QUANTITATIVE AMMONOID BIOCHRONOLOGICAL ASSESSMENT OF

THE ANISIAN-LADINIAN (MIDDLE TRIASSIC)

STAGE BOUNDARY PROPOSALS

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Fig 1 Fig. 2

Nearing the vote on the Anisian-Ladinian GSSP, we reassess the western Tethyan ammonoid stratigraphic record, which could serve as the basis for defining the boundary. There are three competing and widely debated proposals which variably equate the stage boundary with the base of the Reitzi, Secedensis, or Curionii Zones. To provide an unbiased evaluation of the boundary proposals, we analysed the ammonoid distribution of 14 key stratigraphic sections from the Southern Alps and the Balaton Highland using quantitative biochronology. Published ranges of more than 60 taxa were processed by the computer-assisted Unitary Association method in order to assess the correlation potential of the three proposed boundary levels. The most pronounced faunal change occurs within the Reitzi Zone. On the basis of its faunal content, this zone offers the most robust correlation between the Southern Alps and the Balaton Highland, whereas its base is clearly marked by the first appearance of *Kellnerites* in both areas. On the other hand, the Unitary Associations corresponding to the Secedensis and Curionii Zones are characterized by significantly fewer taxa, some of which are restricted to only one area. These results provide an additional argument in favor of the Reitzi Zone as the base of the Ladinian.

Introduction

The Triassic stratigraphic community is coming to an historic decision to fix the Anisian-Ladinian boundary by designating its Global Boundary Stratotype Section and Point (GSSP). Much has been written and discussed about the boundary in question. It is not our goal to review the flurry of research papers leading to the vote on the GSSP scheduled for this year. For thorough summaries, the reader is referred to several recent articles, many of which appeared in Albertiana (e.g., Brack and Rieber, 1993, 1994; Mietto and Manfrin, 1995; Vörös et al., 1996).

Practicality dictates the use of various fossil groups and stratigraphic methods, but tradition justifies that the eventual GSSP be defined primarily on the basis of ammonoid succession in the western Tethys. However, there remains three major candidates for the exact stratigraphic level of the boundary and at least two other possibilities were also raised (Kozur, 1995; Mietto and Manfrin, 1995). The three zones which have been repeatedly proposed to serve as the basal unit of the Ladinian Stage (Gaetani, 1993) are (from older to younger): the Reitzi Zone (Vörös et al. 1996), the Secedensis Zone (originally Nevadites Zone, Krystyn, 1983), and the Curionii Zone (Brack and Rieber, 1993). Without reiterating the point of views previously expressed in favor of one candidate or the other, herein we focus on assessing the utility of the proposals by employing quantitative biochronology to compare their correlation potential. The scope of our analysis is restricted to the ammonoid biochronology of the western Tethys. We feel that such a test of the contending proposals is necessary to ensure that the correlation power, arguably the single most important attribute of any stratigraphic boundary choice, will be duly considered by the voters.

Methods

Quantitative biochronology offers several advantages over the traditional methods: it allows fast processing of large amount of range data from a multitude of sections while it eliminates biases that are often inherent in expert judgements that rely on hand-picked index taxa. From the several available quantitative methods (Edwards, 1991), we chose the Unitary Association (UA) method (Guex, 1991) as best suited to discuss the Anisian-Ladinian boundary and its correlation problem. The UA method is attractive because its underlying principle essentially corresponds to that of the Oppel (or assemblage) zone concept. It is based on a deterministic approach that employs graph theory to establish the succession of elementary units of co-occurring taxa, the Unitary Associations. Its algorithmic formulation, through the BioGraph program (Savary and Guex, 1991), affords relatively easy, computer-assisted data processing. The output offers several possibilities (e.g., number of incoming taxa, reproducibility, estimation of correlation uncertainty, etc.) to quantify the correlation potential of biochronological units. Previously, the UA method was found to efficiently construct biochronologically meaningful zonations from complex data (Baumgartner,, 1984). Notably, it was successfully used for estimating the biochronological dating error (Pálfy et al., 1997) and was demonstrated to closely reproduce the ammonite zonation developed by traditional methods (Dommergues and Meister, 1987).

We considered all published references that deal with Anisian and Ladinian (Trinodosus to Curionii zones) ammonoid faunas of the Southern Alps and Balaton Highland, and provide raw distribution data from measured stratigraphic sections. Priority was given to sections with continuous ammonoid record spanning several zones, preferably with abundant and diverse faunas that are taxonomically well-documented. The selected sections will be discussed in detail below. Care was taken to eliminate those intervals within the sections where mixing or condensation was documented or suspected, which could alter the true stratigraphic relationship of taxa. To ensure that the range data are based on consistent taxonomy, nomenclature and identifications were revised according to Vörös (*in press*). A list of taxa occurring in more than one of the selected sections (i.e. those enabling meaningful correlation) was compiled. We omitted the long-ranging forms with little correlation value, e.g. ptychitids, gymnitids, arcestids, and *Norites*. To complement the species-based approach and strengthen correlation, composite genus ranges were added for each section. Thus the ranges of 61 taxa from 14 sections were entered into the database. The BioGraph program was used to construct a biochronologic scheme of Unitary Associations which were then compared to the traditional zonal scheme. Various outputs of the program form the basis of the present discussion.

Sections and faunal distribution data

Four sections were selected from the Balaton Highland, where a wealth of recently obtained stratigraphic information is summarized by Vörös (*in press*). The original sources and section descriptions can also be found in the following sources: Felsõörs, Mencshely and Vászoly - Vörös et al. (1996), Szentkirályszabadja - Vörös (1993). At Felsõörs, the beds 111/A-111/K were omitted because they are interpreted as debris flow deposits containing mixed faunas in limestone clasts (Vörös et al., 1996). The exclusion of Bed 16/A from the Vászoly section is warranted on the basis of its physical discontinuity (Vörös and Pálfy, 1989) and apparently condensed fauna (Vörös et al., 1996). Other sections, including Vörösberény, Szentantalfa (Vörös, 1993), and Sóly (Vörös, *in press*), were also considered in a preliminary phase, when only the sections from the Balaton Highland were processed. They were found to corroborate the correlations without adding to the list of taxa or the UA scheme. Because these sections mainly contain the record of the Reitzi Zone, we omitted them from the final processing to avoid any potential bias in overemphasizing this zone.

Among the ten sections chosen from the Southern Alps, Adaná and Stabol Fresco (Balini et al. 1993) represent the Trinodosus Zone and are important to provide lower limits of taxon ranges of the studied interval. Bagolino (Brack and Rieber 1993) is the most complete section in the region, whereas Seceda (Brack and Rieber 1993) and Monte San Giorgio (Brack and Rieber, 1993; Rieber, 1973) are important reference sections from the Reitzi Zone upwards. The ammonoid distribution of Pértica and Prezzo (Brack et al., 1995) furnishes supplementary stratigraphic information from the higher part of the critical interval. Three sections (Latemar, Adige Valley and Marmolada) from the Dolomites are also included (based on Fig. 5 in De Zanche et al., 1995) as they contain important new data obtained by the Padova team. Without published and detailed documentation of the fauna and taxon ranges, some doubt remains regarding the comprehensiveness of the available stratigraphic data.

Outside the Southern Alps and the Balaton Highland, another western Tethyan section at Epidauros is known to have exquisitely preserved ammonites from the Anisian-Ladinian interval (Krystyn, 1983). However, both its condensed nature and the lack of detailed ammonoid studies preclude its inclusion in this study.

Results

Processing of the stratigraphic distribution data using the BioGraph computer program resulted in 24 successive Unitary Associations (Fig. 1). Each UA is characterized by a unique suite of co-occurring taxa and represents an elementary biostratigraphic unit that cannot be further subdivided. Based on their faunal content, the UA or groups of them can be readily assigned to the zones or subzones of traditional biostratigraphy, as shown on Fig. 1. A simple measure of the correlation potential of a zone is the number of taxa which first appear in it. Obviously, a higher number of taxa occurring at various localities in a unit allows for its better definition and easier correlation. In the Reitzi Zone, 21 species and 11 genus make their first appearance and are also confined to the unit. The Secedensis Zone contains only three such species and one genus, whereas the Curionii Zone includes four key species and one key genus. The highest standing diversity is observed within the Avisianum Subzone (UA 10-19). The significantly higher number of taxa making up the Reitzi Zone also affords finer subdivions. This zone comprises 14 UA as compared to the two and three UA which make up the Secedensis and Curionii zones, respectively.

However, the UA are only useful as long as they represent reproducible stratigraphic units, i.e. if they are unambiguously recognizable in more than one section. A reproducibility chart (Fig. 2) reveals that 10 out of the total 24 UA are restricted to a single key section. Of the 14 UA within the Reitzi Zone, 9 can only be distinguished at a single locality. Nevertheless, groups of UA, corresponding in scope to traditional zones or subzones, are more readily correlatable among the two areas. Notably the Reitzi Zone comprises UA that are equally or alternately present in the Balaton Highland and the Southern Alps. On the other hand, there is only a single case where a UA belonging to the Secedensis Zone is discernible in the Balaton Highland (UA 21 at Felsõörs) and the UA of the Curionii Zone appear to be restricted to the Southern Alps.

Apart from the assessment of the zones, the distribution of UA also allows a simple test of the proposed boundary levels. For reliable correlation, it is desirable that the UA below and above the boundary be widespread in both key areas. The base of the Reitzi Zone is well-defined as UA 6, the basal horizon of the zone (=*Kellnerites* datum) occurs in both areas, in three sections altogether. The underlying UA 5 is present in two sections in the Southern Alps as well as another two sections in the Balaton Highland. Around the base of the Secedensis Zone, only two occurrences of UA 20 and one occurrence of UA 19 are recorded, all from the Southern Alps. Immediately below the base of the Curionii Zone, UA 21 (=*Chieseiceras* horizon) is the most widespread UA in this study with six occurrences, one of them from the Balaton Highland. However, the actual base of the zone, UA 22, is represented only at three localities, all of them in the Southern Alps.

The two principal metrics to analyze in tandem or to weigh against each other are the correlatability of the adjacent units across the regions and the magnitude of faunal turnover across the boundary. In fact, it is a dilemma of emphasizing the practicality of correlation versus the evolutionary underpinning of biochronology. Having demonstrated the aspects of correlatability, we turn our attention towards the evolutionary implications. It is of paramount importance to quantify the disparity across a boundary. We define a boundary disparity index (D), a binary coefficient to measure the faunal turnover across a stratigraphic boundary.

$$D = F_i + l_{i-1} / n_i + n_{i-1} - n_c$$

where F_i is the number of first apperances in the UA above the boundary, L_{i-1} is the number of last apperances in the UA below the boundary, n_i is the number of taxa in the UA above the boundary, n_{i-1} is the number of taxa in the UA below the boundary, and n_c is the number of common taxa in the two adjacent UA.

Arguably, a logical boundary would represent the highest turnover rate within a given stratigraphic interval. Here the highest turnover of 92% is observed between UA 5 and 6, i.e. at the base of the Reitzi Zone. Successively less high turnover rates occur at the base of UA 21 (83%: base of c*hiesense* horizon), UA 20 and 22 (80%: base of Secedensis and Curionii zones), and UA 10 (69%: base of Avisianum Subzone).

Our conclusions can only be validated if they are based on solid data and robust analysis. The characteristics of the biostratigraphic graph constructed reveal that the quality and consistency of data are satisfactory. Only one strongly connected component and five undetermined relationships were detected during the processing of primary biostratigraphic data. The computer input and output files of this study are available upon request from the first author.

Discussion

On the basis of a quantitative biostratigraphic analysis using the Unitary Association method, a case can be made that the Reitzi Zone is better than the other two candidates for the basal Ladinian in its correlation potential. Among the three proposed units, the Reitzi Zone includes the greatest number of taxa available for correlation and offers the best possibility for further subdivision. Its lower boundary, the potential GSSP level, is more suitable than that of the Secedensis and Curionii zones in that it is defined by two UA which occur in several sections in both key areas, the Southern Alps and the Balaton Highland. It is also characterized by the highest turnover rate. The UA method permits an instructive thought experiment: without any prior history of stratigraphic subdivisions in the studied interval, which level could be selected as a most suitable boundary? Based on the metrics discussed above, the lower boundary of UA 6 (i.e. the base of the Reitzi Zone) scores highest overall among all the boundaries separating the 24 UA distinguished here.

An obvious question is whether the UA-based biostratigraphy and the conclusions presented are applicable globally. Initially we attempted to compile a global database by including the North American record. Two well-known areas outside Europe are Nevada (Silberling and Nichols, 1982) and the Canadian Rocky Mountains (Tozer, 1994) but neither has yielded species which would be common to the western Tethyan sections considered here. Although there are a few common genera, well-established Jurassic examples suggest that first appearances of genera in Europe and in North America may be offset by as much as one ammonoid zone (Smith et al., 1988: Jakobs et al., 1994). Consequently, genus-based intercontinental correlations should not be given chronostratigraphic value until independently proved. At present the best approach is to chose the boundary on the basis of the western Tethyan record and implement its global correlation using integrated stratigraphic methods.

In closing, we shall emphasize that we do not endeavor to offer any definitive judgement, only demonstrated some testable ways to quantify the merits of different boundary levels from the perspective of ammonoid biostratigraphy. The selection of GSSP should still include careful measuring of all arguments put forward so far, particularly in a context of integrated chronostratigraphic correlation.

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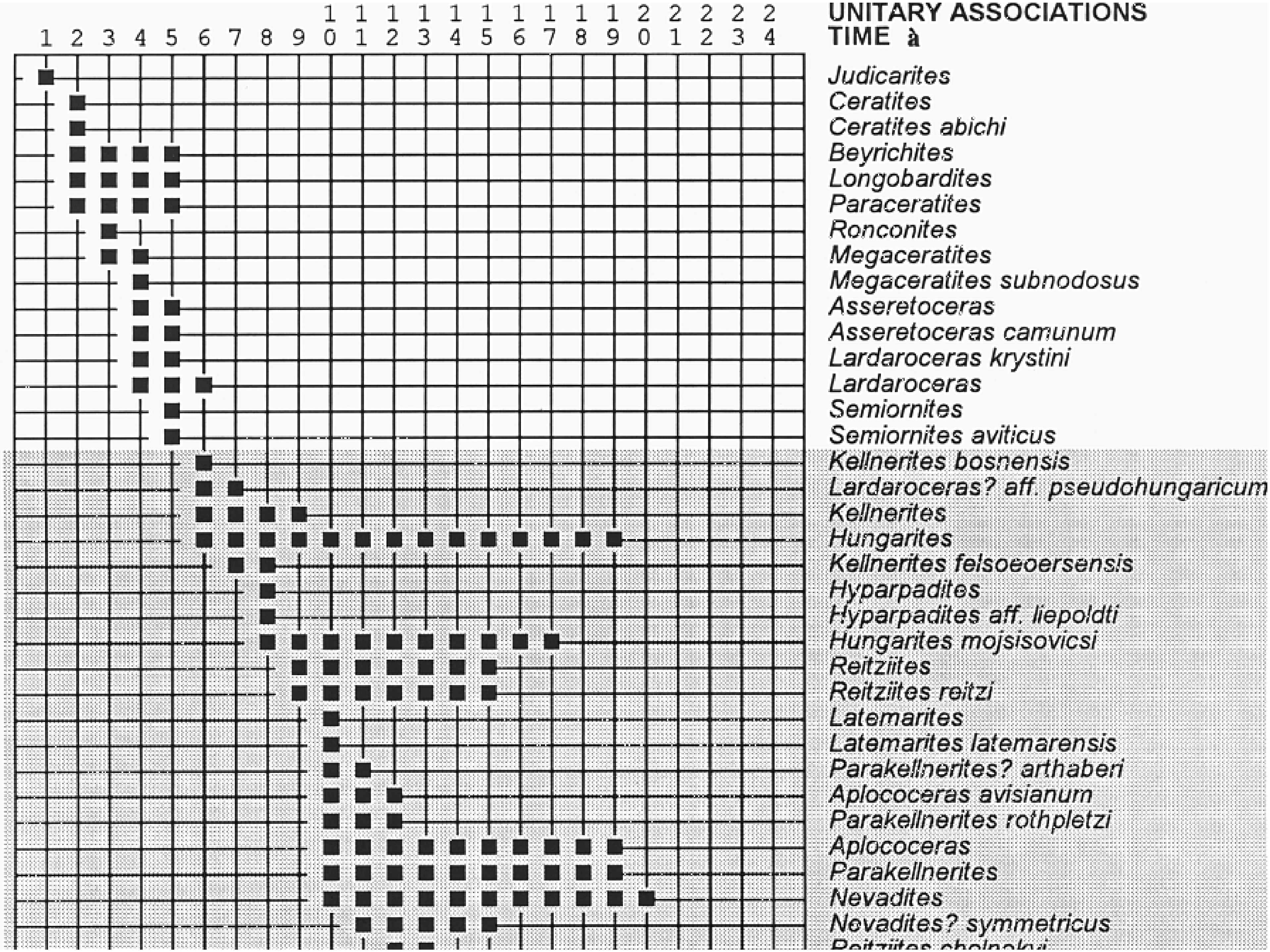

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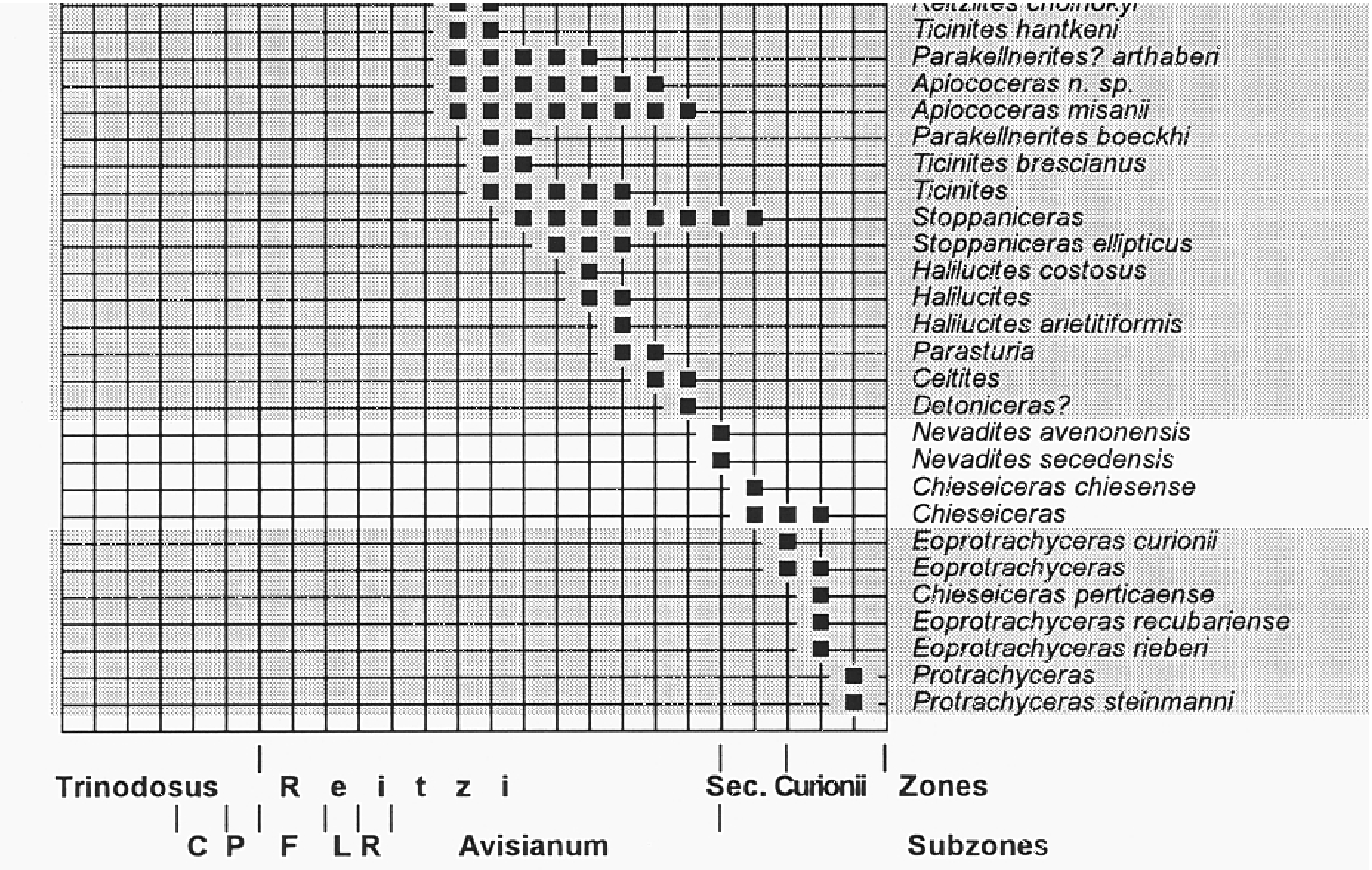
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Avisianum
Subzones

Fig. 1 *Ammonoid taxon ranges in the Anisian–Ladinian boundary interval of the Southern Alps and Balaton Highland, relative to the 24 Unitary Associations produced by the BioGraph program and the traditional zonal/subzonal scheme. Shaded areas contain taxa which first appear in the Reitzi and Curionii Zones, respectively. The intervening unshaded area shows taxa which first appear in the Secedensis Zone.*

Key to zone/subzone names: Sec. – Secedensis, C – Camunum, P – Pseudohungaricum, F – Feolsoersoensis, L – Liepoldti, R – Reitzi.

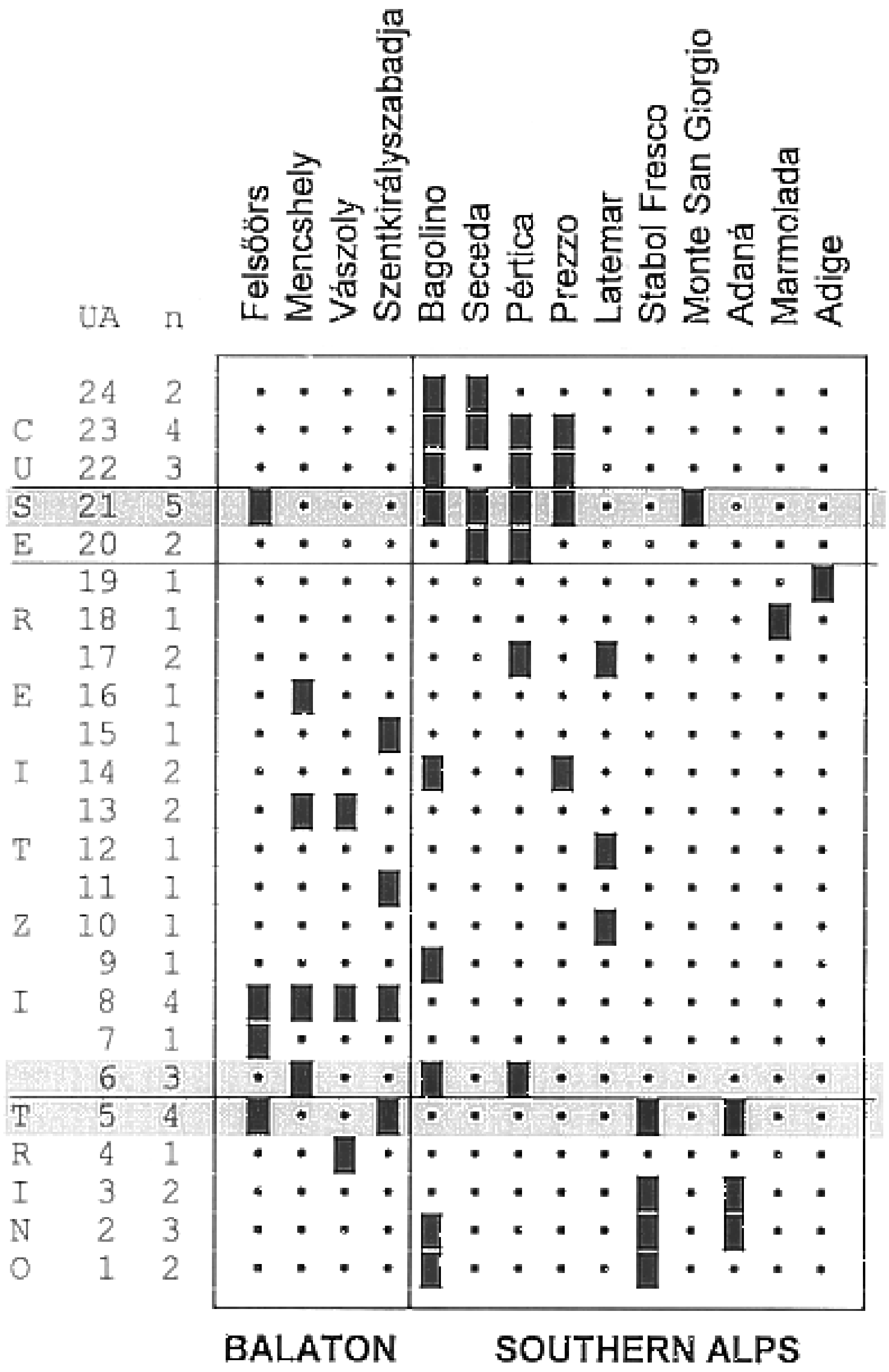

Fig. 2 *Reproducibility of the 24 Unitary Associations in the Anisian–Ladinian boundary interval of the Balaton Highland and Southern Alps. Solid bars denote that a UA is unambiguously recognizable in a given section. Lack of solid bars not necessarily indicate gap in the section, it can also result from ambiguous UA assignment. Shaded levels denote UA which are present in both areas. Proposed boundary levels are marked by horizontal lines.*