Geometric Characterization of Anhydrite Piercement Structures on Ellef Ringnes Island, Canadian Arctic Archipelago

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Summary

Interpretation and characterization of evaporite piercement structures on Ellef Ringnes Island, Canadian Arctic Archipelago, reveal asymmetric geometries that may have resulted from growth along or adjacent to pre-existing basement fault structures. Due to the involvement of dense anhydrite caps, buoyancy contributes less to the total driving forces than in conventional halokinetic systems. We suggest that the existence of basement fault structures played a significant role in the formation of the evaporite structures by acting as planes of weakness that controlled the initiation and direction of salt movement. Offset along the faults also created differential loading due to the accumulation of thicker packages of sediments on down-thrown fault blocks.

Introduction

Ellef Ringnes Island is located in the Sverdrup Basin, a pericratonic trough that began rifting in the Carboniferous. The basin contains up to 13 km of Carboniferous to Tertiary strata of marine and non-marine origin (Balkwill, 1978). Ellef Ringnes Island contains several ovate piercement structures that formed by vertical displacement of evaporites originally belonging to the Carboniferous Otto Fiord formation. The domes are composed of a 300-500 m thick anhydrite-dominant layer underlain by a halite diapir core of unknown thickness. The initiation and rate of vertical migration of the diapirs are poorly constrained due to the lack of high quality seismic imaging, particularly at depths of 8-13 km where the source layer is thought to occur. Buoyancy is argued to provide a fundamental driving force for salt tectonics, however the presence of a dense anhydrite caprock diminishes and possibly reverses the effect of buoyancy driven diapirism (Stephenson et al., 1992a). Several processes have been suggested for the initiation of salt movement, the two most accepted being reactive diapirism due to rift related extension and differential loading from prograding sedimentary sequences.

The purpose of this study is to characterize the structure of the evaporite domes in order to better understand the kinematics and dynamics that govern their initiation and movement. We present results from seismic reflection and well data analysis along with preliminary results of analogue models.

Methods

Interpretation of seismic reflection data and subsidence modeling were carried out to characterize the geometry and present day structure of the evaporite piercement structures, with particular focus on the Hoodoo, Dumbells and Contour Domes. The acquired data consists of archived industry seismic reflection and borehole data dating from the 1970's. The seismic reflection data includes unmigrated single and multi-fold data of varying quality. In cooperation with the Geological Survey of Canada (Calgary), several seismic reflection lines were migrated to better visualize strata that bound the vertical contacts of the evaporite domes. Data collected from boreholes include geological and geophysical logs and check shot surveys. Seismic horizons were interpreted based on formation tops from borehole logs and the intersection of strata with the Earth's surface.

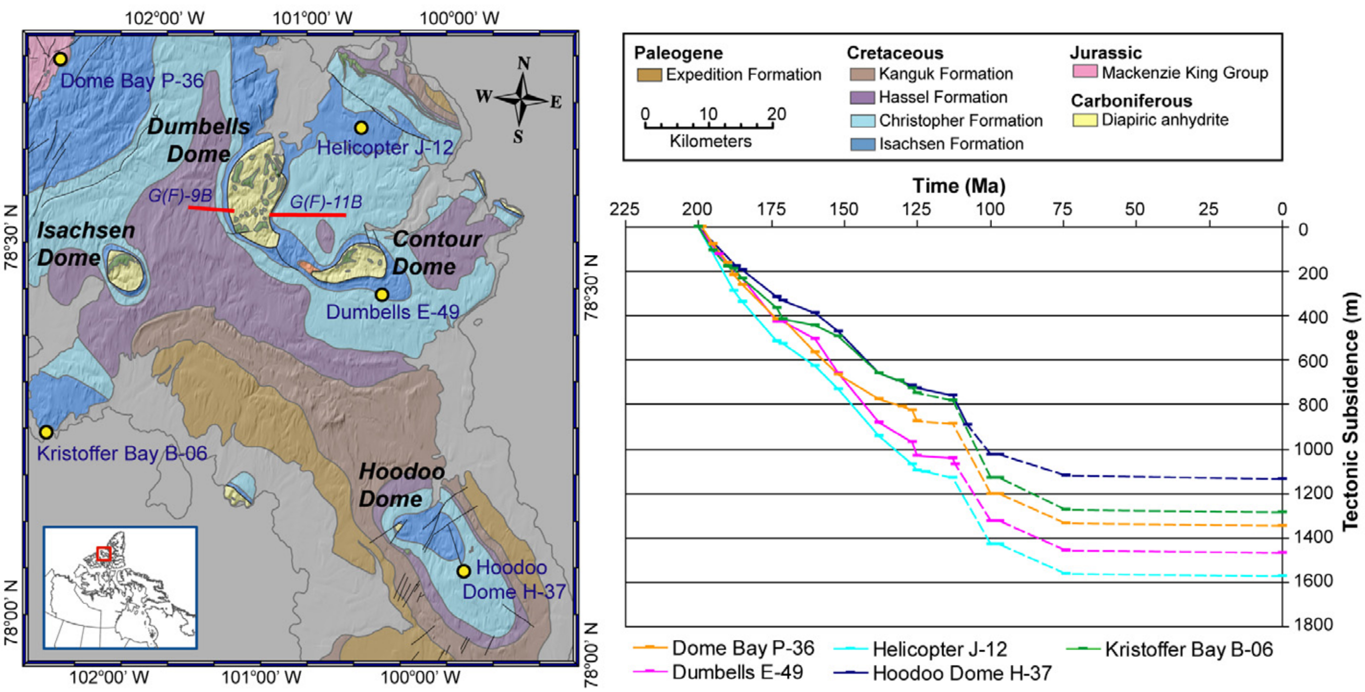

Figure 1: (a) Geological map of south central Ellef Ringnes Island, including the location of wells used for subsidence modelling (yellow circles) and location of seismic profiles shown in Fig. 2 (red). Map also includes outcrop patterns of Cretaceous to Tertiary sedimentary units and location of exposed evaporite domes (yellow: anhydrite; green: inclusions of mafic blocks within the domes). (b) Tectonic subsidence for Jurassic to Tertiary units. Dotted lines are estimated thicknesses of eroded units. Subsidence curves do not include basin inversion in the Tertiary from the Eurekan Orogeny.

Subsidence modelling was carried out to identify where reorganization of sedimentary deposits occurred due to the upward migration of evaporites in comparison to the average sedimentary record of Ellef Ringnes Island. Automated backstripping of sedimentary units was done to produce 1-D subsidence curves (Fig. 1). The wells record a sedimentation history beginning at 200 Ma, therefore only the slowly decaying thermal post-rift subsidence signature is registered, and not the rapid syn-rift subsidence documented by Stephenson et al. (1992b) in other areas of the basin.

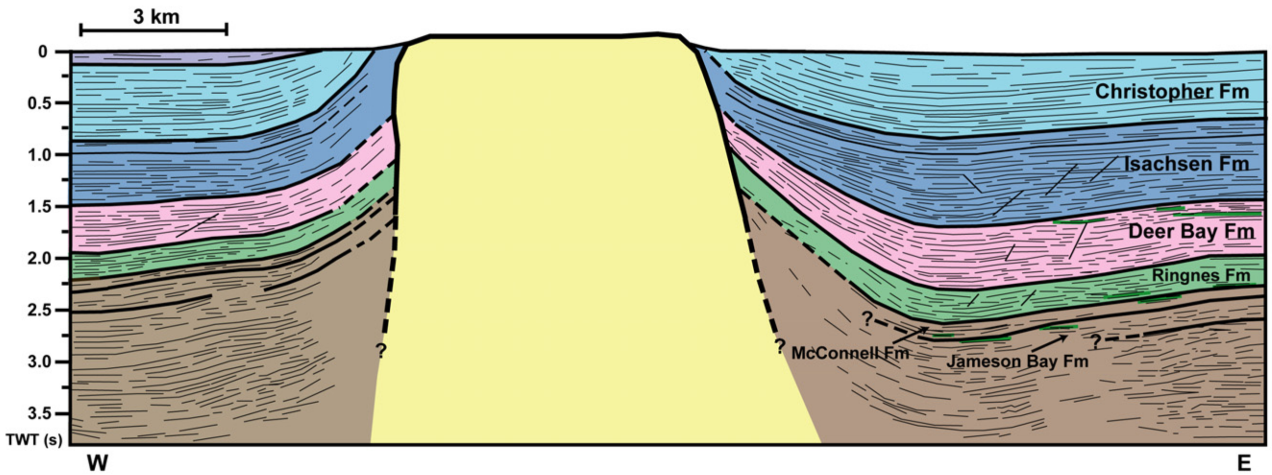

Figure 2: Line drawing and interpretation of seismic profiles G(F)-9B and G(F)-11B. The two seismic profiles image the eastern and western flanks of Dumbells Dome (see Fig. 1 for locations). Green lines represent discontinuous sills. Note the thickening and shallow rim synclines on the east side of the dome. Vertical exaggeration is 1.5.

Discussion

Interpreted seismic profiles that crosscut piercement features reveal an asymmetric geometry with gently arched sedimentary beds on the western margin of the domes and thicker sedimentary packages and rim synclines located on the eastern margins (e.g. Fig. 2). As is suggested in other settings, such as in the Gulf of Mexico (Nelson, 1991) and Nordkapp Basin (Koyi et al., 1993), the asymmetry of the domes may reflect the presence of pre-existing basement faults that continued to be active during the evolution of the evaporite structures. Hoodoo dome in particular contains an almost vertical shear zone on its eastern margin that records stretching, thinning and steepening of sedimentary units. The offset is of normal sense with the hanging wall dropping down to the east towards the Axel Heiberg depocentre. Although this shear zone was not documented by previous mapping (Stott, 1969), it can be identified at surface where units cropping out east of the dome appear steeper and thinner. The early stages of diapirism are not recorded in borehole and seismic data due to the inability to resolve data at depths greater than 4km. However, the sedimentary record from the Early Jurassic to the Early Cretaceous suggests that the domes formed by passive growth as illustrated by gentle arching of strata on their western margins. This growth period corresponds to a low average rate of tectonic subsidence of ~ 10 m/Ma (Fig. 1). The formation of shallow rim synclines on the west margins of the Dumbells and Contour domes may be related to the removal and depletion of the Otto Fiord formation source layer by excessive loading of sediments on the down thrown block. Subsidence curves did not resolve specific periods where sedimentation proximal to evaporite domes differed from regional sedimentation patterns. The lack of modification may be due to poor resolution of sampling locations, or may reinforce the notion that little modification occurred during a passive growth stage in the Jurassic. In the Early Cretaceous, tectonic subsidence curves record a period of quiescence from 125 to 115 Ma followed by rapid subsidence until 100 Ma. This period of tectonic activity is contemporaneous with burial of the domes by the Isachsen and Christopher formations. Piercement of the Cretaceous units occurred by active diapirism triggered in the Eocene by the Eurekan Orogenic event.

Conclusions

The evaporite piercement structures on Ellef Ringnes Island demonstrate an asymmetry that may be directly related to syn-sedimentary and syn-halogenetic movement of basement controlled faults. The observed variation in sedimentation on the west and east sides of the Dumbells/Contour domes and the offset along the shear zone adjacent to Hoodoo Dome suggest that these fault zones remained periodically or continuously active throughout the majority of the Mesozoic until as late as the Late Cretaceous. The fault zones not only provide a conduit for salt migration, but the loading of the downthrown blocks likely led to variations in sediment thickness that may have triggered and/or continuously fed the diapirs.

Future work will include analogue modelling to better understand the role of anhydrite in the formation of the piercement structures on Ellef Ringnes Island. Scaled experiments will involve forced injection of fluids into a downbuilding overburden of sedimentary rocks as analogues for salt diapir growth (viz., Davison et al, 1993). Different rheologies for the anhydrite analogue will be tested in order to understand the mechanics of uplift of competent and relatively undeformed blocks of anhydrite on top of buoyant salt structures.

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