World Potash Developments
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FOREWORD

The 48th Forum on the Geology of Industrial Minerals was held in Scottsdale, Arizona, April 30 - May 4, 2012. From across the U.S., Canada, UK, and Jamaica, more than 80 people attended. This was the Forum’s second appearance in Arizona; the first being the April 9 – 12, 1985, meeting in Tucson. The earlier Forum celebrated the University of Arizona’s centennial. This 48th Forum coincided with celebration of the State of Arizona’s centennial. The Forum on the Geology of Industrial Minerals has been held annually since its inception by the late Professor Robert Bates of Ohio State University nearly 50 years ago.

The 48th FGIM was organized by the Arizona Geological Survey with support from the Arizona Geological Society, Clear Creek Associates, Golder Associates, National Exploration Wells & Pumps, the SME Dryer Fund, Arizona Rock Products Association, Arizona Mining Association, and the Arizona Section of the American Institute of Professional Geologists. Field trips were planned and moderated by the late Doug Shakel and included visits and guest lectures on the Colorado Plateau and Mogollon Rim, the minerals and geology of Eastern Arizona, and Phoenix area industrial mineral sites. Special thanks to: John Bezy for his remarks on Sedona; Paul Lindbergh for cogent discussions of Jerome; Brian Langford for his description of Phoenix Cement; the Jerome State Historic Park rangers for their historical overview; David Pelletier for his remarks at Drake Cement; Ted Eyde’s for his comments at Lyle Hectorite Pit; Melissa Hadley’s overview of Morton Salt; Dan McQuade and Kyle Henderson for guiding us through the Salt River Materials Group Beeline Plant; to Evvy Otis for remarks on Imerys Perlite; and Bob Foster for discussing the Feldman Quarry.

We were fortunate to have Drew Meyer, President of the Society for Mining, Metallurgy, and Exploration (SME), as keynote speaker. His thought-provoking presentation set the tone for dynamic discourse throughout the Forum. The wide variety of papers presented fell into the following categories: Carbonates, Potash, Sandstones & Aggregates, Rare Earth Elements, Education & Outreach, Miscellaneous, and Arizona Geology. Papers from the Forum are posted following light editing for general clarity and standardization of bibliographies.

Thank you to all participants, writers, sponsors, field trip coordinators and guides, the Scottsdale Cottonwoods Resort, and AZGS staff for making the 48th Annual Forum a smashing success.

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# World Potash Developments

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Abstract

Potash is a non-renewable resource that is a key ingredient in fertilizer along with phosphate and nitrogen. Increased demand for fertilizers and potash has driven potash prices from US$96/tonne in September 1990, to US$203/tonne in July 2007, to a current US$495/tonne (April, 2012). A dwindling supply of arable land worldwide coupled with population growth requires increased food production from that land. Potash helps improve crop yields and enhances flavour, color and texture to crops used as food or used to feed livestock. Increasing populations together with higher standards of living in developing countries result in increased demand for food and more protein from meat, as well as more fruits and vegetables. Developing countries like China, Brazil and India have historically under applied fertilizers, so crop yields are low.

Most of the world’s potash production has come from a relatively small number of mines in the United States, Canada, Germany, France, Belarus, Ukraine, and Russia. As of 2012, the leading companies in potash production include Potash Corporation of Saskatchewan (PotashCorp), Uralkali, Mosaic, Belaruskali, Israel Chemicals Ltd. (ICL), K+S, Qinghai Salt Lake Potash, Arab Potash Company (APC), Soc. Quimica y Minera de Chile SA (SQM), Agrium, Intrepid, and Vale. Most of the presently active mines were established in the 1960s and 1970s, so much of their infrastructures are on the order of 40 to 50 years old.

Price increases since 2009 have encouraged mining companies to upgrade production capacity at those mines with extensive reserves. Mine expansion and brownfield exploration (that is adjacent to current mines) is another way to increase potash production capacity. Greenfield exploration has expanded with new projects in Thailand, Laos, Russia, Kazakhstan, Uzbekistan, Belarus, Canada, United States, Eritrea, Ethiopia, Gabon, Congo, Brazil, and Argentina. Companies involved include BHP Billiton, Vale, K+S, several government-owned entities, and many, relatively new, junior companies. While greenfield exploration is valuable in defining new sources of potash, brownfield expansion projects cost considerably less and new production from these projects have ready access to existing infrastructure not likely present in greenfield operations.

During the latter part of 2012 potash price softening has led to suspension of some of the greenfield projects and production shutdowns. A price turnaround in early 2013 has strengthened the potash industry which is now looking at an upturn in prices through the remainder of the year.

Introduction

Potash denotes a variety of mined and manufactured salts, all of which contain the element potassium in water-soluble form (Jasinski, 2011a). Industry uses the term potash to refer to potassium chloride (KCl), as well as potassium sulfate, nitrate, and oxide (K₂O) (Neuendorf and others, 2005). The principal product, KCl, is referred to as muriate of potash or MOP, but potash grades are generally expressed as K₂O. The principal use (95 percent) of potash is for fertilizer along with phosphate and nitrogen. Potassium is an essential nutrient for plants, animals, and humans with no known substitutes. Potash helps improve crop yields and adds flavour, colour and texture to crops used as food or used to feed livestock.

Increased demand for fertilizers and potash in the past 5 to 10 years can be related to the fact that fertilizer allows larger and more frequent crops to be produced. Demand for food has exceeded supply causing world grain prices to double from 2007 to 2011 (Brown, 2011; O’Brien, 2007). A doubling of the world population to 6.9 billion from 1970 to the present has required more food production (Brown, 2011). Potash-bearing fertilizer allows more crops to be produced per acre, but that increased productivity
is offset by the worldwide supply of arable land dwindling from 0.45 hectares per person in 1961 to 0.25 hectares per person in 2010 (North American Potash Developments, 2011). Most of that decrease is related to population growth, although part is related to over pumping of irrigation wells and falling water tables, especially in India and China, as well as desertification of arable land and resulting soil loss (Brown, 2011). In addition, the income of people in developing nations is increasing, and people are improving their diets by adding more protein from meat and more fruits and vegetables (Brown, 2011). Global meat consumption has increased from 19 kg per person in 1980 to 40 kg per person in 2010 (North American Potash Developments, 2011). Better yield fertilizers are required for higher quality feed grains for livestock.

In addition to the need for increased food production, the United States and other countries such as Brazil have increased their appetite for ethanol fuel as a substitute for fossil fuels. Corn production which is a primary source for ethanol has increased from 16 million tons in 2000 to over 126 million tons in 2010 (Brown, 2011). The widespread drought during the summer of 2012 in the United States has severely impacted corn production increasing competition and prices for food, feed for livestock and ethanol production. Developing countries with large populations like China, Brazil and India, which have inadequate or no potash resources, have historically under applied fertilizers, so crop yields are low. The increased need for fertilizer to meet these needs has the potential to drive up the price for potash.

Potash prices have risen from US $96/tonne in September 1990, to US$203/tonne in July 2007, to US$495/tonne in April 2012 (Index Mundi, 2012). In 2008, a temporary surge in potash prices reached a Vancouver spot market price of US $1050/tonne. The Baltic-Black Sea spot market reached a high of US $1020/tonne in 2008 (Stone, 2010). Prices for potash include publically reported spot prices at different global exchange markets and commonly unreported contract prices negotiated between potash suppliers and consumers. In December, 2012, China contracted with Canpotex to purchase potash at $400/tonne. The market turned around in early 2013, with India purchasing 1 million tonnes (Mt) from Uralkali and 1.3 Mt from Canpotex at $427/tonne (Bruno, 2013b), although The Economic Times (2013) predicted potash prices may soften 20 percent in 2013. This price turnaround bodes well for those companies expecting to begin production or increase production during the next several years.

In 2010, world potash mine production was about 33 Mt of K₂O equivalent. Canada is the largest producer of potash (9.5 Mt in 2010) among the 13 major potash-producing countries, followed by Russia, Belarus, Germany, Israel, Jordan, and China (Jasinski, 2011a, b). All of these countries each produced 1 Mt or more in 2010, and production from other countries was less than 1 Mt each. Most of Canada’s potash production is from the Elk Point Basin (fig. 1). The Elk Point Basin was estimated to contain 40 percent of the world’s known potash reserves (Bout and Chiang, 2008), but recent exploration in this basin and other basins may change that percentage.

The world’s potash supply capacity has increased from 42.7 Mt in 2010 to about 70 Mt in 2011 (Bromby, 2012; Berube, 2012a). Although demand for potash has grown to 45 Mt in 2011, potash production capacity has exceeded the increase in demand (Berube, 2012b). Additional increased mine production capacity and scheduled opening of new mines may increase the surplus capacity and result in further weakening of prices.

Developments in Potash Production and Exploration

Currently, world potash production (97 percent) is dominated by ten major companies (fig. 2). These include Uralkali, Potash Corporation (PotashCorp), Belaruskali, Mosaic, K+S, China (Qinghai Salt Lake Industry Co., Ltd., SDIC Xinjiang Luobupo Potash Co., Ltd., and BinDi Salt are variously separated or treated as one in the literature), ICL (Israeli Chemicals Limited), APC (Arabian Potash Company), Agrium, and SQM (Sociedad Quimica y Minera). Some of these production rankings may be more complex than the simple rankings of companies by production. Potash Corp owns significant investments in Sinfert (which owns Qinghai Salt Lake), APC, SQM and ICL. Uralkali merged with JSC Sylvinit in 2011, and owns a portion of Belarus Potash Corporation which owns part of Belaruskali.

Several developments will probably affect world production by 2020. These include:

1) loss of production at older mines (most established in the 1960s and 1970s);
2) increased mine production or expansion; 
3) brownfield mine development; and 
4) greenfield mine development.

Loss of Production

Several potash producing basins which were important producers in the post WWII era, e.g. Sicily, Carpathian, and Rhine Graben in south and central Europe, (fig. 1) have since been either depleted or closed due to economic or environmental pressures. The Zechstein Basin extending across much of north and central Europe (fig. 1) was once the major source of potash from 1868 until production from Canada and the former Soviet Union surpassed it in the late twentieth century. Mines in the Zechstein Basin are facing depletion of reserves within the next 30 years, as well as older, high-cost production (Moore, 2006). Potash mining has been on the decline in the Salado Basin in south-western United States (fig. 1) during the latter part of the 1900s (Moore, 2006). The higher grade potash (sylvinite) has been essentially mined out and the remaining lower grade ores (mixed langbeinite, kieserite and sylvinite) are more expensive to mine and process than the potash ores from Saskatchewan (Barker and Gundiler, 2008). Several mines in the Pripyat Basin in Belarus and the Solikamsk Basin in Russia will deplete their reserves during the next decade or so, depending on their production schedules (Foreign Policy Resource Center, 2011; Truscott, 2011b; Uralkali, 2011).

There is also the unexpected loss in production due to mine flooding. In Germany’s part of the Zechstein Basin more than 255 potash mines were developed since 1851, and by 1968, 119 of these mines experienced some degree of water inflow problems. Eighty-eight of these mines were closed as a result of flooding. 27 were rehabilitated after new shafts were sunk and only 4 were rehabilitated after the production areas flooded (Gimm, 1968; Prugger and Prugger, 1991; Garrett, 1996). Water inflow has occurred in many other potash mines. Uralkali’s Bereznicki III mine in the Solikamsk Basin in Russia (fig. 1) was lost due to flooding in 1986 (Bout and Chiang, 2008). In 2006, Uralkali’s Bereznicki I mine flooded within a 2 month period, the mine was abandoned and production of about 1.2 Mt/year was lost (Andreichuk and others, 2006; Bout and Chiang, 2008; Uralkali, 2012). The Holle mine in the Lower Congo Basin produced potash

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**Figure 1.** World map of significant potash-bearing marine evaporite basins (shown by red polygons). Location of the Cerrado Verde glauconite deposit is shown by a black square.
for only 8 years before it was flooded in 1977 (Rauche and Van der Klauw, 2010). Attempts are made to control water inflow by grouting or otherwise sealing off possible production areas. Continued water inflow into the Patience Lake mine in the Elk Point Basin in western Canada (fig. 1) eventually led to its conversion from an underground mine to a solution mine (Prugger and Prugger, 1991).

Increased mine production

Some potash mines have the reserves or resources to increase production. Several options are available to increase production. Because the principal bottleneck in production is the production shaft headframe or the delivery system up the shaft, one option is to sink an additional shaft(s) to substantially increase the amount of potash hoisted to the surface. The principal problems with this option are the costs involved in sinking a shaft through aquifers overlying the soluble salt and potash and the time required for the shaft sinking and underground development. Although current costs for this type of development in Saskatchewan are on the order of several billion dollars, some companies are using this option. At the Rocanville mine (Potash Corp) a new access shaft is being sunk 16 kilometers from the production facilities and the present access shaft will be converted to production. This will increase the capacity of production from about 1.8 Mt/year to 3.6 Mt/year of MOP (Moore and others, 2011). Total costs for such an expansion are about C$8.2 B and will take approximately 7 years (PotashCorp, 2012a; Moore and others, 2011). Mosaic is expanding the Esterhazy mine complex by adding K3 approximately 9 km from the K1 mine and is scheduled to be completed by 2017 (Bruno, 2012d).

Another option is to increase the size of the ore skip so that more ore is hoisted per trip. The diameter
of the skip is governed by the diameter of the shaft so only the length of the skip can be increased. This requires increasing the height of the headframe to accommodate the extra length. Modification of the Allan mine (PotashCorp) headframe in December, 2010 is shown in figure 3 and will help increase the production capacity from about 1.8 Mt/year to 2.7 Mt/year of MOP (Moore and others, 2010; PotashCorp, 2012b, d). Total costs for such an expansion are approximately C$550 million and will require approximately 6 years (Moore and others, 2010; PotashCorp, 2012b).

Figure 3. Expansion of the Allan mine headframe, Saskatchewan, Canada (December, 2010).

Brownfield mine development

Brownfield exploration is conducted within geological terrain in close proximity to a known ore deposit or current mines and is another way to increase potash production capacity. Probably the most active area of brownfield exploration has been in Saskatchewan where the Potash Permit Area contained only 11 potash mining leases in 2004. In November, 2008, exploration activity expanded to include 176 potash exploration permits with 11 permit applications pending (Berenyi and others, 2008). By the end of 2009, there were 172 exploration permits, and the number of leases increased to 19 (Stone, 2010). At least 3 more leases have been added since the beginning of 2011.

In the Elk Point Basin, several mines in the development stage can be considered as brownfield or greenfield projects. K+S’s considers the Legacy project to be a greenfields project (Hopf and others, 2012), but it is essentially adjacent to Mosaic’s Belle Plaine mine. K+S began development in 2011. K+S expects to initially produce 1.8 Mt of K₂O per year
Greenfield Development

Greenfield exploration and development has been very active during the past decade. In the following basins: Pripyat Basin in Belarus, Pricaspian Basin in Kazakhstan and Russia, Central Asia Salt Basin in Uzbekistan, Turkmenistan, Tajikistan and Afghanistan, Khorat and Sakon Nakon Basins in Thailand and Laos, Danakil Basin in Ethiopia and Eritrea, Lower Congo Basin in the Republic of Congo and Gabon, Amazonas Basin in Brazil, Nequén Basin in Argentina, Maritimes Basin in Canada, and Paradox, Holbrook, and Salado (Permian) Basins in the United States (fig. 1). Several mineral companies, e.g. Vale, BHP, K+S, and Allana Potash, have been aggressive in acquiring other companies’ greenfields properties in the Elk Point and Danakil Basins.

Perhaps the most rapidly developing area is the Danakil Basin (fig. 1). In the Eritrean portion of the Danakil Basin, South Boulder Mines has identified 1.08 Bt at 11.35 percent K₂O (South Boulder Mines, 2012). In the Ethiopian portion of the Danakil Basin, Allana Potash continues development of their Dallo1 project with a measured and indicated sylvinite resource of 171.36 Mt of 19.5 percent K₂O and an inferred sylvinite resource of 46.62 Mt grading 19.1 percent K₂O. Allana Potash’s measured and indicated carnallite resources are 701.55 Mt grading 12.8 percent K₂O, and inferred carnallite resources are 373.71 Mt grading 12.9 percent K₂O. In addition, Allana Potash has a measured and indicated upper carnallitite resource of 78.5 Mt grading 11.6 percent K₂O, an inferred upper carnallitite resource of 155.53 Mt grading 10.7 percent K₂O, a measured and indicated lower carnallitite resource of 269.10 Mt grading 6.9 percent K₂O, and an inferred lower carnallitite resource of 130.7 Mt grading 7.4 percent K₂O (Rauche and van der Klauw, 2012a). Allana Potash began a test solution well on their property in September, 2012 (Bruno, 2012a). With a recently identified source of water, Allana Potash may begin solution mining in late 2014 (Bruno, 2013a).

Several projects in the Lower Congo Basin include the Elemental Mineral’s Kola Project and Mag Industries’ Mengo and Makola Projects. The Kola Project has a measured resource of 230 Mt at 20.56 percent K₂O, an indicated resource of 183 Mt at 20.18 percent K₂O and an inferred estimate of 261 Mt grading 19.16 percent K₂O (Dorling and others, 2012). Mag Industries Makola Project has an inferred resource of 9.2 billion tonnes (Mt) of carnallite mineralization with a grade of 12 percent K₂O and 70 Mt of sylvine mineralization with a grade of 21 percent K₂O in its Makola permit area and a measured resource of 146.7 Mt grading 17.4 percent KCl, an indicated resource of 39.5 Mt grading 11.2 percent K₂O, and an indicated resource of 1.215 Bt at 10.9 percent K₂O (Rauche and Van der Klauw, 2010). The Mengo Project contains proven
reserves of 151.2 Mt of carnallitite at 10.9 percent \(K_2O\), probable reserves of 40.3 Mt of carnallitite at 11.1 percent \(K_2O\) (Rauche and Van der Klauw, 2009).

Uralkali announced plans to construct a 2.5 Mt/year mine in the Solikamsk Basin in Russia (fig. 1) by 2018 (Truscott, 2011a). Vale’s Rio Colorado project in the Neuquén Basin in Argentina (fig. 1) with a reserve of 430 Mt is expected to cost about $6 billion (Keen, 2012). Because of a recent potash price decrease, Vale suspended its development of this project (Spinetto and Gonzalez, 2013). SINO-AGRI announced plans to develop a resource of 500 Mt of \(KCl\) in the Sakon Nakon Basin (fig. 1) in Laos (Wang, 2010).

Several companies are now investigating polyhalite-rich deposits. Sirius Minerals has confirmed 1.35 Bt of 88.7 percent polyhalite at 25.6 percent \(K_2SO_4\) at its York Potash Project in the United Kingdom’s portion (fig. 1) of the Zechstein Basin (RNS, 2012). IC Potash has defined 838 Mt of 80.3 percent polyhalite in the Rustler Formation in the Permian Basin of southeastern New Mexico (Crowl and others, 2012; Keller, 2012).

Another potential potash option is in the form of glauconite. Verde Potash, Ltd. (Verde Potash, 2013) deposit in anticipates the production of \(KCl\) from glauconite from the Cerro Verde deposit in Brazil to supply some of the fertilizer demand in that country. The indicated resource is 71 Mt at 9.22 percent \(K_2O\) and an inferred resource of 2,764 Mt at 8.91 percent \(K_2O\) (Verde Potash, 2013).

**Advantages of Brownfield versus Greenfield Projects**

Brownfield potash developments have a number of advantages over greenfield developments. Costs for brownfield projects tend to be lower, and the time required for completion of brownfield developments are usually faster. The primary factors that favour brownfield projects over greenfield projects include: 1) an established, in-place infrastructure consisting of robust transportation, energy and water systems, 2) an experienced, trained workforce, 3) an established supply system for items such as machinery, parts, and chemicals, and 4) the local potash geology and engineering geology are known and established.

**Challenges for Greenfield Potash Projects**

Greenfield potash projects face a number of challenges, particularly when the projects are located in relatively undeveloped parts of the world. Understanding the geology of the potash deposit develops throughout the lifetime of the mine, but increases substantially during the early phases of the project. Knowledge of the engineering geology related to mine development can, in part, be transferred by expertise obtained in established mines, but may be unique to the deposit. Major challenges include obtaining a major energy source where none may be present, a consistent water supply, safe transportation, and safe storage facilities and effective labor force.

**Energy**

Energy consumption for potash mining operations is considerable but differs on the basis of whether they are conventional underground mines or solution mines. Solution mines are more energy intensive because the mining method involves pumping heated water through the substrate to dissolve the potash and pumping the resultant brine solution to a surface refinery for extraction. Eight of the underground mines in Saskatchewan use a conventional mechanical/flotation process which is less energy intensive than a thermal leaching process employed by one of the operations. A study by Natural Resource Canada (2009) provides a benchmark for energy consumption of Canadian potash mines.

In 2000 and 2001, the two solution mines and the underground mine in Saskatchewan that used a thermal leaching process required an energy intensity of about 1,300 kWh/tonne. The underground mine that used a thermal leaching process required an energy intensity of about 600 kWh/tonne. The energy intensity of the other underground mines in Saskatchewan was less than 400 kWh/tonne (Natural Resource Canada, 2009). In 2011, Uralkali used 140 kWh/tonne of production in their underground mines (Uralkali, 2011). The reason for the difference in energy usage between the Canadian mines and Uralkali mines is not apparent.

In Canada, the main sources of energy were natural gas at 77 percent and electricity at 20 percent. The remainder was supplied by diesel, propane, gasoline, and fuel oil. Natural gas is used for mine
air heating, building heating, steam generation and product drying. Electricity is used for powering mining machines, hoisting, conveying, ventilation, lighting, dewatering, mill operations, tailings management and office/administration facilities. Total natural gas consumption for conventional underground mines ranged from 160 to 360 kWh/tonne (natural gas usage is reported in these units by Natural Resource Canada, 2009). Total electricity consumption for conventional underground mines ranged from 92 to 155 kWh/tonne (Natural Resource Canada, 2009). Usage data was not reported for the solution mines.

Mines in other parts of the world may not require energy for heating and some may utilize solar energy for evaporation instead of other costly types of energy for dewatering. The potash projects in Danakil are good examples for use of solar energy in processing and the lack of a need for heating. On the other hand, cooling may be more of an issue with average daily summer temperatures of 113°F (Rauche and Van der Klauw, 2012a).

Water

Potash mines require a considerable amount of water, both in the processing of the potash ore and in solution mining. In 2010, PotashCorp’s water usage for processing of potash from their conventional underground mines included 550 gal/tonne of product at Lanigan, 1,450 gal/tonne of product at Rocanville, 1,600 gal/tonne of product at Allan, and 6,300 gal/tonne of product at Cory (PotashCorp, 2012c). Uralkali’s water usage for processing of potash from their conventional underground mines in the Solikamsk Basin was 340gal/tonne (Uralkali, 2011).

Reported water usage for solution mining is quite variable and probably is dependent on whether the mine is established or has to create solution chambers in less soluble halite or may be solutioning more soluble carnallite-rich rocks rather than less soluble sylvite-bearing rock. Mosaic’s Belle Plaine solution mine in Saskatchewan uses 5,000 gal/min equal to 2.6 billion gal/yr to produce about 2 Mt/yr which is equal to 1,300 gal/tonne of product (M. Cocker, on-site tour, December, 2009). Western Potash recently contracted with the City of Regina to process their treated effluent at a rate of 21.9 million cubic meters per year or the equivalent of 5.8 billion gal/yr for the first 6 years (Fowler, 2012) to produce 2.8 Mt/yr (Hardy and others, 2011) or 2,066 gal/t product. Karnalyte Resources’ water requirements for a solution mine are 734 cubic meters /hr for a projected 2 Mt/yr of product (Piche and others, 2011) or about 1.7 billion gal/yr. This is equivalent to about 3 cubic meters/tonne or 800 gal/tonne of product.

In very arid places like the Danakil Basin, water that would be needed for solution mining venture may be in scarce supply. However, Allana Potash has acquired a property position that contains groundwater in alluvial fans about 5 km away. The identified reservoir contains an estimated 160 million cubic meters or 42 billion gallons of water (Bruno, 2012a, 2013; Rauche and Van der Klauw, 2012a). Allana Potash projects production of about 2–3 Mt MOP per year which water usage of about 16 million cubic meters, which would translate to about 5 to 8 cubic meters per tonne or 1,300 to 2,100 gal/tonne of product. This projected water usage is very similar to that reported for solution mines in Saskatchewan.

Transportation

Potash is a bulk commodity and transportation is mainly by rail or ship to keep transportation costs low. Potash is presently mined in only 12 countries and transportation to countries with inadequate domestic sources of potash, such as China, India and Brazil, is predominantly via marine transport. Transportation within a country or between adjacent countries is dominantly by rail. Saskatchewan potash is shipped by unit trains either to port facilities in Vancouver, British Columbia, Portland, Oregon or Thunder Bay, Ontario on the Great Lakes. Landlocked countries such as Belarus, or countries with extremely long distances to port facilities such as Russia, have to ship their products either 8,000 km to Vostochny, Russia on the Pacific Ocean to St. Petersburg, Russia, or through other countries Ventspils, Latvia or Klaipeda, Lithuania on the Baltic Sea or Nikolaev, Ukraine on the Black Sea (Moore, 2006, 2010; Lomakin, 2003, 2009). Shipping from the Solikamsk Basin to St. Petersburg or Nikolaev is on the order of 2,800 to 3,000 km (Moore, 2006). When shipping through other countries potash companies may be subject to higher tariffs cutting into their profits (Lomakin, 2003, 2009). Potash is subject to product degradation or destruction by exposure to moisture. Transportation of the potash product must include safe storage facilities at the mine site, at the port facilities, and specialized rail cars or trucks to prevent exposure to moisture.
Canpotex, the overseas marketing and distribution company owned by Mosaic, PotashCorp and Agrium in Saskatchewan, increased the number of its specialized railcars to 5,500 in 2009 (PotashCorp, 2010). PotashCorp owns or leases 3,500 potash railcars, also (PotashCorp, 2010).

If rail or road facilities are non-existent or require upgrades to carry the millions of tons per year (including rail cars or trucks) infrastructure costs may increase substantially. When the former Soviet Union was disbanded in 1991, the export market was essentially non-existent; most potash production was for internal consumption, and a scarcity of specialized rail cars hampered initial start-up of potash exports from Belarus and Russia during the 1990s (Lomakin, 2003). In 2009, Syvinit and Uralkali have a combined shipping capacity of approximately 8,100 railcars (Lomakin, 2009). Anticipated expansion of facilities and production in these countries during the next decade will require increased transit and storage capacities.

Also, many greenfield projects are in parts of the world where adequate railroads or roads are non-existent or presently inadequate. Vale’s Rio Colorado project in the Neuquén Basin will require the renovation of 440 km of railroad track and building of 350 km of new track (Vale, 2012). Specialized hopper cars are required for those projects anticipating rail transportation. Presently, road access from Allana Potash’s Danakil project consists of 300 km of paved road, 295 km of all-weather road and 190 km of off-road (Rauche and van der Klauw, 2012b). Transportation of 2 Mt per year from that site would require heavy and frequent truck transport and would probably require paving of the non-paved roads and upgrades to the paved roads.

Deep water ports and safe storage facilities

Most of the world’s potash deposits are located inland from existing deep-water ports and many greenfield projects would need new deepwater ports facilities to be constructed. Canpotex operates bulk commodity terminals in Vancouver, British Columbia, Canada and Portland, Oregon, U.S.A. from which Saskatchewan potash is shipped. A historical example of the need for new deepwater ports facilities was related to the change in potash markets for potash producers in the former U.S.S.R. In 1988, the only port with a specialized potash terminal available for these potash producers was at Ventspils on the Baltic Sea (Lomakin, 2003). In order to ship potash to other countries such as China, India and Brazil, subsequent improvement of facilities was achieved by increasing shipping capacity at Ventspils in Latvia, and construction of new terminals and storage facilities at the ports of Nikolaev and Klaipeda in Ukraine, Vostochny, and St. Petersburg in Russia (Lomakin, 2003).

Some of the newer facilities that will need to be built will be in South America and Africa. Vale will need to construct a maritime terminal for its potash output from the Rio Colorado project in Argentina (Vale, 2012). The Danakil Basin lies astride the Ethiopia border with South Boulder Mine’s Colluli project in Ethiopia. Because of the political situation, separate port facilities will be needed (South Boulder Mines, 2011; Rauche and van der Klauw, 2012b). South Boulder Mines would have to upgrade a current road about 65 to 75 km to the Red Sea coast where a deep-sea port at Anfile Bay would also need to be constructed (South Boulder Mines, 2011). Djibouti will begin construction of a new port at Tadjourah on the Red Sea for Allana’s potash expected to be in production by the end of 2014 (Bruno, 2012b). The approximately 800 km of road would need to be upgraded.

Capacities of existing terminal facilities are also being expanded. Canpotex is improving its facilities in Portland, Oregon, and Vancouver, British Columbia may build a new terminal in Prince Rupert, Vancouver (Bruno, 2012c).

Mining, maintenance, geological, engineering and management expertise

Because potash is contained within salt, mining differs in many facets from most other types of mining and requires unique mining techniques and expertise to develop the potash-bearing salt deposit and process the ore (see Garrett, 1996; Jones and Prugger, 1982; Piché and others, 2011). Equipment operators and machinists are important to operate and maintain the mining and processing equipment. A trained and experienced geological, engineering and management staff is required for both underground and solution mines as well as for the processing plants (Moore, 2010; Mosaic, 2011). The size of these workforces is quite
varied, but staffing and support of these workforces can be challenging but is critical for successful mining ventures. Present expertise is concentrated in the United States, Canada, Germany, Russia, and Belarus. Labor costs represent 20 to 25 percent of PotashCorp’s production costs (PotashCorp, 2010). Even in Saskatchewan, finding qualified employees can be a significant hurdle for new mining ventures (Bout and Chiang, 2008).

A larger, temporary workforce is needed for construction of both conventional underground and solution mines. Construction of a solution mine may require 150 to 200 employees at Intrepid’s HB mine (Intrepid, 2012) to 1,100 employees at the K+S Legacy mine (K+S Potash Canada GP, 2012). PotashCorp’s Rocanville conventional mine expansion requires 500 workers for construction work (Moore and others, 2011). Allana Potash’s proposed open-pit mine and plant in the Danakil Basin will require an estimated 2,200 personnel while its solution mine alternative will require about 250 personnel (Rauche and Van der Klauw, 2012a).

Conventional underground potash mining and processing require a large, trained workforce that varies considerably. Mines in Saskatchewan employ about 400 to 600 employees (PotashCorp, 2012c). Sirius Minerals’ proposed York mine is anticipated to have a workforce of 1,000; the nearby Boulby mine has a present workforce of 800 (Sirius Minerals, 2012). Competition for the trained workforce may be intense in that area. The Uralkali mining complex that consists of 5 mines and 7 ore-treatment plants in the Solikamsk Basin (fig. 1) has a workforce of about 12,500 (Uralkali, 2011).

Solution mines commonly require a much smaller workforce. At Intrepid’s HB mine in New Mexico, a workforce of 30 to 40 is anticipated (Intrepid, 2012). PotashCorp’s Patience Lake mine in Saskatchewan employs about 95 (PotashCorp, 2012c). In Saskatchewan, K+S anticipates employing 320 workers at its Legacy mine (K+S Potash Canada GP, 2012), and Encanto Potash, Ltd. anticipates employment of 500 (Berube, 2012c). Differences in employment sizes may be related to secondary solution mining of pre-existing underground development at the HB and Patience Lake mines, while the Legacy and Encanto Potash’s projects will be completely new solution mines.

Contracted, specialty outside services are required during maintenance downtimes. These can include engineering services for upgrades or technical inspections, control equipment programming, millwrights and electricians (Hatch, 2012).

**Production downtime**

Potash mine operations are occasionally temporarily curtailed or shut down. These mine production and development downtimes may be due to mine expansion, mine and equipment maintenance, low potash prices, or to reduce potash supplies to the world market. Existing mines commonly use these periods to upgrade or expand the mine facilities as noted in the section on increased mine production. Planned maintenance downtimes may range from a few days to 3–4 weeks (Hatch, 2012). Prolonged, market related downtimes of one or more months require retaining trained mine staff which may be difficult in underdeveloped parts of the world.

**General construction costs and time required**

Construction of a greenfield Saskatchewan-type conventional underground potash mine with a 2 Mt/yr capacity is estimated to require a minimum of 5 to 7 years (Moore, 2010; Doyle, 2010). Construction involves at least 46 major tasks that can be divided into four phases: 1) exploration; 2) establishment of infrastructure; 3) construction of underground mine; and 4) construction of the surface mill (Moore, 2006). In 2010, capital costs were in the order of C$3.5 to C$5 B (Moore, 2010; Doyle, 2010) for developing a greenfield underground potash mine, compared to just C$1.6 B in 2006 (Moore, 2006). Brownfield mine construction usually requires 5 years to bring online a 1 Mt/yr capacity mine and costs less, usually in the range from 25 to 50 percent of a greenfield mine. Initial costs of a mine and mill would depend, in part, on factors such as conventional vs. solution mining, depth of ore body, and geographic location. Infrastructure costs are directly related to geographic location, the absence or presence of nearby roads and railroads, utilities, and distance to port facilities if distribution by water is expected.

Construction of a greenfield Saskatchewan-type underground solution mine is estimated to require 3 to 5 years to reach a maximum production capacity of 3 Mt of potash per year (K+S Potash Canada, Ltd.,
The K+S Legacy solution mine project in Saskatchewan is projected to cost C$3.25 B with construction lasting 4 years (Berube, 2011; Hopf and others, 2012). Karnalyte Resources solution mine is expected to cost C$2 B with a maximum production capacity of 1.3 Mt of KCl per year. This mine will be mainly in carnallite mineralized rock and will also recover 100,000 tons of MgCl2 brine and 104,000 tons of hydromagnesite per year (Karnalyte Resources, 2012).

Living facilities (30 to 50 + years)

Some potential greenfields projects are in remote and sometimes inhospitable parts of the world. Because of the large expenditures to develop a potash mine, they generally should be expected to have a minimum mine life of 30 to 50 years. Providing for living facilities for a permanent workforce for that amount of time may be a problem in some of these areas. The average daily temperature in the Danakil Basin is 113°F (Rauche and Van der Klauw, 2012a).

Potash mining supply chain

A supply chain is essential for successful mining operations, especially if the operations are in remote and relatively undeveloped parts of the world. To be expected, essentials such as food and potable water for 200 to 1,000 mine and support staff need to be delivered on a continual basis. Maintaining a supply chain for the mining and processing operations can be rather challenging and expensive as documented in detail by Hatch (2012). Supply by aircraft is possible for the relatively small staff and equipment needed during the exploration phase. Development and mining phases require a considerably more robust supply chain.

Shaft sinking operations are complex projects commonly requiring ground freezing techniques and complex, high pressure shaft liners (Garrett, 1996; Moore, 2012). Specialized materials must be transported from the manufacturing sites to the project areas. Longwall mining equipment is similar to that used in coal mining, but must deal with variable hardness of the ore, dust, and the prohibitive use of traditional water-cooling systems. Nearly all of the potash mining machines are custom made based on the unique geology of each mine and may weigh up to 250 tons (Moore, 2012). The manufacturers of these machines are based in North America and Europe, so supply of replacement parts can be a critical part of mining operations in remote locations.

Underground mining machines beyond the initial development equipment and supplies, mining maintenance supplies include a myriad of items ranging from electric motors, conveyor belts, idlers, gearboxes, tires, filters, hydraulic pumps, replacement screens, crusher components, flotation drives and belts, to oils, grease, grinding disks, welding rods, paint, and processing chemicals (Hatch, 2012).

Summary

During the past decade global demand for potash has increased because of increasing demand for more production and better quality of food for an increasing and wealthier population. Some sources of potash have been exhausted or lost to mine failure. Increasing prices for potash have led to an increase in potash exploration, new mine development and mine expansion. Both brownfield and greenfield activities have occurred mainly in well-established potash districts such as the Elk Point, Paradox, Zechstein, Pripyat, and Solikamsk Basins. Newer, greenfield, exploration projects that appear to be moving ahead include those in the Neuquén, Lower Congo, Danakil Basins, Pricaspian, and Central Asia Salt Basins. Brownfield mines have certain advantages over greenfield mines because of the established infrastructure available to brownfield mines. Infrastructure advantages would include energy, water, transportation, work force, geological and engineering expertise, and an established supply network. A guaranteed water supply is needed for potash mining and appears to range from 550 to 6,300 gal/tonne of product for processing of conventionally mined ore and range from 1,300 to 2,100 for mining and processing of potash from solution mines. A reliable source of energy is needed for the approximately 400 to 1,300 kWh/tonne to produce the anticipated potash product. New transportation lines, in some instances over several hundred kilometers, will be required for many greenfield projects. Specialty railcars, trucks and storage facilities will be needed to protect the potash product. New deep-water port facilities may also be required. In remote areas, a workforce trained in operating a potash salt mine may be difficult to obtain, especially for much of an anticipated mine lifetime that can extend well past 30 or 40 years.
New greenfield and brownfield potash mines require a timeframe of approximately 3 to 7 years of exploration and development before they reach their anticipated production capacity. Capital costs for developing a greenfield underground potash mine in Canada were in the order of C$3.5 to C$5 B in 2010 and up to C$2.5 B for a solution mine. Energy costs for a solution mine are substantially higher, however.

Mine expansion has occurred where there are opportunities to increase the throughput of ore to the surface. The main options for doing this in a conventional underground mine are to add an additional production shaft or increase the capacity of ore skips and increasing the height of the mine headframe. With increased mine throughput, mill capacity must also be increased. Although current and anticipated brownfield and greenfield mine development is causing an increase in potash production capacity and a surplus over demand, the time required for mine development may range from 3 to 7 years and requires a commitment to anticipated potash prices and markets well beyond the present.

References Cited


Moore, Garth, Danyluk, T.K., Franklin, Bob, Prugger, Arnfinn, and Vander Most, Anastasia, 2010, National instrument 43–101 technical report on Allan potash deposit (KLSA–001) Saskatchewan, Canada: Saskatoon, Saskatchewan, Potash Corporation of


Rauche, H., and Van der Klauw, S., 2009, Updated reserve and resource estimate for Magminerals Kouilou Potash Project, Republic of Congo, prepared for MagMinerals Potash Corp.: Erfurt, Germany, ERCOPSLAN Ingenieurgeellschaft, 144 p. plus appendixes.


Uralkali, 2011, Nourishing the world - merging forces for
global good: Uralkhi annual report and accounts 2011,
140 p. Available (December 11, 2012 for download at
Uralkali, 2012, Uralkali starts repairing soil subsidence area
Website accessed August 2, 2012.
Verde Potash, 2013, At surface potash in the heart of
Brazil’s agricultural region: Verde Potash, Ltd. fact
Wang, Q., 2010, Status of the potash projects in Laos: IFA