Deposit Model for Closed-Basin Potash-Bearing Brines

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Deposit Model for Closed-Basin Potash-Bearing Brines

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Abstract

Closed-basin potash-bearing brines are one of the types of potash deposits that are a source of potash production within the United States, as well as other countries. Though these deposits are of highly variable size, they are important sources of potash on a regional basis. In addition, these deposits have a high potential of co- and by-product production of one or more commodities such as lithium, boron, magnesium, and others.

Introduction

Current global production and resources of potash are dominated by stratabound potash-bearing salt deposits. However, in some areas of the world, closed-basin potash-bearing brines are the main source for production of potash and potash-bearing brine resources (table 1). Closed-basin potash-bearing brines exist in many parts of the world, including the United States. Although typically smaller than stratabound potash deposits, potash-bearing brine deposits have the potential to contain significant economic contents of potash (table 1) and other commodities; these commodities include salt (halite), boron, lithium, and (or) magnesium, and may include other commodities. During the potash-exploration boom of the past few years, multiple new resources have been identified (table 1). Current or past production of potash from this deposit type has been reported in Chile, China, Israel, Jordan, Libya, Uganda, and the United States. In the United States, potash is produced from brines of the Great Salt Lake and at Wendover in Utah and has been produced in the past from Searles Lake brines in California.

Potash denotes a variety of mined and manufactured salts, all of which contain the element potassium in water-soluble form (Jasinski, 2011). The term is used by industry to refer to potassium chloride, as well as potassium sulfate, nitrate, and oxide (Neuendorf and others, 2005). For the purposes of this model, potash refers to potassium ores and minerals, including potassium-bearing brines.

Model Description

The general deposit model provides a descriptive basis for the identification and assessment of closed-basin potash-bearing brine deposits of a type and style similar to those found in the Great Salt Lake in Utah, the Salar de Atacama of Chile, and in the Qaidam Basin of China (fig. 1). The model is intended to provide a basis for assessing the probability of the occurrence of similar deposits using the current U.S. Geological Survey three-part assessment methodology (Singer, 1993; Singer and Menzie, 2010). In addition, the model will aid in the identification of continental closed basins where brines containing potentially economic contents of potassium are most likely to occur.

Closed-basin potash-bearing brine deposits typically contain the potential for extraction of multiple commodities including potash, lithium, boron, magnesium, and salt, and may include sodium sulfate, sodium carbonate, or sulfur. The importance of an individual commodity, such as potash, varies
with local geology, with current and perceived future economic conditions, and with regional need for that commodity. The geology within the drainage basin impacts the chemistry of runoff and spring waters and the resulting brine and thus controls not only which constituents may be concentrated in the brines, but the relative amounts of the constituents and the ease with which a given commodity, such as potash, can be extracted. This model highlights the conditions under which potassium might be expected to be a major component of a brine deposit and those features of the deposit most likely to impact development of the brine. Significant papers upon which the closed-basin potash-bearing brine model is based include: Ericksen and Salas (1989), Casas and others (1992), Bryant and others (1994), Garrett (1996), Carmona and others (2000), Duan and Hu (2001), Jones and Deocampo (2003), Jones and others (2009), and Risacher and Fritz (2009).

**Geology**

Potash-bearing brines may be alkaline or enriched in chloride, sulfate, or calcium, depending on the geology within the drainage basin and the resultant chemistry of the inflows to the basin. Potash-bearing brines form in salt lakes and salars or playas in closed basins in arid environments, where high rates of near-surface evaporation concentrated the brine. The duration of this process can extend from hundreds of years to tens of thousands of years, and in some cases, over a million years. Lake Bonneville existed between 28,000 and 7,000 years ago during a cooler and wetter climate (fig. 2). The potash-bearing brines of the Great Salt Lake and at Wendover, Utah, in the Great Salt Lake Desert are remnants of this lake. These brine-bearing basins are commonly structural basins that formed in volcaniclastic terranes.

The chemical constituents of the water flowing into a potash-bearing basin from precipitation runoff, groundwater, and hydrothermal springs have commonly been scavenged from the local country rocks. Source rocks of the constituents are most commonly acidic to intermediate volcanic rocks, but also include older saline rocks and continental sedimentary rocks (Alonso and Risacher, 1996; Risacher and Fritz, 2009). Sources of potassium in these rocks are weathered minerals, such as orthoclase, microcline, biotite, leucite, and nepheline. Studies have found a positive correlation between potassium, lithium, and boron in brines (Zheng, 1984; Orris, 1997; Carmona and others, 2000), which is probably indicative of their common origin in volcaniclastic terranes that typically are associated with convergent plate boundaries (Orris, 1997). Elevated levels of magnesium are also typical of many of the closed-basin brines.

In addition to the potash-bearing brines, most of these basins have some surface or near-surface evaporites and salts. In some areas, such as the Qaidam Basin in China and the Chott el Djerid in Tunisia, extensive areas of potash minerals may be found (Casas and others, 1992; Bryant and others, 1994). Duan and Hu (2001) reported that potash salt mineralization in the Qarhan playa in China ranges from disseminated potash minerals to stratoid lenses or layered bodies hosted by halite and other evaporites.

Local geologic attributes of potash brine-bearing basins commonly include the presence of Cenozoic continental evaporites. Host rocks may include gypsum and(or) halite, and lacustrine sediments. Associated rocks include volcanic rocks, siltstone, sandstone, and mudstone. The presence of an evaporite-bearing salt lake, salar, or playa may indicate surface or near-surface brines, but the brine may underlie much larger areas that are in part determined by the extent of a pre-existing lake and the porosity and permeability of the host sediments.

Sub-basins may exist within larger basins and have distinctly different characteristics, such as chemistry or grade. These sub-basins may be a result of geologic features, such as faulting in the eastern Tarim Basin, China, in the vicinity of the Luobei sub-basin in which the Lop Nur brine mine is located.

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(Wang and others, 2005). In the Great Salt Lake, a railway causeway has led to higher salinities to the north of the man-made feature (Jones and others, 2009).

Sizes of these deposits are highly variable, both in terms of area and the amount of potash contained within the brines. As shown in table 1, the amount of potash can range from a few million metric tons of K (potassium), KCl (potassium chloride), or K₂O (potassium oxide) to over a thousand metric tons. The largest of these deposits have similar potassium contents to some stratabound potash deposits, although they are still significantly smaller than the stratabound deposits of the Elk Point Basin of western Canada. On a regional basis, these deposits may be a significant source of potash. For example, the brine deposits of the Qaidam Basin (fig. 3) are the major source of potash production within China.

**Exploration Guides**

The dominant exploration guides for this deposit type include the presence of a salar or playa at the surface, an arid environment, and the presence of continental evaporites or young volcaniclastic sequences. Springs with elevated K (potassium), B (boron), Li (lithium), or Mg (magnesium) contents within the basin may also be indicative of the potential for brine concentration. Elevated Li, B, or Mg contents of lacustrine clays may indicate brines at depth. Resistivity logging in boreholes may also be of use in detecting saline brines because of the high conductivity and low resistivity of saline brines; this technique has been used by several of the recent exploration projects, including Salar de Cauchari, where resistivity profiles were constructed as part of the exploration effort (Houston, 2010a).

Explorationists should be aware that brine concentrations can vary significantly with seasonal precipitation in some deposits, particularly in near surface deposits, and plan their sampling accordingly.

Environmental concerns that may be associated with this deposit type include subsidence caused by brine withdrawal and issues associated with improper disposal of saline water and materials.

**Conclusion**

Closed-basin potash-bearing brine deposits are one of the sources of potash occurring within the United States. Potash production from the Great Salt Lake and at Wendover, Utah is from this deposit type. On a global basis, these deposits are of highly variable size in terms of the amount of contained potash. However, these deposits may be regionally significant producers of potash and offer the potential for the production of other commodities in addition to potash.

**References Cited**


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Currey, D.R., Atwood, G., and Mabey, D.R., 1984, Major levels of Great Salt Lake and Lake Bonneville: Salt Lake City, Utah Geological and Mineral Survey Map 73, scale 1:750,000.


Table 1. Known potash-bearing brine deposits in continental closed basins. For size comparison purposes, a 1 billion metric ton stratabound potash deposit on average would contain less than 250 Mt of K2O (400 Mt KCl, 210 Mt K).

[B, boron; est, estimated; H2S, hydrogen sulfide; HAL, salt (halite); inf, inferred; K, potassium; K2O, potassium oxide; KCl, potassium chloride; LI, lithium; MG, magnesium; Mt, millions metric tons; NACO, sodium carbonate (trona); NASO, sodium sulfate; res, resource; rsv, reserve]

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Country</th>
<th>Commodities Present</th>
<th>Development Status</th>
<th>K2O (mg/l)</th>
<th>Reported Reserves/Resources</th>
<th>References</th>
</tr>
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<tbody>
<tr>
<td>Cauchari, Salar de</td>
<td>Argentin a</td>
<td>LI K</td>
<td>exploration</td>
<td>3,480 to 8,328</td>
<td>inf in situ res, north central area—7.7 Mt K (2010)</td>
<td>Houston (2010a), King (2010)</td>
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<td>Centenario, Salar de</td>
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<td>LI K</td>
<td>exploration</td>
<td>up to 10,000</td>
<td>inf res—10.4 Mt K (2011)</td>
<td>Mining Exploration News (2011)</td>
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<td>LI K B</td>
<td>exploration</td>
<td>8,000</td>
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<td>LI K B</td>
<td>exploration</td>
<td>11,200</td>
<td></td>
<td>Houston (2010b)</td>
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<td>Uyuni, Salar de</td>
<td>Bolivia</td>
<td>HAL LI K B</td>
<td>occurrence</td>
<td>8,640^1</td>
<td></td>
<td>Ballivian and Risacher (1981)</td>
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<td>Atacama, Salar de</td>
<td>Chile</td>
<td>LI K</td>
<td>producer</td>
<td>22,200^1</td>
<td>&gt; 120 Mt KCl</td>
<td>Roberts (2008), Pueyo and others (2001)</td>
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<td>Bellavista, Salar de</td>
<td>Chile</td>
<td>HAL K</td>
<td>small past production</td>
<td>5,400 to 11,000</td>
<td>res—&gt;250 Mt “potash”</td>
<td>Ericksen (1963)</td>
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<td>Maricunga, Salar de</td>
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<td>LI K B</td>
<td>exploration</td>
<td>6,000 to 18,000</td>
<td></td>
<td>Li3 Energy (2011), Hains (2011)</td>
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<td>Da Chaidam Salt Lake</td>
<td>China</td>
<td>LI K B MG</td>
<td>production</td>
<td>25,700^2</td>
<td></td>
<td>Yu and others (2001), Gao and others (1993)</td>
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<td>Lop Nur</td>
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<td>5,400 to 11,000</td>
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<td>Tse (2009), Wang and others (2005)</td>
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<td>Grade</td>
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</table>
| Qarhan Salt Plain (Dabusun, others) | China     | HAL K LI B MG producer | 14,400 to 20,900\(^2\) | 440 Mt KCl (1968) | Yuan and others (1996), Duan and Hu (2001) Geological Survey and Mineral Exploration of Iran (2007);  
| Khour                         | Iran      | K HAL MG occurrence | 1,450 to 4000    |                  | Notholt (1983)                                |
| Rezayeh, Lake                 | Iran      | K occurrence       | 1,100\(^2\)      | 60 Mt K\(_2\)O (1983)\(^4\) | Garrett (1996)                               |
| Dead Sea                      | Israel, Jordan | K MG producer | 7,200 to 9,000\(^2\) | 2,050 Mt KCl (1983)\(^4\) | Goudarzi (1982), Van Kauwenbergh (2006), Notholt (1983) |
| Edri                          | Libya     | HAL K S occurrence | 3,050\(^2\)      |                  |                                               |
| Marada                        | Libya     | HAL K MG small past production | 22,600\(^2\)    |                  |                                               |
| Chott el Djerid               | Tunisia   | HAL MG K occurrence | 1,830 to 5,200\(^2\) | inf rsv—19 Mt K\(_2\)O (1983)\(^4\) | Garrett (1996); Notholt (1983) |
| Tuzgolu (Salt Lake)           | Turkey    | HAL K MG occurrence | 8,900 to 46,000  |                  | Kilic and Kilic (2005)                        |
| Searles Lake                  | United States | NACO LI K past production | 17,900 to 31,000\(^2\) |                  |                                               |

\(^1\) from Pavlovic and Fowler (2004); values not necessarily representative of potential production grades.

\(^2\) from Garrett (1996); values not necessarily representative of potential production grades.

\(^3\) includes entire paleo-Lake Bonneville extent, including Great Salt Lake, Great Salt Lake desert, Bonneville Salt Flats, and Sevier Desert area.

\(^4\) from Notholt (1983)
Figure 1. Distribution of closed-basin potash-bearing brine deposits listed in table 1; deposits are shown as green squares.
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