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3.3 Chemicals in Cold Environments

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3.3.1. INTRODUCTION

This section has been prepared using primarily Canadian materials and references. Thus, although the title refers to 'cold environments', most of our attention will be devoted to northern circumpolar regions, i.e. to the Arctic, specifically the Canadian Arctic. Naturally, it is expected that much of the material will be relevant to other circumpolar countries and to alpine regions. Comparisons to such other areas will be drawn from time to time in the text.

3.3.2 BACKGROUND: GEOLOGICAL HISTORY

On a geological time-scale, the arctic areas have not been stable, but have been subjected to migration of continental land masses and also to vast fluctuations in their ambient climate. The same has been true, indeed, for most regions of the planet; however, it is essential to take note of some of these changes for arctic regions in particular since the ecosystems involved take a great deal of time to recover their 'stable' state after major perturbations. It has been suggested that only rarely in history have they been able to enjoy long periods of stability, free from the profound effects of major climatic variations and continental drift.

The lands now surrounding the northern Polar Sea did not, of course, originate there, but formed part of a large land mass, now referred to as Pangea, lying largely in temperate and subtropical regions. It was scarcely 200 million years ago that the mid-ocean ridges opened and the continents moved toward higher latitudes. The North Atlantic Ocean opened, separating North America from Europe only at the end of the Cretaceous period, some 80 million years ago, and the Labrador Sea opened about 50 million years ago. The Greenland Sea appears to have opened a mere 1.5 milion years ago.

Ice ages may not seem relevant to the high Arctic, but the surrounding regions, sources of inward migration of species of all kinds, have been profoundly affected many times in the past 200 000 years. The most recent, a period of extreme glaciation between 20 000 and 10 000 years ago, established the present physiognomy of the Arctic. Its lands, soils and ecosystems are actually quite young, in spite of the fact that in geological terms the underlying rock, particularly in the Canadian Shield, is some of the oldest exposed rock on the planet.

3.3.3 GEOGRAPHICAL AND PHYSICAL CHARACTERISTICS

The North Pole is not, of course, located on land. It lies in a large central ocean of more than 9.5 million km^2, including several basins of depths of up to 5000 m, surrounded by large, relatively shallow epicontinental coastal seas. These seas cover almost 36% of the area, but hold only about a fiftieth of the water. These seas are, furthermore, in relatively poor contact with the worldwide ocean system. The channels connecting the Arctic Sea with more southerly waters are narrow or shallow, with the exception of the Fram Strait, between Greenland and Spitzbergen, which accounts for three-quarters of the flow both in and out of the Arctic Sea.

The main flow is outward; although an influx of (largely surface) waters does take place, the inflow of water from the sizeable northern rivers makes the water balance significantly positive (the northern rivers input about 90 000 m^3/s, which is about half the flow of the Amazon).

This combination of a deep central sea and positive water balance leads to a most important consideration for the Arctic, namely that water circulates in the Polar Sea for a significant time before leaving. This means that an input of heat from the warmer oceans hardly exists at all; it also means that any chemical contaminant has ample opportunity to circulate to all countries bordering on the Arctic Ocean before it can be expected to leave the region. It is very much a situation where the several countries involved have to live with each others' pollution, and for a long period of time at that.

On the lands surrounding the sea, particular conditions must also be considered. The dominant consideration is probably the permafrost, by which we describe the phenomenon of frozen layers of ground, ranging sometimes many metres in depth. This phenomenon makes our conventional ideas of groundwater transport and drainage totally inappropriate. In large regions of the North, there simply is no subsurface water flow, and this in turn must remove from our consideration any thoughts about the earth itself as removing toxic chemicals from areas of immediate concern, as happens to a very large extent in warmer regions.

The other consideration is that rivers flowing from south to north tend to melt at their headwaters earlier in the spring than at their downstream portions. The result is that extensive flooding routinely takes place along the length of these rivers, further complicating the question of environmental behaviour of chemicals and, in fact, making all sorts of activities, including scientific research, immensely difficult.

Finally, we should note that, perhaps surprisingly to many, most northern regions have quite a low level of precipitation. Rey (1983) has pointed out that Phoenix, Arizona has more than three times the average annual precipitation of the interior of Greenland. Although the flow from the rivers draining northward is substantial, most of the water comes from much further South. The amount of water available for a general irrigation of the vast expanses of the North is very small. This also has an effect on the behaviour of pollutants, by making a 'flushing' or 'leaching' phenomenon relatively less important in the process of pollutant or chemical removal.

3.3.4 GEOGRAPHICAL EXTENT

The phrase 'cold environment' is hard to give a definite meaning to, and each of the definitions that might be considered has its shortcomings. There seems little point in using an arbitrary geographical definition, such as all area north of the Arctic Circle or any other latitude, since there is so much variation in climate at the same latitude around the world. In the North Atlantic year-round navigation is possible up to about 75°N, whereas the second coldest capital city in the world is reputed to be Ottawa, Canada (the coldest is Ulan Bator), which lies at approximately 45°N.

Other definitions may be suggested, such as one depending on average annual temperature, maximum yearly temperature, or a temperature-related characteristic, such as the existence of permafrost or, less severely, the guaranteed existence of a month or more of freezing weather every year. Alternatively, an ecological feature could be used, such as defining cold regions as those beyond the tree line. The latter has the advantage of being applicable also to alpine regions.

The author believes that an appropriate definition should be made in the context of whatever feature is being discussed. In what follows, we shall try to make clear what we mean by 'how cold is cold' in the contexts of the various sections, rather than ask the reader to adopt a rigid definition for the entire work. Suffice it to say we regard a region as cold if it is influenced by one or more of the factors we have mentioned.

3.3.5 POLLUTANT TRANSPORT

The entry and initial distribution of chemical pollutants in northern systems also has some features which, although not totally unique, are sufficiently different from temperate and tropical systems to be worthy of examination.

To begin with, northern climates often have fixed or prevailing weather patterns. Meteorologists are quite familiar with the Aleutian Low, the Icelandic Low, and the Canadian and Asiatic Highs. These patterns persist for lengthy periods, providing more or less fixed pathways for airborne contaminants into the northern regions. The result, of course, is that diffusion over large areas is a more limited phenomenon than in temperate regions, and local concentrations of any given chemical may, therefore, be noticeably higher than if it were evenly distributed over the area into which it was introduced.

Another feature of these weather patterns and the air flows to which they give rise is that, as already noted, there is very little precipitation involved. Since many pollutants are removed from air masses primarily by precipitation events, this means that chemicals may be transported for surprisingly long distances before being deposited, and furthermore the low temperatures involved help the chemical to resist degradation to perhaps more innocuous forms.

These general observations lead to predictions that have been clearly verified. Although there is still some dispute about the effectiveness of acid rain at destroying ecosystems, there is no question that it is there. Large quantities of acidic material have been observed in northern regions farther from civilization than would be expected. Many lakes in Canada, Sweden and Norway have been seriously affected by acidic material that is known to originate in regions further south, in the industrial areas of southern Canada and the United States, and in the power generating stations and steel mills of the Ruhr valley and Eastern Europe.

It is interesting to note that the industrial areas of eastern North America, and Japan and Korea, do not seem to contribute to an international problem. This appears to be because they produce pollutants which quickly move over oceans, and the relatively high precipitation rates remove most of the noxious materials. An interesting exception appears to be mercury, for which there is increasing evidence that it travels through the atmosphere in the form of elemental mercury vapour rather than associated with particulate matter, and is hence less easily removed by wash-out. The finding of significant quantities of mercury in the Greenland ice cap lends support to this concept of its transport.

The transport over long distances in the northern regions is not simply due to the general northeasterly drift of air masses in the northern temperate and sub-arctic zones. The stationary weather patterns in the North are now known to provide an actual pathway from European and western USSR sources northward near Novaya Zemlya, over the Arctic Ocean and then westerly to northern Canada and the northern parts of Scandinavia and Greenland. Rey (1983) points out that these aerosols have been carefully examined and are known to be of continental origin because of their ^{210}Pb content; they are known to be anthropogenic because of the differences in the vanadium : aluminium ratio to that in the earth's crust (this ratio is widely used in tracing the sources of airborne contaminants). Furthermore, examination of the ageing of these aerosols by measuring their SO_4 : V ratio shows that they have been airborne for periods of more than 2 weeks (generally, a precipitation event will remove an atmospheric aerosol within 4 or 5 days).

An example of a location affected by such a pattern is Barrow, Alaska: here winds from the Pacific are essentially unpolluted, but northeasterly winds can carry SO_4 at a level of $2\,\mu g/m^3$, a level which would be regarded as worthy of concern in a highly industrialized southern city. We might add that the phenomenon is undoubtedly not limited to Barrow; if sufficient analytical facilities were available, the same situation would surely be found over a wide area of the northern land masses.

Not all movement of pollutants through the atmosphere takes place in a single step, since not all deposition is the end event of a geographical movement process. When relatively volatile substances are deposited, e.g. substances like mercury or chlorinated hydrocarbons, the deposition is often quickly followed by a volatilization and re-suspension. Such substances may make many such short trips before they are removed from the system, either by being deposited into the ocean or by being firmly bound to the surface of the earth—e.g. by being taken up by some kind of biota. As this multiple-step process moves a substance toward colder regions, of course, the re-suspension through volatilization becomes less effective simply because of the lower temperatures encountered. The conclusion is clearly that the northern, colder regions will by diffusion alone become a sink for many pollutants, and again this has been verified by the discovery of relatively large concentrations of such chemicals as DDT in Arctic and Antarctic regions.

3.3.6 DEPOSITION AND SUBSEQUENT MOVEMENT

As pointed out previously, one of the characteristics of low-temperature regions is a shortage of rainfall, and this means that compared to temperate climates a larger fraction of the deposition will be so-called dry deposition, a general settling of dust and small aerosol particles rather than on droplets of rain. The consequence of this is that there is less tendency for pollutants to soak into the soil and be chelated or leached away; direct exposure to plants in particular, through leaves and green surfaces generally, is thereby increased and with it the expectation of direct damage.

That part of the pollutant load which comes directly to the soil will be characterized by a long residence time, both because of little subsequent leaching by rainfall, and because of chemical stability at low temperatures. Since the chemical will also remain close to the surface of the ground, it also follows that it will be more available for uptake by burrowing or browsing animals of all kinds, including insects and birds; the pollutant that is so deposited will, in other words, be more immediately incorporated into the food chain for subsequent bioaccumulation.

Movement in the environment will, of course, take place, but again in a special way which implies that cold environments are in a sense more likely to be damaged by a pollutant burden. This is because movement is most likely to take place suddenly, at a particular time of year, namely at the time of spring thawing and runoff. At this time, there may be extensive flooding because of blocked drainage of the rivers, so the land which has been dry most of the year and on which there has been an almost continuous input of pollutants will suddenly be flushed of its burden. The water which carries out this process will necessarily end up with a large chemical concentration.

In addition, another phenomenon is at work. Such snow and ice as exist on the land surface, and on the surfaces of rivers, will also have a pollutant burden stored from the previous months, and the sudden springtime melting will release this into the waterways and lakes as a sudden large input rather than as a uniform amount spread over the year. Short-term concentrations of pollutants in the spring will, therefore, be noticeably higher than in similar environments without the spring-melt phenomenon.

As if further aggravation of the situation were needed, we have to say that there is yet another consideration. This is the observation that the elevated pollutant concentrations of the spring runoff will typically occur when aquatic organisms are just hatching out or otherwise at their period of maximum growth rate. This in general will mean that they are more sensitive to effects of pollutants than they will be at a larger, older stage. Cases exist where it has been shown quite clearly that fish in a polluted lake appear to be quite healthy, but the population can still be seen to vanish; the explanation has been given that a young generation is not surviving to replace the older adults.

3.3.7 REFERENCES

Rey, L. (ed.) (1983). Arctic Energy Resources: *Proc. of the Comité arctique internat. Conf. on Arctic Energy Resources*, Oslo, Norway, Sept. 22–24, 1982. Elsevier, New York.