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Artikel: A Middle Jurassic-Early Cretaceous low-latitude radiolarian zonation based on unitary sssociations and age of Tethyan radiolarites

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Kapitel: 4: Significance of dating radiolarites and conclusion

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BAUMGARTNER et al. 1980). It is concluded that U.A. 9 (Zone C1) represents the late Kimmeridgian (sensu gallico) and the early Tithonian (Volgian).

U.A. 10 (Zone C2) has been recorded in the Atlantic, Tethys and Pacific. At DSDP Site 367 it is present in the sample 32-4, 9 cm just above samples (up to 32-4, 136 cm) assigned to the *Parhabdolithus embergeri* Nannofossil-Zone, but below samples assigned to the *Nannoconus colomi* Zone, which has its base in sample 32-3, 59 cm. Thus the sample is certainly of middle–late Tithonian age. In Tethyan sections U.A. 10 is found in strata immediately below the basal Maiolica limestone which in some places reach the late Tithonian dated by the first calpionellids corresponding to the *Crassicollaria* Zone A of REMANE. Thus U.A. 10 (Zone C2) may represent the middle and part of the late Tithonian.

U.A. 11 (Zone D) is widely distributed in Atlantic, Tethyan and Pacific localities. Its lowest occurrence coincides with the onset of nannofossil limestone sedimentation of the basal Maiolica Limestone in Tethys and the Blake Bahama Formation in the Atlantic. In the Fiume Bosso section (Umbria, loc. 26) U.A. 11 has been found a few meters above the base of the Maiolica Limestone where it is associated with *Crassicollaria intermedia, C. brevis* and *Calpionella alpina* (MICARELLI et al. 1977) indicating a latest Tithonian age. At DSDP Site 534A, sample 89-2, 47 cm contains U.A. 11, immediately above samples assigned to *Calpionella* Zone B, earliest Berriasian. In the Svinita section (Romania, loc. 9.) U.A. 11 is dated as late Berriasian by ammonites and calpionellids (AVRAM 1976, summary in BAUMGARTNER et al. 1980). Thus U.A. 11 (Zone D) spans the latest Tithonian to late Berriasian.

U.A. 12 (Zone D) has only been found in one section: Trattberg (Austria, loc. 43), its biochronologic significance is thus not yet established.

U.A. 13 (Zone E1) has been positively identified in the Svinita section, where it occurs at the top of the *Calpionellopsis* Zone and in the *Calpionellites* Zone. It does not reach the top of this zone, hence, represents the early Valanginian. At DSDP Site 534A, three samples in Core 81-2 are assignable to U.A. 13–14 and occur immediately below dinoflagellate samples indicating the basal Valanginian.

U.A. 14 (Zone E2) is widely distributed in Tethyan, Pacific, Japanese and possibly also Atlantic sections. In the Svinita section (Romania, loc. 16) it occurs first at the very top of the *Calpionellites* Zone and starts thus in the late early Valanginian. In the Veveyse section (Switzerland, loc. 38) U.A. 14 coexists with the *Callidiscus* Ammonite-zone of the terminal Valanginian. At DSDP Site 167 (Central Pacific, loc. 31) it occurs in samples from core 76-2, 67 cm upwards which according to nannofossils are of Late Valanginian age and younger. The upper limit of this U.A. has not been established.

4. Significance of dating radiolarites and conclusions

4.1 Chronostratigraphy: Correlation of Atlantic and Tethys and timing of Middle–Late Jurassic siliceous sedimentation

4.1.1 Correlation of Atlantic and Tethyan pelagic sequences

The occurrence of the same succession of U.A. at DSDP Site 534 and in various Tethyan basinal sections allows for a detailed correlation of the middle Callovian to

Neocomian pelagic facies (cf. BAUMGARTNER 1983). The middle to late Callovian–early Oxfordian dark-colored, partly organic-rich claystones and calcareous claystones drilled at Site 534 contrast with the coeval very siliceous basal radiolarites (BOSELLINI & WINTERER 1975, Diaspri facies A and B of KÄLIN et al. 1979) of many Tethyan basinal sequences (Fig. 3). The common features of these lithologies and of the cored rocks in the Atlantic are the scarcity or absence of carbonate indicating sedimentation in proximity or below the CCD and the possibly poorly oxygenated sedimentary and/or early diagenetic environment resulting in dark colored, pyrite-rich beds which sometimes preserve a very fine lamination. However, poorly oxygenated conditions must have prevailed in rather small, deeply submerged basins, since coeval sections on adjacent submarine highs (e.g. Trento Plateau cf. WINTERER & BOSELLINI 1981) show well-oxygenated nodular limestones and still other basinal radiolarite sections (Asklipion Nappe, Greece; Oman) show no sign of poor oxygenation. Otherwise, the sedimentation at Site 534 was much more clay-rich and in addition received abundant turbiditic carbonate input from shallower pelagic areas and from carbonate platforms (SHERIDAN, GRADSTEIN et al. 1983). The radiolarian silt layers constitute generally less than 2% and no more than 5.2% of the total sediment in Cores 127–122 (SHERIDAN, GRADSTEIN et al. 1983). Thus, even considering the effects of deep burial diagenesis the sediments in the two realms are not comparable in their silica content.

During the Oxfordian, deposition at Site 534 was predominantly turbiditic and does not compare to the peculiar facies of knobby radiolarites (BOSELLINI & WINTERER 1975, Diaspri facies C of KÄLIN et al. 1979) deposited in a well oxygenated environment at that time in Tethyan basins.

During the Kimmeridgian and most of the Tithonian reddish calcareous claystones and marly chalks assigned to the Cat Gap Formation were deposited both at Site 534 and 367 (Cap Verde Basin). They resemble the Ammonitico Rosso Superiore of Tethyan submarine swells both in faunal content *(Saccocoma)* and dissolution facies (deposited near or above the aragonite compensation depth, SHERIDAN, GRADSTEIN et al. 1983), but are far less siliceous than the coeval Rosso ad Aptici of Tethyan basinal sections, a fact which indicates deeper carbonate dissolution surfaces and/or a shallower seafloor in the Atlantic at that time.

Close to the Jurassic/Cretaceous boundary, in the late Tithonian, sedimentation became more similar in Central Atlantic and Western Tethys with the onset of lightcolored nannofossil chalk or limestone deposition of the Blake-Bahama Formation and the Tethyan Maiolica Formation. On a general scale, Tethyan deposition was still more siliceous. This type of deposition remained remarkably constant and widespread through the entire Neocomian.

4.1.2 Temporal distribution of radiolarite deposition related to subsidence history of Tethyan continental margins and ocean basins

A number of recent papers have dealt with Tethyan Jurassic radiolarite deposition (BOSELLINI & WINTERER 1975, FOLK & MCBRIDE 1978, MCBRIDE & FOLK 1979, KÄLIN et al. 1979, WINTERER & BOSELLINI 1981, BARRETT 1979, 1982, JENKYNS & WINTERER 1982). Much of the interpretations and models in these papers are based on insufficient age control, which led to assumptions like general contemporaneity of radiolarite deposition across oceans and margins. The biochronologic evidence presented in this paper proves a systematic diachronism of the onset of radiolarite deposition and intends to relate this to the subsidence history of the studied paleogeographic realms. As a consequence, some models become very likely and others can clearly be ruled out.

a) Triassic basins – Bathonian onset of radiolarite deposition. – There are a number of basins usually associated with the "Alpine" Triassic that existed prior to the opening of the central Tethys (LAUBSCHER & BERNOULLI 1977) and were the site of deep-water sedimentation at least since the middle Triassic through the entire Mesozoic. Some examples are (Fig. 3): Pindos (FLEURY 1974, 1975, THIÉBAULT et al. 1981, DE WEVER & THIÉBAULT 1981), Asklipion Nappe, Central Argolis Peninsula (BAUMGARTNER 1981) and Hawasina Nappes, Oman (GLENNIE et al. 1974, BERNOULLI & WEISSERT unpubl. mscr.). The Triassic deep-water facies have been dated classically with *Halobia* and more recently by means of conodonts. The Jurassic facies, being very siliceous, have only recently been dated more precisely. At least in the southern Pindos (THIÉBAULT et al. 1980) it appears that carbonate-free radiolarite deposition began in the Bathonian, although this age is based on displaced shallow water foraminifers. The radiolarian data presented herein confirm this early age of onset of radiolarite deposition: U.A. 0 (lower part of Zone A0, Bathonian, see chapter 3) is present in lime-free cherts in the Asklipion Nappe and the Hawasina Nappes.

b) Jurassic basins – early–middle Callovian onset of radiolarite deposition. – Many areas of the Tethyan continental margins are characterized by Early–Middle Liassic tensional tectonics accompanied by rapid subsidence reflected by aprupt changes from shallow water to pelagic facies (e.g. BERNOULLI 1972). The relative basins studied for radiolarians are: The internal Subbetic (AZÉMA 1977, SEYFRIED 1978), Lombardy Basin (BERNOULLI 1964, KÄLIN & TRÜMPY 1977, WINTERER & BOSELLINI 1981) and Umbria (CENTAMORE et al. 1971, BERNOULLI et al. 1979). Subsidence was differential: troughs coexisted with submarine highs on which shallow carbonate sedimentation persisted up to the Pliensbachian (Umbria, etc.) or Aalenian (Trento Plateau) (see below). In the troughs Middle–Late Liassic sediments typically include cherty limestones with abundant redeposited carbonates, ammonite-bearing marls and marly limestones which grade up-section into marls and slightly cherty limestones rich in "pelagic" bivalves *(Bositra)* which were deposited during the Toarcian–Callovian p.p. (KÄLIN et al. 1979) or Aalenian–Bajocian–early Callovian (Umbria: BERNOULLI et al. 1979) below the aragonite solution surface (ibid.). These *Bositra*-rich cherty limestones have furnished radiolarian assemblages assignable to U.A. 0 and to U.A. 1 in their uppermost part. A sudden change to very siliceous or even lime-free radiolarite sedimentation can be observed in all these basins. Since the lowest radiolarites contain usually U.A. 2, this change occurs in all studied sections at the limit between Zone A0 and Zone A1 (a major faunal break, see below), which has been placed within the early Callovian (see chapter 3).

c) Early–Middle Jurassic plateaus and seamounts – late Oxfordian onset of radiolarite deposition. – In many areas affected by the Liassic tensional tectonics, local seamounts or extended plateaus, documented by a remarkably different depositional history, coexisted with adjacent troughs. The examples studied for radiolarians are: Trento Plateau (STURANI 1964, WINTERER & BOSELLINI 1981) and Argolis Peninsula Basal Sequences (BAUMGARTNER 1980, 1981) (seamount sequences from Umbria are in preparation). On these highs shallow water sedimentation persisted up to the Middle Liassic (Argolis Peninsula) or up to the Aalenian (Trento Plateau) and was succeeded, with intervening times of nondeposition/erosion documented by hardgrounds, by condensed pelagic sedimentation. Nodular, marly pelagic limestones typically include Toarcian to Callovian ammonite faunas and *Protoglobigerina.* The first radiolarites generally rest on an important hardground which documents nondeposition during possibly the entire Callovian and early Oxfordian in the Argolis Peninsula and during at least the early Oxfordian on the Trento Plateau. The seamount radiolarites are generally siliceous limestones with chert nodules and stringers interbedded with thin marls or clays (in the Argolis Peninsula calcareous radiolarites [Angelokastron and Ayos Nikolaos Cherts] are overlain by lime-free siliceous mudstones and ophiolitic clastics [Dhimaina Formation] reflecting rapid subsidence related with the Late Jurassic obduction of the Vardar and equivalent ophiolites in eastern Greece, cf. BAUMGARTNER 1981). The lowest seamount radiolarites have furnished radiolarian assemblages assignable to U.A. 7 (Argolis Peninsula) or U.A. 7–8 (Trento Plateau), which would correspond to a Late Oxfordian age.

d) Examples of oceanic crust – middle Callovian–Oxfordian onset of radiolarite deposition. – Dating basal radiolarites resting on pillow lavas, gabbro and serpentinite commonly interpreted as allochthonous remnants of oceanic crust has proven to be delicate owing to the advanced diagenetic or anchimetamorphic stage of these rocks. Nevertheless a few dates are presented here and more are in preparation.

DE WEVER & CABY (1981) determined a late Oxfordian/early Kimmeridgian (U.A. 8) age in metaradiolarites overlying serpentinites and ophiolite breccias in the Chabrières series – the base of postophiolitic schistes lustrés of the western Alps.

On Elba island, the base of the radiolarites resting on what has been interpreted as Ligurian oceanic crust has been dated in two places (cf. locality descriptions loc. 46, 47 and Pl. 12). Surprisingly enough both the base of the probably thickest known radiolarite sequence around Monte Campannello (see also BARRETT 1979, 1982) and the most reduced sequence in the area San Felo–Namia (see also BERNOULLI et al. 1979) show the same age: U.A. 7–8 = Zone B which means a Late Oxfordian to possibly early Kimmeridgian age.

In Liguria the base of anchimetamorphic radiolarites resting on a gabbro boulder conglomerate near Rocchetta di Vara (loc. 48) is dated as U.A. 3–5 (Zones A1/A2) which corresponds to a middle/late Callovian or possibly early Oxfordian age.

In the ophiolites overlying the Pelagonian s.l. units of the internal Hellenides two ages are available at the moment: In the Migdhalitsa Ophiolite Unit of the Argolis Peninsula (loc. 9) a radiolarian sample some m above pillow lavas is assignable to U.A. 3–8, possibly restricted to 3–5, which would correspond to a middle/late Callovian–early Oxfordian age. A well preserved sample from interpillow sediment (J. Simantov, personal communication), of northern Evvoia (loc. 49) is assignable to U.A. 4–5 (Zones A1/A2) which corresponds to a middle/late Callovian possibly early Oxfordian age.

These ages are of prime importance for the paleotectonic reconstruction of the Tethys ocean, which will be discussed elsewhere (WINTERER & BAUMGARTNER, in preparation).

4.2 Paleooceanographic conclusions

The presented radiolarian ages demonstrate fundamental chronostratigraphic relationships which are no longer left to the imagination of the geologist. The proposed age relationships and the following immediate interpretations should be the basis of any paleooceanographic model of the Western Tethys ocean:

1. The contemporaneous deposition of limestone on seamounts/plateaus and of lime-poor to lime-free sediments in immediately adjacent troughs is now firmly established. This clearly implies a bathymetric control of radiolarite deposition (cf. BOSELLINI & WINTERER 1975, etc.).

2. The progressive extension of siliceous radiolarite deposition from older to younger basins and finally onto submarine plateaus shows that the diachronism of the radiolarites is not basin-to-basin as it may appear as for instance in JENKYNS & WINTERER 1982 (Fig. 2) but basin-to-swell, i.e. it is controlled by the subsidence history, reflected by the time of onset of pelagic deposition, of each depositional realm. This implies again a primarily bathymetric control of radiolarite deposition.

3. If it is bathymetry that primarily controlled the sites of radiolarite *deposition,* other factors must have controlled abundant radiolarian *production.* In comparing coeval Atlantic and Tethyan sequences it results that even admitting 6 times higher accumulation rates for the Atlantic to account for detrital and carbonate dilution, radiolarian production/preservation must have been on the order of 5–10 times higher in Tethys to result in the observed silica accumulation rates. Similar conditions may have led to the accumulation of thick Jurassic-Cretaceous chert sequences in western North America (typical example: Marine Headlands, north of San Francisco), southern Central America (Nicoya Ophiolite Complex), Japan and other circumpacific ophiolite-related terranes. The "small-basin" hypothesis, as portrayed by JENKYNS & WINTERER (1982) seems the most plausible way to explain these occurrences.

4. Basins individualized since at least the Middle Triassic had subsided by the end of the Bajocian to depths below the (CCD at that time possibly at 3–4 km) to receive radiolarite deposition.

5. The synchronous early Callovian onset of radiolarite sedimentation in basins created in the early Liassic implies a basinwide paleooceanographic event, related to the paleotectonic evolution of the western Tethys and possibly reflecting also a "worldwide" sealevel rise (see Fig. 3). A rapid rise of the carbonate dissolution surfaces (CCD from 3–4 to 2–3 km) is the most plausible explanation of the observed abrupt change from cherty limestones to chert in many sections (BOSELLINI & WINTERER 1975).

6. The late Oxfordian onset of calcareous radiolarite deposition on seamounts/plateaus may be an indication of a further shallowing of the CCD and/or a relative culmination of radiolarian production or, alternatively, the effect of rapid (rejuvenated) subsidence of these areas to depths close to the CCD.

7. As stressed by many authors, a first-order paleooceanographic change related with an evolutionary bloom of calcareous nannoplankton near the end of the Late Jurassic caused a synchronous change from siliceous or clay-rich to coccolith sedimentation in Atlantic and Tethys and is confirmed by a drastic radiolarian faunal change at this boundary. A drop of the CCD by the order of 2 km (to come to 4–5 km) is reasonable (cf. BOSELLINI & WINTERER 1975). Basins lacking Neocomian limestones

(e.g. southern Pindos, THIÉBAULT et al. 1981) must have subsided to depths below the Neocomian CCD (approx 4.5 km, cf. LAUBSCHER & BERNOULLI 1977).

8. The surprisingly young ages of basal radiolarites on presumable oceanic crust in various ophiolite units contrast with the radiometric ages of the underlying igeous rocks (BIGAZZI et al. 1973). However, age and siliceous facies of the basal sediments on oceanic crust are in agreement with a very shallow (2–3 km) CCD at that time. Likewise, early Middle Jurassic sediments on oceanic crust would have to be calcareous.

These few conclusions refer to the temporal/spatial distribution of radiolarites only. Other aspects like sedimentation processes, duration and intensity of synsedimentary faulting and the subsidence history of the various types of basins and swells need to be reevaluated in view of the new chronologic constraints.

4.3 Radiolarian faunal changes and provincialism related to paleooceanography

As more and more well preserved sample material becomes available, successions of closely related morphotypes can be recognized, which may be interpreted as evolutionary lineages on an intraspecific or intrageneric level (see systematic part of this paper). Several authors have documented the evolutionary nature of vertical faunal change in Mesozoic radiolarians: BAUMGARTNER (1980), PESSAGNO & BLOME (1980, 1982), PESSAGNO & WHALEN (1982), MATSUOKA (1983), etc. However, at most half of the first and final appearances of species included in this study can be related to evolutionary processes, for the other half of the species we do not know possible ancestors nor descendants. Certainly, this can be blaimed to a still fragmentary knowledge of Mesozoic radiolarians owing to a limited amount of samples (the number of studied well preserved samples does, at present, not exceed a few hundreds) and to preservational problems mentioned in the introduction and emphasized in several earlier papers (BAUMGARTNER 1980, 1984, BAUMGARTNER et al. 1980, 1981).

On the other hand, we must be aware of the fact that the presently studied samples are strongly biased towards low and middle paleolatitudes and perhaps towards other paleoecologic niches like small, highly fertile basins with predominantly siliceous biogenic deposition. This would allow for a mecanism of time-related faunal change as suggested in BAUMGARTNER et al. (1980, p. 46): Regional paleooceanographic changes (e.g. changes of water circulation patterns, temperature, salinity and availability of nutrients) would cause a high mortality rate amongst the preexisting radiolarian fauna and subsequent immigration of other species adapted to the new paleooceanographic conditions, rather than evolutionary adaptation of stationary lineages. The ancestors of the newly immigrated and the descendants of the extinct species were to be found in sequences deposited in different paleolatitudinal and/or paleooceanographic settings.

The data presented in this paper do support this hypothesis at least for two events:

1. The early Callovian onset of radiolarite deposition in Jurassic basins of Tethyan continental margins (interpreted as a rise of the CCD in concert with a sea-level rise).

2. The establishment of calcareous nannofossil sedimentation near the end of the Jurassic throughout Atlantic and Tethys (interpreted as a substantial drop of the CCD). Both events coincide with a drastic change in radiolarian faunal composition, which is only partially acknowledged in the present zonation, since a small portion only of the Middle Jurassic and the Early Cretaceous assemblages are included. Of

course, these "faunal changes" were at first hand suspected to be preservational (cf. De Wever in Baumgartner et al. 1980, p. 47), related to changing seafloor and diagenetic environments. However, the same faunal breaks seem to be recorded in sequences which maintain a siliceous record across the mentioned events (e.g. Southern Pindos, Argolis Peninsula, Oman), a fact which would support faunal changes induced by paleooceanographic events.

Further work is needed to establish whether these faunal breaks are limited to Mediterranean Tethys and Atlantic or whether they are found "worldwide" in low latitudes. The published Japanese assemblage-zones compare favorably to the zonation presented herein and suggest similar faunal breaks in Japanese sequences.

There is now definite evidence for Jurassic radiolarian provincialism, which may be either of paleolatitudinal or of paleoecological origin or both. Callovian radiolarian faunas from southern Alaska and eastern Oregon studied by Blome (in press), have virtually nothing in common with Callovian assemblages presented herein and in many Japanese papers (summary in Yao 1983). Blome's (in press) material as well as other Early and Middle Jurassic material presented by Pessagno & Blome (1980) and Pessagno & Whalen (1982) comes from western North American sequences which are predominantly detrital (partly organic-rich sand-, silt- and claystones intermixed with carbonate). These sequences were certainly deposited in a different paleotectonic/paleo-oceanographic setting than was the detritally starved early Central Atlantic–Tethyan seaway, a circumstance which should at least in part account for the different radiolarian faunas.

Alternatively, it may turn out, that the forementioned radiolarian assemblages reflect also a middle to higher latitude influence, although many terranes of western North America are now believed to be of low-latitude origin (e.g. Jones et al. 1982). Much further work of comparing assemblages of known zonal assignment or age is required to substantiate Jurassic faunal provinces. At present it is certainly an oversimplification to distinguish only "Tethyan" (= low latitude) and "Boreal" (= higher latitude) faunal provinces.

4.4 Final conclusions and perspectives

4.4.1 Radiolarian biochronology

Establishing Unitary Associations has proved to be a very effective (if not the only possible) way to integrate a large amount of highly dissolution controlled radiolarian data into a biochronologic framework. The cooccurrence chart of species, formed by vertically ordered U.A., represents maximum ranges of each species with respect to all other species. This is the only type of range which can be accurately defined for radiolarians, based on a given set of data (average ranges are poorly defined and directly contradicted by well preserved samples, see Baumgartner 1984). It is believed that the presented zonation has reached a certain stability in that it should not be altered, but refined by the inclusion of data from further localities and more species in the database.

The geographic reproducibility of many of the proposed zones is still low (see

Fig. 1), owing to the fact that only a few sections cover each time interval. More work is required to test reproducibility within and beyond the studied realms.

The process of further refinement of radiolarian biochronology is twofold:

1. The morphologic units ("morphotypes", "species" or "subspecies") used to establish a range need to be redefined as accurately as possible in terms of vertical morphologic successions (i.e. vertical character change) interpreted as evolutionary lineages. The presented coarse biochronologic framework is the necessary base for this process to ascertain regional correlation and to eliminate local effects of dissolution.
2. More species (drawn from an already existing database of approx. 300 morphotypes) need to be included in order to refine the zonation and to allow better correlation with other zonations.

4.4.2 Extension through the Middle and Early Jurassic

Extending radiolarian biostratigraphy further down into the lower Middle and Early Jurassic in the Tethyan area is mainly a preservational problem. Pelagic limestones in a "starved" continental margin environment have thus far shown a low preservation potential for radiolarians. Much of the replacement chert present in these sequences seems to originate from displaced sponge spicules rather than from radiolarians, but more work is required. Key sections for an Early–Middle Jurassic radiolarian record may be found in basins which inherited pelagic conditions from Triassic times (Lagonegro, Pindos, Asklipion/Othris [internal Hellenides], Antalya, Oman, etc.). These basins were already in the Early Jurassic deep enough to preserve a moderately siliceous sedimentary record, which became entirely siliceous in the Middle Jurassic.

4.4.3 Diachronism of onset of Tethyan radiolarite deposition

A systematic diachronism of the onset of radiolarite deposition, which spans at least the Bathonian to Oxfordian, is documented. The age of the oldest radiolarite clearly relates to the subsidence and bathymetric history of its depositional site expressed by the age of the first pelagic sediment (limestone) underlying the radiolarites. More data, especially from the Umbrian realm, are in preparation to substantiate this relationship. A further step will be the modelling of the Jurassic CCD by means of subsidence curves of individual blocks. However, more direct information on the timing and intensity of synsedimentary block faulting is required to determine the times of rejuvenation of subsidence.

5. Systematic Paleontology

Explanatory remarks

Purpose. – The purpose of the following alphabetic listing of genera and species is twofold:

a) To define as clearly and concisely as possible the morphologic limits of each taxon as they were used in establishing the database and the resulting zonation. Where it seemed practical for routine determination, these morphologic limits were set rather large to deliberately include two or more morphotypes. In other cases, where an increase of vertical stratigraphic resolution was expected, the morphologic limits are defined by differential