BIOSTRATIGRAPHIC DATABASE FOR THE LATE PALEOZOIC OF EURASIA

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Summary
A composite standard biostratigraphic database has been constructed for the Late Paleozoic of Eurasia. This database consists of the total stratigraphic ranges of ~3,600 species of microfossils (fusulinacean and non-fusulinacean foraminifers, conodonts, palynomorphs), ammonoids, brachiopods, and corals as composited from over 40 localities throughout the Arctic, Spain, East European Platform, western Urals, Pricaspian Basin, Pamir Mountains, and Tarim Basin. Traditionally, the composite standard/graphic correlation methodology has been applied in high resolution biostratigraphy. In the present example, graphic correlation of outcrop sections in the Tarim Basin revealed a highly punctuated succession in which four lengthy hiatuses separate five tectono-stratigraphic sequences of generally much shorter duration. Prior to graphic correlation this succession was considered to be depositionally continuous or nearly so. Quite apart from biostratigraphy, the composite standard has been used to evaluate biodiversity trends. Analysis of LADs and FADs in the composite standard showed that time intervals characterized by high rates of speciation invariably also are characterized by high rates of extinction. These intervals generally reflect the extinction of one fauna followed rapidly by the emergence of replacement fauna. In at least one instance, however, the pattern is better explained as an interval of accelerated evolutionary activity in which species' ranges are very short. When normalized to account for uneven data density, the analysis showed that the highest rates of turnover occured within the late Frasnian, at the mid-Carboniferous boundary, and at the Pennsylvanian-Permian boundary. Latest Permian–Earliest Triassic data are too sparse to allow meaningful analysis of the end-Permian mass extinction. Species durations also have been investigated. Highly conservative average species ranges are: 2.37 MA for fusulinaceans; 2.92 MA for conodonts; 8.78 MA for smaller foraminifers; and 9.30 MA for palynomorphs.

Introduction
The "Old World" composite standard (Groves and Brenckle 1997) was constructed to enable graphic correlation of Late Paleozoic strata in the Arctic, Uralian, and paleo-Tethyan realms, which, because of pronounced endemism, differ in their faunal composition from the contemporaneous Midcontinent-Andean realm (Ross 1967). This database consists of the stratigraphic ranges of ~3,600 fossil species as determined by compositing their local ranges at over 40 localities. Fossil taxa included in the database primarily are fusulinacean foraminifers (1570 species), smaller foraminifers (845 species), conodonts (441 species), and palynomorphs (416 species), with smaller numbers of ammonoids, brachiopods, corals, and miscellaneous others. Species' ranges in the database are correctly sequenced relative to one another and they are linearly scaled to the Australian Geological Survey Organization's Paleozoic timescale (Young and Laurie 1995).

One purpose of this article is to demonstrate the superior biostratigraphic resolution obtainable through graphic correlation as illustrated with an example from the Tarim Basin of western China. A second goal is to demonstrate the value of a rigorously constructed composite standard database for analysis of biodiversity trends. Historically, biodiversity patterns have been established at high taxonomic levels (i.e., family rank and higher) for large datasets (Sepkoski 1992), or at the genus and species level for small datasets. By analyzing the stratigraphic distribution of fossils in a composite standard, one can quickly discern patterns at the species level for a very large dataset. Moreover, because species' ranges in a composite standard are compiled from actual occurrences in objective stratigraphic sections, the database has higher integrity and more detail than literature syntheses such as the *Treatise on Invertebrate Paleontology* and similar compendiums.

Applications of the Old World Composite Standard
Graphic correlation.—Fossil occurrences within the Lower Carboniferous–Lower Permian marine beds in the western Tarin Basin have been documented in considerable detail (Zhao et al. 1984; Zhang and Gu 1991; Liao et al. 1992). Chronostratigraphic interpretations derived from previous works are shown in Figure 1. Note that the stratigraphic succession traditionally was depicted as being entirely conformable, without hiatuses, except in the Wuzunbulake area where the Muziduke Group rests unconformably on the Devonian. Although previous authors recognized gaps in the faunal succession, missing biozones were attributed to paleoenvironmental exclusion, not stratigraphic breaks.
Graphic correlation interpretation of the original fossil lists from previous publications led to a radically different chronostratigraphic interpretation (Fig. 1). When graphed against the Old World composite standard, the local ranges of taxa from Tarim Basin sections revealed a highly punctuated stratigraphic sequence of five lithostratigraphic units separated by four regional unconformities. In some areas the unconformities are amalgamated so that as few as two genetic units are present. The development of hiatuses is such that, at any given locality, more geologic time is contained within hiatal gaps than is preserved in the rock record.
Of the four regional unconformities identified, three have associated hiatal gaps of greater than 5 m.y. This suggests that sedimentation in the western Tarim Basin was controlled primarily by local processes rather than by global, third-order eustatic cycles, whose frequency is 1 to 3 m.y. (~1.5 m.y. average; Ross and Ross 1985, 1987). Indeed, the highly punctuated stratigraphic succession is compatible with the depositional scenario described by Carroll et al. (1995) in which complex lithofacies patterns were controlled by tectonic movements associated with plate collisions along the margins of the Tarim continental block.
Biodiversity analysis.—Stratigraphic first and last occurrences of species in the Old World composite standard have been parsed

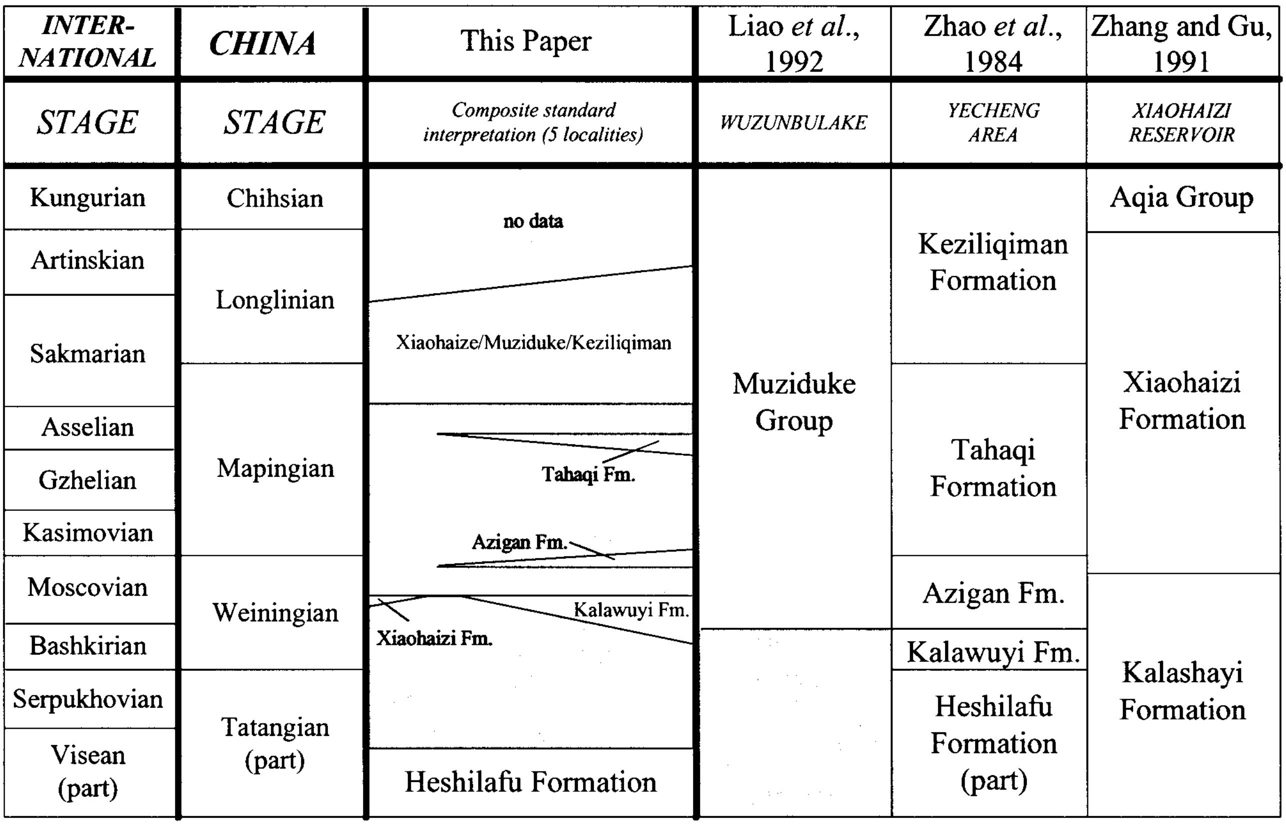

Figure 1. *Traditional vs. graphic correlation interpretation of stratigraphic succession in western Tarim Basin. Shaded areas represent hiatal gaps.*

into 1 m.y. intervals to generate a detailed record of origination and extinction. In terms of raw numbers of events, the Late Devonian, Pennsylvanian, and Early Permian exhibit higher rates of origination and extinction than do the Mississippian and Late Permian. This is somewhat misleading, however, because the Late Devonian, Pennsylvanian and Early Permian also are the most densely populated portions of the database. To normalize for uneven data density, the number of originations and extinctions within a given 1 m.y. interval was divided by the number of stratigraphic sections in the composite standard across that same interval, and the resulting pattern is shown on Figure 2. Remarkably, the curves for originations and extinctions closely mirror one another: i.e., high rates of species origination coincide with high rates of extinction, and low rates of origination coincide with low rates of extinction. This pattern could be consistent with at least two quite different processes. It is likely that episodes of high origination and high extinction reflect the periodic, wholesale elimination of faunas that are then replaced immediately by successor faunas. For example, in the Late Devonian the well documented end-Frasnian extinction seemingly was followed very quickly by the origination of a replacement fauna, and then rates of origination and extinction stabilized at low levels throughout the remainder of the Famennian. Similarly, the pronounced increase in rates at ~314 MA probably reflects the substantial elimination of Mississippian faunas followed by the rapid emergence of Pennsylvanian ones. Extinction followed by replacement does not adequately explain the high rates observed just prior to the Pennsylvanian–Permian boundary. In this instance, species' ranges are uncharacteristically short, particularly among the fusulinaceans. The peaks at and around ~299MA reflect, to a great extent, the origination and extinction of certain species within successive 1 m.y. intervals. Accordingly, the Pennsylvanian–Permian boundary interval was a time of accelerated evolutionary activity, perhaps in response to global ecological pressures, or as a consequence of some evolutionary breakthrough that led to greatly increased rates of morphologic experimentation. Increased rates of origination and extinction within the Late Permian are spurious artefacts of the database caused by stratigraphically isolated records of palynomorphs. Data are too sparse in the Permian–Triassic boundary interval to allow meaningful analysis of the end-Permian mass extinction.

Finally, the composite standard database allows estimation of the duration of species ranges for selected taxonomic groups. The average species range for fusulinaceans is 2.37 MA. This compares with 2.92 MA for conodonts, 8.78 MA for smaller foraminifers, and 9.30 MA for palynomorphs. These averages are highly conservative because they do not include several hundred rare and(or) exceedingly short-ranging species that have been recorded from only one sample.

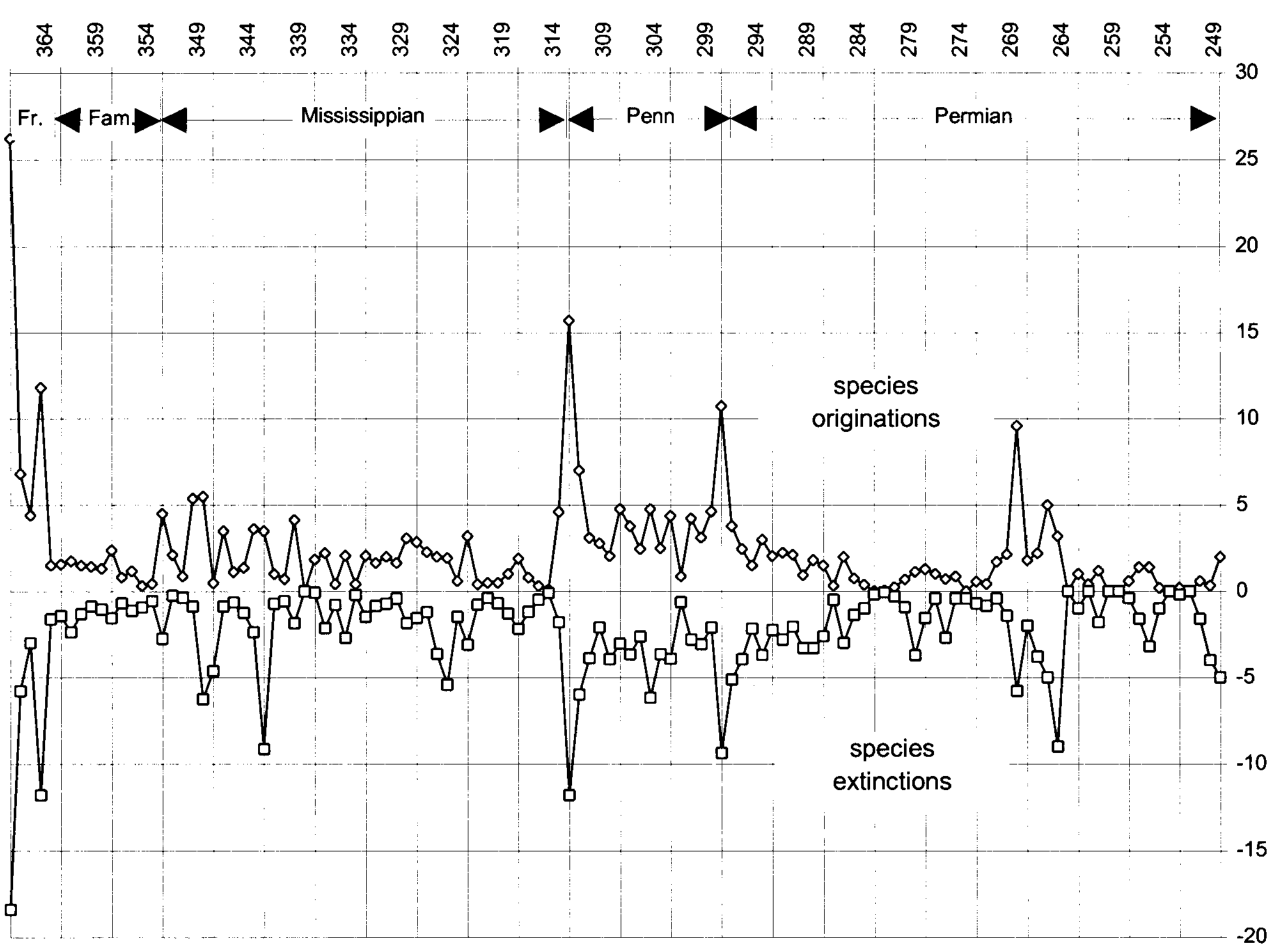

Figure 2. *Normalized rates of species originations and extinctions at 1 m.y. increments.*

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