A NOTE ON ASSESSMENT OF MINERAL RESOURCES IN THE ANTARCTIC

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Abstract: It may be reasonable to assume that the Antarctic Continent would contain as much mineral resources as those in other continental fragments of the Gondwana super-continent. The exploration and exploitation of mineral resources, however, may be much restricted by the hard natural conditions in the Antarctic. The conservation of the environment may also place a severe limitation on the mining activities. Geological investigations oriented to assessment of mineral resources are appraised, but the effect of the exploration and exploitation of mineral resources on the environment of the Antarctic should be carefully considered before the actual commercial-based exploration activities are initiated.

1. Introduction

An extensive knowledge on geology of the Antarctic has been accumulated during the past twenty years of intensive survey by many geologists of various countries. A number of occurrences of various kinds of mineral resources such as coal, natural gas, and many kinds of metals and nonmetals have been reported in the inland, coastal, and also offshore areas of the Antarctic (*e. g.*, WRIGHT and WILLIAMS, 1974). Actual exploration works for mineral resources might be initiated some time in the near future. In this short note, a clue for assessment of potential mineral resources in the Antarctic is considered and possible problems related to exploration and exploitation activities are reviewed briefly. Though indications of gaseous hydrocarbons were drilled in the Ross continental shelf (SCIENTIFIC PARTY FOR LEG 28 OF DSDP, 1973) and fossil fuels may be the most important potential resources in the Antarctic, only metallic mineral resources are considered in this note.

2. A Clue for Assessment of Mineral Resources

Much evidence for the disruption of the Gondwana super-continent into South American, African, Australian, and Antarctic Continents, subcontinent of India, and some other isolated islands has been accumulated by long-lasted geological investigations especially during the past twenty years of intensive survey by many

geologists and geophysicists of various countries. The outline of the reconstructed configuration of the Gondwana super-continent seems to be accepted by many though its details are still partly debated. The reconstructed Gondwana super-continent indicates that the east coast of southern Africa, the east coast of India, and the southern coast of Australia were connected at one time to the East Antarctic in the individual sites located clockwise from Weddell Sea to Ross Sea (*e. g.*, CRADDOCK, 1973). The geology of the West Antarctic is an extension of that of South America (Grikurov, 1978).

Although many parts of the Antarctic have been mapped for geology and various mineral occurrences have been documented, our knowledge of mineral resources of the Antarctic is still quite restricted compared with that of the other fragments of the original Gondwana super-continent. In the present state of our knowledge, a crude assessment of mineral resources of the Antarctic based on the geological similarities among the Antarctic and other fragments of the Gondwana supper-continent may be inevitable. This is a kind of speculation rather than exact assessment, but it should be carried out as the first step. The assessment of this type, which has been made already by some geologists (WRIGHT and WILLIAMS, 1974), can not delineate the real targets for exploration and exploitation of mineral resources, but can depict only vaguely larger areas for exploration. In the following, we will give an outline of the prominent features of geology and mineral resources in the separated areas of the Gondwana super-continent, will pursue the geological trends, and then we will consider the possibility of mineral resources in the Antarctic.

Eastern Australia is underlain by a Paleozoic sedimentary pile intercalated with some volcanics, which is folded intensely, more or less metamorphosed, and penetrated by many granitic intrusives, composing an orogenic belt called the Tasman orogenic belt. There are many, if not very large, base metal deposits such as Captains Flat and Woodlawn massive copper-lead-zinc deposits, Cobar copper deposits in New South Wales, and Mt. Lyell–Rosebery copper or lead-zinc pyritic deposits in Tasmania. Some granitic intrusives together with surrounding sediments are locally mineralized giving several tin-tungsten deposits in Tasmania as well as in New South Wales (MARKHAM and BASDEN, 1974). Part of Victoria is well-known for rich gold deposits, many of which have been exhausted already. The trend of the mineralized orogenic belt seems to be traced to Victoria Land and further southwards in the Antarctic.

In western Australia one of the most ancient continental fragments is extensively exposed. Gold-quartz veins cutting the metamorphic complex in Kalgoorlie and other areas produced formerly a considerable amount of gold. Recently major copper-nickel sulphide deposits associated with Archean ultramafic-mafic volcanics were found and are being worked actively in Kambalda and related areas (*e. g.*, KNIGHT, 1975). The trend of the mineralized areas is nearly in the north-south direction and seems to cut the coast line of the continent, suggesting a possibility of

extension of the mineralized zones to the Antarctic in the area, say, around 110°E longitude.

It is generally considered that the east coast of the Indian subcontinent is properly fitted to the East Antarctic at around 30° to 70°E longitude. In the fitted part of India highly and repeatedly metamorphosed Precambrian rock formations including charnockitic rocks and granitic rocks are predominant. Various types of pegmatites occur in the formations. Similar rocks and pegmatites are distributed in the counterpart of the Antarctic.

Southern Africa is one of the richest areas in the world in terms of the metallic mineral resources. Lower Proterozoic gold deposits associated with quartzose sandstone and conglomerate in the Witwatersrand area, which are considered to be of ancient placer origin (*e. g.*, MINTER, 1976), are by far the leading producer of gold in the world. On the other hand, the Bushveld layered igneous complex of lower Proterozoic is exposed in a composite circular body about 400 km in longer diameter. The igneous body contains a few thin but valuable layers rich in platinum-group elements and a number of horizons with abundant chromite and also with vanadium-bearing magnetite (*e. g.*, CAMERON and DESBOROUGH, 1969; SCHWELLNUS *et al.*, 1976). Thus the igneous complex is a major producer of platinum-group metals and chromite. There are also many presently subeconomic copper-nickel sulphide and tin mineral occurrences which may be considered to be potential mineral resources (WILLEMSE, 1969). Southern Africa is also well-known for its diamond occurrences and carbonatite masses uniquely mineralized (PALABORA MINING CO., LTD., 1976). These mineralized igneous bodies and sedimentary formations are, however, isolated and seem to be closed in their modes of occurrence. Extension of the Precambrian and later rocks of southern Africa is traceable as a whole to the Antarctic, but it seems difficult to delineate the exact extension of the specific mineralized areas. Nevertheless, some mineralized areas may be expected to exist in the areas of the Antarctic once connected with southern Africa. In connection with the Bushveld igneous complex mentioned above, it would be noteworthy that a huge-scale layered mafic intrusion of Jurassic age, called Dufek intrusion, is found in the Pensacola Mountains in the East Antarctic and its petrographic properties as well as its potentiality for mineral resources have been investigated by a party of the United States (HIMMELSBERG and FORD, 1976; FORD *et al.*, 1977).

The Cordillera running along a belt in the western side of South American Continent is traceable even physiographically to the West Antarctic, and thus it is evident that the Andean trend extends through the acutely curved island arc to Graham Land and further southwards. The Cordillera of South America is an orogenic belt composed of deformed sediments and volcanics accumulated on the Paleozoic and possible Precambrian basement. Many granitic intrusives of Cretaceous and early Tertiary ages penetrate the formations. Many large-scale disseminated copper or copper-molybdenum deposits conventionally called porphyry-type copper de-

posits occur in association with the granitic bodies. Chuquicamata, Rio Blanco, El Teniente and some other deposits are well-known (*e. g.*, PETERSEN, 1970). The Cordillera is one of the most intensely mineralized areas for copper. Annual mining production of copper from the areas amounts to about 15 percent or so of the world production, and the reserves of copper ores are estimated to be over 25 percent of those of the world. Major copper deposits are concentrated in central and northern Chile and Peru, but they are rather rare in southern Chile. This may be interpreted as that erosion has already stripped off the capping of volcanics and clastics and also shallow parts of intrusives which are all considered to be favorable sites for porphyry-copper mineralization. Prominent indications of copper mineralization have not yet been reported in the West Antarctic but the peninsular area would be one of the most promising areas for base metal deposits in the Antarctic.

3. Mineral Commodities of Possible Interest

Mineral resources are commonly classified into two principal types, reserves and resources, based on current economic availability. BROBST and PRATT (1973) defined them as follows: "Reserves are known, identified deposits of mineral-bearing rocks from which the mineral or minerals can be extracted profitably with existing technology and under present economic conditions, whereas resources include not only reserves but also other mineral deposits that may eventually become available, either known deposits that are not economically or technologically recoverable at present, or unknown deposits that may be inferred to exist but have not yet been discovered." Moreover, reserves may be limited to the deposits which are legally recoverable. According to this definition we have a little subeconomic or speculative resources, but currently we have no reserves of metallic ores in the Antarctic. WRIGHT and WILLIAMS (1974) listed only geothermal energy, water as ice, fossil fuels and some manganese nodules as potential resources in the Antarctic and surrounding areas. Many of the reported mineral occurrences are hardly considered useful under the present circumstances.

Distribution of mineral resources presently mined is by no means uniform throughout the world. For example, major copper deposits are concentrated in the Cordillera in North and South America, other several areas of the Circum-Pacific mobile belt, the Copperbelt of southern Africa, and some other selected areas (PÉLISSONIER, 1972). It is also true, however, that potential mineral resources as a whole seem to be more or less evenly distributed if larger areas such as of a continent order are considered. The Antarctic having an area of about 13 million km^2 is approximately 1.5 times larger than Australia. It may not be unreasonable to consider that the whole Antarctic including not only the ice-free areas but also the huge terrain covered with thick ice sheets contains a large amount of mineral resources at least comparable to those of Australia. It is unlikely, however, that

in the foreseeable future metallic mineral resources under the thick ice sheets can be mined on the commercial base. The ice-free areas in the Antarctic are very narrow, thus reasonable potentials of mineral resources in the Antarctic are considered to be quite limited despite of its large areal extent of the continent as a whole.

Even if mineral deposits as rich in usable minerals as the deposits profitably in operation in the areas of moderate climate are found to exist in the ice-free areas of the Antarctic, the high cost of mining operation in difficult environment of the Antarctic would make us give up an attempt to extract the minerals on the commercial base. We have seen in the past that technological improvement in mining, mineral processing, and extraction methods converted subeconomic mineral resources into profitable reserves. However, the environment of the Antarctic does not seem to be so easy to make mining operation possible for all sorts of mineral commodities in the foreseeable future even if major progress is attained in technology.

On the other hand, increasing consumption of mineral resources is becoming a source of anxiety whether the resources are enough for future demand. The mineral commodities which are assumed to become insufficient for demand in the not so distant future may be a center of interest in the areas unfavorable for exploration and exploitation of mineral resources like the Antarctic. SKINNER (1976) suggested that the tonnage of ores of abundant metals such as iron and aluminum increases continuously as grade or metal content of ores is decreased, then the potential resources of abundant metals are considered quite large, while there is a gap between the grade of ores of geochemically scarce metals presently mined and the crustal abundance, thus the tonnage of ores of scarce metals does not increase materially if the grade of ores is decreased and the potential resources of such metals may be much restricted. The latter type of metals such as copper, lead, zinc, and many others may encounter serious shortage much earlier than the former. Actually various kinds of statistics indicate that the current reserves of many of geochemically scarce metals might be exhausted in not so distant future if the trend of consumption and that of acquisition of new reserves do not change materially. The ores of such scarce or rare metals would be attempted to exploit in the remote areas in future when shortage of the metals become real. In this respect it may be worthwhile to make clear the distribution of mineral deposits geologically anywhere in the world, including the Antarctic, for future demand.

4. Effect of Exploration and Exploitation on Environment

Any exploration and exploitation activities may inevitably result in various kinds of environmental impact, trivial or serious. Several areas have been already closed to activities such as exploration and exploitation of mineral resources for conservation of natural environment of the Antarctic. The disturbance of the ecological system may be caused by drilling for exploration, mining of ores, and disposals of

tailings or other waste materials. Accidents possibly attended by the exploration and exploitation activities would produce an unexpected serious effect to the environment even if every possible cares are taken for protection of environment in the routine operation. The effect of the activities to the environment should be carefully assessed in various subjects. Scientific Committee on Antarctic Research responded to this problem and issued recommendations for assessment of effect of exploration and exploitation of mineral resources to the environment and for monitoring program (SCAR, 1977). The cost for conservation of environment may become another factor to discourage development of mineral resources of the Antarctic. At any rate, the effect of the exploration and exploitation of mineral resources to the environment of the Antarctic should be carefully considered before the actual commercial-based exploration activities are initiated.

5. Conclusion

The Antarctic probably contains various kinds of metallic mineral resources like the other continental fragments of the Gondwana super-continent. It is unlikely that the possible metallic mineral resources under the thick ice sheets are exploited in the foreseeable future, but in the ice-free areas the exploration and exploitation to some extent would be commenced in the not so distant future. The mineral deposits of geochemically scarce or rare elements would be main targets for exploration in such remote and difficult environment as the Antarctic. More geological investigations oriented to mineral resources assessment would be required, while the effect of the exploration and exploitation of mineral resources on the environment should be assessed carefully before the commercial-based exploration works are initiated.

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