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Rapidly changing styles of subsidence inferred from a high-resolution allostratigraphic study of Coniacian mudstones in southern Alberta and northwestern Montana

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Summary

A high-resolution allostratigraphic study of the Muskiki Member in southern Alberta reveals subtle yet regional bevelling unconformities that allow the member to be divided into three main packages, each of which was deposited under a different tectonic regime. The lower and middle packages thicken to the NW and SW respectively and indicate flexural subsidence that is a typical response to loading by Cordilleran thrust sheets. The upper package forms a NW-trending trough-shaped structure that thickens to the SE, and can not be explained by Cordilleran loading. This unusual subsidence pattern is tentatively attributed to syn-depositional extension on deep-seated normal faults that formed a surficial trough through forced folding of surficial strata. Muskiki isopach patterns show correspondence with aeromagnetic lineaments and faults mapped in regional seismic surveys, suggesting some genetic link. Although the study area embraces the Bow Island arch and Kevin-Sunburst Dome, which influenced sedimentation during Santonian and Campanian time, strata of the Muskiki Member show no evidence that these structures influenced sedimentation during the Coniacian.

Introduction

The mudstone-dominated Muskiki Member in southern Alberta represents the lowermost member of the Upper Cretaceous Wapiabi Formation, and was deposited in a shallow marine, storm dominated setting. A detailed correlation of Foothills outcrop sections to the subsurface is demonstrated for the first time. The Muskiki Member is broadly equivalent to the Verger Member of the southern Alberta Plains, and to the lower and part of the middle Kevin Member of the Marias River Shale Formation in northwestern Montana. The Muskiki Member unconformably overlies the Cardium Formation, the contact marked by the 'E7' surface. The Muskiki Member grades upward into silitier sediments of the overlying, Upper Coniacian Marshybank Member. Across much of the study area however, the Marshybank Member is thin or absent in outcrop and subsurface, and siltstones of the Dowling Member unconformably overlie the Muskiki strata instead.

The study area embraces parts of the Bow Island Arch and the Kevin-Sunburst dome; both structures have been shown to have influenced sedimentation during Santonian and Campanian time. However, our high-resolution allostratigraphic study found no evidence that either of these two areas of uplift had any effect on sedimentation in Coniacian time. Instead, there is evidence for a linear zone of localised subsidence in the ?Upper Coniacian that may be related to extensional faulting in the basement rocks.

Methods

The Muskiki Member was subdivided allostratigraphically by tracing marine flooding surfaces and unconformities through a grid of more than 700 geophysical well logs distributed over an area of ~60,000 km^2. Allomembers in subsurface range from 3-15 m in thickness, and permit a very high resolution stratigraphic analysis of the Muskiki Member. Well log signatures were calibrated using sedimentological and biostratigraphic data from 14 outcrop sections and eight cores. Isopach maps, from which subsidence patterns were deduced, were constructed using the Golden Software SURFER® mapping program.

Results

Regional Subsidence Patterns

High resolution allostratigraphic analysis of the Coniacian Muskiki Member in southern Alberta shows that overall, the member is a southwestward thickening wedge of sediment, thinning from ~120m in the southwest to ~30m in the northeast. The Muskiki Member is divided into three main packages by four regional erosional surfaces, the lower and upper of which show evidence for subaerial emergence. Each of the four erosion surfaces (here designated E7, ME1, ME7 and DE1 in ascending order) demonstrates subtle yet persistent bevelling of underlying strata, indicative of basin tilting and wave planation in shallow water.

Isopach maps for the lower (E7-ME1) and middle (ME1-ME7) packages of the Muskiki Member show wedges of mudstone that thicken to the NW and to the SW, respectively. The anti-clockwise movement of flexural subsidence patterns between the two packages is attributed to a shift in the locus of activity in the growing accretionary wedge. The upper package (ME7-DE1) is dominated by a NW-SE trending elongate trough that thickens south-eastward and is filled with eastward accreting mudstone clinothems. Mudstone clinothems toplap against the DE1 surface and suggest deposition in a subaqueous delta, comparable to modern subaqueous deltas in the Adriatic Sea (Cattaneo et al., 2007). Thin sections from core show that silt sized aggregates of clay can be recognized, as well as siliceous silt grains. Mud is interpreted to have been transported as bedload by storm-generated geostrophic currents. None of the three main packages comprising the Muskiki Member, nor their component allomembers, appear to have been influenced by syn-depositional movement on the Bow Island arch or the Kevin-Sunburst dome. Both antiforms are located within the study area and have previously been shown to have influenced sedimentation patters during Santonian and Campanian time.

Extensional Faulting and Basement Structures

Superimposition of the isopach map of the lower Muskiki package on the regional aeromagnetic map shows subtle thinning of strata northward across the Vulcan Structure, in agreement with similar trends observed in underlying Cardium Formation units (Shank and Plint, 2011). The isopach map of the middle package however shows no relationship to the Vulcan Structure; instead, the middle package shows abrupt south-westerly thickening about a NW-trending hinge zone that bounds the SW margin of a prominent aeromagnetic low. The NW-SE trough in the upper package correlates well with a prominent aeromagnetic low in the Precambrian basement (Pilkington et al., 2000), which is bounded to the northeast by a southwest dipping Archean crustal shear zone (Lemieux et al., 2000). Late Cretaceous extensional reactivation of Precambrian fault(s) or shear zones, has been previously revealed by seismic profiles (Lemieux, 1999). We postulate that extensional reactivation of the principal Archean shear zone may have led to forced folding in surficial strata, making a linear sag that filled with eastward-accreting mudstone clinothems deposited in a few tens of metres of water.

Biostratigraphy

Inoceramid bivalves and ammonites collected from various outcrops in Alberta and northwestern Montana show that most of the Muskiki Member was deposited during late early Coniacian to late middle Coniacian time. At one outcrop in Montana, upper Coniacian strata are represented by only about 4 m of rock, and this package thins and pinches out when traced northward into Alberta. Over most of southern Alberta, upper Coniacian strata appear to be absent. However, north of about township 47, upper Coniacian strata, represented by the Marshybank Formation, reappear and thicken to about 50 m (Plint, 1990). It appears that, following deposition of the middle Coniacian Muskiki Member within the study area, the locus of Cordilleran loading, and sedimentation, shifted ~500 km to the north. At this time, southern Alberta lay beyond the flexural moat and in consequence, accommodation for sediment was minimal. This late Coniacian depositional hiatus is represented by the Muskiki-Dowling unconformity ‘DE1’, above which appear early Santonian faunas.

Conclusions

Mudstone of the Coniacian Muskiki Member show evidence for deposition on a shallow, storm influenced ramp, with mud transported as bedload in the form of mud floccules. A new high resolution allostratigraphy of the Muskiki Member in southern Alberta reveals rapidly changing subsidence patterns that divide the member into three main packages, bounded by four regional bevelling unconformities. The two lower packages show that subsidence was dominated by the flexural effect of static loading by Cordilleran thrust sheets. The upper package is best explained in terms of forced folding above extensionally-reactivated fault(s) in the Precambrian basement. Subtle but regionally-traceable flooding surfaces within the Muskiki Member may reflect subtle eustatic fluctuations on a timescale of < 100 kyr that punctuated tectonic events that operated for 100’s of kyr.

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