The Breggia section of southern Switzerland

Objekttyp: **Chapter**

Zeitschrift: **Eclogae Geologicae Helvetiae**

Band (Jahr): **78 (1985)**

Heft 2

PDF erstellt am: **16.08.2024**

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comites in Core 80, indicating Valanginian, is of great help in interpreting the Berriasian–Valanginian limit.

It is interesting to note that aptychi in the Atlantic are conspicuously accumulated within the interval considered to represent the Valanginian. This coincides also with the distribution of aptychi observed in the Breggia section (Fig. 2).

C. The Breggia section of southern Switzerland

a) Late Jurassic to Barremian post-rift sediments of the southern Tethyan margin

The Late Jurassic and Neocomian sediments of the Southern Alps formed part of the southern continental margin of a narrow Tethyan ocean. Three lithological units, all of them deep water sediments, are distinguished. In ascending order, these are: The Radiolarite Group, the Rosso ad Aptici Formation, and the Maiolica Formation. In a plate tectonic context, these sediments are part of the "Apulia" or "Adria" Plate which according to BIJU-DUVAL (1977) had been detached from the African mother plate in Early Jurassic. The rifting process at the northern end of the Apulian Plate resulted in the birth, probably during Middle Jurassic, of a narrow Tethyan ocean. Crustal stretching of its complex southern margin had been accompanied by the drowning of its shallow-water carbonate platforms during Late Triassic, Early and Middle Jurassic. By Late Jurassic, after the birth of the Tethyan ocean, a post-rift situation had been created with strike slip faulting becoming prominent, possibly due to the rotation of the Adria Plate. The Late Jurassic Tethyan ocean, perhaps subdivided by elongate cordilleras, lasted throughout the remainder of Jurassic time but ceased to widen during the Tithonian (WINTERER & BOSELLINI 1981) and Early Cretaceous. The great ophiolite masses of the Piemont, the Valais, Graubünden and the Malenco Valley – now incorporated in the Penninic and lower Austroalpine nappes – provide ample evidence of its existence. The absence of Mesozoic ophiolites in the Ticino sector is obviously due to later tectonics, such as large-scale uplift of the Penninic Ticino Alps during Late Tertiary and associated compression and strike-slip movement. Most prominent among these faults is the "Insubric line" which separates the Penninic and lower Austroalpine Alps from the Southern Alps with a down-to-the-south vertical offset estimated at 20 km in the Ticino sector (TRÜMPY 1980). The amount of alpine compression, too, seems to reach a maximum in this sector (SPICHER 1980).

The post-rift character of the Radiolarite Group, of the Rosso ad Aptici- and of the Maiolica Formation is reflected in their uniformly moderate thickness corresponding to slow subsidence and a calm tectonic regime (KÄLIN & TRÜMPY 1977, WEISSERT 1979, WINTERER & BOSELLINI 1981).

b) Water depth during Late Jurassic and Early Cretaceous

The Radiolarite Group was deposited below the Calcite Compensation Depth (BERNOULLI & JENKYNS 1974), the Rosso ad Aptici and the Maiolica Formation between the Aragonite Compensation Depth (ACD) and the Calcite Compensation Depth (CCD). The end-Jurassic ACD may have been at 1400 m, the CCD at 4200 m (WINTERER & BOSELLINI 1981); but the uncertainties inherent in their model preclude an exact

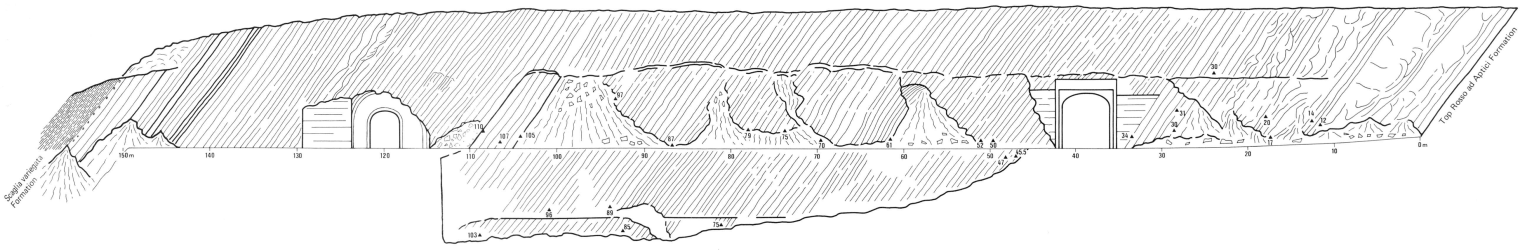

Fig. 1. Outcrop of the Maiolica Formation in the Breggia gorge in southern Switzerland.

definition of the depositional depth of these rock sequences. However, for the Maiolica Formation, the absence of Early Cretaceous planktonic Foraminifera suggests a depositional depth greater than the lysocline for Foraminifera which according to BERGER (1970, 1976) occurs between 2500 and 4500 m. The lysocline for coccolithophorids is presently assumed as deep as 4000 m (BERGER 1973, ROTH & BERGER 1975). These data are in favour of a great depth of deposition for the Maiolica, as it was proposed by BERNOULLI & JENKYNS (1974).

c) Late Jurassic Rosso ad Aptici Formation of the Breggia gorge

The Radiolarite Group (BERNOULLI 1964, p. 90) is overlain concordantly by the Rosso ad Aptici Formation, composed of purplish-red calcilutites and only 15 m in thickness. Three thin intercalations of smectite are interpreted as devitrified cineritic tuffs (BERNOULLI 1980b). Most conspicuous are aptychi, occurring abundantly. The latest *Laevaptychus (L. latus)* was observed on the top layer of the formation which consists of a red-yellowish, resistant limestone, forming an outstanding dip slope. On its surface aptychi, indicating a late Tithonian age, are exposed abundantly (Pl. 1, Fig. 1).

d) Early Cretaceous Maiolica Formation of the Breggia gorge

At the end of late Tithonian a conspicuous change from red calcilutites (Rosso ad Aptici Formation) into white, platy, fine-grained, cherty limestones (Maiolica Formation) occurred. This facies is widely distributed in the western Tethys where it is also known by other names such as Biancone, Lattimusa, Aptychenkalk and Vigla Limestone (BERNOULLI & JENKYNS 1974).

The white limestones of the Breggia section are uniform in lithology and facies and attain a thickness of 130 m (WEISSERT 1979). The frequently intercalated chert nodules and layers are of vitreous- and grain-supported varieties. Among subordinate lithologies are white, thinly bedded limestones with dark grey, coaly films (75–79 m above base) and thin intercalations of dark grey to black, more or less bituminous shales in the uppermost part (BITTERLI 1965, WEISSERT 1979). Bedding is usually very pronounced, disturbed only occasionally by slumped intervals. Such subaquatic sliding is particularly evident within the basal 15 m of the section (Fig. 1). For detailed description of lithology and sedimentology the reader is referred to WEISSERT (1979).

Contact relationships: The contact of the Maiolica Formation with the underlying Rosso ad Aptici Formation is very distinct and favourably exposed (BERNOULLI 1964). The contact with the overlying Scaglia variegata Formation likewise is very distinct, indicating an abrupt facies change. A glauconitic hardground occurs at the boundary which may indicate an interruption in sedimentation (RIEBER 1977, WEISSERT 1979).

Fossil contents and age: Coccoliths and Radiolaria are the dominant microfossils. The latter are most abundant in grain-supported varieties of chert (WEISSERT 1979) while coccoliths are common in limestone where they occur together with diagenetic calcite. Calpionellids and calcispheres are subordinate microfossils restricted to the stratigraphically lower part of the Maiolica. Of the utmost stratigraphic importance is the occurence of aptychi throughout the section. As explained in chapter D of the present paper, it is now possible to establish a stratigraphic subdivision of the Early Cretaceous based on aptychi. Berriasian, Valanginian, Hauterivian, and Barremian have all been identified by aptychi. Of particular value is an ammonite of the genus *Pulchellia* of Barremian age in the uppermost Maiolica Formation (RIEBER 1977). It allows a safe correlation with Hole 534A in the Blake-Bahama Basin, from where this ammonite has been recognized at the top of the coeval Blake-Bahama Formation. *Pulchellia* indicates a Barremian age for the upper part of the Maiolica Formation, where among aptychi *Lamellaptychus angulocostatus* is representative. Within the white limestones of the Maiolica Formation the presence of Ammonites is indicated by faint impressions. During the present sampling a poorly preserved ammonite *(Neocomites)* was obtained to which a Valanginian age might be assigned (Pl. 5, Fig. 26).

Effects of diagnesis: From the results of DSDP Site 534A it has become evident that the Maiolica limestones originated from coccolith ooze by a succession of diagenetic processes. In the course of these, the very high porosity – up to 70% in calcareous oozes according to MATTER et al. (1975) – was reduced to zero by compaction.

e) Aptian(?) to late Cenomanian deep-water pelagic sediments

The Maiolica of the Breggia section is conformably overlain by 300 m of deep-water pelagic sediments known as Scaglia, a succession composed of varicoloured clays, marls, and marly limestones (GANDOLFI 1942, BITTERLI 1965). It includes one principal layer of bituminous siliceous shale containing fish remains and additional minor bituminous intercalations. On top of the Maiolica about 10–20 cm of greenish glauconitic marl indicates not only a sharp break in the character of sedimentation but possibly also a hiatus (BITTERLI 1965). An open-marine, quiet environment is suggested, with short episodes of oxygen-deficient, stagnant water.

f) Late Cenomanian to Campanian Flysch sediments

Transitionally above the Scaglia follow deep-water shales which alternate with turbiditic sandstones. There are a few occurrences of pebbly mudstones and associated coarser arenites, most conspicuously the Missaglia Megabed (BICHSEL & HÄRING 1981, BERNOULLI et al. 1981). The E–W elongated Flysch trough, bordered in the south by the Malossa High, was fed from the north and east. A total of over 2000 m of Late Cretaceous Flysch was deposited in this trough as the well exposed sections east of Como indicate. These Flysch sediments reflect the early phases of Alpine mountain building. In a plate tectonic context, this phase corresponds to the anticlockwise rotation of Africa–Apulia which ended with the Continent/Continent collision and elimination of the Tethys during uppermost Cretaceous.

g) Diagenesis and Alpine deformation

The compaction process which changed the original coccolith ooze into Maiolica was mainly a consequence of overburden pressure during Late Cretaceous Flysch deposition rather than being caused by Alpine deformation. Stylolite formation in the Maiolica progressed during burial and during Alpine deformation. An analysis of stylolite character and distribution is beyond the scope of the present paper; a few observations, though, may be of interest. Stylolites are most prominent in the slumped section near the base, which may have been a "pièce de résistance". In the thin- and even bedded Maiolica above the basal slumped section stylolites are usually small. Mostly they seem to occur along roughly conjugated and not very regular shear planes at high angles to the bedding. Offsets of one set by the other are not common. Calcite steps (LAUBSCHER 1979), often steeply dipping, are rather frequent and so are calcite-filled tension cracks. Visible dislocations of entire strata are absent or minimal. Degree of organic metamorphism had not advanced very far, the Staplin index of sporomorphs being estimated at around 2 (pers. communication P. A. Hochuli). Obviously, such a level was attained towards the end of the depositional history and ramained practically unchanged during the subsequent Alpine compressional deformation.

Folding, faulting and thrusting affected the Mesozoic rocks of the Monte Generoso–Breggia sector during the Tertiary. The resulting tectonics is in line with the regional compressional tectonic style of the Lombardy Alps which also included the northern Po valley, as demonstrated by ERRICO et al. (1980). The course of events can tentatively be reconstructed in the following manner: During Oligocene/early Miocene: A hinge line formed, spearating the rising Generoso area from the subsiding Po valley to the south, which was being filled with clastics derived from the Alps. During the interval spanning middle Miocene to earliest Pliocene, folding and thrusting occurred, and in consequence of these movements the hinge line was accentuated.

Towards the end of this interval, major thrusting ceased, and erosion and peneplanation affected the Po valley. The hinge zone remained active and a canyon was cut into the folded Cretaceous of the Breggia gorge which was filled with coarse fluviatile clastics (Pontegana Conglomerate) thought to be of early Pliocene (BERNOULLI 1966) or latest Miocene (LAUBSCHER & BERNOULLI 1980) age. Subsequently, marine Pliocene transgressed over the peneplained Po valley, reaching the southern tip of Switzerland at Balerna west of the border town of Chiasso. Both the Pontegana Conglomerate and the marine Pliocene remained in their depositional, nearly horizontal, position.

Tertiary uplift at the site of the Maiolica section of the Breggia gorge is estimated to have amounted to between 2000 and 3000 m, a figure suggested by the estimated combined thickness of the Scaglia, the Flysch, and the Oligocene–early Miocene clastics.

D. Paleontological analysis

Fig. 1, 2; Pl. 1–5

Class Cephalopoda LEACH 1817
Order Ammonoidea ZITTEL 1884
Aptychus MEYER 1829

a) General remarks

Little attention has generally been paid to the occurrence of aptychi, in spite of their value for stratigraphic zonations and correlations with holes in the Atlantic, mainly in sediments deposited below the Aragonite Compensation Depth.

Descriptions of aptychi are stratigraphically arranged, from the top of the Rosso ad Aptici Formation until the contact of the Maiolica Formation against the Scaglia Variegata Formation (Fig. 2).