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New Early Cretaceous Geosites with Palaeogeographical Value from the Northwestern Caucasus

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Abstract: Field investigations in the northwestern segment of the Greater Caucasus, a Late Cenozoic orogen, have permitted the establishment of two new geosites, namely the Ubin and Bezeps geosites. Both represent Berriasian–Middle Valanginian (Early Cretaceous) marine deposits with abundant trace fossils. The latter are attributed to the *Nereites* ichnofacies and indicate on deep marine palaeoenvironments (this interpretation challenges previous reconstructions). The geosites represent the palaeogeographical type of geoheritage. They are characterized, particularly, by high scientific and aesthetic importance, but restricted accessibility. Further geoheritage inventory in the central Northwestern Caucasus seems to be promising.

Keywords: Berriasian; Caucasus; geoheritage; palaeoenvironments; trace fossils

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1. Introduction

Geoheritage studies constitute an important trend in contemporary geological research [1–5]. However, despite numerous achievements, there are still many issues to address. Two of these are determining clear distinctions between geoheritage types and the need to find representative examples of these types in different geological domains. In other words, classifying and cataloguing geoheritage are on the agenda. These tasks are especially urgent for the relatively poorly-known but geologically-rich regions.

Palaeogeography, which deals with ancient environments and ecosystems, is an important field of geology. Evidently, there are many geological objects which can provide us with interesting information about the Earth's past. Such objects can be found both in the field [6–8], and in the cultural, urbanized environment [4,9,10]. Bruno et al. [11] conceptualized the palaeogeographical type of geoheritage and defined it as the entity of unique features representing palaeoenvironments (sensu lato). These specialists also suggested the classification of these types into facies (palaeoenvironmental), palaeoecosystem, ichnological, taphonomic, event (catastrophic), geoarchaeological, and palaeomapping subtypes. The latter was specially addressed by Habibi et al. [12]. More recently, Henriques et al. [13] emphasized the complexity of this geoheritage type and proposed to interpret it as a cluster of types. Importantly, these experts demonstrated the utility of particular geoheritage sites (geosites) for conceptual, classification-related discussions. This means that classifying and cataloguing geoheritage are mutually important.

The objective of the present contribution is to report two new geosites from the Northwestern Caucasus. The latter is a geologically-rich domain, stretching from the northern periphery of the Alpine orogenic belt across Southern Europe, the Middle East, and Central Asia [14,15]. Previous studies paid attention to small portions of geoheritage from the northwestern and eastern parts of this domain [5,16–19]. New field works undertaken in the central part of the Northwestern Caucasus have permitted the discovery of two

localities representing the Early Cretaceous environments of the Caucasian Sea. These geosites need examination, the outcomes of which contribute to the better understanding of the considered geoheritage type and the unique geological features of the Northwestern Caucasus, which remains poorly-known to the international research audience despite its evident peculiarities.

2. Geological Setting

The study area is situated in the Krasnodar region of the Russian Federation. It belongs to the northern slope of the Greater Caucasus mountains and lies between Krasnodar city in the northeast and the Black Sea Coast in the southwest (Figure 1).

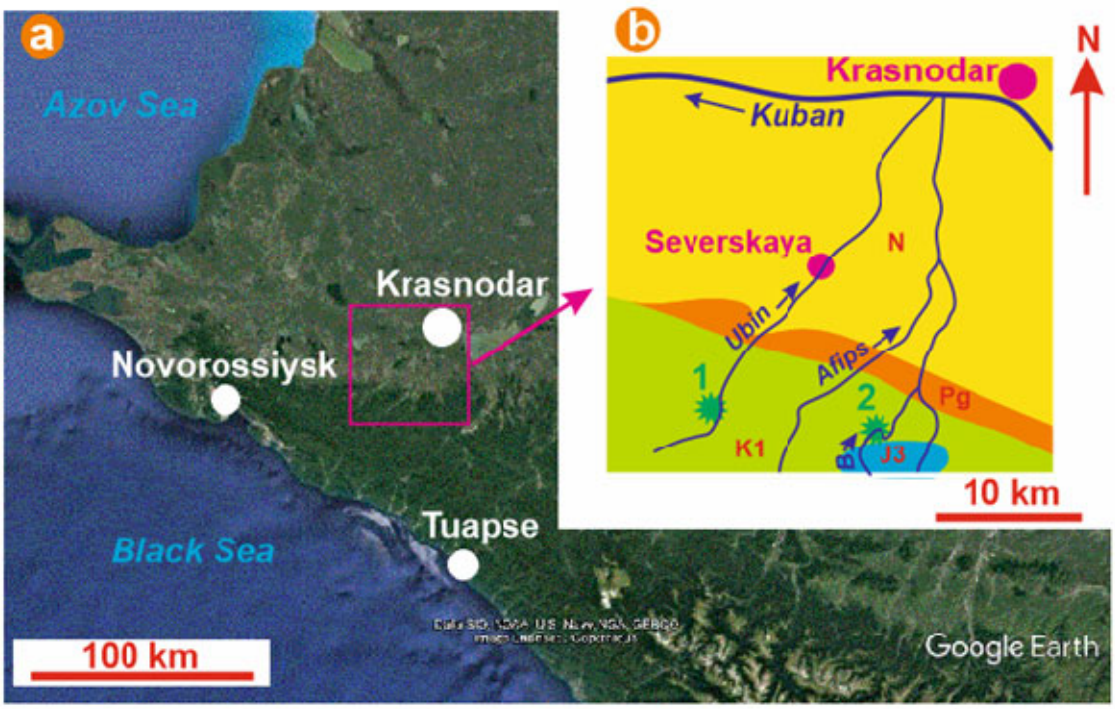


Figure 1. Geographical (**a**) and geological (**b**) location of the considered geosites (base satellite image from Google Earth); river: B—Bezeps; geosites: 1—Ubin, 2—Bezeps; stratigraphy: J3—Upper Jurassic, K1—Lower Cretaceous, Pg—Paleogene, N—Neogene.

Geologically, the study area represents the northwestern segment of the late Cenozoic orogen of the Greater Caucasus; this segment is known as the Northwestern Caucasus. It is dominated by folded and faulted Jurassic–Paleogene deposits accumulated in the Caucasian Sea. which occupied a back-arc basin between the island arc in the south and stable platform in the north [20–24]. The Cretaceous mixed siliciclastic–carbonate deposits are widely spread. In the study area, these are represented by the Berriasian–Middle Valanginian sandstones, claystones, and marlstones, with thin interlayers of limestones of the Machmalovskaya and Chatalovskaya formations (MCF), with a total thickness up to 1000 m [25] (Figure 2). These deposits were formed in a rather shallow tropical sea with rich ecosystems [26], although the palaeoenvironmental reconstructions are yet to be justified. The identified localities, namely the Ubin and Bezeps sections, are natural outcrops of the MCF in small river valleys (Figure 1), and their characteristics are provided below.

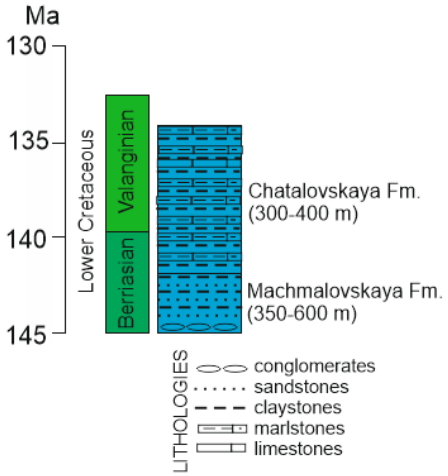


Figure 2. Composite section of the MCF (based on [25], geological time scale after [27]).

3. Methodology

The general examination of the established localities in the field resulted in the discovery of abundant trace fossils (ichnofossils). These were studied in regard to the current state of the ichnological knowledge [28–30]. Although precise identification and systematical description of ichnospecies is yet to be carried out, the main ichnogenera are established. This preliminary knowledge is enough for making ichnofacies interpretations and the related palaeoenvironmental reconstructions. The ichnological knowledge and the related interpretations constitute significant novelty and extend our understanding of the Cretaceous geology of the Northwestern Caucasus.

In regard to the established richness of the trace fossil assemblages, both localities seem to be unique, and, thus, can be defined as geosites. However, the latter needs to be characterized systematically. Several approaches have been proposed for such tasks [31–36]. These approaches reflect significant advances in the study of geoheritage, but such solutions are often only relevant for particular tasks or applications in particular socio-economical contexts. In this study, another approach, which has much in common with those indicated above, is referenced. This was proposed by Ruban [19] and tested, particularly, at other geosites in the Northwestern Caucasus [5]. This means its application in this study is reasonable for consistency with the regional geoheritage investigations. The criteria include uniqueness (global, national, regional, or local), number of geoheritage types [see classification in Ruban [37]), accessibility (easy in populated area, easy in remote area, or difficult), vulnerability (no danger, potential danger, partly damaged, or fully destroyed), need for interpretation (absent, basic geological knowledge required, professional geological knowledge required, scientific analysis required), scientific importance (international or local), educational importance (international or local), touristic importance (international or local), and aesthetic importance (high, medium, or low). In this study, the only criteria, not the entire approach proposed by Ruban [19], are employed. This means that the geosites are evaluated qualitatively, and the quantitative evaluation is left for future investigations when more geosites will be established in the study area, as the solution of this task may take several years.

4. Results

The Ubin geosite (44°43′ N, 38°31′ E) is situated ~50 km southwest of the city of Krasnodar (Figure 1). This is a natural outcrop along the Ubin River, which is a left tributary of the large Kuban River. The Berriasian–Valanginian calcareous claystones, with intercalations of siltstone and sandstone, crop out in the valley slopes and directly near the stream (Figure 3a). The Bezeps geosite (44°41′ N, 38°44′ E) is situated ~40 km southwest of the city of Krasnodar and ~10 km southeast of the Ubin geosite (Figure 1). This is a natural outcrop along the Bezeps River, which is a small stream in the drainage network of the

Afips River, another left tributary of the Kuban River. Berriasian marlstones with interbeds of sandstones and claystones crop out at the bottom of the rather wide valley, and they are crossed by the stream's channels (Figure 3b). Generally, both geosites can be regarded as important sections of the Berriasian Stage. This lowest stage of the Cretaceous System started at 145 Ma and ended at 139.8 Ma [27], with a duration of ~5 Ma.



Figure 3. General views of the considered geosites: (**a**)—Ubin, (**b**)—Bezeps.

Abundant trace fossils are found in the sandstones in the Ubin locality and in the marlstones in the Bezeps locality (Figure 4). Despite the differences in the hosting lithologies, the assemblages of the identified ichnotaxa from these localities are rather similar, and they represent the *Nereites* ichnofacies. The degree of bioturbation seems to be higher at the Ubin locality, and the presence of graphoglyptids appears to be slightly stronger at the Bezeps locality. The relative richness of these assemblages provides an indication of the activity of the earliest Cretaceous benthic organisms (marine invertebrates) at the bottom of the Caucasian Sea in the study area. The general knowledge of the recorded ichnofacies [28–30] and its case studies [38–40] indicate a relatively deep-marine palaeoenvironments and, particularly, a flysch-type depositional setting. If so, it can be hypothesized that the Caucasian Sea could have been much deeper, at least in its central part, in the Berriasian, than previously expected (for instance, [26]).

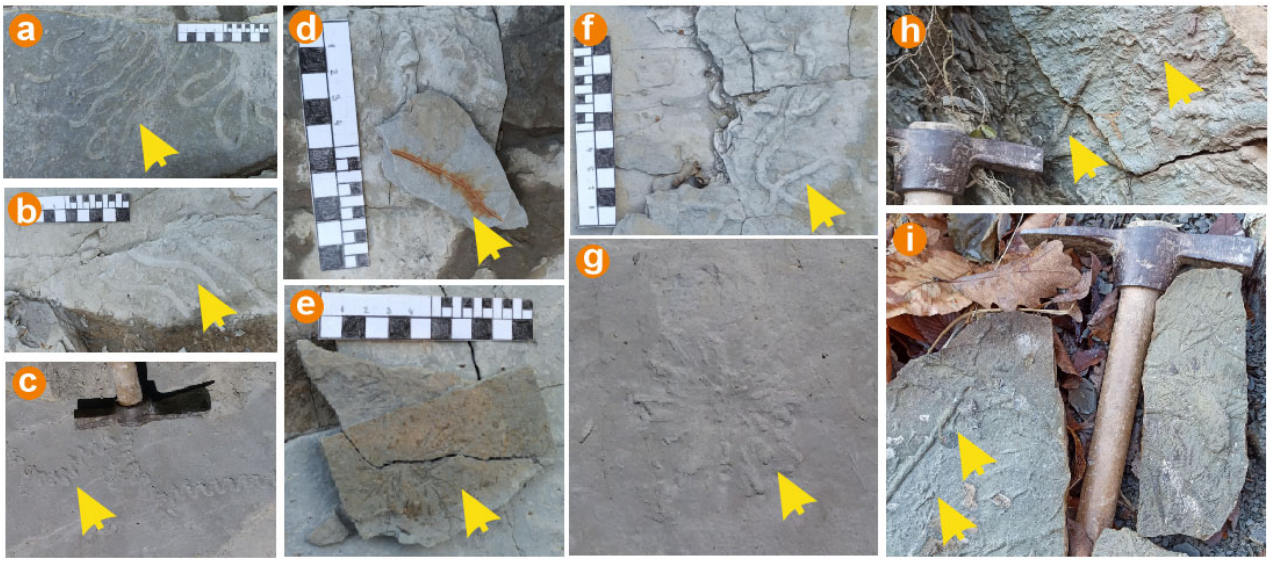


Figure 4. Selected trace fossils from the considered geosites (only dominating ichnofossils are labeled): (**a**), (**b**)—*Helminthorhaphe*, (**c**)—*Helicolithus*, (**d**)—*Ophiomorpha*, (**e**)—*Chondrites*, (**f**)—*Planolites*, (**g**)—*Glockerichnus*, (**h**)—*Belorhaphe* and *Ophiomorpha*, (**i**)—*Ophiomorpha* and *Chondrites*.

The uniqueness of the Ubin and Bezeps geosites is fully determined by the abundance of trace fossils. These geosites are reference Berriasian ichnological localities of the Northwestern Caucasus, and, thus, their rank is, at the very least, regional. However, it cannot be excluded that further investigations will prove the national importance of these geosites, if similar localities are found in the Feodosia area, another geological domain west of the Northwestern Caucasus. [41]. Moreover, the palaeogeographical value of the Ubin and Bezeps geosites is enlarged by the palaeoenvironmental interpretations of the trace fossil assemblages and, particularly, the reconsideration of the marine basin palaeodepth (see above).

Both geosites are represented by only one geoheritage type, namely the palaeogeographical type. According to Bruno et al. [11] (see also Henriques et al. [13]), this type includes unique trace fossil localities, and the special ichnological subtype of this type is distinguished. Moreover, the Berriasian was a time of global palaeoenvironmental and biotic stress [42–46], which was registered, particularly, in the Greater Caucasus [47]. If so, the event (catastrophic) subtype of the palaeogeographical type exists potentially in these geosites, although detailed palaeontological and geochemical investigations of the sections are required to prove its presence. Indeed, tectonic distortion of the MCF's deposits (Figure 3a), rare marine macroinvertebrates (for instance, ammonites, belemnites, and bivalves [48]), and peculiar water erosion of the geological formations (Figure 3b), can be related to the tectonic, palaeontological, and hydro(geo)logical types, respectively. Similar features are widely distributed across the Northwestern Caucasus and even in the nearby areas [5,19] and, thus, the local uniqueness cannot be established for these types. However, there is potential for the presence of the stratigraphical type. The Berriasian Stage is the focus of contemporary geoscience research because its general status and the position of its boundaries need justification with the possible modification of the geological time scale [49–55]. The Ubin and Bezeps sections can provide some helpful information for discussing these issues in the regional stratigraphical context. This requires further in-depth investigation of the fossil record, and such an investigation can take several years.

The accessibility of the geosites is not ideal. Although both are located not far from well-populated areas and Krasnodar city with population up to 2 mln, the study area can be considered as remote because it lies in a mountainous, densely-forested area with rare settlements and sparse infrastructure. Local roads can be used to reach these geosites. The Bezeps geosite can easily be accessed from such a road throughout the entire year, whereas the quality of the road to the Ubin geosite only allows for seasonal access and requires well-equipped cars. Principally, it is possible to access the geosites from the nearby settlements, but this requires several kilometers of hiking across rather wild terrain, as such, this option may only be suitable for groups of well-trained persons with an appropriate knowledge of the local geography. Accessibility of the Bezeps geosite is easy despite it being in a remote area, while access to the Ubin geosite is difficult. The vulnerability of the geosites is minimal, although potential danger can be identified in the natural damage of the layers with trace fossils by the running water, especially during seasonal flooding. At the Bezeps geosite, the stream crosses the outcrops, which are actively eroded (Figure 3b). Interpretation is essential for both geosites. Explanation of their palaeogeographical importance and, particularly, trace fossils, requires professional geological knowledge. Moreover, further scientific analysis of bioturbation is necessary for the comprehensive understanding of the geosites' uniqueness.

Indeed, the Ubin and Bezeps geosites are of significant, international-level scientific importance because they shed light on Berriasian trace fossils from the deposits of the former, semi-enclosed Caucasian Sea, which was a large palaeogeographical element on the northern periphery of the Neo-Tethys Ocean. The potential for ichnological, as well as palaeoenvironmental, palaeontological, and stratigraphic investigations is huge. Indeed, these geosites could be used to train university students from Krasnodar and other cities in Southern Russia. However, the accessibility issues restrict the potential for geoeducational excursions. Similarly, the geosites would be interesting to local geology and fossil amateurs,

but the same concerns around accessibility make geoexcursions questionable. However, a combination of geotourism and adventure tourism would be perfect in this case. Finally, the aesthetic importance of the geosites seems to be high because of two reasons. First, the natural landscapes, which have significant wilderness, are picturesque (Figure 3). Second, the general views of trace fossils (especially, the "geometric-looking" graphoglyptids), many of which are large in size and well-visible (Figure 4), leave impressions of artificial drawings and patterns, and such features seem to be very attractive. Previously, Baucon [56] and Xing et al. [57] demonstrated and explained the outstanding aesthetic importance of trace fossils, and such geology–beauty relationships matter in the study area.

Generally, the geoheritage values of the Ubin and Bezeps geosites are comparable, although the slightly superior accessibility of the latter increases its importance. It should be noted that although these are sites of the same kind, it would not be reasonable to designate only one of them as a geosite or to judge that one of them is a full equivalent of the other. On the one hand, they represent different lithologies of the MCF. On the other hand, their ichnofossil assemblages differ to a certain degree. Both localities seem to be mutually important Early Cretaceous geosites.

5. Discussion

The Ubin and Bezeps localities seem to be typical geosites with palaeogeographical value, and the latter is almost fully determined by abundant trace fossils. Several examples of similar geoheritage are known from the other parts of the world. For instance, Gutiérrez-Marco et al. [58] reported the Early Ordovician ichnological locality from Central Spain, Lkebir et al. [59] described the Late Cretaceous dinosaur tracksite from coastal Morocco, and Lopes et al. [60] characterized the Early Cetaceous sauropod footprints locality from central Brazil. Principally, all these geosites share sedimentary, palaeontological, and palaeogeographical features, and this fact echoes the ideas of Henriques et al. [13]. Nonetheless, trace fossils are not only palaeoenvironmental indicators, but also direct evidence of ancient organism–sediment interactions, which are palaeoecological patterns. If so, the attribution of the unique ichnological localities to the palaeogeographical geoheritage type seems to be reasonable, as it has been proposed by Bruno et al. [11].

One characteristic of all palaeogeographical geosites is their "fragility". The presently-observed geological features can be linked to the ancient environment through state-of-the-art interpretations. The latter depend strongly on how well-preserved the palaeoenvironmental indicators are. These are usually specific features, the loss of which "disrupts" the link between the present and the geological past. This is the case for trace fossils, which can easily be eroded by running water, destroyed by occasional visitors, or even overcollected. Moreover, some trace fossils need to remain in-situ for their correct identification and interpretation. These concerns raise questions about the necessity of special geoconservation procedures for the Ubin and Bezeps geosites. The practices employed at the Cabeço da Ladeira geosite in Portugal, including making casts and temporary exhibitions [61], can be applied locally. The biggest danger is natural erosion, which can be very intense during seasonal flooding. Although costly, some engineering solutions to protect these trace fossil localities physically would be suitable. Indeed, trace fossils should also be collected properly to preserve the most precious specimens in local museum collections.

Another characteristic, which seems to be typical of many, if not all, ichnological geosites, is their high aesthetic importance (see above), which can attract visitors. Taken alone, the Ubin and Bezeps geosites cannot be used for geotouristic developments due to accessibility issues. However, further geoheritage inventory in the Northwestern Caucasus will result in the discovery of other geosites, many of which will also be Cretaceous in age, and these may be able to be linked by an excursion route. This is an efficient solution to the issues in geotourism [62–65], and the Italian experience in spatial planning of geotourism [66–70] is also notable. Such a route will need certain infrastructure developments, including trail construction and the installation of interpretive panels and signs. These are

reasonable demands when a series of geosites are exploited for geotourism purposes. Both geosites can contribute to geotourism growth in such conditions.

In conclusion, this pioneering report into the palaeogeographical value of the Ubin and Bezeps geosites, as determined by trace fossil abundance, proves the presence of Early Cretaceous geoheritage in the central part of the Northwestern Caucasus. The necessity of further geoheritage inventory in this domain should be stressed. It is expected that new palaeontological, sedimentary, stratigraphical, palaeogeographical, and geomorphological geosites will be found there in the course of field investigations. This seems to be an initial, but nonetheless very important, step towards geoconservation and geotourism development in this area. The latter is poorly-known to the international, and even a part of national, geoscience research community, and, thus, the geoheritage inventory will fill some gaps in our understanding of the evolution of the northern Neo-Tethyan margin and the subsequent growth of the Greater Caucasus orogen.

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