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Descriptive Model of Stratabound Sulfur

and

Contained-Sulfur Model of Stratabound Sulfur

by

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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).

Model 35ah

DESCRIPTIVE MODEL OF STRATABOUND SULFUR

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BRIEF DESCRIPTION

Deposit synonyms: Bedded sulfur.

Principal commodities produced: Sulfur.

By-products: None.

End uses: As sulfuric acid: production of phosphate fertilizers, leaching of metal ores, chemicals, synthetic materials, pulp and paper products, explosives. As native sulfur: agricultural chemicals, petroleum/coal products, pulp and paper products.

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): Anhydrock-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 H_2S gas which must be trapped and oxidized to native sulfur to produce an economic deposit. H_2S may migrate higher into the host rock, where it may be trapped by impermeable clay layers and oxidized by ground or sea water; alternatively H_2S may be oxidized during hydration of anhydrite to gypsum along an oxidizing/reducing fluid interface within the host rock; or H_2S may be converted into polysulfides, and then reduced by CO_2 during bacterial reduction of anhydrite.

Typical ore dimensions: Native sulfur is found in recoverable concentrations (20% 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): H_2S 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 ^{32}S (-10.8 to +15.3 $\delta^{34}S_{NBS}$) and anhydrite/gypsum is enriched in ^{34}S (+12.2 to +61.7 $\delta^{34}S_{NBS}$). Biogenic limestone has a $^{12}C/^{13}C$ ratio (-21.7 to -51.1 $\delta^{13}C_{PDB}$) higher than that of sedimentary limestone. Organic carbon in biogenic limestone is isotopically similar to local crude oils (-24.9 to -27.1 $\delta^{13}C_{PDB}$).

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.

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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.

Deposit	Location	Tonnes Contained Sulfur	Rank	Source
Comanche Creek	USTX	3.1	8	[1]
Coronation	CNAL	0.36	13	[2]
Culberson	USTX	83	3	[3]
El Arish	EGPT	18	5	[4]
Fort Stockton	USTX	3.1	8	[1]
Grzybow	PLND	24	4	[5]
Heiner	USTX	3.0	9	[6]
Huaxcana	MXCO	1.1	11	[7]
Magenta Trough	USTX	0.47	12	[8]
Mishraq	IRAQ	245	2	[9]
Mustang Draw	USTX	7.4	6	[10]
Phillips Ranch	USTX	6	7	[11]
Pokornoy Ranch	USTX	1.2	10	[12]
Rustler NW	USTX	0.03	15	[13]
Rustler SW	USTX	0.006	16	[13]
Swoszowice	PLND	0.2	14	[14]
Tarnobrzeg	PLND	500	1	[15]

Sources:

[1] Manderson Associates (1977).

[2] Hollister (1984) p. 241 (maximum estimate).

[3] Wallace and Crawford (1992) p. 94.

[4] Mining Journal (1989) v. 312, no. 8017, p. 326.

[5] U.S. Bureau of Mines Minerals Yearbook (1983) v. 3, p. 629. Estimated from a production rate of 800,000 tonnes/year sulfur from 1966 to 1983 and year-end reserves in 1983 of 10 million tonnes sulfur.

[6] Manderson Associates (1979) v. 2, p. 130 (reserves in 1979); Crawford (1990) p. 143 (production to 1979).

[7] Gonzalez (1956) p. 372 (production); U.S. Bureau of Mines Minerals Yearbook (1970) v. 3, p. 536 (remaining reserves).

[8] Miller (1972) p. 172.

[9] Barker and others (1979) p. 490.

[10] Ruckmick and others (1992) p. 135.

[11] Smith (1980) p. 279.

[12] Klemmick (1992) p. 121.

[13] Miller (1992) p. 171.

[14] Pawlowski and others (1979) p. 475.

[15] Niec (1992) p. 23.

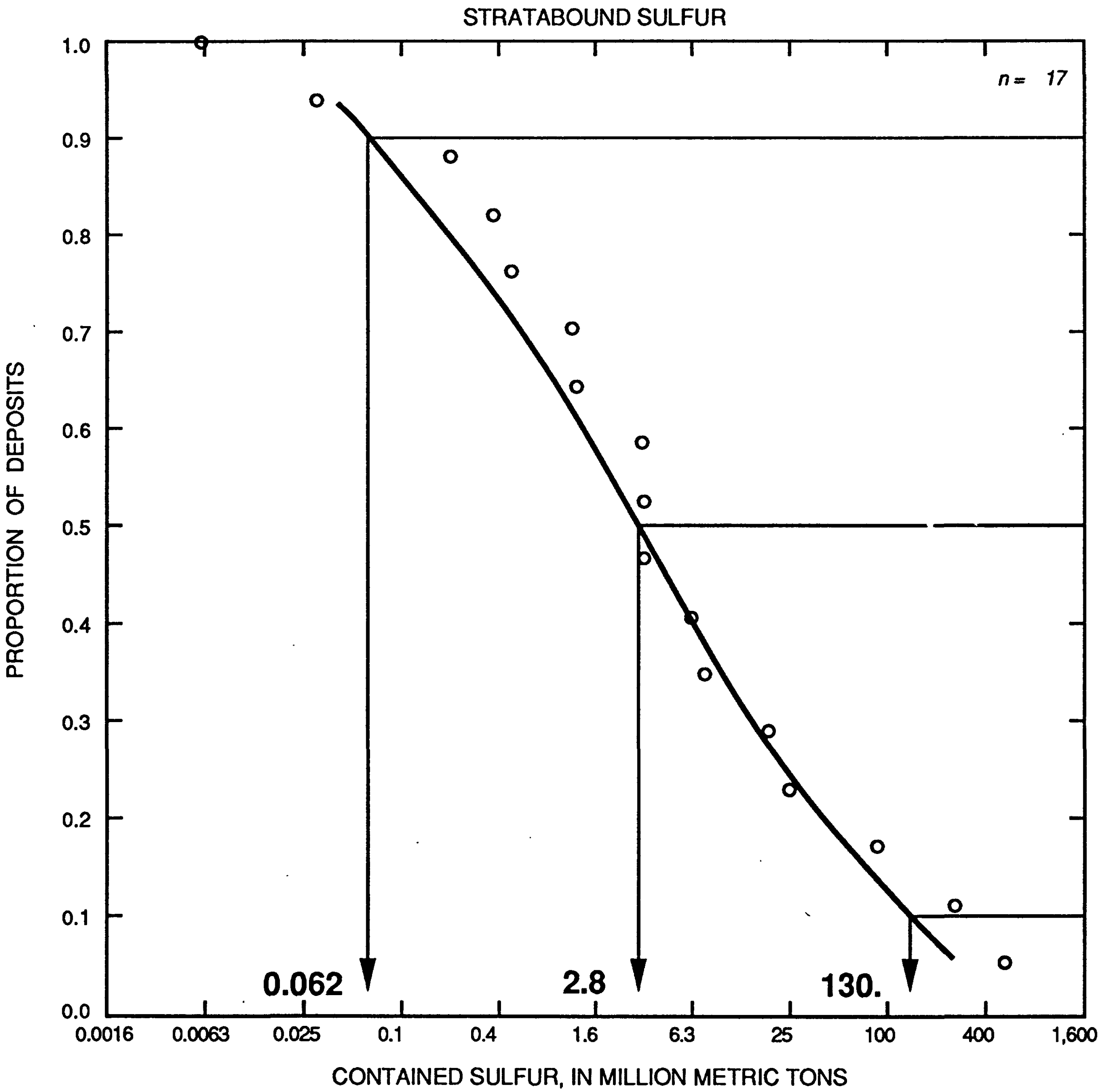

Figure 1. Contained sulfur in stratabound sulfur deposits.