Lucas, S.G. and Spielmann, J.A., eds., 2007, The Global Triassic. New Mexico Museum of Natural History and Science Bulletin 41.

CONODONTS VIEWED AS EVOLVING HEAVY-MINERAL GRAINS

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Abstract—Conodonts are common in lag deposits near unconformities. Within these lag deposits, conodonts behave as heavy-mineral grains and represent the ages of the units underlying the unconformity rather than the age of the overlying rock unit. More importantly, the biology of conodonts is unknown, as are the ranges and phylogenies of many species. The burden of proof that any conodont has not been reworked rests with those conodont investigators who have, thus far, generally failed to demonstrate this fact conclusively. Furthermore, we believe that the "Standard Zonation" and environmental interpretations based on conodont biofacies is open to question. Much more attention should be given to "the stratigraphic evidence of a well-marked unconformity" than to these "other classificatory or correlative criterion."

INTRODUCTION

Are conodonts a panacea of stratigraphic and sedimentologic information or are they biologically derived heavy minerals? Conodonts are microscopic (generally 0.1 to 1 mm maximum dimension) hard parts of an unknown group of organisms and are composed of apatite (approximating the mineral fancolite; Epstein et al., 1977). Conodonts are never preserved as whole organisms (except for a very few questionable soft-body traces, Benton, 1987) and their biology is unknown. They have been considered as either internal supports for soft tissues (Hass, 1941) or as teeth of everything from worms to vertebrates (Benton, 1987). Contenders for the conodont-bearing animal extend back to Silurian time, although conodonts occur as early as the Cambrian (Epstein et al., 1977; Mikulic et al., 1985). We have examined the literature to assess some of the applications of conodont studies to geologic problems. This examination brings to mind myriad questions about the validity of these applications, and we conclude that particular care must be taken in the interpretation of this organic silt.

Conodont biostratigraphy accounts for much of the present interpretation of the Paleozoic record. In fact, many of the geologic models presently in use, especially in the Midwest and in the eastern Great Basin, are conodont-driven paleogeographic reconstructions (see, for example Sandberg and Poole, 1977; Metzger, 1989).

Conodont biostratigraphy has been offered as an error-free means of dating strata and as the key to detailed biofacies interpretations used for paleogeographic reconstructions (see, for example Sandberg et al., 1982, and references cited therein). Conodonts, it is claimed, provide "the most refined time-measuring tool for the Late Devonian" (Ziegler and Sandberg, 1990, foreword), and Upper Devonian conodont zones are thought to represent times spans as short as 0.3 Ma (Sandberg et al., 1983, Ziegler and Sandberg, 1982). Conodonts are the basis of a "Standard Zonation" to act "as a standard [sic] against which all other biozonal schemes can be measured" (Ziegler and Sandberg, 1990, p. 14). Conodonts have been used to date tectonic activity with amazing precision, even when most workers cannot agree on anything else about the event (see, for example, Sandberg in Nelsen and Stewart, 1980; Sandberg, 1981). Conodonts have also been used as golden spikes to tag three of the most elusive boundaries in the geological column—the Devonian-Mississippian, the Mississippian-Pennsylvanian, and the Permian-Triassic (Sandberg in Streel, 1972; Sweet, 1988; Brown et al., 1990). Conodonts have also been used by the petroleum industry as an inexpensive tool to measure thermal maturation (the conodont alteration index or CAI; Epstein et al., 1977)

Proponents of conodont biofacies models differentiate many sedimentary environments in minute detail based solely on the conodont fauna. Conodonts have been interpreted as key indicators of eustatic sea-level fall (Sandberg and Ziegler, 1984), bolide impacts (Sandberg et al., 1988; Wang et al., 1991), and many other facets of geology, only a few of which we can enumerate here. If the predictions and interpretations based on this phosphatic Rosetta stone are valid, conodont studies should revolutionize the way geology is done. Before field geologists retire their rock picks, however, an examination of the literature is in order. Because conodonts are so similar to heavy mineral grains, the positions of faunal collections in relationship to "well-marked" unconformities are especially important.

Most of our examples are from the Devonian and Mississippian. Thus reference to Gunter Bischoff, E.B. and E.R. Branson, Charles Collinson, W.M. Furnish, Gilbert Klapper, M.G. Mehl, C.B. Rexroad, C.A. Sandberg, A.J. Scott, and Willi Ziegler seem conspicuous only because these workers have been among the most prolific conodont specialists working on this geologic time period.

CONODONT OCCURRENCES AND EXPLANATIONS

When, as commonly happens, conodont studies contradict macrofaunal and sedimentologic interpretations, conodont specialists offer a host of ad hoc explanations (compare, for example, Williams, 1943 and Scott and Collinson, 1961, and see Alberti et al., 1974). Most of these fall into one or a combination of seven categories: reworking, stratigraphic leakage, homeomorphy, polyphylogeny, multiple morphotypes, ontologenetic development, and subspeciation. Our examination of the literature suggests that reworking of conodonts near unconformities explains many of these contradictions and casts doubt on many of the claims for the utility of conodonts.

Reworking and Stratigraphic Leakage of Conodonts

Conodont abundances, measured as specimens per kilogram of sample, are extremely variable. Most marine sedimentary rocks sampled for conodonts, it appears, do not contain them (see, for example, Uyeno et al., 1982; Sando and Sandberg, 1987). Limestones commonly contain on the order of one to ten specimens per kg (see, for example, Scott and Collinson, 1961), although Uyeno et al. (1982) report recovering only four conodonts from a 263 kg limestone sample. Conodonts, however, are often extremely abundant, especially near the bases of marine sedimentary rock units. These conodont-rich horizons have been the target of extensive study (see, for example, Branson and Mehl, 1934b; Sandberg and Klapper, 1967).

Conodonts are so common at some horizons that they can be expressed as percent phosphate. Sandberg and Klapper (1967) report phosphate content, primarily as conodonts, of 4-15 percent P_2O_5 from the Cottonwood Canyon Member at the base of the Mississippian Madison Limestone in Montana. These horizons would be targets for mining, except they are generally only a few inches thick. These horizons are invariably near unconformities where the conodonts have been hydraulically concentrated (see, for example, Ellison, 1987). Although conodonts are remnants of the material removed by erosion, they have been used frequently to date overlying units (see, for example, Sandberg and Klapper, 1967).

Conodont specialists recognize that many horizons contain reworked conodonts and weed out the older forms to compile "representative" faunal lists (see, for example Sandberg and Klapper, 1967, p. B48). A common assumption used to recognize reworked conodonts is that water-transported conodonts show signs of "marked wear" (Branson and Mehl, 1934b, p. 267). Broadhead and Driese (1991) demonstrated, however, that conodonts, like other heavy mineral grains, may not be abraded during subaqueous sedimentary transport. In order to identify indigenous conodonts, therefore, specialists must depend on the a priori knowledge of the age of the host formation and of the ranges and habitats of the conodonts (see, for example, Ziegler and Sandberg, 1990, foreword) rather than on physical evidence.

Examples of conodonts collected from lag deposits overlying unconformities are quite common in the literature, although they are not always cited as such. These lag deposits include, for example, the basal Chattanooga and New Albany Shale of Tennessee and adjacent areas (Devonian: Ulrich and Bassler, 1926; Bassler, 1932; Hass, 1956); the Mississippian Bushberg Sandstone of Missouri (Branson and Mehl, 1934b); the clastic unit at the base of the Madison Limestone in South Dakota, Wyoming, and Montana (Klapper and Furnish, 1963; Sandberg and Klapper, 1967); the Mississippian fish "tooth" beds of Iowa (Straka, 1968); and the uppermost part of the Jacobs Chapel bed at the top of the New Albany in southern Indiana (considered Mississippian in age by Rexroad, 1969, and others).

Horizons containing less than thousands or tens of thousands of conodonts per kilogram of sample also can contain reworked conodonts, and reworking is not confined to beds immediately overlying unconformities. Examples of such include the lower Hannibal Formation (Mississippian) at Monroe City, Missouri (Branson, 1934), the "Devonian clays" of Iowa (Stauffer, 1940), and the lower Milligen Formation (Devonian (?) and Mississippian) of Idaho (Sandberg et al., 1975). Although reworked conodonts commonly occur with detrital clastics, there are many examples of reworked conodonts in limestone. The Middle Devonian Lingle Formation of southern Illinois (Orr, 1964) and the Cedar Valley Limestone in Iowa (Stauffer, 1940) include reworked specimens, as does the lower Chappel Limestone of Texas (Mississippian: Hass, 1959; Ellison, 1987), and the Louisiana Limestone of Illinois and Missouri (considered Devonian in age by Scott and Collinson, 1961). Examples of faunal mixing are especially common near the Devonian-Mississippian boundary.

In the Mississippi Valley, several workers have reported conodonts from the Devonian Grassy Creek Formation reworked into the Mississippian Bushberg Sandstone and the equivalent Hannibal Formation in some areas but not in others (Branson, 1934; Branson and Mehl, 1934b; Ziegler et al., 1974; Chuauff and Bombrowsik, 1977). The New Albany Shale in southern Indiana and the Chattanooga Shale in Alabama and correlative formations in neighboring areas (Ulrich and Bassler, 1926; Holmes, 1928; Huddle, 1934; Hass, 1956), including the Grassy Creek in Missouri (Branson and Mehl, 1934a), contain conodonts that commonly are reworked into younger strata (see, for example *Polygnathus rhomboidea* in Collinson et al., 1962).

So many species of conodonts are considered as reworked within their ranges that reports of their indigenous occurrences are open to question. The Sheffield (Devonian), Maple Mill (Devonian or Mississippian), and Prospect Hill (Mississippian) Formations of Iowa contain specimens of *Polygnathus semicostata* that "appear to be reworked" because "some specimens are abraded" as well as specimens of *Polygnathus perplexus* and *Polygnathus praehassi* that Metzger (1989, p. 521) considered reworked in the Prospect Hill but indigenous to the Sheffield and Maple Mill. Conodonts that Ellison (1987) considered to be reworked in the Canutillo Formation (Mississippian) of Texas (see, for example, *Polygnathus nodocostatus*) have been reported as indigenous in many other formations of Upper Devonian and Lower Mississippian age including the Grassy Creek Formation (Branson, 1944) and the Louisiana Limestone of the Mississippi Valley, the New Albany and Chattanooga Shales (Campbell, 1946; Hass, 1956), the Sheffield Formation (Anderson, 1966), the Sappington Member of the Three Forks Formation and the Leatham and Pinyon Peak formations of Wyoming, Montana and adjacent areas (considered Devonian in age by Sandberg, 1976), as well as the Upper Devonian Wabamun Formation of southern Alberta (Mound, 1968).

In Europe, a Lower Carboniferous conglomerate of the western Harzgeröder Zone (Südharz) graphically illustrates the problems of reworked conodonts. Only about half the samples from the conglomerate include Lower Carboniferous conodonts. All samples show stratigraphic admixture of conodonts, mostly of Late Devonian age, but Early Devonian conodonts and rare Middle Devonian forms are also present (Buchholz and Luppold, 1990). Understandably, a Carboniferous conglomerate containing clasts of Early, Middle, and Late Devonian age should contain older conodonts, but what happens to the conodonts basinward of the conglomeratic facies?

The Frasnian and Famennian type sections in Europe appear to be no more reliable a guide to conodont distributions than are many of the American sections. The basal Frasnian zone "was originally defined in extremely condensed sequences in the Rhenish Slate Mountains, West Germany" (Klapper, 1989, p. 449), and the Frasnian-Famennian boundary in Belgium is largely a section of mixed detrital clastics and carbonates (Bouckaert et al., 1972). The type section of the Famennian Stage (Upper Devonian) in Belgium is largely detrital clastic material (see, for example, Bouckaert and Ziegler, 1965).

Conodonts that are considered younger than the age assigned to the host formation can present an awkward problem, but they are dismissed by a second working hypothesis—stratigraphic leakage (see, for example, Branson and Mehl, 1934b). Sandberg and Klapper (1967) report that Mississippian age "conodonts have infiltrated downward through cracks" into the top 2.5 cm of the Sappington Sandstone (p. B11) at one locality and have leaked downward 2 m through "hairline fractures" in a regolith at another (p. B13).

Homeomorphy and Polyphylogeny

Not all the difficulties that have arisen in application of the standard conodont sequence have been attributed to faunal mixing. "Past inconsistency in the taxonomic concepts" also "precludes direct application of the . . . standard zones" in many instances (Klapper and Lane, 1989, p. 469).

Two related "taxonomic concepts" commonly invoked by conodont specialists are homeomorphy and polyphylogeny—recurring leitmotifs in the conodont literature. Look-alike species and look-alike genera, generally referred to as homeomorphs, appear throughout the geologic column. Specialists supply these look-alikes with distinct ancestry, although some are explicitly described as morphologically indistinguishable. Homeomorphy implies that evolution has repeated itself. Polyphylogeny, on the other hand, implies that multiple ancestors (as many as three) converged to form a single species (see, for example, *Palmatolepis marginifera duplicata, P. marginifera*, and *P. quadrantinodosa quadrantinodosa* in Sandberg and Ziegler, 1973; *Bispahtodus costatus* in Ziegler et al., 1974; *Scaphignathus ziegleri* in Sandberg and Ziegler, 1979; and *Palmatolepis praetriangularis* in Ziegler and Sandberg, 1990). The similarity of conodont species is frequently tucked away in formal synonymies and cloaked in erudite terms that thwart the uninitiated.

Homeomorphy of species may be valid in instances involving multielement taxonomy. The multielement genus *Kladognathus* Rexroad has been described as an example of related species that differ only in one or two elements used to give the assemblage its specific epithet (Rexroad, 1981). In another case of multielement taxonomy, the genus *Cavusgnathus* Harris and Hollingsworth, several of the elements appear to be shared among closely related species (Brown et al., 1990). In single-element taxonomy, however, the claims of homeomorphic development are more tenuous and generally include unwarranted assumptions about intraspecific variability.

The genus *Gnathodus* Pander offers an entertaining story of homeomorphy and polyphylogeny (for a discussion of the phylogeny of the genus *Gnathodus*, see Rhodes et al., 1969). *Gnathodus commutatus* is reported in the Lower Carboniferous in Germany (Bischoff, 1957), Spain (Thompson, 1972), and Great Britain (Reynolds, 1970), and the Late Meramecian through middle Chesterian in North America (Upper Mississippian, Thompson, 1972). Branson and Mehl (1941, p. 98) noted that "this species [*G. commutatus*] is of special interest because of its similarity to the simpler gnathodids . . . It is likely that a comparable species of an earlier time gave rise to [the genus] *Gnathodus." G. commutatus*, under its various generic and specific aliases, or one of its look-alikes, has also been reported from the Devonian Gassaway Member at the base of the Chattanooga Shale (Hass, 1956), and from supposedly Upper Devonian units, including the Saverton and Louisiana in Illinois and Missouri (Scott and Collinson, 1961), and the Sappington, Leatham, Pinyon Peak, and related units in Utah, Wyoming, and Montana (Sandberg, 1976).

To avoid the problem of a Mississippian genus occurring in the Devonian, Ziegler (1969) defined a new genus, *Protognathodus*. In the definition, he explains that "Die neue Gattung [*Protognathodus*] ist eine homeomorphe Vorläufer-Form der Gattung *Gnathodus*, mit ihr aber phylogenetisch nicht direkt verbunden." Ziegler therefore claims that the genus *Protognathodus* is homeomorphic with, but unrelated to, the genus *Gnathodus*. Numerous species and subspecies of the genus *Protognathodus* have been defined, redefined, combined, and otherwise offered up for examination by conodont specialists. *Gnathodus*, *Protognathodus*, and "broadly homeomorphic" Silurian forms (Rhodes and Austin, 1971, p. 342) are apparently only distinguishable by their ages although conodonts specialists have given them distinct phylogenies. Because all of these genera have been reported from numerous horizons known to contain reworked conodonts, their continued use in chronostratigraphy seems to be an act of faith.

Alberti et al. (1974) reviewed the conodont and macrofauna, information bearing on the age of the "*Protognathodus* fauna" of Ziegler (1969) and concluded that the fauna was unsatisfactory for defining the Devonian-Carboniferous boundary. Nonetheless, despite the problems of homeomorphy and polyphylogeny, the genus *Protognathodus* has been used to redefine the ranges of ammonites (the ammonite genus *Imitoceras* in the Stockum Limestone of Germany: Ziegler, 1969), and the *Protognathodus* fauna is considered an important key to the Devonian-Mississippian boundary by many specialists.

Other examples of alleged homeomorphically and polyplylogenetically derived genera abound. For example, Chauff and Klapper (1978, p. 151) consider the Late Devonian genus *Apatella* to be a possible homeomorph of the Osagean (Early Mississippian) genus *Bactrognathus*: "Despite the considerable stratigraphic gap in occurrence (Kinderhookian Series), the possibility that the two genera are of the same phyletic lineage can not be excluded, thus the homeomorphous relationship is suggested with question."

Multiple Morphotypes and Ontogenetic Development

At the opposite end of the spectrum from the problems of homeomorphy is that of intraspecific variability, generally labeled under the headings of multiple morphotypes and subspecies. Most commonly, multiple morphotypes are delineated and justified because all the morphotypes are within a single sample, whether or not the sample is known to contain reworked conodonts. Examples of both multiple morphotypes and polyphylogenitic lineages seem to be especially common from stratigraphically mixed assemblages. Many subspecies and morphotypes are named and abandoned, depending on who is doing the taxonomy.

Polygnathus inornata Branson and Mehl and *P. communis* Branson and Mehl are two examples of species containing multiple morphotypes (Scott and Collinson, 1961; Straka, 1968). *P. communis* has been described as "a characteristic Lower Mississippian fossil" (Hass, 1959, p. 390), although it has been reported from the lower Upper Devonian in Europe (Delfour and Gigot, 1985). *P. inornata* and *P. communis* have been reported from many horizons containing reworked conodonts.

Icriodus latericrescens robustus Orr, originally described from the Middle Devonian Dundee Formation of Ontario, is an example of a subspecies having three morphotypes that show "no apparent stratigraphic restrictions" (Uyeno et al., 1982, p. 32). The Dundee shows signs of subaerial exposure and reworking, and, not surprisingly, "yielded the most diverse conodont fauna of any unit in the Devonian of southwestern Ontario" (Uyeno et al., 1982, p. 17).

Siphonodella sulcata and *Siphonodella praesulcata* present an even more disturbing problem, primarily because the change from *S. praesulcata* to *S. sulcata* is the golden spike for the Devonian-Mississippian boundary (Sandberg et al., 1972, 1978), a convention followed by most conodont specialists. In their definition of *Siphonodella praesulcata*, Sandberg et al. (1972, p. 19) state: "The great differences in shape, length, and ornamentation of the platform of *Siphonodella praesulcata* n. sp. appear to be intraspecific, because they occur within single collections, no two individuals of which bear entirely the same characteristic. . . . *Siphonodella praesulcata* n. sp. closely resembles *S. sulcata*, and transitional forms, which are difficult to assign, have been observed."

All the units from North America from which Sandberg, Streel, and Scott's collections were derived have been discussed earlier, including the Sappington, the Cottonwood Canyon, the Leatham, the "Glen Park" (and a "pre-'Glen Park' regolith"), the basal Hannibal, and the New Albany. We have already alluded to problems with the upper Famennian. *S. sulcata* is also reported from the Hangenberg Limestone in Germany (Klapper's 1963 resampling of Voges' (1959) localities, cited in Sandberg and Klapper, 1967; also Ziegler, 1969, who cites Sandberg and Klapper, 1967), which is a mixed limestone and detrital clastic section (Voges, 1959). The problems of multiple morphotypes of *S. sulcata* is compounded by Sandberg et al.'s (1972) identification of a specimen called *S. sulcata* by Canis (1968) as a gerontic form.

Pseudopaleontologic Dating: The Myth of the Golden Spike

Siphonodella is considered to be a "characteristic Mississippian genus" (Hass, 1947, p. 137) that "has not been noted in strata older or younger than the Kinderhook" (Branson and Mehl, 1934b, p. 295) and is "perhaps the most distinctive 'Early' Carboniferous genus in North America, Germany, and elsewhere" (Rhodes and Austin, 1971, p. 330). *Polygnathus plana*, described by Huddle (1934) from the New Albany Shale in southern Indiana and reported from the base of the Upper Devonian in Germany by Bischoff and Ziegler (1956), however, has been synonomized by Rexroad (1969) with *S. duplicata*, the type species of the genus.

Siphonodella sulcata, the golden spike for the Devonian-Mississippian boundary, is not without problems. It occurs rarely and generally with reworked conodonts. Huddle (1934) reported a single broken specimen of *S. sulcata* (*Polygnathus sulcata*) from the upper part of the New Albany at Rockford, Indiana. Hass (1959) reported one broken specimen from the Chappel Limestone of Texas (reported as *Siphonodella duplicata* according to Canis, 1968). Boogaert (1967) reported a single broken specimen of *S. sulcata* from the Devonian and Lower Carboniferous of the Cantabrian Mountains, Spain, and two specimens of *Siphonodella*? n. sp. a, which were from a sample containing reworked fauna. Boogaert (1967, p. 186) suggested "it is very probable that *S.*? n.

sp. a . . . is also reworked." One of the highest concentrations of *S. sulcata* (23 specimens) reported is from a lag deposit in the Cottonwood Canyon (Sandberg and Klapper, 1967, p. B51). The lag deposits of the Cottonwood Canyon "are characterized by abundant conodonts; fish plates, teeth, bones, and scales; glauconite grains; phosphatic coprolites, nodules, and pellets; large quartz sand grains and granules; and granules, pebbles, and cobbles derived from the underlying rocks" (p. B29).

Paproth and Streel (1984, p. 256), discussing the absence of specimens transitional between *S. praesulcata* and *S. sulcata* at the type boundary locality, quote Sandberg and Ziegler (1984): "'a brief eustatic fall in sea level' occurred just before the first entry of *S. sulcata* and that the 'short stratigraphic interval wherein the pelagic siphonodella biofacies is interrupted' might be recognized by a shallower protognathodid biofacies, characterized by *Pr. kockeli* (the lower *Protognathodus* Fauna)."

DISCUSSION

All the tales of homeomorphs, heterochronic homeomorphy, polyphylogeny, stratigraphic leakage, subspeciation, ontogeny, and intraspecific variability provide colorful reading. More than that, however, they provide a clue to the truth. All these tales point toward a single cause: reworking of conodonts.

Many species, especially the platform elements, have been reported somewhere in the geologic literature as having been reworked or as occurring with reworked forms. The common occurrence of reworked specimens near the Devonian-Carboniferous boundary is relatively simple to explain. The Late Devonian and Early Mississippian was generally a time of orogenesis along all of the North American margins and in northern Europe. Orogenesis was accompanied by erosion and sedimentation.

Furthermore, conodonts are frequently sampled from units in which they have been hydraulically concentrated for obvious reasons: limestones may require tens of kilograms of sample to produce a reasonable number of conodonts. Naturally occurring concentrates, on the other hand, can provide hundreds or thousands of individuals from a small sample (see, for example Sandberg and Klapper, 1967; Sandberg and Ziegler, 1973). Multielement taxonomic analysis of conodonts suggest that conodont assemblages contain four to eight bars and blades and only one or two platform elements. Conodont suites that deviate from the ratio of elements established using recurring natural assemblages undoubtedly represent a hydraulically sorted population. One rule of thumb for recognizing reworked conodont suites has been proposed: a suite that contains 60-80 percent platform elements probably represent a hydraulically concentrated sample (Ellison, 1987). Even this estimate is probably too high.

Information Loss

When a mixed population from a lag concentrate is treated as a representative time slice, a great deal of evolutionary development is packed into a single species under the label of intraspecific variability. Intraspecific variability is commonly assumed simply because all specimens were derived from a single sample. Incorrect interpretation of intraspecific variability can mask evolutionary development and results in a loss of stratigraphic information.

Further loss of information also occurs when reworking of specimens during erosional intervals is incorrectly interpreted. Reworking of conodonts at higher levels in the geologic column can lead to extension of species ranges and, at least in some instances, to apparent repetition of evolution cloaked in the guise of homeomorphy. The potential of conodonts for the study of erosional history is unique in the sedimentary record. Just as a zircon or another radiometrically datable heavy mineral grain can provide useful information about sources of clastic material and timing of tectonic events, so too, could conodonts provide information on source areas and uplifts. Much of the previous application of conodonts, however, has precluded this potentially important avenue of investigation.

Information Gain

From a geologic perspective, as important as the loss of information caused by the study of mixed faunal populations is the gain of meaningless information, which comes in many forms. One is a misconception of the amount of geologic time represented by the rock record. Conodont assemblages embodied in the "Standard Zonation" may be recognized within lag deposits, which produces phantom zones that expand the apparent time represented by a rock interval and represent clastic provenance and hydraulic sorting rather than time. Workers commonly cannot agree on the number of zones in a section. One such example is the upper *Bispathodus costatus* through *Siphonodella sandbergi* Zones in the Pinyon Peak Limestone and the Fitchville Formation, Late Devonian-Early Mississippian in Utah, zones that may or may not be present (compare Gosney, 1982, with Sandberg and Poole, 1977).

Phantom zones have greatly influenced the geologic interpretation of Paleozoic rocks throughout North America. Examples include the Deseret basin in the eastern Great Basin and the Borden basin in the Illinois basin. Nichols and Silberling (1990) demonstrated that the relative numbers of different kinds of conodonts used to calibrate the conodont deep-basin biofacies in the eastern Great Basin are a function of dissolution of limestones and consequent concentration of insoluble elements, including conodonts. Macke (1991) questioned the conodont-based interpretation of rapid subsidence in the Illinois basin postulated by earlier workers. These postulated starved basins and events of rapid crustal subsidence necessary to form them have been based largely on conodont biostratigraphy applied to rocks containing reworked assemblages. As such, and lacking any other reasonable corroborative evidence, we conclude that these deep basins are part of the myth that surrounds conodont biostratigraphy and are unreasonable in light of more substantiative geologic evidence.

Mixed conodont assemblages can also produce phantom thermal maturities. Because conodonts in mixed assemblages represent the thermal maturity of the source rocks rather than of the host sediments, a variation in CAI should be one of the hallmarks of stratigraphic admixtures. Interpretation of the thermal maturity, therefore, depends on the conodonts having been thermally altered within the host sediments and not within older formations from which they were derived.

Many geologists feel a certain uneasiness when faced with a list of italicized Latin names, especially for fossils that cannot be readily studied, even with a hand lens, and that are present only as fragments in the rocks. This uneasiness has frequently given way to blind faith in the conodont specialists. Reviewing the literature on conodonts suggests that the uneasiness is justified. Many conodont studies seem unconstrained by the geology of the host formations and buck the common sense we acquired in our biology and paleontology classes. Conodonts must be viewed primarily as heavy mineral grains and secondarily as fossils. Conodont studies graphically illustrate the assertion of Keyes (1912, p. 156) that "In the delimitation of geologic formations" too much weight has been placed on "the occurrences of a fauna" and not enough weight has been placed "on the stratigraphic evidence of a well-marked unconformity."

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