geoconvention
Calgary • Canada • May 13-17 2019

Evolving coastal and alluvial systems, subsidence patterns, and eustatic changes in SW Alberta during the Late Albian and earliest Cenomanian

Slavena Galić and A. Guy Plint
Department of Earth Sciences, The University of Western Ontario

Problem

This study addresses the problem of establishing temporal relationships between marine and alluvial rocks. The study is focussed on the Late Albian and earliest Cenomanian rocks of the Lower Colorado Group, embracing the marine Basal Colorado, Joli Fou, Viking, Westgate and Fish Scales formations, the deltaic/marginal marine Bow Island Formation, and the marginal marine to alluvial Mill Creek formation. If the depositional history, and controls on accumulation of these rocks is to be understood in any detail, it is necessary to establish time lines, in the form of natural stratal discontinuities, that can be mapped from offshore marine to alluvial environments.

Background

It has long been recognized that two broad cycles of sea-level change are recorded by Late Albian shallow-marine strata deposited across the Western Canada Foreland Basin in southern Alberta and Saskatchewan. An unconformity spanning the Middle Albian separates the early Late Albian Basal Colorado Sandstone and Joli Fou mudstone from underlying Early Albian non-marine strata of the Mannville Group. The Basal Colorado and Joli Fou strata record overall relative sea-level rise whereas overlying Viking sandstones are broadly regressive (e.g. Stelck et al. 1956; Stelck 1958; Banerjee, 1991; Banerjee et al. 1994; Leroux, 2000). The succeeding Westgate mudstones record a second transgressive event, terminated by sea-level fall in the earliest Cenomanian when the regional Base Fish Scales unconformity was formed (Bloch et al. 1993). This relatively simple succession of transgressive and regressive units becomes progressively more difficult to recognize in SW Alberta where Joli Fou and Westgate mudstones pass laterally into sandstone-rich deltaic facies, thus becoming difficult to differentiate from sandy, marine Basal Colorado and Viking facies. Rocks in this transitional region are ascribed to the lithostratigraphic Bow Island Formation (Glaister, 1959; Cox, 1993; Pedersen et al. 2002). In the most westerly subsurface, and continuing into Foothills outcrop, Bow Island strata grade laterally into marginal marine bay, lake, and alluvial facies, collectively mapped as the Mill Creek Formation (Mellon, 1967). McCarthy et al. (1997) and Leckie and Burden (2001), divided the Mill Creek Formation into a brackish-water, wave-influenced marginal-marine Lynx Creek Member and an overlying, alluvial Bruin Creek Member. The stratigraphy of the Bruin Creek Member is complicated by intercalations of re-sedimented volcaniclastic rocks of the Crowsnest Formation (Peterson et al. 1997).

These well-established lithostratigraphic units provide an adequate basis for mapping broad depositional environments on a timescale of 1-2 Myr. They do not, however, provide the temporal resolution necessary to reconstruct evolving paleogeography or patterns of tectonic subsidence and/or uplift on time-scales of the order of 100- to 200 kyr. To achieve this degree of stratigraphic resolution, it is necessary to employ an allostratigraphic approach, based on mapping stratal discontinuities (principally composite subaerial unconformities/marine flooding surfaces). Such an allostratigraphic scheme was initially proposed by Boreen and Walker (1991), and subsequently elaborated by Roca et al. (2008) for Late Albian and Early Cenomanian rocks in western Alberta. This scheme has subsequently been extended to other parts of the basin (e.g. Angiel, 2013; Morrow, 2017; Vannelli et al. 2017; Plint et al. 2018; Drljepan, 2018). The present study extends the scheme of Roca et al. (2008) southward into

the marginal-marine and alluvial strata of the Bow Island and Mill Creek formations. Regional discontinuities have been traced into marginal-marine and coastal plain rocks, permitting a high-resolution temporal framework to be established.

Method

The study area covers ~43,000 km² between Townships 1 and 24, and Range 6W4 to the Foothills outcrop belt. 2700 gamma ray and resistivity log pairs, typically using three to five wells per township, were compiled into 44 cross-sections, one for each Township and Range. Major allostratigraphic bounding surfaces (subaerial unconformities/flooding surfaces) were traced southward from the study areas of Roca et al. (2008) and Drljepan (2018), to define the boundaries of the Joli Fou, Viking, Westgate and Fish Scales alloformations, and their component allomembers. A southward-thickening wedge of Basal Colorado strata was also recognized and mapped using the same principles. Allomembers are composed of several smaller-scale parasequences that were mapped wherever reliable correlation could be established. Bounding surfaces were systematically correlated in loops throughout the grid to ensure a consistent stratigraphy.

Parasequences, allomembers and alloformations were isopached using *SURFER*® software in order to illustrate patterns of accommodation at different temporal scales. The thickness of 'clean' sandstone within each parasequence was also mapped and isopached in order to reconstruct the distribution of nearshore sandstone, and hence map the margins of nearshore sandbodies.

Mill Creek and Crowsnest strata were examined in 18 outcrop sections between Mill Creek in the south and Burnt Timber Creek in the north, and spectral gamma ray logs were made for key sections using an Exploranium GR-130 spectrometer, with readings typically at 1 m intervals, or less. The gamma ray data provided a crucial objective basis for correlation with borehole logs. The location of each outcrop section was palinspastically restored using the most recent structural cross-sections available, and the same technique was used to restore subsurface sections in wells drilled in the fold and thrust belt. Outcrop sections were then correlated, via intervening, thrust-displaced wells, with the regional subsurface stratigraphic framework established in the undeformed area to the east.

Core, selected to provide a representative selection of samples through the main allostratigraphic units, will be examined in the Spring of 2019 in order to calibrate facies interpretations made from wireline logs.

Results

The Basal Colorado alloformation is separated from the underlying Mannville Group strata by the BE0 surface and from the overlying Joli Fou alloformation by the JE0 surface. The Basal Colorado alloformation comprises a westward-thickening wedge of five mappable parasequences comprising progradational, sandier-upward successions, each typically <10 m thick. As a whole, the Basal Colorado alloformation onlaps surface BE0 towards both the east and north, with successively younger parasequences onlapping progressively from SW to NE. In the far SW, the Basal Colorado reaches a maximum thickness of ~40 m. Correlation from logs to outcrop on Mill Creek and Carbondale River shows that the thickness, depositional cyclicity and wave-reworked sandstones of the Basal Colorado alloformation are essentially identical to those that form the Lynx Creek Member of the Mill Creek Formation. Leckie and Burden (2001) presented somewhat ambiguous palynological evidence that the Lynx Creek Member was correlative with the Middle Albian Harmon/Hulcross mudstones, some 800 km distant in NW Alberta. The palynological basis for this conclusion was questioned by Plint et al. (2018). Given the great mappable extent of the Basal Colorado parasequences and the similarity in thickness between outcrop and nearby well logs, it is here concluded that the Lynx Creek Member is the outcrop equivalent of the Basal Colorado alloformation. Towards the north, the Basal Colorado alloformation can be traced in Foothills exposures as a distinctive, northward-thinning package of grey stratified mudstone and sandstone that lack evidence of significant wave action. Simple sand-filled burrows are present, as are dinosaur under-tracks and well-preserved angiosperm leaves, the latter indicative of a Late Albian age. Collectively this evidence suggests deposition as deltaic mouth bars in shallow, fresh to ?slightly brackish water. The northward-thinning seen in outcrop is mirrored by that seen in subsurface. The

Basal Colorado alloformation is therefore interpreted to be represented in outcrop by a lacustrine unit between about Twps. 8 and 29, north of which it laps out. Banerjee (1991) concluded that the Basal Colorado sandstone was exposed on Ghost River, but our regional correlations show that this sandstone is actually the Fish Scales alloformation.

The Joli Fou alloformation is bounded below by surface JE0 and above by surface VE0, and in Twp. 24 consists dominantly of offshore mudstone. However, in the region of Twp. 17, mudstone is increasingly replaced by stacked, sandier-upward successions interpreted to represent prograding deltas. Traced southward to Twp. 1, the Joli Fou becomes progressively more sandstone-rich as nearshore facies thicken. However, southward, the alloformation thickens slightly from ~35 to ~45 m along Rge. 24. Sandier-upward deltaic successions can be traced westward into more 'ragged' log signatures in the outer Foothills, and correlative strata in outcrop are entirely of alluvial aspect.

The Viking alloformation comprises allomembers VA, VB and VD, bounded by surfaces VE0, VE1, VE3 and VE4. Each Viking allomember comprises several, metre-scale parasequences with a complex stacking pattern. All three Viking allomembers show a consistent spatial change in facies, with 'marine' sandier-upward successions predominant in the north, east and south. In the west, a distinctive 'ragged' log signature can be mapped over a broadly triangular area with an east-facing apex centred on ~ Twp. 12 Rge. 22. The 'ragged' log signature is interpreted to correspond to a region dominated by delta-plain deposits, characterized by m-scale lake and bay-fill facies, channel-fills and floodplain deposits. Correlative rocks in outcrop are entirely of alluvial aspect.

From north to south, all Viking allomembers change thickness. For example, in Rge. 24, allomember VA thickens southward from 20 m in Twp. 24 to 30 m in Twp. 1. In contrast, allomember VB is 15 m thick in Twp. 24 but pinches out southward in ~ Twp. 15, such that surfaces VE1 and VE3 merge into a composite unconformity over the southern part of the study area. Similarly, allomember VD thins from 25 m in Twp. 24 to <10 m in Twp. 1. It therefore appears that, during Viking time, the pattern of tectonic subsidence was not consistent.

The Westgate alloformation is bounded by surface VE4 below and BFSM above. Regional correlation (Roca et al. 2008), shows that, in the study area, only the uppermost Westgate allomember, WC is present. Allomembers WA and WB lap out onto VE4 further to the north, and therefore a substantial hiatus separates Westgate WC strata from VD strata. Westgate allomember WC is dominated by marine mudstone in ~Twp. 24, but towards the south, the unit includes several shallow-marine and estuarine sandstone bodies (Pederson et al, 2002). As a whole, the alloformation thickens y towards the south, from <30 m in Twp 24 to ~50 m in Twp. 1. However, internally, the stacking pattern is complex, with lower parasequences thinning northward and upper parasequences thinning and onlapping southward. Traced westward to outcrop, it is evident that the Westgate also thins markedly, and it is completely truncated in the more westerly outcrops, such as Livingstone River and Sheep River. The thickness distribution of the Westgate therefore indicates uplift in the region of the present Foothills, and both subtle subsidence and then uplift in the south.

The Fish Scales alloformation comprises dark mudstones and fine-grained phosphatic sandstones (Pedersen et al. 2002), not well sampled in core, but it has a distinctive, highly radioactive log signature. Traced westward to outcrop, the Fish Scales alloformation is expressed as a few m of fine- to coarse-grained, wave-rippled sandstone interstratified with dark, largely unbioturbated pyritic mudstone. This facies is known locally as the lower 'Barons Sandstone' (Roca et al, 2008), and represents a wave-reworked nearshore deposit. The top of the sandstone is a pronounced flooding surface that correlates northward with the FSU surface, which is a regional downlap surface beneath the middle Cenomanian Dunvegan alloformation. In the south, the FSU surface is a major non-depositional hiatus, probably spanning up to 2 Myr and reflects winnowing over a forebulge peripheral to a major depocentre in the NW (Roca et al. 2008; Plint et al. 2009; Plint et al, 2012). Traced westward across successive thrust slices, sandstone of the Fish Scales alloformation onlaps and pinches out against the underlying surface BFSM.

The entire Late Albian succession is characterized by high-frequency transgressive-regressive sequences, or parasequences, that can be mapped for hundreds of km. The spatial and temporal scale of these depositional packages strongly suggests a high-frequency eustatic control, within the

Milankovitch band. The wedge shape of many allomembers and alloformations also provides evidence of subtle differential tectonic subsidence, upon which a higher-frequency eustatic signal was superimposed. There is, however, no evidence for the development of a major flexural depocentre at any time within the study area.

Conclusions

The Basal Colorado Sandstone is correlative with the Lynx Creek Member of the Mill Creek Formation in outcrop, and represents wave-influence brackish bays in the south, and freshwater lakes in the north. The entire package laps out northward and eastward. The Joli Fou alloformation becomes progressively more sandstone-rich southward, in which direction it thickens subtly. The Viking alloformation comprises sandy deltaic succession over much of the study area, but passes laterally into delta plain and alluvial sediments in the west. Different Viking allomembers show thickening towards both south and north. The Westgate alloformation is represented only by the uppermost allomember, WC, which in Twp. 24 is dominantly marine mudstone but, but which towards the south contains an increasing proportion of shallow- and marginal-marine sandstone. Parasequences within the Westgate also thicken both towards the south and north. The Westgate onlaps and pinches out westward within the Foothills deformed belt. The Fish Scales alloformation comprises fine-grained phosphatic marine sandstone and mudstone in the east, passing westward into coarse-grained granular sandstones and dark pyritic mudstones in the Foothills. These sandy packages onlap and disappear in the western Foothills exposures.

Acknowledgements

We thank the Natural Sciences and Engineering Research Council of Canada, and Husky Energy Inc. for financial support of this research.

References

Angiel, P. J., 2013. Allostratigraphy, sedimentology and paleogeography of the Cretaceous Upper Fort St. John Group (Upper Albian-Lower Cenomanian) in northeastern British Columbia. Unpub. PhD thesis, University of Western Ontario, 402 p.

Banerjee, I.B., 1991. Tidal sand sheets of the Late Albian Joli Fou-Kiowa-Skull Creek marine transgression, Western Interior seaway of North America. In: Smith, D.G., Reinson, G.E., Zaitlin, B.A. and Rahmani, R.A. (eds.), Clastic Tidal Sedimentology. Canadian Society of Petroleum Geologists, Memoir 16, 335-348.

Banerjee, I.B., Ghosh, S.K., Abercrombie, H.J. and Davies, E.H., 1994. An integrated subsurface study of the Mannville-Colorado Group boundary in the Cessford Field, Alberta. Canadian Journal of Earth Sciences, 31: 489-504.

Bloch, J., Schröder-Adams, C., Leckie, D.A., McIntyre, J., Craig, J. and Staniland, M., 1993. Revised stratigraphy of the Lower Colorado Group (Albian to Turonian), Western Canada. Bulletin of Canadian Petroleum Geology, 41: 325-348.

Boreen, T. and Walker, R.G., 1991, Definition of allomembers and their facies assemblages in the Viking Formation, Willesden Green area, Alberta. Bulletin of Canadian Petroleum Geology, 39: 123-144.

Cox, J., 1993, The stratigraphy and sedimentology of the Bow Island Formation, south-west Alberta. Unpub. PhD thesis, University of Aberdeen, 172 p.

Drljepan, M., 2018. Allostratigraphy of the Viking and Joli Fou formations, of the Lower Colorado Group (Upper Albian), central Alberta and Saskatchewan, Western Canada Foreland Basin. Unpub. PhD. thesis, University of Western Ontario, 258 p.

Glaister, R.P., 1959. Lower Cretaceous of southern Alberta and adjoining areas. American Association of Petroleum Geologists, Bulletin, 43:590-640.

Leckie, D.A., and Burden, E.T., 2001. Stratigraphy, sedimentology, and palynology of the Cretaceous (Albian) Beaver Mines, Mill Creek, and Crowsnest Formations (Blairmore Group) of south western Alberta. Geological Survey of Canada, Bulletin 563, 105 p.

Leroux, M.S., 2000, Sedimentological and ichnological characterization of reservoir types in a transgressive systems tract, Cretaceous (Albian) Basal Colorado interval, south-central Alberta. Unpub. MSc. thesis, Simon Fraser University, Canada, 253 p.

McCarthy, P.J., Martini, I.P. and Leckie, D.A., 1997. Anatomy and evolution of a Lower Cretaceous alluvial plain: sedimentology and palaeosols in the Upper Blairmore Group, south-western Alberta, Canada. Sedimentology, 44:197-220.

Mellon, G.B., 1967. Stratigraphy and Petrology of the Lower Cretaceous Blairmore and Mannville groups, Alberta Foothills and Plains. Research Council of Alberta, Bulletin 21, Edmonton, Alberta, 270 p.

Morrow, S.B. 2017.Allostratigraphy, paleogeographic evolution and accommodation controls on the Lower Colorado allogroup in west-central Alberta, Canada. Unpub. MSc thesis, Univ. Western Ontario, 140 p.

Pedersen, K., Schröder-Adams, C.J., and Nielsen, O., 2002. High resolution sequence stratigraphic architecture of a transgressive coastal succession: Albian Bow Island Formation, south-western Alberta. Bulletin of Canadian Petroleum Geology, 50: 441-477.

Peterson, T.D., Currie, K.L., Ghent, E.D., Bégin, N.J. and Beirsdorfer, R.E., 1997. Petrology and economic geology of the Crowsnest Volcanics, Alberta. In: Macqueen, R.W. (ed.), Exploring for minerals in Alberta. Geological Survey of Canada, Bulletin 500, 163-184.

Plint, A.G., Tyagi, A., Hay, M.J., Varban, B.L., Zhang, H. and Roca, X., 2009. Clinoforms, paleobathymetry, and mud dispersal across the Western Canada Cretaceous foreland basin: evidence from the Cenomanian Dunvegan Formation and contiguous strata. Journal of Sedimentary Research, 79: 144-161.

Plint, A.G., Tyagi, A., McCausland, P.J.A., Krawetz, J.R., Zhang, H., Roca, X., Hu, Y.G., Varban, B.L., Kreitner, M.A. and Hay, M.J., 2012. Dynamic relationship between subsidence, sedimentation, and unconformities in mid- Cretaceous, shallow-marine strata of the Western Canada Foreland Basin: Links to Cordilleran Tectonics. In: Busby, C. & Azor A., (eds.), Recent Advances in the Tectonics of Sedimentary Basins, 480-507. Wiley-Blackwell Publishing Ltd., Oxford.

Plint, A.G., Krawetz, J.R., Buckley, R.A., Vannelli, K.M. and Walaszczyk, I., 2018. Tectonic, eustatic and climatic controls on marginal marine sedimentation across a flexural depocentre: Paddy Member of Peace River Formation (Late Albian), Western Canada Foreland Basin. The Depositional Record, 4: 4-58.

Roca, X., Rylaarsdam, J. R., Zhang, H., Varban, B. L., Sisulak, C. F., Bastedo, K., and Plint, A.G., 2008. An allostratigraphic correlation of Lower Colorado Group (Albian) and equivalent strata in Alberta and British Columbia, and Cenomanian rocks of the Upper Colorado Group in southern Alberta. Bulletin of Canadian Petroleum Geology, 56: 259-299.

Stelck, C.R., 1958. Stratigraphic position of the Viking Sand. Journal of the Alberta Society of Petroleum Geologists, 8: 2-7.

Stelck, C.R., Wall, J.H., Bahan, W.G. and Martin, L.J., 1956. Middle Albian foraminifera from Athabasca and Peace River drainage areas of Western Canada. Alberta Research Council, Report No. 75, Edmonton, Alberta, 60 p.

Vannelli, K.M., Plint, A.G., Buckley, R.A., Krawetz, J.R. and Cunningham, C.M., 2017. An allostratigraphic and paleogeographic framework for the Joli Fou and Pelican formations and contiguous strata (Late Albian, Early Cretaceous) in central Alberta. Bulletin of Canadian Petroleum Geology, 65**:** 387-423.