Increased Hemoglobin-Oxygen Affinity at Extremely High Altitudes

Eaton *et al.* (*1*) stated that "increased, rather than decreased, oxygen affinity is an effective mode of short-term adaptation to markedly reduced environmental oxygen pressures" and pointed out the need to reevaluate the idea that "decreased hemoglobin-oxygen affinity is of adaptive value to humans at high altitudes."

We fully agree with these authors and wish to call attention to the fact that human natives of high altitudes are unique in having a right shift of the oxygen dissociation curve in their hypoxic environment. Thus, camelids (alpaca, vicuña, llama), rodents (chinchilla, vizcacha), ruminants (yak), and birds (ostrich, huallata) that are native to high altitudes have a higher oxygen affinity than their relatives at sea level (camel, rabbit, ox, and a variety of sea level birds) (*2, 3*).

We have recently shown that the Peruvian high-altitude native increases his hematocrit as a function of both age and altitude (*4*) and, in collaboration with Sime (*5*), we have found that this is due to a decrease in ventilatory rate with age. Since the changes observed in the ventilatory function and the hemoglobin-oxygen affinity at high altitude do not seem to be of long-term adaptive value, the physiology of human adaptation to very high altitudes needs to be reevaluated.

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12 August 1974

Oil Spills in the Arctic Ocean: Extent of Spreading and Possibility of Large-Scale Thermal Effects

Campbell and Martin (*1*) have considered the possibility that a major oil spill might significantly change the heat balance of the Arctic Ocean and trigger widespread melting of the pack ice. Based on assumptions regarding the thickness to which oil will spread on open water and the percentage of open leads in the Arctic ice pack, they estimated the area that would be "affected" by an oil spill of 2×10^6 barrels (3.2×10^5 m^3). Their estimates ranged from 240 km^2 to 8×10^5 km^2. The upper limit is about 8 percent of the total area covered by pack ice (10^7 km^2).

We believe the assumptions leading to the higher values in the quoted range are too pessimistic. Furthermore, the "affected area" calculated by Campbell and Martin, that is, the area of the entire region where oil would be found in open leads, including all the ice not covered by oil between the leads, is not a good indicator of the potential effect on the Arctic heat balance. Open water has a high absorptivity for solar radiation (*2*), which is not increased much by the presence of an oil film. Neither is the albedo of a clean ice floe altered by the presence of an oil film on the surrounding water. Significant thermal effects are expected only from oil on the ice surface where it could cause a drastic change in reflectivity. Therefore, a more relevant indicator of the potential thermal effect of an oil spill would be the ice surface area that is actually covered by oil.

We also believe that the assumed spill volume of 2×10^6 barrels is very unlikely to occur in any single accident. The *Torrey Canyon* spill (7×10^5 barrels) (*3*) is the largest on record, and estimated spill volumes from other major spill accidents have been significantly less (*3, 4*). Current emphasis on safer oil transportation techniques should reduce the chance of large spills occurring in the future. Furthermore, it is unrealistic to assume no cleanup operations for a spill of this size. Most observers (*5–7*) believe that cleanup in the Arctic would be more effective than in open waters because the ice would serve as natural containment booms and work platforms. Nevertheless, like Campbell and Martin, we will base our estimates on a spill of 2×10^6 barrels with a 25 percent evaporation loss (leaving an oil volume of 2.4×10^5 m^3) without cleanup operations.

Oil spreading on water. The equilibrium thicknesses of oil slicks on ice-covered water are much greater than those on open water. In the presence of ice, the spreading forces can be balanced by the wind stress acting on the surface of the oil. Using equations developed by Hoult (*8*), we estimated typical film thicknesses of oil confined by floating ice barriers to range from 0.1 to 1 cm for wind speeds from 1 to 5 knots (1 knot = 1.854 km/hour). This agrees with observations by Glaeser and Ayers, who took part in the U.S. Coast Guard oil spill test in the Chukchi Sea (*5*). For a film thickness of 0.1 cm, the slick area would be 240 km^2. Campbell and Martin suggested that "lead-matrix pumping" could disperse oil over much wider areas. This appears reasonable. However, should extensive dispersion occur by this or any other mechanism, the experience cited above indicates that the oil would form individual patches whose aggregate surface area would still not exceed the estimated maximum of 240 km^2.

Mechanisms of oil spreading over and under ice. As noted above, to cause significant melting, oil must find its way onto the ice surface. Aside from direct over-ice or under-ice spilling, the most obvious mechanism by which oil can be incorporated in or on sea ice is by the freezing of oil-covered leads. Typically, the newly formed ice is subject to compression by adjacent floes, a process that will greatly reduce the surface area of contaminated ice. Another mechanism is lateral transport by wave action from open leads onto or under the adjacent ice, that is, in the form of spray or entrained droplets, respectively. Oil trapped below the ice would eventually reach the surface by alternating processes of summer melting on top and winter freezing at the bottom of the ice sheet. Thus, we must consider spreading at both the ice-water and the ice-air interface.

Gravity provides the main spreading mechanism at both interfaces, with possible contributions from meltwater runoff on top (*9*) and current-induced shear forces below the ice. In addition, spreading below the ice may result from under-ice transport of dispersed oil droplets. Campbell and Martin visualized this mechanism as perhaps the most efficient method of diffusing oil over a large area. However, as discussed below, field evidence and laboratory data indicate that under-ice transport of dispersed oil would probably be negligible under Arctic conditions.

Under-ice transport of dispersed oil. Two different mixing processes must be distinguished. One is the formation of water-in-oil emulsions of the "chocolat-mousse" type (*10*). These are stable emulsions formed by most crude oils in the presence of waves. Because of their high viscosity and rigidity, these emulsions resist spreading more than the oil from which they were formed. The second process is dispersion in the water column. Dispersions of crude oil in seawater tend to be less stable than the water-in-oil emulsions. Both processes were observed in the Chedabucto Bay spill, where heavy fuel oil was spilled under stormy conditions (*11*). Most of the oil remained on the surface forming emulsions of high water content, but suspended oil droplets occurred down to a depth of 80 m. Several aspects of this spill are of interest: (i) oil droplets appeared to have been formed by wave action, particularly in the surf on oiled beaches; (ii) the volume of oil suspended at any one time did not exceed 1 percent of the volume spilled; (iii) the oil particles were positively buoyant and were kept in suspension by wave action; (iv) about 10 tons of dispersant (Corexit 8666) had been sprayed on the spill to increase the tendency to form oil-in-water emulsions.

The above observations indicate that dispersion in the water column would not be significant in ice-covered waters. Wave action in open leads is usually minimal because of the limited fetch over which wind can act on the water surface. Thus, the mixing energy necessary for both formation of small particles and vertical dispersion in the water column is not available. Oil particles that do get under the ice would be relatively large and would rise to the ice-water interface.

Movement of the pack ice can give rise to a turbulent boundary layer in the water. However, compared to a breaking wave, the mixing energy available in the relatively large eddies in this boundary layer will be small and much less likely to break up an oil layer at the ice-water interface or to divide suspended oil particles into smaller droplets. Laboratory (*12*) and field observations (*6*) support this conclusion.

Finally, Wolfe and Hoult (*13*) have shown that oil trapped below ice should be frozen in place during the winter months. Oil in this configuration cannot be further dispersed until the ice melts or is broken up. Thus, the amount of oil available for spreading under ice by any mechanism in subsequent summers would be limited.

Extent of spreading under and over ice. Equilibrium oil film thicknesses at ice-water and ice-air interfaces are greater than on a free water surface. Wolfe and Hoult (*13*) found experimentally that the thickness of an adhering oil layer under sea ice would range from 0.25 to 1.3 cm. They estimated the shear force due to ice movement and concluded that it was too small to alter this thickness. Their lowest value (0.25 cm) yields a maximum under-ice spread area of 96 km^2 for the hypothetical 2×10^6 barrel spill. Our worst-case estimate of 100 km^2 is based on this number.

Perhaps the most notable characteristic of the Arctic pack ice is its roughness. Pressure ridges and hummocks dominate the surface at both the ice-air and the ice-water interface. A realistic estimate of the spread area must include this factor. McMinn (*14*) found that surface roughness governed the spreading of oil spilled on Arctic ice and that the "effective roughness height" was seldom less than 3 cm. Using this value, we find that a 2×10^6 barrel spill on ice would cover 8 km^2. This might be considered as a realistic upper limit for spreading under ice also, since the lower surface of pack ice is usually rougher than its upper surface (*15*).

The following conclusions may be drawn from the above discussion:

1) Oil-spreading mechanisms acting at the air-water interface have to compete with other mechanisms that tend to concentrate the oil, that is, "herding" by wind and ice and the closing of oil-covered leads. Although the spilled oil might in time be distributed in discontinuous patches over a large area, these processes limit the surface area actually covered by oil.

2) Significant heat balance effects will result only from oil on the ice surface and only when the oil is not covered by snow.

3) The maximum oil-covered area at the ice-air or ice-water interface is estimated to be 100 km^2 for a 2×10^6 barrel spill. This corresponds to roughly 0.001 percent of the pack ice area. Even drastic albedo changes over an area of this size cannot significantly change the heat balance of the entire Arctic Ocean.

Our comments should not be construed as an attempt to minimize the importance of oil spill prevention in Arctic operations or the need for effective means of dealing with an oil spill, should one occur. On the contrary, the Arctic environment will require special precautions to minimize the risk of an accidental spill and special techniques for cleanup in ice-infested waters.

Continuing research will be required to improve our understanding of the Arctic environment. However, concern about the possibility of a significant alteration of the heat balance of the Arctic Ocean from a major oil spill appears to be unwarranted.

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21 December 1973; revised 29 March 1974

We are pleased that our report (*1*) has stimulated interest in the problem of how oil interacts with the highly mobile sea ice cover of the Arctic Ocean. As we showed (*1*), oil spilled into the Arctic will undergo a very slow rate of biodegradation; moreover, the circulation of the Beaufort Sea gyre will tend both to contain for a long time any oil spilled into the ocean off the northern coasts of Alaska and Canada and to diffuse the oil within the gyre where it will eventually end up on the ice surface. In our reply we would like first to discuss the effect that oil spillage during normal shipping and drilling operations in the Beaufort Sea would have on the ice albedo over the time needed to pump the presently estimated reserves and then to answer the specific criticisms of Ayers *et al.* of our proposed diffusion mechanisms.

Ayers *et al.* show that if the oil spreads as a slick, its thickness ranges from 0.1 to 1 cm. To estimate the albedo change caused by such a slick, we assume through the diffusive processes described below that the oil in the slick is scattered uniformly over the pack ice in "spots" of the appropriate thickness. We further assume that each spot initiates the melting of an area of ice that is ten times the spot size. This physical assumption, which is susceptible to both field and laboratory checks, is based on our observation that small amounts of surface debris initiate the growth of much larger melt ponds; further, once the snow melts, melt ponds occur *earlier* around debris than on clean ice. The Maykut-Untersteiner model (*2*) [cited in (*1*)] shows that a 10 percent reduction in the albedo of sea ice causes a 60 percent reduction in the equilibrium ice thickness, and a 20 percent reduction in the albedo causes the ice to disappear. To cause a 10 percent albedo change over 1 km^2 for spots with a thickness of 1 cm requires 10^2 m^3 of oil; the same albedo change for spots with a thickness of 0.1 cm requires 10 m^3 of oil.

Estimates of the offshore reserves in the Beaufort Sea range from 30×10^9 barrels or 4×10^9 m^3 (*3*) to about 100×10^9 barrels or 10^{10} m^3 (*4*). To estimate how much of this oil might be spilled, we follow Glaeser (*5*), who states that for the Cook Inlet 0.03 percent of the oil produced and handled is spilled, with most of the spillage coming from the 15 offshore wells, and that for the North Atlantic 0.1 percent of the oil transported is spilled. In the Beaufort Sea, according to Glaeser, the hazards of drilling offshore will probably be greater than in the Cook Inlet, and, on the assumption that there will be many more drilling platforms, we expect that oil spillage in the Beaufort Sea will be of the order of 0.1 percent. Therefore, over the lifetimes of the offshore fields, say a half century, the spillage will range from 4×10^6 m^3 to 10^7 m^3, depending on the field size. For oil spots with a thickness of 0.1 cm, the area affected by this spillage will range from 0.4×10^6 km^2 to 10^6 km^2, or from 20 to 50 percent of the area of the Beaufort Sea.

We would now like to comment on the criticisms of Ayers *et al.* of our proposed oil diffusion mechanisms. First, one must distinguish between the difficulties associated with the cleanup of oil spills in shorefast ice and those in the pack ice. Ayers *et al.* say "Most observers . . . believe that cleanup in the Arctic would be more effective than in open waters because the ice would serve as natural containment booms and work platforms." The papers which they cite (*6*) refer to a spill of 1100 metric tons on the shorefast ice of Hudson Bay and a controlled spill of approximately 0.3 m^3 in a melt pond on the pack ice of the Chukchi Sea, with both spills occurring in the summer. Although spills in shorefast ice or in melt ponds appear to be relatively easy to clean up compared with the case for open water, we feel strongly that quite the contrary would be true concerning spills in the leads of the highly mobile and deformable pack ice.

At all times of the year, ice velocities of 10 km/day are common, even in the shear zones adjacent to the coasts. Further, the ice does not move as a rigid body; in fact, strong shearing motions occur regularly. Even if all the oil from a large spill accumulated both in open leads and on the ice, the logistical difficulties associated with getting containers for this oil to the moving ice, filling them, and getting them off the ice would be extremely great and very expensive. If instead the oil was burned, the resultant fallout from the smoke cloud might cause an albedo change over an area that could be greater than that caused by the oil remaining on the surface.

Although we can conceive of an attempt to clean up a small spill in the summer, the difficulties of carrying out a cleanup during the other 9 months of the year appear staggering. Consider the comment of McMinn and Getmen (*7*) concerning the winter cleanup of an intentional spill of 0.3 m^3 on the ice: "blowing snow in winter temperatures tended to mix with the cold oil, forming a 90% snow 'mulch' that could not be burned, absorbed/adsorbed, or dispersed. Additionally, the extreme temperature and wind conditions created working conditions for personnel and equipment that were hazardous at best."

The cleanup problem will be further complicated by three mechanisms: (i) mixing into the water column, (ii) entrapment within pressure ridges, and (iii) absorption by the growing ice. First, the question of how much oil will go into suspension in the water column beneath the ice during an oil spill or well blowout is still open. For example, studies (*8*) of the Deception Bay, Hudson Strait, spill of 10^3 metric tons of arctic diesel fuel show that approximately 10 percent of the oil entering the water was mixed to a depth of 20 m in the water column. This figure is ten times the 1 percent cited by Ayers *et al.* for the bunker C oil spill at Chedabucto Bay, and no dispersant was used at Deception Bay. Further, the turbulent water, gas, and oil velocities that would accompany a hot oil and gas blowout in the ocean may lead to larger percentages of suspended oil. The combination of oil emulsification with the currents under the ice will cause the oil to be spread over a much larger area than that affected by a continuous surface spill of the same volume.

Second, as Ayers *et al.* state, oil in the leads will not change the albedo; however, leads are constantly opening and closing in the pack ice, with the young ice growth in the open leads being crushed into pressure ridges. Any oil in the leads would be bound up in the crushed ice, forming both the oily pressure ridges described in (*1*) and also oiling the much larger amount of ice which makes up the pressure ridge keel. This oil will be practically inaccessible for cleanup. The melting of the dirty ridge will change the albedo of the surrounding ice while the ablation of the dirty keel will slowly release oil into the seawater. Since keel depths range from 5 to 40 m, some of this oil will be released into the currents below the ice-water boundary layer. Therefore, oil released from the slow ablation of keels would be dispersed over large areas over a period of years.

Third, as Ayers *et al.* point out, part of the spilled oil will be entrained within the ice, thus reducing the areal extent of a spill. If the spillage occurs during winter, most of this entrained oil will be entrapped by growing ice, which will make the cleanup virtually impossible until either the ice melts or the oil reaches the surface. In the 1 to 4 years that it may take for the oil to melt out onto the surface, the ice containing the oil may move a distance of thousands of kilometers while undergoing strong shearing motions. This dispersion around the gyre of the entrapped oil before the oil melts out onto the ice surface would again complicate any cleanup.

In summary, we stress that no data exist on the dispersion of a medium-to-large oil spill in pack ice and that the data for small spills obtained from either accidents in shorefast ice or controlled spills in pack or laboratory ice do not allow an accurate assessment of the extent of the albedo decrease caused by the cumulative effects of oil spills in the Arctic Ocean. The question of scale is an important one, and we believe that, until more relevant studies are carried out, a cause for concern still exists (*9*).

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10. We acknowledge the use of an unpublished literature survey furnished by B. E. Keevil of the Glaciology Division, Environment Canada, Ottawa, Ontario, in the preparation of this reply. We also acknowledge conversations with various participants in the Beaufort Sea Project about oil spills, and with T. McCulloh of the U.S. Geological Survey about oil reserves. Supported by the Office of Naval Research under project NR307-252 and contract N00014-67-A-103-0007. Publication authorized by the director, U.S. Geological Survey.

28 August 1974

How Specific Is Specific?

We immunologists and immunochemists are fond of using the adjective "specific," yet few of us use it correctly. Strictly, a specific antibody for antigen Q would react only with antigen Q, yet cross-reactions, when they are looked for, are generally found. In fact Landsteiner (*1*), probably the leading student of the subject, defined specificity as merely "the disproportional action of a number of similar agents on a variety of related substrata." In light of this definition, I was correct when, having discovered the lectins in 1945, I wrote down the Lima bean agglutinin as A-specific, although the relevant page of my notebook (*2*) showed that the bean extract agglutinated group B erythrocytes weakly also.

However, if this was a loose use of the word "specific," I have not been guilty of some of the misstatements ascribed to me. Etzler and Kabat (*3*), in reporting that the lectin of *Dolichos biflorus* reacts with both A_1 and A_2 blood group substances, say this contradicts "previous studies in which the lectin was said to be A_1 specific (cf. Boyd and Shapleigh, 1954a, b)" (*4*). I did not quite say this. In the second of the 1954 papers referred to, I said that "an extract of *Dolichos biflorus* precipitates with the saliva of secretors of subgroup A_1, but not with A_2 . . ."; nothing more general than this. In the first paper I said, "Some preparations of *Dolichos biflorus* . . . seem *at first glance* to be entirely specific for A_1 . . . but we have obtained indicators that they react weakly with A_2 also" (emphasis added). In 1963 (*5*) I was more precise. "*Vicia cracca* and *Dolichos biflorus* . . . react so weakly with A_2 that they are virtually specific for A_1. The affinity of *D. biflorus* extracts for A_1 cells is over 500 times that for A_2 cells."

I should now be inclined to suggest that the word "virtually" probably applies to all the cases of "specificity" we know, and that complete specificity, like perfect virtue, is seldom if ever encountered in this world.

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26 April 1974