ANN. INST. GEOL. PUBL. HUNG. | vol. LXX. | Budapestini, 1987

Proceedings of the VIIIth RCMNS Congress

THE PLIOCENE/PLEISTOCENE BOUNDARY FROM THE POINT OF VIEW OF LATE CENOZOIC GEOHISTORICAL SCALE

by

V. A. ZUBAKOV, G. S. GANESHIN, B. A. BORISOV,
YU. F. CHEMEKOV, M. F. VEKLICH, G. I. LAZUKOV, and N. A. LEBEDEVA

Introduction. The present-day state of art in Cenozoic stratigraphy is quite contradictory. On the one hand, there is an established system of traditional regional stages for different basins and countries of the world, which is a customary one and well suited for the purposes of mapping, however, enabling no minute interregional correlation. The General Scale of Cenozoic is, at present, in fact, limited to 6 series. On the other hand, in the past 10 to 15 years, an enormous amount of data was accumulated on nontraditional means of detailed stratigraphic subdivision and a high-resolution stratigraphic correlation of Cenozoic deposits by means of micropaleontological zones, dating levels, polarity zones, isotopic and climatic trends and chronometric data. Therefore, it is even now possible to outline the global high-precision and minute geochronological scale of the Cenozoic, differing from traditional Phanerozoic scales.

Practice calls for the quickest settling of this contradiction. However, there is as yet no single strategy two approaches and two basic philosophies exist.

The first approach, formulated by Hedberg and presented in the Stratigraphic Guide (1976), may be defined as a chronostratigraphic one. Hedberg places major emphasis on the choice of stratotypes of stratigraphic boundaries, which are eventually defined by agreement. All regional stratigraphic units should be correlated with the boundary stratotypes by "any means". Drawing of a new Pliocene/Pleistocene boundary with the stratotype in the Vrica section is suggested as an example, demonstrating a successful application of this pragmatic approach.

The second approach, proceeding from the experience of European stratigraphers and presented in the papers by LIBROVICH, MENNER, SCHINDEWOLF, ERBEN, WALLISER etc as well as the ISC documents, places major emphasis on searching and fixation of the natural geohistorical limits, which may be followed interregionally by traces of ecological reconstructions. This approach may be defined as signal or "event" stratigraphy. For drawing valid boundaries of global stratigraphic units within the framework of this approach, not only one "golden spike" is needed, which could be easily put in a wrong place, but a reliable synchronization of a possibly greater number of reference sections in different facies zones, different basins and at different latitudes. The authors of the present paper, who are in favour of the second approach, consider the drawing of the Pliocene/Pleistocene boundary with a stratotype in the Vrica section as a vivid example of an erroneous stratigraphic solution.

Historical note

The problem of the Pliocene/Pleistocene boundary and a closely related, but not identical problem of the Neogene/Quaternary boundary came into being at the very outset of stratigraphy. In 1829, DESNOYERS proposed to distinguish the Mastodon Formation in the Paris basin, corresponding to the contemporary Pliocene and a part of the Upper Miocene, as a Quanternary system. In 1830—33, LYELL distinguished Pliocene and post-Pliocene; and in 1839, he subdivided the post-Pliocene into "old" and "young" or Pleistocene. FORBES in 1946 used, without any good grounds, the term "Quaternary system" as a synonym of the new Pliocene and post-Pliocene, which gave rise to many misunderstandings and discussions. He also made a justified conclusion that the sense of distinguishing Pleistocene lies in the fact that its lower limit corresponds to the latest reconstruction of the latest reconstruction of the organic kingdom and that this subdivision is of climatostratigraphic nature. GIGNOUX (1910) made the basal boundary of Pleistocene coincident with the base of the Sicilian regional stage; and A. P. PAVLOV, with the base of the Baku and Chaudine regional stages of Paratethys.

On ZEINER's initiative, the IGC Session, held in London in 1948, passed a recommendation on lowering the Pliocene /Pleistocene boundary under the base of Calabrian and Villafranchian and on the choice of stratotype of this boundary in the marine section of southern Italy. However, in 1952, ZEINER himself acknowledged that this recommendation was erroneous, and SELLI showed that the base of Villfranchian is older than that of Calabrian. Later RUGGIERI and SPROVIERI (1977) proved that the Calabrian beds are a later synonym of the Sicilian beds. Thus, even the early history of this problem indicates that IGC recommendations (that of 1948 and a more precise one of 1952) were based on erroneous premises.

Nevertheless, an idea about drawing the Pliocene/Pleistocene boundary, and more exactly, the Neogene/Quaternary boundary at a lower level appeared to be highly vital owing to an apparent discrepancy between the Quaternary "system", reduced to the range of Pleistocene, and other Phanerozoic systems. These arguments were presented in a most distinct way by HAUG, and later by V. I. GROMOV (1952), who proposed to draw the boundary of the Quaternary system at a lower level, below Akchaghylian and even Pliocene. Overall, no less that 6 versions of lowering the basal boundary of Quaternary—Pleistocene have been proposed.

The proposed versions of the lower boundaries of Quaternary system (age in Ma according to the present-day estimates)

1 Under the traditional boundary of Pleistocene at the base of the Sicilian regional stage of the Mediterranean (GIGNOUX, 1910) and its equivalents in the Ponto-Caspian (=Chaudine—Baku) on continents, at the top of Villafranchian and at the base of the till of the first sheet glaciation in Europe (FORBES, PENK, PAVLOV, GORETSKY, MARKOV, MENNER, NEVESSKAYA etc), 1.0 to 1.15 Ma.

2 At the base of Apsheronian (YAKOVLEV, 1956) and Santerno (NIKIFOROVA et al., 1982) —sapropelic bed "e" in the Vrica section (AGUIRA, PASINI, 1985)—base of Olduvai, 1.64 to 1.87 Ma.

3 At the base of Amstelian and Pretiglian in Netherlands (ZAGWIJN, 1974)—Neogloboquadrina atlantica Zone in the Mediterranean (DRIEVER, 1984)—Wucheng Loess in China (LIU TUNG-SHENG et al., 1985), 2.3 to 2.5 Ma.

4 At the base of Villafranchian (HAUG, 1930)—Akchaghylian (GROMOV et al., 1961)—the replacement of alluvial accumulation by lacustrine in the Pannonian Basin (KRETZOI, PÉCSI, 1982; RÓNAI, 1982), 3.2 to 3.5 Ma.

5 At the base of Pliocene—Pontian—beginning of glaciation of the Northern Hemisphere (NIKOLAEV, 1950; GROMOV, 1950; YAKHIMOVICH, 1960; ZUBAKOV, 1977), 6.6 to 7.4 Ma.

6 By appearance of the Mastodon—Hipparion fauna (DESNOYERS, 1829)—base of Sarmatian (NALIVKIN)—Serravalian—beginning of the sheet glaciation in the Antarctic, 12 to 14 Ma.

The latest version (2), elaborated by the Working Group on IGCP Project 41, will be discussed in detail below. It should be noted that the 38-year—old history of this problem testifies, firstly, to the fact that it arose on the basis of a logically unfounded mixing of two problems, viz. the choice of the stratotype of the Pliocene/Pleistocene boundary, i.e. of units with fairly distinct stratigraphic range and content, and a classification and determination of the volume of deposits distinguished as the Quaternary system, which has always been and still remains debatable.

What have we rejected

Earlier, stratigraphers, only by intuition, were convinced quite sure that the limit which was in different parts of the planet accepted as the Pliocene/Pleistocene boundary (under Sicilian—Chaudine—Baku and till of the first continental glaciation of Europe), was synchronous. In the USSR, on the basis of the first, in fact, reconnaissance paleomagnetic measurements, a theory was developed that the base of the Baku and Chaudine deposits is younger than the Brunhes/Matuyama boundary and it does not coincide with the Pleistocene boundary under the Sicilian—Menapian and Nebraskan, as accepted in Europe and America (GROMOV et al., 1965; NIKIFOROVA et al., 1958). This assumption, which, as will be shown below, is erroneous, was used as one of the reasons for drawing the Pliocene/Pleistocene boundary in the USSR at a lower level.

The investigations, carried out in the last years, have shown that the Chaudine regional stage in parastratotype sections of Georgia, where it is best represented, for 2/3 belongs to the Matuyama R-zone, and its base coincides with the second (from the top) event of normal polarity with a computed age of 1.1 Ma (ZUBAKOV et al., 1975). In the Azov area, finds of the Taman mammal assemblage are correlated with the Lower Chaudine (LEBEDEVA, 1978), which in itself testifies to the Matuyama age of the Lower Chaudine. In the sections of Azerbaijan, the Tyurkyan subcontinental break in which a N/R inversion has been recorded, presumably of Brunhes—Matuyama age (0,73 Ma), was dated by the ash track method as 0.95 to 1.05 Ma (GANZEI 1984). And, finally, A. V. MAMEDOV and B. D. ALESKEROV (1985) found *Didacna nalivkini*, which is an index fossil for the Baku regional stage, in drilling cores from boreholes, penetrating the Tyurkyan Formation in the Kura Lowland. Thus, the initial conclusion, drawn by G. I. POPOV et al. (1947) about the synchroneity of the Chaudine and Baku deposits, has been confirmed in the light of the latest evidence. However, the age of the base of the Chaudine—Baku regional stage appeared to be 400,000 years older, than it had be assumed before, and reaches 1.0 to 1.1 Ma.

In the same years, it was established that the age of the base of the Sicilian regional stage is also estimated at 1.15 Ma (RIO, 1982; COLALONGO et al., 1981). The Menapian Glaciation, according to the latest evidence, preceeded the Jaramillo, being dated between 1.2 and 1.1 Ma (ZAGWIJN, 1985). The age of the Nebraskan "B" till in North America also appeared to be about 1.2 to 1.0 Ma (EASTERBROOK, BOELLSTORFF, 1981), as well as that of the maximum glaciation till in the Patagonian Andes (MERCER, 1978). The last major reconstruction in the organic kingdom, viz. the replacement of the Villafranchian fauna assemblage by mammals of the Tiraspolian—Galerian, i.e.

Pleistocene proper fauna, also took place in the interval from 1.3 to 0.9 Ma (Geochronology of the USSR, 1974; AZZAROLI, 1983). The appearance of Homo genus is also recorced at this limit (LEINDERS et al., 1985). And, finally, the erosional phase in the Alps, accepted by PENK and BRÜCKNER (1909) for the beginning of Diluvium—Pleistocene, and similar phases in the mountains of Central Asia and Altai, according to paleomagnetic evidence, are dated to the interval from 1.1 to 0.9 Ma.

It is quite surprising that long before precise dating and correlation techniques came into being, our predecessors could find a synchronous stratigraphic level in different regions and define it unanimously as the Pliocene/Pleistocene boundary. Therefore, the history itself has confirmed the efficiency of the methodological principles of "event" stratigraphy. To the abovesaid, it should be added that this level is also easily distinguished in the deep-sea section by appearance of a small *Lephyrocapsa Kampteri* as 1.13 Ma (RIO, 1982); *Mesocena elliptica*, 1.3 to 1.0 Ma; *M. quadrangula*, 1.1 to 1.8 Ma (BUKRY, 1984) etc.

What have we come to

On agreement (and more exactly, by voting) of the Working Group 41 members* the sapropelic "e" horizon in the 300 m mighty Vrica section, south of the Crotone town in the Calabrian Peninsula, has been elected for the new stratotype of the Pliocene/Pleistocene boundary (AGUIRRE, PASSINI, 1985). This sapropelic bed lies 7 to 10 m above the top of the normal polarity zone N2 and 80 m below the base of zone N3. Thirty-five metres above sapropelic bed "e", there is an ash horizon, "m", with *K/Ar* dates of 1.99±0.8 Ma (OBRADOVICH et al., 1982). At the level of the sapropelic bed "e" , *Neogloboquadrina atlantica* disappear and several other species of planktonic foraminifers appear, as well as ostracods, viz. *Cyteropteron testudo* etc.

Due to the fact that abundant datings of ash "m", the overlying tuff and the Pliocene ash, occurring 280 m below the sapropelic bed "e", give a considerable scatter in the interval of 1.99 to 3.6 Ma (ARRIAS et al., 1978; OBRADOVICH et al., 1982), paleomagnetic data have been used for determining the computed age of sapropelic bed "e" of 1.64 Ma (TAUXE et al., 1983). Thus, the lower double zone of normal polarity "N1—N2" has been identified with the Olduvai (1.86 to 1.67). For instance, it was noted that it lies between LAD *Discoaster brouweri* and FAD *Gephyrocapsa oceanica* (RIO, 1982). In other words, the age of the so-called "golden spike", as well as that of N1—N2 polarity zone in the Vrica section, has been obtained by interpolating estimates of dating levels from the oceanic sections.

These interpolations are not unquestionable. Thus, in a more complete section of Santerno in the Appennines, NAKAGAWA et al. (1974) distinguish 7 intervals of normal polarity above the Globorotalia crassaformis Zone; the uppermost one should be assigned to Jaramillo on the basis of *Archidiskodon meridionalis* presence (ARRIAS et al., 1978), whereas the fourth one from the polarity zone N, dated by the appearance of *Arctica islandica*, should be assigned to the Reunion event. However, since RIO (1982) takes FAD *Arctica islandica* and *Cytoropteron testudo* as a synchronous level, in the Vrica section, the lower zones N1—N2 may be assigned to the Reunion. This is in full agreement with FAD *Gephyrocapsa oceanica*, recorded 25 m above the sapro-

* Including, which is highly significant, only those who adhere to drawing the boundary at a lower level, in different versions.

pelic bed "e", if it is dated as 1.77 Ma, according to BERGGREN et al. (1980). The last appearance of *N. atlantica* in the Vrica section, associated with "d—e" sapropels, is dated by DRIEVER (1984) as 2.27 Ma. This means that the lower polarity N1—N2 zones in Vrica could be older than Reunion, i.e. they could correspond to a normal polarity event with an age of 2.33 Ma. The doubts, presented herein, are in good agreement with the appearance of *Hyalinea baltica* in other parts of the world (e.g., near the coasts of Jawa or New Zealand) within the time interval of 2.5 to 2.3 Ma. As is seen, the age of the "golden spike" in the Vrica section is not uniform.

Let us assume that the estimate of sapropelic bed "e" as being 1.64 Ma old is correct, and let us discuss the problem of correlating continental sections with this stratotype. As it is known, the stratigraphy of the continental Pleistocene, as well as of the Upper Pliocene is also mostly based on paleoclimatic evidence. However, these data have been rejected by the Working Group on IGCP Project 41 as a criterion for drawing the Pliocene/Pleistocene boundary and a tool of its interregional tracing (AGUIRE, PASINI, 1985), and the Vrica section has not been studied at all from the viewpoint of climatostratigraphy. Therefore, the only means of correlating continental sections with the Vrica reference section are paleomagnetic and chronometric data.

However, radiological evaluations of continental formations in the interval between 2 and 1 Ma are quite scare and unreliable. As to the zone of normal polarity in the Matuyama orthomagneteme, the picture is also not clear. In different sections, a different number of N zones is distinguished, viz. from 3 to 7, and their correlation is, as yet, extremely difficult. It can be carried out only on the basis of a set of data by distinguishing bio-magnetostratigraphic steps or "seasons" (KOCHEGURA, ZUBAKOV, 1978). However, the position of the Olduvai event relative to biostratigraphic zones in the continental sections is quite unhappy, since it lies within the Upper Villafranchian and Lower Apsheronian. The newly proposed boundary with the age of 1.64 Ma can be "recognized" in continental sections only on the basis of rodent fauna, viz. FAD *Allophaiomys* and LAD *Mimomys pliocaenicus* (HORACEK, 1981). Such sections are still rare. That is why, the Siberian Group in its report on Project 41 makes quite a reasonable conclusion that "the stratotype in Vrica... would rather be called disappointing (similar to the earlier known ones of Le Castella and Santa Maria di Catanzaro), than giving hopes" (ARKHIPOV, 1984, p. 21).

Thus, the Pliocene/Pleistocene boundary at the Vrica "e" level, which, because of its correlation potentialities, is well-suited for deep-sea sediments, is less appropriate for continental formations. That is why, and not by chance, those, who are in favour of drawing the boundary of the Quaternary system on a lower level and are studying continental deposits, let it go down to (3) —2.5 Ma (ZAGWIJN, LIU THUNG-SHENG et al.) (4) —3.2—3.5 Ma (HAUG, GROMOV, KRETZOI, PÉCSI, RÓNAI), or (5) —5.2—7 Ma (YAKHIMOVICH). It is quite obvious, however, that when choosing a stratotype in a marine section, one should take into account the fact, how realistic this boundary is for continental sections.

An indispensable condition for the existence of the International Stratigraphic Scale is the stability of boundaries of valie stratigraphic units. If they are shifted, a new boundary should be better, more practical and convenient than the older one. This condition was not met, when the lower boundary of Pleistocene was transferred from the base of Sicilian (Calabrian) regional stage onto the Vrica "e" level. The new regional stage, viz. Selinuntian (RUGGIERI, SPROVIERI, 1977, etc) is an artificial unit, since the most significant stratigraphic limit is within this stage.

Characteristic features of modern practice of high-resolution stratigraphic correlation and its requirements to boundaries of general stratigraphic units of Late Cenozoic

Below the authors will give a brief account of their ideas about the necessary qualities of boundaries of general stratigraphic units of the Late Cenozoic at a contemporary level. They should be clearly distinguished and easily followed in deep-sea, shelf, and continental sections. Consequently, they cannot be established by agreement of investigators about a particular section, but this should be done by a "natural selection" of signals, traced in practice in all three environments.

Such common signals for the ocean, shelf, and continent are polarity inversions and temperature trends. The second group is more important, for, firstly, they are not registered by one method, as the inversions are, but by a whole set of data and techniques, viz. lithological—facies changes, ecological—paleontological changes, variations of stable isotope composition, fluctuations of the ocean level, geochemical cycles etc. This allows to follow climatostratigraphic units and their boundaries from one section to another and mapping them. In this way, maps of Quaternary deposits are compiled, and this experience has been successfully applied to the Pliocene, too.

Secondly, climatic signals in the interval from the first tens of thousands years to 1.2 Ma are genetically related to variations in the Earth's orbital parameters, viz. precession, axis tilt to ecliptic, and eccentricity, i.e. to astronomic rhythms studied by MILANKOVICH. Modern stratigraphy empirically established climatic sedimentary cycles with duration of 13 to 20, 40, 80 to 100, 400 and 1,200 thousand years respectively, which may be regarded as "signals of precise geological time".

An enormous amount of data, obtained from the studies of deep-sea sediments, particularly isotopic curves (SHACKLETON, DUPLESSY, VERGNAUD—GRAZZINI, SAVIN et al.), temperature factor curves (KELLER, BARRON, THUNELL, BARASH etc), carbonate cycles (GARDNER etc), including information the Mediterranean Sea, to say nothing of a century-long experience of Quaternary geology, testify to the realistic character of climatostratigraphy. It has a long history and has been making rapid progress. Therefore, one cannot be surprised at the position of the authors of the new North American Stratigraphic Code, who have removed climatostratigraphic units from their classification. It is quite obvious that many geologists, among them members of the Working Group on Project 41, who discarded the use of a paleoclimatic criterion for following global stratigraphic boundaries, have got a wrong orientation due to the philosophic concept by Hedberg.

The modern stratigraphic scale with the ever increasing possibilities of dating stratigraphic limits and boundaries, should be very flexible ("spike" less). Valid limits in this scale will be determined more precisely, erroneous boundaries will disappear by themselves. An "event" (=signal) concept of stratigraphy provides for the best progress of the General Stratigraphic Scale, since it regards the latter simultaneously as a tool, and a synthesized draft of geohistorical periodization. The duration and significance of geological events are regarded as interrelated objective criteria for the taxonomic evaluation of certain stages in the geological history and the corresponding section intervals. The strategy, aimed at improving the General Stratigraphic Scale of the Cenozoic should, in our opinion, be based on three aspects:

1 Following the stability of valid stratigraphic limits of the type of the traditional Pliocene/Pleistocene boundary drawn at the base of Sicilian (=Chaudine—Baku);

2 Detailization of the Scale with the help of intergated climatostratigraphic, and micropalaeontological data;

3 Revision of the relations between units, determining the geohistorical content of the Scale.

Let us dwell on point 3. It is clear, that the lowering of the Pliocene/Pleistocene boundary to the level of 1.6, 2.5, and 3.4 Ma does not make this interval a system, comparable with other systems. In this case, Pliocene looses its right to the rank of a series (MENNER, 1977). That is why, the problem of the number of systems, included into the Cenozoic Erathem is quite a special one, and should not be identified with the problem of the Pliocene/Pleistocene boundary. It is apparent, that there cannot, be more than 2 systems in the Cenozoic. These may be either Paleogene and Neogene or Tertiary and Quaternary. In the latter case, the boundary between systems could be made coincident with the base of Zanclian (5.2 to 5.3 Ma), or Serravalian—Sarmatian, 12 to 14 Ma*. The latter would be best founded. In any case, Pleistocene with a boundary of 1.1 ± 0.1 Ma remains the upper stage of the second Cenozoic system.

Conclusions

1 The traditional Pliocene/Pleistocene boundary drawn at the base of Sicilian (Chaudine—Baku), as its dating in different regions has shown, represents a distinct synchronous level, which is traceable on a global scale and equally well on continents and in the ocean. An objective value of this boundary has been confirmed by a long-term practice of the Geological Survey of the USSR.

2 A resolution on making the Pliocene/Pleistocene boundary coincident with sapropelic bed "e" in the Vrica section, the age of which remains debatable, is a sad mistake, which continues a series of similar erroneous recommendations, passed earlier (in 1948 and 1972) concerning this problem. This boundary has got no reliable criteria, which enable fixing it in continental sections. Thus, practical works, which are sponsored by the Geological Survey of the USSR cannot be accomplished on the basis of such a boundary.

3 The cause of erroneous recommendations on changing the position of the Pliocene/Pleistocene boundary lies in the mixing of two problems, viz. a more precise definition of the correlation datum, which is represented by the base of Pleistocene in its traditional sense and improving the geohistorical (-taxonomic) content of the General Scale of Cenozoic.

4 Choice of a local limit, viz. the sapropelic bed "e" in the Vrica section, made on agreement by an initiative group of investigators, as a stratigraphic limit of two series, and, practically, systems, with regard for all the consequences of such a solution, demonstrates the ungrounded character of a new "chronostratigraphic" concept of stratigraphy, formulated by Hedberg and the Stratigraphic Guide (1976).

Suggestions: 1 It is time to discuss urgently all problems, connected with the elaboration of a minute global geochronological scale of the Cenozoic and its geohistorical periodization. The data on the Mediterranean are of paramount interest

* Naturally, there can be no objections to solving such problems by agreement, since in this case, valid boundaries are retained, practice does not suffer, and geohistorical periodization is improved.

for this. Therefore, such a discussion should be undertaken at the next RCMNS Congress.

2 Before this discussion, the solution concerning the choice of sapropelic bed "e" as a stratotype of the Pliocene/Pleistocene boundary should be frozen.

B. A. BORISOV, Y. F. CHEMEKOV and
G. S. GANESHIN,
VSEGEI
199026 LENINGRAD
Sredny Prospect 74

G. I. LAZUKOV
Moscow State University
117234 MOSCOW
Leninskie Gory

N. A. LEBEDEVA
GIN of the USSR Ac. Sci.
109017 MOSCOW
Pyzhevsky Lane 7

M. F. VEKLICH
Geography Division of the
Ukr. SSR Ac. Sci.
252003 KIEV
Vladimirskaya Street 44

V. A. ZUBAKOV
Hydrological Institute
199053 LENINGRAD
2nd line, 23