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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 $\delta^{13}C$) 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 $\delta^{13}C$ 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 $\delta^{13}C$ 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–upper 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 Khayrkhan 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 Khayrkhan 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 (Missarzhevsky, 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 $\delta^{13}C$ 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

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absence of trilobites in the Salaany Gol Formation, which in their view makes this interval older than the Siberian Atdabanian and, thus, renders it a Tommotian equivalent. However, numerous other papers have long shown that Atdabanian-Botomian–equivalent successions may lack trilobites and may have "late" appearances 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 Baltica; e.g., Landing et al., 1989, 2013; Landing and Westrop, 2004).

Smith et al. (2016, p. 462, 467) repeatedly describe 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 identifications by F. Debrenne and A.Yu. Zhuravlev). It is noteworthy that 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 species 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 diagnostic of the Atdabanian and Botomian were either misidentified or have longer stratigraphic ranges than was previously thought." They further 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 is applicable throughout the Siberia–Far East–Mongolia region (for a recent English-language compilation, see, for example, Varlamov et al., 2008). The Siberian zonation was and remains the preeminent succession for global archaeocyath correlation.

Smith et al. (2016) acknowledge the apparent conflict between their $\delta^{13}C$ isotope-based correlations and the Salaany Gol Formation archaeocyath data, and they put forward a resolution of this supposed conflict. They propose that archaeocyath biostratigraphy was developed largely in Siberia and may not be appropriate for correlations elsewhere. It is true that archaeocyath species are provincial and lithofacies controlled (e.g., Kruse et al., 1996, and references therein). However, the strong faunal commonality between Mongolian and late Atdabanian–Botomian faunas of the Siberia–Far East region noted here belies this claim. Even at the genus level, the Salaany Gol Formation fauna can be confidently correlated, because *Ajacicyathus*, *Robustocyathellus*, *Rotundocyathus*, *Urcyathus*, *Leptosocyathus*, *Baikalocyathus*, *Bipallicyathus*, *Pretiosocyathus*, *Ladaecyathus*, *Plicocyathus*, *Agyrekocyathus* (= *Mennericyathus*), *Fransuasaecyathus*, *Alataucyathus*, *Archaeopharetra*, and *Tabulacyathellus* are globally limited to Atdabanian-equivalent and, in some cases, younger strata, while *Ichnusocyathus*, *Fallocyathus*, *Chouberticyathus*, and the non-archaeocyathan spongelike *Acanthinocyathus* 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 archaeocyaths: They correlate the lower Salaany Gol Formation archaeocyaths with the Nemakit-Daldynian Stage of Siberia. Elsewhere, archaeocyaths have their global lowest known appearance 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 appearance of archaeocyaths in Mongolia. Smith et al.'s (2016, their fig. 11) evidence for such old archaeocyaths lies only in their interpretation of the carbon isotope excursions of the Salaany Gol Formation. As noted already, Smith et al. (2016, p. 447, 462) depict the entire formation variously as a Tommotian equivalent (Smith et al., 2016, their fig. 12) or as Nemakit-Daldynian–Tommotian (their fig. 11). Alternatively, they also equated a strong positive $\delta^{13}C$ 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 Formation is more likely to be the local expression of the IV excursion within the lower Atdabanian 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 Atdabanian–Botomian as they surmised that this would require a 6–10 m.y. hiatus within the "middle–upper Salaagol Formation" as marked by a "medium sandstone to pebble conglomerate." This argument is confusing, as only one of their sections (E1340 *in* Smith et al., 2016, their fig. 9) shows a sandstone or conglomerate within the Salaany Gol Formation, and this alone does not suggest a regional unconformity within the unit. However, a more plausible hiatus of such a length may be marked by the thick conglomerate and sandstone interval at the base of the formation (Brasier et al., 1996b, fig. 7), as also suggested by Smith et al. (2016, p. 456, their fig. 9) for their section E1340 southeast of Khukh-Davaa.

Mixed carbonate and siliciclastic rocks of the Bayan Gol Formation underlie the Salaany Gol Formation. Correlation of the Bayan Gol 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 correlation of this unit to the Nemakit-Daldynian, even though Landing et al. (2013) and Landing and Kouchinsky (2016) had earlier used the Early Skeletalized Fossils of the unit to establish 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 continuous section. This means that the $\delta^{13}C$ 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 simple, not "multistage," subsidence history for the Zavkhan terrane, with apparently continuous 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 "Precambrian–Cambrian transition" interval. They place much emphasis on the lowest (and only) occurrence 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 about the base of their informal unit BG4). This correlation may be regarded as forcing the numbered 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* cf. *miocenica*, *Spatangopsis*, 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, orthothecimorphs, tommotiids, cap-shaped 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 crosbyi* 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

Astashkin, Y., Jacobsen, S.B., Knoll, A.H., Butterfield, N.J., and Swett, K., 1995, The Cambrian System of the foldbelts of Russia and Mongolia: International Union of Geological Sciences Publication 32, 132 p.

Bowring, S.A., Grotzinger, J.P., Isachsen, C.E., Knoll, A.H., Pelechaty, S.M., and Kolosov, P., 1993, Calibrating rates of Early Cambrian evolution: Science, v. 261, p. 1293–1298, doi:10.1126/science.11539488.

Brasier, M.D., 1989, China and the palaeotethyan belt (India, Pakistan, Kazakhstan, and Mongolia), *in* Cowie, J.W., and Brasier, M.D., eds., The Precambrian-Cambrian Boundary: Oxford Monographs on Geology and Geophysics 22, p. 40–74.

Brasier, M.D., 1992, Background to the Cambrian explosion: Journal of the Geological Society [London], v. 149, no. 4, p. 585–587, doi:10.1144/gsjgs.149.4.0585.

Brasier, M.D., and Sukhov, S.S., 1998, The falling amplitude of carbon isotope oscillations through the Lower to Middle Cambrian: Canadian Journal of Earth Sciences, v. 35, no. 4, p. 353–373.

Brasier, M.D., Anderson, M.M., and Corfield, R.M., 1992, Oxygen and carbon isotope stratigraphy of early Cambrian carbonates in southeastern Newfoundland and England: Geological Magazine, v. 129, no. 3, p. 265–279, doi:10.1017/S001675680001921X.

Brasier, M.D., Dorjnamjaa, D., and Lindsay, J., 1996a, The Neoproterozoic to early Cambrian in southwest Mongolia: An introduction: Geological Magazine, v. 133, no. 4, p. 365–369, doi:10.1017/S0016756800007548.

Brasier, M.D., Shields, G., Kuleshov, V.N., and Zhegallo, E.A., 1996b, Integrated chemo- and biostratigraphic calibration of early animal evolution: Neoproterozoic–early Cambrian of southeast Mongolia: Geological Magazine, v. 133, no. 4, p. 445–489, doi:10.1017/S0016756800007603.

Debrenne, F., Zhuravlev, A.Yu., and Kruse, P.D., 2015, General features of the Archaeocyatha. Systematic descriptions: Archaeocyatha, *in* Selden, P.A., ed., Treatise on Invertebrate Paleontology, Part E, Porifera Revised, Hypercalcified Porifera, Volume 5: Lawrence, Kansas, University of Kansas, Paleontological Institute, p. 845–1084.

Esakova, N.V., and Zhegallo, E.A., 1996, Biostratigrafiya i Fauna Nizhnego Kembriya Mongolii: Moscow, Sovmestnaya Rossiysko-Mongol’skaya Paleontologicheskaya Ekspeditsiya, Trudy 46, 214 p. [in Russian].

Evans, D.A., Zhuravlev, A.Yu., Budney, C.J., and Kirschvink, J.L., 1996, Palaeomagnetism of the Bayan Gol Formation, western Mongolia: Geological Magazine, v. 133, no. 4, p. 487–496, doi:10.1017/S0016756800007615.

Gibsher, A.S., and Khomentovsky, V.V., 1990, The sections of the Tsagaan Oloom and Bayan Gol formations of the Vendian–Lower Cambrian in the Zavkhan zone of Mongolia, *in* Pozdniy Dokembriy i Ranniy Paleozoy Sibiri: Voprosy Regional’noy Stratigrafii: Novosibirsk, Instituta Geologii i Geofiziki, p. 79–91 [in Russian].

Khomentovsky, V.V., and Gibsher, A.S., 1996, The Neoproterozoic–Lower Cambrian in northern Govi-Altay, western Mongolia: Regional setting, lithostratigraphy, and biostratigraphy: Geological Magazine, v. 133, p. 371–390, doi:10.1017/S001675680000755X.

Knoll, A.H., Kauffman, A.J., Semikhatov, M.A., Grotzinger, J.P., and Adams, W., 1995, Sizing up the sub-Tommotian unconformity in Siberia: Geology, v. 23, no. 12, p. 1139–1143, doi:10.1130/0091-7613(1995)023<1139:SUTSTU>2.3.CO;2.

Kruse, P.D., Gandin, A., Debrenne, F., and Wood, R., 1996, Early Cambrian bioconstructions in the Zavkhan Basin of western Mongolia: Geological Magazine, v. 133, no. 4, p. 429–444, doi:10.1017/S0016756800007597.

Landing, E., and Kouchinsky, A., 2016, Correlation of the Cambrian evolutionary radiation: Geochronology, evolutionary stasis of earliest Cambrian (Terreneuvian) small shelly fossil (SSF) taxa, and chronostratigraphic significance: Geological Magazine, v. 153, p. 750–756, doi:10.1017/S0016756815001089.

Landing, E., and Westrop, S.R., 2004, Environmental patterns in the origin and evolution and diversification loci of early Cambrian skeletalized Metazoa: Evidence from the Avalon microcontinent, *in* Lipps, J.H., and

Wagoner, B., eds., Neoproterozoic–Cambrian Biological Revolutions: Paleontological Society Papers 10, p. 93–105.

Landing, E., Narbonne, G.M., Myrow, P., Benus, A.P., and Anderson, M.M., 1988, Faunas and depositional environments of the Upper Precambrian through Lower Cambrian, southeastern Newfoundland: New York State Museum Bulletin, v. 463, p. 18–52.

Landing, E., Myrow, P., Benus, A.P., and Narbonne, G.M., 1989, The Placentian Series: appearance off the oldest skeletalized faunas in southeastern Newfoundland: Journal of Paleontology, v. 63, no. 6, p. 739–769.

Landing, E., Geyer, G., Brasier, M.D., and Bowring, S.A., 2013, Cambrian evolutionary radiation: Context, correlation, and chronostratigraphy—Overcoming deficiencies of the first appearance datum (FAD) concept: Earth-Science Reviews, v. 123, p. 133–172, doi:10.1016/j.earscirev.2013.03.008.

Maloof, A.C., Schrag, D.P., Crowley, J.L., and Bowring, S.A., 2005, An expanded record of early Cambrian carbon cycling from the Anti-Atlas margin, Morocco: Canadian Journal of Earth Sciences, v. 42, no. 12, p. 2195–2216, doi:10.1139/e05-062.

Maloof, A.C., Ramezani, J., Bowring, S.A., Fike, D.A., Porter, S.M., and Mazouad, M., 2010a, Constraints on early carbon cycling from the duration of the Nemakit-Daldynian–Tommotian boundary $\delta^{13}C$ shift, Morocco: Geology, v. 38, no. 7, p. 623–626, doi:10.1130/G30726.1.

Maloof, A.C., Porter, S.H., More, J.L., Dudás, F.Ö., Bowring, S.A., Higgins, J.A., Fike, D.A., and Eddy, M.P., 2010b, The earliest Cambrian record of animals and ocean geochemical change: Geological Society of America Bulletin, v. 122, no. 11–12, p. 1731–1774, doi:10.1130/B30346.1.

Marshall, C.R., 1990, Confidence intervals on stratigraphic ranges: Paleobiology, v. 16, no. 1, p. 1–10, doi:10.1017/S0094837300009672.

Missarzhevsky, V.V., 1982, Raschlenenie i korrelyatsiya pogranichnykh tolshch dokembriya i kembriya po nekotorym problematichnym gruppam skeletnykh okamenelostey: Byulleten' Moskovskogo Obschchestva Ispytateley Prirody, otdel' Geologicheskiy, v. 57, no. 1, p. 52–68 [in Russian].

Peng, S., and Babcock, L., 2008, Cambrian Period, *in* Ogg, J.G., Ogg, G., and Gradstein, F.M., eds., The Concise Geologic Time Scale: Cambridge, UK, Cambridge University Press, p. 37–46.

Smith, E.F., Macdonald, F.A., Petach, T.A., Bold, U., and Schragg, D.P., 2016, Integrated stratigraphic, geochemical, and paleontological late Ediacaran to early Cambrian records from southwestern Mongolia: Geological Society of America Bulletin, v. 128, no. 3–4, p. 442–468, doi:10.1130/B31248.1.

Van Couvering, J.A., and Berggren, W.A., 1977, Biostratigraphic bases of the Neogene time scale, *in* Kaufman, E.G., and Hazel, J.E., eds., Concepts and Methods of Biostratigraphy: Stroudsburgh, Pennsylvania, Dowden, Hutchinson & Ross, p. 283–306.

Varlamov, A.I., Rozanov, A.Yu., Khomentovsky, V.V., et al., 2008, Kembriy Sibirskoy Platformy. Kniga 1: Aldano-Lenskiy Region [The Cambrian System of the Siberian Platform. Part 1: The Aldan-Lena Region]: Moscow, Novosibirsk, Paleontologicheskiy Institut imeni A.A. Borisyaka RAN, 300 p.

Voronin, Yu.I., Voronova, L.G., Grigor'eva, N.V., Drozdova, N.A., Zhegallo, E.A., Zhuravlev, A.Yu., Ragozina, A.L., Rozanov, A.Yu., Sayutina, T.A., Sysoyev, V.A., and Fonin, V.D., 1982, Granitsa dokembriya i kembriya v geosinklinal'nykh oblastyakh (opornyy razrez Salany-Gol, MHR): Sovmestnaya Sovetsko-Mongol'skaya Paleontologischeskaya Ekspeditsiya: Trudy, v. 18, p. 1–180. [in Russian].

Wilhem, C., Windley, B.F., and Stampfli, G.M., 2012, The Altaids of Central Asia: A tectonic and evolutionary review: Earth-Science Reviews, v. 113, no. 3–4, p. 303–341, doi:10.1016/j.earscirev.2012.04.001.

Zhuravlev, A.Yu., Liñan, E., Gámez Vintaned, J.A., Debrenne, F., and Fedorov, A.B., 2012, New finds of skeletal fossils in the terminal Proterozoic of the Siberian Platform and Spain: Acta Palaeontologica Polonica, v. 57, no. 1, p. 205–224, doi:10.4202/app.2010.0074.

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