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Descriptive Model of Salt-Dome Sulfur

and

Contained-Sulfur Model for Salt-Dome Sulfur

by

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Introduction

Salt-dome sulfur deposits are biogenic sulfur deposits that form in the anhydrite-gypsum caprocks of salt domes. They differ from other biogenic sulfur deposits due to the restrictions imposed upon their size and occurrence by the size and location of the host salt-dome caprocks. Biogenic sulfur deposits that occur within bedded evaporites contain as much as 500 million tonnes of sulfur (Long, 1992), considerably larger than the largest known salt-dome sulfur deposit which contains 89 million tonnes of sulfur.

The factors which control the distribution of sulfur in salt-dome caprocks are very different from those which control sulfur deposits in bedded evaporites. 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 strait forward. 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 (this paper) and stratabound sulfur (Long, 1992).

This model draws on data from the Gulf Coast of the United States and Mexico. Sulfur-bearing salt domes are known in Russia (Samarkin and others, 1983) and may occur in other salt-dome provinces. Data on these other occurrences are scarce, in particular for contained sulfur, and of little use for constructing this model. The available geologic descriptions of these other occurrences do not suggest any significant difference between them and the deposits used in developing this model.

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BRIEF DESCRIPTION

Deposit synonyms: Caprock 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 cementing porosity and replacing matrix of anhydrite-gypsum-limestone caprock of salt domes. Sulfur is produced by sulfate-reducing anaerobic bacteria feeding on hydrocarbons trapped in the salt-dome caprock.

Typical deposits: Boling Dome, USTX (Samuelson, 1992)
Sulphur Dome, USLA (Kelley, 1926)

Relative importance of deposit type: Salt-dome sulfur deposits accounted for 92.5 % of U.S. Frasch sulfur production to 1979, 56 % of U.S. Frasch sulfur reserves in 1990, and 10 % of world sulfur production in 1980.

Associated/related deposit types: Salt-dome oil and gas; salt-dome salt; caprock limestone; caprock gypsum; polymetallic sulfide/sulfate and strontium sulfide/sulfate salt-dome deposits.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Evaporite basins that have experienced salt diapirism.

Regional depositional environment: Salt domes.

Age range: Gulf Coast salt domes intrude rocks as young as Miocene in age, placing a maximum age on the sulfur deposits.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Limestone-anhydrite-(gypsum) caprock of salt domes.

Associated rock(s): Salt.

Ore mineralogy: Native sulfur.

Gangue mineralogy: Calcite, anhydrite (sometimes hydrated to gypsum).

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

Zoning: N/A

Structural setting: Intrusive salt structures.

Ore control(s): Overburden of 300-600 m is required to initiate salt movement. Anhydrite caprock is formed by dissolution of salt by ground or sea water within 1500 m of the surface or ocean floor. Caprock and sulfur deposits may subsequently be buried to 4000 m depth or more. 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 caprock, 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 caprock; 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 70 m thick within zones up to 150 m thick. Recoverable sulfur may cover an area of up to 600 hectares; associated domes may be up to 8 km in diameter. Sulfur may sometimes be found on the flanks of salt domes, to depths as much as 1000 m deep. Sulfur-productive caprocks yield 1 unit sulfur per 4 units limestone by volume.

Typical alteration/other halo dimensions: N/A

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

Effect of metamorphism: Sulfur deposits are likely to be lost prior to 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 caprock or issuing from salt dome-related structures.

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 $\delta^{34}S_{NBS}$). Caprock 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 caprock is isotopically similar to local crude oils (-24.9 to -27.1 $\delta^{13}C_{PDB}$).

Geophysical signature(s): Shallow and outcropping salt domes are easily located by field mapping, and photo or image interpretation. Deep seated salt domes may have surface expression, but have generally been located by gravity and seismic methods. Certain configurations of salt (specific gravity 2.2), anhydrite (specific gravity 2.96) and sulfur-bearing limestone (specific gravity 1.80-2.20) may yield potentially measurable negative gravity lows. Oxidizing sulfide minerals in a caprock may yield thermal infrared anomalies as well as magnetic and induced polarization anomalies.

Frequency of occurrence: In the Texas-Louisiana Coastal salt basin 161 salt domes occur onshore and 67 offshore. Of the 91 onshore salt domes with caprocks, 25 have produced sulfur commercially, at least 13 have non-commercial sulfur deposits, at least 9 others have been tested with unreported results, and 14 have caprocks deeper than 900 m and thus have not been tested. Of the 67 offshore salt domes 2 are commercially productive and at least 10 others have been leased for sulfur exploration. In the Rio Grande salt basin there are 6 salt domes, 3 with caprocks, one of which was commercially productive, and another that has a non-commercial deposit. In the Louisiana-Mississippi Interior salt basin of 76 salt domes, 61 have caprock, 23 of which are more than 900 m deep and 1 has a showing of sulfur. Of the 18 salt domes in the North Louisiana salt basin, 15 have caprocks, 4 more than 900 m deep, but no sulfur has been reported. Likewise, no sulfur has been reported for the 19 salt domes of the East Texas basin of which 10 have caprocks, 2 deeper than 900 m. All of these salt basins are productive of oil and gas.

Other exploration guide(s): Most salt-dome sulfur deposits have been discovered accidentally in the course of oil and gas exploration or by drilling of salt domes that appear to meet genetic requirements for the formation of a sulfur deposit.

Most readily ascertainable regional attribute: Regional salt tectonic features.

... local attribute Salt dome-related structures.

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 caprock 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 FOR SALT-DOME SULFUR

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Sizes of salt-dome 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 31 salt dome-sulfur deposits in Texas (USTX), Louisiana (USLA), and Mexico (MXCO). These data were used to construct the contained-sulfur model in Figure 1.

Table 1. Sulfur Contained in Salt-Dome Sulfur Deposits.

Deposit	Location	Tonnes Contained Sulfur	Rank	Source
Amezquite	MXCO	14.2	7	[5]
Bay Sainte Elaine	USLA	1.2	24	[1]
Boling Dome (New Gulf)	USTX	89	1	[2]
Bryan Mound	USTX	17	6	[6]
Bully Camp Dome	USLA	2.5	21	[2]
Caillou Isle	USLA	3	20	[3]
Caminada Pass (Grande Isle Block 16)	USLA	12	9	[4]
Chacahoula	USLA	1.4	23	[5]
Clemens Dome	USTX	3	19	[5]
Damon Mound	USTX	0.14	31	[5]
Fannett Dome	USTX	3.5	17	[5]
Garden Island Bay	USLA	31	5	[2]
Grande Isle Block 18	USLA	34	4	[2]
Gulf Hill (Old Gulf)	USTX	13	8	[5]
High Island	USTX	0.15	30	[5]
Hoskins Mound	USTX	11	10	[5]
Jefferson Island (Lake Peigneur)	USLA	0.44	27	[5]
Lake Hermitage (Lake Harnil)	USLA	0.45	26	[5]
Lake Pelto	USLA	6	15	[4]
Lake Washington (Grande Ecailie)	USLA	41	3	[2]
Long Point Dome	USTX	9	14	[4]
Main Pass Block 299	USLA	68	2	[7]
Moss Bluff	USTX	9	13	[8]
Nash Dome	USTX	0.33	28	[5]
Nopalapa	MXCO	3	18	[5]
Ojapa	MXCO	1.5	22	[8]
Orchard Dome	USTX	5.5	16	[5]
Palangana Dome	USTX	0.24	29	[5]
Spindletop Dome	USTX	10	11	[4]
Starks	USLA	0.86	25	[5]
Sulphur Mine Dome	USLA	9.6	12	[5]

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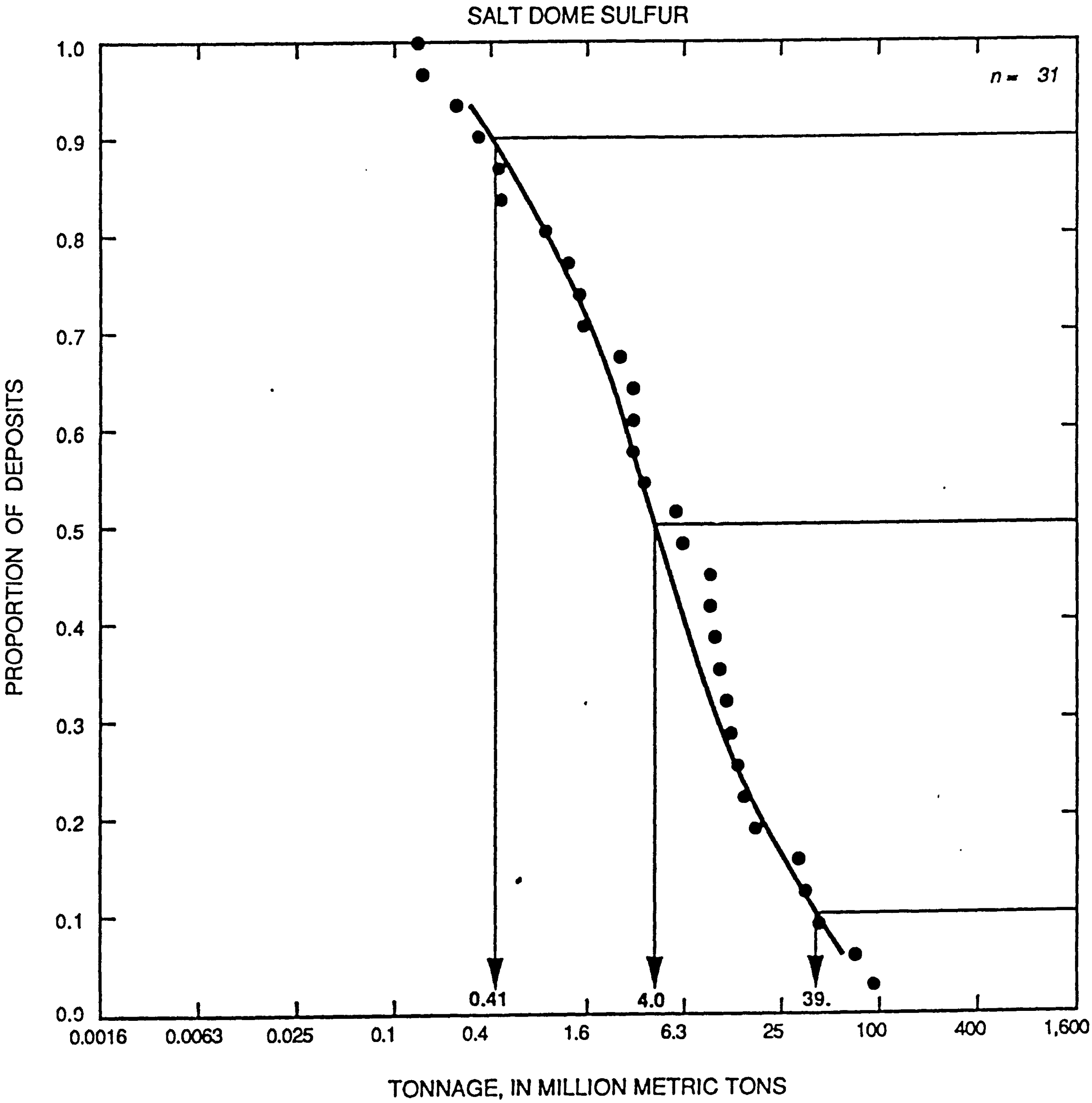

FIGURE 1. Contained-Sulfur Model for Salt-Dome Sulfur.