Integrated stratigraphic, geochemical, and paleontological late Ediacaran to early Cambrian records from southwestern Mongolia: Comment

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Global correlation of sedimentary rock successions requires an integrated approach that uses all fossil-based and alternative (lithostratigraphic, geochemical, paleomagnetic, geochronologic, sequence stratigraphic) data (e.g., Van Couvering and Berggren, 1977). Proposed global correlations and their role in interpreting Earth and biotic history require a thorough examination of the utility and temporal resolution allowed by each correlation technique in comparison to the others. The article by Smith et al. (2016) is a welcome contribution to understanding the Upper Ediacaran (?)-Lower Cambrian succession of the Zavkhan terrane in the Khasagt-Khairkhan Range of southwestern Mongolia. Their work complements earlier syntheses on the Zavkhan terrane completed by Soviet-Mongolian teams (e.g., Voronin et al., 1982; Esakova and Zhegallo, 1996) and under international geoscience programme (IGCP) Project 303, “Late Precambrian-Cambrian Event Stratigraphy” (Brasier et al., 1996a; see associated papers in Geological Magazine, v. 133, no. 4).

Smith et al. (2016) provide a more comprehensive understanding of onshore-offshore and lateral shelf lithofacies changes along the highly tectonized sections of the Khasagt-Khairkhan Range (i.e., their Figs. 6B–6E). However, their strong reliance on proposed global geochemical excursions (primarily δ13C) and the incompletely documented geochronology of the terminal Ediacaran-Lower Cambrian (e.g., Maloof et al., 2005, 2010a, 2010b) has led to a number of questionable correlations that significantly affect global correlation, as well as a “too old” earliest appearance of diverse biomineralized small metazoan fossils, and an anomalously early appearance of archaeocyaths. Smith et al.’s (2016, p. 461) technique assumes that terminal Ediacaran-Cambrian δ13C excursions “mark synchronous, global markers” and are a way to avoid “poorly established, facies-dependent, and highly regional biozones.” Although we are strong advocates of the potential utility of carbon isotope excursions in correlation (e.g., Landing et al., 2013), avoidance of the fossil record is certainly not part of the “integrated … geochemical and paleontological … record” of their report’s title. Smith et al.’s (2016, p. 458) use of the fossil record is seemingly limited to “plac[ing] previously reported small shelly fossil horizons … into the new stratigraphic and δ13C chemostratigraphic context.”

It is unfortunate that fossils from their “new small shelly fossil horizons” have “not yet been dissolved, identified, or imaged” (Smith et al., 2016, p. 458), as this means that all comment on Cambrian biostratigraphy of the Zavkhan terrane, including the present evaluation, must, in the interim, rely on older reports (e.g., Voronin et al., 1982; Gibsher and Khomentovsky, 1990; Brasier et al., 1996b; Kruse et al., 1996; Esakova and Zhegallo, 1996; Khomentovsky and Gibsher, 1996). Similarly, their report of unexpectedly low occurrences of archaeocyaths in the basal Salaany Gol Formation (Salaagol Formation of Smith et al., 2016) remains undocumented (Smith et al., 2016, p. 458, their fig. 12), as no earlier study has ever recovered archaeocyaths at that level in the formation, and these fossils would provide an important lower age bracket on the Salaany Gol Formation. In this comment, we discuss Smith et al.’s (2016) use of earlier documented fossil distributions in the Mongolian sections and interpretations of the chronostratigraphic significance of these fossil assemblages.

The Zavkhan terrane features a thick terminal Ediacaran-Lower Cambrian, mixed carbonate-siliciclastic succession that complements the biostratigraphic and geochemical record of the coeval, carbonate-dominated Siberia and South China Platforms and the siliciclastic-dominated, global stratotype section of the Ediacaran-Cambrian boundary interval in Avalonian eastern Newfoundland (e.g., Brasier et al., 1996a). The forearc succession of the Zavkhan terrane includes the siliciclastic-dominated, upper Lower Cambrian, foredeep Khairkhan Formation (ca. >200 m to 500 m thick), which unconformably overlies or is in thrust contact with units as low as the Bayan Gol Formation (Brasier et al., 1996b, p. 455; Smith et al., 2016, their Khairkhan and Bayangol Formations).

Smith et al.’s (2016) report focuses on two units. One of these is the Salaany Gol Formation (their Salaagol Formation), which commonly underlies the Khairkhan Formation. The Zavkhan terrane was apparently latitudinally separated from the Siberian Platform through much of the early Cambrian (e.g., Evans et al., 1996; Wilhelm et al., 2012). However, the presence of many Siberian archaeocyath genera and species in the limestone-rich, upper Salaany Gol Formation (Brasier, 1989, p. 61; Kruse et al., 1996) indicates extensive faunal exchange between the Siberian Platform and the Zavkhan terrane. The lower Salaany Gol did not yield fossils in earlier studies (e.g., Brasier et al., 1996b, and references therein) and locally features a thick interval of conglomerates (~150 m) that emphasizes the likely unconformable base of the formation and a lengthy intra-early Cambrian hiatus (Missarzhovsky, 1982; Astashkin et al., 1995; Brasier et al., 1996b).

Earlier studies by archaeocyath specialists concluded that the upper Salaany Gol Formation bears two archaeocyathan faunas that can be readily correlated with the upper Lower Cambrian (upper Atdabanian and Botomian Stages) of Siberia (e.g., Voronin et al., 1982; Esakova and Zhegallo, 1996; Brasier et al., 1996b). This correlation was followed by Kruse et al. (1996), yet Smith et al. (2016, p. 447, 462) repeatedly claim that Kruse et al. (1996) assigned a much older, Tommotian to Botomian age to that fauna. To add to the confusion, Smith et al. (2016, their fig. 12) limit the Salaany Gol Formation to the Tommotian, while also recognizing the significantly older δ13C 6p excursion of the Siberian Nemakit-Daldynian Stage (e.g., Maloof et al., 2010b) in the Salaany Gol Formation (Smith et al., 2016, their fig. 11, left column).

This Tommotian equivalency is justified by Smith et al. (2016, p. 462) on the basis of an...
absence of trilobites in the Salaany Gol Formation, which in their view makes this interval older than the Siberian Atabdanian and, thus, renders it a Tommotian equivalent. However, numerous other papers have long shown that Atabdanian–Botomian–equivalent successions may lack trilobites and may have “late” appear- 
ances of trilobites if they represent very shallow habitats, were paleogeographically isolated (as in the case of Avalonia), or have carbonate-poor lithofacies that may have led to dissolution of early trilobite remains (as, for example, in Balti- 
ca; e.g., Landing et al., 1989, 2013; Landing and Westrop, 2004).

Smith et al. (2016, p. 462, 467) repeatedly de- 
scribe the Salaany Gol Formation archaeocyath fauna as comprising only “a few” species— even though Voronin et al. (1982, their fig. 3) recorded 78, and Kruse et al. (1996) resampled 34 constituent nominal species (the latter identifi- 
cations by F. Debrenne and A. Yu. Zhuravlev). It is noteworthy that in 43 of the 78 species (55%) 
listed by Voronin et al. (1982) are also known from the Siberia–Far East region. Perhaps the question is: How many archaeocyath spec- 
ies are needed before they can be regarded as more than just “a few”? In addition, Smith et al. 
(2016, p. 462, col. 2) conclude, “We suggest that the few archaeocyath species from the upper 
Salaagol Formation that are thought to be diag- 
nostic of the Atabdanian and Botomian were 
neither misidentified or have longer stratigraphic ranges than was previously thought.” They fur- 
ther claim (Smith et al., 2016, p. 465, col. 2) that these are “archaeocyath species with poorly 
constrained age ranges.” Smith et al. (2016) 
seemingly have not used decades of research on 
Siberian archaeocyaths that have established 
a well-founded biostratigraphic scheme that is 
tied to other fossil groups, such as trilobites and 
a variety of Early Skeletalized Fossils, and the bay- 
only one of their sections (E1340 in 
trilobites–Botomian faunas of the Siberia–Far East re- 
gion noted here belies this claim. Even at the 
genus level, the Salaany Gol Formation fauna 
can be confidently correlated, because Ajaci- 
cyathus, Robustocyathellus, Rotundocyathus, 
Urcyathus, Leptosocyathus, Baikalocyathus, 
Bipaliclyathus, Prettosicyathus, Ladaeocyathus, 
Plicocyathus, Aygrekocystus (= Memneri- 
cyathus), Fransuasaeocyathus, Alataucyathus, 
Archaeopharetra, and Tabulacyathellus are 
globally limited to Atabdanian-equivalent and, 
in some cases, younger strata, while Ich노so- 
cyathus, Fallocyathus, Chouberticyathus, and 
the non-archaeocyathan spongelike Acanthino- 
cyathus are restricted to Botomian equivalents 
(Debrenne et al., 2015).

Smith et al. (2016, p. 462, their fig. 11) state 
that they have found the oldest known archaeo- 
cyathus: They correlate the lower Salaany Gol 
Formation archaeocyaths with the Nemakit- 
Daldynian Stage of Siberia. Elsewhere, 
archaeocyaths have their global lowest known 
analysis in the overlying Tommotian Stage of 
Siberia and have never been recovered from 
the Nemakit-Daldynian Stage and equivalents 
(Landing et al., 1989, 2013; Knoll et al., 1995; 
Brasier et al., 1996a; Landing and Kouchinsky, 
2016), and strong evidence is needed for a 
claim of a Nemakit-Daldynian–equivalent ap- 
pearance of archaeocyaths in Mongolia. Smith et al.’s (2016, their fig. 11) evidence for such 
old archaeocyaths lies only in their interpreta- 
tion of the carbon isotope excursions of the 
Salaany Gol Formation. As noted already, Smith 
et al. (2016, p. 447, 462) depict the entire for- 
mation variably as a Tommotian equivalent 
(Smith et al., 2016, their fig. 12) or as Nemakit- 
Daldynian–Tommotian (their fig. 11). Alterna- 
tively, they also equated a strong positive δ13 C 
excursion in the lower part of the formation 
with excursion 6p of the Nemakit-Daldynian 
(Maloof et al., 2005, 2010a, 2010b; = excursion 
I of Brasier and Sukhov, 1998). However, based 
on the biostratigraphic evidence, the prominent 
“6p” excursion in the basal Salaany Gol Forma- 
tion is more likely to be the local expression of 
the IV excursion within the lower Atabdanian 
of Siberia (e.g., Landing et al., 2013).

Altogether, these considerations warrant 
discounting Smith et al.’s (2016) correlation 
of the Salaany Gol Formation, and indeed cast 
doubt on their entire scheme. Smith et al. (2016, 
p. 462, their fig. 8) supported their argument 
against correlation of the upper Salaany Gol 
with the upper Atabdanian–Botomian as they 
surmised that this would require a 6–10 m.y. 
interval to estab- 
lish a “medium sandstone to 
mixed carbonate and siliciclastic rocks of 
the Bayan Gol Formation underlie the Salaany Gol Formation. Correlation of the Bayan 
Formation has long been problematic, with 
correlations to the Nemakit-Daldynian and/or 
Tommotian Stages of Siberia long advocated 
(see summary in Landing and Kouchinsky, 
2016). However, Smith et al. (2016, p. 458), 
on the basis of carbon and strontium isotope 
excursions, claim to be the first to limit corre- 
lations to the Nemakit-Daldynian, even though Landing et al. (2013) and Land- 
and and Kouchinsky (2016) had earlier used the 
Early Skeletalized Fossils of the unit to estab- 
lis a Nemakit–Daldynian equivalency of the 
Bayan Gol Formation. The latter conclusion 
was presaged by Brasier et al. (1996a, p. 367), 
who noted that the abundant calcimicrobial 
buildups of the Bayan Gol Formation lacked 
archaeocyaths (Kruse et al., 1996), and that one 
explanation was that the formation was a pre- 
Tommotian equivalent.

A highly resolved interregional correlation of 
the Nemakit-Daldynian–equivalent Bayan Gol 
Formation remains problematic, particularly as 
it seems unlikely that the Bayan Gol–Salaany 
Gol contact is part of a stratigraphically continu- 
ous section. This means that the δ13 C excursion 
record through the two formations cannot 
be directly compared with the supposed excursion “standard” of Maloof et al. (2010b) without a 
greater concern for stratigraphic discontinuities 
and biostratigraphy. Smith et al. (2016, p. 462, 
their fig. 12) are disposed to believe in a sim- 
ple, not “multistage,” subsidence history for 
the Zavkhan terrane, with apparently continu- 
ous deposition and a continuous carbon isotope 
excursion history from the Bayan Gol through 
Salaany Gol Formations. However, no evidence 
is provided by Smith et al. (2016, p. 462) for a 
Zavkhan terrane that continuously subsides for 
“~16–20 m.y.”

Smith et al. (2016, fig. 12) assign the Zuun-
Arts Formation and most of the lower half of 
the overlying Bayan Gol Formation to a “Precam- 
bian–Cambrian transition” interval. They place 
much emphasis on the lowest (and only) occur- 
cence of the ichnofossil Trichophycus pedum in 
only one of their sections as suggesting the “P-C boundary, as defined at GSSP [global stratotype 
section and point]” in the middle Bayan Gol...
Formation (at the base of their informal unit BG4). This correlation may be regarded as forcing the named carbon isotope excursion history presented in their figure 12 into incorrect correlations.

The base of the Cambrian is defined at the first appearance datum (FAD; i.e., lowest) of *T. pedum* in the Fortune Head GSSP section in Newfoundland. The FAD of any fossil typically underestimates the lowest range of that taxon in any section (e.g., Marshall, 1990). It should be noted that *T. pedum* has a range of ~220 m in the Fortune Head GSSP section (Landing et al., 1988). Thus, the single known horizon with *T. pedum* in Mongolia does not provide a basis for highly resolved correlation. Indeed, the trace fossils *Helminthoida cl. miocenica, Spathagnostis*, and *Rusophycus* that appear below *T. pedum* in the Bayan Gol Formation appear above the lowest *T. pedum* and, more importantly, in the lowest Cambrian at the GSSP section.

Given the stratigraphic range of *T. pedum*, its local FAD need not necessarily represent the base of the Cambrian, and this is the case in the Zavkhan terrane sections. In the Smith et al. (2016, fig. 12) report, the FAD of anabaritids is near the base of the Bayan Gol Formation, and the lowest occurrence of this group of trilobed tube-forming Early Skeletalized Fossils has been regarded as providing the most likely approximation to the base of the Cambrian (e.g., Brasier, 1992; Brasier et al., 1992, 1996b; Bowring et al., 1993). However, several caveats are associated with definition of the base of the Cambrian near the lowest occurrence of anabaritids in the Zavkhan terrane. As noted herein, Smith et al. (2016, p. 458) did not acid-disaggregate any Early Skeletalized Fossil–bearing horizons, so that the lowest occurrence of anabaritids is presently unknown in their sections, while Brasier et al. (1996b) and Khomentovsky and Gibsher (1996) recorded anabaritids in lower strata from what is now the underlying Zuun Arts Formation. The lowest occurrence of anabaritids can only be said to fall in the Ediacaran-Cambrian boundary interval, with Zhuravlev et al. (2012) recording members of the group notionally from the terminal Ediacaran.

Similarly, the list of body fossils reported by Smith et al. (2016, fig. 12; e.g., coeloscleritophorans, orthotheccmorphs, tommotidi, capsule fossils [possibly *Purella]*) to appear lower in the Bayan Gol Formation (their unit BG2) are all taxa that indicate a lowest Cambrian correlation. Voronova et al. (1982, fig. 12) and Brasier et al. (1996b, fig. 6) have provided more comprehensive lists of fossils through the Bayan Gol Formation.

With excursion 6p of Maloof et al. (2010a, 2010b) placed in the Salaany Gol Formation by Smith et al. (2016), as discussed above, a confident correlation of the carbon isotope peaks and nadirs in the Nemakit-Daldynian–equivalent Bayan Gol Formation is not possible. Excursion 6p of Maloof et al. (2010a, 2010b) may actually equate to excursion “5p” of Smith et al. (2016, fig. 12), as the mollusk *Watsonella croshyi* occurs high in the Bayan Gol Formation and just below the I’ positive excursion (? = 6p) in Siberia (Landing and Kouchinsky, 2016).

If this alternative correlation of Smith et al.’s (2016) “5p” positive excursion (as representing 6p) were accepted, their lowest positive excursion termed “2p” in the Bayan Gol would become Maloof et al.’s (2010b, fig. 5) excursion 3p, which lies just below the lowest range of mollusks, cap-shaped shells, and hyoliths in Siberia but is not associated with any faunal change in Mongolia. Although Smith et al. (2016, fig. 12) regard the Mongolian lowest Cambrian faunal succession as complementing that known from other paleocontinents, a diverse Early Skeletalized Fossil assemblage occurs at the level of their excursion “3p,” which would be equivalent to Maloof et al.’s (2010b, fig. 5) excursion 4p. If true, then the carbon isotope excursions of the lower Bayan Gol Formation demonstrate a higher known appearance of diverse Early Skeletalized Fossils in the Zavkhan terrane than in Siberia, South China, and Avalonia (Landing and Kouchinsky, 2016). An obvious caveat to both this and the Smith et al. (2016, fig. 12) correlations is that, as reported by Brasier et al. (1996b), this more diverse *Purella* zone assemblage appears at a lithofacies and environmental change in the lower Bayan Gol Formation, marked by the replacement of sandstones and shales by thick limestones, and it does not necessarily record the oldest global appearance of diverse Early Skeletalized Fossil faunas. Only relatively crude estimates exist on the ages of faunal assemblages through the Nemakit-Daldynian and equivalents. Thus, a date of 530 Ma may be more appropriate as an estimate of the age of the (herein) renumbered 4p peak in Mongolia (Landing and Kouchinsky, 2016).

A highly resolved Ediacaran-Cambrian boundary level remains undetermined in the Mongolian sections. Excursion 1p of Smith et al. (2016) in the lower Zuun Arts Formation may correspond to the terminal Ediacaran 1p excursion of Maloof et al. (2005, 2010b). This is succeeded by a strongly negative peak higher in the Zuun Arts Formation, which likely corresponds to excursion W of Brasier et al. (1996b) and possibly to the basal Cambrian carbon isotope excursion (BACE) in South China (e.g., Peng and Babcock, 2008, fig. 4.4).

REFERENCES CITED


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