Descriptive Model of Stratabound Sulfur

and

Contained-Sulfur Model of Stratabound Sulfur

by

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Open-File Report 92-0705

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1992

1 Tucson, AZ
Introduction

Stratabound sulfur deposits are biogenic sulfur deposits that form within anhydrite-gypsum-bearing strata other than salt-dome cap rocks. They differ from salt-dome sulfur deposits in size and in structural and stratigraphic ore controls. Biogenic sulfur deposits that occur within bedded evaporites contain as much as 500 million tonnes of sulfur, considerably larger than the largest known salt-dome sulfur deposit which contains 89 million tonnes of sulfur (Long, 1992).

The factors that control the distribution of sulfur in anhydrite-gypsum-bearing strata are very different from those which control salt-dome sulfur deposits. Salt-domes are distinct geologic bodies that are easy to detect and delineate by geophysical methods. Sulfur, if present, is limited to the caprock. These elementary criteria render exploration and assessment of salt domes for sulfur quite straightforward. Biogenic sulfur deposits that occur in bedded evaporites, however, are controlled by a variety of structural and stratigraphic relationships that are more difficult to recognize and utilize in exploration and mineral resource assessment. Hence, biogenic sulfur deposits have been divided into two models, salt-dome sulfur (Long, 1992) and stratabound sulfur (this paper, 1992).
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BRIEF DESCRIPTION

Deposit synonyms: Bedded sulfur.

Principal commodities produced: Sulfur.

By-products: None.


Descriptive/genetic synopsis: Native sulfur filling pores and replacing matrix of anhydrite-gypsum-bearing strata. Sulfur is produced by sulfate-reducing anaerobic bacteria feeding on hydrocarbons trapped in the host strata.

Typical deposits: Culberson, Texas (Wallace and Crawford, 1992)
Tarnobrzeg, Poland (Niec, 1992)

Relative importance of deposit type: Stratabound sulfur deposits accounted for 7.5 % of U.S. Frasch sulfur production to 1979, 44 % of U.S. Frasch sulfur reserves in 1990, and 15% of world sulfur production in 1980.

Associated/related deposit types: Bedded gypsum; biogenic limestone.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Evaporite basins and evaporite-bearing reef complexes.

Regional depositional environment: Gypsum/anhydrite-bearing facies of evaporite and carbonate reef complexes.

Age range: Known deposits are hosted by evaporites of Paleozoic to Recent age, but the mineralization may be much younger than the host rock.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Biogenic limestone within anhydrite-(gypsum) strata or reefs.

Associated rock(s): Anhydrotrock-gyprock, dolostone (in carbonate reefs).

Ore mineralogy: Native sulfur.

Gangue mineralogy: Calcite, anhydrite (sometimes hydrated to gypsum). Barite, celestite, and various metal sulfides may be present in small quantities.

Alteration: Oil-bearing anhydrite altered to sulfur-bearing limestone by bacterial action.

Zoning: N/A

Structural setting: Most deposits exhibit strong structural controls that vary from basin to basin. West Texas (Delaware Basin) deposits occur along structurally-controlled solution collapse structures within Middle Miocene grabens (Hentz and Henry, 1989; Miller, 1990). Polish and Ukrainian (Carpathian Basin) deposits likewise occur along solution collapse structures albeit within uplifted blocks on the northern basin margin. Other deposits are stratigraphically controlled, such as those within evaporite-bearing carbonate reef complexes of the Permian Basin, Texas (Ruckmick
and others, 1992), or updip pinch-outs of evaporites in carbonate sequences of the Alberta Basin, Canada (Hollister, 1984).

**Ore control(s):** Sulfate reduction by bacteria occurs within 900 m of the surface and requires considerable quantities of hydrocarbons, about 0.3-0.6 cubic meters of oil per tonne sulfur produced. Bacterial reduction of sulfate yields $\text{H}_2\text{S}$ gas which must be trapped and oxidized to native sulfur to produce an economic deposit. $\text{H}_2\text{S}$ may migrate higher into the host rock, where it may be trapped by impermeable clay layers and oxidized by ground or sea water; alternatively $\text{H}_2\text{S}$ may be oxidized during hydration of anhydrite to gypsum along an oxidizing/reducing fluid interface within the host rock; or $\text{H}_2\text{S}$ may be converted into polysulfides, and then reduced by $\text{CO}_2$ during bacterial reduction of anhydrite.

**Typical ore dimensions:** Native sulfur is found in recoverable concentrations (20% $\text{S}$ or better) in irregular bodies up to 26 km long within zones up to 120 m thick.

**Typical alteration/other halo dimensions:** N/A

**Effect of weathering:** Breached sulfur-bearing limestone weathers to a distinctive sulfur-bearing soil, known as "sour dirt."

**Effect of metamorphism:** Sulfur deposits are likely to be lost during the onset of low-grade metamorphism by migration of molten sulfur and reaction with metals in subsurface brines.

**Maximum limitation of overburden:** Sulfur melts at 118.9 °C at 1 atmosphere pressure, however, the melting point of sulfur rises with increasing pressure. Even with a geothermal gradient as high as 17°C/km, sulfur will not melt above about 11 km depth.

**Geochemical signature(s):** $\text{H}_2\text{S}$ gas may be detected in outcropping biogenic limestone or issuing from faults and fractures in overlying strata. Sulfur-bearing ground waters may leach potassium from feldspars, precipitate silica, carbonates, gypsum, and uranium. Leakage of biogenic carbon dioxide may result in precipitation of calcite with isotopically light carbon in near-surface rocks and soils.

**Isotopic signature(s):** Native sulfur is enriched in $^{33}\text{S}$ (-10.8 to +15.3 $\delta^{34}\text{S}_{\text{NBS}}$) and anhydrite/gypsum is enriched in $^{34}\text{S}$ (+12.2 to +61.7 $\delta^{34}\text{S}_{\text{NBS}}$). Biogenic limestone has a $^{13}\text{C}/^{12}\text{C}$ ratio (-21.7 to -51.1 $\delta^{13}\text{C}_{\text{PDB}}$) higher than that of sedimentary limestone. Organic carbon in biogenic limestone is isotopically similar to local crude oils (-24.9 to -27.1 $\delta^{13}\text{C}_{\text{PDB}}$).

**Geophysical signature(s):** Certain configurations of anhydrite (specific gravity 2.96) and vuggy sulfur-bearing limestone (specific gravity 1.80-2.20) may yield potentially measurable negative gravity lows. The larger deposits can usually be detected by gravity methods, but the weak anomalies generated by smaller deposits are difficult to distinguish from those produced by barren solution-collapse structures (Salisbury, 1992). Sulfur-bearing ground waters destroy magnetite, yielding magnetic lows. Larger deposits yield significant magnetic anomalies (Quigley, 1966). Sulfur-bearing fluids may cause oxidation reactions detectable by spontaneous potential methods but these anomalies may be difficult to distinguish from other near-surface oxidation reactions. For smaller deposits, combinations of gravity, magnetic, gamma-ray spectrometry, and geochemical methods may be successful (Salisbury, 1992).

**Other exploration guides:** Geomorphologic and structural interpretation of solution-collapse structures aided by aerial photography, remote sensing, gravity, and aeromagnetic surveys may also be useful.
Most readily ascertainable **regional attribute:** Evaporite facies.

... **local attribute** Solution collapse structures, facies changes.

**ECONOMIC LIMITATIONS**

**Physical/chemical properties affecting end use:** Low carbon content (< 0.3%) required.

**Compositional/mechanical processing restrictions:** Economic recovery by the Frasch process requires a host rock with a uniform porosity of at least 10% overlain by an impermeable seal. Minimum sulfur grade is 20% over an interval of at least 30 m, at a depth between 60 and 760 m.

**Distance limitations to transportation, processing, end use:** Sulfur may generally be transported in a liquid form to local markets or in a solid form to regional markets.

**REFERENCES**


CONTAINED SULFUR MODEL OF STRATABOUND SULFUR
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Sizes of stratabound sulfur deposits and production of salt-dome sulfur deposits are normally reported in terms of contained or produced sulfur. Very little data on sulfur grades or volumes or tonnages of sulfur-bearing rock were found in the literature. Table 1 gives the amount of contained sulfur, in tonnes, for stratabound sulfur deposits in Texas (USTX), Poland (PLND), Alberta (CNAL), Iraq (IRAQ), Mexico (MXCO), and Egypt (EGPT). These data were used to construct the contained-sulfur model in Figure 1.

Table 1. Sulfur Contained in Stratabound Sulfur Deposits.

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Location</th>
<th>Tonnes Contained Sulfur</th>
<th>Rank</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comanche Creek</td>
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<td>3.1</td>
<td>8</td>
<td>[1]</td>
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<tr>
<td>Coronation</td>
<td>CNAL</td>
<td>0.36</td>
<td>13</td>
<td>[2]</td>
</tr>
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<td>83</td>
<td>3</td>
<td>[3]</td>
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<td>EGPT</td>
<td>18</td>
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<td>[4]</td>
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<td>[1]</td>
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<td>9</td>
<td>[6]</td>
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<td>11</td>
<td>[7]</td>
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<td>12</td>
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<td>2</td>
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<td>USTX</td>
<td>7.4</td>
<td>6</td>
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<td>Phillips Ranch</td>
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<td>1</td>
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Sources:


Figure 1. Contained sulfur in stratabound sulfur deposits.