Facies and sequence stratigraphy of two Cambrian grand cycles: implications for Cambrian sea level and origin of grand cycles

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ABSTRACT

The Pika, Arctomys and Waterfowl formations comprise two “grand cycles” as originally defined by Aitken (1966, 1978, 1981). A detailed across-strike facies stratigraphic reconstruction based on measured outcrop sections and subsurface data reveal that the Pika and Waterfowl Formations consist of five transgressive–regressive sequences of subtidal facies and tidal flat facies each up to 100 m thick and some 10^5 to 10^6 years duration. The bulk of the Arctomys Formation consists of terrestrial to marginal marine playa deposits, correlates with an unconformity in the adjacent subsurface, and was deposited during a sea level low stand. The upper third of the Arctomys Formation records a single minor marine transgressive–regressive cycle. Transgressive facies can extend eastward onto the craton up to 1000 km from the platform to slope transition and record local relative increases in sea level of various magnitudes. Maximum transgressive or regressive phases do not necessarily correspond with the bottoms or tops of grand cycles. A sea level curve derived from our facies stratigraphy is different than the curve proposed by Bond et al. (1989) from R2 analysis, and also different to the sea level curve of Montanez and Osleger (1993) for the southern Great Basin.

RÉSUMÉ

Les formations de Pika, d’Arctomys et de Waterfowl comprennent deux “grands cycles” comme Aitken (1966, 1978, 1981) l’a défini initialement. Une reconstruction stratigraphique détaillée des faciès à travers la direction structurale, basée sur des données de mesures de sections d’affleurement et souterraines, révèlent que les Formations de Pika et de Waterfowl sont composées de cinq séquences transgressives–régressives de faciès infralittoraux et de replats de marées, chacune de plus de 100 m d’épaisseur, et qui s’étendent sur un intervalle d’une durée de quelques 10^5 à 10^6 années. La Formation d’Arctomys, en grande partie, se compose de dépôts terrestres à playa marine marginale, est corrélée avec une discordance qui se trouve dans la subsurface adjacente, et s’est formée durant un abaissement du niveau marin. Le tiers supérieur de la Formation d’Arctomys enregistre un seul cycle mineur marin transgressif–régressif. Les faciès transgressifs peuvent se prolonger vers l’est sur le craton au-delà de 1000 km depuis la plateforme jusqu’à la transition de la pente, et ils enregistrent des augmentations relatives du niveau marin de magnitudes diverses. Les phases maximum de transgression ou de régression ne correspondent pas nécessairement avec les bas ou les hauts des grands cycles. La courbe du niveau marin dérivée de notre stratigraphie du faciès est différente de la courbe proposée par Bond et al. (1989) dans l’analyse R2, et elle diffère également de la courbe du niveau marin proposée par Montanez et Osleger (1993) pour la partie au sud du Great Basin.

Traduit par Gabrielle Drivet
INTRODUCTION

The sedimentary record of shallow-marine deposits is the result of the interplay of subsidence, eustatic sea level changes, and sedimentation. Subsidence includes a tectonic component, an isostatic component, and a compaction component. Eustatic sea level changes may involve complex superimposed signals of different amplitude and frequency, particularly during glacial periods as exemplified by the Plio–Pleistocene eustatic record. Sedimentation factors are internal to the depositing system and include previous depositional topography, sediment input, intrabasinal sediment production and sediment distribution pathways. One approach toward separating the effects of subsidence, eustasy, and sedimentation comprises the seismic stratigraphic principles introduced by Exxon Production Research (Vail et al., 1977; Vail et al., 1984; Haq et al., 1987). Bally (1988) provides documentation from seismic lines of many examples of the internal geometry and facies within unconformity-bounded “third-order” (approximately 10^6 year duration) depositional sequences that are the fundamental stratigraphic units of seismic stratigraphy.

Unfortunately, in outcrop, the characteristic truncations of seismic reflectors due to subaerial erosion, onlap, offlap, and toplap that allow identification and interpretation of third-order sequences in seismic lines are not easily observed. Instead, vertical measured stratigraphic sections are divided into facies and constituent subfacies based on sedimentary textures, sedimentary structures, fossils and the like (Hardie and Shinn, 1986; Demicco and Hardie, 1994). Haq et al. (1987) coined the term “sequence stratigraphy”, directly applying the terminology and interpretations of seismic stratigraphy to the facies and subfacies of outcrop measured sections. Their contention was that identification of “sequence boundaries” and the “maximum flooding surface” between two sequence boundaries allowed outcrop sections to be divided into genetic “systems tracts” from which interpretations of sea level history could be obtained. These system tracts were taken to be direct analogs of the onlapping and offlapping packages of seismic reflectors characteristic of sequences in the subsurface. Since the work of Haq et al. (1987) the literature on sequence stratigraphy has grown rapidly (c.f. Posamentier and others, 1993; Emery and Myers, 1996; Kerans and Tinker, 1997; among many others).

One classic North American locality where third-order sequence-scale alternations of subtidal and peritidal facies are exposed in three dimensions at a scale comparable to seismic sections is the Cambrian section of the southern Canadian Rocky Mountains (Aitken, 1966; 1978; 1981). Here, Cambrian and younger rocks are exposed on a number of parallel, eastward-verging thrust sheets. The stratigraphy of Middle to Upper Cambrian deposits of the Western Ranges, Eastern Ranges, Foothills and adjacent plains is shown on Figure 1. The Middle and Upper Cambrian carbonate rocks of the Eastern Ranges and Foothills are alternations of shales and carbonates that are hundreds of metres thick and span 1–2 trilobite zones. Equivalent formations of the Western Ranges are dominantly shales with minor carbonates, and represent

<table>
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<th>WESTERN RANGES</th>
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<th>FOOTHILLS</th>
<th>EASTERN PLAINS</th>
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<td>Lynx Gp</td>
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<td>Bison Creek Fm</td>
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<td>Arctomy Fm</td>
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<td>Pika Fm</td>
<td>Eldon Fm</td>
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<td>L. Chancellor Fm</td>
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<td>Mount Whyte Fm</td>
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Fig. 1. Stratigraphy of the study area. Western Ranges and Eastern Ranges are based on outcrop measured sections. Foothills and Eastern Plains sections are in the subsurface. Large arrows delineate “grand cycles”; see text for details.
off-platform deposits (Aitken, 1966, 1971; 1978; McIlreath, 1971; Bond and Kominz, 1984; Stewart, 1991). The stratigraphy of the Cambrian rocks of the Eastern Ranges and foothills as originally envisioned by Aitken (1966, 1978, 1981) consisted of formations dominantly comprising subtidal shales (Mount Whyte, Stephen, Lower Pika, Arctomys Sullivan and Bison Creek formations) alternating with formations dominantly comprised of peritidal carbonates (Cathedral, Eldon, Upper Pika, Waterfowl, Lyell and Mistaya formations) that he referred to as “grand cycles” (Fig. 1). The direct comparability of grand cycles as envisioned by Aitken, and sequences as described by Vail and his co-workers, is made stronger by two factors. First, the tops of grand cycles are apparently correlative throughout the Cordillera (Palmer, 1981); and second, grand cycles are interpreted to be due to eustatic rises and falls of sea level superimposed over a thermally-subsiding passive margin. Bond et al. (1989) employed a quantitative stratigraphic approach to interpreting Canadian Rocky Mountain grand cycles but came up with substantially the same picture of their significance (Fig. 2). Their “R2” analysis entails comparison of a subsidence-history curve derived from detailed backstripping of vertical measured sections with a “best fit” uniform exponentially decreasing subsidence curve predicted by thermal decay models. Discrepancies between the two curves were interpreted as third-order eustatic events based on their apparent correlation across North America.

We have taken a fundamentally different tack in our studies of two Cambrian grand cycles in the southern Canadian Rocky Mountains: the Pika Formation grand cycle and the Arctomys–Waterfowl formations grand cycle (Fig. 1). These three formations represent approximately 6 million years of deposition (Bond et al., 1989) and the Arctomys Formation–Waterfowl Formation grand cycle is particularly significant, because Bond et al. (1989) use the Arctomys Formation as their datum in North-America-wide correlation of third-order sea level oscillations derived from R2 analysis. However, the Arctomys–Waterfowl grand cycle is “aberrant” (Aitken, 1978; 1981) because unlike the monotonous, fossiliferous, turbidite-bearing, deep water shales that comprise the base of “traditional” Cambrian grand cycles, the Arctomys Formation is noted for its mudcracks, salt casts, lack of fossils, and restricted easterly extent. Indeed, most of the Arctomys Formation represents non-marine playa lake and mudflat deposits (Spencer and Demicco, 1993).

We use detailed measured sections across the disturbed belt to document the facies stratigraphy (Hardie and Shinn, 1986; Demicco and Hardie, 1994) of these two grand cycles. We then interpret the facies in terms of sequence stratigraphy, to reconstruct a sea level history for these formations based on standard sequence interpretations and backstepping relationships of deeper water facies based on the measured sections. Our detailed facies studies suggest that the traditional rock mineralogy boundaries used to identify grand cycles do not directly reflect relative sea level oscillations over this ancient passive margin. Furthermore, the sea level curve we derive for this portion of the Cambrian section is at odds with the curve derived by Bond et al. (1989), and also differs somewhat from the sea level curve of Montanez and Osleger (1993) for the southern Great Basin.

The purpose of this paper is threefold: 1) to document the facies stratigraphy of the Pika and Arctomys–Waterfowl grand cycles; 2) to compare our sequence stratigraphy-based interpretations of grand cycles with those of Aitken (1966, 1978; 1981); and 3) to compare the sea level curve derived from our analysis with the sea level curves of Bond et al. (1989) and Montanez and Osleger (1993).

**FACIES OF THE PIKA AND ARCTOMYS–WATERFOWL GRAND CYCLES**

Figures 3, 4 and 5 are measured sections of the facies that comprise the Pika, Arctomys and Waterfowl formations, respectively. Locations of the measured sections are given on Figure 6. Table 1 gives sedimentologic details of the facies and subfacies that comprise the sections. Further sedimentologic details of the sections, facies and subfacies are given in Waters (1986), Waters et al. (1989), Cloyd et al. (1990), Mason (1990), Demicco et al. (1991), Spencer and Demicco (1993), and Moore (1994). Figure 7 is a simplified cross-strike section of
the Pika, Arctomys, and Waterfowl formations based on details described in the references above that shows correlations of sedimentary facies across the restored depositional strike of the platform and our sequence stratigraphic interpretation (line of section given in Fig. 6). The cross-section extends from the platform-to-basin transition on the west, eastward across the mountain belt and into the subsurface. Aitken (1968) presents subsurface data from this stratigraphic interval.

The Arctomys and Waterfowl formations are present in the Shell Burnt Timber G-26 well, 10 km east of the mountain front. They are 20 m and 34 m thick, respectively (Aitken, 1968). However, in the California Standard East Gilby 4-5 well, 125 km to the east, shales and mudstones of the Sullivan Formation unconformably overlie approximately 90 m of Pika Formation. Drill hole data show rocks correlative with the Pika Formation extend approximately 500 km eastward beyond the mountain front into the subsurface of Saskatchewan (Fig. 8). In marked contrast, the Arctomys Formation and the Waterfowl Formation extend only a few tens of kilometres east of the McConnell Thrust under the Foothills and adjacent plains (Figs. 2, 4). Shales of the Sullivan Formation, the base of the grand cycle overlying the Waterfowl Formation, extend 700 km further eastward into the craton (Aitken, 1968; Pugh, 1971; Van Hees, 1964).

**Interpretation of Cambrian Sea Level History for the Southern Canadian Rocky Mountain Area**

We divide Pika, Arctomys and Waterfowl formations into 5½ sequences (lettered CR-1 through CR-6 on Fig. 7), each with a duration of 10⁴ to 10⁵ years (third-order sequences). Our interpreted positions of sequence boundaries and maximum flooding surfaces are given on Figures 3 to 5. Sequence boundaries are mostly of type 2, and the exact stratigraphic position of sequence boundaries that pass into the Arctomys Formation are problematic. The relative magnitude of the sea level changes represented by the sequences is determined by assessing the eastward extent of the maximum flooding surface and its encasing wedge of subtidal facies. This is similar to the extent of “coastal onlap” measured in seismic stratigraphy. Subtidal facies of sequences CR-2, CR-3, CR-4 and CR-5 variably extend a few tens of kilometres onto the platform. However, if our correlations are correct, the shales that mark the maximum flooding surface in subtidal facies of sequences CR-1 and CR-6 extend hundreds of kilometres to the east. Indeed, the transgressive carbonate subtidal facies of sequence CR-6 is gradational in all exposed sections upward into the deep-water shales of the Sullivan Formation that encase the maximum flooding surface of sequence CR-6.

In some places, peritidal cycle thicknesses are related to position in the sequence. For example, in sequence CR-5 in the Waterfowl Formation the initial transgressive peritidal cycles (overlying the sequence boundary in the underlying playa deposits of the Arctomys Formation) are thin and thicken upwards (Fig. 5). However, in the regressive systems tract of sequence CR-5, there are no systematic cycle thickness changes and the thinnest peritidal cycles simply denote the sequence boundary between sequence CR-5 and CR-6. The peritidal facies at the base of sequence CR-1 in the Pika Formation merge with other tidal flat facies near the mountain front (Fig. 4). This implies either that there is an unrecognized sequence boundary in the subtidal deposits of the Pika Formation in section 8 or that the sequence boundary is in the underlying Eldon Formation.

The bulk of the Arctomys Formation is interpreted as a terrestrial playa based on its lack of fossils and details of its desiccating-upward cycles (Table 1; Spencer and Demicco, 1993). Much of the time represented by the Arctomys Formation is recorded in soils at the top of individual cycles (Spencer and Demicco, 1993). We follow Aitken (1981, p. 10) in interpreting the Arctomys Formation to represent a low stand of sea level where sea level was just at or below the platform and terrestrial deposition obtained.

**Discussion**

Our interpretation of the significance of grand cycles is somewhat different from the original interpretation presented by Aitken (1966, 1978, 1981). Furthermore, our interpretation of sea level history for the Pika Formation and Arctomys–Waterfowl formations grand cycles is at odds with the sea level history presented by Bond et al. (1989; and our Fig. 2, Fig. 9, column A).

**Legend Figures 3-5**

| desiccating-upward playa-lake cycles |
| massive cross-cutting dolomite dikes & pipes |
| mudcracked shales |
| undifferentiated tidal flat deposits |
| shallowing-upward sequence with mudcracked laminit cap |
| - (dashed boundaries = incomplete exposure) |
| shales |
| subtidal ribbon rocks |
| stromatolites |
| grainstone |
| thrombolites |
| flat pebble conglomerate |
Fig. 3. Measured sections of the Pika Formation; section locations given in Figure 6. Interpreted location of sequence boundaries (SB) and maximum flooding surfaces (MFS) are indicated, as are interpreted third-order sea level cycles numbered CR-1 to CR-3. Rock type symbols are given in the legend, and details of rock types are given in Table 1.
The R2 analysis of the Cambrian section in this area by Bond et al. (1989) indicates that the greatest increase in “accommodation potential” (sea level change + subsidence) occurred during deposition of the Arctomys Formation (Bond et al., 1989; their Fig 9, p. 51). Therefore, in their “best fit” sea level curve, they have lowest sea level at the boundary between the Pika and Arctomys formations, with significant sea level rise throughout the Arctomys Formation, culminating in maximum water depth at the contact between the Arctomys and Waterfowl formations. It is not clear from their facies descriptions (Bond et al., 1989, their Table 2, p. 48) what initial water depths were used to compute Arctomys Formation accommodation potential insofar as they did not identify the Arctomys Formation as a mudcracked, cyclic shale-carbonate facies. However, it is apparent from their results that the decompaction of mudstones must be an important factor in their model because all of their “accommodation events” coincide with fine-grained rocks. Pure carbonate formations are not significantly decompacted in their R2 analysis and coincide with reduced accommodation potential. Bond (1990) and Bond and Kominz (1991) correctly point out that the sedimentary facies are unreliable in gauging “accommodation potential” at any location because, if sedimentation rates are high enough, sedimentation can keep up with any “accommodation event”.

Fig. 4. Measured sections of the Arctomys Formation; section locations given in Figure 6. Interpreted location of sequence boundaries (SB) and maximum flooding surfaces (MFS) are indicated as are interpreted third-order sea level cycles numbered CR-3 (top portion) and CR-4. Rock type symbols are given in the legend, and details of rock types are given in Table 1.
Fig. 5. Measured sections of the Waterfowl Formation; section locations given in Figure 6. Interpreted location of sequence boundaries (SB) and maximum flooding surfaces (MFS) are indicated as are interpreted third-order sea level cycles numbered CR-5 and lower portions of CR-6. Rock type symbols are given in the legend, and details of rock types are given in Table 1.
However, it is exactly these local sedimentation effects that large, cross-strike sections of facies reconstructions are designed to identify and avoid.

Any large-scale sea level rise over a stable platform must result in depositional backstepping onto the craton even though the facies deposited may not be easily predictable. This is exactly the case for the Pika Formation. Tidal flat cycles and undifferentiated tidal flat deposits extend to the western margin of the platform at the top of the Eldon Formation or base of the Pika Formation. A relative sea level rise resulted in deposition of subtidal sediments across the entire width of the platform — transgressive subtidal systems tract of sequence CR-1 in Figures 3 and 7. Similar depositional backstepping occurs for each subtidal core of sequences CR-1 through CR-6 in Figure 7. We interpret the variable widths of the subtidal facies wedges as the result of variable magnitudes of relative sea level rises. Sea level rise during deposition of the Pika Formation and the Sullivan Formation resulted in deposition many hundreds of kilometres back from the platform edge. Subtidal facies in sequences CR-3 (upper Pika Formation), CR-4 (upper Arctomys Formation) and CR-5 (middle Waterfowl Formation) extend only a few tens of kilometres onto the platform indicating lesser relative sea level rises.

Bond (1990) and Bond and Kominz (1991) suggested that the Arctomys Formation at one time extended hundreds of kilometres onto the craton, but that its present thinning and restricted easterly extent are the result of erosion associated with an unconformity at the top of the Waterfowl Formation. However, the Arctomys Formation thickness decreases tenfold (from 170 m at section 5 to 17 m at section 9) beneath the Waterfowl Formation and is clearly not removed by an unconformity at the top of the Waterfowl Formation. Indeed, measured sections of the facies changes across the Arctomys–Waterfowl Formation contact show that these facies preserve transitional sedimentary environments.
Fig. 7. Facies and interpreted sequence stratigraphy of the Pika and Arctomys–Waterfowl grand cycles (see Fig. 6 for section locations and line of section). Playa-lake cycles comprise the Arctomys Formation, marine carbonates of the Pika Formation below and Waterfowl Formation above. CR-1 through CR-6 denote inferred sequences. Interpreted sea level curve is on the left; the dashed portion indicates sea level off platform with subaerial deposition of playas and playa lakes on the platform.
The thinning of the Arctomys Formation is clearly depositional and not the result of erosion at the end of deposition of the Waterfowl Formation.

In his original grand cycle interpretation of the Cambrian formations of the Canadian Rockies, Aitken (1966, 1978, 1981) places an unconformity at the top of each carbonate formation. Moreover, the sea level curve of Bond et al. (1989) indicates minimum water depths at the top of both the Pika and Waterfowl formations. Our measured sections show that there is no unconformity between the Pika and the Arctomys formations, nor between the Waterfowl and Sullivan formations. Rather, the facies from the Waterfowl Formation into the overlying Sullivan Formation shales are transitional and preserve an overall general deepening of paleoenvironments. The contact between the Pika Formation and the overlying Arctomys Formation is likewise transitional with respect to depositional environments but in this case the facies record the change from supratidal to terrestrial paleoenvironments. In fact, wherever we have examined the vertical change from one grand cycle to another (Mount Whyte–Cathedral to Stephen–Eldon, Stephen–Eldon to Pika, Pika to Arctomys–Waterfowl and Arctomys–Waterfowl to Sullivan–Lyell) we have found transitional paleoenvironments.

Aitken (1966, 1978, 1981) originally defined grand cycles on the basis of rock type (shale versus carbonate). Aitken interpreted each grand cycle as the result of one cycle of sea level rise and fall where the shale represented transgressive deposits and the carbonates, regressive deposits. Our facies and their sequence stratigraphy interpretations suggest that grand cycles are actually composites of transgressive–regressive cycles with duration on the order of 10^5 to 10^6 years. Furthermore, maximum transgressive or regressive phases do not necessarily correspond with the bottoms or tops of grand cycles. Aitken envisioned a carbonate-rimmed platform with tidal flats prograding shoreward from west to east over a subtidal lagoon. Our observations suggest a different system of ramp-like configuration with tidal flat progradation from shoreward positions in the east toward a deeper basin on the west (also see Waters, 1986).

**Comparison with the Southern Great Basin**

The trilobite biostratigraphy of the stratigraphic interval examined here is quite problematic (Fig. 9). The base of the Pika Formation is about at the base of the *Bolaspidella* trilobite zone (Palmer, 1981; Aitken, 1997). The position of the top boundary of the *Bolaspidella* trilobite zone and the overlying *Cedaria* trilobite zones in the southern Canadian Rocky Mountain sections is problematic due to the unfossiliferous nature of both the Arctomys Formation and the Waterfowl Formation in the region. Palmer (1981) and Aitken (1993) place the base of the *Cedaria* zone within the upper Waterfowl Formation. The Sullivan Formation, which overlies the Waterfowl Formation, comprises the *Cedaria* and *Crepicephalus* trilobite zones (Aitken, 1993).

Montanez and Osleger (1993) and Montanez et al.(1996) deduced a sea level curve for the Middle to Upper Cambrian platform carbonates from the southern Great Basin in Nevada and California which is displayed in column C of Figure 9 for comparison to our inferred sea level curve. Their approach to sea level interpretation was much the same as ours, but
Table 1. Description and interpretation of facies and constituent subfacies.

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<th>Facies</th>
<th>Description of Subfacies</th>
<th>Interpretations</th>
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<tbody>
<tr>
<td>SUBTIDAL SILICICLASTIC FACIES</td>
<td>Fissile gray shale</td>
<td>Bioturbated, subtidal siliciclastic mud deposited below photic zone</td>
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<tr>
<td></td>
<td>Decimetre graded beds of ooids with climbing, small-scale cross-stratification and/or parallel lamination</td>
<td>Turbidites of ooids shed off platform margin or ramp shoals developed to the east</td>
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<tr>
<td>SUBTIDAL CARBONATE FACIES</td>
<td>Ribbon rocks: interbeds of peloidal fine-grainstone with wavy lamination and dolomitic mudstone, both with variable amounts of bioturbation disruption</td>
<td>Shelf storm (grainstones) and fair-weather (mudstones) deposits</td>
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<td></td>
<td>Thrombolites: decimetre to metre-thick bioherms imbedded in other subfacies that can contain finger-size clots with vague stromatolitic textures rarely encrusted with Renalcis and other problematic microfossils</td>
<td>Subtidal cryptomicrobial bioherms</td>
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<td>Flat pebble conglomerates composed of reworked clasts of grainstone or mudstone</td>
<td>Storm lag deposits</td>
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<td>Cross-stratified grainstones: commonly peloidal with large-scale cross-stratification, metre-wide channels or beach cross-laminae</td>
<td>Shoals with channels and exposed beach bars</td>
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<tr>
<td>TIDAL FLAT CYCLES (1–5 m thick)</td>
<td>Conglomeratic grainstones in thin beds with parallel laminae or imbrication</td>
<td>Lags at the base of cycles recording flooding over existing hardened surface</td>
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<td>Mudcracked ribbon rocks: wavy and lenticular interbeds of peloidal fine grainstones and mudcracked dolomitic mudstones</td>
<td>Lower intertidal flats</td>
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<td>Prism-cracked laminites with crinkled and wavy laminae geometries</td>
<td>Upper intertidal flats</td>
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<td>UNDIFFERENTIATED TIDAL FLAT CYCLES</td>
<td>Up to tens of metres of mudcracked planar to wavy laminated mudstone with thin interbeds of peloidal grainstone: no recognizable shallowing-upwards cycles</td>
<td>Tidal flats or tidal flat wash-over complexes</td>
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<tr>
<td>PLAYA LAKE DEPOSITS</td>
<td>Grainstones with parallel lamination or wave ripple cross-stratification, rare rip-up conglomerates</td>
<td>Perennial lakes, some saturated with carbonate, others siliciclastic filled</td>
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<td>Thin beds that become increasingly disrupted by mudcracks up section</td>
<td>Aggrading playas</td>
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<td></td>
<td>Brecciated mudstones with &quot;crumb&quot; fabrics</td>
<td>Long-duration exposure soils on playas</td>
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employed Fischer Plots as well as sequence analysis. They correlated facies from sections measured across a 250 to 300 kilometre-wide platform within the Banded Mountain Member of the Bonanza King Formation. These sections ranged in thickness from about 1300 m toward the western platform margin to about 400 m on the eastern edge.

Correlations between our sea level curve and Montanez and Osleger’s (1993) sea level curve are difficult. Palmer (1981) places the base of the *Bolaspidella* trilobite zone at the base of the Banded Mountain Member of the Bonanza King Formation whereas Montanez and others place the base of the *Bolaspidella* trilobite zone in the Banded Mountain Member as shown in Figure 9. However, this assignment leaves only sea level cycle BM-5 and the unnumbered rise over it to span the entire *Cedaria* and *Crepicephalus* trilobite zones as the Nopah Formation above the Bonanza King member contains the *Aphelaspis* trilobite zone (Palmer, 1981). As in the southern Canadian Rocky Mountains, the exact stratigraphic position of contacts among these trilobite zones is not known in the southern Great Basin. From the discussion above, it seems likely that more third-order sea level oscillations are preserved in the Pika, Arctomys and Waterfowl formations than in equivalent portions of the Banded Mountain Member of the Bonanza King Formation. In fact, the entire Arctomys Formation, and most of the Waterfowl Formation, (nearly an entire “Grand Cycle”) are apparently absent in the southern Great Basin. (Preliminary C, O, and Sr isotope data from work in progress by C. Augereau and R.J. Spencer are consistent with this interpretation.)

**CONCLUSIONS**

The Pika and Waterfowl formations comprise transgressive-regressive sequences of subtidal facies and tidal flat facies up to 100 m thick that are $10^2$ to $10^3$ years duration. Transgressive facies extend eastward onto the craton up to 1000 km from the platform-to-basin transition, and represent local relative increase in sea level of various magnitudes.
The bulk of the Arctomys Formation consists of terrestrial to marginal marine playa deposits, correlates with an unconformity in the adjacent subsurface, and was deposited during a sea level low stand.

During Pika, Arctomys and Waterfowl formation deposition, the platform probably did not have a raised rim and cycles prograded from east to west. In addition, grand cycles are actually composites of transgressive–regressive cycles with duration of the order of 10^3 to 10^4 years, and maximum transgressive or regressive phases do not necessarily correspond with bottoms or tops of grand cycles.

The sea level curve derived from observations 1 and 2 is substantially different from the curve proposed by Bond et al. (1989) from R2 analysis.

The sea level curve derived from observations 1 and 2 is similar to that of Montanez and Osleger (1993) and Montanez et al. (1996) for the southern Great Basin. However, the Arctomys–Waterfowl “Grand Cycle” does not appear to be present there.

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