FORUM

Testing the marine and continental fossil records: Comment and Reply

COMMENT

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Benton and Simms (1995) have presented a fascinating comparative analysis of the fossil records of continental vertebrates and echinoderms and have shown, quite unexpectedly, that the two are of comparative "quality," at least at the familial level. Apart from the direct implications of this result, it begs further analyses of other groups with complex, multielement skeletons, such as the marine vertebrates, marine arthropods, and terrestrial arthropods. However, in interpreting their results, I believe that the authors have been overcautious and have failed to fully delineate the differences between vertebrate and echinoderm paleontology.

I am sure that Benton and Simms are absolutely correct when they say (1995, p. 603) that "the surprisingly good quality of the continental vertebrate fossil record may reflect the fact that it has been exploited more intensively than has that of echinoderms." However, the quality of the fossil record is not just due to the fact that there are more taxonomists working on tetrapods than on echinoderms (Gaston and May, 1992). Rather, it is also a function of differing taxonomic methodologies, which are in turn determined by the amount of variation in gross skeletal patterns shown within the groups in question. The unexpectedly good results obtained for continental vertebrates is undoubtedly at least partially due to the better understanding of how to identify, interpret, and utilize fragmentary specimens of this group in taxonomic studies. The comparatively high quality of the vertebrate fossil record is the result of the superior methodology of vertebrate paleontologists, who have made much better use of their fragmentary fossils than we echinoderm workers. To give but one continental vertebrate example as an illustration, Gillette (1994) was able to reconstruct the sauropod *Seismosaurus* on the basis of only limited postcranial material. Even if no other sauropod had been hitherto described, reconstruction would have been possible due to the relatively conservative arrangement of bones in the continental vertebrate skeleton. In contrast, similar studies in fossil echinoderms are rare. Whereas fossil echinoderm specimens may be locally abundant in many deposits, they usually occur as fragmentary material dominated by skeletal plates that are not generally used in taxonomic studies even at high levels, such as crinoid columnals in the Paleozoic (Ausich, 1990) and echinoid spines in the post-Paleozoic (Gordon and Donovan, 1992). Although these deposits represent potentially important sources of paleontologic data, they are largely ignored by echinoderm taxonomists who concentrate their research efforts on more complete material. This is probably because, even within families and genera, echinoderms may show considerable variation in the number and morphology of plates. Further, plate homologies may make identification to even class level problematic (for example, the columnals of crinoids and blastozoans). Complete echinoderm specimens are usually preserved under an unusual suite of taphonomic conditions (Donovan, 1991), and they thus represent only a selected sample of a sample, that is, the echinoderm fossil record. In contrast, a bone bed composed of more or less disarticulated fragments may be a treasure trove to the vertebrate taxonomist.

These observations have implications for interpretation of the pattern identified by Benton and Simms (1995) at higher and lower taxonomic levels than the family. As consensus is reached on the relationships of the families within the continental vertebrates and the echinoderms, cladistic analysis will change in focus to teasing out the details of subfamilial relationships. Here, I would anticipate that the echinoderm evidence, at the generic and species level, would be superior to that for continental vertebrates, if full use can be made of the record of fragmentary elements. In contrast, at suprafamilial levels it may be that the vertebrates are better known, as is at least suggested by the still not infrequent identification of new echinoderm (sensu lato) classes in the lower Paleozoic (see, for example, Robison and Sprinkle, 1969), based on the sporadic discovery of rare, complete specimens.

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REPLY

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Donovan supports our finding (Benton and Simms, 1995) that, at familial level, the fossil records of continental vertebrates and echinoderms are of comparable quality. We suggested that this might be caused by the fact that more paleontologists have studied fossil continental vertebrates than echinoderms. Donovan makes the interesting additional suggestion that taxonomic methodology might also play a part: Vertebrate paleontologists may be better than echinoderm paleontologists at recognizing taxa from fragmentary specimens. Certainly, there has been a long and heroic tradition

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in the comparative morphology of vertebrates, dating back to Cuvier and Owen, of reconstructing animals from single bones (tests of the technique, based on the subsequent discovery of complete specimens, have usually shown that it works).

Echinoderm fragments have generally been ignored, especially when material is abundant, but also when intact specimens are extremely rare, such as in the Cambrian and Early Ordovician. Two lines of evidence suggest that this is not a problem at familial level, although it affects diversity measures significantly at the specific and generic level. First, the discovery in the last two decades of numerous rich echinoderm faunas from the early Paleozoic (e.g., Sprinkle 1982) has had little impact on our understanding of phylogenetic relationships at family level and above. Instead, progress has been achieved largely through the application of new analytical techniques (e.g., Paul and Smith, 1984) or reinterpretations of homology (Simms, 1994). Second, where efforts have been made to identify fragmentary echinoderms, it is found that species-level diversity increases, but the overall phylogenetic picture remains little changed. These studies suggest that the difficulties encountered are little worse than those for vertebrates. For instance, in a monographic study of Lower Jurassic crinoids (Simms, 1989), simple morphometric and descriptive techniques were found sufficient to identify most fragmentary crinoids to at least family level, and more usually genus and species. Indeed, these techniques revealed that almost 25% (five species) of the British fauna had not been described previously, yet all but one of these new species had been recognized initially on the basis of fragmentary material. Other faunas are under study in the same way (e.g., Donovan, 1986). If such an approach can be implemented more widely, then Donovan's hope, that our knowledge of subfamilial taxa will reflect more closely the true diversity of fossil echinoderms, may be realized.

Comparisons of different sectors of the fossil record may reveal how uniform it is. For example, studies of the tetrapod fossil record have already indicated a number of important points: (1) macroevolutionary patterns change little with big changes in fossil record data (Maxwell and Benton, 1990), (2) the stratigraphic order of appearance of fossils matches node order in cladograms (Norell and Novacek, 1992), and (3) new collecting and taxonomic revision have filled cladistically implied gaps in the tetrapod fossil record to the tune of 5% in 26 years of research (Benton, 1995; Benton and Storrs, 1994, 1995). One test of these assertions was carried out for non-tetrapods when Sepkoski (1993) established that 10 years of family-list revision for marine animals did not substantially affect macroevolutionary conclusions. Further tests of the quality of the fossil record for echinoderms, and indeed for all clades, are required.

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Proterozoic low-Ti iron-oxide deposits in New York and New Jersey: Relation to Fe-oxide (Cu–U–Au–rare earth element) deposits and tectonic implications: Comment and Reply

COMMENT

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Foose and McLelland (1995) is an interesting contribution to the century-old debate over the origin of iron-oxide deposits in New York and New Jersey. The following comments apply specifically to the northeastern Adirondack region and are based on numerous published descriptions of the ores and their host rocks (Postel, 1952; Buddington, 1966; Whitney and Olmsted, 1993, and references therein) and unpublished field observations by the writer. They are intended to show that (1) emplacement of the ores in late- or post-tectonic plutonic rocks as proposed by Foose and McLelland (1995) is inconsistent with field evidence, and (2) a pretectonic, volcanic protolith for the host rocks (Whitney and Olmsted, 1988) is not necessarily precluded by the 1070-1050 Ma U/Pb zircon ages obtained by McLelland et al. (1988).

The host rock of the iron deposits, informally called the Lyon Mountain Gneiss (LMG), consists chiefly of heterogeneous fine to medium-grained leucogneisses, including extreme Na-rich and K-rich facies, interlayered with metasedimentary rocks and amphibolite. These rocks have metamorphic textures, and although the dominant metaluminous leucogneisses contain few diagnostic metamorphic assemblages, almandite garnet and sillimanite both occur locally. Abundant centimetre-scale lenses and laminae of coarse granitic material, generally parallel to foliation, suggest anatexis at upper amphibolite or granulite facies. Hypersthene is commonly present in interlayered amphibolites. Olivine metagabbro lenses up to 2 km long, wholly within LMG, have garnet amphibolite envelopes and are indistinguishable from similar rocks elsewhere in the granulite facies terrane of the Adirondack Highlands.

The claim that these rocks lack strongly developed tectonic fabrics is baffling. Deformation in the LMG is similar in style, intensity, and trend to that in surrounding metasedimentary, granitic, and anorthositic rocks. Moderate to strong foliation is ubiquitous and plainly visible on weathered surfaces even in the most leucocratic facies. Mylonitic fabrics occur locally. Lineation is common, parallel to the regional north-northeast trend. Complex tight to isoclinal folds are present throughout at both regional and outcrop scales; some outcrops display hook-shaped refolds. Amphibolite borders of metagabbro lenses have foliation and lineation parallel to that in the leucogneisses. Thus, it is clear that the LMG predates at least the most recent major deformation and metamorphism. This is implicitly recognized by Walton and de Waard (1963), who assign the ore-bearing leucogneisses of the Mineville and Hammondville districts to "pre-Grenville basement," and by McLelland and Isachsen (1986), who include the LMG in their Piseco Group of "basal" gneisses.

LMG has been variously interpreted as intrusive granite, granitized metasedimentary rocks, partly metasomatic ortho- and paragneisses, and diagenetically altered metavolcanics. Foose and McLelland (1995) infer a plutonic origin but present no new evidence. Some earlier workers (e.g., Gallagher, 1937) also argue for posttectonic intrusion and attribute the foliation to magmatic flow, which, however, hardly explains the lineation, large-scale folding, and metamorphic textures. Leucogranitic dikes that cut neighboring granitic rocks are correlated with the LMG by Postel (1952). If correct, this shows only that the LMG is younger, not that the LMG as a whole is intrusive. No other crosscutting relationships have been described and Postel (1952, p. 32) observes that "rocks of all ages . . . from the Grenville series to the [LMG] show parallel arrangement of their foliation planes. Contact areas . . . are always parallel regardless of the complexity of the local structure." Strong compositional layering in the felsic rocks, and the conformable layers and lenses of metasedimentary rocks, make plutonic origin tenable only if the layering is tectonic. A protolith of felsic volcanics and sedimentary rocks, including some subvolcanic intrusives, is more consistent with the field evidence. Late- or posttectonic intrusive activity is limited to pegmatites and quartz veins, some of which are undeformed and cut both the ore and foliation in the gneisses.

Magnetite ore occurs as tabular bodies parallel to foliation in the gneisses, and as cigar-shaped "shoots" parallel to lineation and fold axes. Local crosscutting features do not obscure the large-scale structural control of the ore, which is most easily explained if pretectonic stratabound ores were deformed together with their host rocks. Syn- or posttectonic replacement, controlled by preexisting structures as suggested by Buddington (1966), is possible but unlikely in the absence of a large-volume igneous source for mineralizing fluids. Localized replacement of host-rock silicates by magnetite, secondary albitization of feldspars, and crosscutting of host rocks by ore may be caused by fluids associated with the pegmatites; they do not require late origin of the ore itself. Pretectonic origin of the ores does not preclude their being of the Fe oxide (Cu-U-Au-REE) type if ore-forming fluids associated with volcanism replaced permeable tuffaceous layers in the protolith. However, the consistent spatial association between ore and the Na-rich or K-rich rocks in most of the deposits described by Hitzman et al. (1992) is not present in the Adirondack ores (Postel, 1952, p. 46; Hagner and Collins, 1967).

The zircon ages and the field evidence can both be taken at face value if the Ottawan deformation and metamorphism in the Adirondack Highlands were significantly later than the 1090-1070 Ma interval proposed by Foose and McLelland (1995). That estimate, evidently based in part on the assumption that the LMG is late- or posttectonic, has little independent evidence to support it. Other U/Pb zircon ages from the Highlands (Silver, 1969; Chiarenzelli and McLelland, 1993) include two clusters at about 1060-1050 and 1030-990 Ma. The latter group coincides with internal Sm/Nd isochrons from an oxide-rich metagabbro (Ashwal and Wooden, 1983) and with several U/Pb garnet and sphene ages (Mezger et al., 1991). Chiarenzelli and McLelland (1993) and Mezger et al. (1991) interpreted these as metamorphic ages. They infer that the former group records the main Ottawan event and attribute the younger ages to later, localized metamorphic events or slow, asynchronous cooling. If, instead, the younger ages date the principal deformation and metamorphism, and the older group an earlier thermal event (possibly associated with LMG volcanism), the LMG and the ores can be *both* 1070-1050 Ma *and* pretectonic.

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REPLY

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Whitney raises several points concerning the origin of the Lyon Mountain Gneiss (LMG) and its relation to low-Ti iron deposits in the Adirondacks. We welcome the opportunity to comment on the most important of these: specifically, (1) isotopic data that bear on the timing of deformational events associated with the Ottawan orogeny and the emplacement of the LMG, (2) the field evidence for a late- to posttectonic emplacement of the LMG, and (3) the relationship of LMG to the low-Ti Fe-oxide ores.

First, Whitney questions whether the published isotopic data demonstrate that LMG emplacement postdated peak Ottawan deformation. New unpublished data obtained by McLelland clearly establish the termination of regional Ottawan deformation in the Adirondacks. The data include a ca. 1045 Ma single grain U-Pb zircon determination from a fayalite granite at Au Sable Forks in the northeastern Adirondacks. This granite is assigned to the LMG by Whitney and Olmsted (1993) and is chemically and physically identical to a larger body of fayalite granite at Wanakena in the western Adirondacks. At both localities the fayalite granite is undeformed, and at Wanakena it crosscuts older rocks ca. 1095 and 1150 Ma as well as their deformational fabrics. Also, single grain zircon determinations obtained on weakly to undeformed quartz-microperthite LMG near Schroon Lake and Port Leyden yield ages of ca. 1048 and 1035 Ma, respectively, and an undeformed, crosscutting quartz-albite pegmatite at the Port Leyden locality has a single grain zircon age of ca. 1035 Ma. These results demonstrate that regional Ottawan deformation ended in the Adirondacks by ca. 1045 Ma, and that granitic LMG of that age, or younger, is clearly late- to posttectonic and consequently cannot be metavolcanic. These zircon ages also suggest that the 1030-990 Ma events referred to by Whitney may be local and are not, in any case, indicative of regional Adirondack deformation or orogeny.

Second, Whitney's assertion that we "claim that these rocks [LMG] lack strongly developed tectonic fabrics" reflects a misreading of the text. We state clearly (p. 666) that LMG "commonly exhibits tectonic fabrics and gneissic layering that are considerably less intense than those in older Adirondack units, indicating that it generally postdates most regional deformation." This observation can be widely demonstrated and has been cited by many previous workers. Specifically it has been noted by Buddington and Leonard (1962), Leonard and Buddington (1964), and Postel (1952) and was important in leading these investigators to insert a period of deformation between an older "quartz-syenite" gneiss and the emplacement of LMG (referred to by Buddington and Leonard as the younger granite). Further, Postel (1952, p. 18–21), Buddington and Leonard (1962, p. 88–89), and Leonard and Buddington (1964, p. 44, 52) go to great lengths to show that the LMG crosscuts both older fabrics and rock units. Significantly, Postel (1952, p. 18) observes that dikes of LMG are discordant to the foliation of surrounding rocks with which they share knife sharp contacts.

Nevertheless, much of the LMG clearly has been deformed to some degree, and we follow many of the earlier workers in assigning these deformed occurrences of LMG to a late orogenic emplacement. Thus, LMG that is dated at ca. 1070-1050 Ma did, in fact, experience Ottawan deformation, but to a lesser extent than rocks in place prior to the onset of orogeny at ca. 1090 Ma.

The syn- to posttectonic emplacement of some LMG also explains the "metamorphic textures" cited by Whitney. He asserts that the high-temperature minerals like garnet and sillimanite associated with some LMG preclude a late- to posttectonic origin. However, we suggest that some LMG was emplaced during the collapsing stages of an overthickened orogen when temperatures are likely to be high and these minerals would be stable.

Third, Whitney expresses skepticism that Fe-oxide ores are hydrothermal and argues instead for a stratabound, pretectonic origin. However, the transgressive nature of many of the ore bodies is well documented (Leonard and Buddington, 1964, p. 39, 40, 44, 69, 75) and led these investigators to conclude that the Fe-oxide deposits are postdeformational replacements on the limbs and noses of earlier folds. Likewise, Postel (1952, p. 37, 44) noted a case of magnetite replacing cataclasite in a postmetamorphic fault and assigned a late-deformational age to iron deposition. Although the concordance of many ore bodies is recognized, the transgressive and replacement features of many others are well documented and preclude a pretectonic, stratabound origin.

Similarly, Whitney denies that the Adirondack low-Ti Fe-oxide ores exhibit any consistent association with Na-rich and K-rich rocks. However, Buddington and Leonard (1962) and Leonard and Buddington (1964) emphasized the association of K-rich rocks with the iron ores in St. Lawrence County and noted that this contrasts with the association of Na-rich rocks and ore that occur to the east in the Clinton County magnetite deposits. Postel (1952, p. 46) showed that 38% of iron deposits in Clinton County are closely associated with rocks whose dominant feldspars are sodic and that have experienced some degree of Na-metasomatism. This association is so striking that Postel (1952, p. 45) specifically called on Na-rich hydrothermal fluids as part of the ore-forming process.

Significantly, Whitney ignores the skarns that are associated with many of these deposits and often host ore. They, like the ore, have a close and consistent association with LMG and are generally undeformed or only weakly deformed. They also commonly contain abundant large crystals of biotite and hornblende, hydrous phases that are not likely to have survived the intense deformation and granulite-facies metamorphic dewatering experienced by their older country rock. We reiterate that the locally discordant ores, locally intense K- and Na-alteration, and skarn are most consistent with a hydrothermal origin.

Finally, we suggest that Whitney's comments may have been unduly influenced by a narrow focus on the northeastern Adirondacks. The genesis of the LMG cannot be resolved by investigating only one area. For example, the LMG in the area discussed by Whitney is well known for its locally intense deformation (Whitney and Olmsted, 1993), but it also is recognized as having prominent north-northeast lineations that are atypical of most of the Adirondacks. These features may reflect a localized deformation during which these rocks were caught between two isostatically rising domes of more rigid anorthosite. Other parts of the Adirondacks contain more diverse examples of LMG, including those with fabrics that are commonly far less deformed than those in older rocks, consistent with the zircon geochronology.

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