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The AAAS-Newcomb Cleveland Prize, which previously honored research papers presented at AAAS annual meetings, is now awarded annually to the author of an outstanding paper published from September through August in the Reports section of *Science*. The second competition year under the new rules starts with the 2 September 1977 issue of *Science* and ends with that of 25 August 1978. The value of the prize is $5000; the winner also receives a bronze medal.

To be eligible, a paper must be a first-time publication of the author's own research. Reference to pertinent earlier work by the author may be included to give perspective.

Throughout the year, readers are invited to nominate papers appearing in the Reports section. Nominations must be typed, and the following information provided: the title of the paper, issue in which it was published, author's name, and a brief statement of justification for nomination. Nominations should be submitted to AAAS-Newcomb Cleveland Prize, AAAS, 1515 Massachusetts Avenue, NW, Washington, D.C. 20005. Final selection will rest with a panel of distinguished scientists appointed by the Board of Directors.

The award will be presented at a session of the annual meeting at which the winner will be invited to present a paper reviewing the field related to the prizewinning research. The review paper will subsequently be published in *Science*. In cases of multiple authorship, the prize will be divided equally between or among the authors; the senior author will be invited to speak at the annual meeting.

Reports

Mercury Dispersal from Lode Sources in the Kuskokwim River Drainage, Alaska

Abstract. *The Kuskokwim River is not industrially polluted, but it does have an anomalous mercury content due to cinnabar particles in bottom sediments near natural mineralized sources; the mercury content is rapidly diluted downstream by physical mixing with other sediments. Mercury anomalies extend the greatest distance downstream in the tributaries, the finest size fraction of bottom sediment, the riverbank deposits, the suspended sediment, and water; the last two of these categories contribute the bulk of the mercury to the marine environment.*

Recent studies of Hg dispersal in rivers have concentrated on systems that are polluted by industrial development and population centers (*1*). To provide a natural base line for evaluating dispersal in polluted systems, this study focuses on Hg dispersal from natural mineralized sources in the Kuskokwim River drainage, a remote region in Alaska isolated from population centers and industrial development. The numerous cinnabar (HgS) lode sources (Fig. 1) (*2, 3*) in this region provide excellent opportunity to compare Hg dispersal processes downstream from lode deposits that are either eroding naturally or more rapidly as a result of mining.

Several earlier studies have included descriptions of Hg distributions in mineralized areas (*4*). However, sampling intervals have not been closely spaced through complete stream sediment systems; Hg partitioning and dispersal pathways in water, suspended sediment, and various size fractions of bottom sediment have not all been traced throughout the same freshwater system to marine waters, and sample size has not been adequate to provide statistically significant results for bottom sediments containing Hg primarily in discrete mineral particles of cinnabar.

In an earlier study (*5*) in the Bering Sea region Nelson *et al.* have shown that Hg dispersing in sediments from mineralized shoreline areas of the coast is transported mainly as the heavy mineral cinnabar (specific gravity, 8.1). The relatively soft cinnabar is most concentrated in the heavy mineral fraction of the finest grain size of any sediment type and accumulates in heavy mineral fractions of beach areas with strong wave action. Offshore, the cinnabar concentrations are rapidly diluted as a result of physical mixing with sediment from nonmineralized areas. To ascertain if physical dilution is the dominant dispersal process in natural rivers, we have examined the dispersal distance (the distance required for the Hg content to return to background values) in filtered water, suspended sediment, bulk sediment, and various size fractions of heavy mineral concentrates downstream from mineralized areas over 840 km of the Kuskokwim River system.

Natural erosion and erosion caused by mining have provided the dominant supply of Hg to the river because retorting of Hg ores was done on only a modest scale up to 1972 when it was discontinued. A total of about 40,000 flasks (35 kg per flask) of Hg has been mined in this area in the past 50 years compared to 60,500 flasks of Hg mined at the world's largest mine in Almadén, Spain, in the year 1972 (*6*). Because the Kuskokwim region remains relatively poorly prospected and exploited, the size of its deposits may be greater than these mining rates indicate (*3, 7*).

We processed water and suspended-sediment samples (*8*) from 32 stations, and we collected bulk bottom sediment from 299 stations; sampling intervals for bottom sediments were 3 to 5 km, except in tributaries and coastal areas where the intervals were greater (Fig. 1). Bulk samples were collected with a drag dredge from a boat or by hand where possible. A small split of the original bulk sediment was analyzed for Hg content, but most of the 1- to 3-kg sample was hand-panned to a heavy-mineral concentrate containing cinnabar particles. The concentrate was separated into the following size fractions: > 0.25 mm, 0.25 to 0.062 mm, and < 0.062 mm. The two larger fractions were ground to less than 0.1 mm with a hand mortar and pestle prior to the analysis of Hg and the associated elements As, Ca, Fe, and Mn (*9*).

Analytical subsamples less than 1 g in weight from bulk river sediments near mineralized sources do not always yield representative subsamples because the Hg present is concentrated in a few large cinnabar particles. Pan concentration and grinding eliminated these effects of a possible scarcity of cinnabar particles in the analytical subsamples (*10*) by removing much of their lighter mineral content and reducing the size of cinnabar particles, both of which increase the relative number of cinnabar particles in the analytical split. The concentration averaged 17 : 1 (parts of bulk sediment to parts of heavy mineral concentrate) for the entire set of bottom samples; these concentrate samples thus had approximately 95 percent of the light minerals eliminated. The concentration averaged less for the bulk samples containing mainly sand (10 : 2), showing, as expected, that this sediment type contains a higher content of heavy minerals than gravel or mud. The fact that, on the average, panning removed 90 percent of the bulk sediment from each sandy sample suggests that the slight differences in pan concentration for different sediment types had little effect on downstream trends in the Hg values.

The mean value of all samples (Table 1A) indicates that the Hg content of filtered water and suspended sediment appears to be slightly above normal throughout the entire Kuskokwim study area (in the water Hg = 0.34 ± 0.13 μg/liter; in the suspended sediment Hg = 3.9 ± 0.52 mg/kg) (Fig. 2A) as compared to background values in other similar, but nonmineralized graywacke and volcanic terranes (in the water Hg = 0.085 to 0.19 μg/liter; in the suspended sediment Hg = 0.1 to 1 mg/kg) (*11*). The mean content of Hg in filtered water remains the same throughout the Kuskokwim system (Fig. 2A); however, in suspended sediments the mean value is anomalously high in the tributaries where numerous sources exist (Figs. 1 and 2A) and then varies erratically to become nearly normal in the upper and lower river and slightly above normal nonmineralized background in the middle river and bay areas. The higher Hg values in the middle river and bay areas cannot be attributed to specific mineralized sources or to varying organic carbon content in the suspended sediments.

In suspended sediment and filtered water, the highest individual Hg anomalies occur near the largest mineralized sources of tributary streams; however, values decline rapidly downstream. The Hg anomalies in source areas for both water and suspended sediment usually are significantly lower than the anomalies in the bed sediment, and the Hg content of water is much lower than the Hg

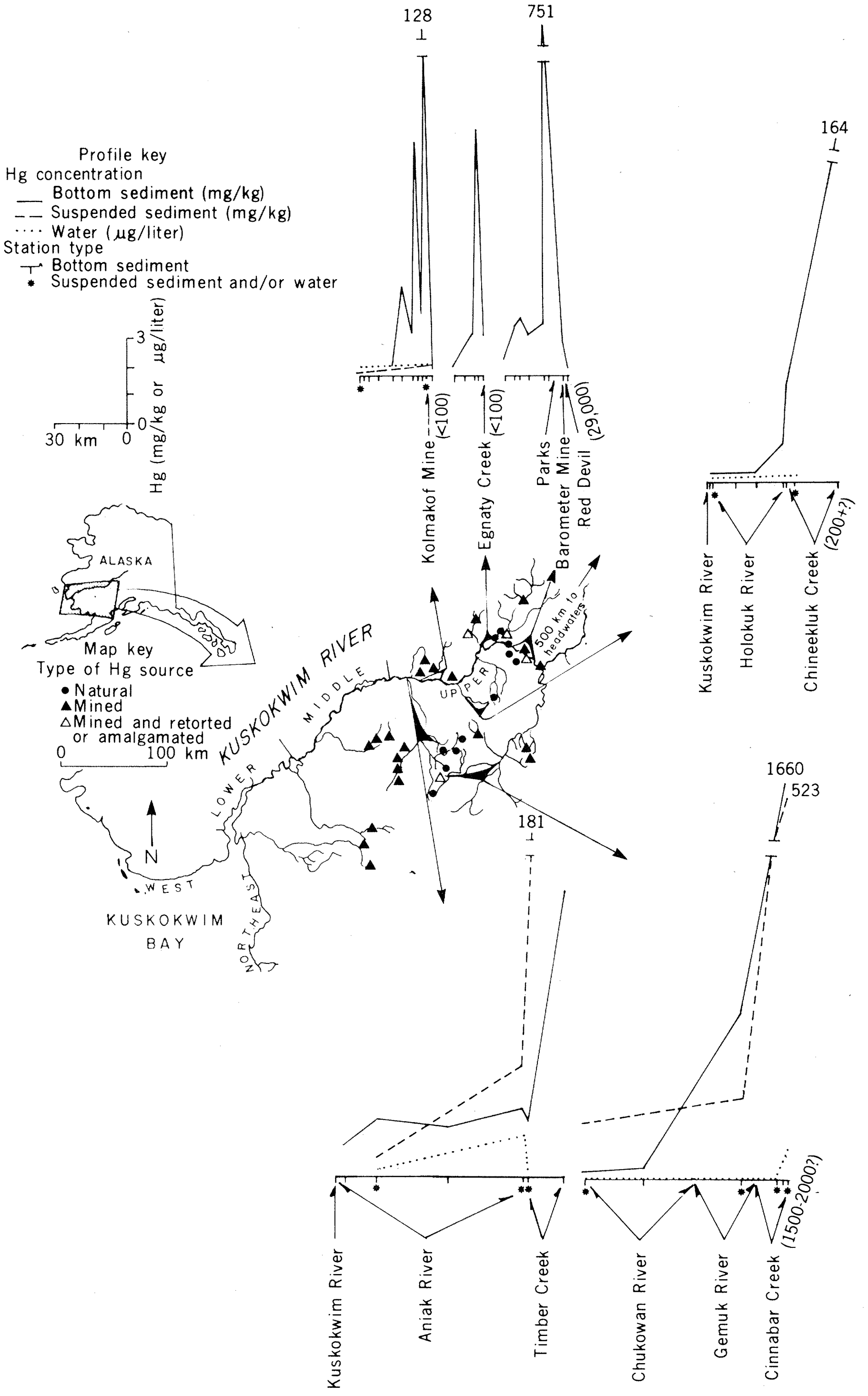
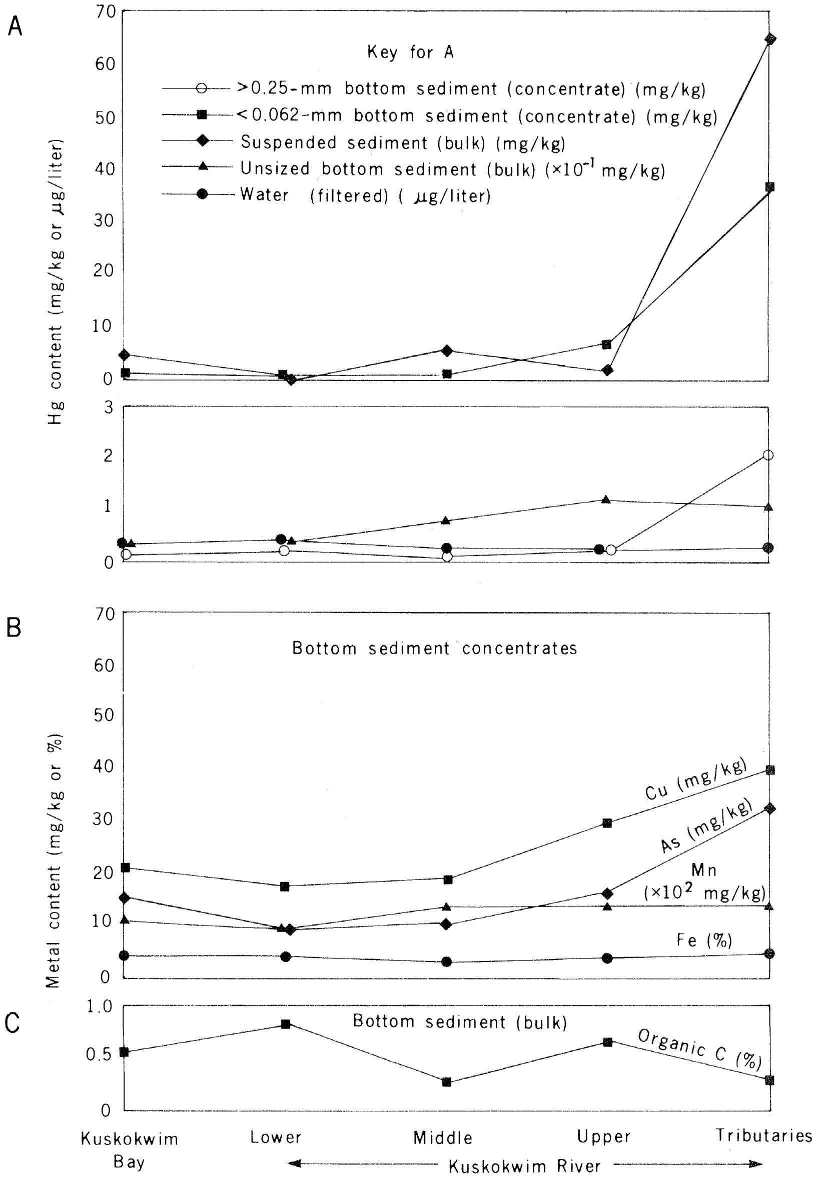


Fig. 1. Location and type of Hg source in the middle and lower Kuskokwim drainage (*2, 3*) and selected profiles of downstream dispersal of Hg based on pan concentrate, suspended sediment, and filtered water samples. The total number of 35-kg flasks mined is given in parentheses at the largest sources (*7*). Records are not available for other minor sources, but probably less than 100 flasks have been produced at each.

content of either suspended or bottom sediment at a given source. This dispersal pattern of anomalies probably results because (i) most of the Hg appears to be entering the river system as particulate cinnabar in bottom sediment and (ii) the diluting effect of water discharge always is greater than the sediment discharge in any river, and similarly the bottom sediment load of this river is estimated to be only about 10 percent of the annual suspended sediment load (*12*).

Throughout the Hg source areas in tributaries and the upper river (Fig. 1), local background Hg contents (0.1 mg/kg) in bulk sand and silt bottom sediment are slightly higher than normal background values (0.01 to 0.06 mg/kg) for similar sediment from nonpolluted and nonmineralized areas elsewhere around the Bering Sea (*5*) (Fig. 2A). Local background values return to normal (0.06 mg/kg) in bulk sediment of the lower Kuskokwim River and Bay. This finding suggests that cinnabar-bearing sediment eroded from the upstream sources (Fig. 1) has not enriched the Hg content sufficiently above normal background to be detectable in these downstream bulk bottom sediments.



Type	Kuskokwim Bay	Lower	Middle	Upper	Tributaries
	Number of samples				
Bottom sediment	31	45	58	82	23
Suspended sediment	1	3	3	4	13
Water	1	3	3	4	14
Carbon (organic)	4	7	4	3	4

Fig. 2. Average (geometric mean except for unsized bulk bottom sediment where median values are given) content of Hg (A) and associated elements (B and C) in bulk suspended and bottom sediments, coarse and fine fractions of pan concentrates, and water for tributary, upper, middle, and lower Kuskokwim River and Bay. (The number of samples is as noted at the bottom of the figure except that the > 0.062-mm size fractions of the middle and upper Kuskokwim River have only 16 samples each.)

The rate of dilution caused by the mixing of nonmineralized sediment with mineralized sediment is less in the tributaries than in the main river. As a result, the highest mean and individual sample Hg values in whole pan concentrates (including all size fractions) occur in those taken from channels, levees, and banks of tributaries (Fig. 1) (Table 1, E and F). Anomalous Hg values in concentrate samples also continue downstream for the greatest distance in tributaries (Figs. 1 and 2A). The distance required for the Hg content in pan concentrates to return to the normal concentrate value of < 1 mg/kg (Table 1) is 10 to 25 km even below the largest river sources (Fig. 1; see Red Devil), whereas it ranges from 32 to 72 km in tributaries (Fig. 1). Nevertheless, the initial dilution of Hg values away from a source is extremely rapid, decreasing from a high of 500 to 1000 mg/kg to less than 5 mg/kg within a few kilometers downstream from either tributary or river sources.

Data from pan concentrates show that the Hg content in bottom sediment partitions physically by size, which affects the Hg dilution rate and dispersal distance (*5*) (Fig. 2). For either individual samples or sample averages from the entire river, Hg values in the finest size fraction (< 0.062 mm) are much higher than in the coarse fraction (< 0.25 mm) of bed sediment concentrates, and the dispersal distance of the finer sizes is greater (Fig. 2A). Cinnabar in the finest size fraction contributes the largest proportion of the Hg content, even in Hg-rich gravelly deposits that are characteristic of the tributary and upper river source areas (Fig. 2A and Table 1C).

Partitioning and dispersal of Hg suggest that dilution from physical mixing and not chemical mobilization is the main cause of the downstream decrease in the sediment Hg content. This relation seems true regardless of whether the Hg source is a natural cinnabar deposit or a Au deposit for which Hg amalgamation was used to refine ores. Every Hg anomaly in bottom sediment correlates with some nearby placer or lode cinnabar source, associated mineral deposit [that is, stibnite (Sb_2S_3) or livingstonite ($HgS\text{-}2Sb_2S_3$), or amalgamation site, or both (Fig. 1)] (*2*, *3*, *5*) rather than with any parameter of chemical mobilization (*13*). The highest positive correlation coefficients with Hg values in bottom sediments are found for Cu, Sb (not shown in Fig. 2B), and As (0.53, 0.51, and 0.49, respectively); minerals bearing these elements are commonly associated with the cinnabar deposits of the Kuskokwim region (*7*). These elements show downstream physical dilution patterns similar to those of Hg, except that the Hg values decrease more rapidly as would be expected in view of the fact that its source minerals are denser than those of Cu, As, and Sb (specific gravity, about 4 to 6) (Fig. 2B). In contrast, the correlation of Hg with Fe and Mn in bottom sediments is much less positive (0.26 and 0.26, respectively) (Fig. 2B), which further suggests that Hg is not being rapidly mobilized into the water phase in source areas and then absorbed by oxides of Fe and Mn, as has been suggested for polluted rivers (*13*).

Increased Hg values in bulk bottom sediments from the tributaries and upper Kuskokwim River show no relation to the organic C content (Fig. 2C). However, in the lower river and bay, the fluvial, tidal flat and delta sediments that contain the finest grain size (*14, 15*) and the highest organic C content ($\geq$ 1.0 percent) do show a slightly higher mean content of Hg (0.11 mg/kg) than those sediments (0.04 mg/kg) from nonmineralized locations containing less clay or organic matter ($\leq$ 0.5 percent C). This mean Hg value of 0.11 mg/kg is quite close to the normal range of 0.01 to 0.1 mg/kg for bulk sediment with high organic C content (*5*); relatively high Hg values ($\leq$ 1.5 mg/kg) in individual samples containing the maximum organic C content (20 percent) have lower Hg contents by many orders of magnitude than upstream sediments associated with lode sources (Fig. 1). These data and the fact that clay and organic debris are absent in concentrate samples emphasize that physical mixing of cinnabar-rich sediment with bed sediments containing low Hg concentrations clearly controls the dispersal process in mineralized regions. This result contrasts with chemical mobilization and incorporation of Hg with clay, organic debris, or $Fe(OH)_3$ grain coatings in polluted fluvial systems (Fig. 2) (*1, 12*).

Levee and bank depositional sites consistently have the greatest Hg values throughout the river system (Table 1E) and show the most positive correlation of Hg content with the depositional environment. In the upper river the geometric mean is about twice as high for levee and bank deposits as that for the coarser adjacent channel sediments and ten times greater than that for nonmineralized sediments away from Hg sources (Table 1E) (*5*). The levee deposits typically are finer grained (sand and sandy silt) than the gravelly sand of the upper channel (*14*) and consequently are a depositional site for fine-grained cinnabar, which is most abundant (Fig. 2A). Probably the fine-grained cinnabar is preferentially carried to overbank deposition sites during spring flooding, whereas coarser particles remain in channel deposits.

An increased dispersal distance for Hg resulting from the retorting of Hg ore and possible correlative effects of chemical mobilization of Hg could not be verified for either river or tributary sources because the largest natural sources were also the sites where retorting had taken place. However, greater dispersal distance in bottom sediments can be attributed to increased erosion from physical disturbance at mining sites. On the main river, Egnaty Creek and Kolmakof Mine are both small deposits (Fig. 1) (*7*), but the dispersal distance is nearly twice as great for the mined deposit (Kolmakof) (Fig. 1) as for the naturally eroding source. The dispersal distance from Cinnabar Creek Mine also is nearly double that of a recently discovered naturally eroding deposit of small size on Chineekluk Creek (Fig. 1) (*7*).

Table 1. Concentrations of Hg in water (in micrograms per liter), suspended sediment (in milligrams per kilogram), and both bulk and pan concentrates of bottom sediment (in milligrams per kilogram) of different depositional environments and texture classes in the Kuskokwim River system. All data are based on pan concentrate samples of bottom sediments except where noted; bulk indicates whole samples with grinding but no pan concentration; however, the > 0.175-mm fraction was removed from group I samples prior to analysis. All values were manually rounded to one or two significant figures, depending on the reliability of the original analyses and according to computer parameter calculations.

Sample type	Samples (No.)	Geometric mean	Range of first geometric deviation	Minimum value	Maximum value
A. All bulk samples					
Water	11	0.34	0.13 - 0.9	<0.01	1.4
Suspended sediment	22	3.9	0.52 - 30	<0.04	520
Bottom sediment					
Group I	143	0.060	0.011- 0.33	0.01	370
Group II	156	0.18	0.038- 0.83	0.02	10
B. Bottom sediments (all textures and depositional environments)					
All	275	0.35	0.056- 2.1	0.024	1700
Kuskokwim River plus all tributaries	208	0.49	0.074- 3.3	0.69	1700
Kuskokwim Bay plus local streams	40	0.12	0.043- 0.32	0.025	1.8
C. Texture (all depositional environments)					
Gravelly deposits	51	0.64	0.062- 6.6	0.029	1700
Sandy deposits	167	0.31	0.059- 1.7	0.024	51
Silty deposits	36	0.24	0.059- 0.94	0.025	9.2
Clayey deposits (bulk)					
D. Sandbars and islands (all textures)					
Kuskokwim River	28	0.26	0.066- 0.99	0.024	3.1
E. Levees and banks (all textures)					
All	113	0.57	0.94 - 3.4	0.049	750
Tributaries	16	2.1	0.29 - 15.0	0.14	160
Upper river	46	1.1	0.18 - 6.8	0.13	750
Middle river	27	0.22	0.073- 0.66	0.054	5.1
Lower river	24	0.20	0.068- 0.58	0.049	2.6
F. Channel (all textures)					
All	56	0.50	0.059- 4.3	0.040	1700
Tributary	3	570	180 -1800	170	1700
Upper river	33	0.57	0.18 - 1.8	0.096	11
Middle river	15	0.14	0.044- 0.44	0.040	3.8
Lower river	5	0.053	0.043- 0.066	0.404	0.070
G. Kuskokwim Bay depositional environments (all textures)					
West beach	3	0.04	0.02 - 0.08	0.03	0.062
Northeast beach	16	0.13	0.059- 0.26	0.029	0.89
West tidal flats	6	0.10	0.03 - 0.33	0.025	0.53
Northeast tidal flats	5	0.14	0.04 - 0.45	0.10	1.8
All tidal flats (bulk)	10	0.035	0.018- 0.070	0.01	0.09
All delta (bulk)	11	0.13	0.059- 0.29	0.01	0.46

In summary, even in this moderate-sized river (discharge, about 44.6 km^3/year) (*12, 16*), physical mixing is very effective in diluting the Hg content a short distance downstream from each source so that the Hg content of the bottom sediment returns to normal by the time the sediments reach the lower river (Fig. 2); in comparison, effective downstream dilution in polluted European rivers is not achieved until the estuaries are reached (*17*). Overbank and channel deposits close to lode Hg sources are important depositional sinks that remove Hg from dispersing bed load sediment. Unlike nonmineralized or polluted river systems elsewhere (*1, 11*), tidal flats and carbonaceous delta swamps are not such important Hg sinks on a per unit weight basis as river levees and banks in the Kuskokwim drainage system.

Cinnabar-rich sediment disperses the greatest distance in the finest size fraction (< 0.062 mm); it extends farther downstream in tributaries than in the main river where relatively more sediment and water from nonmineralized terrane are available for dilution. Mining activity appears to artificially increase the dispersal distance of cinnabar-rich sediment because Hg is found greater distances downstream from mining sites than from similar-sized Hg deposits that are eroding naturally (Fig. 1).

On the basis of the average Hg content measured in our study and discharge estimates (*12, 16*) at the river mouth, we calculate that a total of 16,700 kg of Hg per year enters the marine environment from the Kuskokwim River. Of this total Hg content, 80 percent (13,400 kg) is transported by the water, 19 percent (3,130 kg) within suspended sediments, and 1 percent (160 kg) within bed load sediment.

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8. Water samples were collected in acid-washed polyethylene bottles, forced through 0.1-mm cellulose acetate membrane filters with N_2, and preserved by freezing as soon as possible on the day collected; an aliquot of $KMnO_4$ was added to the frozen sample just prior to thawing to prevent any possible loss of Hg by vaporization during thawing and to recover any Hg loss to the sample container which may have occurred during filtration and freezing; the same procedure was used for filters containing suspended sediment [P. Avotins and E. A. Jenne, *J. Environ. Qual.* **4**, 515 (1975)]; digestion was carried out at 80°C after transfer to Pyrex bottles and the addition of $K_2S_2O_8$. In the analysis of Hg we used cold vapor atomic absorption, with a $KMnO_4$-H_2SO_4 trap to eliminate both positive and negative interferences [S. H. Omang, *Anal. Chim. Acta* **53**, 415 (1971)].
9. Samples of bottom sediment were analyzed with an atomic absorption mercury vapor detector [W. W. Vaughn and J. H. McCarthy, *U.S. Geol. Surv. Prof. Pap. 501-D* (1964), p. 123], 30-element semiquantitative emission spectroscopy [D. J. Grimes and A. P. Marinizino, *U.S. Geol. Surv. Circ. 591* (1968)], and colorimetric analyses for Sb plus As [F. N. Ward *et al.*, *U.S. Geol. Surv. Bull. 1152* (1963)]. Samples of suspended sediment and bottom sediment with a Hg content of greater than 10 mg/kg were analyzed by flameless atomic absorption. Bed sediments were hand-ground to minimize the effects of a scarcity of Hg particles in the samples without significant frictional heat being introduced. Sediment was removed from the membranes with an ultrasonic probe in the presence of $KMnO_4$ to prevent volatilization. Sediments were solubilized in Teflon-lined bombs and then digested and analyzed (*8*). All analyses are in the U.S. Geological Survey RASS computer file (Bering Sea II). Data sets have been compiled from different regions, sediment types, and depositional environments; STATPAC functions [A. T. Miesch, *U.S. Geol. Surv. Prof. Pap. 574-B* (1967)] have been used on the data to calculate geometric means and geometric deviations, in the correlation analyses, and in developing graphical representations of the frequency distributions.
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15. Fine-grained suspended sediment, delta deposits, and tidal flats of this fluvial system are dominated by silts in this as well as other arctic to subarctic drainages (*13*). The clay content rarely exceeds 25 percent.
16. Calculations are based on Lisitsyn's (*12*) estimates of yearly water, suspended sediment, and bottom sediment discharge, which appear to be verified by data from the U.S. Geological Survey in *U.S. Geol. Surv. Water Supply Pap. 1959* (1970), *1966* (1970), *1996* (1971), and *2016* (1972).
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Anomalous Solar Rotation in the Early 17th Century

Abstract. *The character of solar rotation has been examined for two periods in the early 17th century for which detailed sunspot drawings are available: A.D. 1625 through 1626 and 1642 through 1644. The first period occurred 20 years before the start of the Maunder sunspot minimum, 1645 through 1715; the second occurred just at its commencement. Solar rotation in the earlier period was much like that of today. In the later period, the equatorial velocity of the sun was faster by 3 to 5 percent and the differential rotation was enhanced by a factor of 3. The equatorial acceleration with declining solar activity is in the same sense as that found in recent Doppler data. It seems likely that the change in rotation of the solar surface between 1625 and 1645 was associated with the onset of the Maunder Minimum.*

For more than a century it has been known that the solar photosphere rotates differentially with latitude, the equator completing a turn around the sun appreciably faster than the poles. Differential rotation, both in latitude and radius, is now generally believed to be a principal cause of the cyclic behavior of solar activity, through its coupling with the sun's magnetic fields in a solar dynamo (*1*).

Until recently the character of solar differential rotation has been assumed to be constant. The present pattern was identified empirically by Carrington in 1863, from observations of sunspots as tracers over a 7-year period (*2*). Examination of subsequent sunspot data (*3, 4*) has produced no evidence for any systematic variation with solar activity, from minimum to maximum in the 11-year cycle, or from cycle to cycle. Differences of several percent were noted in the disk-averaged rotation rates derived before the time of Carrington (*5*), but