Significance of Middle Cambrian mixed carbonate-siliciclastic units for global correlation: southern Nevada, USA

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Abstract

Sequence-stratigraphic analysis of the Middle Cambrian Highland Peak, Bonanza King, Swasey, and Wheeler formations in the Great Basin refines platform-to-basin correlations and distinguishes local tectonic events from eustasy. This analysis provides a reliable sea-level history through the \textit{Ptychagnostus gibbus} and \textit{Ptychagnostus atavus} trilobite intervals and confirms that the Global Stratotype Section and Point (GSSP) at the first appearance datum (FAD) of \textit{P. atavus} was deposited during an overall sea-level rise. Deposition during the Middle Cambrian \textit{Ehmaniella}/\textit{Bolaspidella} biozones in the western U.S. is represented by two lithologically distinct successions: (1) a poorly fossiliferous, shallow-water, mixed carbonate-siliciclastic succession that is widespread across southern Nevada and southeastern California and (2) a highly fossiliferous, deeper water, fine-grained, siliciclastic succession in central Nevada and western Utah. The deeper water succession was deposited within the fault-controlled House Range Embayment and contains the \textit{P. atavus} GSSP. Correlation of these disparate successions had been hampered by a lack of high-resolution biostratigraphic data, and limited chemostratigraphy and sequence stratigraphy. In this study, sequence-stratigraphic analysis indicates that the Condor Member of the Highland Peak Formation and the “mixed unit” of the Bonanza King Formation are the shallow-water platform equivalents of the basal Wheeler Formation encompassing the \textit{P. gibbus} and lower \textit{P. atavus} zones. The deepening event that is recorded in the \textit{P. gibbus} Zone represents a major flooding surface that may be used as an important event marker for regional and global correlation. The overlying \textit{P. atavus} GSSP, however, is within the later stage of transgression and may represent a globally synchronous event that can be correlated from platform to basin.

Keywords: Cambrian; GSSP; Laurentia; Stratigraphy; Nevada; Utah

1. Introduction

Global Stratotype Sections and Points (GSSP) provide important references for establishing a global chronostratigraphic framework. Because the appearance and disappearance of species are not necessarily synchronous globally and their preservation varies according to sedimentary facies, an integrated bio-, chemo- and sequence-stratigraphic approach is essential for a broad regional and global correlation of GSSPs.

The GSSP at the FAD of the cosmopolitan agnostoid trilobite \textit{Ptychagnostus} (or \textit{Acidusus}) \textit{atavus} in the Drum Mountains of Utah, USA (Rowell et al., 1982; Langenburg, 2003; Babcock et al., 2004; Fig. 2) was deposited during a transgression that began near the base of the underlying \textit{Ptychagnostus gibbus} Zone in the basal Wheeler Formation (Rowell et al., 1982; Langenburg, 2003; Babcock et al., 2004; Fig. 2). The \textit{P. atavus} GSSP marks the base
Fig. 1. Paleogeographic reconstruction of the northwestern margin of Laurentia during the Middle Cambrian. Shown are prominent formations and their areas of deposition (modified from Palmer, 1971). North arrow indicates the direction of Cambrian North. Chp: Highland Peak Formation; Cbk: Bonanza King Formation; Cwh: Wheeler Formation. The Panaca section is marked with a triangle, a square marks the Indian Ridge (in the Spring Mountains) location, and the black star indicates the location of the Drumian Stage GSSP, marked by the first appearance of Ptychagnostus atavus, in the Drum Mountains, Utah (Babcock et al., 2004).

of the Drumian Stage (formerly known provisionally as Stage 6) of the Cambrian (Babcock et al., 2005). The existence of this GSSP within a slope-to-basin deposit (Rees, 1986), however, limits correlation to a wide range of environments including those on the adjacent shallow-water platform. A broader correlation has had limited success because *P. atavus* is virtually unknown from shallow-water platform rocks. General correlation of this GSSP to shallow-water platform equivalents has relied mostly on broad lithostratigraphic correlations and low-resolution biostratigraphy of restricted polymerid trilobite faunas. This study integrates biostratigraphy with lithostratigraphy and sequence stratigraphy to enhance the applicability of the GSSP at *P. atavus* and to provide a framework for future detailed chemostratigraphic studies across this interval.

## 2. Geologic setting

During the middle part of the Cambrian, the western margin of North America (northwestern margin of Laurentia) was rapidly subsiding in response to the breakup of Rodinia during the late Neoproterozoic (Bond and Kominz, 1984; Levy and Christie-Blick, 1991; Prave, 1999). A broad continental terrace composed of terrigenous sediment was formed during subsidence, and subsequently became the location of a broad carbonate platform (Palmer, 1971; Fig. 1). Conditions were excellent for carbonate production along the continental shelf because of the low-latitude location of Laurentia and the global greenhouse climate, with only slight evidence for glacial activity in the interior of Gondwana (Erdtmann and Miller, 1981; Scotese and McKeever, 1990).

Near the end of deposition recorded by the *Ehmaniella* biozone (marked by the beginning of the *P. gibbus* trilobite zone), shallow-water carbonate deposition was interrupted by a fault-controlled asymmetric trough through Nevada and western Utah: the House Range Embayment (Kepper, 1976; Robison, 1982; Rees, 1986; Fig. 1). House Range Embayment deposition consisted of fine-grained siliciclastic and carbonate sediments of the Wheeler Formation and equivalents (Fig. 2). Siliciclastic sediments were thought to have bypassed the nearby shallow-water platform where sediments of the Highland Peak and Bonanza King formations were being deposited (Rees, 1986). Because of the paucity of fossils in the platform deposits, detailed correlation between the Wheeler and members of the Highland Peak and Bonanza King formations had not been available. Based on lithological similarities and polymerid biostratigraphy, Merriam (1964) and Palmer (1971) both correlated the Swasey Limestone below the Wheeler Formation to the Step Ridge Member of the Highland Peak Formation (Fig. 2). The base of the Condor Member of the Highland Peak Formation correlates with the base of the “mixed unit” of the Bonanza King (Osleger and Montañez, 1996; Howley and Rees, 2001; Howley, 2002). It is concluded in this study that the bases of the mixed carbonate-siliciclastic deposits of the Condor Member and the “mixed unit” of the Bonanza King Formation are equivalent to the base of the Wheeler Formation in the House Range Embayment.

## 3. Stratigraphic study results

An approximately 80-m-thick interval encompassing portions of the Step Ridge, Condor, and Meadow Valley members of the Highland Peak Formation was studied near Panaca, Nevada and placed in a sequence-
Fig. 2. Diagram illustrating correlation of major depositional units and trilobite zones associated with the House Range Embayment and the southern platform (modified from Hintze and Robison, 1975). Trilobite zones are from Robison (1976) and Geyer and Shergold (2000). Dashed lines are inferred. The shaded interval through *P. gibbus* is the focus of this article.

stratigraphic framework (Fig. 3). The upper 34 m of the Step Ridge Member contains subtidal cycles composed of burrow-mottled wackestone overlain by cross-stratified oolite that shallows upward into thin-bedded mudstone, wackestone and peloidal packstone with intraclasts, pseudomorphs of halite, and crinkled cryptomicrobial laminites. Merriam (1964) reported that a minor unconformity was present at the top of this unit near Pioche, Nevada, and intraclastic breccias are present in this interval in the Bonanza King Formation at Indian Ridge (Fig. 4). Osleger and Montañez (1996) interpreted these breccias as paleokarst features formed on exposure surfaces on the platform.

The 15-m-thick Condor Member is composed of mixed siliciclastic-carbonate lithologies including sandy and silty dolostone, calcareous siltstone, very fine-grained sandstone, and dolomitic siltstone. Siliciclastic grains consist predominantly of quartz, with minor detrital zircon, muscovite mica, plagioclase feldspar, potassium feldspar, and microcline. Parallel lamination, lenticular and flaser bedding, ripple cross-lamination, desiccation cracks, trace fossils, and the alternating laminae of microcrystalline dolomite and siliciclastic siltstone allow us to identify several subtidal to intertidal/supratidal cycles that correspond to the basal cycles reported from the basal Wheeler Formation (Langenburg, 2003; Babcock et al., 2004). The intertidal–supratidal dominated facies of the Condor Member gradually change to intertidal–subtidal dominated carbonate facies of the Meadow Valley Member.

The basal 5 m of the Meadow Valley Member contains carbonate intraclastic breccia, mudstone, chert-rich oolite, peloidal laminates, and domal stromatolites with no siliciclastic material. Intraclasts are composed mainly of lime mudstone, and were derived from reworking of thin, desiccated lime mudstone layers along minor exposure surfaces. The remainder of the Meadow Valley Member also is carbonate dominated, but is composed of burrow-mottled wackestone and peloidal packstone with microbialite-dominated intervals, and rare intraclastic packstone lenses and desiccation features. Desiccation features and intraclasts are not present above the first 8 meters of the Meadow Valley Member indicating deepening over the platform.

4. Interpretations

Within a biostratigraphic framework, sequence-stratigraphic analysis of the Highland Peak Formation, Bonanza King Formation, Swasey Limestone, and Wheeler Formation refines platform-to-basin correlations (Fig. 2) and distinguishes local tectonic events from sea-level changes, providing an improved understanding of the House Range Embayment and global signals. The Step Ridge-Condor-Meadow Valley interval of the Highland Peak Formation is placed into an overall sequence stratigraphic-framework based on data collected during this study and correlations to the Bonanza King Formation (Howley and Rees, 2001; Howley, 2002; Fig. 3). The top 8 m of the Step Ridge Member record a shallowing-upward trend, possibly representing deposition of the highstand systems tract (HST) during falling sea level. We base this HST interpretation on the transition from oolitic grainstone and
wackestone to thin-bedded lime mudstone interbedded with cryptic-microbial laminites. The presence of micro-karstic features including dissolution cavities and breccias at the top of the Step Ridge Member indicates subaerial exposure. The overlying siliciclastic-dominated rocks of the Condor Member contain swaley cross-stratification, wave-ripples, lenticular and flaser bedding, and common desiccation cracks that record deposition in peritidal siliciclastic environments. The exposure surface between the Step Ridge and Condor
members, along with intraclastic breccias present in the basal “mixed unit” of the Bonanza King Formation, indicate a platform-wide unconformity or sequence boundary overlain by siliciclastic-dominated sediments that were deposited during transgression (transgressive systems tract, TST) over the previously exposed platform. Overlying the siliciclastic-rich Condor Member are siliciclastic-free carbonate rocks of the Meadow Valley Member that record an overall deepening trend from intertidal–supratidal grainstone and lime mudstone to subtidal, bioturbated wackestone and packstone. Meter-scale shallowing-upward cycles are present in the Condor and basal Meadow Valley members, recording small-scale shoaling events in an overall deepening-upward succession that was deposited during a major transgression (TST).

Previous biostratigraphy provides the necessary constraints to tie the sequence stratigraphy of the platform to that of the basin. With the long established general biostratigraphic framework (Hintze and Robison, 1975; Robison, 1976), the new Highland Peak Formation sequence stratigraphy correlates to House Range Embayment stratigraphy of the Swasey Limestone and Wheeler Formation (Fig. 2). The Swasey Limestone can be correlated to the Step Ridge Member (Fig. 5A). Unlike the shallowing-upward trend recorded in the Step Ridge Member, the Swasey Limestone records a deepening-upward trend from oolitic grainstone and wackestone to open-marine bioclastic grainstone with hematite-stained hardgrounds (White, 1973; Caldwell, 1980; Rees, 1986). The contrasting trend of the Step Ridge and Swasey can be explained by local tectonically driven deepening during formation of the House Range Embayment. In this scenario, the House Range Embayment was not initiated at the Swasey-Wheeler contact but at the contact between oolitic grainstone and bioclastic grainstone within the Swasey (Fig. 5B). The top few meters of the Step Ridge Member represents a HST, and the boundary between the Step Ridge and Condor members is interpreted as a regional unconformity formed during the
lowstand (Fig. 5C). Therefore, we can interpret the bioclastic grainstone at the top of the Swasey as a reworked deep-water deposit representing the lowstand systems tract (LST; Fig. 5B and C). This interpretation also was offered by Schneider (2000) and Babcock et al. (2004) and can now be confirmed based on regional correlations.

The bioclastic grainstone at the top of the Swasey is abruptly overlain by non-calcareous shale, calcareous shale and interbedded argillaceous limestone of the Wheeler Formation. Similarly, the Step Ridge is overlain by siliciclastics of the Condor Member. Influx of siliciclastic sediment associated with both the Condor Member and Wheeler Formation are interpreted as the result of a major sea-level transgression where nearshore sands and muds were reworked and deposited on the platform and in the basin during time represented by the P. gibbus trilobite zone (Fig. 5D).

The Wheeler Formation indicates a deepening-upward trend and contains the FAD of P. atavus (Babcock et al., 2004). Correlative strata on the platform also record an overall deepening-upward trend from the Condor Member to Meadow Valley Member of the Highland Peak Formation (Fig. 5E). Several small-scale shallowing-upward events are present within the overall TST in the basal Wheeler Formation (Langenburg, 2003; Babcock et al., 2004) and similar shallowing-upward events also are recorded in the Condor Member and the basal Meadow Valley Member. Therefore, despite the contrasting shallowing- and deepening-upward trends within the Step Ridge and Swasey, which is explained by House Range Embayment initiation, both platform and basin successions appear to record the same sea-level events.

5. Conclusions

The Transgressive Systems Tract within the Wheeler Formation that contains the Drumian Stage GSSP is documented in the adjacent shallow-platform deposits of the Step Ridge, Condor, and Meadow Valley Members of the Highland Peak Formation. This TST begins near the FAD of P. gibbus at the base of the Wheeler Formation and also at the base of the Condor Member of the Highland Peak Formation during the late Ehmaniella biozone. This confirmation provides further evidence for the applicability of the Drum Mountains GSSP section. We also have concluded that the tectonic initiation of the House Range Embayment occurred during a Highstand Systems Tract that is recorded on the stable platform and during deposition of the Swasey Limestone in the House Range Embayment.

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References


