Precambrian-Cambrian transition: Death Valley, United States

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ABSTRACT

The Death Valley region contains one of the best exposed and often visited Precambrian-Cambrian successions in the world, but the chronostratigraphic framework necessary for understanding the critical biologic and geologic events recorded in these sections has been inadequate. The recent discovery of *Treptichnus (Phycodes) pedum* within the uppermost parasequence of the lower member of the Wood Canyon Formation allows correlation of the Precambrian-Cambrian boundary to this region and provides a necessary global tie point for the Death Valley section. New carbon isotope chemostratigraphic profiles bracket this biostratigraphic datum and record the classic negative carbon isotope excursion at the boundary. For the first time, biostratigraphic, chemostratigraphic, and lithostratigraphic information from pretrilobite strata in this region can be directly compared with similar data from other key sections that record the precursors of the Cambrian explosion. Few Precambrian-Cambrian boundary sections contain both the facies-restricted boundary fossil *T. pedum* and carbon isotope data, as found in Death Valley. Thus, the Death Valley succession provides a critical link toward our understanding of the correlation between siliciclastic-dominated and carbonate-dominated Precambrian-Cambrian transition sections.

Keywords: Precambrian-Cambrian boundary, Death Valley, Cambrian explosion, chemostratigraphy.

INTRODUCTION

The Precambrian-Cambrian transition records one of the most important intervals in the history of life, as it encompasses the advent and diversification of metazoans, dramatic paleoceanographic and atmospheric changes, and major plate tectonic reconfigurations (e.g., Bengtson, 1994). From the time of Walcott (1884) to the present day, the thick, superbly exposed, and highly fossiliferous Lower Cambrian strata from the southwestern United States have proved instrumental to the understanding of the Cambrian biotic explosion, and have even been suggested as a possible basal Paleozoic stratotype (Cloud, 1973). The exact position of the Precambrian-Cambrian boundary in the southern Great Basin, however, has remained unclear, despite a wealth of literature available for the region (see summary in Signor and Mount, 1986). However, new faunal and chemostratigraphic data from the Death Valley region of eastern California allow us to address this gap so that we can confidently bracket the timing of Precambrian-Cambrian events and provide an integrated framework for the correlation of these sections to other sections around the globe.

The ability to correlate sections from one part of the globe to another is key to understanding biologic and oceanographic changes surrounding the Precambrian-Cambrian transition. The Precambrian-Cambrian boundary global stratotype section and point are currently defined in Newfoundland and locally coincide with the first occurrence of the trace fossil *Treptichnus (Phycodes) pedum* (Narbonne et al., 1987). The choice of the Newfoundland section is not without controversy, as *T. pedum* is restricted to siliciclastic facies, making it difficult to correlate the siliciclastic-dominated Newfoundland stratotype to carbonate-dominated sections elsewhere. The following data strengthen our ability to correlate the Precambrian-Cambrian interval on a global scale by integrating trace fossil biostratigraphy with carbon isotope chemostratigraphy. The result provides an important link between carbonate-dominated trace fossil-poor sections and siliciclastic-dominated trace fossil-rich sections.

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GEOLOGIC AND PALEONTOLOGIC BACKGROUND

The Proterozoic–lower Paleozoic strata in the southern Great Basin thicken from southeast to northwest and can be grouped into four distinct but interfingering successions: the Cratonal, Mojave, Death Valley, and White-Inyo successions (Figs. 1 and 2B; Nelson, 1978). Each broadly reflects deposition in cratonal, craton-margin, proximal-shelf, and outer-shelf environments, respectively; for paleoenvironmental interpretations of these strata, see Cooper and Stevens (1991). The Cratonal and Mojave successions contain an erosional disconformity that has removed the Precambrian-Cambrian boundary interval (Diehl, 1979; Fedo and Cooper, 1990). The White-Inyo succession is thickest but is poorly fossiliferous with respect to earliest Cambrian index fossils (Signor and Mount, 1986). The Death Valley succession contains both lowest Cambrian index fossils and sufficient carbonate rocks, providing an ideal combination of data to characterize the Precambrian-Cambrian transition (Wright and Troxel, 1966; Stewart, 1970) (Fig. 1).

Despite its thickness, the lack of age-diagnostic fossils and datable igneous material has hampered efforts to constrain the age of post-1.08 Ga strata within the Death Valley succession (but see Heaman and Grotzinger, 1992). In Death Valley, the first demonstrably Cambrian fossils occur in the Wood Canyon Formation (e.g., Nelson, 1978), and probable Neoproterozoic index fossils have been reported from the underlying Stirling Quartzite (Langille, 1974); thus efforts to characterize the Precambrian-Cambrian transition have focused on the Stirling–Wood Canyon interval.

PREVIOUS BIOSTRATIGRAPHIC WORK

Until recently, fossils of diagnostic age were not known from the pretrilobitic units in the Death Valley succession. Unpublished or informal reports on faunas of broad biostratigraphic utility, however, coupled with recent discoveries, allow construction of a more rigorous stratigraphic framework for this interval (Fig. 1). Biostratigraphic constraints are based on the following:

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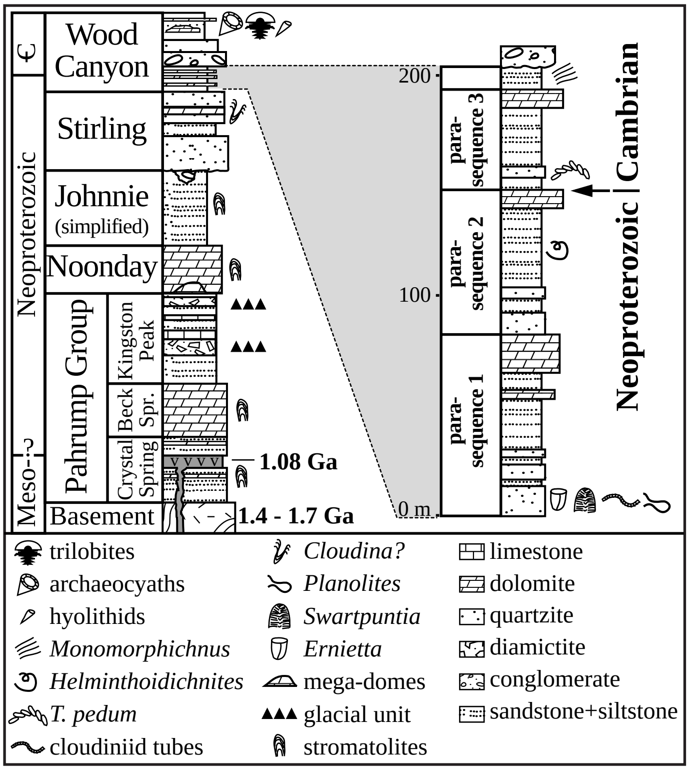

Figure 1. Generalized stratigraphic context for Death Valley region. Arrow indicates suggested position of Precambrian-Cambrian boundary in this region. Fossils depicted in inset reflect only first occurrences. See Hagadorn and Waggoner (2000) for description of cloudiniid tubes.

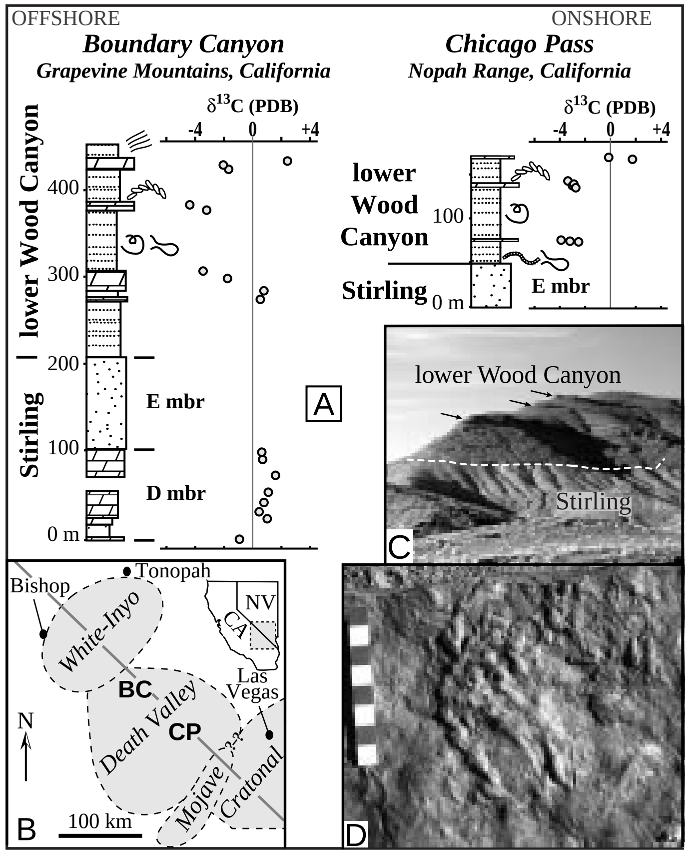

Figure 2. A: Carbon isotope chemostratigraphy for Precambrian-Cambrian interval in Death Valley region. PDB—Peedee belemnite. B: Location map; BC—Boundary Canyon, CP—Chicago Pass. C. Field photograph, Boundary Canyon section. Arrows indicate three ledge-forming carbonate units. D: *T. pedum* from Chicago Pass (scale is in centimeters). Symbols as in Figure 1.

Calcareous microfossils. Small, poorly preserved mineralized cones have been reported, but not figured, from the carbonate-rich D member of the Stirling Quartzite (Langille, 1974) and may be the terminal Proterozoic index fossil *Cloudina* (Grant, 1990).

Trace fossils. Although dubiofossils have been reported from the Stirling Quartzite (Langille, 1974), the only biostratigraphically useful trace fossils are in overlying members of the Wood Canyon Formation. These include occurrences of *T. pedum* (documented from the lower member of the Wood Canyon Formation; Horodyski et al., 1994) and more typical Early Cambrian traces (such as *Skolithos* and *Rusophycus* from the upper member Wood Canyon Formation; Langille, 1974; Diehl, 1979). Although *T. pedum* constrains the Precambrian-Cambrian boundary, most of the aforementioned fossils have yet to be figured or described in the systematic literature or published in association with stratigraphic reference sections.

Megascopic body fossils. The upper member of the Wood Canyon Formation has long been known to contain a number of diagnostic Early Cambrian skeletonized faunas, including archaeocyathids, echinoderm debris, Olenellid trilobites, and inarticulate brachiopods (e.g., Nolan, 1924; Diehl, 1979). Although the middle member of the Wood Canyon Formation is barren of body fossils, the lower member contains rare Ediacaran-style body fossils (including *Ernietta* [Horodyski, 1991], *Swartpuntia*, and a variety of tubular forms [Hagadorn and Waggoner, 2000]) in the lowest parasequence of the unit. In rare cases, Ediacaran-style fossils occur in Cambrian strata, but *Ernietta* is known only from terminal Proterozoic deposits.

TRANSITION INTERVAL—A DETAILED LOOK

The lower member of the Wood Canyon Formation (sensu Stewart, 1970) contains three carbonate-capped parasequences (Fig. 1; Stewart, 1970; Diehl, 1979; Horodyski et al., 1994). The contact with underlying cross-bedded quartzites of the upper (E member) Stirling Quartzite is sharp and disconformable at most localities. Each parasequence contains shallow subtidal siliciclastic rocks at the base that are gradationally overlain and capped by shallow-marine, ledge-forming carbonate rocks. The pebbly conglomerates of the middle member overlie and incise the lower member (Fedo and Cooper, 1990), forming a prominent sequence boundary that may reflect the base of the Sauk I sequence (Cooper and Fedo, 1995; Runnegar et al., 1995). Considered together, these two disconformities define the lower member of the Wood Canyon Formation as a sequence (Prave et al., 1991). In the Death Valley region, incision by the middle member is minimal and three ledge-forming carbonate units occur in the lower member (Stewart, 1970) at almost all localities. However, some offshore localities may contain additional thin carbonate beds interstratified between the more prominent ledge-forming carbonates (e.g., Boundary Canyon section; Fig. 2).

Ediacaran fossils, tubular fossils, and simple bed-parallel trace fossils are present in siliciclastic units of the first parasequence, directly above the contact with the Stirling Quartzite but below the first ledge-forming carbonate unit (Horodyski et al., 1994; Hagadorn and Waggoner, 2000). The siltstone and quartzite units in the second parasequence (above the first major ledge-forming carbonate) are poorly fossiliferous, containing only bed-parallel trace fossils such as *Helminthoidichnites*, *Palaeophycus*, and *Planolites*. Interbedded siltstone and sandstone units of the third parasequence, overlying the second major carbonate unit at most sections, contain an easily recognizable suite of bed-parallel trace fossils, as well as several forms demonstrating a vertical burrowing component, including *T. pedum* (Fig. 2D). Thus, the Precambrian-Cambrian boundary can be correlated to the basal siliciclastic units of the third parasequence in the lower member of the Wood Canyon Formation

(Fig. 2). Arthropod scratch marks (e.g., *Monomorphichnus*) occur in siliciclastic strata above the third carbonate unit where incision by the middle member is less intense.

CHEMOSTRATIGRAPHY

When combined with lithostratigraphic or geochronologic approaches, carbon isotope chemostratigraphy is a powerful tool for correlating Neoproterozoic and Cambrian stratigraphic successions, particularly when sections are sparsely fossiliferous (see Kaufman and Knoll, 1995). Although a carbon isotope reference curve does not exist for the interval, similar chemostratigraphic patterns exist among many Precambrian-Cambrian sections (noted in Fig. 3). In ascending order, these trends include: (1) a latest Neoproterozoic major positive carbon isotope excursion (slightly older than 548 Ma; Grotzinger et al., 1995) associated with *Cloudina*, simple horizontal trace fossils, and Ediacaran forms; (2) a drop to near zero values ca. 548 Ma in Namibia (Saylor et al., 1998); (3) a minor positive carbon isotope excursion (Kaufman et al., 1997); (4) a plateau of positive carbon isotope compositions with diverse Ediacaran assemblages (between about 548 and 544 Ma; Bowring and Erwin, 1998); and (5) a pronounced negative carbon isotope excursion nearly coincident with the Precambrian-Cambrian boundary, at 543.9 ± 0.3 Ma in Siberia (Bowring et al., 1993; Knoll et al., 1995a).

To compare Death Valley strata with other well-constrained sections, the Stirling Quartzite and lower member of the Wood Canyon Formation were examined at Chicago Pass in the Nopah Range (a thinner, more onshore locality) and Boundary Canyon in the Grapevine Mountains (a thicker, more offshore locality). These sections were chosen because they approximate stratigraphic end members between onshore and offshore facies in the Death Valley succession and *T. pedum* occurs at both sections (Horodyski et al., 1994; Hagadorn and Waggoner, 2000). All chemostratigraphic samples were microdrilled from primary marine phases and extensively evaluated for postdepositional alteration as outlined in Kaufman and Knoll (1995). Data and locality information are in the GSA Data Repository.[1]

[1]GSA Data Repository item 200035, sample positions and isotopic and elemental data, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/drpint.htm.

INTERPRETATION OF THE ISOTOPIC DATA

Samples of the D member of the Stirling Quartzite from Boundary Canyon record a near-monotonic positive excursion from –0.9‰ to +1.6‰ relative to PDB (Peedee belemnite) (Fig. 2A). It is possible that the positive excursion may represent the rising limb of the Neoproterozoic peak (trend 1) or the return to positive values before the +2 plateau (trend 3) (Fig. 3). Isotopic compositions from the lowermost carbonate unit at Boundary Canyon remain positive, demonstrating that Ediacaran forms found directly above the Stirling Quartzite–Wood Canyon contact were deposited during an interval of mildly positive carbon isotope values, similar to sections in Namibia (Grotzinger et al., 1995; Saylor et al., 1998) and Canada (Narbonne et al., 1994). A pronounced negative carbon isotope excursion to ~–4‰ occurs in the lower member of the Wood Canyon Formation directly below the Precambrian-Cambrian boundary interval in both sections (Fig. 2A). A more complete excursion (from positive to negative carbon isotope values) is in the thicker, offshore Boundary Canyon section, demonstrating the time-transgressive nature of carbonate units within the lower member of the Wood Canyon Formation. Runnegar et al. (1995) noted that carbon isotopes recorded from the lower Wood Canyon Formation were predominantly negative, but they sampled a more onshore locality and did not capture the complete isotopic excursion. At both localities, upper carbonate units record a return to positive isotope values, but the Boundary Canyon section contains a more complete isotopic excursion from negative to positive values. Comparison of a composite stratigraphic column for the region with isotopic events outlined here suggests that the D member of the Stirling Quartzite and the lower member of the Wood Canyon Formation were deposited between 548 and 544 Ma (Fig. 3).

GLOBAL IMPLICATIONS

The Death Valley section is one of two boundary sections known to contain both the index fossil *T. pedum* and carbonate carbon-derived carbon isotope excursions bracketing the Precambrian-Cambrian boundary. Strauss et al. (1997) noted the same pattern in organic carbon from Poland. Unlike trace fossil–rich siliciclastic sections (e.g., Newfoundland; Narbonne et al., 1987) or carbonate-dominated chemostratigraphically constrained sections (e.g., Siberia [Magaritz et al., 1991; Knoll et al., 1995a, 1995b], China [Brasier et al., 1990], and Morocco [Tucker, 1986]), the mixed siliciclastic-carbonate nature of the Death Valley succession contains both siliciclastic-restricted trace fossils and sufficient carbonate rocks to allow chemostrati-

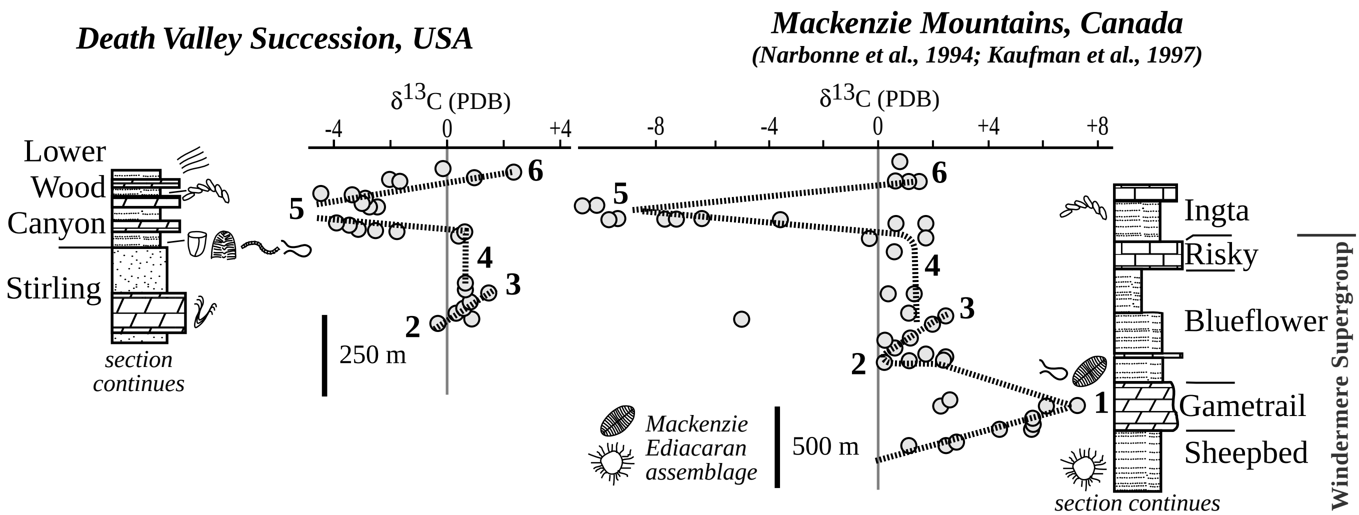

Figure 3. Chemostratigraphic and biostratigraphic correlation of Precambrian-Cambrian boundary interval between Death Valley, western United States, and the Mackenzie Mountains, northwestern Canada. Numbers represent isochronous isotopic events of global significance (see text). We prefer correlation shown here, based on complex nature of Ediacaran fossils in Death Valley. Note, however, that it may be possible to correlate positive isotopic compositions in Stirling Quartzite with event 1, rather than event 3. Scale for Death Valley is 2× relative to that for Mackenzie Mountains. Symbols as in Figure 1. PDB—Peedee belemnite.

graphic correlation. Thus, it is possible to correlate between Death Valley, the Newfoundland type section, and carbonate-dominated, chemostratigraphically constrained sections elsewhere. The thick Mackenzie Mountains section in northwestern Canada is the only other section in the world with isotopic data from carbonate carbon and basal Cambrian occurrences of *T. pedum* (Narbonne et al., 1994). Death Valley and the Mackenzie Mountains exhibit strikingly similar isotopic and paleontologic records (Fig. 3), but unlike Death Valley, the Mackenzie section is not readily accessible. Furthermore, the diversification of small shelly faunas noted in carbonate-dominated sections (e.g., Siberia, China) seems nearly coincident with the appearance of *T. pedum* in siliciclastic-dominated sections.

CONCLUSIONS

This study provides a robust stratigraphic framework spanning the Precambrian-Cambrian transition in one of the best-exposed sections in the world. The location of the boundary in the Death Valley section is constrained to the base of the third parasequence of the lower member of the Wood Canyon Formation by the first occurrence of *T. pedum* immediately above carbonate units that record a pronounced negative carbon isotope excursion typical for this interval (Knoll et al., 1995a, 1995b; Magaritz et al., 1991), and only tens of meters above complex Ediacaran-type fossils and probable terminal Proterozoic index fossils. Chemostratigraphic correlation of this succession to radiometrically dated sections elsewhere suggests that the D member of the Stirling Quartzite through the lower member of the Wood Canyon Formation may represent the time interval between ca. 548 Ma and 544 Ma.

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