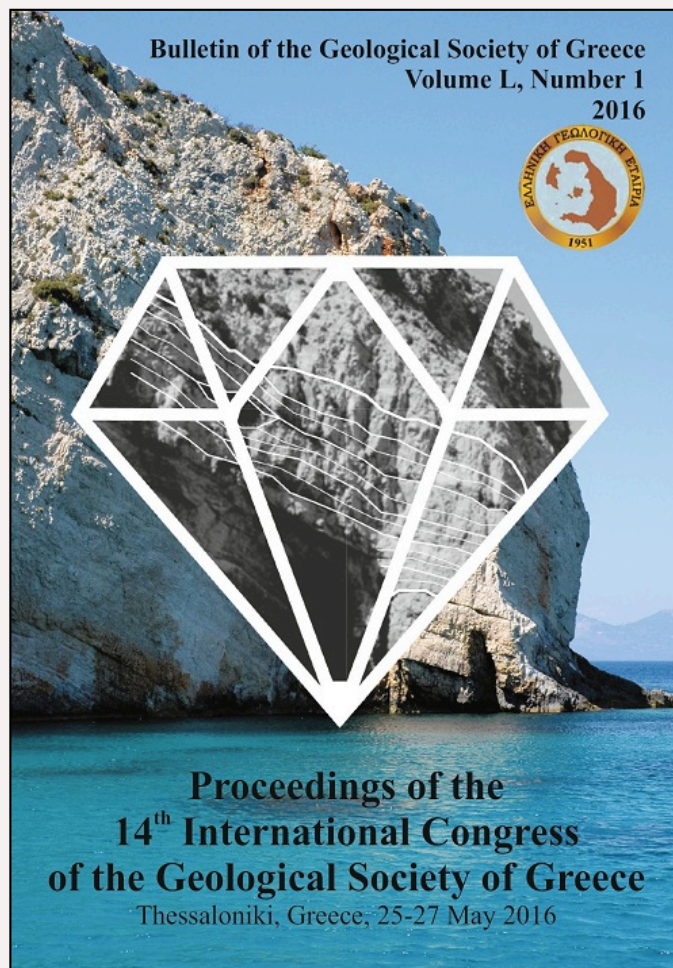


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| Scherreiks R. | Bayerische Staatssammlung, Department of Geology, University of Munich |
| Meléndez G. | Departamento de Geología (Paleontología), Universidad de Zaragoza |
| Bouldagher-Fadel M. | Earth Sciences, University College London |
| Fermeli G. | Department of Historical Geology and Paleontology, University of Athens |
| Bosence D. | Department of Earth Sciences, Royal Holloway University of London |

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THE CALLOVIAN UNCONFORMITY AND THE OPHIOLITE OBDUCTION ONTO THE PELAGONIAN CARBONATE PLATFORM OF THE INTERNAL HELLENIDES

Scherreiks R.¹, Meléndez G.², Bouldagher-Fadel M.³, Fermeli G.⁴ and
Bosence D.⁵

¹*Bayerische Staatssammlung, Department of Geology, University of Munich, Luisenstr. 33,
80333 Munich, Germany, r.scherreiks@hotmail.com*

²*Departamento de Geologia (Paleontología), Universidad de Zaragoza, 50009 Saragossa, Spain,
gmelende@unizar.es*

³*Earth Sciences, University College London, Gower Street, London WC1E6BT, UK,
m.fadel@ucl.ac.uk*

⁴*Department of Historical Geology and Paleontology, University of Athens, Panepistimioupolis,
Zographou, 15784 Athens, Greece, gfermeli@geol.uoa.gr*

⁵*Department of Earth Sciences, Royal Holloway University of London, Egham TW20 0EX, UK,
d.bosence@es.rhul.ac.uk*

Abstract

The carbonate-platform-complex and the oceanic formations of the central Pelagonian zone of the Hellenides evolved in response to a sequence of plate-tectonic episodes of ocean spreading, plate convergence and ophiolite obduction. The biostratigraphies of the carbonate platform and the oceanic successions, show that the Triassic-Early Jurassic platform was coeval with an ocean where pillow basalts and radiolarian cherts were being deposited. After convergence began during late Early-Jurassic - Middle Jurassic time, the oceanic leading edge of the Pelagonian plate was subducted beneath the leading edge of the oceanic, overriding plate. The platform subsided while a supra-subduction, volcanic-island-arc evolved. Biostratigraphic and geochemical evidence shows that the platform and the oceanic floor, temporarily became subaerially exposed during Callovian time. This "Callovian event" is suggested to have taken place as oceanic lithosphere first made compressional, tectonic contact with the carbonate platform, initiating a basal detachment fault, along which the platform was thrust upwards. The central Pelagonian zone became an extensive land area that was supplied with laterite from an ophiolite highland. A similar emergence of Vardar ophiolite most likely took place in the Guevgueli area. The Callovian emergence shows that the initial ophiolite obduction onto the platform took place about 25 million years before the final emplacement of the ophiolite during Valanginian time.

Keywords: *Bio-facies, litho-facies, Foraminifera, Radiolarite, Plate convergence, Laterite, Callovian event, Ophiolite obduction.*

1. Introduction

The Pelagonian carbonate complex of the Hellenides is covered by sporadically-distributed remnants of an ophiolite sheet (Fig.1) which was obducted onto the Pelagonian micro-plate during Valanginian time. The convergence of the oceanic (ophiolite) plate with the Pelagonian plate has been postulated to have begun around late Early-Jurassic time as a result of intra-oceanic subduction (Bèbien *et al.*, 1980, and Spray and Roddick 1980) (compare Scherreiks *et al.*, 2014). However, about 25 ma prior to the final emplacement of the ophiolite during Valanginian time, both the platform and the ophiolite became subaerially exposed during late Bathonian to early Oxfordian time. This major tectono-stratigraphic event of Callovian time is the main theme of this contribution which is founded on the interpretations and re-evaluations of bio- and litho-stratigraphic- and geochemical-analyses, and field investigations (Scherreiks *et al.*, 2014). In a regional context, this palaeogeographic conception generally corresponds to the palaeogeographic evolution that has been forwarded for the Vardar Ocean Unit of the Balkan (Robertson *et al.*, 2013; Kukoc *et al.*, 2015). Basic previous research has been done by Aubouin and Guernet (1964), Katsikatsos (1976), Machairas (1978), Katsikatsos *et al.* (1980, 1981, 1984) and Scherreiks (2000).



Figure 1 - The study area in the Pelagonian zone of the Internal Hellenides (Ophiolite remnants shown in green).

2. Stratigraphy, litho-facies and palaeontology (cf. Fig. 2)

2.1. The Late Triassic-Early Jurassic, peritidal carbonate-platform and the coeval oceanic realm prior to plate convergence

A peritidal carbonate platform evolved between the Late Triassic and the Sinemurian (Fig.2). The typical cyclical peritidal facies (Bosence *et al.*, 2009) are characterised by pervasively dolomitized microbial mats (stromatolites), pisolite rudstone with meniscus cements, intraclast floatstone, and

intertidal mudstones. The bio-stratigraphy verifies Late Triassic through Sinemurian age of the peritidal platform (Table 1), which evolved concurrently with an oceanic realm, characterised by (MORB) pillow basalt and (below CCD) radiolarites of Late Triassic age (Table 2a).

Table 1 - Rhaetian - Sinemurian foraminifera, determined in co-operation with Boudagher-Fadel (2008).

<p>Grillina sp. Auloconus permodiscoides Aulotortus friedly Siphovalvulina gibraltarensis Siphonina gibraltarensis</p>
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Table 2 - Radiolarians cherts above pillow basalts, determined in co-operation with P. O. Baumgartner (Baumgartner *et al.* 1995).

<p>a. Carnian to Lower Norian <i>Annulotriassocampe</i> ? sp. <i>Castrum</i> ? sp. <i>Corum</i> ? sp. <i>Capnuchosphaera</i> cf. <i>crassa</i> Yeh. <i>Capnuchosphaera</i> sp.</p>	<p>b. Middle to Upper Jurassic <i>Spongocapsula hooveri</i> Meyerhoff Hull. <i>Parvicingula dhimenaensis</i> s.l. Baumgartner <i>Transhuum brevicostatum</i> Ozvoldova <i>Protunuma</i> sp. <i>Sethocapsa</i> sp.</p>
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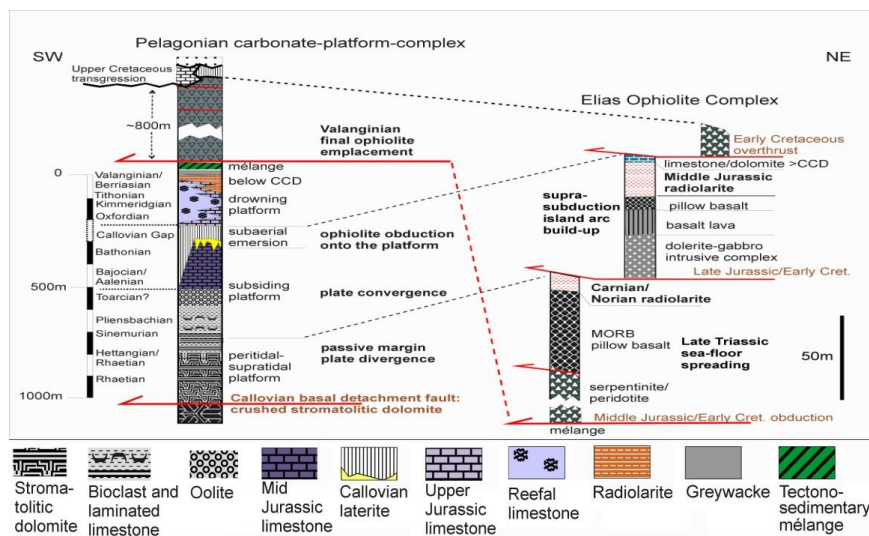


Figure 2 - Composite stratigraphies of the platform and ophiolite complexes of northern Evvoia.

2.2. Pliensbachian-Bathonian plate convergence, platform subsidence and ocean-floor uplift

From the Sinemurian onwards the platform subsided continuously until Bathonian time, which is indicated by a succession of deepwater carbonates: thin-shelled (filament) wackestone, siliceous spiculite - radiolarian wackestone, and calcisphere-spiculite-radiolarian packstone. The bio-stratigraphy Table 3a-c) verifies Pliensbachian through Bathonian age.

The Middle Jurassic subsidence of the platform is attributed to the convergence of the eastern ophiolite sheet over the oceanic leading edge of the Pelagonian micro-plate (Fig. 3a). This is documented by Middle Jurassic radiolarians which have been found in the melange below the overriding ophiolite sheet (Danelian and Robertson, 2001; Scherreiks *et al.*, 2014), showing that the ophiolite advanced over an ocean floor during Middle Jurassic time (Fig.3a). Coeval Middle Jurassic radiolarites also occur, in sedimentary contact, with basalts of the eastern Vardar ophiolite (Guevgueli Ophiolite Complex of Macedonia: Kukoc *et al.*, 2015).

The upper part of the oceanic stratigraphic-column (Fig. 2) consists of gabbro, flood- basalt, and pillow basalt covered by radiolarite of late Middle Jurassic age (Table 2b). Nodular-chert carbonates occur toward the top (Fig 2 Elias complex), indicating that the ocean floor had been uplifted above the concurrent CCD during late Middle Jurassic time (Fig. 3b). Previously carried out geochemical analyses (Scherreiks *et al.*, 2014) have shown that the gabbros and basalts conform to the calc-alkaline magmatic series which is related to volcanic island-arc realms. This has also been confirmed in tectonic discrimination diagrams (Scherreiks *et al.*, 2014). A supra-subduction, volcanic, island arc is thought to have evolved during the Middle Jurassic and is represented by the Elias Complex (Fig. 2 and Fig. 3a), which became uplifted during the convergence of the two plates.

Table 3 - Pliensbachian-Oxfordian bio-stratigraphy, determined in co-operation with Boudagher-Fadel (2008).

<p>a. <i>Lithiotis</i> sp. (Pliensbachian)</p> <p>b. <i>Mesoendothyra croatica</i> (Aalenian-Bathonian)</p> <p>c. Bathonian-Callovian foraminifera: below the laterite</p> <p><i>Pseudomarssonella bipartita</i></p> <p><i>Redmondoides medius</i></p> <p><i>Andersenolina elongata</i></p> <p><i>Riyadhella</i> sp.</p> <p><i>Ammobaculites</i> sp.</p> <p><i>Textularia</i> sp.</p> <p><i>Trocholina</i> sp.</p> <p><i>Palaeodasycladus</i> cf. <i>mediterraneus</i> sp.</p> <p><i>Pseudopfenderina</i> sp.</p> <p><i>Everticyclammina</i> sp.</p> <p><i>Siphovalvulina</i> sp.</p> <p><i>Riyadhoides</i> sp.</p> <p>d. Callovian-Oxfordian: on top of laterite</p> <p><i>Chablaisia</i> sp</p> <p><i>Septatrocholina banneri</i></p> <p><i>Andersenolina elongata</i></p> <p><i>Andersenolina</i> sp.</p> <p><i>Palaeodasycladus</i> sp.</p>

2.3. The Callovian event: ophiolite obduction and sub-aerial exposure of the ophiolite and the platform]

Unconformities of Callovian age are widespread in the Mediterranean region (Meléndez, 1989 and Meléndez and Martínez, 2007). In the central Pelagonian zone, laterite occurs in discontinuous karst vugs and caverns and as lateritic crusts on top of shallow marine limestones (Fig.2). Previous analyses have shown that these laterites are bauxites (Guernet and Robert, 1973). The foraminiferal assemblage of the limestones subjacent to the laterite (Table 3c) contains *Pseudomarssonella bipartita* Redmond (Bou Dagher-Fadel, 2008; Scherreiks *et al.*, 2014) of Late Bathonian age, verifying that the event of emersion, during which time the laterites were deposited, must have occurred during or after the late Bathonian. The laterite is an aluminium-enriched bauxite (>71 %

Al₂O₃) with high trace element contents of Co, Cr, Ni and V, which have been verified in the 10-500 PPM range in numerous laterite occurrences of the study area (Scherreiks *et al.*, 2014). The high aluminium content and the trace element contents of Co, Cr, Ni and V, fingerprint basalt as having been the most probable source of the lateritic deposits, definitely indicating that oceanic crust had been subaerially exposed during later Bathonian time and had undergone lateritic weathering. Ophiolite-derived laterite apparently had been transported and deposited onto the contemporaneously exposed, karstic platform surface, forming lateritic regolith that infiltrated pervasive fractures, karstic vugs and karst collapse breccias.

The limestones cropping out immediately above the laterites are shallow marine, peloid-bioclast grainstones and packstones. They contain a Callovian-Oxfordian foraminiferal assemblage (Table 3d) in which the presence of *Chablaisia* shows them to be not younger than early Oxfordian (Bou Dagher-Fadel, 2008; Scherreiks *et al.*, 2014). They document an early Oxfordian transgression over the laterites. From the above, the period of emergence during which the platform and ophiolite had been exposed occurred between late Bathonian and before the transgression of the early Oxfordian shallow marine carbonates.

The emersions of the ophiolite and platform were coeval with the carbonate deposition on top of late Mid Jurassic radiolarites of the rising oceanic island arc (Fig. 2, Table 2b, and Fig. 3b-c).

2.4. Oxfordian-Valanginian: platform drowning prior to the final ophiolite emplacement

Shallow marine carbonates devoid of ophiolite detritus appear on top of the Callovian laterite (Fig. 2). The temporarily exposed ophiolite of Late Bathonian to early Oxfordian time apparently became submerged during early Oxfordian time. Reef limestones occur (Fig. 2), which are characterised by *Cladocoropsis mirabilis* Felix (Scherreiks *et al.*, 2014), of the middle Oxfordian *Cladocoropsis* Zone (Turnsek *et al.*, 1981). The upper stratigraphic range of the *Cladocoropsis* zone, in the study area, most probably extends into the Berriasian, because *C. mirabilis* occurs together with *Zergabriella embergeri*, which has a stratigraphic range from Tithonian to Valanginian (Granier, 1989). *Cladocoropsis* and *Zergabriella* were found together (Scherreiks *et al.*, 2010) in turbidite that interfingers with radiolarian cherts and shales that range in age from Berriasian to Valanginian (Baumgartner and Bernoulli, 1976).

Lenses of fine-grained turbiditic, siliciclastic sandstones interdigitate with cherts and shales in the upper part of the drowned platform radiolarite sequence (Fig. 2). Inasmuch as this greywacke succeeds Berriasian-Valanginian radiolarite, it is most probably of later Valanginian age. The ophiolite nappe together with sub-ophiolite mélange advanced over and scraped up greywacke and radiolarite and terminated platform sedimentation in the vicinity of the study area during Valanginian time. However, it is noteworthy that the actual ophiolite obduction onto the platform began 25 ma earlier during late Bathonian time (see above).

3. Discussion

Intra-oceanic subduction and convergence initially led to the obduction of the overriding ophiolite sheet onto the oceanic leading edge of the Pelagonian micro-plate (Fig. 3a). This was a diachronic process that began around late Early Jurassic to early Mid Jurassic time and finally led to the emplacement of the ophiolite on top of the Pelagonian carbonate platform during Valanginian time. The evidence for this time-schedule stems from the dating of radiolarians from the mélange beneath the ophiolite and the radiolarians from the drowned carbonate platform. The mélange contains mid oceanic pillow basalt with Mid Jurassic radiolarite, indicating that the ophiolite sheet must have been advancing over oceanic crust during Mid Jurassic time, whereas the age of the youngest drowned-platform radiolarians is Valanginian. But when did the ophiolite begin its obduction over the carbonate platform?

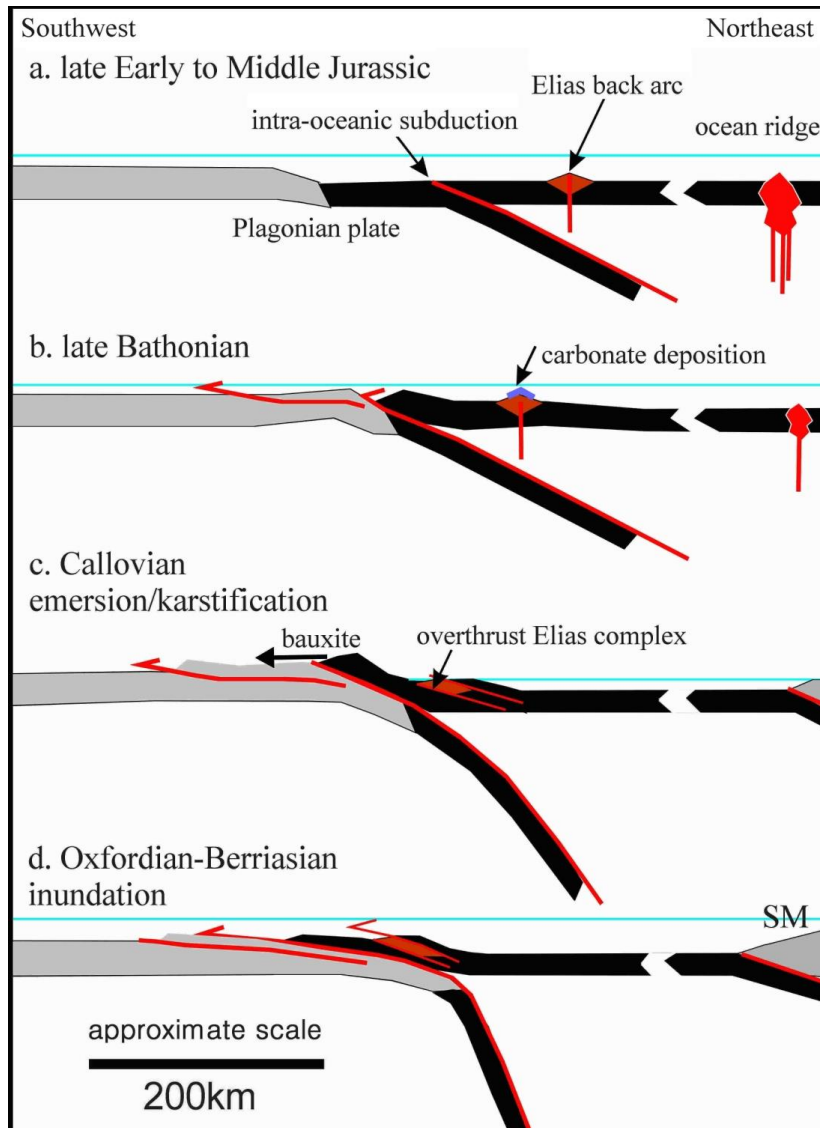


Fig. 3 - Schematic plate-tectonic episodes of obduction and emersion of the ophiolite and the platform during Callovian time (SM: Serbo-Macedonian Massif). a) Intra-oceanic subduction initiates back-arc volcanism. b) Ophiolite obduction leads to thrust faulting in the platform and uplift of back-arc. c) Platform is thrust upward and the overriding ophiolite becomes emergent, resulting in karstification and laterite deposition. d) Platform loading and continued obduction initiates the Oxfordian-Berriasian inundation.

The earliest evidence that the ocean floor began to rise above the CCD is found in the stratigraphy of the Elias complex which shows a succession of late Middle Jurassic pillow basalt and radiolarite covered by pelagic limestone (Fig. 2 and Fig. 3b). The stratigraphy of the carbonate platform shows that as the ophiolite rose during the late Middle Jurassic, the platform also rose during late Bathonian time. The platform then became emergent during Callovian time, was karstified, and was covered by laterite having an ophiolitic geochemical signature. Thus, it is apparent that the ophiolite must also have been emergent. In spite of the evidence, it appears illogical that a plate that is being overthrust would be uplifted, it should have subsided. This paradox is resolved by postulating that the platform was thrust upwards as it made contact with the advancing ophiolite (Fig. 3b-c). Evidence for a basal detachment fault is given by the crushed Triassic carbonates at the base of the carbonate platform (Fig. 2). As the ophiolite initially overrode the Pelagonian plate it was uplifted (Fig. 3c) and was weathered before it was inundated together with the carbonate platform during Oxfordian time (Fig. 3d).

4. Conclusions

The ophiolite sheet advanced over Mid Jurassic oceanic lithosphere toward the Pelagonian platform while a supra-subduction volcanic arc (Elias complex Fig. 2) evolved within the overriding plate (Fig. 3b). The actual tectonic contact of oceanic lithosphere with the Pelagonian platform began during late Bathonian time and is thought to have initiated the detachment fault within the platform (Fig. 2). The platform was thereby thrust upwards while the front of the ophiolite sheet and the platform became emergent (Fig. 3b-c). As a result, a karstic land area and an ophiolite highland, that underwent lateritic weathering, existed in the central Pelagonian zone during Callovian time. Ophiolite subaerial weathering has also been reported from the Guevgueli Complex (Robertson *et al.*, 2013; Kukuc *et al.*, 2015) and most likely correlates with the Callovian event of the central Pelagonian area. The Late Jurassic conglomerates of the eastern Vardar Unit (Kukoc *et al.*, 2015) are suggested here to have been derived from the eastern side of an uplifted back-arc complex, of which the Elias Complex is a small preserved more westerly situated remnant.

Renewed subsidence of both the ophiolite and the platform during the Late Jurassic is suggested to have been caused by gravitational pull and rollback of the subducted leading *oceanic* edge of the Pelagonian plate (Fig. 3c-d). Subsidiary thrust faults formed within the ophiolite as it advanced during the Late Jurassic (Fig. 2 and Fig 3c-d). The ophiolite sheet continued to advance *in the study area* until Valanginian time. The basal detachment fault beneath the platform may have been reactivated after Valanginian and post-Cretaceous time, as the Serbo-Macedonian massif advanced and closed the adjacent eastern Vardar ocean (Fig. 3c-d) (Scherreiks *et al.*, 2014). The closure of the Vardar ocean and the collision between the Serbo-Macedonian massif and the Pelagonian plate most probably caused the Upper Cretaceous erosional unconformity (Fig. 2).

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