Gypsum-Anhydrite Caps of Arctic Salt Domes, Queen Elizabeth Islands: Products of Active and Passive Diapirism

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ABSTRACT

Unlike the salt-dissolution caps of classical salt stocks in northern Germany and Texas-Louisiana, the stratified gypsum-anhydrite caps of the Arctic domes are made of metasedimentary anhydrite with limestone interbeds. This strange type of cap is structural rather than chemical in origin. Its formation requires that, at the onset of diapirism, the $CaSO_4$ *material behaves actively like a ductile buoyant medium, and gives rise to incipient salt-anhydrite domes. Such behaviour can be expected of an anhydrite mush produced by dehydration of primary gypsum and leads to a mechanical concentration of* $CaSO_4$ *material above low-amplitude salt domes. The anhydrite mush proceeds to lose water during continued diapirism and rapidly changes into dense imporous anhydrite. The resulting competent cap has most mechanical attributes of a salt-dissolution cap and acts like a semi-brittle battering-ram which passively pierces the overlying sedimentary strata while being driven by a growing dome of buoyant rock salt.*

INTRODUCTION

Among the well-studied salt domes of major sedimentary basins, the Arctic structures (Figure 1) are unique in that they are capped by huge masses of metasedimentary anhydrite containing many limestone beds, locally recrystallized into marble (Gussow, 1954; Heywood, 1955 & 1957; Fortier *et al.*, 1963; Gould and DeMille, 1964; Hoen, 1964; Schwerdtner and Clark, 1967). All geologists who have visited these structures agree that the bedded anhydrite is not a conventional cap rock produced by dissolution of impure rock salt (cf. Goldman, 1952). Primary sedimentary structures are locally preserved within the anhydrite (Figure 2) and provide further evidence that the present caps are not composed of lithified $CaSO_4$ residue.

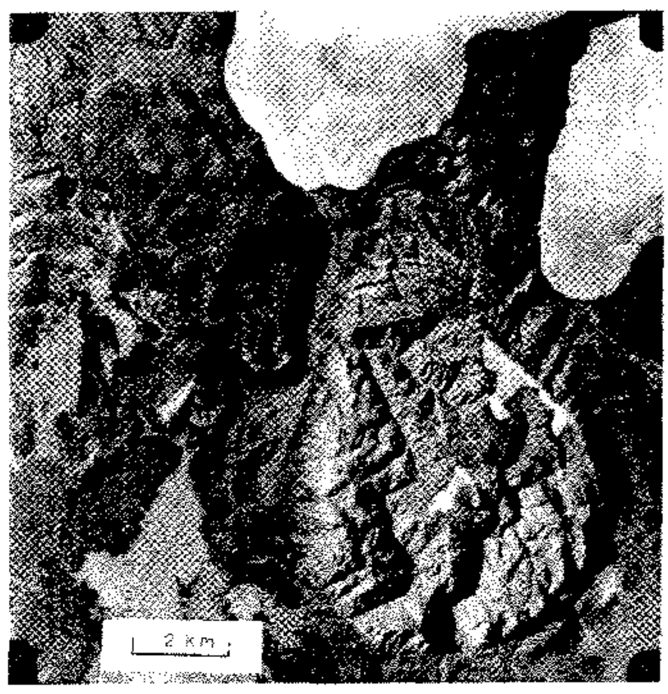

Figure 1. Vertical aerial photo of the South Fiord dome, western Axel Heiberg Island (R.C.A.F. Photo A16186-73).

BIPARTITE DOMES

In the coastal regions of Axel Heiberg Island, oval anhydrite masses form buff-grey mountains that rise as much as 700 m above sea level and have horizontal diameters of up to 10 km. The strained anhydrite sequence is at least 800 m thick in one of the domes studied and apparently corresponds to the Otto Fiord Formation of Ellesmere Island (Thorsteinsson, 1974). This anhydrite formation is exposed in normal stratigraphic succession near

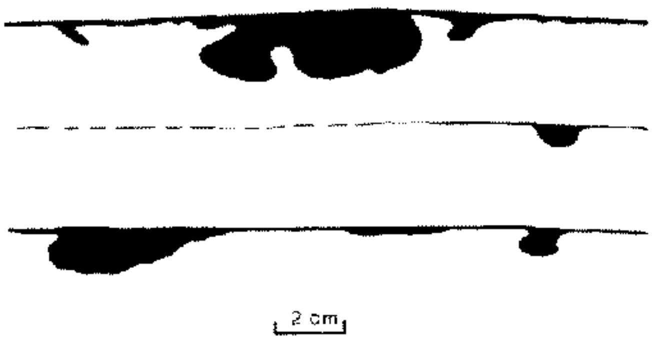

Figure 2. Load casts between white medium-grained anhydrite containing some carbonates and argillaceous impurities. The features must have formed before the $CaSO_4$ material was imporous anhydrite, probably at an early sedimentary stage. Drawing by A. R. Clark from a large specimen of weakly deformed rock, southwestern Mokka Fiord dome on eastern Axel Heiberg Island (Gould and DeMille, 1964), Station 616, Notebook #7 of Schwerdtner and Clark (1967).

the northeastern margin of the Sverdrup Basin, where it reaches a minimum stratigraphic thickness of about 400 m (Nassichuk and Davies, 1980).

Rock salt has only been reported from two domes (Davies and Nassichuk, 1975; Hugon and Schwerdtner, 1982), but gravity studies leave little doubt that most of the anhydrite masses are underlain by large amounts of halite (Spector and Hormal), 1970; Nassichuk and Davies, 1980). Accordingly, the Arctic evaporite domes are bipartite because they are composed of rock salt as well as bedded anhydrite (Gould and DeMille, 1964, p. 745; Thorsteinsson, 1974, pp. 74–81). Most recent workers have assumed that the Pennsylvanian evaporite deposit of the central Sverdrup Basin was composed of two major units: a thick lower unit of rock salt and an upper unit of gypsum with numerous limestone interbeds (Hugon and Schwerdtner, 1982).

DEFORMATION OF ANHYDRITE MASSES

Throughout the structures analysed to date (Hoen, 1964; Schwerdtner and Clark, 1967; Schwerdtner and Osadetz, 1983), the attitude of limestone beds was measured systematically to obtain a crude indication of the external form of the anhydrite masses. Although these beds are folded and/or disrupted in many localities, the map pattern of bedding suggests that the form of the outer contact is broadly domical. Study of the ductile-strain pattern of the limestone beds (upright buckle folds, radially-oriented boudins, etc.) reveals that the anhydrite masses have been strongly thickened (Schwerdtner and Clark, 1967; Schwerdtner and Osadetz, 1983), in the early stages of doming. Superimposed on the early ductile-flow features are (1) gypsiferous shear zones (2) major extension gashes, and (3) semi-brittle faults (Schwerdtner and Clark, 1967; Schwerdtner and Osadetz, 1983, van Berkel *et al.*, 1983). Apparently, the $CaSO_4$ material of the domes turned into a dense semi-brittle mass after having flowed upward like buoyant rock salt, in the early stages of diapirism.

Model experiments reveal that had the $CaSO_4$ material been dense imporous anhydrite at the onset of diapirism, it would have been thinned rather than thickened as a whole (Schwerdtner and Osadetz, 1983). The observed thickening requires that the $CaSO_4$ material had the density of salt and, most probably, was anhydrite mush produced by dehydration of buried, primary gypsum. Owing to continued deformation, the $CaSO_4$ material gradually lost its water and turned into dense competent anhydrite (Schwerdtner and Osadetz, 1983). At that stage, however, the $CaSO_4$ material formed the upper part of an immature diapir (Figure 3) and could no longer be pierced by the rising salt plug. Like the composite caps of Gulf Coast domes (Goldman, 1952), it was driven through the overlying strata by the buoyant salt, without breaking up into separate fragments. The thick anhydrite caps of the Arctic domes must have behaved like battering-rams, in the latter stages of diapirism, which passively penetrated most of the clastic overburden. However, the present topographic relief of most domes (Figure 1) reflects the resistance of gypsum-anhydrite to mechanical weathering in a cold arid climate (Gould and DeMille, 1964, p. 746, Hoen, 1964).

TIMING OF DIAPIRISM

Stott (1969) collected stratigraphic data which prove that diapirs were rising as early as Late Jurassic time. Gould and DeMille (1964) noted that individual clastic strata tend to thin toward the salt domes, suggesting that diapiric movements occurred in the Upper Cretaceous. Schwerdtner and Osadetz (1983) found strong evidence that the anhydrite cap of one dome was already being eroded in Upper Cretaceous times, and proposed that diapirism started much earlier, possibly in the uppermost Carboniferous or lowermost Permian.

Undeformed igneous sheets occur in the stretched bedding surfaces of some domes, and most post-date the overall ductile flow of the $CaSO_4$ material (Schwerdtner and Clark, 1967; Schwerdtner and Osadetz, 1983). The diapiric contact of a small anhydrite-marble mass on eastern Axel Heiberg Island is cut by a radial mafic dyke (van Berkel et al., 1983). Determination of the absolute age of these concordant and discordant igneous bodies should yield an upper limit for the time at which the $CaSO_4$ material turned into competent anhydrite.

If it is indeed true that gypsum cannot exist below a burial depth of 600 m (cf. Thorsteinsson, 1974, p. 81), except near major fault zones and deep fractures connected with the surface, then the active diapirism of the envisaged anhydrite mush must have occurred no later than in the Lower Triassic (cf. Thorsteinsson, 1974, Table 1).

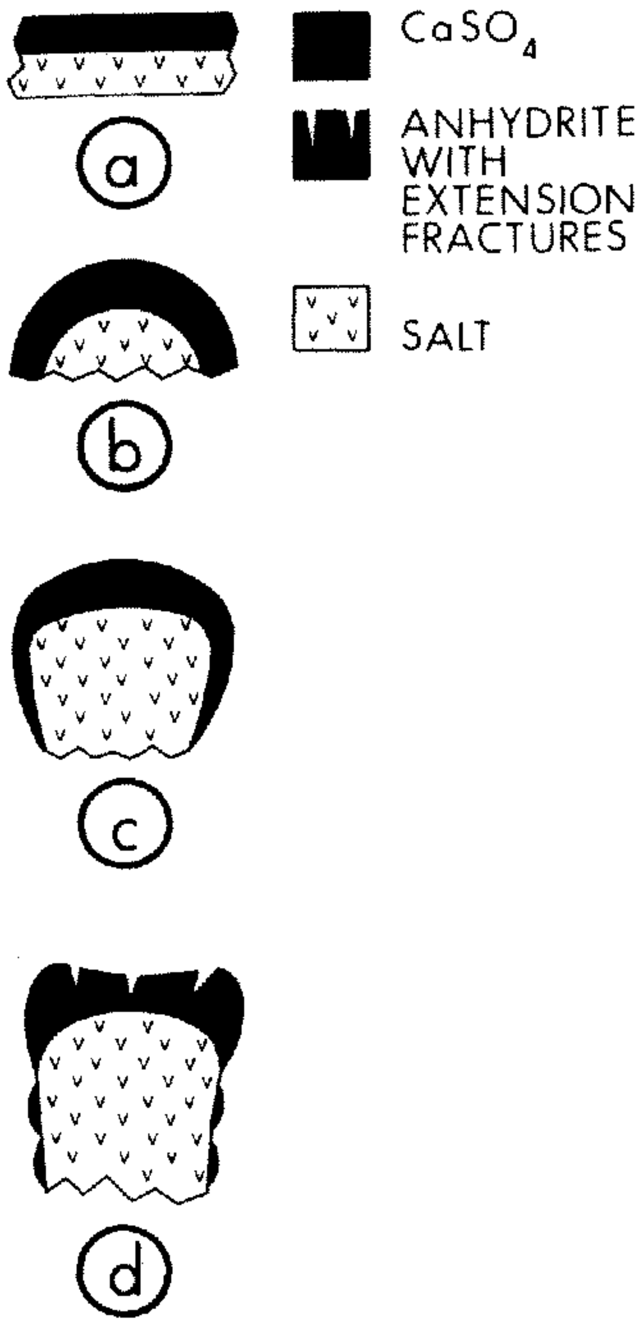

Figure 3. Schematic illustration of the development of structural gypsum-anhydrite caps in the Sverdrup Basin; (a) underformed evaporite deposit, (b) incipient dome of rock salt and buoyant anhydrite mush, (c) all crystal water has escaped and structural cap is being formed, (d) bulging and partial breakup of gypsum-anhydrite cap above mature diapir.

COMPARISON WITH CLASSICAL SALT DOMES

Like the classical salt domes of northern Germany and the Gulf Coast region, the Arctic salt domes carry a cap of $CaSO_4$-$CaCO_3$. The composite cap of the classical domes is clearly zoned, mainly chemical in origin, and made up of lithified and recrystallized residues of dissolved salt and potash rocks. The stratified cap of the Arctic domes, on the other hand, is mainly structural in origin. Being composed chiefly of metasedimentary anhydrite, the cap owes its existence to profound changes in density and equivalent viscosity of the $CaSO_4$ material. Presumably, the primary gypsum lost its crystal water, upon shallow burial, and became a buoyant crystal mush which gradually turned into dense imporous anhydrite.

Once formed, the two types of caps assumed similar mechanical roles; they behaved as competent masses on top of the rising salt domes and pierced the clastic sedimentary strata ahead of the rock salt (Figure 3). Goldman (1952, p. 1) has given a detailed description of the structural features within the anhydrite cap of a salt dome in Louisiana which clearly illustrates the mechanical behaviour of the cap. He suggested that the cap has been bent by the advancing salt while undergoing discontinuous internal deformation. The cap of the Arctic domes was bent at an early stage but partly unbent later on, while being compressed in a vertical direction (Figure 3c). This process is suggested by the inward-dipping boundaries of anhydrite masses (Schwerdtner and Osadetz, 1983) whose form cannot be attributed to a "mushrooming" of the salt. Most probably, the stratified caps were forced to bulge (Figure 1) when stressed severely in a vertical direction.

Unlike the caps of most classical salt domes, those of the eastern Sverdrup Basin were further deformed in a regime of thin-skinned tectonics. Field projects are underway on Axel Heiberg Island that will attempt to isolate the effects of superimposed regional deformation (van Berkel et al., 1983).

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