THE CRETACEOUS/TERTIARY TRANSITION IN THE BARRANCO DEL GREDERO, SPAIN

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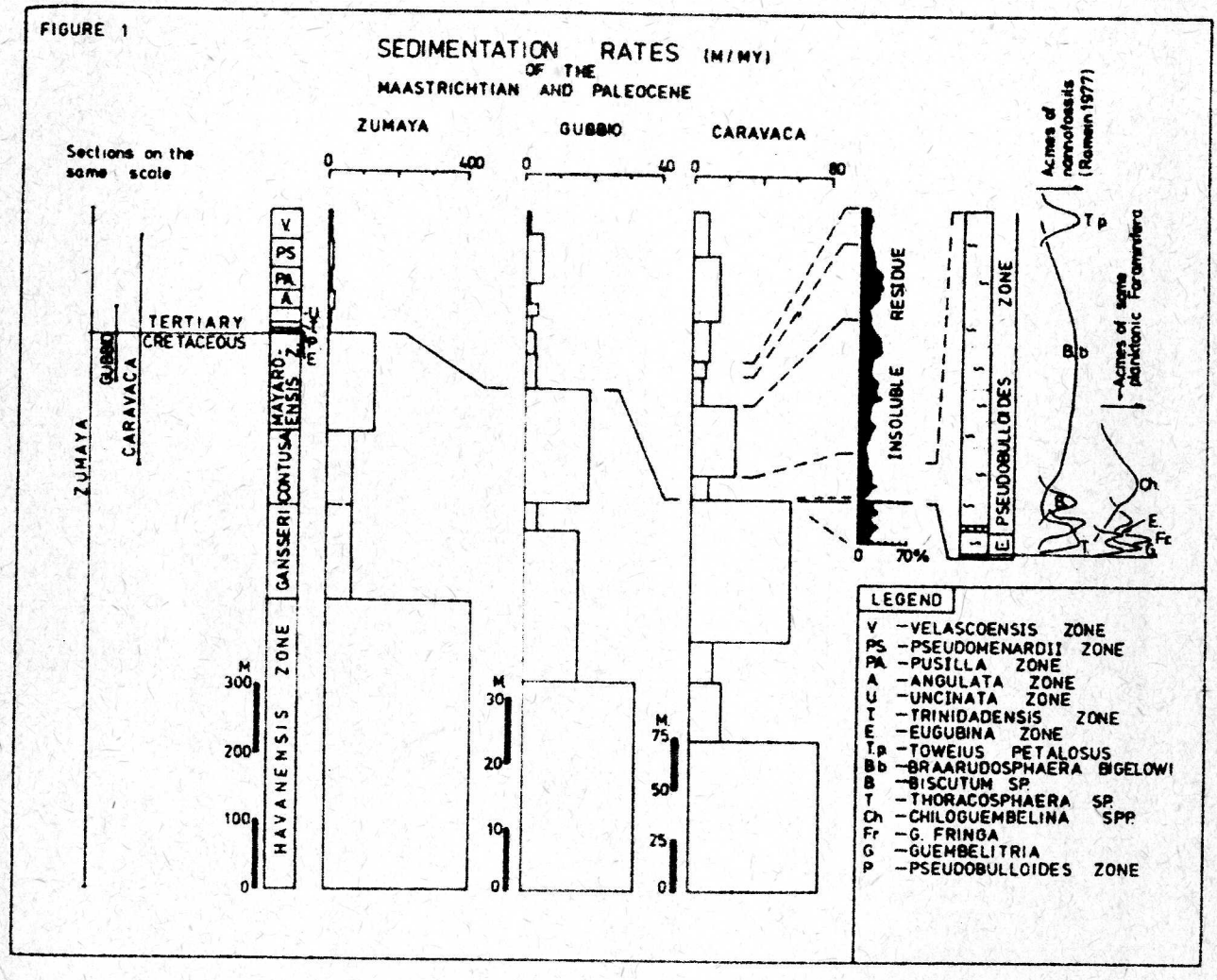
In the north Subbetic zone of the Betic Cordilleras, 3 km SW of Caravaca, the Cretaceous/Tertiary boundary appears in a series of outcrops along a distance of about 1 km in the Barranco del Gredero, within a well preserved and remarkably thick - about 1000 m - sequence of Upper Cretaceous and Paleogene pelagic sediments. The sediments consist of nannofossil/planktic foraminifera bearing soft limestones in the so-called Scaglia Rossa or Couches Rouges facies of the circum-Mediterranean Alpine chains. However, the deposits are incompletely indurated and therefore the foraminifera and nannofossils can be extracted and examined. In contrast to the Scaglia Rossa, only some beds are reddish in colour.

FORAMINIFERAL ZONATION

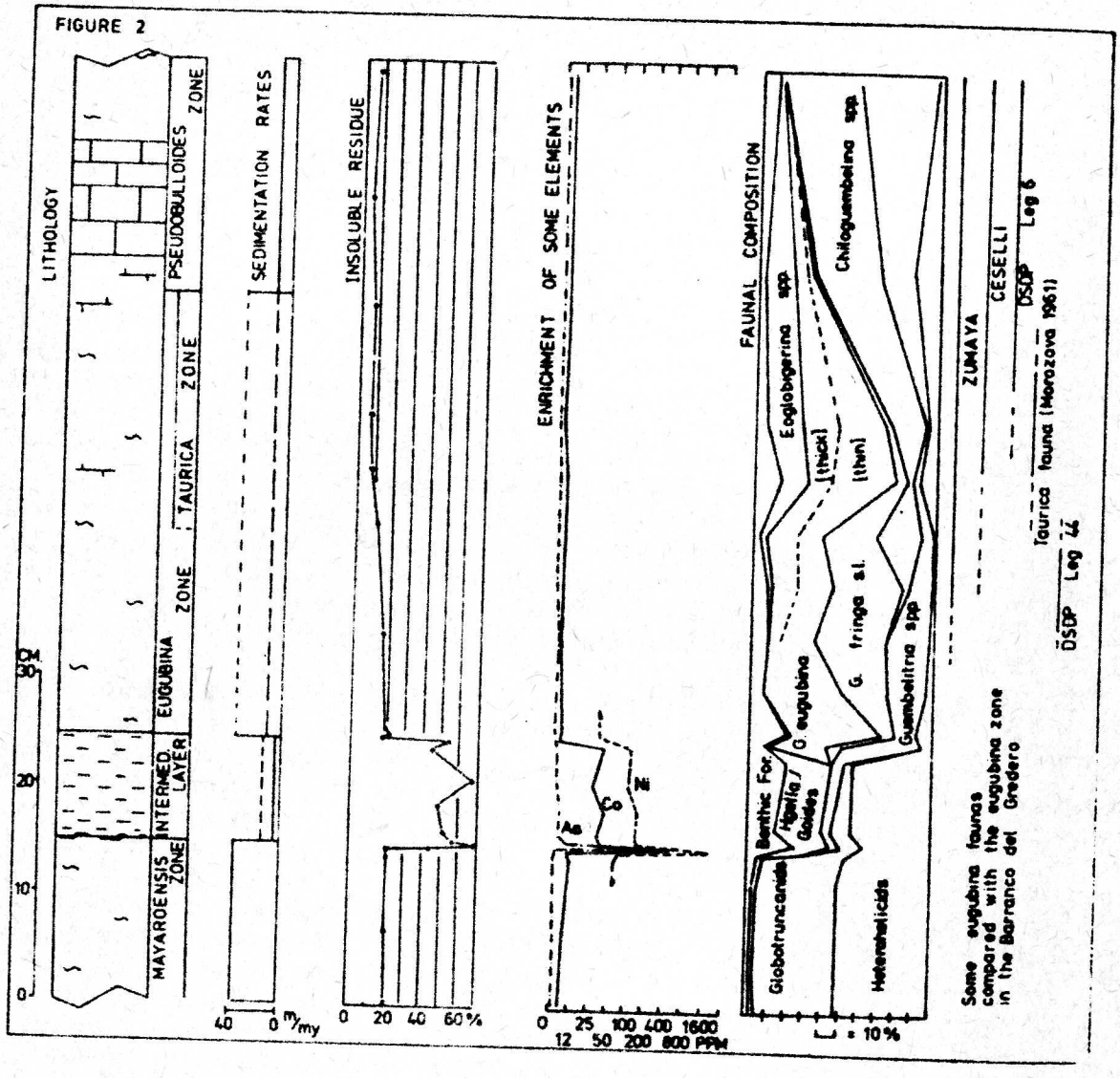
In the whole sequence from Cenomanian to Middle Eocene not a single foraminiferal zone is missing and, moreover, at the Cretaceous/Tertiary boundary an interval is present which may be inserted in the zonal scheme, i.e. between the mayaroensis and eugubina Zones (Fallot *et al.*, 1958; von Hillebrandt, 1974; Smit, 1977; van Veen, 1969). The rock sequence in the Bco. del Gredero near the boundary is divided into six foraminiferal zones (Smit, 1977). A 70 m thick uppermost Cretaceous mayaroensis Zone is followed by an 'Intermediate' interval of 10 cm clayey marl in which neither globotruncanids nor Tertiary faunas occur. These are overlain by a 40 cm thick eugubina Zone, a 11 m thick pseudobulloides Zone and a 35 m thick trinidadensis Zone, respectively.

RATES OF SEDIMENTATION

In order to estimate the duration of the subsequent events at and around the boundary I have calculated the rates of sedimentation on the basis



of numerical timescales of van Hinte (1976) and Hardenbol & Berggren (1978) (Fig. 1). These range from about 70 m/my in the mayaroensis Zone to about 6 m/my in the pseudobulloides Zone. A comparable variation may be observed in the Gubbio and Zumaya sections (Fig. 1). It is hard to see, however, how this picture of strongly differing rates fits with the measured insoluble residue (IR) content (Figs 1/2). This IR has only slightly different values in the mayaroensis Zone on the one hand and the eugubina/pseudobulloides/trinidadensis Zones on the other. In other words, the IR and the monotonous lithology suggest a continuous and not too much fluctuating terrigenous supply, and thus a more uniform sedimentation rate than suggested by the 'equal stage' numerical scales. Palaeomagnetic measurements which will be carried out this year on the section, and/or a revision of the numerical timescale may settle this question.



To avoid the discrepancy, I used the mean sedimentation rates of the entire Maastrichtian and Paleocene (38.6 m/my and 12.2 m/my respectively) and assumed a constant supply of terrigenous material. For the 'Intermediate' layer and the eugubina Zone both rates were used. The events at the boundary occur clearly around the time of deposition of the 'Intermediate' layer (Fig. 2). This layer shows a c. 2½ - fold increase in IR content. Some elements (Co,Ni,Zn,As and Sb) are even more enriched, especially in the basal few mm of the 'Intermediate' layer (Fig. 2). The significance of this enrichment is not yet clear (Smit & Ten Kate, in prep.).

LITHOLOGICAL AND FAUNAL CHANGES AT THE BOUNDARY

The boundary between the mayaroensis Zone and the 'Intermediate' layer is, in fact very sharp. A transition layer of 2-5 mm may be observed, which may even be redeposited owing to physical reworking processes. Within these few mm the Cretaceous planktic foraminifera disappear. If the assumptions mentioned above are correct, this means that within 50-130 yrs (Cretaceous rate) or 160-400 yrs (Paleocene rate) a rich marine fauna became extinct. These are maximum figures; if the period of time had been shorter, this would probably not have been recorded in the sediment. The 'Intermediate' layer itself may have been deposited in 6000-25000 yrs. This represents the time interval in which the extinctions had taken place, and a new fauna had not yet replaced the old one. At the end of this interval quite suddenly, like a 'bloom', the rich eugubina Fauna appears as a kind of 'spontaneous generation'. This fauna lasted for about 15000-50000 yrs.

The occurrence of a hiatus at the Cretaceous/Tertiary boundary in the Bco. del Gredero cannot entirely be excluded, although neither traces of hardground nor induration of the top of the Cretaceous have been observed, sedimentary features occurring, e.g., in the Scaglia Rossa near Gubbio and in so many other Cretaceous/Tertiary transitions (Luterbacher & Premoli Silva, 1964).

Apparently, burrows like *Zoophycos* and *Chondrites* underwent a temporary relapse at the boundary. On the other hand, whereas the whole section has been bioturbated and possible lamination has been destroyed, both the 'Intermediate' layer and, to a lesser extent, the eugubina Zone show lamination and occasional burrows. A similar story is also applicable to the benthic foraminifera and smooth-walled ostracods: temporary impoverishment in the 'Intermediate' layer, after which most species return (B. Romein pers. comm.). Ornamented ostracods seem to disappear, but this subject awaits more detailed research.

I do not believe any indication is to be found in the topmost Cretaceous for the threatening extinctions in the Bco. del Gredero. In spite of so many investigations, no change has been observed in the faunas, benthic or planktic, up to and including the last cm of the Cretaceous (Abtahi, 1975; Smit, 1977); IR and trace elements (Fig. 2) do not show any gradual increase or decrease prior to the few mm transition; lithologically no change at all could be observed nor any increase in activity of turbidity currents. The same lack of 'announcement' may be concluded from two other essentially complete pelagic sections sampled for comparison; from Zumaya in northern Spain and Gubbio in the Italian Appennines (Luterbacher & Premoli Silva, 1964). An increase of benthic foraminifera, as reported by Herm (1963) in the last 1.5 m has not been confirmed by our more detailed sampling. His topmost Cretaceous (50 cm), containing very small foraminifera, represents in fact the eugubina Zone, which is weakly laminated and rich in planktics only in the basal 10 cm.

THE FAUNAS OF THE BOUNDARY LAYERS

Mayaroensis Zone

The faunas of the mayaroensis Zone in the Bco. del Gredero are very diversified; over 55 species of planktic foraminifera have been identified (Abtahi, 1975; Smit, 1977). In the 70 m of this zone only minor changes can be observed; e.g. *G. gansseri* disappears about 10 m below the boundary.

In particular the size fraction of 0.05 - 0.15 mm has been closely examined in search of species which might continue into the Tertiary. Superficially some may resemble the earliest globigerinas, but the general morphology and wall structures as examined in several hundred SEM-graphs show considerable differences. In the 'Intermediate' layer some unornamented forms like *Hedbergella*, *Globigerinelloides* and *Guembelitria* and perhaps some heterohelicids, apparently succeeded in surviving the mass-extinctions for a while (Smit, 1977) as they clearly are relatively enriched in this layer. However, apart from *Guembelitria*, which develops probably into *Globoconusa*, among these species no forms related to *G. eugubina* or other globigerinas could be identified.

Eugubina Zone

The beginning of the eugubina Zone saw the already mentioned sudden 'resurrection' of new planktic faunas. The morphology of *G. eugubina* has already been fully developed. These forms may have had a chance by lack of competition or predation in the earliest Tertiary. Throughout the eugubina Zone, I found a rapid succession of various dominant elements. In order to examine these variations, the eugubina Zone was carefully sampled at 5 cm levels and the faunas were thoroughly prepared and counted (Fig. 2). These acmes resemble in a way the nannofossil acmes, mentioned by many authors in many places over the world (Bramlette & Martini, 1964; Romein, 1977 and ref.). They were also observed in the Gredero section at the base of the Paleocene, though they occur in part in younger levels than the foraminiferal 'blooms' (Fig. 1). About 1 m above the beginning of the pseudobulloides Zone the faunas begin to stabilize, and remain stable in the Paleocene.

Though *G. eugubina* shows strongly variable features, it may easily be recognized. The persistent characteristics of its test are the low trochospire in combination with the closed umbilicus, the long slit-like aperture and the 4 - 8 flattened triangular chambers in the last whorl. In younger specimens the aperture is bordered by a thin lip. The chamber-wall is smooth, recrystallized and shows only rarely some very small pores even in the very well preserved specimens of DSDP leg 44, hole 390. The last chamber may be displaced towards the umbilicus,

thus increasing the trochospirality. This type of *G. eugubina* ranges well into the base of the pseudobulloides Zone, with as most important changes the increase in size from 0.10 - 0.15 to 0.15 - 0.25 mm and the decrease of the mean number of chambers in the last whorl (from 5½-6 to 4½). In the basal 10 cm this flattened type is the exclusive one; from there on there is an increase in number of specimens having different characteristics; the chambers get more globular, the test becomes thicker, the aperture shorter and more circular, and the trochospirality may increase. The umbilicus, however, stays closed, even though the last chambers show a tendency to open it. While the number of pores increases, there is no reticulation to be found in these forms either.

These more developed forms also show a strong variation, e.g. in trochospirality and the number of chambers in the last whorl. All varieties described by Morozova (1961) *(Eoglobigerina trifolia, G. tetragona, G. pentagona, G. taurica* and *G. hemisphaerica)* match these more globular *G. eugubina* individuals quite well, which to a large extent make up the top of the eugubina Zone. It seems that the taurica Zone of Morozova is the same as the top of our eugubina Zone. After comparison of the faunas of the eugubina Zone with those from other areas, on the basis of specimens from these areas as well as from published figures, (Premoli Silva & Bolli, 1973; Krasheninnikov & Hoskins, 1973) it appeared possible to fit these faunas more or less accurately into the 'scheme' of the eugubina Zone of the Bco. del Gredero (Fig. 2). In the Zumaya section, e.g., (Herm, 1963) a similar variation in the eugubina Zone may be found, though the faunas are not as well preserved, while the 'Intermediate' layer and the basal eugubina Zone are missing altogether. The type locality of the eugubina Fauna (at Ceselli; Luterbacher & Premoli Silva, 1964) does not represent the basal eugubina Zone either. Therefore, the type descriptions of this fauna are comparable to the variations of *G. eugubina* as described above, and are even quite close to the taurica Zone faunas. From the Shatsky rise (Hofker, 1978) there is only material from the base of the pseudobulloides Zone, characteristic *G. eugubina* does not occur and the taurica Fauna is present. Species pictured by Krasheninnikov & Hoskins (1973) seem to fit the top of the eugubina Zone, and thus the taurica Zone.

CONCLUSIONS

On the basis of the previous data some conclusions can be drawn and speculations be made. Because of the short period within which the extinctions occur a catastrophic cause is quite likely. The effect of this catastrophe may have been an 'empty' ocean with a potentially large food supply. For 6000-15000 yrs the oceans remain 'empty', with possibly a very small faunal remainder. Quite suddenly an unstable,

and perhaps initially geographically restricted repopulation of fauna and flora occurs. In a rapid succession the one or the other species seems to be dominant. Not until the adaptive ('strong') forms like *G. pseudobulloides* appear, do the less adaptive ('weak') thinshelled species like *G. eugubina* lose the competition and disappear. Thus, the condition for the appearance, and acceleration of speciation, of these 'weak' species seems to be the lack of rivalry and predation. This, too, may be an argument for a sudden worldwide catastrophic extinction.

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