may have been developed during the waning stage of the transgression but before the shift of the Yukon River to its present location.

Studies just being completed on sediments of the Chukchi Sea to the north of Bering Strait suggest that there was no significant influence by sediment sources other than surrounding drainage basins until 11,000 to 13,000 years ago. At about this time, the aspect of sediments deposited in the southern Chukchi Sea was changed markedly by the introduction of quantities of silt-sized inorganic particles, which are most readily explained by a northward shift of the Yukon River to a position where its discharge of silt became a significant factor in the sedimentary environment of the Chukchi Sea.

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6. A scheme for paleoenvironmental interpretation of sediments from the east-central Bering Sea shelf based on the tests of foraminiferans is presented by Knebel *et al.* (*11*).
7. Radiocarbon ages were determined by Teledyne Isotopes, Westwood, New Jersey, and were based on the carbonate-free carbon content of the sediments. In an attempt to correct the ages for contamination by inactive carbon, the "readily oxidizable organic material" (*14*) was determined for the samples by using the Walkley-Black analysis and was subtracted from the carbonate-corrected total carbon contents. The remainder was attributed to inactive carbon. Corrections suggested by Broecker and Kulp (*15*) were applied.
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Alpha Particles in Solar Cosmic Rays over the Last 80,000 Years

Abstract. *Present-day (1967 to 1969) fluxes of alpha particles from solar cosmic rays, determined from satellite measurements, were used to calculate the production rates of cobalt-57, cobalt-58, and nickel-59 in lunar surface samples. Comparisons with the activities of nickel-59 (half-life, 8×10^4 years) measured in lunar samples indicate that the long-term and present-day fluxes of solar alpha particles are comparable within a factor of approximately 4.*

The solar helium abundance is an important parameter for astrophysical considerations of stellar burning processes. Among the techniques used to investigate the helium abundance near the surface of the sun have been spectroscopic studies of prominences and the chromosphere (*1*) and measurements of the composition of the solar wind (*2*) and solar cosmic rays (*3*). Inferences about the helium abundance deep within the sun have been drawn from the results of the ^{37}Cl solar neutrino experiment (*4*).

Spectroscopic measurements indicate that the number ratio of alpha particles to protons (α/p ratio) in prominences and the chromosphere is approximately 0.06 (*1*). Another analysis of the solar spectrum yielded $\alpha/p \sim 0.1$ (*5*). Although the helium composition of the solar wind varies a great deal, the α/p ratio infrequently rises above about 0.1 (*6*) and is about 0.045 from long-term measurements (*2*). From the rather low limits set on the solar neutrino fluxes, a value of $\alpha/p \lesssim 0.07$ is obtained (*4*).

Measurements of the fluxes of alpha particles in solar cosmic rays by rocket and balloon techniques during solar cycle 19 (April 1954 to September 1964) seemed to indicate that the fluxes of alpha particles and the α/p ratio differed from flare to flare. When particles of equal energy per nucleon are compared, the α/p ratio changed even during a single flare event (*3*). These results have been confirmed for lower-energy ($\lesssim$ 10 Mev/nucleon) alphas during the maximum of solar cycle 20 (which began in October 1964) by continuous measurements made from satellites during the events (*7, 8*). Further results have shown that frequently the α/p ratio during a single flare event is constant only when the particles are compared on the basis of equal energy per charge, but that this ratio also changes from flare to flare (*7, 9*). From these cosmic ray studies, the α/p ratio is generally found to be less than about 0.1 for particles of equal energy per nucleon.

It is desirable to obtain information about solar conditions, and particularly the solar helium abundance, in the past. The fluxes of energetic particles from ancient solar flares can be studied by measuring the long-lived radionuclides produced by these particles in extraterrestrial matter. No radionuclides produced by solar cosmic rays have been observed in meteorites, since their original surfaces undergo considerable ablation in the earth's atmosphere. Cosmogenic radionuclides are also produced in cosmic dust (micrometeoroids) in interplanetary space (*10, 11*). Since meteoric material continuously falls onto the earth and is accumulated in ocean sediments, measurements have been made in marine sediments for cosmogenic radionuclides (*11, 12*). There are

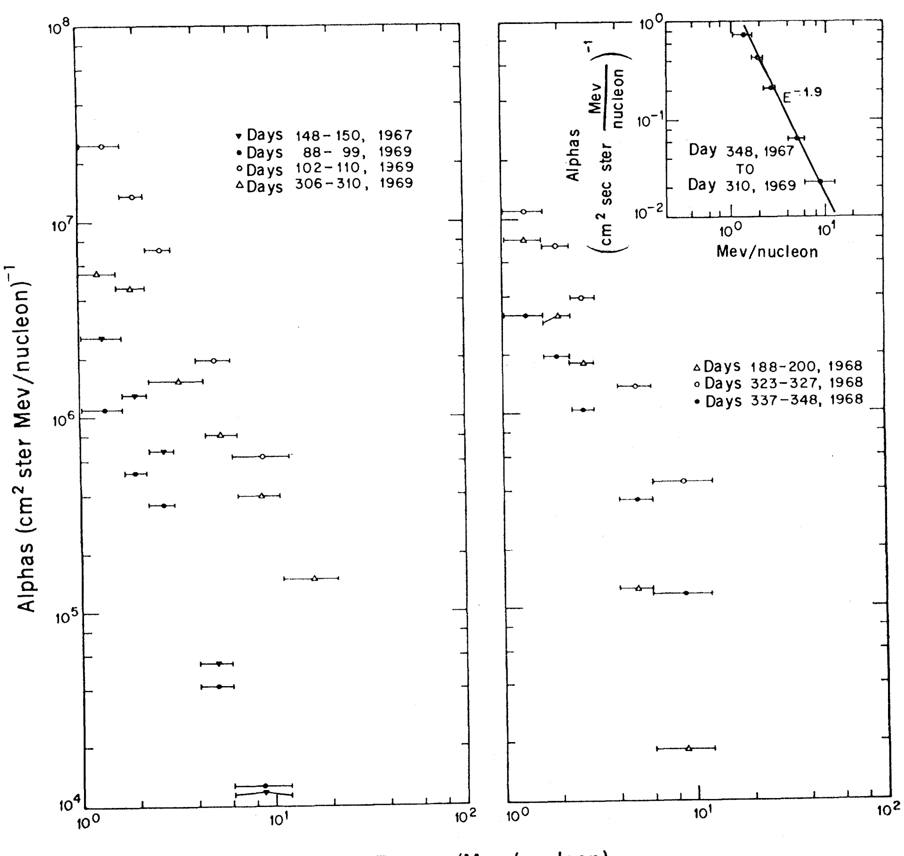

Fig. 1. Fluxes of alpha particles produced from seven large solar flares in the period 28 May 1967 to 1 January 1970. The fluxes plotted are summed over the duration of the individual events. The inset contains the average alpha particle spectrum over the approximately 900-day period.