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Industrial Mineral Deposit Models--
Descriptive models for three lacustrine deposit types

by

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INTRODUCTION

This report is composed of three descriptive deposit models to accompany Open-File Reports OF91-11, *"Some industrial mineral deposit models: Descriptive deposit models"* (Orris and Bliss, 1991), and OF92-437, *"Industrial minerals deposit models: Grade and tonnage models"* (Orris and Bliss, 1992). The three models are for continental lacustrine deposit types associated with stratified lakes and (or) evaporative conditions. These deposit types may occur in the same basins. The general references at the end of each model were used to help compile the models. The reader should keep in mind that these models are designed for regional assessment use and not as target exploration guides. Comments, corrections, additions, and modifications to the models should be sent to G.J. Orris, U.S. Geological Survey, 210 E. 7th St., Tucson, Arizona, 85705.

REFERENCES

Orris, G.J., and Bliss, J.D., 1991, Some industrial mineral deposit models: descriptive deposit models: U.S. Geological Survey Open-File Report 91-11A, 73 p.

Orris, G.J., and Bliss, J.D., 1992, Industrial minerals deposit models: grade and tonnage models: U.S. Geological Survey Open-File Report 92-437, 84 p.

Preliminary Descriptive Model of Lacustrine Borates

BRIEF DESCRIPTION

Deposit synonyms: Tincal deposits, borax deposits, playa borates, bedded borates, B-bearing lacustrine brines.

Principal commodities produced: Borax pentahydrate, borax decahydrate, boric acid, colemanite, anhydrous borax, ulexite.

By-products: Typically none, but other commodities may be spatially and genetically associated, especially in playa environments.

End uses: Fiberglass, borosilicate glass, soaps and detergents, flame retardants, agriculture, metallurgy, advanced composite materials, nuclear shielding, refractories, abrasives, medical, other.

Descriptive/genetic synopsis: Borate minerals precipitated from brines in permanent or semi-permanent hydrologically stratified or shallow lakes in arid to semi-arid climates. May include borates deposited as crusts or crystals in playas or as precipitates from thermal springs found within the lake basin. Borate may also be present in economic concentrations in brines within the lacustrine or evaporite sediments. Diagenesis may lead to higher grade deposits through dehydration and mineral partitioning. Several sub-types of this deposit type are frequently distinguished based on mineral form, mineral type, and (or) fine geologic divisions. These subtypes include borax-kernite deposits, bedded colemanite (ulexite), playa ulexite, and boron-bearing playa-lacustrine brines. In some basins, multiple forms of mineralization are known. The borax-kernite deposits are the most rare and most economically important.

Typical deposits:

Kramer (Boron), USCA *(borax, kernite)*
Emet, TRKY *(colemanite)*
Laguna Salinas, PERU *(ulexite)*
Searles Lake, USCA *(brine)*

Relative importance of the deposit type: Massive, bedded lacustrine deposits, especially borax-kernite deposits, are the major source of borates.

Associated/related deposit types: Li-, K-, Mg, sodium sulfate-, and (or) sodium carbonate-bearing brines, lacustrine evaporite deposits (gypsum, halite), hectorite, lacustrine diatomite, zeolites.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Convergent plate boundaries and extensional terrains with associated volcanism.

Regional depositional environment: Closed or semi-closed basins, typically structural basins.

Age range: Tertiary to Recent.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Lacustrine sediments and evaporites, especially siltstone, limestone or calcareous shale, and gypsum.

Associated rock(s): Contemporaneous, commonly bimodal, calc-alkaline volcanic flows and tuffs.

Ore mineralogy: ± borax ± kernite ± ulexite ± colemanite ± probertite ± tincalconite ± priceite ± szaibelyite ± brine ± others.

Gangue mineralogy: May include gypsum, dolomite, orpiment, realgar, calcite, anhydrite, thenardite, trona, hectorite, zeolites, native sulfur, aragonite, stibnite, celestite, halite, potash, others.

Alteration: Diagenesis leads to recrystallization of many borate minerals (cation and hydration changes).

Structural setting: Basins are commonly fault-controlled.

Ore control(s):

- Closed to semi-closed structural basins at time of deposition;
- Boron source within basin drainage;
- Arid to semi-arid climate;
- Contemporaneous volcanism;
- Water inflow over time is large enough to introduce significant quantities of dissolved material;
- Preservation of soluble borates by overlying clay or other insoluble unit.

Typical ore dimensions: Most borate-bearing bodies form elongate lenses with the lengths of the largest known mineralized areas exceeding 4 km in plan view. Deposit thickness may approach 100 m. More typical borate-bearing bodies are hundreds of m in length and less than 10 m thick.

Typical alteration/other halo dimensions: N/A

Effect of weathering: Older deposits reexposed at the surface may undergo hydration or dissolution of borate minerals that can eventually lead to destruction of the deposit.

Effect of diagenesis/metamorphism: Metamorphism destroys deposits. Diagenesis leads to removal of water, Na, B, and Ca from deposits. In initial stages, the net effect of diagenesis is higher grade deposits. Over longer periods of time and extreme conditions, diagenetic changes contribute to destruction of deposits.

Maximum limitation of overburden: Unknown, but some deposits with more than 100 m of overburden have been mined.

Geochemical signature(s): $B \pm Li \pm Sr \pm As$

Geophysical signature(s): No distinctive signatures, but various techniques may be useful for delineating shape or structure of known deposits and their environments. For instance, B-bearing horizons produce large negatives (absorbs neutrons) relative to some host rocks using down-hole neutron logging techniques.

Other exploration guide(s):

- Presence of contemporaneous volcanic rocks and (or) thermal springs within basin drainage;
- Efflorescences of soluble saline minerals, especially borates.

The following features are indicative of potential lacustrine host environments:

- Aragonite laminae in muds indicates a local saline environment or stratified lake. Dolomite or the presence of minerals with contrasting solubilities (like halite and aragonite) within the muds could indicate a saline environment or a stratified lake (Smith, 1966);
- At basin perimeter, alluvium (generally thin) interbedded with lacustrine sediments would indicate lake contraction and increasing salinities towards basin center. Sediment unconformities or interbedded soils at the perimeters would also indicate periods of lake evaporation (Smith, 1966);

- Collapse brecciation of lacustrine sediments and (or) development of sinks and pits may be indicative of soluble minerals at depth.

Most readily ascertainable regional attribute: Presence of lacustrine sediments in a closed basin with spatially associated contemporaneous volcanic rocks and (or) thermal springs.

Most readily ascertainable local attribute: Borate mineral (commonly ulexite) efflorescences at the ground surface. However, a lack of surficial borate expression is not a negative feature.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: Cation (Na, Ca) of product may determine or limit usage. Arsenic content may restrict use of some borate ores by the glassware industry if the arsenic cannot be easily removed from the borate mineralization.

Compositional/mechanical processing restrictions: Unknown.

Distance limitations to transportation, processing, end use: Borates are a high value product and transportation costs are not commonly a significant limiting factor.

OTHER--ENVIRONMENT

For some deposits, As may be of concern as a waste product.

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Preliminary Descriptive Model of Lacustrine Gypsum

BRIEF DESCRIPTION

Deposit synonyms: Bedded gypsum.

Principal commodities produced: Gypsum, (anhydrite).

By-products: None.

End uses: Calcined gypsum (plaster of Paris) -- Wallboard (70% of gypsum use); soil conditioning; Portland cement; fillers.

Descriptive/genetic synopsis: Continental evaporite deposits formed in lacustrine basins in semiarid to arid climates. Gypsum deposits of lacustrine origin occur in continental basins of many sizes. These deposits may be of large areal extent and (or) of considerable thickness, but are, on average, smaller than marine bedded gypsum deposits. Deposits formed in playas and coastal sea-water lakes are included in this model.

Typical deposits: Fish Creek Mountains deposit, USCA
Lake Brown, AUWA
Ballah, EGPT

Relative importance of the deposit type: Important only locally where marine bedded gypsum deposits are not available; for example, Australia.

Associated/related deposit types: May be spatially associated with other lacustrine deposits including other lacustrine evaporites and brines, lacustrine borates, clays, and zeolites.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Convergent plate boundaries, extensional terranes, and other settings conducive to basin formation.

Regional depositional environment: Closed to semi-closed basins, typically structural basins.

Age range: Largely Tertiary to Recent, but in rare cases may be as old as Paleozoic.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Lacustrine carbonates, shale, and evaporites.

Associated rock(s): Anhydrite, halite.

Ore mineralogy: Gypsum, (anhydrite-- anhydrite content commonly increases with depth). Commonly interlaminated with gangue minerals.

Gangue mineralogy: Calcite, halite, clay.

Alteration: Gypsum may form from hydration of anhydrite.

Structural setting: Basins commonly fault-controlled.

Ore control(s):
-- Closed to semi-closed structural basins;
-- Source of salines within basin;
-- Water inflow over time is large enough to introduce significant quantities of dissolved material, i.e. lead to saline brine formation;
-- Arid to semi-arid climate allowing sufficient evaporation to form brine concentrations.

Typical ore dimensions: Ore thickness may exceed 30 m.

Typical alteration/other halo dimensions: N/A

Effect of weathering: Weathering leads to dissolution of gypsum exposed at the surface in most climates, but gypsum will be preserved at the surface in more arid climates.

Effect of diagenesis/metamorphism: Metamorphism leads to eventual destruction of the deposit and alteration of surrounding rocks.

Maximum limitation of overburden: Not known, but gypsum is a low value product and only minimal overburden can be economically removed from a deposit.

Geochemical signature(s): No distinctive signature.

Geophysical signature(s): No distinctive signature.

Other exploration guide(s): Sulfates, including gypsum, can be identified using remote sensing imagery.

Most readily ascertainable regional attribute: Closed or semi-closed basin.

Most readily ascertainable local attribute: Saline mineral efflorescences; presence of aragonite.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: Gypsum is the main ore mineral and it must have a low level of impurities. Anhydrite is commonly considered to be a contaminant and its uses are largely speculative although small amounts have been produced.

Compositional/mechanical processing restrictions: Material purity must be high enough to minimize the need for physical beneficiation.

Distance limitations to transportation, processing, end use: The low value of this commodity and its products can severely limit shipping distances.

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PRELIMINARY DESCRIPTIVE MODEL OF LACUSTRINE HALITE

BRIEF DESCRIPTION

Deposit synonyms:

Principal commodities produced: Sodium chloride (halite, salt).

By-products: See associated deposit types.

End uses: Chemicals, food industry, snow and ice removal.

Descriptive/genetic synopsis: Massive and bedded deposits of halite formed in continental basins. The deposits may be of large areal extent and hundreds of meters thick, but are, on average, smaller than marine halite deposits.

Typical deposits: Salar de Uyuni, BLVA
Luke Salt, USAZ
Piceance Basin, USCO

Relative importance of the deposit type: Important locally where marine halite deposits are not found; for example, Australia.

Associated/related deposit types: Other continental evaporites and lacustrine deposits, including brines, lacustrine gypsum, clay, zeolites.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Convergent plate boundaries, extensional terranes, other settings conducive to basin formation.

Regional depositional environment: Closed or semi-closed basins, typically structural basins.

Age range: Late Tertiary to Recent, but in rare cases may be as old as Paleozoic.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Lacustrine sediments and evaporites.

Associated rock(s): Gypsum, potash, anhydrite.

Ore mineralogy: Halite.

Gangue mineralogy: Calcite, gypsum, clay, anhydrite.

Alteration: Ground and surface water dissolution can modify the layering, porosity, or grain size of a deposit or destroy it altogether.

Structural setting: Basins, commonly fault-controlled.

Ore control(s):
-- Closed or semi-closed basin
-- Source of sodium and chloride within basin;
-- Arid climate;
-- Basin brine concentrated through evaporation to a salinity high enough to precipitate halite.

Typical ore dimensions: Highly variable. Horizontal dimensions of known deposits range from tens of meters to greater than 5 kilometers. Thickness can vary from less than 1 m to over 2000 m.

Typical alteration/other halo dimensions: N/A

Effect of weathering: Surface weathering, except in extremely arid climates, destroys salt deposits.

Effect of diagenesis/metamorphism: Plastic flow of salt is enhanced with burial, doming of salt may occur in thick sequences of evaporites. With increasing metamorphism, the deposit is destroyed.

Maximum limitation of overburden: Can be mined by conventional methods to a depth exceeding 100 m. May be solution-mined at depths greater than 500 m.

Geochemical signature(s): None distinctive.. Lacustrine halite deposits commonly have less Br and I than marine deposits.

Geophysical signature(s): Halite gives low response on gamma-ray well logs. Large bodies of halite form relative gravity lows.

Other exploration guide(s): Groundwater may have elevated salinity.

Most readily ascertainable regional attribute: Existence of closed basin in arid environment.

Most readily ascertainable local attribute: Efflorescences of saline minerals; saline springs or wells; known gypsum or other evaporite outcrops.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: Impurities must be low.

Compositional/mechanical processing restrictions:

Distance limitations to transportation, processing, end use: Transportation represents the major cost of this commodity.

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ABBREVIATIONS

Country Code	Country
BLVA	Bolivia
EGPT	Egypt
PERU	Peru
TRKY	Turkey
USAZ	United States, Arizona
USCA	United States, California
USCO	United States, Colorado
USWA	United States, Washington