Calcitized Anhydrite: Its Significance as an Exploration Tool in the Mississippian Tilston Beds of Southeastern Saskatchewan

by John Kaldi and Alf Hartling[1]

The Tilston Beds occur as the lowermost portion of the Mission Canyon Formation of the Mississippian Madison Group in southeastern Saskatchewan (Fig. 1). The Madison Group is composed of cyclic carbonates and evaporites which thicken toward the centre of the basin in west-central North Dakota, reaching a maximum thickness of 700 m.

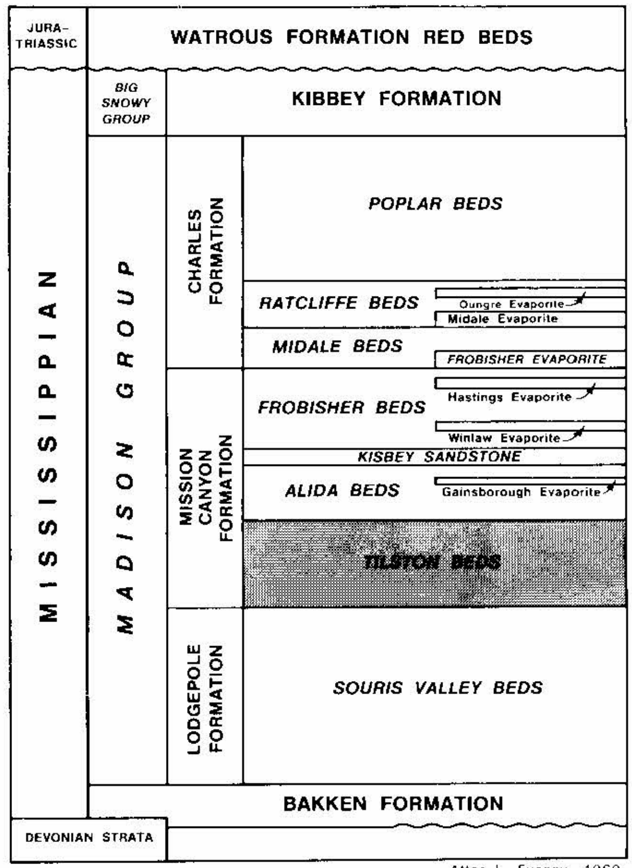
The general depositional model for the Madison cycles comprises quiet water carbonate sediments on a broad, flat shelf interior which intermittently gave way to higher energy deposits of a relatively narrow shelf margin. Supratidal sabkha deposits prograded from the northeast to blanket much of the shelf-interior and shelf-margin areas while basin-slope and basin sediments accumulated further downdip (Kent, 1980).

Post-Mississippian erosion truncated Madison sediments such that progressively younger beds subcrop basinward. Producing oilfields in southeastern Saskatchewan generally are aligned roughly parallel to these subcrop traces. The area of study for this report is immediately downdip from the Tilston Beds subcrop (Fig. 2).

Description of Sediment Types

The uppermost Tilston Beds contain nodular to enterolithic anhydrite which displaces surrounding patterned, pink to red, microcrystalline dolomite (Plate 1). These evaporites resemble ones forming in modern sabkha sediments (Evans et al., 1969; Kinsman, 1969; Shearman, 1978), and a similar supratidal origin is postulated. The supratidal sediments of the Tilston Beds range from 1 to 5 m in thickness throughout the study area.

Locally, anhydrite nodules from the Tilston Beds are calcitized ($CaSO_4$, has been replaced by $CaCO_3$); the distribution of calcitized nodules is presented in Fig. 2. Calcitized nodules are recognized by their opaque white colour which contrasts markedly with the transluscent blue-greys of unaltered anhydrite. The full range of replacement textures, from unaltered to wholly calcitized nodules, is shown in Plate 1 and can be seen in many other cores.



After L. Fuzesy, 1960

Figure 1 – Mississippian stratigraphic chart for southeast Saskatchewan.

Microscopic examination of calcitized nodules reveals relic rectangular cleavage traces (which correspond to the tabular habit of the precursor anhydrite) in an otherwise nondescript calcite mosaic texture. This is similar to features described by Shearman and Fuller (1969) from the Middle Devonian Winnipegosis Formation of Saskatchewan. Scanning electron photomicrographs show lath-shaped calcite pseudomorphs after anhydrite (Plate 2). Traces of hydrocarbons are present on a few crystal faces.

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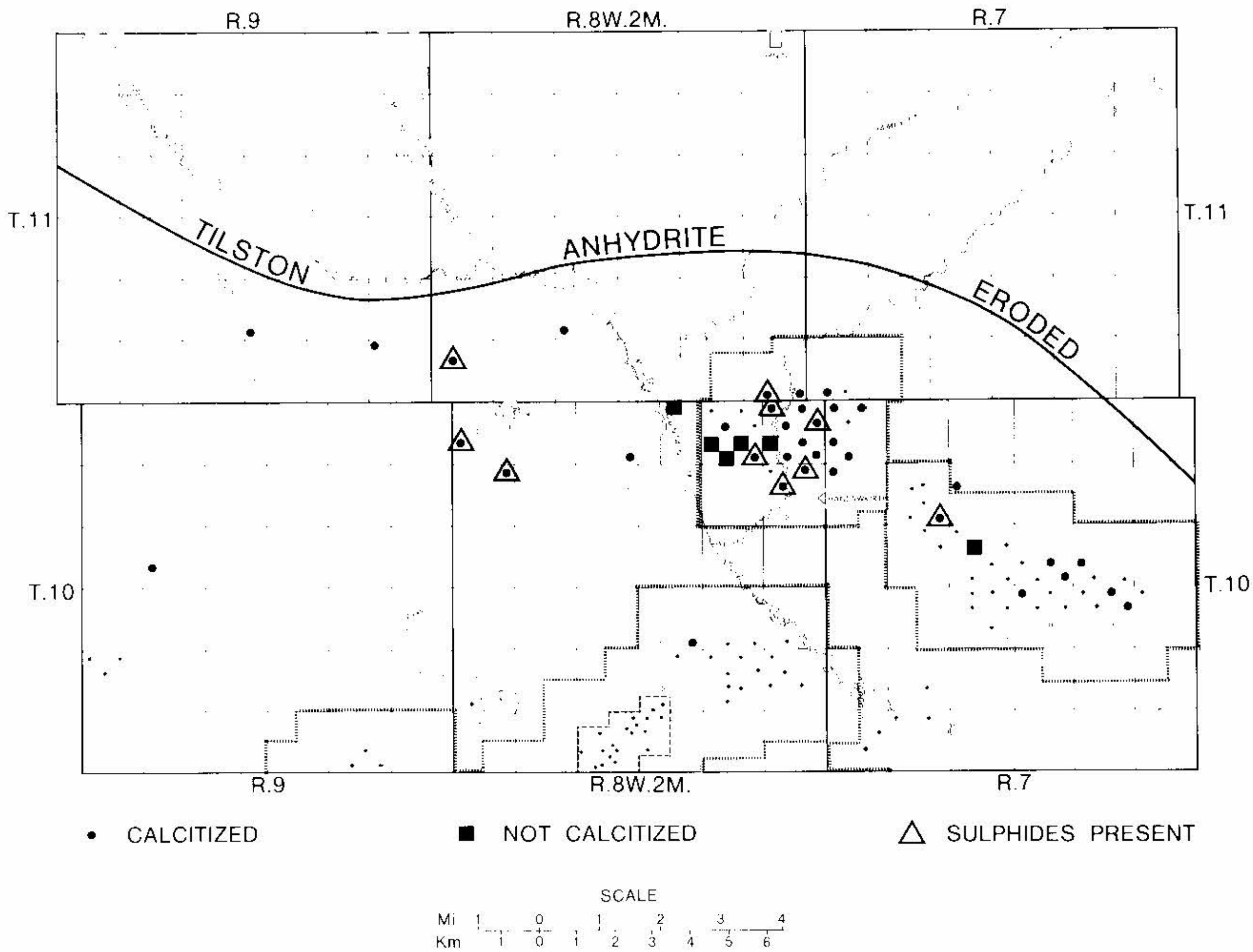

Figure 2—Distribution of calcitized anhydrite and associated sulphide mineralization within the study area.

The patterned dolomite interbedded with the evaporites is similar to features described by Dixon (1976), Kendall (1977) and Elliott (1982). This patterned texture results from the dissolution of ephemeral evaporites at or very near the sabkha surface during rainy seasons. The colour variations result from the weathering of insoluble residues or of disseminated sulphides which formed by the reduction of original sulphates (Kendall, 1977).

Minor amounts of galena, sphalerite and possible marcasite occur in the outer portions of calcitized nodules, but not in the unaltered nodules. Sulphide mineralization is attributed to the local activity of sulphate-reducing bacteria. A similar process is detailed by Harwood (1980) to account for sulphides associated with calcitized anhydrite nodules in Permian carbonates of England.

Several calcitized nodules are surounded by a "rind" of ferroan dolomite which, in some cores,has been oxidized to give it a deep red hue. The presence of ferroan dolomite suggests that a localized reducing environment surrounded at least some of the calcitized nodules.

Model for Calcitization

A three-stage model to account for the calcitization of anhydrite nodules in the Tilston Beds is proposed (Fig. 3).

Stage 1: Deposition of Tilston carbonates took place in the shelf-marginal zone. Shoaling produced carbonate buildups of bioherms and/or ooid sand bodies which created local positive topographic features on the sea-floor. A normal marine faunal assemblage was present.

Stage 2: As the Tilston sea regressed, the carbonate build-ups may have remained as isolated islands in a generally restricted marginal sea

Plate 1—Core slab showing relationship of calcitized nodules (ca) to unaltered anhydrite nodules (anh) and patterned dolomite (pd).

Plate 2—SEM micrograph of lath-shaped calcite pseudomorphs after anhydrite precursor. Note hydrocarbon residue on crystal faces (arrow).

whose waters were most likely anoxic, allowing the survival of few organisms. Sabkha sediments, consisting of nodular to enterolithic anhydrite interbedded with mottled dolomite, prograded across the shelf interior and filled local topographic depressions.

Stage 3: Meteoric water was introduced onto the sabkha surface during rainy seasons. This water percolated through the carbonate build-ups (which protruded through much of the sbkha sediments) and dissolved $CaCO_3$ to cause minor karsting in the carbonate bodies.

Groundwater enriched with CO_3^{2-} moved down the gentle regional dip and entered laterally equivalent sabkha sediments. These fluids, in the presence of sulphate-reducing bacteria, caused calcitization of anhydrite and sulphide mineralization according to the reaction:

$$CaSO_4 + (Pb,Zn)SO_4 + (H_2 + CO_2) \rightarrow CaCO_3 + (Pb,Zn)S + H_2O + H_2S$$

The zone of calcitization is therefore found down-dip and, to a lesser extent, laterally to the carbonate build-ups. As the CO_3^{2-} in the groundwater is used up, the process decreases in intensity.

Implications of the Model

The most significant aspect of calcitized anhydrite is its potential use in hydrocarbon exploration. For example, Fig. 4 shows a fairly typical Williston Basin stratigraphic trap. A permeability decrease is formed by the pinch out of a more permeable carbonate build-up (bioherm or ooid shoal) against less permeable lime muds. Where the sequence is capped by dense evaporites, its reservoir potential is high. These build-ups are very difficult to map in the subsurface, even using the most sophisticated seismic techniques. The presence of calcitized anhydrite in a well may thus provide the explorationist with an indication of a nearby build-up, and a potential oil pool. Subsequently, the development geologist may use the limits of extent of calcitized nodules to help define pool boundaries during delineation drilling.

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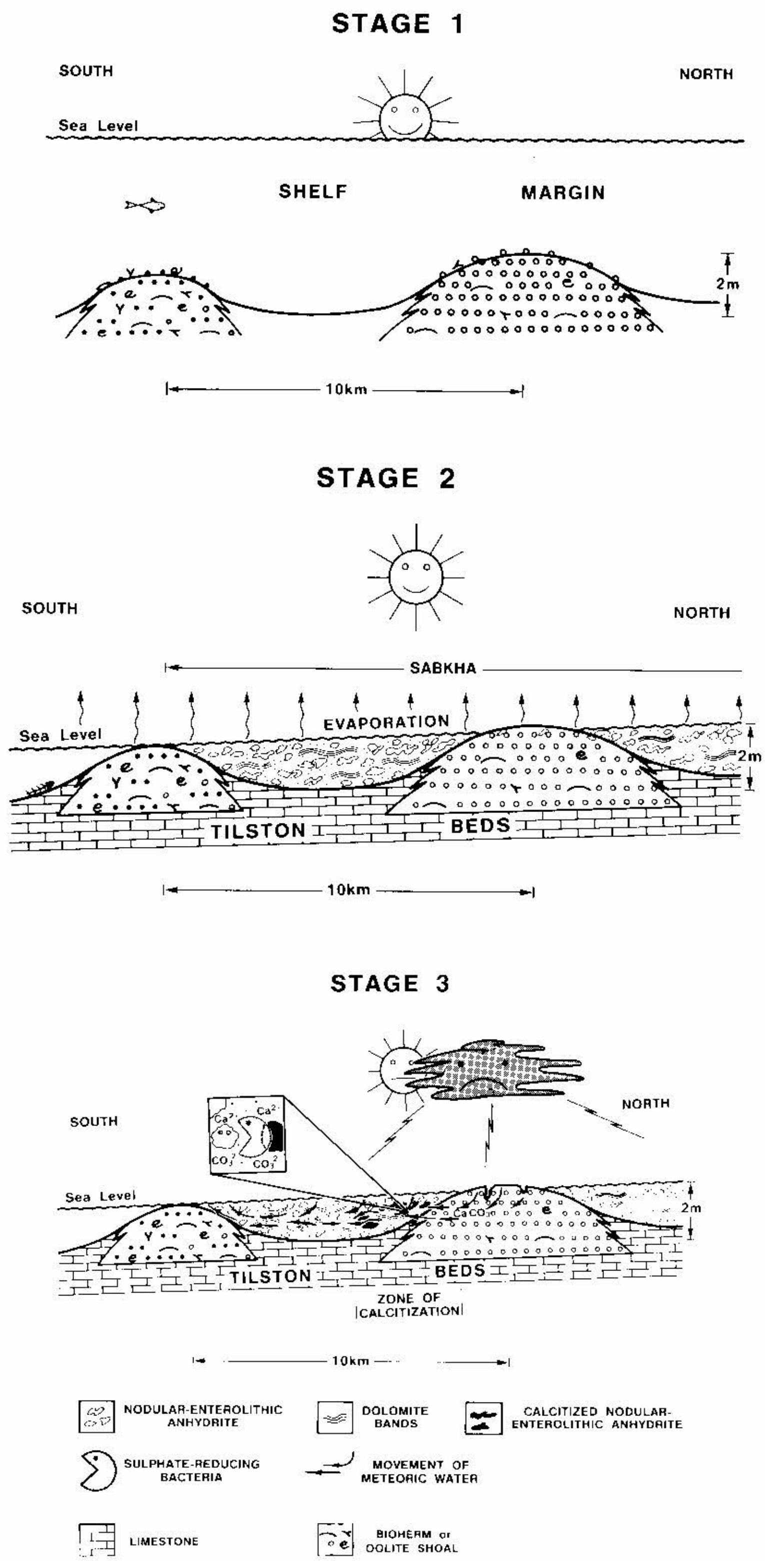

Figure 3—General calcitization model:
a) Stage 1: Normal marine shelf margin carbonate sedimentation. Bioherms and/or oolite shoals form local relief on sea floor.
b) Stage 2: Progradation of sabkha sediments over marine carbonates.
c) Stage 3: Influx of meteoric water during rainy seasons; recharges through carbonate build-ups penetrating sabkha surface and calcitizes laterally equivalent anhydrite nodules in association with sulphate-reducing bacteria.

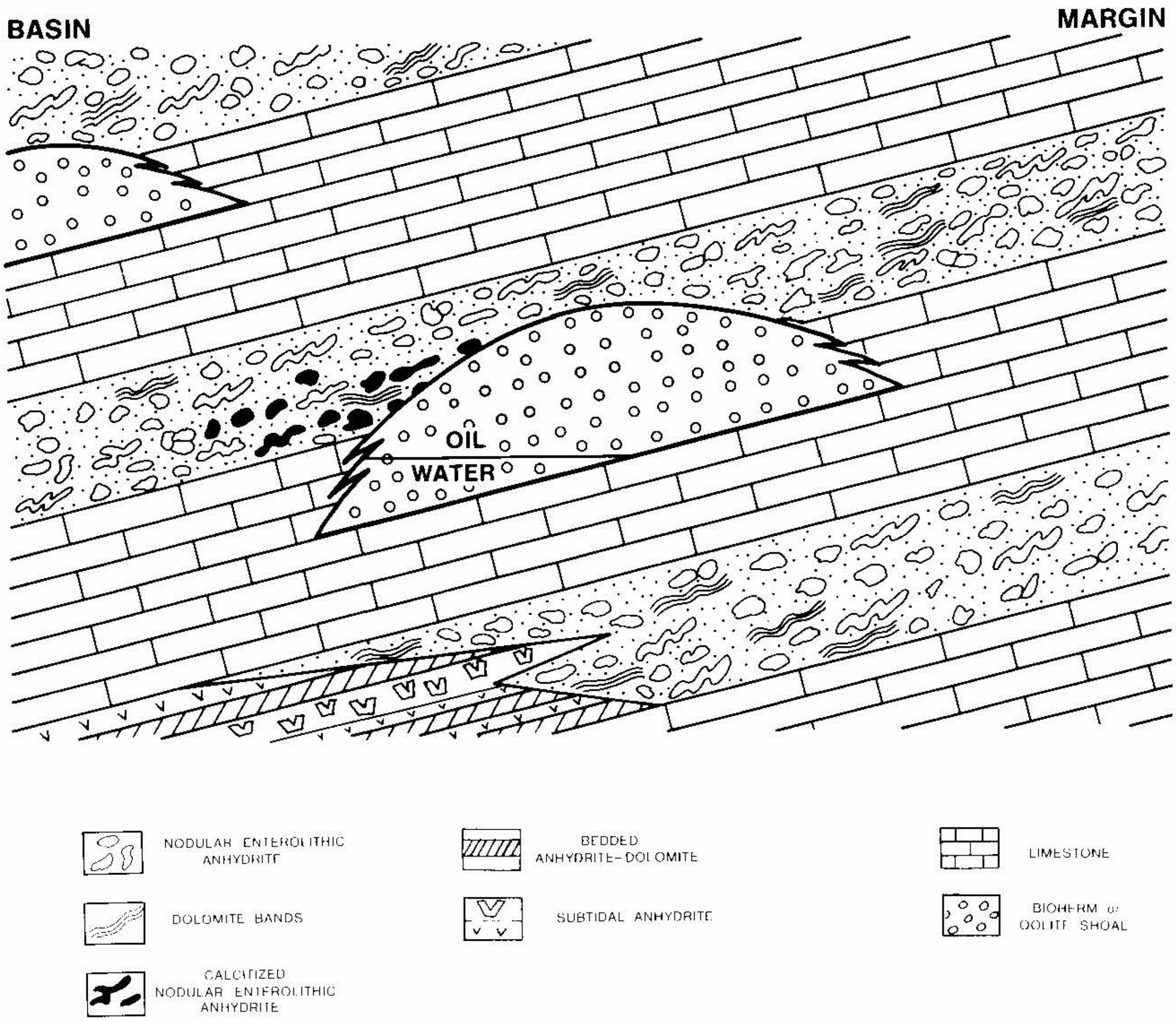

Figure 4—Typical stratigraphic trap found in the Williston Basin.

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