Antarctic oil and mineral resources: a subject off limits or future reality?

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Abstract

On-going trade wars combined with the increasing consumption and depletion of known resources will necessitate the search for new deposits in poorly explored or unexplored areas, such as the polar regions. Antarctica is unique among the world's continents in having no native population and state sovereignty; the continent has also been identified as potentially harboring extensive hydrocarbon and mineral resources. To protect the fragile Antarctic environment, the Protocol on Environmental Protection to the Antarctic Treaty (1991) banned any mineral activity for a 50-year period, except for scientific purposes. The Protocol will be renewed in 2048, and discussions of possible future mining in the region has already begun. With the improvement of drilling and mining technology, the risk of future mining activity on the continent is increasing. Moreover, extensive mining operations in the Arctic demonstrate the technical and economic feasibility of mining activities in harsh polar environments. The protection of the fragile Antarctic environment must be prioritized; however, maintaining the balance between environmental protection and commercial and national interests in resource development is problematic.

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Key Points:

- Any mineral activity in Antarctica is banned till 2048 but the future of mining in this area remains uncertain
- There is continuing debate about distribution of potential resources in Antarctica between the states of interest
- Economical and environmentally safe of mining activities in Antarctica remain questionable to optimally aid decision-making

Abstract

On-going trade wars combined with the increasing consumption and depletion of known resources will necessitate the search for new deposits in poorly explored or unexplored areas, such as the polar regions. Antarctica is unique among the world's continents in having no native population and state sovereignty; the continent has also been identified as potentially harboring extensive hydrocarbon and mineral resources. To protect the fragile Antarctic environment, the Protocol on Environmental Protection to the Antarctic Treaty (1991) banned any mineral activity for a 50-year period, except for scientific purposes. The Protocol will be renewed in 2048, and discussions of possible future mining in the region has already begun. With the improvement of drilling and mining technology, the risk of future mining activity on the continent is increasing. Moreover, extensive mining operations in the Arctic demonstrate the technical and economic feasibility of mining activities in harsh polar environments. The protection of the fragile Antarctic environment must be prioritized; however, maintaining the balance between environmental protection and commercial and national interests in resource development is problematic.

1 Introduction

The recent trade wars between the US and China and the EU and Russia, as well as the Saudi-Russia oil price war, the US shale industry crisis, and the recent pandemic lockdowns have caused significant stock market turbulence and negative economic impacts in many countries. To protect the economy, many developed and industrial countries are focusing on energy and mineral independence. Oil and mineral resources are disproportionally distributed across the world, with some countries having significantly higher resources than others. Based on data from Organization of Petroleum Exporting Countries (OPEC) at the end of 2019, Venezuela, Saudi Arabia, Iran, Iraq, and Kuwait hold two-thirds of the global proved oil reserves (OPEC, 2020). China, responsible for more than 90% of the world's supply of rare-earth elements, recently prioritized its own economic demands and began to limit exports (Richard, 2013). Only two mines in South Africa supply more than 80% of the world's platinum, which is essential for catalytic converters and new fuel cell technologies. Additionally, more than 30% of the total copper supplies—a widely used metal—is produced in Chile. The political risks related to the disproportionate geographical spread of key raw materials were clearly demonstrated when China temporarily ceased the export of rare-earth elements to Japan in 2010 for almost two months. Thus, to continue the rate at which we use mineral resources, the global race for oil and critical minerals will require the discovery of new deposits in poorly explored or unexplored areas, such as the polar regions.

The issue of mineral exploitation in Antarctica was first addressed in the 1972 Antarctic Treaty Consultative Meeting in Wellington, New Zealand, which was the first discussion of non-living resources (SCAR, 1972). Attendees agreed on the possibility of potential mineral exploitation in the Antarctic, and thus, regulations were required to control future activity. The first mining regulations in Antarctica were developed by the Convention on the Regulation of Antarctic Mineral Resource Activities (CRAMRA) issued in 1988 (SCAR, 1988); however, unresolved environmental issues were a dominant reason for the document's collapse.

The Protocol on Environmental Protection to the Antarctic Treaty (referred to as the Madrid Protocol, 1991) was developed in 1991 and regulates any future oil and mineral resource activity

in the region (SCAR, 1991). Article 7 of the Madrid Protocol prohibits all activities relating to Antarctic mineral resources, except for scientific research. In addition, the prohibition of mineral resource activities cannot be removed unless a binding legal regime on Antarctic mineral resource activities is enforced. The Madrid Protocol will be reviewed in 2048, and in the meantime, the treaty can only be modified by the unanimous agreement of all Consultative Parties to the Antarctic Treaty.

Mineral extraction in Antarctica would be extremely expensive and dangerous due to the continent's weather, ice, and distance from industrialized areas. However, the risk of mineral extraction is increasing with improving technology. The global concerns are shifting toward environmental protection in response to the increased awareness of anthropogenic impacts on the natural environment. Moreover, the risk of mineral operations is expected to increase with increasing accessibility, as the Antarctic ice sheet continues to shrink. Under the strongest climate forcing scenario, ice-free areas are projected to expand by over 17,000 km^2 by the end of the century, which is equivalent to a ~25% increase (Lee et al., 2017). Most of this expansion is expected to occur in the Antarctic Peninsula, where a threefold increase in ice-free area could significantly enhance mineral resource availability and alter the local environment.

Although the renewal of the Madrid Protocol is not due for another 27 years, discussion on the future of Antarctic resources has already resumed. However, fundamental questions still remain. For example, it is highly unclear as to whether mining activities will be economical and environmentally safe in the Antarctic. Further discussions are also required to determine how potential resources will be distributed between the states of interest.

2 No man's land

Antarctica is a unique continent due to the absence of native populations and state sovereignty. Historically, seven states—Argentina, Australia, Chile, France, New Zealand, Norway, and the United Kingdom—maintain a claim on eight territories in Antarctica (Hughes and Grant, 2017) (Fig. 1). Significantly, Russia and the USA have no claim in Antarctica; however, the Russian explorer, Fabian Bellingshausen, was the first to discover the continent in January 1820, and the American Admiral, Richard Byrd, discovered and claimed Marie Byrd Land for his country in the 1930s.

Some of the Antarctic territories overlap; for example, most of the British territory is overlapped by Chilean and Argentinean territories. Only a region of Marie Byrd Land (90°W to 150°W) remains unclaimed. The Antarctic Treaty entered into force in 1961 and put aside all existing and new territorial claims (*402 UNTS 71*, 1959). Article IV of the Treaty declared that: "*No acts or activities taking place while the present Treaty is in force shall constitute a basis for asserting, supporting or denying a claim to territorial sovereignty in Antarctica. No new claim, or enlargement of an existing claim, to territorial sovereignty shall be asserted while the present treaty is in force*." However, the United States and Russia (the successor state of the Soviet Union) maintain their right to make claims in future.

Nevertheless, almost all scientific observations and study facilities of the seven claimant states continue to be located within their claimed territories. The only exception is the joint French-Italian Concordia Station located at the Dome C ice sheet within the Australian Antarctic Territory. In contrast, non-claimant countries with multiple year-round research stations (Russia,

United States, China, Korea and India) have dispersed their stations across more than one of the claimed territories. Due to the position of the United States Amundsen-Scott South Pole Station, all claimed Antarctic territories are occupied.

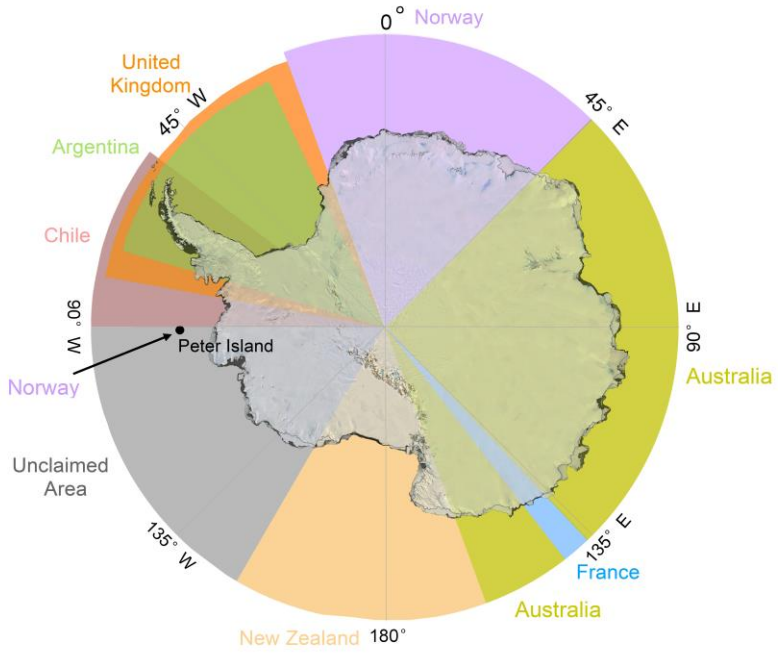

Figure 1. Territorial claims in Antarctica (based on the data published by Hughes and Grant, 2017).

Therefore, geopolitical factors have strongly influenced the distribution of the Antarctic Treaty Party's logistical facilities within the continent. Territorial claims still exist and are acknowledged by the Antarctic Treaty. As a result, claimants are still entitled to assert their territorial claims and implement sovereign state actions (but not expand upon or make new claims). At present, no country owns Antarctica, but the question of ownership remains unresolved while states agree to handle the issue under the Treaty's umbrella.

3 Behind-the-scenes activities

Article IV of the Antarctic Treaty placed all territorial claims in abeyance; however, a number of claimant states submit claims to the United Nations Convention on the Law of the Sea (UNCLOS) to extend their potential sovereignty on the Antarctic continental shelf (all referred claims are published on-line at https://www.un.org/Depts/los/clcs_new/commission_ submissions.htm). Australia was the first to submit a claim with respect to the Australian Antarctic Territory in November 2004. The submission included full coordinates of the Australian continental shelf margin and proposed extending the continental shelf in this region by up to 687 km^2 beyond the 200-mile zone. However, Australia mentioned in the attached note that the Commission on the Limits of the Continental Shelf (CLCS) was requested simply to store the data and not examine it.

In April 2009, Argentina submitted a claim to the CLCS regarding an exceptionally large continental shelf area spanning the Atlantic and Sothern Oceans, including the Antarctic shelf in the Weddell and Bellingshausen Seas (Fig. 2). In May 2016, the Commission publicized its recommendations, and only a small proportion of the Argentine claim was endorsed. This paper explained the legal regime and the political process that led the Commission to refuse the endorsement of the Argentine claim to the Antarctic shelf.

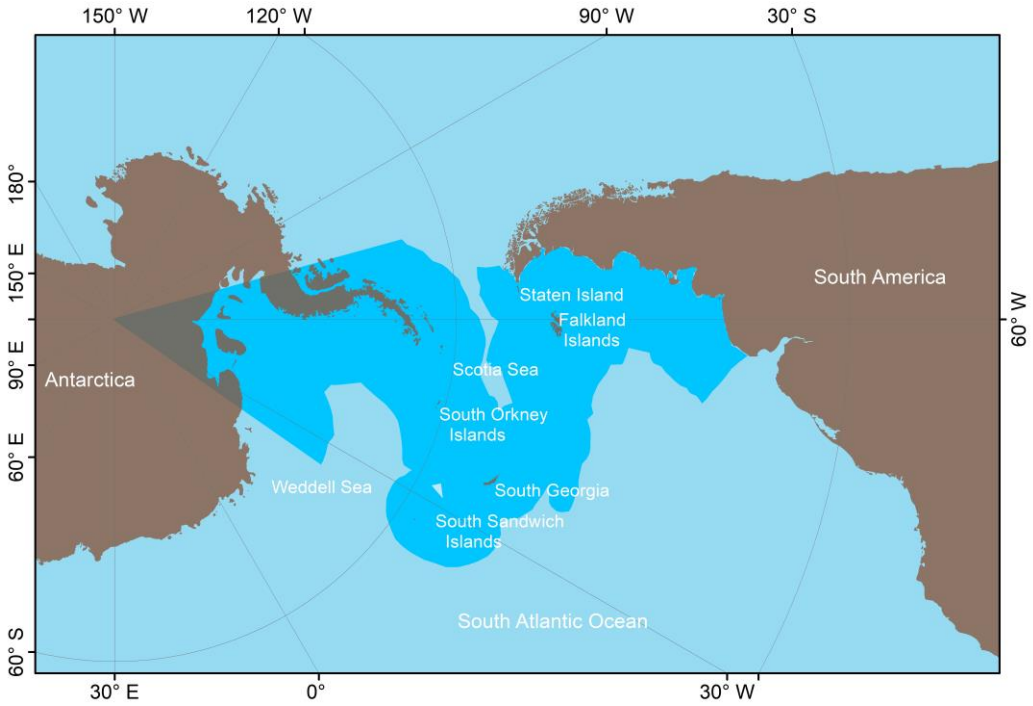

Figure 2. Argentine claim for the continental shelf between Antarctica and South America, April 2009.

In May 2009, Norway submitted a claim to CLCS for the continental shelf of Dronning Maud Land, but the same as Australia requested "*the Commission, in accordance with rules, not to take any action for the time being with regard to the information in this submission that relates to the continental shelf appurtenant to Dronning Maud Land*."

Chile, France, New Zealand, and the United Kingdom have not made claims on the Antarctic shelf. The UK notified the CLCS in May 2008 that it would not be submitting data for the continental shelf around the British Antarctic Territory but reserved the right to do so in future. It is therefore apparent that submissions to the CLCS are unable to resolve the primary issue of Antarctic sovereignty.

4 Current understanding of Antarctic resources

Due to the Madrid Protocol ban, the publication of research on Antarctica's mineral potential was almost prevented after the 1990s. Current knowledge on Antarctica's mineral resources is limited due to the ban on mineral exploration, lack of exposed land, and difficult field logistics.

Mineral occurrences have been heavily mapped in ice-free areas; however, little is known about Antarctica's mineral resources, as most of the rocks are covered by a thick ice sheet. According to samples collected from small areas of exposed rock and from observations in South Africa and South America, Antarctica is predicted to have large and valuable mineral deposits below its ice sheet. Prior to 180 million years before present, Antarctica formed part of the Gondwana supercontinent and was attached to South America and the southern parts of Africa, India, and Australia (Fig. 3). These continents subsequently detached and drifted to their current positions. Major ore-forming processes occurred approximately 800–150 million years ago during the time of the supercontinent; thus, Antarctica has a high potential for large-scale deposits.

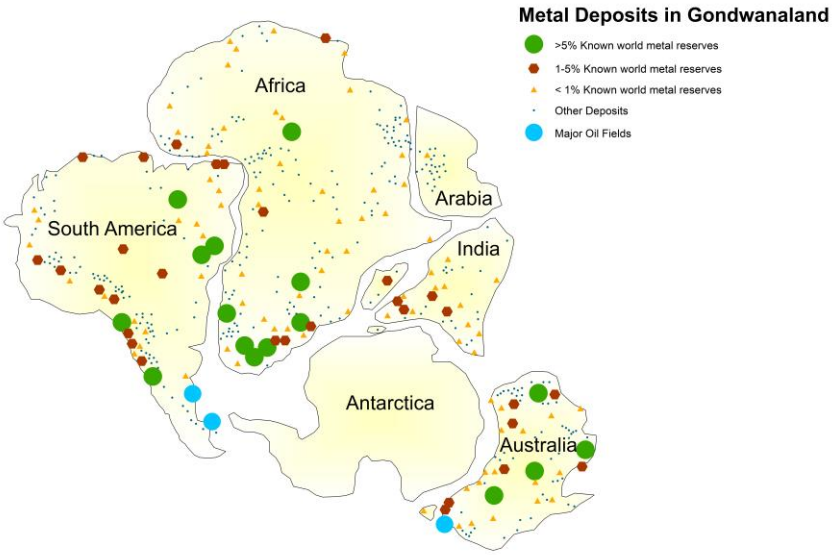

Figure 3. Reconstruction of Gondwana approximately 180 million years ago. Mineral deposits and oil fields are indicated by the solid dot and circle, respectively (based on the data published by Willan et al., 1990).

There are currently no known mineral deposits in Antarctica, though the continent has significant potential in this regard. To date, a considerable number of mineral occurrences have been observed in the ice-free areas of Antarctica (Fig. 4). The Dufek Massif is a mafic igneous intrusive complex in the northern Pensacola Mountains and possesses the most significant mineral reserve potential in Antarctica (Ford, 1990). Geologists speculate that the Dufek Massif contains significant quantities of platinum-group metals; these minerals have not yet been identified in the Dufek intrusion, although some rock analyses have identified trace amounts of these elements. Apatite in the Dufek intrusion is fluorine rich and exhibits systematic variations in the contents of iron, strontium, and rare-earth elements.

The East Antarctic iron metallogenic province includes rocks with banded iron formations along the east coast from Enderby Land to Wilkes Land; Dronning Maud Land also consists of a ferrous vein province (Rowley et al., 1983). The largest iron deposits are located in the Prince Charles Mountains, notably at Mount Rucker, with the occurrence of 70-m thick individual jaspilite beds (Willan et al., 1990).

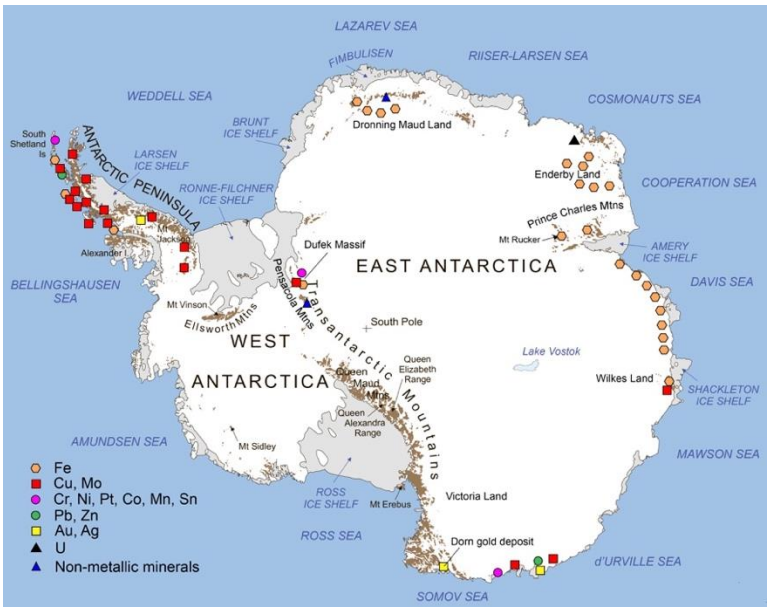

Figure 4. Antarctic mineral occurrences (based on the data of Crispini et al., 2011; Ford, 1990; Polar Prospects: A Minerals Treaty for Antarctica, 1989)

West Antarctica has a higher rock exposure—particularly in the Antarctic Peninsula and the off-lying islands. The northern Antarctic Peninsula has the potential for porphyry copper-style mineralization and is known as the Andean metallogenic province (Polar Prospects: A Minerals Treaty for Antarctica, 1989). Mineralization in the South Shetland Islands and the Antarctic Peninsula includes a volcanogenic iron deposit, porphyry (copper, molybdenum, iron), and polymetallic (copper, lead, zinc, silver) occurrences (Hawkes, 1982). Kimberlite samples were discovered in Mt. Meredith in the northern Prince Charles Mountains, inferring the high potential for diamonds (Yaxley et al., 2013). The Dorn lode gold deposit in northern Victoria Land is the first described significant occurrence of gold mineralization in Paleozoic terranes of the Antarctic continent (Crispini et al., 2011). These regions are considered the prime areas for mineral exploration.

Coal is widespread across many parts of Antarctica' exposed rocks—particularly in the Transantarctic Mountains. The coal measures in the Transantarctic Mountains are part of the Beacon Supergroup and are considered roughly equivalent to the coal of the Karroo in Southern Africa (Crockett and Clarkson, 1987). Coals of similar age are also located in the Prince Charles Mountains (Splettstoesser, 1985) (Fig. 5). However, coal deposits are considered uneconomical due to the logistical challenges of extraction and due to the occurrence of large coal reserves on other more accessible continents.

Petroleum reserves are likely to be present in Antarctica based on geological structures and geophysical evidence—particularly offshore in the thick sedimentary basins of the Amery Ice Shelf, Ronne-Filchner Ice Shelf, Ross Sea and Ice Shelf, and Weddell Sea (Mitchell, 1977). Petroleum and natural gas were detected during the US Deep Sea Drilling Program Leg 28 in 1973 on the continental shelf in the Ross Sea. The discovery of hydrocarbons along the Atlantic coasts of Africa and South America, the east coast of India, and the south coast of Australia infer the possibility of similar accumulations along the coasts of Antarctica that were once in

proximity to the petroliferous margins of other continents. In 1973, the US Geological Survey therefore estimated the potential for petroleum and natural gas resources on the continental margin of West Antarctica. The Bellinghausen, Ross, and Weddell Seas are estimated to store a total of 7.15×10^9 m3 of oil and 3.25×10^{12} m^3 of natural gas.

Figure 5. Coal cropping at Northern Prince Charles Mountains, Antarctica, January 2015 (Credit: Xiaochun Liu, Institute of Geomechanics, Chinese Academy of Geological Sciences)

The modeling of biogeochemical processes in sub-Antarctic marine sediments suggests the presence of methane hydrate reserves storing $1.31–7.28 \times 10^{14}$ m^3 and 2×10^{13} m^3 of methane gas beneath the East Antarctic Ice Sheet (biogenic production in frozen bed sectors) and West Antarctic Ice Sheet (thermogenic production in wet-based, geothermally active areas), respectively (Wadham et al., 2012).

5 How to drill and how to mine

Drilling and mining operations in polar regions are complicated by the presence of ice, snow, and permafrost and the absence of roads and infrastructure. Extremely harsh climate conditions magnify operational and logistical problems, leading to high costs, lengthy delays, and abnormal situations. Even prior to the Madrid Protocol ban, no country had planned prospecting and exploration work for new oil reserves or mineral deposits in Antarctica. Geological and environmental drilling activities in Antarctica were concentrated mainly in the Antarctic Peninsula (Bockheim et al., 2013) and in the McMurdo Dry Valleys and McMurdo Sound (Talalay and Pyne, 2017). A few hundred holes, mainly with shallow depths of less than 50 m, were drilled for the purpose of studying the distribution and properties of permafrost and active-layer dynamics.

However, in recent decades, researchers have conducted intensive geological drilling in the McMurdo Sound region to study past ice sheet behavior, including the evolution of both the East and West Antarctic Ice Sheets. Drilling began with the Dry Valley Drilling Project (DVDP) in 1973, resulting in 15 boreholes ranging from 4 to 381 m in depth. Nine offshore sites were cored from the local sea ice in McMurdo Sound and the McMurdo Ice Shelf, with penetration depths of

64.6 m (DVDP-15 borehole, 1975) to 1284.9 m (AND-1B borehole, 2006) below the seafloor. The experience gained during these geological drilling projects formed the basis for the following section on drilling technology, which considers drilling requirements in generic drilling sites on land, sea ice, and ice shelf platforms.

To date, only five bedrock samples have been successfully recovered from beneath the Antarctic ice sheet, three of which were recovered by US and Chinese drillers in the last few years (Fig. 6). Despite the significant progress in the recovery of Antarctic subglacial bedrock samples, issues related to the drilling fluid, ice hydrofracturing, ice cutting removal, and other factors have not yet been fully resolved and require further research to improve efficiency and safety.

Figure 6. Drilling to the bed of the Antarctic ice sheet: (a) a ~8-m-long bedrock core near the Pirrit Hills, January 2017 (Kuhl et al., 2020); (b) a short, 6-cm-long bedrock core at the flank of the Dålk Glacier near the Chinese Zhongshan Station in the Larsemann Hills, February 2019 (Talalay et al., 2020); (c) a ~2-m-long bedrock core at Minna Bluff, January 2020 (Credit: J. Goodge, University of Minnesota Duluth).

Mining activity has not been conducted in Antarctica to date, except for earthwork operations to construct buildings, power stations, roads, and runways. Potential fields have not yet been discovered and must be resource rich to encourage exploration. US, Canada, and Russia have significant experience in oil and mineral exploitation in the Arctic. For example, the Red Dog mine in Alaska produces approximately 10% of the world's zinc (Loeffler, 2015). Moreover, the Canadian Diavik mine—located in the North Slave Region of the Northwest Territories—is one of the world's pre-eminent sources of gem diamonds, producing approximately 7 million carats of diamonds annually since operations began in 2003 (Shigley et al., 2016). The Russian Norilsk Nickel Plant in the northern part of Krasnoyarsk Krai produces more than 10% of the world's nickel (Lindholt, 2006). The success of these and some other Arctic mines confirm the technical and economic viability of mining operations in harsh polar environments.

Rapid advances in drilling and mining industries are fundamentally changing how these sectors operate. Automation, replacement of diesel-powered machinery by electric ones, drones providing real-time data, safer underground equipment, deep-sea robots and water-neutral processing are only some of the changes that already significantly decrease environmental impact. For the foreseeable future, the new mining technologies, no doubt, will become more and more environmentally sustainable.

6 Looking forward

To date, it remains unclear as to which country has the rights to mineral exploration in Antarctica, which is why no past territorial claims have been accounted for. Antarctica is the dominant focus of the entire international community, and therefore Antarctic resources should be shared across all nations (McColloch, 1992). This view, known as the common heritage principle, supports the proposition that Antarctica, like the ocean and space, is a common heritage of mankind and is not subject to national jurisdiction; any benefits derived therefrom must inure to the international community.

With the increasing risk of mineral exploitation in Antarctica, environmental impacts must be considered and regulated before the initiation of mining activity. The exploitation of Antarctic minerals must therefore be regulated in the same manner as that implemented for marine resources in international waters. The International Seabed Authority ensures that marine minerals are equitably distributed among the world's countries and that damage to seabed habitats is minimized (Beaulieu et al., 2017).

The Scientific Committee on Antarctic Research (SCAR) has a long and successful record of summarizing policy-relevant scientific knowledge to policy makers (Hughes et al., 2018). Some CRAMRA regulations can still be considered in the case of future exploitation. However, in addition to approved management schemes that prescribe the specific terms and conditions for mineral resource exploration and development, comprehensive environmental monitoring and environmental impact assessments must also be established and implemented throughout the exploitation phase and after mine abandonment. Moreover, mining and drilling activities should not be permitted in environmentally sensitive zones in Antarctica.

Commercial mining activity in Antarctica is not expected to take place before the expiration of the Madrid Protocol. However, the withdrawal of the U.S. from the Paris Agreement demonstrated instability of international environment agreements (Schiermeier, 2020) and thus, the future of Antarctic mining following the renewal of the Madrid Protocol in 27 years remains uncertain. The current discussion is divided into two strongly opposed perspectives: those who promote the extension of the resource exploration and exploitation bans to the end of the century, and those who promote the possibility of limited exploration.

Supporters of the exploitation ban opine that mineral extraction would cause serious damage to Antarctic ecosystems; they also argue that the discovery of substantial mineral wealth could lead to the unfreezing of claims on the Antarctic territory, which would destabilize the Antarctic Treaty System. Supporters of limited Antarctic exploration claim that the depletion of known reserves on other continents will inevitably necessitate the exploration of reserves in Antarctica. They suggest to permit for the next 50 years mineral resource prospecting of a district with the

view to mine the resource at a profit in future. This step includes airborne geophysical surveys, geochemical surveys, geophysical surveys on surfaces, and wildcat drilling. All of these technologies are environmentally safe and allow for the accurate scaling of oil and mineral distributions in Antarctica. In addition, prospecting will help to solve existing scientific problems regarding the behavior of Antarctic geologic features.

Exploitation of economic minerals in Antarctica is a controversial topic, as it is the only continent on Earth that is not largely affected by human activity. The international community must therefore carefully assess the pros and cons of this decision before 2048.

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