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Research article

Tribute to Jean Dercourt

Synthesis of micropaleontological age constraints for the reconstruction of the Tethyan realm in the Lesser Caucasus (Armenia, Karabagh)

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Abstract. We present new biostratigraphic results from two ophiolite outcrops in Armenia. The discovery of upper Tithonian–lower Berriasian diagnostic radiolarian species (*Vallupus gracilis* Li and Sashida) in the lower radiolarites of the Dali section allows to date more accurately submarine lava eruptions of transitional to alkaline composition. The radiolarian results also indicate that blocks of shallow-water carbonates slid into the basin during this time interval. At Vedi, upper Coniacian–Santonian calcareous nannofossils identified in marls of the post-obduction sedimentary cover refine previous age data. Synthesis of the existing bio-chronostratigraphic constraints in Armenia and Karabagh sheds light to the depositional and magmatic history of Tethys in the Lesser Caucasus and highlights the age constraints of fossils on the timing of ophiolite obduction in the region.

Keywords. Micropaleontology, Radiolaria, Ophiolite, Tethys, Armenia, Lesser Caucasus.

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1. Introduction

Micropaleontology is particularly helpful for the establishment of an accurate chronostratigraphic framework for the depositional and geodynamic history of Tethys. More particularly, radiolarians are extremely useful for dating radiolarites that are often stratigraphically associated with submarine lavas. Dating these past siliceous oozes, which accumulated presumably under mesotrophic waters and in a depositional environment starved of any carbonate or siliciclastic material [Baugmgartner, 2013], is of great significance for the geodynamic and paleoenvironmental reconstruction of the various Tethyan realms, often preserved in tectonically complex areas [e.g., Al-Riyami et al., 2002, Avagyan et al., 2017, Cordey, 2022, De Wever and Baudin, 1996, De Wever et al., 1994, Danelian et al., 2006, 2008a, Ferrière et al., 2015, Goričan et al., 2012, Robertson et al., 2013, 2021, 2022, Vrielynck et al., 2003]. Foraminifera and calcareous nannofossils are also useful in providing important biochronostratigraphic constraints for the timing of ophiolite obduction by dating the thrust sequences beneath the ophiolites and the post-obduction sedimentary cover [Danelian et al., 2014, Okay et al., 2022, Sosson et al., 2010].

The Lesser Caucasus (Armenia and Karabagh) represents a key component of the Alpine-Himalayan mountain belt, as it preserves the remnants of a Neotethyan Mesozoic oceanic realm that continues westwards into northeastern Turkey [e.g., Zakariadze et al., 1983, Galoyan, 2008, Galoyan et al., 2007, 2009, Rolland et al., 2009a, 2010, Sosson et al., 2010, 2016], representing thus an over 700 km-long coherent Tethyan suture zone. The ophiolitic units preserved in the Lesser Caucasus are the relics of an oceanic domain that existed during the Mesozoic between the Somkheto-Karabagh volcanic arc, considered as part of the southern margin of Eurasia [Sosson et al., 2010] and the South-Armenian Block (SAB), a Gondwana derived micro-continent that was detached from it during the Late Paleozoic–Early Mesozoic [Dercourt et al., 1986, Barrier and Vrielynck, 2008].

Initial results on radiolarians extracted from the sedimentary cover of the ophiolites in the Lesser Caucasus were obtained at the time of the Soviet Union [Zakariadze et al., 1983, Belov et al., 1991, Knipper et al., 1997, Vishnevskaya, 1995], but the bulk of existing radiolarian data was published during the last 15 years following a number of French-Armenian joint projects. These results provided relatively accurate ages, generated from coherent successions of radiolarian cherts, which are either intercalated between successive lava flows or lie stratigraphically over them [Asatryan, 2009, Asatryan et al., 2010, 2011, 2012, Danelian et al., 2007, 2008b, 2010, 2012, 2014, 2016, 2017, Sosson et al., 2010]. Special attention was paid in stating explicitly the provenance of studied samples with respect to their geological and stratigraphic setting, as well as in documenting with illustrations the identified fauna (or at least the age diagnostic species); the latter is important for communicating the species concept used during the process of identification.

We have recently undertaken additional micropaleontological studies in two sectors that are of key significance for the understanding of the evolution of the Tethyan realm in Armenia (Figure 1). In the Dali sector, north-east of lake Sevan, we have obtained more precise datings for the lower radiolarite interval that is intercalated between lavas of enriched tholeiitic (E-MORB) and alkaline affinities, as shown recently by Seyler et al. [2023]. In the Vedi sector, south-east of the capital city Yerevan, new datings using calcareous nanofossils confirm and further indicate the age of the marly sequence that is part of the transgressive post-obduction sedimentary cover, which helps to constrain the timing of obduction. Finally, a review of the currently available biochronological constraints in the context of their specific depositional and geodynamic settings allows us to illustrate the main contributions of micropaleontology in the reconstruction of the Tethyan realm preserved in the Lesser Caucasus. We thus attempt to address the following questions: (1) what is the age range of radiolarite accumulation that is stratigraphically related to volcanic events? (2) what are the age constraints for the obduction of ophiolites?

2. Geological outline and geodynamic significance

The ophiolites in the Lesser Caucasus are organized along two subparallel belts (Figure 1).

• The Sevan–Hakari (Akera) ophiolite extends in the east and south-east of lake Sevan; it is considered as representing the suture zone of the Tethys ocean in the region [Sosson et al., 2010, and references

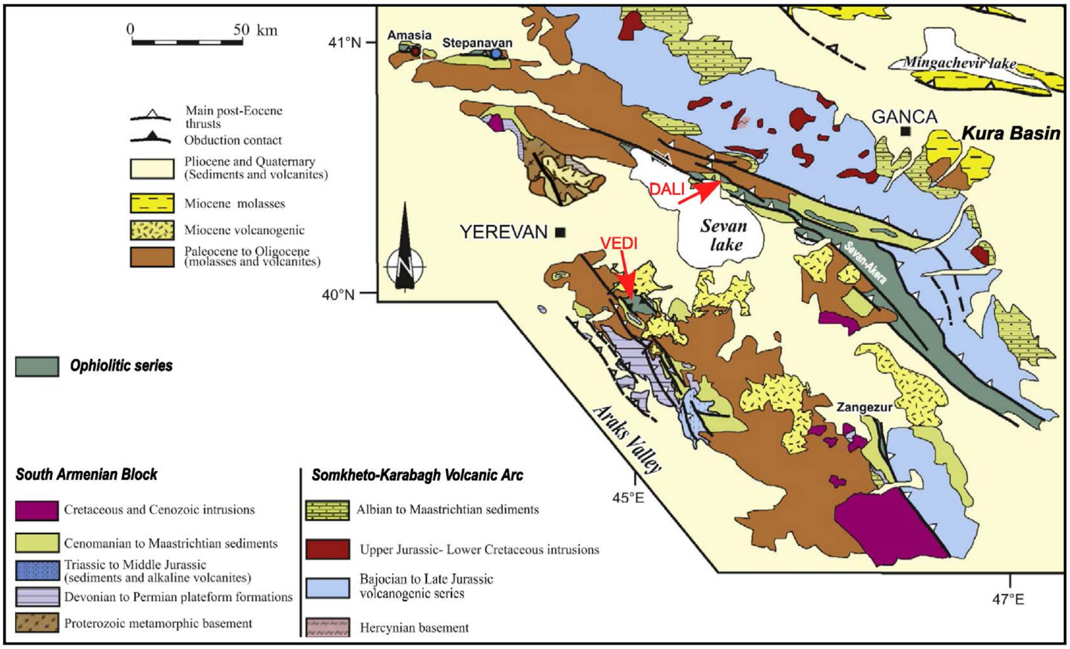

Figure 1. Schematic geological map of the Lesser Caucasus [modified after Sosson et al., 2010 and Hässig et al., 2015].

therein]. The Amasia and Stepanavan ophiolites, situated at the northwest of the country, are regarded as the northward extension of the Sevan-Hakari ophiolites, making the link to the Izmir-Ankara suture zone [e.g., Galoyan, 2008, Galoyan et al., 2007, Hässig et al., 2013a, 2016a,b].

• The Vedi ophiolite [Aslanyan and Satian, 1977, Knipper and Khain, 1980, Sokolov, 1977], located at the south-east of Yerevan, is a folded klippe unit that is transgressively overlain by Coniacian–Santonian sedimentary sequences following the obduction of ophiolites over Cenomanian carbonates and flysch of the SAB [Sosson et al., 2010, Danelian et al., 2014].

The Tethyan ophiolites preserved in the Lesser Caucasus are regarded as remnants of oceanic crust generated in an intra-oceanic supra-subduction [Seyler et al., 2023] or back-arc basin setting [Galoyan, 2008, Galoyan et al., 2009, Sosson et al., 2010, Rolland et al., 2020]. They are represented by lavas of different geochemistry (island-arc tholeiites, N-MORB, E-MORB and alkaline), oceanic sedimentary rocks (mainly radiolarites), covering in some places (i.e., the Dali sector) relics of a complex paleo-seafloor, composed essentially of serpentinites, hornblende-bearing gabbros and diorites [Galoyan, 2008, Sosson et al., 2010], as well as mélange units with metric blocks of igneous-ophiolitic and sedimentary lithologies.

The Dali sector east of lake Sevan was previously described in a number of publications [Galoyan, 2020, Galoyan et al., 2009, Asatryan et al., 2012, and references therein] and the reader is referred to them for a more detailed presentation. The petrology of the lavas have been recently studied by Seyler et al. [2023], who distinguished two main lithotectonic units. The lower unit is represented by a small dioritic massif intruded by trondjhemites and unconformably overlain by an undated sequence of island-arc tholeiitic pillow lavas [group A lavas of Seyler et al., 2023]. The upper unit is a ca. 100 m-thick volcano-sedimentary sequence of basaltic to trachybasaltic pillow lavas intercalated with radiolarites (Figure 2). Based on their Nb, Zr, Y and heavy REE contents and ratios, the volcanics range from low-K, enriched tholeiites (E-MORB; group B) to alkaline and OIB-like (group C). Despite high Nb concentrations, some of the lavas also exhibit Nb–Ta negative anomalies and enrichment of Th relative to Nb, which suggest a subduction influence. Moreover, alkaline amphiboles occur as phenocrysts in trachy-

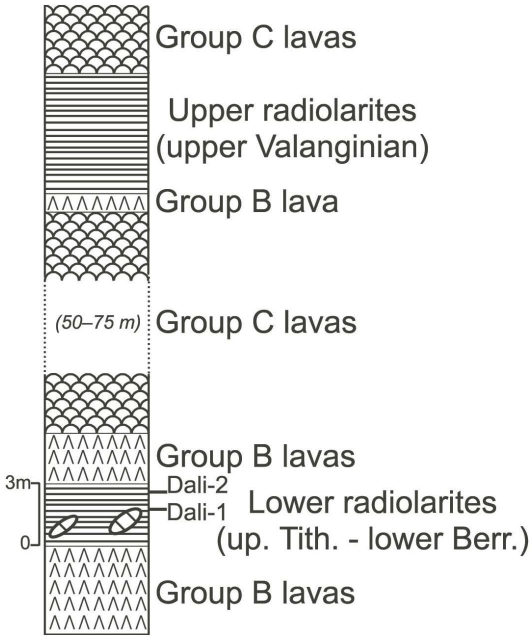

Figure 2. Synthetic lithostratigraphic column of the Tithonian–Valanginian volcano-sedimentary sequence at Dali [after Asatryan et al., 2012 and Seyler et al., 2023, modified]. Group B: enriched MORB-type. Group C: amphibole-phyric alkali trachybasalts and alkali basalts. Both groups of lavas may exhibit slight subduction-related signature.

basalts (group C1 lavas) or only in groundmass in alkalibasalts (group C2 lavas), indicating crystallization from hydrous magmas. This double geochemical signature (e.g., within-plate and subduction-related) was interpreted by Seyler et al. [2023] as the result of the decompression melting of a heterogeneously enriched mantle during rifting of the previous intra-oceanic island-arc.

3. New biochronostratigraphic constraints

3.1. *The Dali sector (northeast of lake Sevan)*

Two prominent radiolarite intervals, each of them several metres thick, are intercalated in the upper volcano-sedimentary unit (Figure 2). The lower radiolarites are ca. 3 m-thick and located within a group B lava sequence. As reported by Seyler et al. [2023], the basaltic andesitic lava flow exposed just above the sediments is partially intermingled with claystones of the underlying radiolaritic sequence. After digging a small trench, reddish shales were observed being intercalated in the upper levels of the group B lavas; this radiolarite interval has the particularity of containing in it metric and fairly rounded blocks of oolitic grainstones with crinoid fragments that have clearly slid into the deep basin (olistolithes) from the shallow water, wave-agitated environments, in which they were initially deposited. The lower radiolarites and group B lavas are in turn overlain by a ca. 50–75 m-thick lava sequence of alkaline lavas belonging to groups C1 and C2 (group C on Figure 2), themselves overlain by a thin basaltic flow of Group B lavas, then overlain by the upper interval of dark purple radiolarites, ca. 6 m-thick. Finally, the studied section is topped by Group C2 alkaline basalt. The contacts are not clearly visible on the field, but judging by the general arrangement of the rocks, they are inferred to be stratigraphic.

Based on the biozonation of Baugmgartner et al. [1995], Asatryan et al. [2012] were able to assign the lower radiolarites to the Unitary Association Zones (UAZ) 13–17, correlated with the latest Tithonian–Valanginian interval and the upper radiolarites with the UAZ 17 only, correlated with the late Valanginian. Thus, in spite of the more numerous species identified in the two radiolarian assemblages obtained from the lower radiolarites, no age discrimination could be made with the more precise age obtained for the upper radiolarites.

In an attempt to better date the lower radiolarites we undertook additional laboratory work on the two previously studied radiolarian-bearing samples. Only the sample Dali 2 delivered radiolarians of additional biochronological significance, as compared to the age established by Asatryan et al. [2012]. More particularly, we were able to identify the species *Tethysetta mashitaensis* (Mizutani) (Figure 3a), which is known to occur in the UAZ 8–15 of Baugmgartner et al. [1995], correlated with the Callovian/Oxfordian to late Berriasian/earliest Valanginian time interval. However, we also obtained a single specimen of *Vallupus gracilis* Li and Sashida, which is easily distinguished by the shape of its cortical collar that is gradually constricted to a small aperture (Figure 3b). To our knowledge, this species is only known from a tuffaceous radiolarian claystone sample (181-R003) recovered from the Mariana trench that contains

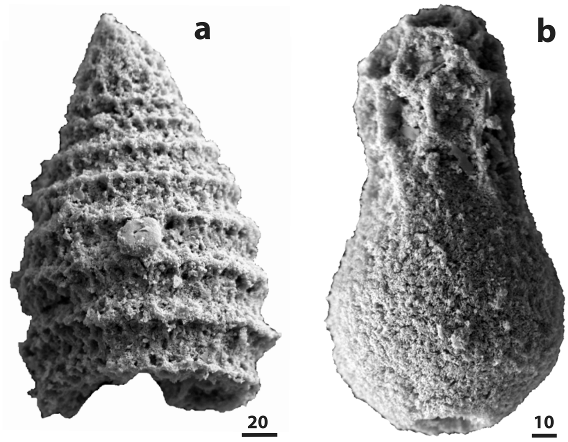

Figure 3. Age diagnostic radiolarians extracted from sample Dali-2; (a) *Tethysetta mashitaensis* and (b) *Vallupus gracilis*. The scale refers to microns.

an exceptionally well preserved and diverse (over 500 species) radiolarian assemblage [Li and Sashida, 2013]. The sample contains also calcareous nannofossils assigned to the CC1 zone and correlated with the early Berriasian. Therefore, the age of the lower radiolarites may be now restricted to the latest Tithonian–early Berriasian interval.

3.2. *The Vedi sector*

In the Vedi natural reserve exists the best outcrop to document the obduction of Tethyan ophiolites on the SAB, as well as the post-obduction sedimentary cover. Following Sokolov's [1977] detailed study, the general geological structure, lithological relationship and various contacts of the Vedi ophiolite are well described in Sosson et al. [2010] and reproduced here in Figure 4. Danelian et al. [2014] studied the 150 uppermost metres of the carbonate sequence of the SAB at the northern edge of the Spitakadjur anticlinal fold (south-western part of the section in Figure 4) and based on microfacies analysis and the frequent presence of rudist clasts they characterized them as back-reef limestones. They are stratigraphically overlain by a flysch-type sequence that contains, in its upper part, numerous blocks or olistoliths of various lithologies (limestones, lavas, etc.).

Eastwards, and just after the entry to the Mankouk valley (one of the right tributaries of the Vedi River), one may observe over the ophiolitic lavas a thick transgressive sequence of red conglomerates. They are overlain by a ca. 50 m-thick sequence of marls and siltstones. The entire sequence is preserved in a synclinal form [Galoyan, 2008, Sosson et al., 2010]. In the middle of this valley, at the base of the synclinal structure, a stounding rudist reef is developed between the transgressive sequence of conglomerates-marls and the lavas that are underneath.

We have recently sampled a ca. 30 m thick sequence of fragile marls that are located at the north-eastern part of the synclinal structure and deposited above the red-gray conglomerates. The two samples we collected come from the lower part (Vd22-03) and the middle/upper part (Vd22-02) of the marls (see Figure 4).

New observations confirm the presence of species *Zeugrhabdotus diplogrammus*, *Z. embergeri*, *Tranolithus orionatus* and *Reinhardtites anthophorus* in sample Vd.22.02, while species *Eiffellithus turriseiffelii,* ? *Micula concava* and *Lithastrinus grillii* were identified in sample Vd.22.03 (Figure 5).

Hence, the combined biochronostratigraphic constraints of the species *Z. diplogrammus* and *L. grillii*, suggest a biostratigraphic assignment of the gray-greenish marls to biozones UC11a–UC12 of Burnett [1998] that correlates with the late Coniacian–Santonian time interval [86–84 Ma in the recent geological Time scale of Gradstein et al., 2020].

4. Discussion

A synthesis of all biochronostratigraphic results available in the Lesser Caucasus allows to improve our understanding of the geological evolution of Tethys in the region (Figure 6). In this synthesis we thought it interesting to position also the absolute isotope ages known in the region and obtained from crustal magmatic rocks (i.e. gabbros and diorites) and the single lava flow dated by Rolland et al. [2010].

4.1. *Reconstruction of the Tethyan oceanic realm*

The oldest radiolarian assemblage reported from the Lesser Caucasus is late Carnian in age and comes from the Old Sotk Pass, in the Armenia–Karabagh border area [Knipper et al., 1997]. The authors describe an over 200 m-thick volcano-sedimentary sequence displaying alternations of distal turbidites

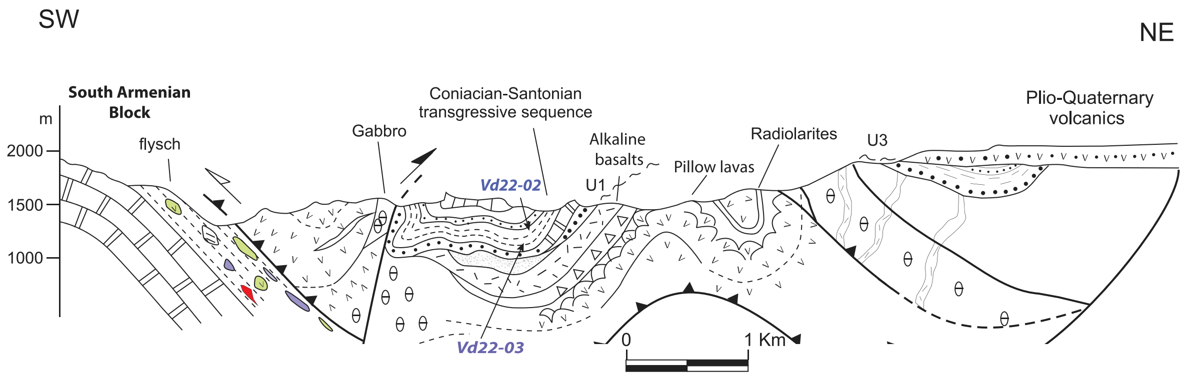

Figure 4. Geological section of the Vedi ophiolite obducted southwestwards onto the South Armenian Block and covered by the post-obduction conglomerates and marls [after Sosson et al., 2010, modified].

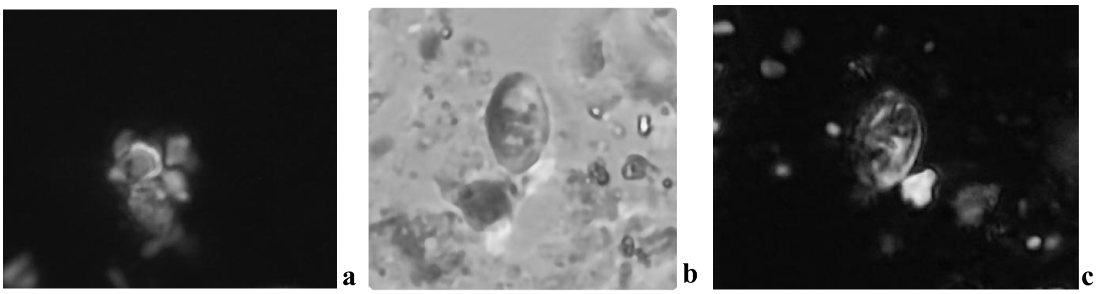

Figure 5. Age diagnostic coccoliths observed in the marls of the post-obduction sedimentary cover at Vedi (1000×). (a) *Lithastrinus grillii* identified in sample Vd.22.03. (b) *Tranolithus orionatus* identified in sample Vd.22.02. (c) *Zeugrabdotus diplogrammus* identified in sample Vd.22.02.

and greywackes and siliceous shales with basaltic lavas and breccias with gabbro-diabasic elements [see Figure 2 of Knipper et al., 1997]. The upper Carnian radiolarians were recovered from a 20 m-thick interval of siliceous shales (pelites), while a younger assemblage of Toarcian affinity is reported from cherts situated at the middle part of their column, above which two levels of basaltic lavas are reported to include limestone blocks with Norian bivalves and conodonts. The study of Grigoryan [2005] showed that the Upper Triassic limestone olistolithes have a wide geographic distribution at the Old Sotk Pass, but they all have a short age range (early-middle Norian) and similar lithological composition. Vishnevskaya [1995] has also reported radiolarians from this section, stressing mainly on details concerning the Toarcian radiolarian assemblage. According to her, the sedimentary sequence at this locality displays three intervals: a lower 10 m-thick interval, which yielded the upper Carnian radiolarians, is overlain by a 5 m-thick interval of "sediments with indistinct bedding and sorting, pelites and radiolarites" that yielded the Toarcian radiolarian assemblage; the sequence is finally overlain by a 100 m-thick "Jurassic volcano-sedimentary" interval that contains blocks of Norian limestone.

Having visited this locality ourselves, we prefer to consider this entire sequence at Old Sotk Pass as a highly tectonized mélange zone. Nevertheless, the report of upper Carnian radiolarian shales and Toarcian radiolarian cherts is significant. In combination with the Upper Triassic gabbros dated by Bogdanovski et al. [1992] in Karabagh, they may be regarded as elements of a Tethyan oceanic crust that were accreted during the Late Cretaceous obduction of the ophiolites.

Based on their stratigraphic relation with dated radiolarites, lavas of Middle Jurassic age are

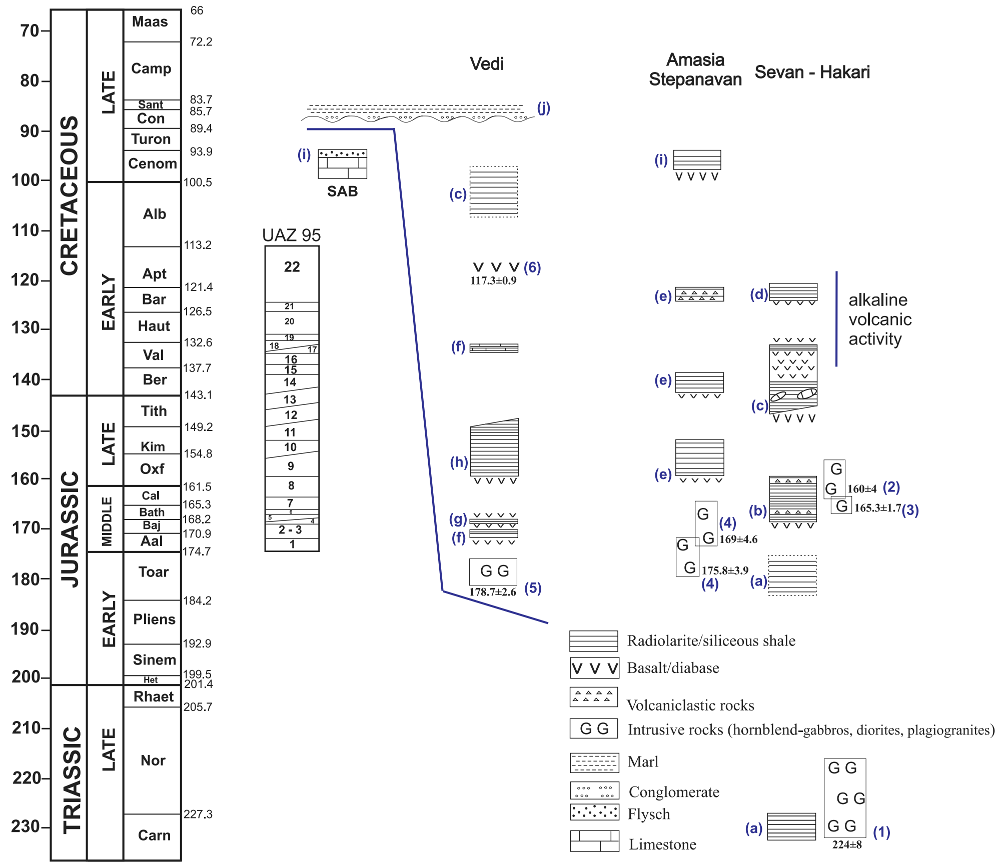

Figure 6. Synthesis of all dated radiolarites in the ophiolitic units of the Lesser Caucasus, the top of the sedimentary sequence of the South-Armenian Block on which they are obducted and the lower part of the post-obduction sedimentary cover. (a) Knipper et al. [1997], Vishnevskaya [1995]; (b) Asatryan et al. [2010]; (c) Asatryan et al. [2012], Danelian et al. [2012], this study; (d) Asatryan et al. [2011]; (e) Danelian et al. [2016]; (f) Danelian et al. [2017]; (g) Danelian et al. [2008b], Asatryan [2009]; (h) Danelian et al. [2010]; (i) Danelian et al. [2014]; (j) Sosson et al. [2010], this study. (1) Bogdanovski et al. [1992]; (2) Zakariadze et al. [1983]; (3) Galoyan et al. [2009]; (4) Hässig et al. [2013b]; (5) Rolland et al. [2010]; (6) Rolland et al. [2009b]. Time scale according to Gradstein et al. [2020].

well-established both in the Vedi and Sevan ophiolites. More specifically, in Vedi, radiolarites intercalated between pillow and massive variolitic lavas were dated initially as middle-late Bajocian [UAZ 3–4, Danelian et al., 2008b], but it was later clarified that the radiolarian assemblage may be assigned to the single UAZ 4 and thus to be correlated only with the late Bajocian [Asatryan, 2009]. Older radiolarites, assigned to the UAZ 2–3 (late Aalenian–middle Bajocian) were recently revealed by Danelian et al. [2017] in a block preserved in the ophiolitic mélange of the Erakh anticline, near Vedi. Here, the radiolarians were extracted from cherts that are in stratigraphic contact with lavas, but it is unclear whether the radiolarites are younger or older than the lavas.

Within the Sevan-Hakari ophiolite zone, Vishnevskaya [1995] dated Bajocian to lower Bathonian radiolarian cherts at the Mt. Karawul of Karabagh, overlying basaltic lavas. In the same ophiolitic zone, Asatryan et al. [2010] studied at the valley of Sarinar (north-east of lake Sevan) a 40 m-thick sequence of radiolarites that is sandwiched between two lava flows; the lower lavas are stratigraphically overlain by radiolarites that are dated at their base (ca. 3 meters above the contact with the lavas) as latest Bajocian–early Bathonian in age (UAZ 5). Several metric tuffite levels were observed in the lower 20 m of the radiolarite sequence and may be correlated with the Bathonian–Callovian, as one of the chert samples (Sar-10), situated close to the uppermost tuffite level, yielded well preserved radiolarians assigned to the UAZ 7–8 (late Bathonian–early Oxfordian).

All these radiolarian ages need to be examined in parallel with the radiometric ages obtained on diorites and hornblende-bearing gabbros from ophiolitic units at Sevan [Bathonian–early Callovian, Galoyan et al., 2009], Vedi [Toarcian, Rolland et al., 2010] and Amasia [late Toarcian–early Bajocian and Aalenian–Bathonian; Hässig et al., 2013a,b], the petrographic and geochemical signature of which have all an oceanic arc component. All this evidence is consistent with the formation, at least since the Toarcian [Hässig et al., 2017], of an intra-oceanic volcanic arc following the initiation of an intra-oceanic subduction in the interior of an oceanic realm, which was over 2000 km wide during the Middle Jurassic, between the SAB and the Eurasian margin [Bazhenov et al., 1996, Meijers et al., 2015]; the latter is represented by the Somketo-Karabagh continental arc [Sosson et al., 2010] or island arc [Galoyan et al., 2018], which is also considered to represent evidence for a northward Andean-type subduction under the Eurasian continent or a southwad "Mariana-type" subduction in Paleotethys, respectively. The radiolarian age evidence discussed above and the important Bajocian volcanism known from the Somkheto-Karabagh belt [Sosson et al., 2010, Galoyan et al., 2018, and references therein] argue for a Bajocian pulse in geodynamic activity. The latter correlates well with the Bajocian (170–168 Ma) onset of a convergence setting in the Neo-Tethyan realm preserved in the Hellenides [Jones and Robertson, 1991, Jones et al., 1992, Ferrière et al., 2016]. They may both be the result of a more general plate tectonic reorganization following the opening of the Central Atlantic Ocean since ~175–170 Ma [Smith and Spray, 1984, Maffione and van Hinsbergen, 2018, and references therein].

The evidence for Late Jurassic submarine volcanic activity in the Tethyan realm of the Lesser Caucasus is not conclusive. Upper Jurassic radiolarites are in stratigraphic relation with lavas in Stepanavan, Amasia and Vedi [Danelian et al., 2007, 2010, 2016], but the obtained ages are not accurate enough yet (i.e., UAZ 9–10 or 9–11).

The data of the Dali sector, discussed above and in Seyler et al. [2023], provide important chronostratigraphic constraints for submarine volcanic activity during the Jurassic/Cretaceous transitional interval generated by partial melting of a heterogeneous mantle source in the extensional regime of an intraoceanic arc-back-arc setting. Given the new, more precise age (latest Tithonian–early Berriasian) for the lower radiolarites, it can be now established for the first time that the enriched mantle-derived volcanism was initiated since at least the Berriasian. Therefore, given the early Aptian radiometric age (ca. 117 Ma) of alkaline lavas dated by Rolland et al. [2010], it may be now inferred that the E-MORB and alkaline, OIB-like volcanism lasted for at least 20–25 million years (ca. 143/138–117 Ma; early/late Berriasian to early Aptian) in the Tethyan realm of the Lesser Caucasus.

Seyler et al. [2023] consider that this enriched subalkaline–alkaline magmatic activity that took place during the Jurassic/Cretaceous transition may reflect a major change in the geodynamic regime of Tethys in the Lesser Caucasus, as they bear geochemical signatures of within-plate lavas, locally showing a subduction influence.

Finally, our new radiolarian results establish that it is during the latest Tithonian–early Berriasian time that blocks of oolitic limestones with clasts of echinoderms slid into the deep-sea basin of radiolarite accumulation. Although the age of these limestones is unknown, their facies attests to the presence of islands in the neighbourhood of the radiolarite basin, on which shallow water carbonate sedimentation accumulated. A second outcrop of radiolarites containing blocks of limestones is reported by Danelian et al. [2012] from a megablock in the Dzknaged mélange, north of the lake Sevan; the megablock displays a sequence of 6–7 m thick radiolarites with thin-bedded intercalations of lava flows and several small (20 cm-wide) rounded blocks of limestones with debris of echinoderms. The radiolarian assemblage extracted from a sample (Sevan-1) is correlated with the latest Tithonian–Valanginian (UAZ 13–17), but it may be reasonably assumed that it is of similar age as at Dali valley.

It is noteworthy, that the late Valanginian interval (UAZ 17) is dated both in the Vedi and Sevan ophiolite zones. However, the block dated at the Erakh anticline [Danelian et al., 2017], contains intercalations of bedded radiolarian cherts and pelagic limestones and theferore attests for an ocean floor situated above the Calcite Compensation Depth (CCD) of the time, in contrast with the upper radiolarites intercalated between alkaline lavas at Dali [Asatryan et al., 2012, Seyler et al., 2023].

Two volcanic events of late Barremian–earliest Aptian age are indirectly dated by radiolarians and may be correlated with the radiometrically dated lavas at Vedi [ca. 117 Ma; Rolland et al., 2010]. The first comes from Karabagh, where middle upper Barremian to lowermost Aptian radiolarites overlying pillow lavas were dated by Asatryan et al. [2011], in a volcano-sedimentary sequence that is regarded as covering unconformably a complex paleo-seafloor of serpentinized peridotites. It is worth noting that in this case it is the discovery of the end member of the *Aurisaturnalis carinatus* evolutionary lineage that allowed a more accurate dating than the Zones (UAZ 18–22) of Baugmgartner et al. [1995] to which the diverse and moderately well-preserved radiolarian assemblage was assigned. Indeed, the age range of species *Aurisaturnalis carinatus perforatus* Dumitrica and Dumitrica-Jud found in the Ar-10-16 sample coincides with the magnetozone M1 and is anterior of the OAE1a [Dumitrica and Dulitrca-Jud, 1995]. The second volcanic event is dated in the Amasia ophiolite; here, Danelian et al. [2016] extracted upper Barremian–lowermost Aptian radiolarians from a volcaniclastic-chert sequence suggesting a subaerial volcanic activity more or less synchronous with submarine volcanism in the Sevan-Hakari ophiolite zone.

Finally, the youngest evidence for submarine volcanism comes also from the Amasia ophiolite, where Danelian et al. [2014] dated Cenomanian radiolarites overlying oceanic basaltic lavas. Here the assemblage is assigned to the *Dactyliosphaera silviae* Zone of O'Dogherty [1994].

4.2. *Age constraints for the obduction of the ophiolites*

The Vedi natural reserve and the Erakh anticline hold some key bio-chronostratigraphic elements to constrain the age of obduction of ophiolites in the Lesser Caucasus.

The first type of data comes from the uppermost carbonate sequences of the SAB. Hakobyan [1978] mentions the presence of upper Cenomanian layers with *Bicarinella bicarina* and *Pyrazopsis quinquecostatus* (both gastropods) and lower Turonian layers with *Radiolites peroni* (a rudist bivalve) and *Omphaloacteonella ovata* (a gastropod). In addition to these old data, which are difficult to be confirmed, Danelian et al. [2014] studied the 150 uppermost metres of the carbonate sequence of the SAB at Vedi and found benthic foraminifera suggesting a Cenomanian age, especially based on the presence of *Daxia cenomana*.

Regarding the age of the terrigenous sequences that are situated underneath the obducted ophiolites, Hakobyan [1978] considers the mélange unit at Erakh as early Coniacian in age; he mentions the presence of ammonites (*Barroisiceras onilahyense*) and several gastropod species found in siltstones and quartz-feldspar sandstones of the mélange unit.

Sosson et al. [2010] presented some calcareous nannofossil biostratigraphic results from the Vedi sector based on identifications by Carla Müller (see their Table 1). Here, we attempt to discuss their results based on the biostratigraphic scheme of Burnett [1998] and biostratigraphic information available in the Nannotax online database (https://www.mikrotax.org/Nannotax3/index.php?dir=ntax_mesozoic).

At the Vedi valley, the ARS16 sample was collected from the base of the flysch capping the SAB carbonate sequence. The species *Podorhabdus albanius* (now *Axopodorhabdus albanius*), mentioned in the assemblage, is known between the Albian and the Cenomanian (biozones BC25-UC5a); however, the contemporaneous presence of *Corollithion exiguum* (Turonian–Maastrichtian) in the assemblage points to a Cenomanian–Turonian age, therefore diverging from the Cenomanian age assignment provided in Sosson et al. [2010].

Similarly, the samples AR63 05, AR64-65 05 and AR67 05, coming from the upper part of the flysch sequence at Vedi are featured by the presence of *Reinhardites anthophorus* (Turonian–UC15d to Campanian) and *Lucianorhabdus cayeuxii* (UC11c in latest Coniacian to Maastrichtian), pointing to a latest Coniacian to Campanian time interval.

The second type comes from the age of the lowermost sedimentary levels of the transgressive sequence. Sosson et al. [2010] presented results of calcareous nannofossils from the marls overlying the red conglomerates and found a Coniacian–Santonian age. Samples AR72-73 05, coming from the upper part of the flysch sequence at Vedi, are featured by the presence of *R. anthophorus* (Turonian–UC15d to Campanian) and *L. cayeuxii* (UC11c in latest Coniacian to Maastrichtian), pointing to a latest Coniacian to Campanian time interval. Our results confirm and slightly improve this age assignment.

5. Conclusions

In the Tethyan realm preserved in the Lesser Caucasus radiolarian biochronology suggests episodic or continuous submarine volcanic activity for over 70–75 million years (Bajocian to Cenomanian) in relation to an intra-oceanic supra-subduction geodynamic regime. The significant volcanic activity recorded during the Bajocian in both the oceanic realm and the Somkheto-Karabagh volcanic arc may reflect a Bajocian pulse in geodynamic activity due to a plate re-organisation in the western Tethys in response to the opening of the Central Atlantic Ocean.

In addition, the new radiolarian ages from the Dali sector of the Sevan ophiolite establish that the onset of enriched subalkaline–alkaline volcanism dates back to the Berriasian, reflecting also a major change in the geodynamic regime of Tethys in the Lesser Caucasus. The geochemical affinity of lavas at Dali confirms that ophiolites were formed in the context of an intra-oceanic subduction. The shallow water carbonate olistoliths that slid into the deep water radiolarite basin from a nearby island arc may be also interpreted as the echo of such a tectonic event. E-MORB and alkaline volcanic activity lasted for at least 20 million years (Valanginian to early Aptian).

Radiolarian biochronology establishes also episodic or continuous subaerial volcanic input to the radiolarite basin for at least 45 millions years (Bathonian to Barremian), with the oldest tuffite deposits dated in the Sevan ophiolite [Asatryan et al., 2010] and the youngest in the Amasia ophiolite [Danelian et al., 2016]. This evidence is in good agreement with the presence of a volcanic island arc in the neighborhood of the oceanic basin in which the lava-radiolarite sequences were formed.

Our new results on calcareous nanofossils confirm and provide more accurate ages for the post-obduction sedimentary cover; the marls overlying the red transgressive conglomerates may be safely assigned to the late Coniacian–Santonian interval, UC 11a–UC 12 zones, which is correlated with the 86–84 Ma interval [Gradstein et al., 2020]. It is also clear that the carbonate sequence of the SAB accumulated at least up to the Cenomanian. Therefore, the ophiolite obduction took place some time during the Turonian–Coniacian interval. However, further work is needed in the future to better constrain the obduction by clarifying the age of the flysch deposited on the SAB and of the mélange sequence that accumulated in the trench formed in front of the advancing ophiolite thrust belt.

Conflicts of interest

Authors have no conflict of interest to declare.

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