

<b>Zeitschrift:</b>	Eclogae Geologicae Helvetiae
<b>Herausgeber:</b>	Schweizerische Geologische Gesellschaft
<b>Band:</b>	77 (1984)
<b>Heft:</b>	3
<b>Artikel:</b>	A Middle Jurassic-Early Cretaceous low-latitude radiolarian zonation based on unitary associations and age of Tethyan radiolarites
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<b>Kapitel:</b>	1: Introduction
<b>DOI:</b>	<a href="https://doi.org/10.5169/seals-165530">https://doi.org/10.5169/seals-165530</a>

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## 1. Introduction

Much of the present state of Mesozoic radiolarian paleontology and biostratigraphy is the result of the past ten years. After a period of active study of Mesozoic radiolarians in Europe at the turn of the century (RÜST 1885, 1898, PARONA 1890, SQUINABOL 1914, etc.) the interest declined and the biostratigraphic usefulness of radiolarians was questioned.

A number of favorable circumstances revitalized the field in the early seventies: The Deep-Sea Drilling Project was coring Cenozoic and Mesozoic sediments in the oceans which furnished well preserved radiolarian assemblages greatly stimulating biostratigraphic work on this group, as it did for other fossil groups. Radiolarian biostratigraphy, first worked out for the Cenozoic (summary in RIEDEL & SANFILIPPO 1978), rapidly was extended to the Cretaceous (FOREMAN 1971, 1973, 1975, 1978; MOORE 1973, RIEDEL & SANFILIPPO 1974, SCHAAF 1981). The use of hydrofluoric acid to extract fossils from siliceous rocks, known for a long time to palynologists (LEJEUNE 1936) was successfully applied to radiolarians (DUMITRICA 1970, PESSAGNO & NEWPORT 1972) and allowed the observation of isolated forms also from highly lithified siliceous limestones and cherts, leading to systematic work and first Late Jurassic–Cretaceous zonations mainly derived from land-based samples from California (PESSAGNO 1971, 1972, 1973, 1976, 1977a, b). Meanwhile, the Scanning Electron Microscope (SEM) began to be regularly used by micropaleontologists. It produced accurate illustrations even of internally recrystallized or opaque fossil material, inappropriate for transmitted light microscopy.

Only recently, Mesozoic radiolarian biostratigraphy became revitalized in the European area (see DE WEVER et al. 1979) and resulted in first zonations for Tethyan radio-

larites (BAUMGARTNER et al. 1980, KOCHER 1981). In the mean time, Japanese workers, based on the results of the late seventies, began to multiply their efforts and presented a wealth of new information on Mesozoic radiolarian biostratigraphy (e.g. volume edited by NAKASEKO 1982).

Radiolarian dating of siliceous oceanic sediments has since greatly increased the understanding of tectonically complex areas like the Californian Coast Ranges, the Alpine-Mediterranean and the Japanese orogens.

Mesozoic radiolarian biostratigraphy was approached under the aspect of different philosophies: 1. The assemblage concept in which the presence of several characteristic species and/or the co-occurrence of species is used as criterion for the definition of a biostratigraphic interval. 2. The "datum" concept, in which biostratigraphic units are defined by the first or final appearance of "marker" species.

Early workers (e.g. FOREMAN 1973, 1975) recognized, that the advantage of the assemblage concept is its wide applicability also to poorly preserved samples, where some of the defining species may be absent. The recent Japanese radiolarian biostratigraphic work (summary in YAO 1983) is largely based on the concept of the assemblage zone.

As pointed out in several earlier papers (BAUMGARTNER 1980, 1984, BAUMGARTNER et al. 1980, 1981) radiolarian abundance and preservation is extremely dependent on lithology reflecting sedimentary environment and diagenetic history. Especially in land based Mesozoic radiolarian-bearing rocks, which underwent deep burial diagenesis, the number of identifiable morphotypes may vary from a few to over 100 within a few centimeters of the sequence. This is simply to demonstrate that the *absence* of a species from a certain part of a sequence does not necessarily have a chronologic significance. The result of these documentary gaps is obvious: In general, the sequence of first and final appearances greatly differs from section to section; therefore, these events are not useful for establishing biochronologic limits.

The basic problem is to know whether an absence from a certain interval is consistent or not. The only way to find out is to systematically analyze the mutual co-occurrences of species in all available sections, in order to find out which species do co-occur and which are mutually exclusive and thus represent consistent absences from certain stratigraphic intervals. GUEX (1977) coined the term *Unitary Associations* (U.A.) for maximal sets of mutually coexisting species and has since elaborated the logics and mathematics to calculate U.A. from the locality data (GUEX & DAVAUD 1982, 1984). The concept of U.A. has been successfully applied to radiolarians (BAUMGARTNER et al. 1980, KOCHER 1981) and the zonation presented in this paper is based on a recent computation of U.A. as discussed in BAUMGARTNER (1984).

This paper represents a synthesis of the majority of the presently available radiolarian samples from the Central Atlantic and Western Tethys and some other samples all around the world. The presented database (appendix) is founded on earlier work by BAUMGARTNER et al. (1980) and KOCHER (1981). However, much of the sample material has been revised under the aspect of sharper defined and more numerous morphotypes included. Very well preserved late Middle and Late Jurassic samples from DSDP Site 534 (Leg 76) have greatly facilitated the definition of species used in the zonation, and at this site a good part of the zonation can be tied to chronostratigraphy (see chapter 3).

### *Principal objectives*

The main focus of this paper is to document as complete as possible the data used for the elaboration and calibration of the presented zonation.

In chapter 2 the procedures which led to the present zonation by means of U.A. are summarized from BAUMGARTNER (1984) and modifications are explained.

In chapter 3 the established zonation is compared to earlier radiolarian biostratigraphic work and to chronostratigraphy.

Chapter 4 draws the consequences resulting from the radiolarian dating of the studied sequences: A chronostratigraphic correlation between Atlantic and Western Tethys and the timing of Middle–Late Jurassic siliceous sedimentation in Tethys and its paleooceanographic significance. Radiolarian faunal changes are related to paleoceanography.

Chapter 5 gives an alphabetic listing of genera and the 110 species used in the zonation, including 5 new genera, 16 new species and 2 new subspecies.

Chapter 6 gives the data pertaining to the studied localities: Access, lithology, location of samples and radiolarian and other biostratigraphic data for those sections not illustrated in Plate 12. Detailed objectives and procedures are given in the introduction to each chapter.

## **2. Radiolarian biochronology**

### *2.1 Introduction*

In a recent paper (BAUMGARTNER 1984) the Middle Jurassic–Early Cretaceous database (as included herein except minor revisions) was used to compute Unitary Associations (U.A.) and probabilistic ranking and scaling (RASC, AGTERBERG & NEL 1982a, b), in order to test “deterministic” versus probabilistic quantitative biostratigraphic methods applied to radiolarians. Since the Mesozoic radiolarian fossil record is largely dissolution-controlled, the sequence of first and final appearances of taxa differs greatly from section to section and the scatter of these events along a relative time scale is large compared to the range of the taxa. Thus, these data do not satisfy the statistical assumptions made in probabilistic methods. U.A. produce maximum ranges of the taxa relative to each other by stacking cooccurrence data from all sections and therefore compensate for local dissolution effects (poor preservation). Ranking and scaling, assuming a symmetrical, random scatter of the events narrowly clustered around the endpoints of a species range, produces “average” ranges which are for most species much shorter than the maximum U.A. ranges and can easily be contradicted by any well preserved sample. It is therefore clearly indicated to use U.A. for the elaboration of a radiolarian biochronology which should account for the nature of the data and produce a zonation of wide, non-contradictory applicability.

The procedures which led to the presented zonation by means of Unitary Associations (U.A.), computed by a program by DAVAUD (in GUEX & DAVAUD 1982, 1984) is explained in detail in BAUMGARTNER 1984 and will not be repeated here.