CHROMITE MINING

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INTRODUCTION

Cliffs Natural Resources Inc., an international mining company, has announced their intent to develop a world-class chromium mine and processing infrastructure in the McFaulds Lake area of northern Ontario. Cliffs' stake, located in the mineral rich region known as the "Ring of Fire", offers one of the most advanced developments in this remote and still relatively untouched region (see Figure 2). Chromite has never before been mined in Canada, let alone in such an extreme environment as is found in the Far North of Ontario. Because of this, there is a large degree of uncertainty concerning the risks and potential environmental impacts that may result from such a development.

The vast majority of chromite mining has previously occurred in warmer, drier climates or areas marked by distinctive 'wet and 'dry' seasons. Few chromite mines operate in regions where the temperature falls below 0 degrees Celsius. Chromite mining is a relatively complex process with hydrology, climate and geochemistry acting as crucial variables in the impacts mining may have. Because of this researchers are challenged with a lack of comparable case studies highlighting what the effects of a northern chromite mine might be.

This report is specifically directed towards explaining the chromite industry: the mine infrastructure proposed by Cliffs, examination of the chromite market, overview of the history of chromite mining and, importantly, the environmental impacts that may threaten those affected by the proposed development. It should be clarified that, though there are a myriad of socio-economic and environmental impacts that will arise should Cliffs' proposed mine become a reality, this paper looks at those impacts directly tied to or unique to mining the ore itself. This document is intended to be considered as only a fraction of the total cumulative impacts of this mine.

BACKGROUND

Chromite/Chromium

Chromium is the 24th element on the periodic table and is what makes steel stainless. It gives steel a high resistance to corrosion and makes it appear shiny. Chromium is found within the ore mineral chromite ($FeCr_2O_4$) which is iron-black to brownish-black in colour, has a metallic luster, and a hardness value of 5.5 (scale is from 1 to 10). Chromite is also one of the first crystallizing minerals to form from cooling mafic magma (rich in dark, ferromagnesian minerals) or ultramafic magma (containing mainly mafic minerals). The chromite deposits found in the Ring of Fire are stratified and fall into the Chromium/Nickel/Copper/Platinum Group Elements category (OMNDM 2011).

Uses

Ninety percent of the chromite mined across the world is converted into ferrochrome for use in stainless steel production. Ferrochrome is an alloy composed of iron and chromium, created in an electric arc furnace when processing chromite ore. The importance of ferrochrome lies in the fact that there is no substitute for it. Mined chromite is also used to manufacture refractory bricks, furnace linings, and foundry sand. It is used in these objects because it has a very high melting point and can withstand very high temperatures (OMNDM 2011).

World Chromite Supply

The global resources of chromite are recognized to be adequate for the needs of the world for many more years, with world reserves being estimated at 7,600 million tonnes. South Africa, the dominant chromite ore supplier, is expected to hold its 35% share in the supply, with some marginal increases expected in Turkey, Russia, and Zimbabwe. There is some worry about supply shortages of ferrochrome. Figure 1 shows two pie charts illustrating the location of world chromite reserves (South Africa having by far the largest), and world chromite production for 2011 (South Africa again dominating) (Industrial Minerals 2011).

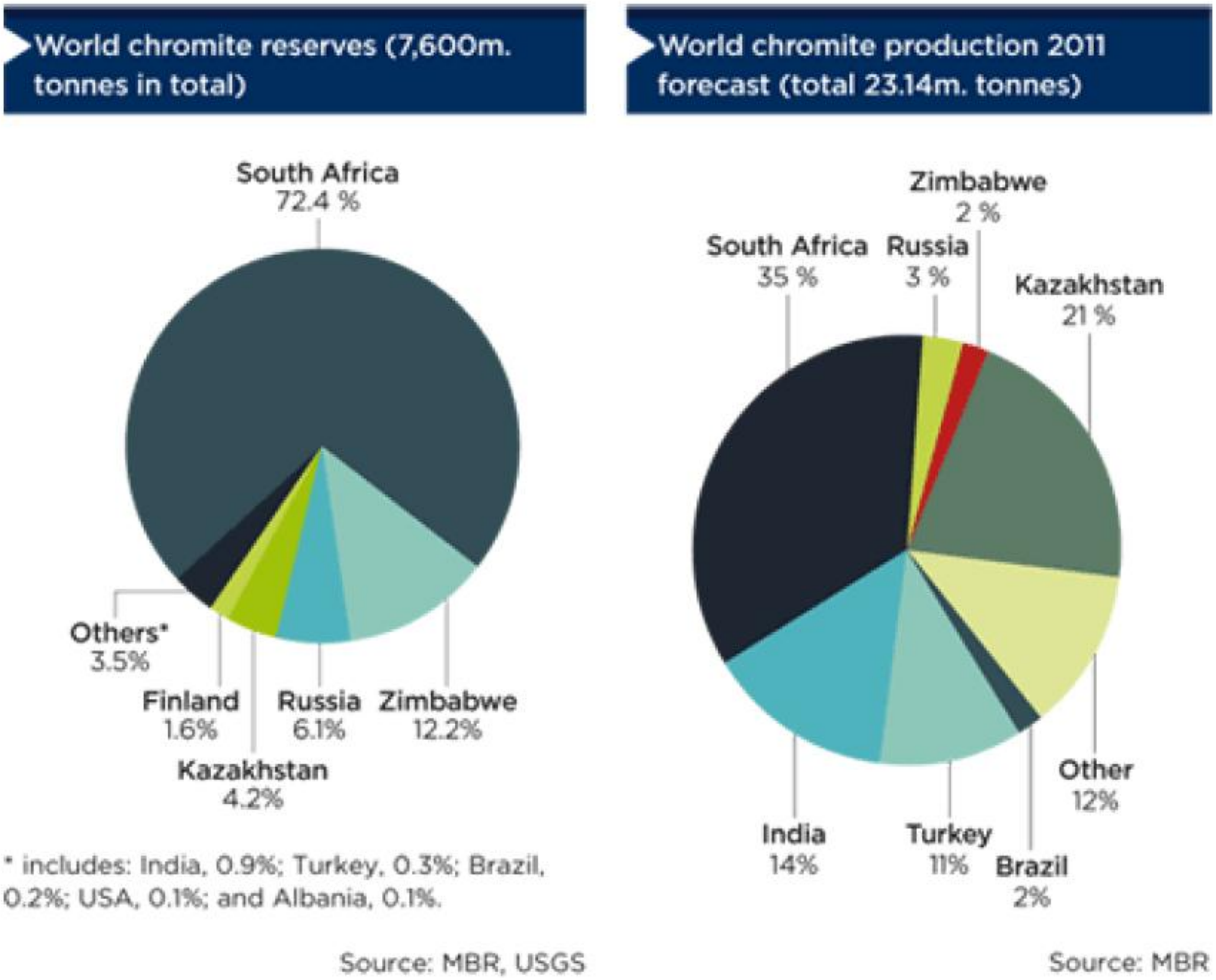

Figure 1. World chromite reserves and production graphs
Source: Industrial Minerals 2011

Table 1. World chromite production capacity of major producers

Country	Production capacity (1000s of tonnes)	Percentage of Total
South Africa	15,340	44.9%
Kazakhstan	6,300	18.5%
India	3,250	9.5%
Madagascar	2,280	6.7%
Turkey	1,850	5.4%
Finland	1,300	3.8%
Russia	1,300	3.8%
Brazil	900	2.6%
Philippines	440	1.3%
Iran	400	1.2%
Albania	240	0.7%
China	230	0.7%
Zimbabwe	170	0.5%
UAE	100	0.3%
Oman	30	0.1%
Total	34,130	100%

Source: Industrial Minerals 2011

Chromite Market Demand

Table 1 above further demonstrates the world chromite production capacity of the top producing nations. China currently consumes the largest amount of ferrochrome, accounting for some 50% of the total supply. The price of ferrochrome has risen as a result of increased world demand, mainly stemming from China and India (OMNDM 2011). Due to stainless steel production increasing about 5.7% per year, continuous growth will most likely cause increased ferrochrome consumption, potentially reaching 10.4 million tonnes in 2015. The consumption of stainless steel by Asian countries is estimated to increase 7 to 10%, while consumption in Europe is hoped to rise by 10%. The economic recovery of the ferrochrome and stainless steel sectors has resulted in the current higher demand for chromite. This strong demand has helped the weak performance of a number of South African mines that have had logistical and infrastructural problems, in part due to heightened energy costs. At present, there is tight supply and rising prices (Industrial Minerals 2011). This has promising connotations for Cliffs' entrance into the chromite market and would potentially position Canada as an important global chromite supplier. According to the ferrochrome production rate that Cliffs is forecasting (1,250 to 1,750 tonnes per day), Canada is likely to surpass South Africa in ferrochrome production (Golder Associates 2011).

Exploration in Ontario

Chromite was first surveyed in Ontario in the 1930's by a small operation, Chromite Mining and Smelting Corporation Limited. The company mapped out a 25,000 ton deposit in 1934 from the Puddy–Chrome Lakes area. The extent of this operation was extraction of bulk samples that were tested for suitability as a concentrate. The company went out of business in 1937, effectively stalling further chromite exploration. In 1979, the Ontario Geological Survey examined potential chromite deposits across the province and made the discovery of 5 significant occurrences near Big Trout Lake, Puddy - Chrome Lakes, Crystal Lake Gabbra, Shebandowan and Dundonald Township (depicted in Figure 2) (OMNDM 2011).

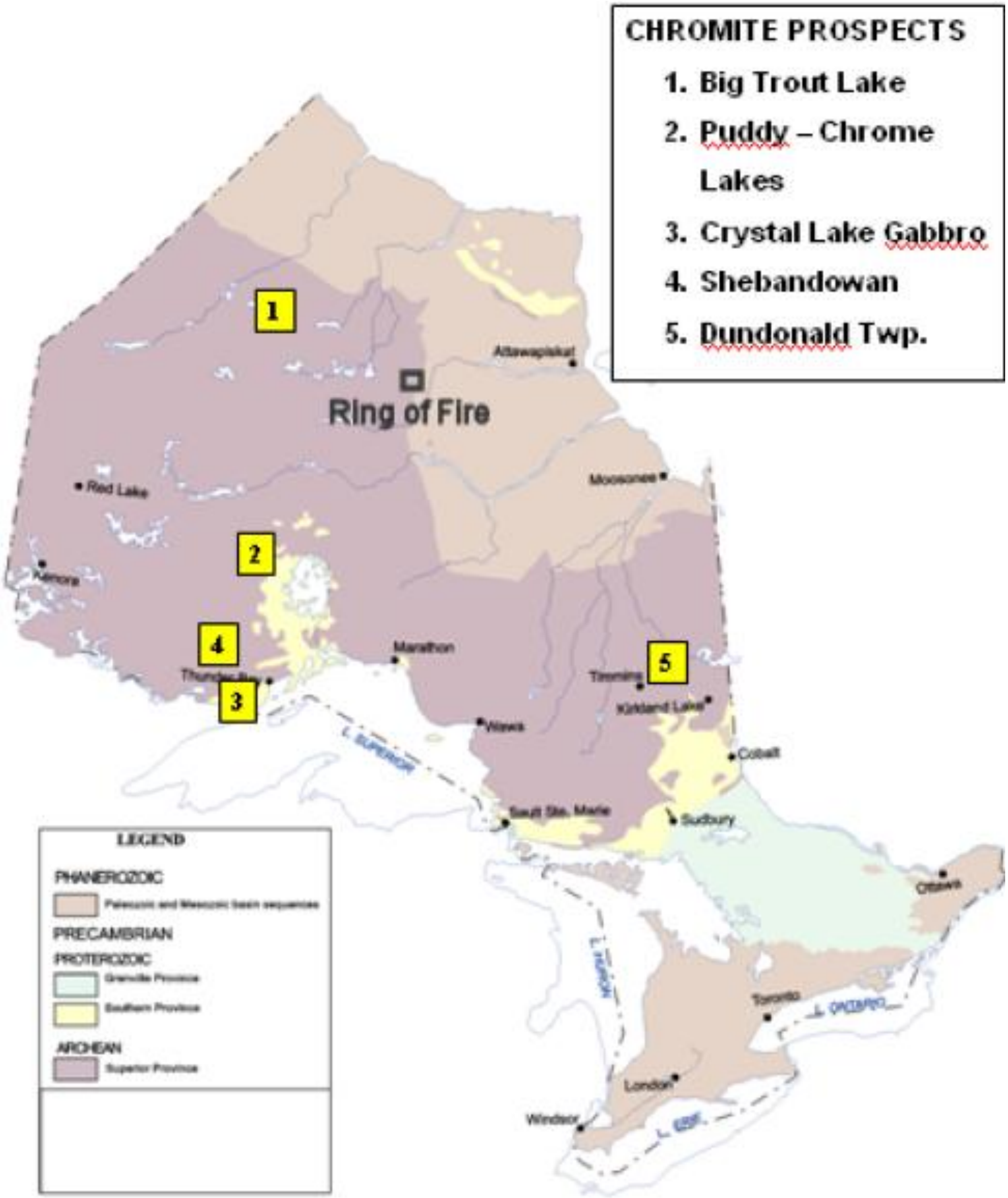

Figure 2. Chromite prospects in Ontario
Source: OMNDM 2011

Most recently, chromite deposits have been found along a 12-14 kilometer stretch in the area of Northern Ontario known as the “Ring of Fire”. In Figure 3, various mineral locations are displayed with chromite deposits shown in red. Cliffs Natural Resources holds the primary chromium stake in the area (OMNDM 2011).

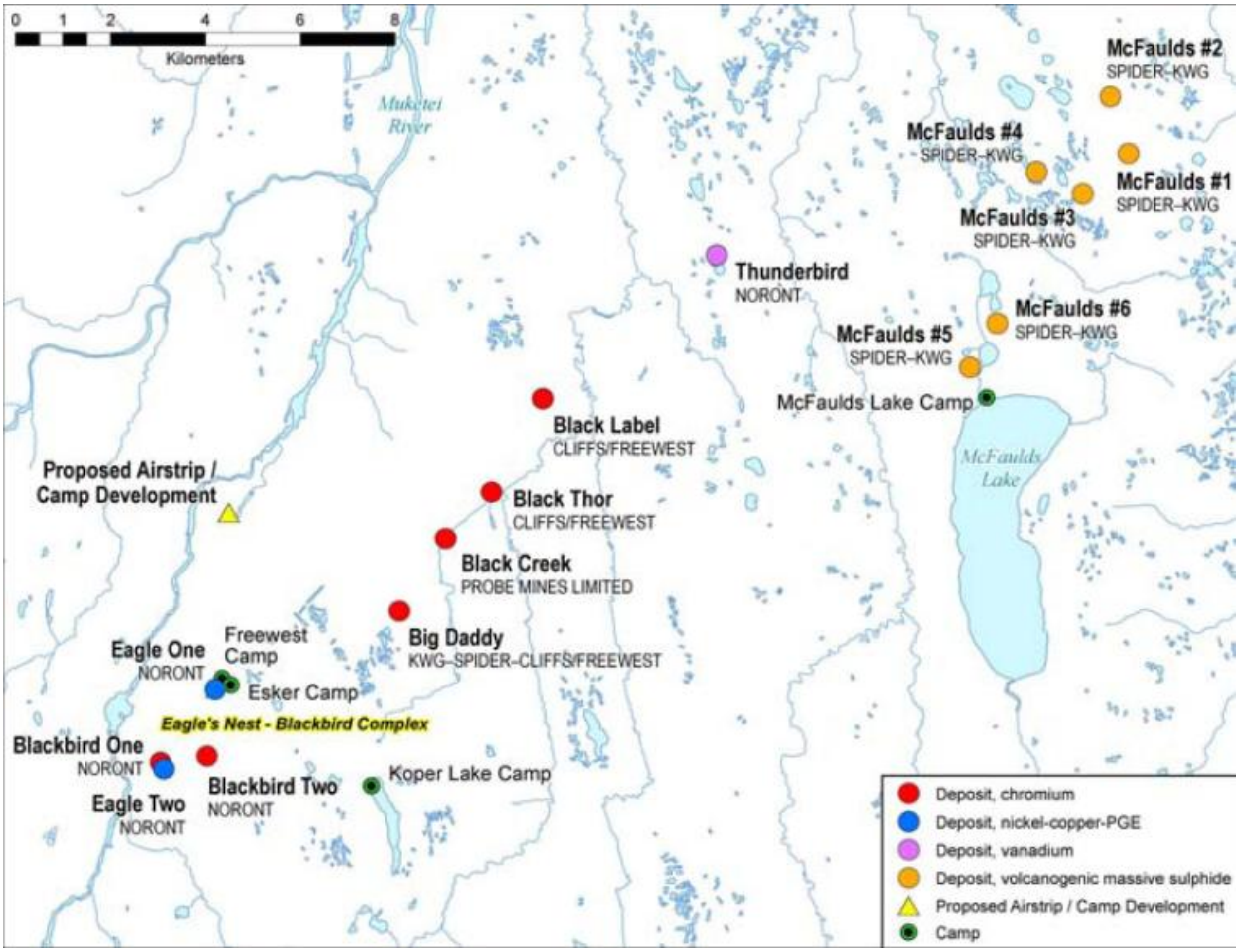

Figure 3. Chromite deposit locations in red
Source: OMNDM 2011

Cliffs Natural Resources Inc.

Cliffs Natural Resources Inc. is a multifaceted company. They are the primary producer of iron ore pellets in North America, major suppliers of direct-shipping lump and fines iron ore from Australia, and are also producers of metallurgical coal for the steel industry. The current proposed development of the Black Thor chromite deposit represents the company's first foray into the ferroalloy industry. Cliffs currently enjoys a major share in three of the known chromite deposits in the Ring of Fire (OMNDM 2011). Cliffs has stated that more feasibility and project milestone studies are required before major capital will be directed towards the chromite mine projects (Cliffs 2012). Because development of the Cliffs Chromite Mining Project would mark both the first Canadian chromite mine, and Cliffs' first attempt at mining chromite, it is felt that additional precautionary measures should be taken in the planning stage.

MINING PROCESS

Cliffs Proposal – Ore Extraction

Cliffs' proposed mining project currently remains at the conceptual level, with plans likely to change as research accumulates. At this point in time, Cliffs is engaged in the early stages of the environmental assessment comprehensive study process, regulated by the Canadian Environmental Assessment Act. On March 1, 2012 an open house was held to offer public review and input towards development of the EA terms of reference. Cliffs has prepared a base case project proposal and has begun the process of determining what baseline studies must be conducted to assess potential social and environmental impacts of the mining development. As such all "proposed plans" are described in reference to this base case and are subject to change depending on research findings and financial feasibility.

The current planning model predicts the life of the mine to be approximately 30 years, with operation of an open pit for a 10 to 15 year period, then transitioning to underground mining for the remainder of operations (Golder Associates 2011).

The open pit mine will have a mining rate of 6,000 to 12,000 tonnes per day from two open pit mines: the North-east Pit (1500 m long x 300 to 700 m wide x 300 m deep) and the South-west Pit (1300 m long x 500 m wide x 200 m deep). Equipment for these mines includes haul trucks, excavators, drills, service vehicles, and personnel transport vehicles. Ramps will need to be constructed to move equipment to and from the mine along with ore and waste rock to the surface. Ammonium nitrate/fuel oil explosives will be necessary to create the open pit (Golder Associates 2011). Dewatering wells to prevent flooding will be a complicated process due to the hydrology of the landscape. The area is poorly drained and consists of islands of spruce trees surrounded by peat bogs and stream channels. The water table fluctuates greatly (Golder Associates 2011).

The current mine proposal calls for the draining of a small pond and realignment of Kooper Creek and two of its tributaries. Overburden (the material residing above the desired chromite ore) 10 to 60 metres deep will be stripped and stored at the surface, in preparation for mine construction. Topsoil is planned to be stored for future revegetation and closure efforts, as well for construction and rehabilitation activities. Remaining waste rock will be stockpiled (Golder Associates 2011).

The underground mine has the same estimated production rate as the open pit mine and will require construction of an additional ramp. Excavating underground ore necessitates the use of blasthole stoping. This requires that ore is blasted and excavated, creating a cavity (or stope). Electric-hydraulic drills are used to create holes in the rock bed, which are then filled with explosives, and machinery is used to move ore to the surface. Once the ore has been removed, the stope is then backfilled. Mine backfill may include waste rock, sand, cement, or tailings (undetermined at this time). This process is repeated until all targeted ore has been extracted. Primary crushing in the underground mine may also occur if it is determined feasible. Ore crushing processes on the surface crush ore to a size of 20 cm or less, then a second time to a diameter of 8 cm. Ventilation will be necessary to inject oxygenated air into the mine shafts and tunnels and to remove nitrogen oxides, carbon monoxide, sulphur dioxide, and methane (by-products generated by diesel emissions and blasting). Ventilation also removes mineral dust as is required for worker safety (Golder Associates 2011). Mining operations are expected to generate some 65,000 tonnes of waste rock per day (Golder Associates 2011).

Cliffs Proposal – Ore Processing

Ore processing will occur over a 55-hectare area near the mine. Ore is first downgraded in size, and then wet gravity separation is used to divide out the heavier chromite mineral from the waste rock. This wet concentrated chromite is then thickened and filtered to create a final concentrate. This is done to increase the grade of the ore. Concentrate is produced at 6,000 to 7,000 tonnes per day. Rejected materials (tailings) from processing activities are stored on surface in an engineered tailings management area. Water requirements for ore processing will come from recycled mine water, but fresh water from the Muketei River may be substituted if needed (Golder Associates 2011).

The base case calls for processed concentrate to be shipped to Sudbury where it will be transformed into the final product. However, because this represents only one plausible option, this is only a tentative location. Concentrate may also be sold directly to the market. The total economic benefit to be seen within Canada from development of the Cliffs mine will depend greatly on the amount of ore that is able to undergo ferrochrome production within the county (Cliffs Natural Resources is a United States company based out of Ohio).

Cliffs Proposal – Waste Management

Tailings are pumped as slurry, a semi-liquid mixture, to the first of two tailing cells. Dams around each cell are designed to withstand flood and earthquake events. The second cell is used only in the event of excess tailings material and will be built to the same specifications as the first cell. Cells are constructed with low permeability materials to prevent metal leaching and acid rock drainage processes from occurring (Golder Associates 2011). Metal leaching and acid rock drainage from mine tailings and waste rock are significant ground and surface water impact concerns (Carta Exploration Ltd. 2012).

For the first two years of water storage, the starter dam should be hydraulically stable. Cliff plans to limit contamination to the surrounding muskeg by utilizing a low permeability core over top of a geotextile and geogrid-reinforced foundation. Stabilizing berms will help to make the structure more secure. Internal central decant ponds will be created in the tailings cells away from the perimeter dam for the purpose of allowing gravity to settle tailings material to the base of the pond. Recycled water and surplus water will be pumped from a water barge. Surplus water is to be treated and discharged into the Muketei River, which flows to the Attawapiskat River and eventually into James Bay (Golder Associates 2011). Further testing of tailings will need to be conducted as the site needs, especially for coarse-grained tailings. Tailings are not expected to be acid-generating when exposed to the atmosphere, however, there is a potential for heavy metal leaching (Golder Associates 2011). Further testing is being conducted to establish exactly which metals pose the greatest risk for the area.

The last step will be development of an on-site load-out facility that would serve to load and ship out 6,000 to 7,000 tonnes of concentrate per day to the final destination (currently Sudbury). Other potentially dangerous infrastructure includes fuel, chemical, and explosives storage areas, and waste management areas (Golder Associates 2011).

ENVIRONMENTAL IMPACTS

Scope

The proposed mining development offers a large number of potential environmental impacts ranging from dust generation, alteration of fish habitat, clearing of land to potentially catastrophic effects such as heavy metal contamination and acidic mine drainage. The focus of this section is directed towards explaining some of the threats directly associated with chromite ore and its waste products. This document is intended to be taken in consideration with further research documenting environmental risks distinctive to the Far North landscape. The following represents a selection of impacts that may occur as a result of chromite mining:

Acid Mine Drainage

Cliffs estimates that there will be approximately 230 million tonnes of waste rock created throughout the mine's projected 30 year lifespan (Golder Associates 2011). This raises concern as waste rock can distribute acidic and toxic contaminants into the environment. Polluted water from waste rocks may take centuries to decontaminate, depending on the minerals or metals responsible for the pollution (SDWF n.d.). Currently 20% of rock tested throughout the Black Thor deposit shows potential for acid generation (OMNDM 2011). Because this represents such a small fraction of waste rock, acid mine drainage (AMD) potential is considered to be relatively low. AMD is a process whereby sulphuric acid is produced when sulphides in rocks are exposed to air and water. The sulphides will continue to leach from the rock as long as exposure to oxygen and water continues or until the sulphides are completely leached out of the host rock (anywhere from a decade to hundreds of years) (SDWF n.d.). AMD makes water unusable and poses a serious threat to plant and aquatic life as well as to any who consume the contaminated water (Environmental Mining Council of B.C. 2010). Though the risk may be low for acidic leaching at the Cliffs Chromite mine, the company must dedicate careful attention and research to studying the unique lithography of the area and its interaction with determining factors such as pH, hydrology and climate to plan for any AMD that does occur (Carta Exploration Ltd. 2012).

Reclamation of areas contaminated by AMD is extremely difficult and costly (Environmental Mining Council of B.C. 2010). As a result, the key to avoiding such environmental disaster is to prevent interaction between potential acid leaching rocks and the surrounding hydrological system (Cardiff et al. 2012, Meck et al. 2006). This involves proper containment of waste rock likely to cause acidic drainage through use of impermeable liners and covers to limit oxidization and contain any pollution that may occur (Cardiff et al. 2012). Potentially acid-generating tailings/waste rock should be kept below water to prevent oxidation. Puumala (2011) recommends tailings impoundment sites be located in a low-lying area with low permeability soil and a high water table. Cardiff et al. (2012) advocate for the presence of constructed liners to further prevent seepage from occurring. Submerging the rocks in water allows for creation of a wet cover and prevents oxidization, a crucial step in the leaching process. Cliffs' planned tailing management strategy is in keeping with these recommendations. An impermeable liner is planned to protect the pond and water filled tailings cells will keep rocks submerged. Monitoring and adherence to these processes will be crucial as once the acid mine drainage process has begun, naturally occurring bacteria accelerate the process and make it virtually impossible to halt. Even with such stringent acid rock management strategies, many mines still encounter problems with acid mine drainage as engineered solutions are rarely sufficiently adaptable to changing environmental conditions (Environmental Mining Council of B.C. 2010).

Heavy Metal Contamination

Heavy metal contamination is another threat to the surrounding region. This type of contamination operates upon different principles and as such requires separate management strategies than does AMD.

The mineralized zone containing the Black Thor chromite deposit consists of ultramafic intrusive rock with zones separated by a horizon of disseminated chromite hosted within pryoxenite and dunite (OMNDM 2011). Geochemically, ultramafic rocks are enriched with heavy metals such as nickel, manganese, chromium, cobalt and copper. When the host rock becomes excavated and dumped on the surface, it creates potential for these heavy metal cations to leach into the surrounding environment (Maponga and Ruzive 2002). Metal leaching occurs when metals become mobile and leach into the soil profile. Most metals have significant mobility only at low pH, but some are mobile under neutral pH conditions. Under the correct conditions, there is an opportunity for mobile metal cations to leach into the water and soil supply causing contamination. The conditions causing metal mobility are highly site specific but involve an interplay of pH, temperature, climate, hydrology, presence of bacteria and geochemical composition of minerals (Maponga and Ruzive 2002, Farmer et al. 2006). The risk is heightened during open pit mining because chromite has a high stripping ratio (meaning that significantly more waste is generated in comparison to ore produced) and thus the more waste rock, the higher the odds leaching will occur (Maponga and Ruzive 2002). Less waste rock will be generated after the transition to underground mining and a backfilling technique will furthermore be used to increase the stability of the mine and decrease the environmental impacts caused by stockpiling of waste rock.

Research into chromite mines in Vietnam found that nickel, copper and chromium were the heavy metals of primary concern for leaching in chromite mining (Kien et al. 2010). In Zimbabwe, erosion of overburden dumps was found to cause dispersion of toxic heavy metals in soils and watercourses, and regeneration of flora in areas where overburden had been dumped was limited to those species capable of tolerating high pH levels caused by phytotoxic metals in the soils (Maponga and Ruzive 2002).

Most minerals are essential components of the both human and wildlife diets if consumed in proper quantities. The risk with metal contamination from leaching is that the environmental levels of these nutrients greatly increases. This results in much higher accumulations of metals in those regularly eating vegetation that has grown from contaminated soil or drinking water (Lenntech 2011). Leaching from waste rock also makes available different forms of certain minerals that may be carcinogenic or otherwise toxic to humans and animals. Nickel, for example, is an essential component of the diet, but consumption of unusually high quantities has been linked to lung cancer, heart conditions, embolisms, skin problems and birth defects (Lenntech 2011). The majority of research concerning nickel has focused upon its effects on humans; however, it is known that in certain instances nickel causes reduced growth rates in plants which could be theorized to have a ripple effect upon the entire foodchain (Lenntech 2011).

Hexavalent Chromium

Another contaminant of concern is hexavalent chromium (Cr(VI)) which, though it can be produced from waste rock, is most commonly associated with tailings, chromium ore processing residue (COPR) and dust. People can be exposed to chromium through breathing, eating or drinking and through skin contact with chromium or chromium compounds.

It is important to note that chromium, or more specifically trivalent chromium (Cr(III)), is a necessary nutrient in the human diet and deficiencies have been associated with disruptions of metabolism, diabetes and heart conditions. Hexavalent chromium, on the other hand, is caused primarily by anthropogenic sources such as ore processing and is a carcinogen linked to health conditions such as skin rashes, ulcers, respiratory problems, lung cancer, weakened immune system, alteration of genetic material, kidney, liver damage and death (Kien et al. 2010, Das and Singh 2011, Lenntech 2011). Hexavalent chromium compounds are ranked as a water hazard class 3 and are considered very toxic to both plants and animals (Lenntech 2011).

In 2007 the Blacksmith Institute declared Orissa, India one of the top 10 most polluted places in the world. The Orissa Valley holds India's largest chromite deposits with a number of operational and abandoned mines in the area. The Institute states that the air and soil of the area are so heavily affected by leaching of hexavalent chromium that intestinal bleeding, asthma and birth defects have become common in communities surrounding the mines. Further studies of the health of the population support that the death rate in that district is markedly higher with a large quantity of deaths attributed to hexavalent chromium-related afflictions (Das and Singh 2011).

Risk occurs if either leaching from waste rock or reactions during ore processing allow hexavalent chromium to be created and distributed in water or soil systems. Cr(VI) breaks down relatively easily into Cr(III) and primary contamination remains concentrated within a 1-2 km radius of the mine or dump sites (Kien et al. 2010). This finding was demonstrated both in Vietnam mine studies (see Kien et al. 2010) and in studies of management of chromium ore processing residue in the United States (see Farmer et al. 2006).

Hexavalent chromium is particularly dangerous because it is absorbed much more readily than is Cr(III). Once consumed, it breaks down into Cr(III), but releases byproducts which cause damage to organs and DNA (Lenntech 2011).

Tailings

Tailings are non-chromite rock produced from ore processing. As the definition implies, tailings would be generated from the ore processing facility located near the mine site. Tailings pose significant environmental threat as, in addition to potential for heavy metal leaching and formation of hexavalent chromium, chemical agents, such as cyanide or sulphuric acid, used by mining companies to separate the target mineral from the ore may spill, leak, or leach from the mine site into nearby water bodies (Earthwork and MiningWatch 2012). These chemicals can be highly toxic to humans and wildlife (SDWF n.d.). No feasible technology exists to remove and treat mine tailings dumped into large bodies of water and current clean-up methods for tailings contamination in lakes are extremely expensive (Earthwork and MiningWatch 2012).

One risk inherent with tailings management is dam failure. A tailings dam collapse in Spain resulted in the catastrophic contamination of the nearby Donata Park. The park, known for its key role in bird migration, saw a massive influx of toxic metals, acidic waters and mud with thousands of fish smothered or killed as a result (Grimalt et al. 1999). Though Cliffs is taking strong measures to prevent against dam breakages with development of tailing cells, this example highlights that mechanical or structural failures are always a possibility and pose a significant risk should they occur. To further put this risk in perspective, 92% of all hazardous material spills recorded by the Government of the Northwest Territories State of the Environment Report (GNWT ENR 2011) were attributed to waste water spills, notably sewage leakages and mine tailings.

It is especially important that backup systems and emergency procedures be developed early in the planning stages of this mine. MiningWatch Canada (2012) makes three recommendations for tailings management including minimizing the production of waste (transitioning at the earliest feasible time to an underground mine) and utilization of dry stacking and/or backfilling techniques. Dry stacking involves removal of most of the water from tailings so that the resulting product can be disposed of in a lined and covered management dump. This is a preferred method because the less water involved, the less likely the mine is to cause surrounding water contamination with dam failures or leakages (MiningWatch 2012). Dry stacking techniques are not suitable for management of waste rock with acid drainage potential.

Cliffs' chromite project has a unique challenge because of the climate of the Far North. Spring melt sees a significant change in water levels and this needs be budgeted for, as does the presence and variable nature of ice jams and permafrost. Many scientists predict a warming climate with impacts to northern Ontario being significant. Mine structural planning must budget enough flexibility to adequately account for the uncertainty regarding changing climate and hydrological dynamics. External climate change will further stress flora and fauna as they try and adapt to changing conditions. It is therefore additionally important that the mine pay close attention to minimizing anthropogenic pressures. A tailings spill could have extremely negative implications in this environment. The risk will only increase should other mining developments follow Cliffs in "opening up the Far North".

Current mine planning shows the mine site located in proximity to the Muketei River, an important and relatively pristine water course for the region. The complete extent of contamination for a tailings breach is unknown.

Earthwork, MiningWatch Canada (2012) and the Environmental Mining Council of B.C. (2010) further advocate that, if it is decided that waste cannot safely be stored on site, the risks of mine development are too high and the mine should not be constructed in that area.

Air contamination: Dust and ammonium nitrate/fuel oil

Dust poses a real threat to both employees working around the mine site and wildlife in immediate proximity of the mine. It has been found that dust generated from excavation, dumping, loading and transporting activities poses the highest risk for hexavalent chromium-related illness (Das and Singh 2011). Inhalation of particulate hexavalent chromium has been linked to increases in lung cancer, lung embolism and various other respiratory ailments. Dust that is distributed into the air eventually settles either on the soil or on water and, in either case, can lead to contamination of these sources. Capping sites to reduce airborne contamination will minimize risks as will strategic placement of certain facilities away from streams or water sources (Farmer et al. 2006). Ventilation in the underground mine will be required for workers' safety. It is likely that Cliffs has experience in dust management from its previous mining activities. Watering of roads and other key areas may be required to keep airborne particulate matter within acceptable levels.

Another respiratory risk is presented by the use of explosives necessary to create the open pit mines. The explosive mixture to be used, ammonium nitrate/fuel oil, contains 94% ammonium nitrate and 6% hydrocarbon solvent fuel oil, and can be a health hazard if inhaled (Donoghue 1998). Again it is important that health precautions be considered in the planning and development of the mine through all its stages.

Stripping of Overburden

Such large quantities of waste rock, as are predicted for Cliffs mining operations, create a myriad of environmental hazards with potential to threaten ecosystem functioning and surrounding wildlife, as well as human health. Waste rock offers the obvious impact of altering the natural landscape (predicted waste rock will cover some 600 hectares and be piled up to 30 m high) (Louttit 2011). Furthermore such extensive waste rock dumps offer significant risk for erosion. In Zimbabwe erosion of chromite mine waste rock and overburden dump sites led to siltation of nearby streams, causing blockage of channels, flooding, decreased oxygen content and reduced capacity of fish breeding grounds (Maponga and Ruzive 2002). Erosion from non-chromite mines in British Columbia has furthermore shown sediment to smother plants and destroy key aquatic habitats (Environmental Mining Council of B.C. 2010).

There is currently no system available to avoid stripping of overburden. Stripping is necessary to expose mineral bearing seams but causes massive disturbance to the land. Beyond surface contamination, stripping and generation of waste rock clears vegetation to open up the mining area as well as to construct roads or supporting infrastructure. This destroys wildlife and fish habitat. The opened up area becomes easily erodible by either fluvial or wind processes and sediment acts as physical pollutants by altering the light, temperature and oxygen contents in streams (Maponga and Ruzive 2002, SDWF n.d.). In some instances erosion has led to damming of areas and caused severe flooding, which further distributes contaminants and spreads pollution throughout the system (Maponga and Ruzive 2002, Kien et al. 2010).

Remediation

A number of strategies have been explored for long term remediation of chromite mining facilities and dumps. The general consensus is that no one solution fits all scenarios. As with predicting risk, the most appropriate remediation strategy is highly dependent on environmental factors such as pH, temperature, and geochemical structure as well as surrounding hydrology and climate patterns (Farmer et al. 2006). Many remediation techniques have been developed, some with quite high levels of success. Examples of possible techniques include utilization iron (Fe(II) or Fe) and organic compounds or bacteria to remediate the site. Treatments with sludge and similar processes also exist, though these treatments have met some criticism as they may release different chemicals into the environment (Farmer et al. 2006). What remediation strategy should be used in the case of Cliffs proposed mine cannot be determined without in-depth research into pH and natural phase retention for the area (Farmer et al. 2006). It is, however, essential that plans and research into reclamation begin now at the earliest stage of mine planning. Experimentation by Dhal et al. (2010) in India offers some of the most promising developments in terms of reclamation of chromium-contaminated soil and water by using native bacteria. Similar options would present a relatively environmentally friendly solution as they do not expose the system to any additional chemical treatment.

One way or another, despite a mine life of only 30 years, if AMD or metal leaching become a problem for Cliffs' chromite mine, remediation will require many more years, perhaps centuries, to restore the integrity of the area.

Other

There are a wide range of other environmental impacts that may occur as a result of development of Cliffs Chromite Mine, but they are not dealt with in depth in this report. In particular, the Ring of Fire landscape represents an important wetland complex that provides not only crucial habitat for a large number of species, including certain threatened species, but also acts as a global carbon sink. Stripping of this area will have long-lasting ramifications and further attention needs to be directed towards evaluating the full costs of this action. Soil compaction, threats from increased access, and the new transportation corridor offer further risks to the area. Noise pollution and the impacts of water withdrawal, and rerouting the tributaries must further be studied. Socio-cultural risks include the influx of workers who will come to construct and operate the mine. There are well-documented cases of large influxes of relatively temporary workers having significant negative ramifications on surrounding communities and this is an issue that will be of considerable concern for the remote First Nations located in the areas surrounding the mine. In short, this development poses significant planning challenges as there are very few known variables or outside case studies with clear application to this context.

The potential for negative impacts is substantial given the lack of experience of all parties involved. If sufficient time and funds are dedicated towards the environmental assessment process, it is likely the majority of negative impacts can be mitigated.

DISCUSSION

Though the exact contamination levels differ, it can be concluded that above-ground dumping of waste rock and storage of tailings will result in land degradation and destruction of vegetation if metals and toxic chemicals are allowed to leach into the surrounding environment. Examples from chromite mining in Zimbabwe show the possibility for contamination of water bodies 1-2 km from waste dump sites (Maponga and Ruzive 2002, Meck et al. 2006). Chromite mines in Vietnam were found to leach heavy metals into water and soils in agricultural paddy lands raising levels of certain metals in produce grown in the surrounding area (Kien et al. 2010) and extensive chromite mining in India was linked to increased prevalence of certain diseases and cancers in humans living and working in the vicinity of the mines (Das and Singh 2011).

However, it is uncertain which, if any, of these issues will be in the forefront in Cliffs' proposed chromite mine in northern Ontario. The most significant impacts of chromite mining seem to be experienced in the immediate vicinity of the mine (1-2 km radius), though the potential for accidents along the proposed access route greatly increase the scope of contamination. Because the area is undeveloped and relatively isolated from human populations, it is likely that humans will not experience the majority of the immediate mine effects. Too little is known concerning the impact of certain metals and contaminants on fish and wildlife and, as a result, until further research is complete, it is difficult to assess with any certainty the risks faced by those involved with this development. The sheer volume of waste material makes it highly likely that significant impacts will occur as a result of mining activities. Whether Cliffs' will be able to mitigate these impacts is not clear in their project description. Undoubtedly mining activity and waste rock storage will alter First Nation people's ability to trap and hunt the area as they once did.

If the potential risks are understood early enough, there is sufficient international experience as to suggest possible solutions for mitigation or avoidance. However, because the majority of chromite mines are located in developing, not developed countries, it is difficult to predict the real efficiency of certain mitigation strategies. In places like India and Zimbabwe, these strategies remain more policy than practice.

Generally accepted strategies for managing mine waste include strategic placement of waste rock away from water courses (Maponga and Ruzive 2002, Farmer et al. 2006, Meck et al. 2006, SDWF n.d), stabilization of waste rock stockpiles using vegetation or structural supports (Meck et al. 2006), maintenance of a low angle slope for increased plant growth and decreased erosion (Maponga and Ruzive 2002), and utilization of impermeable liners and caps to limit water contamination for those waste rocks at risk of causing AMD or leaching heavy metals into the environment (Meck et al. 2006, Environmental Mining Council of BC 2011, SDWF n.d). In the Sukinda Valley, India it was found that interactions of workers with tailings ponds required the construction of fences to limit access with contaminated water sources (Das and Singh 2011). Similar action may be useful in deterring wildlife from consuming waste water.

CONCLUSION

In conclusion, there is a considerable amount of unknown variables at play which complicate evaluation of the mines feasible ecological and economic options. As proposed, Cliffs Chromite would stand to be one of the most environmentally sensitive chromite mines in the world, yet the degree of effectiveness of mitigation strategies is difficult to judge based upon the Far North's unique hydrology and climate.

Areas for future research include evaluation of what conditions lead to certain toxic metal mobilities, close examination of the proposed mine sights current hydrology and flow dynamics and how this could threaten tailings pools or infrastructure stability. Also attention should be directed towards evaluating construction materials best suited for swelling and shrinking associated with wide ranges in temperature and high moisture content. Collaboration should be made with local First Nations to properly evaluate this mine in a regional context, and especially in conjunction with future mining developments. Soil, people, plants and wildlife should all be considered a part of the same food chain, and strategic evaluation should be conducted to predict any risks that may arise from mine development.

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