

ALPINE BASEMENT OUTCROPS AT NORTHERN PELOPONNESUS: IMPLICATIONS FOR THE EARLY STAGES IN THE EVOLUTION OF THE CORINTH RIFT

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Abstract

We focus on the central and eastern southern onshore parts of the Corinth Rift (CR), where basement outcrops are few and of limited extent, to study three key locations: a basement inlier east of Xylokaastro, a new outcrop of the Tripolis Unit at the western edge of the Xylokaastro horst, and a re-mapped and re-evaluated outcrop of the Pindos Unit northwest of Nemea. The results of this study show that there are elements which could help overcome the significant difficulties in our understanding of the structure and evolution of the rift, posed by the lack of basement outcrops in the central and eastern onshore parts of the Rift. This, in turn, calls for a reconsideration of the generally accepted idea that the broader onshore eastern sector of the CR lacks significant basement and intrabasinal faults.

Keywords: Post-orogenic extension, Tripolis Unit; Pindos Unit.

Περίληψη

Η παρούσα εργασία εστιάζει στο ανατολικό και νότιο χερσαίο τμήμα της Κορινθιακής Τάφρου, όπου μελετώνται τρεις περιοχές: μία απομονωμένη εμφάνιση υποβάθρου ανατολικά του Ξυλοκάστρου, μία αχαρτογράφητη μέχρι σήμερα εμφάνιση της ενότητας της Τρίπολης στο δυτικό άκρο του τεκτονικού κέρατος του Ξυλοκάστρου και μία εμφάνιση της ενότητας της Πίνδου, βορειοδυτικά της Νεμέας, όπου αναθεωρείται παλιότερη χαρτογράφηση και επανεκτιμάται η σημασία της. Στην περιοχή αυτή, η απουσία εμφανίσεων του υποβάθρου, σε συνδυασμό με το μεγάλο πάχος των συνταφρικών αποθέσεων έχει οδηγήσει στην εικόνα μιας ευρείας περιοχής με πρακτικά απόντα τεκτονικό ιστό. Ωστόσο τα αποτελέσματα των υπό εξέλιξη ερευνών δείχνουν την ύπαρξη μεγάλων ή μικρότερων ρηγμάτων, τα οποία διαμορφώνουν μια νέα θεώρηση αναφορικά με τη δομή και εξέλιξη της Τάφρου.

Λέξεις κλειδιά: Μετα-ορογενετικός εφελκυσμός, Ενότητα Τρίπολης, Ενότητα Πίνδου.

1. Introduction

The Gulf of Corinth Rift (CR), one of the most rapidly extending continental rifting zones worldwide, is a young structure, overprinting at high angles the tectonic grain of the Hellenides, inherited from the alpine orogeny. At its present form it is ca 100 km long and it comprises an active, mainly offshore

part 30-40 km wide, which corresponds to the Gulf of Corinth and a less active, onshore landstrip (ca 40 km wide) along the Northern Peloponnesus (Fig. 1). Current extension rates across the rift are in the order of 10-16 mm/yr (e.g. Avallone *et al.*, 2004), with extension oriented approximately N-S (e.g. Clarke *et al.*, 1998). The origin of extension, in general and particularly the strain focusing on the CR is still matters of debate; suggested models involve subduction-driven rollback and back-arc extension, gravitational collapse of thickened crust, or influence from the westward propagation of the North Anatolian Fault (e.g. Armijo *et al.*, 1996; Jolivet *et al.*, 2010).

The understanding of the Corinth rift evolution calls, among others, for constraints on the pre-rift (alpine) structure and geometry. The quantification of parameters such as the displacement of rift-bounding faults (but also of intrabasinal ones) is facilitated if a known marker can be located both on their hanging- and footwalls. The tectonic contacts between the geotectonic units that build the tectonic edifice of the pre-rift basement have been used as markers for the estimation of the extension across the CR, the displacement of the onshore rift-forming faults and the palinspastic reconstruction of the rift (e.g. Ford *et al.*, 2013). One such marker, which was used in other parts of the CR, is the tectonic contact of the Pindos Unit pelagic limestones over the flysch of the Tripolis Unit (e.g. Sorel, 2000; Skourtsos and Kranis, 2009). However, this is mainly true for the western southern onshore part of the rift, because its southern eastern onshore segment (i.e. between Xylokastro in the west and Corinth in the east), the absence of basement outcrops has led to the assumption that this part of the rift is devoid of large faults and follows a different evolutionary pattern.

In the light of the above, we focus on the central and eastern southern onshore parts of the CR, where basement outcrops are few and of limited extent. We study three locations: a basement inlier east of Xylokastro, which has been mapped and appears in the published IGME map (Koutsouveli *et al.*, 1989), a newly mapped outcrop of the Tripolis Unit, at the western edge of the Xylokastro horst, and a re-mapped and re-evaluated outcrop of the Pindos Unit North-west of Nemea. These may aid our understanding of the structural grain in a relatively poorly investigated area within a continental rift of world-wide importance.

2. Geological and Tectonic Setting

The southern onshore part of the CR extends from Mt Panakhaikon in the west to Corinth in the east (Skourtsos and Kranis, 2009). Terrestrial and marine sediments, with thickness exceeding 2.8 km, were deposited during the phases of the CR evolution. These synrift deposits were classified in three groups, namely (i) a lower group, of probable Pliocene age, which comprises terrestrial deposits, including alluvial fans in the west and lacustrine sediments in the east; (ii) a middle group, which includes large marginal fan deltas; and an upper group, which comprises the marine and fluvial terraces that flank the southern onshore part of the CR at Northern Peloponnesus (Rohais *et al.*, 2007). This broad zone has been undergoing uplift, albeit at varying rates along the rift axis, and synrift sediments are now found at altitudes above 1.6 km (Dufaure, 1977).

The pre-rift Hellenide ('alpine') basement of the CR comprises various Tethyan fragments, which were successively detached from the subducting African plate and accreted to the southern margin of the Aegean microplate on the Hellenic subduction zone.

As regards the central part of the Northern Peloponnesus, the tectonically lower Unit is the Phyllites-Quartzites (PQ) Unit, which consists of high-pressure mica schists and quartzites, along with rare ultramafic rocks. The Tripolis Unit (TU), which overlies the PQ is characterized by a thick shelf U. Triassic- U. Eocene carbonate sequence, deposited on an Upper Palaeozoic – L. Triassic volcanosedimentary complex, collectively known as the Tyros Beds. This carbonate sequence is capped by a flysch sequence, of L. Eocene – Oligocene age. The uppermost Unit of the pre-rift basement is the Pindos Unit (PU), a Mesozoic sequence of pelagic sediments (limestones and cherts), topped by a Palaeocene – Eocene flysch. At the eastern onshore part of the CR (Corinth and Perahora peninsula), the pre-rift basement is represented by the rocks of the Sub-Pelagonian Unit (SU) and comprise mainly Upper Triassic to Jurassic neretic limestones, followed by Mid-Upper Jurassic

shales, sandstones and cherts. Finally, an ophiolite thrust sheet is found at Geraneia Mountains, in the eastern edge of the Gulf of Corinth.

The synrift sediments in the Northern Peloponnese have been deposited upon the alpine, pre-rift basement and the western and central portions of the CR are characterized by E-W to ESE-WNW faults that acted during the early stages of rift evolution now juxtapose basement outcrops against synrift sediments (Skourtso and Kranis, 2009; Ford *et al.*, 2013).

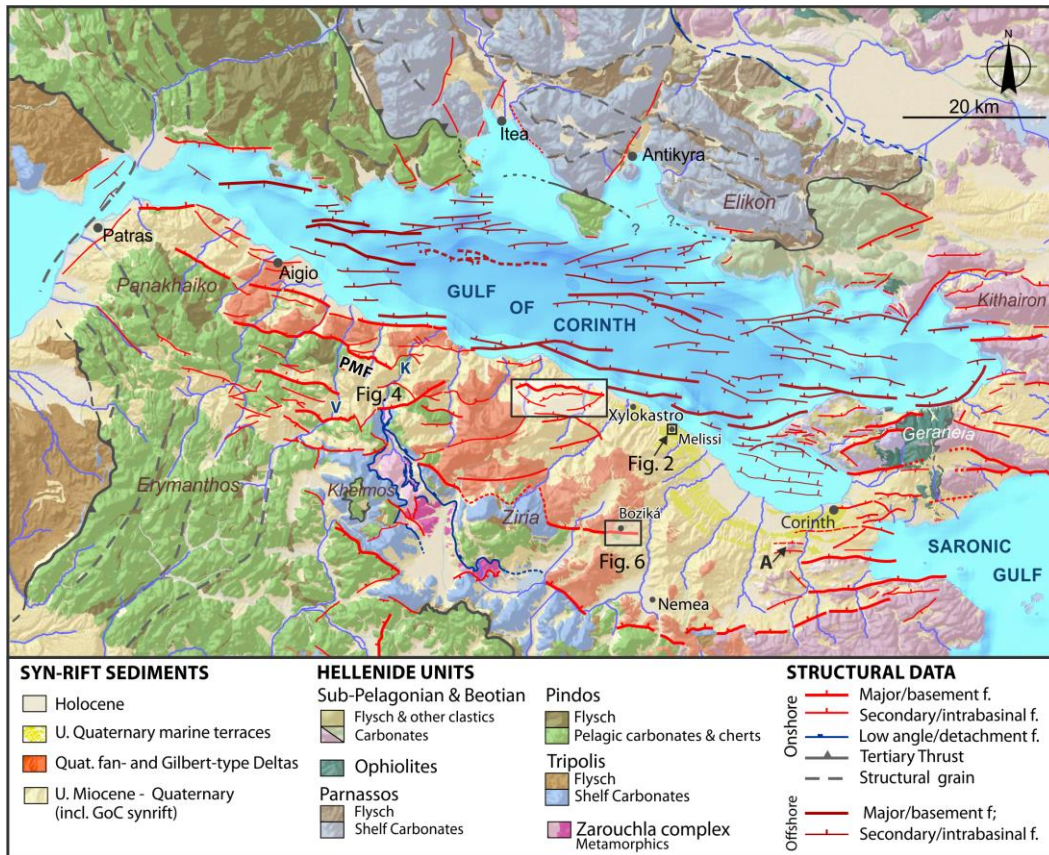


Figure 1 - Synthetic tectonic map of the Gulf of Corinth, to show the Hellenide Units that constitute the basement to the GoC Rift, modified after Kranis *et al.* (2015). Structural data from Beckers *et al.* (2015), Charalampakis *et al.* (2014), Nixon *et al.* (subm.) (offshore), Ford *et al.* (2009, 2013) (south –western onshore), Skourtso and Kranis (2009) and Leeder *et al.* (2013) (southern central) Freyberg (1973), Collier and Dart (1991) (eastern onshore); and own mapping. Dashed line offshore delineates the possible eastern margin of the External Hellenides beneath the Gulf. A: Akrocorinth; V: Vouraikos; K: Krathis.

3. The Melissi inlier

A minor basement outcrop (area ca 0.02 km²) consisting of carbonates and clastics, is located at the seaside town of Melissi, 5 km SE of Xylokastro. The carbonates occupy a small knoll, just north of the Corinth-Patras highway, while the clastics were mainly exposed on the roadcut, covered, capped by an U. Pleistocene marine terrace (Fig.2). The construction of the new highway, through widening of the original route exposed the clastic sequence for a distance of ca 300 m along the road, but subsequently involved the erection of retaining walls, which have now covered almost the entire outcrop of the clastics.

The clastics consist of brown clays, intercalated with dm-thick banks of calcareous conglomerates and fine-grained sands and include rare angular to well-rounded limestone blocks (<0.5 m³). The sequence appears deformed in tight folds at the eastern part of the exposure, but towards the west it presents a steady NW-dipping geometry. Information provided by professional drillers in the area (F. Chatoupis, 2012, pers. comm.) confirms that the within a ca 5 km distance to the SE and S from the Mellissi outlier, the synrift deposits are underlain by clastic sediments with close affinities to the clastic sediments exposed along the roadcut.

The carbonates are whitish, massive or thick-bedded and densely fractured limestones, while small, irregular calcite veins run through the carbonate mass. The nature of the contact between the clastics and the carbonates could not be verified in the field, as it obscured by the national road. The northern, steep boundary of the calcareous mass is densely fractured by E-W steep planar discontinuities and corresponds to a degraded fault scarp.

A number of samples was obtained both from the clastic sequence, especially from the olistholites and the conglomeratic intercalations and from the calcareous mass. The microfacies analysis of the breccia and conglomerate banks, included in the clastic sequence revealed that their elements may be composed of fragments of one stratigraphic level or different stratigraphic levels of the Tripolis platform. The elements may be of small size (up to 1mm) or be coarser ones. More specifically, in a microbrecciated bank of Tertiary, age evidenced by the presence of *Globorotalia* sp. (Fig. 3), small sized elements of exclusively Late Cretaceous age are found in the cement, including fragments of bivalves, rudists, echinoids, as well as *Orbitoides media*, *Lepidorbitoides* sp., *Siderolites calcitrapoides*, *Cuneolina* sp, indicating L. Campanian-Maestrichtian age.

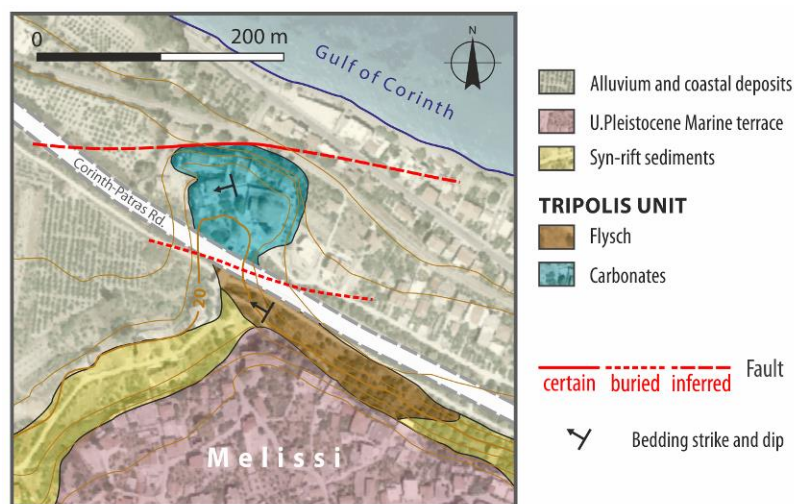


Figure 2 - Map of the Mellissi inlier (see Fig 1. for location). The knoll north of the highway is an outcrop of L. Paleocene - E. Eocene age limestones, in faulted contact with the flysch of the Tripolis Unit. The marine terrace that caps the hill south of the highway corresponds to the MIS3.3 (ca 55 ka BP) Kariotika -1 terrace (Armijo *et al.*, 1996).

In other cases, finer and coarser unsorted elements are found. Different stratigraphic levels are recognized: Elements of mudstone containing Ophthalmidiids, ostracods, *Bolivinopsis*, *Aeolisaccus kotori* indicate a Late Cretaceous age, of inner platform provenance. Ped and fenestra structure consisting of ellipsoidal to round pelletoid elements, separated by irregular pore spaces, observed in certain breccia elements, indicate an intertidal to supratidal provenance.

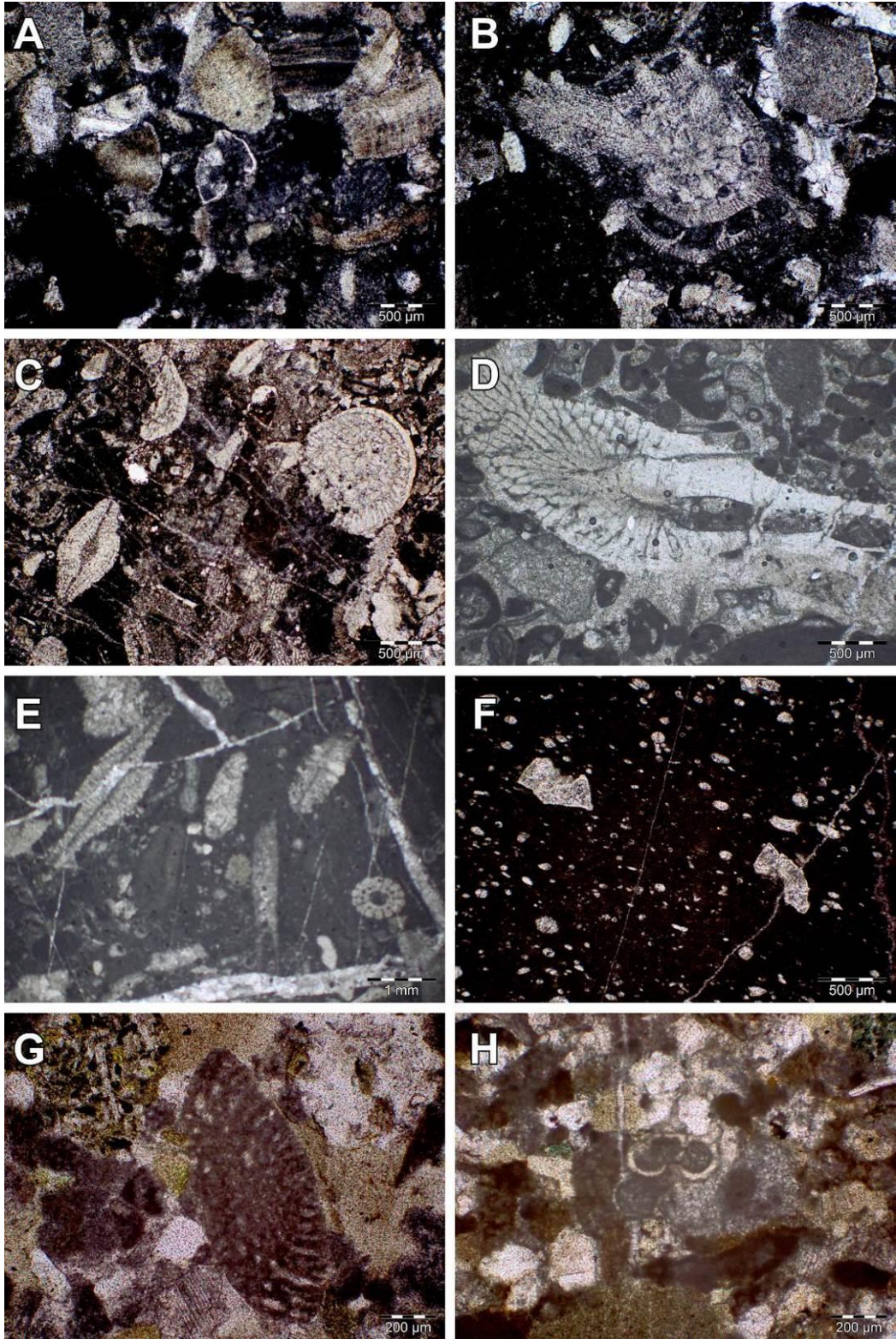


Figure 3 - Microphotographs from samples obtained from the study sites. Samples A-C and D-E are from the clastics and the carbonates of the Melissi inlier, respectively; F-H are from the Pindos outcrops at Boziká. (A): *Globorotalia* sp. in the matrix of a microbreccia containing fragments of bivalves and rudists; (B): *Siderolites calcitrapoides*; (C): bioclastic limestone with *Chapmanina* and *Asterodiscus*; (D): Biosparite with *Ranikothalia*; (E): Biomicrite mudstone with *Discocyclina* and echinoid spine; (F): Biomicrite mudstone with *Globotruncanidae*; (G): Orbitolinid in clastic limestone; (H) *Hedbergella cf trochoidea* (Gandolfi).

Similar facies are observed in different levels of the upper Cretaceous sequence of Tripolitza platform (Zambetakis Lekkas *et al.*, 1988, 1998, 2007; Pomoni-Papaioannou and Zambetakis-Lekkas, 2009), but also of Lower Cretaceous age (Zambetakis-Lekkas *et al.*, 1995). These elements are found among others of sandstone and microfossils that are transported as independent breccia elements. Their different stratigraphic attribution and their occasional intensively eroded appearance testify their transportation.

On the other hand, the micropalaeontological study of the carbonates showed that they consist of biomicritic-biosparitic limestones, mudstones-wackestones or grainstones and are characterized by the abundance of corals. Hydrozoans, bivalves, echinoderms *Algues Melobesia* and rare gastropods are also present, along with foraminifera as miliolids, rotaliids, *Discocyclina sp.* and *Ranikothalia*, which yield a Late Paleocene - Early Eocene age (Fig. 3). The fact that the carbonates belong to the underlying stratigraphic level of the clastics (i.e. U. Eocene) points to the existence of a tectonic contact between these two formations, which is interpreted as a fault that has been obscured by the construction of the motorway.

4. Occurrence of the Tripolis Unit in the Xylokaastro horst block

A major basement outcrop occurs south-west of Xylokaastro. This is elongated fault block, uplifted in the footwall of the Xylokaastro fault. Recently published work (Leeder *et al.*, 2012) shows that this block corresponds to an intrabasinal horst, faulted against syn-rift sediments both on its northern margin (via the Xylokaastro F.), but also on its eastern and southern margins, via the Koutsos fault. Until recently, the basement outcrops within the Xylokaastro block were considered to comprise solely the formations of the Pindos Unit. However, geological mapping in the area showed that the underlying (lower) Tripolis Unit is also exposed in this horst block.

The Tripolis outcrop is located at the western edge of the horst and covers an area of ca 0.6 km² at a moderately north-dipping slope. It consists solely of carbonate rocks and specifically thick-bedded to massive light or dark grey limestones, which are intensely brecciated and dolomitized. This is partly attributable to the fact that the slope that the carbonates occur practically coincides with the fault surface (i.e. a 'fault-slope') of the Xylokaastro fault. Nonetheless, the facies and sedimentary structure of the carbonates have close affinities to the Late Cretaceous-Eocene limestones of the Unit.

The outcrop occurs as a lower-order horst within the Xylokaastro block, meaning that it is in faulted contact with the Pindos limestones in the south and south-east and with the syn-rift sediments in the north and north-west. The southern margin of the outcrop is an E-W, south-dipping fault, which juxtaposes the Tripolis carbonates against the Pindos limestones. Its northern margin corresponds to the western termination of the main, north-dipping Xylokaastro fault, which juxtaposes the Tripolis rocks against synrift sediments. The latter are deformed in a well-defined fault-drag fold, with northerly structural dips increasing towards the trace of the Xylokaastro Fault.

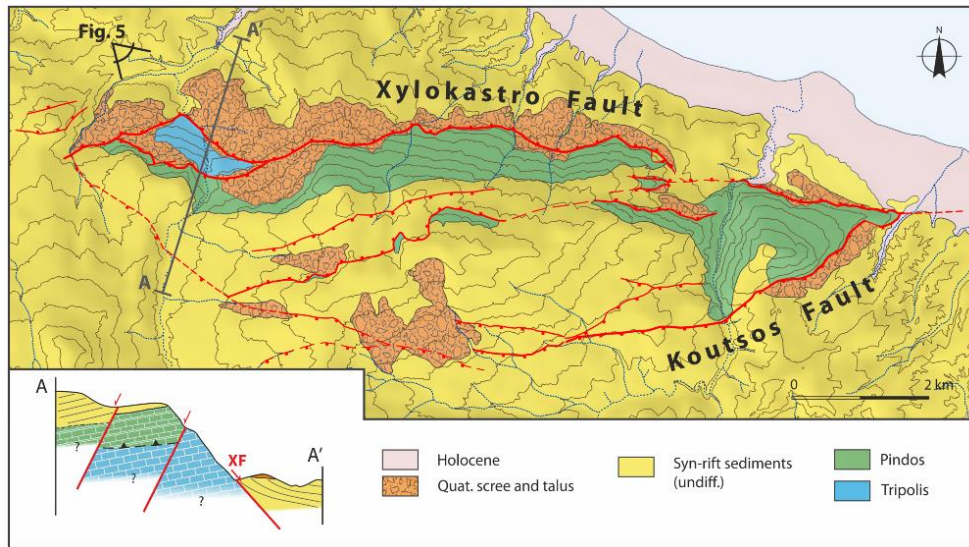


Figure 4 - Geological map of the Xylokaastro horst. See Fig. 1 for location. The basement outcrops within the horst belong to the formations of the Pindos Unit (cherts and limestones), with the lower Tripolis Unit outcropping at the western part of the horst.

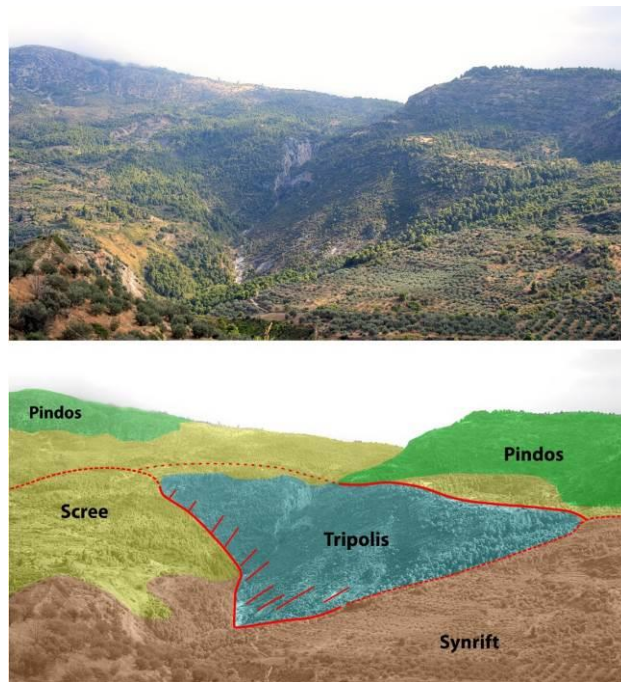


Figure 5 - The previously unmapped outcrop of Tripolis Unit limestones at the western tip of the Xylokaastro horst. View to ESE.

5. The Pindos inlier group at Boziká

Geological mapping in the area of the Boziká settlement (Fig .6), showed a number of occurrences of the Pindos Unit, overlain by synrift deposits of the CR. The northernmost outcrop consists of green mudstones, clastic limestones with red and green clasts and muddy radiolarites that pass

southwards to red mudstones and further the south to laminar, thin-bedded, and whitish to beige limestones with thin black chert nodules. The limestones (biomicrites, mudstones) contain *Globotruncana asymetrica* (Sigal) and *Globotruncana concavata* (Grotzen) are determined, indicating Santonian age (Fig. 3). The medial outcrop consists of green sandstones, mudstones and fine conglomerates containing quartzitic and volcanic clasts, and intercalations of clastic limestones that include Orbitolinidae and Miliolidae and *Hedbergella cf trochoidea* (Gandolfi). (Fig. 3). The latter narrows down the age of the formation to Aptian- E. Cenomanian. The southernmost outcrop has also comparable lithology, although green mudstones and sandstones dominate. The fossils, and the microfacies both in the clastics and in the carbonates show that these outcrops belong to the “first flysch” of the Pindos Unit as it was named by Aubouin (1959) and was included by Fleury (1980) in the Radiolarites Formation (upper member).

The clastics are folded in places with closed to tight folds striking N30°, but also isoclinal folds and microbending, striking N150° and N-S, respectively, were observed.

The southernmost occurrence of the Pindos Unit is covered unconformably by sandstones, mudstones and conglomerates with dips up to 40° to the S-SSW, which further south are covered by a thick sequence of conglomerates and sandstones that are part of a large alluvial fan delta. The alpine outcrops are faulted by a suite of E-W, N-dipping high-angle normal faults, which juxtaposed them against the synrift sandstones and mudstones which exhibit high-angle southerly dips. The latter are covered unconformably by a group of conglomerates and coarse sandstones of another alluvial fan delta.

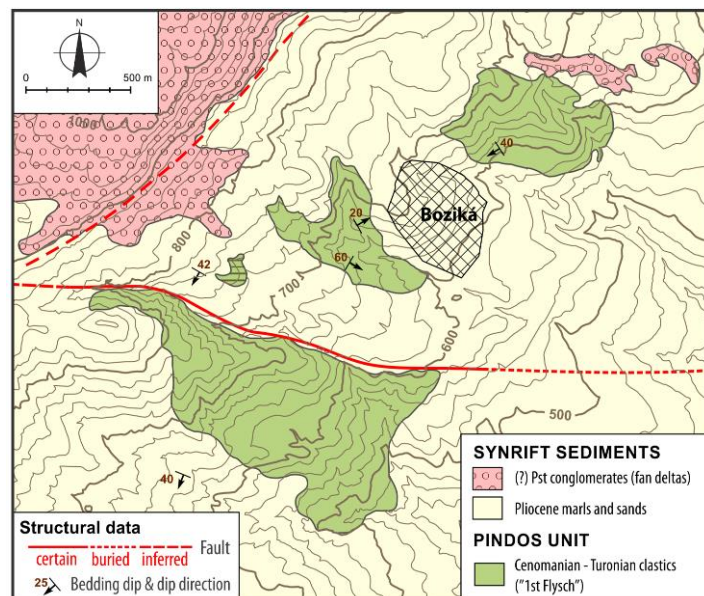


Figure 6 - Geological map of the area around Bozika (see Fig. 1 for location).

6. Discussion - Implications

The lack of basement outcrops in the central and eastern onshore parts of the Corinth Rift poses significant difficulties in our understanding of the structure and evolution of the rift. Detailed geological and structural mapping, in the last few years, however, has shown that there are elements which could help overcome some of these obstacles.

The Melissi inlier is one of these ‘stepping stones’ between the Xylokaastro block in the west (which is the easternmost basement outcrop along the Gulf of Corinth shore) and the next significant basement exposure, which is at the Akrocorinth horst block in the east (Fig. 1). The importance of

this outcrop is enhanced by the results of offshore geophysical surveys. Specifically, Taylor *et al.* (2011) show that a set of N-dipping offshore faults, located off the coast of Melissi (the Sythas and offshore Xylokaastro faults) are responsible for the formation of a secondary footwall basin, while the continued activity of these faults has led to significant footwall uplift, eventually leading to the subaerial exposure of basement rocks, such as at the Melissi inlier.



Figure 7 - Outcrop of the '1st Flysch' Pindos formation at Boziká.

The Tripolis outcrop at the Xylokaastro horst and the Melissi inlier are the two northernmost exposures of the Unit at Northern Peloponnesus, within the onshore landstrip of the Corinth Rift. Other Tripolis outcrops are located at the footwalls of rift-related faults, such as the Valimi and Pyrgaki-Mamoussia Faults, in the valleys of Krathis and Vouraikos, respectively (Fig. 1). In these locations the contact between the Tripolis and Pindos Units is mappable and it corresponds to an extensional fault that has replaced the original thrust contact between these units. Such extensional structures could be related the early syn-orogenic extension that has affected the central and southern Peloponnesus in the U. Miocene (Skourtsos, 2002; Skourtsos and Lekkas, 2010), but they can also be linked to the formation and evolution of the Corinth Rift. In the latter case the magnitude of extension across the rift has to be greater than what was calculated through palinspastic reconstructions (e.g. Sorel, 2000), which do not take into account these south-dipping faults.

Geological mapping and micropalaeontological analysis of the Pindos Unit outcrops at Boziká show that they belong to the middle Cretaceous clastic series of the Unit, instead of the Palaeocene – Eocene Pindos Flysch, as shown by Tataris *et al.* (1970). The presence of *Hedbergella cf trochoidea* (Gandolfi) within a stratigraphic horizon from the middle part of the formation shows that the onset of the deposition of the “First Flysch” in the area was earlier than the age indicated by the fossil itself, probably during the Barremian, as suggested by Fleury (1980) for central Greece.

The Pindos outcrops at Bozika can be described as rotated fault blocks, controlled by E-W, north-dipping normal faulting, which is connected to a major marginal fault along the northeastern flanks of Mt Ziria. Additionally, the presence of two big alluvial fan deltas north and south of these faulted outcrops can be compared to the evolution of the central onshore CR where multiple and diachronous fan deltas were deposited along the southern margins of the rift, as fault activity migrated northwards.

Finally, the occurrence of the basement outcrops themselves and the fact that they are fault - controlled, raises the issue of re-consideration of the structural grain in the onshore eastern sector of the Corinth Rift, where the image of an extended area devoid of significant basement and intrabasinal faults is based on dated data and maps, which should be revised.

7. Acknowledgments

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8. References

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