Geologic reconnaissance of the island of Velika Palagruža (central Adriatic, Croatia)

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ABSTRACT

Velika Palagruža (Pelagosa) is the largest island of the Palagruža archipelago (central Adriatic Sea, Croatia). Despite its minute size the island bears a certain geological interest being the only exposed piece of land in the central part (Mid-Adriatic ridge) of the common Adriatic foreland of the Apenninic and the Dinaridic orogenic domains. The litho-, bio-, and chemostratigraphic (strontium and sulphur isotopes) characteristics of the sedimentary units, along with tectono-structural and geomorphic characteristics of the island, are described in this paper. The oldest Žalo unit is composed of highly deformed siliciclastics containing gypsum, and carbonates of Middle Triassic (Ladinian) age. This unit represents a transitional fluvial-to-shallow marine, occasionally evaporitic environment, typical of the Middle Triassic rifting phase of the Adriatic microplate. Soft and strongly deformed Žalo unit deposits are found along a probably still active, WNW–ESE striking, subvertical, oblique-slip fault that crosses the entire length of the island. The Žalo unit is probably in diapiric contact with the Lanterna unit, poorly defined as Late Triassic, and characterized by dolomite with chert and dolomite breccia, presumably deposited in a transitional platform-to-basin environment of an evolving Adriatic basin. The Lanterna unit deposits are capped by Miocene biocalcareinites of the Sala-mandrija unit over an almost perpendicular discordance, possibly representing an unconformity, suggesting that an early deformational phase preceded a Miocene marine transgression. Talus, landslide deposits, and humic soil make up the cover of the bedrock sedimentary succession, and they represent the ultimate phase of emersion of the island, which probably occurred during Pliocene(?) to Quaternary times. An active neotectonic regime of the central Adriatic is evidenced by present-day seismicity, while recent uplifting of the island is shown by the presence of remnants of pebbly palaeobeach deposits, marine (erosional) straths, and cyanobacterial supratidal encrustations (pelagosite) currently observed at various elevations above mean sea level.

Keywords: carbonate platform, basin, Triassic, Neogene, Mid-Adriatic ridge, recent uplift
1. INTRODUCTION AND PREVIOUS WORK

Velika Palagruža (Pelagosa in Italian) is a small island in the central Adriatic Sea, the largest within the Palagruža archipelago (Fig. 1). The island is placed within the common Adriatic foreland of the Apennines and the Dinarides, 57 km from the Gargano promontory to the south, and 60 km from the Island of Lastovo to the northeast. The distance from the mainland as well as steep slopes and a hostile rocky coast, makes access to the island rather difficult. A handful of published studies be counted since the first geological and palaeontological reconnaissance of the island of Palagruža was carried out by STUR (1874), at about the time when the Austrians were building the monumental lighthouse on the highest point of the island. Palagruža was then revisited by STACHE (1876) and, independently, by MARCHESETTI (1876).

Further geological studies were carried out by BOŽIČEVIĆ et al. (1965). The authors proposed a Middle Jurassic age for the basal dolomite formation based on the presence of Lithothamnion, and a Miocene age for the biocalcarenitic limestone at the top of the succession, according to the foraminiferal and mollusc association. The stratigraphic bedrock succession of Velika Palagruža is capped by Pliocene (?) to Quaternary talus breccias and humic soil.

The authors of the explanatory notes for the basic geological map sheet (KOROLIJA et al., 1977) proposed a Jurassic age for a siliciclastic unit with gypsum exposed near the beach of Žalo (see Fig. 2 for location), based on a general lithological analogy with the Komiža complex on the island of Vis (at the time considered to be of Jurassic age), and stratigraphic relationships with the underlying dolomites containing chert nodules of proposed Late Jurassic age. KOROLIJA et al. (1977) argued for the Late Cretaceous age of the overlying biocalcarenites exposed in a quarry pit at Salamandija (see Fig. 2 for location).

SOKAČ et al. (1980) identified the foraminifera *Meandrospira pusilla* from a small outcrop of siliciclastic-evaporitic rocks near Žalo containing sandstones, gypsum, clay, and silt, which, along with results from mineralogical analyses, indicated an Early Triassic or possibly even older (Late Permian) age. The authors, in agreement with the interpretation of KOROLIJA et al. (1977), viewed this siliciclastic-evaporitic unit at Žalo as a diapir. The diapiric setting of the Palagruža block was suggested by GRANDIĆ et al. (2002) following seismo-stratigraphic interpretation. GRANDIĆ et al. (2002) also referred the broader area of the Palagruža archipelago to the Jurassic to Palaeogene Adriatic basin domain.

Gypsum often occurs in Upper Permian to Triassic formations throughout the Alpine domain, and represents shallow water evaporitic environments during an early subsidience phase of the Adriatic microplate, which was probably attached to the African continental crust (e.g. CHANNELL et al., 1979; BOSELLINI, 2002). However, the stratigraphic position of Adriatic evaporites and associated rocks is often doubtful, mainly due to their chaotic setting.

From the few geologic reports cited above it appears that Palagruža has a geological complexity and overall importance much bigger that its own minute size, which definitively demands more detailed study. The results of a preliminary geological survey are reported here, which highlights the stratigraphic and structural complexity of this island. While some uncertainties still remain in the accurate chronostratigraphic assessment of the main rock formations, structural and geomorphic features exposed in the island offer new evidence for a past and recent history of geodynamic events.

2. REGIONAL GEOLOGICAL AND TECTONIC SETTINGS

Palaeogeographically, the central Adriatic area is considered to represent a Jurassic to Palaeogene Adriatic basin enclosed between the Apulia carbonate platform to the southwest (Italy), and the Adriatic (Dalmatian) carbonate platform to the northeast (Croatia) (ZAPPATERRA, 1994; BOSELLINI, 2002; GRANDIĆ et al., 2002; TARI, 2002; VLAHOVIĆ et al., 2005). At present, the succession of mostly pelagic for-
motions of the central Adriatic Basin is covered by thick Neo-
gen siliciclastic deposits (BERTOTTI et al., 2001). These
formations are known from boreholes and seismic profiles
(e.g., GRANDIĆ et al., 2002, and references therein), and
Palagruža is the only place in the whole region where some
of these units are exposed above sea level.

BOGNAR (1995) proposed that Palagruža represents a
“pop-up” structure, which consists of a fault-bounded frag-
ment of continental crust that is being pushed laterally and
vertically by compressional tectonic forces. In other words,
Palagruža is uplifting due to the head-on collision between
the converging Apenninic and Dinaridic orogenic systems
(Fig. 1), and, for this very reason, it is subject to seismic ac-
tivity.

Through modelling GPS measurements of crustal veloc-
ity along a transverse profile across the southern Adriatic
microplate and south-central Dinarides, BENNETT et al.
(2008) assumed a NNE dipping thrust fault, which surfaces
along the offshore of southern Dalmatia, between the islands
of Vis and Palagruža, not far north of Palagruža. BENNETT
et al. (2008) argued for SW-migrating deformation in an ac-
tive fold-and-thrust belt as a consequence of uninterrupted
subduction of the southern Adria mantle lithosphere beneath
Eurasia since the Eocene. In this tectono-seismic scenario,
Palagruža is located on the footwall of the thrust not far from
its line of emergence to the north, and its present horizontal
movement toward the NE in respect to fixed Eurasia is about
5 mm/yr (BENNENET et al., 2008).

Recent regional seismic-stratigraphic data (GRANDIĆ
et al., 2002) suggest that diapirism probably contributes to
the current crustal uplifting along two WNW–ESE divergent
reverse faults (suggesting transpression), which delimit the
Palagruža submarine rise – Palagruža high (BERTOTTI et
al., 2001) or Mid-Adriatic ridge (GRANDIĆ et al., 1997;
GELETTI et al., 2008), in the southern and northern off shore
of the island. GELETTI et al. (2008) argued for a Miocene
onset of the diapirism, according to seismostratigraphic in-
terpretations, whereas the related deformations continue to
date.

At present, the central Adriatic is seismically active (e.g.
HERAK et al., 1996; GRANDIĆ et al., 2002; CHIARABBA
et al., 2005; RIDENTE & TRINCARDI, 2006). The most
important seismic event in recent times was represented by
the 1988 swarm, which started in February 1988, and ended
early in 1989. More than 100 quakes > 3M were recorded
during this period, with epicenters spread over an area about
30 km long (in a NE–SW direction) and 20 km wide (HERAK
et al., 1996). The largest earthquake of this sequence reached
a magnitude of 5.3, and its epicenter was located 38 km SE
of Palagruža, with a focal mechanism indicating slightly ob-
lique reverse faulting with an E–W strike (RIDENTE &
TRINCARDI, 2006). This is consistent with the general de-
formation on strike-slip and thrust faults resulting in NE–SW
shortening along the eastern coast of the Adriatic Sea (BATT-
AGLIA et al., 2004).

In summary, the Mid-Adriatic ridge belongs to the Adri-
atic foreland, and its origin is related to combined strike-slip
faulting and vertical salt movement. Palagruža is probably
placed at the topmost part of an active diapirc structure char-
acterized by a very deep root.

3. SEDIMENTARY UNITS AND TECTONICS

The sedimentary units exposed at Velika Palagruža are de-
scribed according to direct observations of key outcrops and
their distribution in our original geologic map (Fig. 2), which
highlights the remarkably complex geology of this tiny is-
land. However, it should be stressed that a more precise age
determination, as well as more detailed stratigraphic and tect-
onic relationships between the sedimentary units, requires
further research. Nevertheless, the units are described below
and are organized according to their proposed stratigraphic
position.

3.1. Žalo unit

An outcrop of stratified yellowish siltstones and green-grey
claystone associated with gypsum is located in the southern
central part of the island, about 50 m west of a fishermans
shack at the western end of Žalo beach (Location 1, Fig. 2).
These rocks comprise a stratigraphic succession from a basal
homogeneous green-gray clay unit, to a lens of fractured
white gypsum about 1.5 m thick, overlain by a finely strat-
fied clay-rich siltstone unit containing disperse gypsum, and
terminating with a second horizon of green-gray clay-rich
siltstone (Fig. 3A). Fragments and whole shells of microgast-
rups, and small vertebrate bones were observed in a sam-
piece of green-gray clay/claystone from the Žalo outcrop, but
have not so far yielded a taxonomic determination.

The succession is covered by a rockfall of dolomite boulders.
Apart from the fractured gypsum, where green-gray clay fills the fractures (Fig. 3B), this outcrop appears
undeformed, with regular, parallel bedding constantly dipping
32°NE.

The green-gray clay of the Žalo unit is also exposed in the
lower part of a ravine at Picokare, about 200 m further
west (Fig. 4A). Some metres above this outcrop, a package
of thin-bedded, beige-yellowish dolomite layers are exposed,
with a dip of 27°NW. Unfortunately, the contact between
the clay and this thin-layered unit is not exposed, but it seems
that the Žalo unit occupies this part of the island, from the
fisherman shack at Žalo beach to the Picokare gully, and it is
covered by boulder rock fall and south-dipping coarse talus
(see Figs. 2 and 4A). On the other hand, the contact between
the Žalo unit clay and the Lanterna unit dolomite with chert
(see section 3.2.) to the west of the Picokare ravine, is well
exposed, and it is represented by a sharp discordance (Fig.
4A). Practically, the thick-bedded dolomite layers with chert
of the Lanterna unit (unit A, see below), which dip steeply
to the SW, are cut by a flat and smooth undulatory surface,
with a dip of about 45° toward the E. The clay of the Žalo
unit is found resting on top, against this surface (Fig. 4B).
We are still uncertain on the exact nature of this discordance,
which does not appear to be a simple angular unconformity.
We do not exclude that the flat discordance surface is actu-
ally a deformed fault plane, as some oblique slickenside striations on the smooth surface suggest, and that the Žalo unit has been put in place against the already tilted Lanterna dolomites by the combined action of oblique-slip faulting and diapiric uplifting. However, the age relationship between the Žalo unit and the Lanterna unit is still uncertain (see below), which limits the plausibility of the interpretation for this rather odd structural situation.

Another key exposure of the Žalo unit is located on the southeasternmost coast of the island, south of a locality called Jonkova Njiva (Fig. 5A). As at Picokare, the Žalo unit rests on top of thick-bedded dolomite layers of the lower part of the Lanterna unit (i.e., unit A in the legend of Fig. 2). The rocks, which include marly siltstones containing disperse nodules of gypsum, and a few layers of stromatolitic limestone, are strongly deformed (Fig. 5B). On the north side of
this outcrop a WNW–ESE striking subvertical oblique-slip fault puts the Žalo unit in contact with strongly deformed, medium-thick bedded dolomites and dolomite breccias of the presumed upper part of the Lanterna unit (unit B). This fault is probably the continuation of the oblique-slip fault that dissects the whole length of the island from Stara Vlaka on the NW, to the southeastern point of Jonkova Njiva, where Žalo unit rocks occur in a strongly deformed fault zone.

A similar situation is found on the south side of the Stara Vlaka cove (Figs. 2 and 6), where strongly deformed thin-bedded dolomites and green-grey clay are found within the highly tectonized zone of the same oblique-slip fault (Fig. 6A and B).

### 3.1.1. Palynostratigraphy of the Žalo unit

To overcome the age uncertainty of the Žalo unit, and assess its palaeoenvironmental and biostratigraphic attributes, a detailed palynological study of a number of soft rock samples from various outcrops throughout the island, was undertaken.

Sample Pal–5 (Žalo unit gypsum, W of Žalo beach, location 1 on Fig. 2) is palynologically barren.

Sample Pal–6 (Žalo unit silty claystone, W of Žalo beach, location 1 on Fig. 2). Palynoflora of the sample Pal–6 (APPENDIX I and Fig. 7) is represented by a diverse and well-preserved assemblage of predominantly sporomorphs and may well be correlated to the palynoflora of the European and Circum-Mediterranean independently dated Ladinian sections (VISSCHER & BRUGMAN, 1981; WARRINGTON, 2002; SCHULZ & HEUNISCH, 2005).

In the Alpine region of the Dolomites in Italy, the palynoflora of sample Pal–6 corresponds to the palynological **secatus – dimorphus** phase of VAN DER EEM (1983). This type of palynoflora has been described from sections of southeastern Switzerland (SCHEURING, 1978) and the Dolomites (BLENDINGER, 1988; HOCHULI & ROGHI, 2002), as well as from Liechtenstein, western Austria (BRÜHWILER et al., 2007) and Hungary where it has been designated as **meieri – scheuringii** phase (GÓCZÁN & ORAVECZ-SCEFFER, 1993; KOVÁCS et al., 1994). The **secatus – dimorphus** phase concurs with the ammonoid **gredleri** zone and **archelaus** zone (VAN DER EEM, 1983; BRUGMAN, 1986), which, according to BRACK et al. (2005), are Late Fassanian–Early Langobardian in age. Among the stratigraphically significant sporomorphs that are shared between the **secatus – dimorphus** phase and the palynoflora of sample Pal–6, **Heliosaccus dimorphus** has a range within the **secatus – dimorphus** phase whilst **Camerospores secatus**, **Duplicisporites gran-
ulatus, Sellaspore rugoverrucata, Kyrtomispos ervei and Brachysaccus neomundanus first appear at the base of the early Fassanian ammonoid curionii zone (Earliest Ladinian), i.e. plurianulatus – secatus phase (VAN DER EEM, 1983; BRUGMAN, 1986). According to BRÜHWILER et al. (2007), the first appearance of C. secatus and D. granulatus is higher and corresponds to the base of secatus – dimorphus phase of the ammonoid gredleri zone. Last appearance of Cannanarapolis scheuringii is at the top of Late Langobardian (Latest Ladinian) secatus – vigens phase which correspond to the ammonoid regoledanus zone (VAN DER EEM, 1983; BRUGMAN, 1986). The last appearance of this taxon has been found at the top of the Ladinian also in other parts of the Alpine facies (SCHEURING, 1978; GÖCZÁN & ORAVECZ-SCHEFFER, 1993; KOVÁCS et al., 1994). Several taxa of the Pal–6 palynoflora also occur in other Alpine sections, e.g. Haberkornia parva/gudati and Podosporites amicus, ranging approximately with the secatus – dimorphus phase, and Doubingerispora filamentososa, which first appears at the base of the Ladinian. Sample Pal–6 also contains the stratigraphically significant sporomorphs Stanosaccites quadrifidus, Ovalipollis pseudoolatus and Partitissporites spp., which first appear at the base of the plurianulatus – novimundanus phase of the ammonoid Nevadites sp. (=secedensis) zone, previously considered as early Fassianian (earliest Ladinian) by VAN DER EEM (1983) and BRUGMAN (1986). After the acceptance of the GSSP for the base of the Ladinian stage at the base of the ammonoid curionii zone (BRACK et al., 2005), the plurianulatus – novimundanus phase represents the latest Anisian palynofloral development. The plurianulatus – novimundanus phase contains, in the lower part, the Late Anisian sporomorphs Stellapollenites thiogartii and Dyupetalum vicentinense, and its top is defined by the last appearance of Illinites chitonoides and Concentricrisporites plurianulatus (BRUGMAN, 1986). Since these sporomorphs have not been identified in the sample Pal–6, the presence of S. quadrifidus, O. pseudoolatus and Partitissporites spp. alone suggests an age not older than earliest Ladinian. Considering the highest range of the sample Pal–6 palynoflora, the lack of Enzonalasporites vigens, Weylandites magnus, and “Lueckisporites” cf. singhii, which first appear at the base of secatus – vigens phase of the ammonoid regoledanus zone, treated as Late Langobardian (Latest Ladinian) (VAN DER EEM, 1983, BRUGMAN, 1986; BROGLIO LORIGA et al., 1999), suggests an age not younger than Latest Ladinian.

In the Germanic facies, the palynoflora of sample Pal–6 corresponds to the palynological record of the Lettenkohle successions (Lower Keuper). In Poland, ORŁOWSKA-ZWOLINSKA (1983) designated the Lettenkohle palynoflora as representing the Heliosaccus dimorphus Zone. In Germany, several palynological zones, phases and subphases have been described, which allowed correlation to the Alpine time equivalents (REITZ, 1985; HEUNISCH, 1986; VAN DEN BERGH, 1987; BRUGMAN et al., 1988; VAN BERGEN & KERP, 1990; BRUGMAN et al., 1994; BEUTLER et al., 1996; HEUNISCH, 1999). The palynoflora of the Lettenkohle successions in France correspond to the correlatives in other parts of the Germanic facies (ADLOFF et al., 1984; COURTINAT & RIO, 2004).

The palynoflora of the Lettenkeuper has been dated based on both independent control and palynological correlation with the Alpine record. The palynofloral record from southern Germany, which is enhanced within the iliacoides – dimorphus subphase (VAN DEN BERGH, 1987; BRUGMAN et al., 1988) and perforatus – dimorphus phase of (VAN BERGEN & KERP, 1990; BRUGMAN et al. (1994), corresponds to the Alpine secatus – dimorphus phase.

In the Circum-Mediterranean region of Spain, the palynoflora of sample Pal–6 corresponds to the secatus – meieri subphase of BESEMS (1983) which represents the lower part of the Camerosporites secatus phase (VISSCHER & KRYSTYN 1978; VISSCHER & VAN DER ZWAN, 1981; VAN DER EEM, 1983) and is similar to the palynoflora of Lettenkohle as described by GARCÍA GIL & DIEZ (2006). In Libya, ADLOFF et al. (1986) reported on a palynoflora, which they correlate, to the Alpine secatus – dimorphus phase of VAN DER EEM (1983). In Israel, ESHET (1990) described the palynoflora from the ammonoid controlled section which has been assigned to the Podosporites amicus Zone corresponding in many elements to the European correlatives. Syrian subsurface sections revealed a palynoflora which YAROSHENKO & BASH IMAM (1995) and LUCIĆ et al. (2003) compare to the palynofloras of the Circum-Mediterranean and European Ladinian correlatives.
Along with the authochtonous Ladinian palynoflora, sample Pal–6 also contains reworked sporomorphs (APPENDIX 2, Fig. 7/16, 17), among which, *Endosporites papillatus* and *Densoisporites nebjurgii* suggest reworking from Lower Triassic successions. Several sporomorphs assigned as cf. *Lueckisporites virrkiae*, *Limitisporites* sp. and cf. *Nuskoisporites* sp. indicate reworking most likely from Permian successions.

From the palynological point of view, the palynoflora of sample Pal–6 is almost identical to the palynoflora from the surface sections of the diapiric structure at Komiža, the island of Vis (BELAK et al., 2005), which has been designated as the *dimorphus* Interval Zone and interpreted as Late Fassanian–Early Langobardian in age. At the Komiža site, BELAK et al. (2005) also reported discovery of the dasyycladal alga *Diplopora nodosa* with a Late Anisian–Ladinian range according to GRGASOVIĆ & SOKAČ (2003) as well as the problematic taxon *Plexorarea cerebriformis* with a Middle Anisian–Carnian range according to GORIČAN et al. (2005). At present, the findings of *D. nodosa* represent the stratigraphically narrowest independent control of the described palynoflora in the area under consideration.

Sample Pal–14 (Žalo unit clay, Stara Vlaka cove, location 3 on Fig. 2) contains a moderately to poorly preserved palynoflora, predominantly of sporomorphs, generally similar to the palynoflora of sample Pal–6, and may therefore be considered Ladinian in age.

Sample Pal–22 (Žalo unit stromatolitic limestone, SE of Jonkova Njiva, location 2 on Fig. 2) contains a small amount of degraded palynological organic matter and only a few poorly preserved bisaccate pollen grains and cf. *Camerosporites secatus* suggesting a Ladinian–Carnian age.

Sample Pal–23 (Žalo unit marly siltstones, SE of Jonkova Njiva, location 2 on Fig. 2) contains palynoflora similar to Pal–14. However, the assemblage is less diverse allowing an age assignment within a wider Ladinian–Carnian range.

### 3.1.2. Age of the Žalo unit

According to the palynostratigraphy reported here (section 3.1.1., APPENDIX 1, Fig. 7/1–15), the Žalo unit was dated as Middle Triassic in age (Ladinian).

The Žalo unit was dated as Lower Triassic by SOKAČ et al. (1980), according to the Lower Triassic foraminifera *Meandrospira pusilla* found in limestone microlithoclasts of quartzose calcarenitic sandstones. Unfortunately, neither the sandstones mentioned by Sokac and co-workers, nor the microfossils were found within analysed outcrops or elsewhere in the Žalo unit. However, redeposited Lower Triassic palynomorphs were found (see chapter 3.1.1., APPENDIX 2, Fig. 7/16, 17). Thus, it is suggested that SOKAČ et al. (1980) reported on presumably Ladinian sandstones containing redeposited Lower Triassic limestone microlithoclasts.

### 3.1.3. Palynofacies of the Žalo unit

The composition of the palynological organic matter of samples Pal–6, Pal–14 and Pal–23 is almost identical. Sample Pal–6 (Fig. 7/15) is characterized by a better preservation state of the organic matter in respect to other samples. Most of the organic matter consists of fragments of woody tissue (90%) followed by leaf (cuticle) remains (5%), and palynomorphs (5%). Opaque clasts of presumably woody tissue (as suggested by the shape of the clasts) are rare (<1%). Amorphous organic matter and structureless organic matter occur in traces showing their liptinitic origin under blue light. Woody tissue is represented by brown to brown-dark, partly well structured, variably sized (mostly 5–50 μm, partly up to 400 μm) and shaped (equidimensional to lath-shaped) particles that are predominantly angular and weakly sorted. Cuticle remains mostly occur as well preserved, structured fragments (50–500 μm). Most of the palynomorphs are well preserved and represented predominantly by terrestrial palynomorphs, i.e. sporomorphs (94%) of which bisaccate pollen (64%) is most abundant, followed by Circumpolles (20%), spores (10%), monosaccate pollen (3%), and asaccate pollen (3%). Aquatic palynomorphs (6%) are mostly represented by prasinophyceans (60%) followed by acritarchs (34%), and chlorophyceans (6%). Pyrite inclusions have not been observed. Samples Pal–14 and Pal–23 differ from Pal–6 in a somewhat lower abundance of cuticle fragments as well as their lower abundance and diversity of sporomorph assemblages.

The palynological composition of the sedimentary organic matter of the analyzed samples indicate that this silty claystone was deposited in a low-energy, dysoxic environment, proximal to the input of terrestrial organic matter and under fluvial and open marine influence, and may, therefore, be characterized as marine-brackish-fluvial tidal flat (cf. TYSON, 1995 and BATTEN, 2002). The environmental interpretation of sample Pal–6 can be also applied to that for samples Pal–14 and Pal–23 since their palynofacies features are almost identical.

Sample Pal–22 contains a small amount of palynological organic matter mostly consisting of amorphous organic matter (95%), part of which is represented by clasts of fragmented cyanobacterial laminae. Woody tissue (5%) is weakly structured. Sporomorphs occur in very low frequency. Except for a few *Leiopsisphaeridia*, other aquatic palynomorphs have not been observed.

The palynofacies features of sample Pal–22 suggest a carbonate, shallow water depositional setting with scarce terrestrial input.

### 3.1.4. Palaeoclimatological and palaeoenvironmental interpretation of the Žalo unit

For the purposes of palaeoclimatological/palaeoenvironmental interpretation, the palynomorphs are grouped into categories indicating their botanical affinity and ecological sensitivity (APPENDIX 3) according to VISSCHER & VAN DER ZWAN (1981), BRUGMAN et al. (1994), VISSCHER et al. (1994) and ROGHI (2004).

Groups A–G are of equisetophytic, lycopodiaphytic and pterophytic and category H of bennettitalean and gnetalean affinity. Groups A–H reflect hydrophytic plant communities of swamps, marshes, mangroves and generally wet and water-saturated substrates of brackish and lacustrine environ-
ments. Group I is of bryophytic and group J is of pterido-
sperm origin while groups K–P are of coniferal affinity,
respectively. Groups I–P reflect xerophytic plant commu-
nities of hinterland vegetation. Group P represents phy-
toplankton of marine environments.

The quantitative distribution of the groups within the pal-
ynoflora of Pal–6 (APPENDIXES 1 and 3) shows that the
groups K–P constitute 80% of the whole palynological as-
semblage indicating predominantly xerophytic plant communities
which suggests semi-arid climate conditions. This may well
be supported by high frequencies of group L (Ovalipollis/Stau-
rosaccates; 26.6%) and group P (Circumpolles; 19.8%), which
are indicators of regional aridity, and a high frequency of bi-
saccate pollen (64%) indicating the proximity of xerophytic
plant communities of the hinterland vegetation.

3.1.5. Sulphur isotopes of the Žalo unit gypsum

To separately test the Triassic age for the Žalo unit, we ana-
lyzed the sulfur isotope composition (δ³⁴S) of selenitic gyp-
sum from the outcrop Pal–5, (location 1, Fig. 2). Sulfur iso-
tope measurements were made both on original evaporite
minerals and on samples that were leached in water and re-
precipitated as barium sulfate prior to isotope analysis. Both
replicates are presented in Table 1. The isotopic analyses are
in parts per thousand or ‰ and the standard is the Canon
Diablo Troilite (CDT). The analytical error of the isotope
measurement is ±0.2‰.

In theory, the δ³⁴S of marine gypsum or other sulfate-
evaporite mineral should be related to the δ³⁴S of global ma-
rine sulfate at the time the evaporite formed (SIFTAR, 1987).
The δ³⁴S of global ocean sulfate was distinct in the Miocene
(22‰) from the Permian to Triassic (~10 to 15‰). Using the
δ³⁴S of an evaporite mineral as a geochronological indicator
can however be problematic. First, there can be isotope dy-
namics associated with evaporating basins; sulfur isotopes
can be fractionated during precipitation and progressive ex-
uvaporation and this will impact on the δ³⁴S of the sulfate in the
evaporitic brine. Second, and more problematically, the sulf-
ate that is used to form the evaporite mineral could come not
from ocean-sulfate but from oxidized hydrogen sul-
fide (H₂S). H₂S forms from bacterial sulfate reduction in anoxic
sediments and rocks; because of sulfur isotope fractionation
during bacterial sulfate reduction, the H₂S formed has a δ³⁴S
that is 10 to 50‰ lower than the original sulfate. If this H₂S
migrates and then oxidizes, the sulfate formed during oxida-
tion will also be isotopically “light” and distinct from sea-
water sulfate. For example, the microcrystalline gypsum
slush mass found in the Frasassi caves (Italy) has δ³⁴S of
–13.7‰, and was likely formed from subaerial reaction be-
 tween H₂S and a lower Jurassic limestone of the Calcare
Massiccio Formation (e.g. MARIANI et al., 2007, and ref-
erences therein). In this case, the H₂S originates from reduc-
tive dissolution of a Triassic anhydrite in the underlying
Triassic Burano Formation.

The sample from Palagruža (GYP) has a similar δ³⁴S of
–11.4‰, which suggests that the source of the sulfate for this
gypsum is not seawater, but instead oxidized H₂S. If the
Palagruža gypsum were precipitated directly from Miocene,
Triassic or Permian seawater then we would expect values
similar to those typical for marine evaporites. Therefore, we
cannot use the δ³⁴S of the Palagruža gypsum to place this
unit in the chronological context.

3.2. Lanterna unit

The most widespread rocks found at Palagruža are grey,
hard, cryptocrystalline dolomites, all of which make up the
Lanterna unit. Except for the area covered by humic soil,
rock fall, and talus on the northern side of the island and at
Picokare, this unit is well exposed on the coastal cliffs all
along the perimeter of the island (Fig. 2), and it includes me-
dium- to thick-bedded dolomite and irregular bodies of mas-
sic dolomite breccia. However, in many places the rocks
are strongly deformed, fractured, and tectonically brecciated
to the point that it is often difficult to discern primary bed-
ding. Moreover, dolomitization has also obliterated internal
structures and fossils of the source limestone, which pre-
vents palaeontological age and palaeoenvironmental deter-
minations. Nevertheless, we have distinguished two subunits
in the whole dolomite body of the island (unit A and unit B;
see legend in Fig. 2) on the basis of bedding thickness and
style, and the presence of nodular chert. However, the strati-
graphic relationship between these two subunits is uncertain
as they are separated by the oblique-slip fault, which cuts
across the whole length of island from WNW to ESE.

The Lanterna unit A makes up the southwestern, most
elevated part of the island, and both the northeastern and
southeastern points of the Jonkova Njiva promontory. This
unit would correspond to “the basal dolomite” described by
BOŽIČEVIĆ et al. (1965). In the southern cliffs below the
lighthouse between Picokare and Biljovka, beds dip steeply
(subvertically) to the southwest (Fig. 2). Elsewhere in the
northern sector of the island, bedding is not clear due to
strong tectonization and the presence of massive bodies of
course dolomite breccia. Its most distinguishing feature is
medium- to thick-bedded cryptocrystalline dolomite contain-
ing nodules and lenses of gray chert aligned along bedding
(Fig. 8). Thin-bedded dolomites interbedded with softer silty
dolomite occur in the lowermost part of the unit (Fig. 9).

Gray to beige, medium to thin-bedded dolomite devoid of
chert nodules is the distinguishing feature of the Lanterna unit
B, which makes up most of the central-northern part of the
island (Fig. 2). The unit B is often strongly tectonized, and con-
tains massive bodies of course dolomite breccia (Fig. 6B).

Table 1: δ³⁴S isotope data from samples of Palagruža Žalo unit gypsum
(location 1 on Fig. 2; Fig. 3)

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>δ³⁴S VCDT</th>
<th>Elemental Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>GYP-A</td>
<td>–11.4</td>
<td>16.1</td>
</tr>
<tr>
<td>GYP-C</td>
<td>–11.5</td>
<td>12.7</td>
</tr>
<tr>
<td>GYP-D</td>
<td>–11.1</td>
<td>12.0</td>
</tr>
</tbody>
</table>
3.2.1. Palynology of Lanterna unit A

We analyzed a soft interbed of yellowish silty dolomite of the Lanterna unit A exposed at the first switchback on the trail to the lighthouse (Sample Pal–12D; location 5 on Fig. 2; Fig. 9), and in the coastal outcrop SW of Stara Vlaka (Sample Pal–16; location 4 on Fig. 2). Sample Pal–12D is palynologically barren whereas Sample Pal–16 revealed a poorly preserved, undiversified sporomorph assemblage containing cf. *Patinasporites densus*, which first appears close to the base of the Carnian, i.e. at the base of the ammonoid *aon* zone palynologically characterized as the *vignes–densus* phase by VAN DER EEM (1983), and at the base of the ammonoid *canadensis* zone designated as Assemblage B by BROGLIO LORIGA et al. (1999), respectively. Occurrences of weakly preserved cf. *Camerosporites secatus* may suggest that sample Pal–16 is likely to be Carnian in age since its last appearance is placed at the top of Carnian (VISSCHER & BRUGMAN, 1981; WARRINGTON, 2002).

Sample Pal–16 contains a small amount of organic matter, insufficient for palynofacies analysis or palaeoclimatological/palaeoenvironmental interpretation.

3.2.2. Age and paleoenvironment of the Lanterna unit A

The age of the Lanterna unit A is poorly defined as Late Triassic, according to palynological results (see section 3.2.1.).

Radiolarians reported by KOROLIJA et al. (1977) from the chert nodules of Lanterna unit A, and traces of *Lithothamnion* reported by BOŽIĆEVIĆ et al. (1965), would indicate an age not older than Middle Jurassic for this formation. Unfortunately, neither microfossils nor macrofossils could be determined in the numerous samples of dolomite inspected in the field, or studied in thin sections. It is likely that dolomitization of the parent limestone, which led to a cryptocrystalline textural homogenization of these rocks, would have obliterated any original internal structure or microfossil trace.

The study of thin sections from the Lanterna unit chert nodules (Picokare and Stara Vlaka, Fig. 8) did not reveal any radiolaria or any other kind of microfossil, nor lithic grains, which could have aided age assessment and determination of a palaeoenvironment setting for these rocks. However, the poorly preserved palynoflora of Pal–16 including *Patinasporites, Enzonalasporites, Camerosporites* and bisaccate pollen, suggests a semi-arid climate since these taxa represent coniferallean, xerophytic plant communities.

3.3. Salamandrija unit

The central part of Velika Palagruža (Salamandrija) is characterized by a regular, flat area, which dips toward the NNE, and is mostly covered by humic soil. A small quarry pit located some 50 m NE of the archaeological site of Salamandrija (KIRIGIN & ČAČE, 1998; FORENBAHER & KAISER, 2005; Fig. 2) reveals that this point of the island is composed of thick layers of light-grey to yellowish, porous bio-intra-lithoclastic to skeletal packstones and grainstones (biocalcarenites). Another outcrop occurs on the trail to the lighthouse, along the WNW–ESE striking fault (Fig. 2), separating the unit from the underlying rocks. Therefore, it is not possible to determine the exact stratigraphic relationship of this unit with the underlying rock units without new detailed field investigations. Nevertheless, the bedding attitude of the Salamandrija unit exposed in the quarry pit is appro-
approximately perpendicular in respect to the Lantera unit B exposed along the crest of the island, suggesting a sharp angular unconformity.

3.3.1. Biostratigraphy and depositional environment of the Salamandrija unit

Study of thin sections of the Salamandrija biocalcarenite (samples Pal–10 and Pal–13, location 6 on Fig. 2) confirmed the presence of some microfossils reported by BOŽIĆEVIĆ et al. (1965). Within recrystallized bioclastic-skeletal-lithoclastic grainstones (Fig. 10) biogenic debris mostly made up of bioclasts of sea urchins, red algae, mollusc shells and tests of benthic foraminifera was discovered. Among the latter, the most abundant are *Elphidium* sp. (including *Elphidium crispum*), followed by *Asterigerinata* sp., *Melonis* sp., *Heterolepa* sp., *Gyroidinoides* sp., *Ammonia* sp., *Neoeponides* sp., etc. *E. crispum* occurs, in the Mediterranean region, in Miocene sediments (AGIP, 1982).

In a preliminary study of the fossil content of the Salamandrija unit, BOŽIĆEVIĆ et al. (1965) reported, besides casts and fragments of molluscs, fragments of calcareous algae, and recrystallized globigerinids, a number of benthic foraminifera including *Robulus* sp., *Amphistegina* sp., *Nonion granosum*, *N. soldanii*, *Rotalia beccarii*, *Elphidium crispum* and ostracod species *Cythereis tricostata*. According to BOŽIĆEVIĆ et al. (1965), this fossil assemblage indicates a general Neogene age, similar to a marine Pliocene assemblage found in southern Apulia. However, the abundance of *Elphidium* sp. is suggestive of a Miocene age, and, in any case, as a detrital limestone made up of reworked bio- and lithoclasts, the fossil assemblage of the Salamandrija unit is not conducive to precise age determination.

The foraminiferal association indicates an inner shelf environment (cf. BOLTOVSKOY & WRIGHT, 1976). BOŽIĆEVIĆ et al. (1965) suggest a coastal sedimentary environment based on the abundance of *Amphistegina* sp. Undefined subangular lithoclasts of older rocks are also present, including micritic limestones containing calpionellids (tintinnids). These redeposited subangular lithoclasts suggest that older rocks (including Mesozoic deeper-water micritic limestones) were deformed and exposed during sedimentation of the Salamandrija unit.

3.3.2. Strontium isotopes of the Salamandrija unit

As an independent method to determine age for the Salamandrija unit, the $^{87}\text{Sr}/^{86}\text{Sr}$ composition of a bulk biocalcarenite sample from the Salamandrija quarry pit were analysed. (location 6 on Fig. 2), along with the shells of two modern intertidal gastropods, *Natica millepunctata* and *P. coerulea*, collected at the island of Hvar and representing the present strontium isotopic composition of Adriatic seawater. In addition, a sample of pelagosite, which represents a biaragonite related to the cyanobacterial activity in the supratidal zone (see section 4.3.), and a sample of dolomite from the Lanterna unit A were also analysed. Analysis was undertaken at the Berkeley Institute for Isotope Geochemistry, using sample preparation and an analytical procedure similar to that described by DePAOLO & INGRAM (1985).

The results are shown in Table 2, and plotted in Fig. 11 against the curve of seawater strontium composition from the Permian to Recent (McARTHRU et al., 2001). The composition of the Lanterna unit A dolomite resulted in an ambiguous age determination, because of strong diagenetic alteration of the parent rock. The $^{87}\text{Sr}/^{86}\text{Sr}$ value of 0.709072 from the Salamandrija biocalcarenites provides a minimum age of about 9 Ma (i.e. lower Tortonian).

3.3.3. Age of the Salamandrija unit

Salamandrija biocalcarenites contain a wealth of microfossils and skeletal fragments of shallow-marine benthic fora-
minifera, which indicate a broadly Neogene age (section 3.3.1., Fig. 10). Combining the biostratigraphic data with the chemostratigraphy (section 3.3.2.; Fig. 11) a broadly Mio-
cene age is proposed here for the Salamandrija unit.

3.4. Talus units and rock falls

The stratigraphic succession making up the bedrock of Vel-
ika Palagruža is covered, particularly in the central part of
the island, by loose or locally cemented talus, including brecc-
cia, rock-fall boulders, and soil. In the area of Stara Vlaka,
a wedge of dip-slope, coarse, poorly cemented detritus cov-
ers up the dolomites of the Lanterna unit B. A cross section
of the wedge and the underlying bedrock is exposed in the
Stara Vlaka cove (Fig. 6A), offering the opportunity to de-
termine the relationship between the cover and the underly-
ing bedrock. Here, the dolomitic breccias of the Lanterna
unit B are strongly tectonized, and displaced by the WNW–
ESE striking oblique-slip fault, which puts them in contact
with the equally tectonized Žalo unit (Fig. 6B). The fault as
well as the contact between the Žalo unit and the Lanterna
unit A is capped by the detrital wedge, which clearly dips
downslope toward the NE. The wedge is composed of lay-
ers of poorly cemented dolomite breccia resting on top of
finer, reddish debris, probably representing a lateritic soil.

Near the contact with the underlying dolomite bedrock,
at 13 m asl, a deposit of rounded pebbles suspended in a red-
dish sandy matrix (Fig. 12A) occurs. In between the pebbles,
rare fragments of bivalve shells and pebbles showing the
typical superficial texture produced by perforating algae sug-
gest a palaeo beach depositional environment. One pebble
we collected is perforated by a lithodomus burrow, which
still contains the original bivalve shell (Fig. 12B).
It is uncertain whether this deposit represents the remnant of a Quaternary palaeobeach or an older deposit formed during a Miocene transgression or Pliocene(?) to Quaternary marine regressions (i.e., during the emergence of the island). As for the bedded talus, it appears that it formed in recent times after the emersion of the island, and it does not represent a sedimentary continuation of the Salamandrija unit.

A similar talus exposure, which suggests a post-Miocene, post-deformational talus deposit, is observed on the west side of the Picokare ravine (see Fig. 4A). Here the poorly cemented breccia layers dip south, thus representing a talus slope with a bedding direction essentially perpendicular to the Salamandrija unit and the Stara Vlaka talus wedge. It is worth mentioning that just below the saddle between Salamandrija and the lighthouse peak, at about 50 m asl at the head of the Picokare ravine, we found some sparse rounded pebbles, which may represent yet another, older paleobeach deposit.

The slope on the south side of Salamandrija, between Žalo and Picokare, is littered by loose rock waste and boulders, some of which are so large that they may in fact represent bedrock remnants of a strongly eroded cliff topography. It is also to be noted that, it has been reported that catastrophic rock falls occurred in very recent times (FORENBAHER & KAISER, 2005).

4. NEOTECTONICS AND RELATED FEATURES

The island of Velika Palagruža can be described as a vertical topographic feature, in which the bedrock has been emerging from the sea in response to active tectonics, and is affected by marine erosion. In Section 2 we reviewed the present seismotectonic situation of the central Adriatic, which places Palagruža near the emergence of a large, seismically active thrust fault (BENNETT et al. 2008), and/or in an area where wrench tectonics and salt diapirism causes uplifting (e.g. GRANDIĆ et al., 2002; GELETTI et al., 2008). While surveying the island in recent years, several features were discovered, which testify to the recent uplifting of the island. These are flat areas (marine straths), palaeobeach deposits, and pelagosite, all occurring at different elevations throughout the island.

4.1. Marine straths

There are only few places where the topography is flat at Palagruža, which contrasts with the otherwise vertical topography of the island. These areas may represent marine straths (see Fig. 2 for locations). Of course, in this tiny island there are no extensive flat surfaces that may strictly be defined as a marine strath or peneplain. Thus, we use here the term of marine strath in a general sense, indicating a flat and nearly horizontal erosional surface cutting across steeply dipping bedrock layers.

One such marine strath is found at about 75 m asl, just above the Biljovka cove (Figs. 6A and 13A). Another possible case of marine strath is represented by Salamandrija, which is the largest flat area of the island at about 60 m asl, and, in fact, this has been the site of human settlements since the Early Neolithic (FORENBAHER & KAISER, 2005).

4.2. Palaeobeach deposits

One palaeobeach deposit made up of rounded pebbles is described in Section 3.4. (Fig. 12A). A relatively conspicuous beach deposit is found at the western foot of the Picokare ravine resting at about 6 m asl, and consisting of rounded pebbles, cobbles, and boulders (up to 40 cm in diameter) free of any matrix (Fig. 14). Some pebbles exhibit a perforated surface possibly caused by burrowing algae or lithophagous bivalves, but no shells, nor encrusting algal remains have been found so far. A deposit of rounded pebbles was observed filling a ledge on the vertical sea cliff just above the palaeobeach deposit of Picokare, at about 13 m asl (Fig. 14).

Although the boulders could be deposited 6 m asl from the recent shoreline by gigantic waves under specific hydro-
dynamic regimes, the deposit was still interpreted as a remnant of a palaeobeach, since in the footwall of the cliff pebbly beach deposits have not been observed. Thus, the palaeobeach also indicates recent uplifting of the island.

Fortunately there are no means to determine an age for these palaeobeach deposits due to the absence of fossil remains. A more thorough survey of the cliffs around the lighthouse peak may reveal other deposits of this kind at different elevations, and chances are that fossil remains of sea molluscs can be found, providing material for radioisotopic dating.

4.3. Pelagosite

Further evidence for the recent tectonic uplifting of Palagruža comes from black mineral incrustations with a vitreous lustre resembling tar, which covers, in irregular patches, the rocky coast of the island from just above the tide line up to 13 m asl (Fig. 15A). This strange substance was first reported by Marchesetti (1876), and, one year later, it was named "pelagosite" (from Pelagosa, the Latin name of Palagruža) by Stossich (1877).

The reports by Marchesetti and Stossich were followed by 50 years of debate in the international scientific community about the nature and origin of this strange mineral (e.g. Cloez, 1878; Squinabol & Ongaro, 1901; Clerici, 1920). Finally, ONORATO (1926) published a comprehensive paper on the morphological, mineralogical, physical, chemical, and microbiological characteristics of pelagosite samples from the Tremiti islands, which are located some 75 km southwest of Palagruža. Pelagosite turned out to be pisolithic aragonite. It consists of pearl or mamillon-shaped objects with a concentric ring internal structure “similar to tree rings”, made of a pure aragonite, and solidly attached to the rocky substratum. According to ONORATO (1926), pelagosite is produced by “blue-green algae” (i.e., cyanobacteria) where the supralittoral rock is frequently wetted by sea aerosol.

Optical microscopy by Montanari et al. (2007) confirmed the pisolithic structure of pelagosite, as originally observed by ONORATO (1926), and showed that 2–3 μm thick alternating dark-light laminae are arranged rhythmically through mm-thick sections of pelagosite crusts (Fig. 15B). Thicker laminae contain submicron-size inclusions of organic matter (Fig. 15C), including fragments of cyanobacterial cells (Fig. 15D) similar to those observed by ONORATO (1926) in the Tremiti pelagosite. By assuming that these laminae represent yearly accretions (just like the rings in a tree trunk), Montanari et al. (2007) determined that their arrangement bears cyclicity with frequencies comparable to those of the periodic climate changes controlled by El Niño and the North Atlantic Oscillation (i.e., dry-wet/cold-warm meteorologic conditions alternating approximately every 3, 8, and 12 years).

In a recent microbiological study of pelagosite samples from Palagruža, MACALADY et al. (2008) confirmed ONORATO’s conclusion of a biogenic origin for this aragonite and, through DNA analysis of the organic fraction, they determined the presence of cells belonging to Xenococcus (Fig. 15D), a rare genus of cyanobacteria, and apparently a new species never described before.

The fact that pelagosite apparently forms within a couple of metres above tide line, but today is found up to 13 m above sea level, suggests that Palagruža is currently uplifting. The uplifting rate of the Gargano promontory (Apulia domain, Fig. 1), estimated by MASTRONUZZI & Sansò (2002) from U/Th dating of bioherms and other paleo-sea level indicators, is 1.5 mm yr⁻¹. In contrast, the coastal areas of NE Adriatic (Croatia) are presently under a regime of subsidence (Benac et al., 2004; Antonioli et al., 2007).

The preliminary U/Th dating of pelagosite from Velika Palagruža by Montanari et al. (2007), yielded ages around 2200 years for samples collected between 3 and 4 m above sea level at Picokare, and 6500 years for a sample from 6 m above sea level, suggesting that Palagruža is uplifting at a rate comparable with the uplifting rate of the Gargano promontory estimated by MASTRONUZZI & Sansò (2002). This encourage further work to better evaluate the potential of this bimineral for assessing vertical tectonic movements of littoral environments.

5. SUMMARY AND CONCLUSIONS

The tiny islands of the Palagruža archipelago represent the only pieces of dry land exposed in the middle of the central Adriatic Sea. The outcrops offer the unique opportunity to study Mesozoic and Cenozoic deposits in the central part (Mid-Adriatic ridge) of the common Adriatic foreland of the Apenninic and Dinaridic orogenic domains. Our geological reconnaissance of the island of Velika Palagruža, the largest in the archipelago, allows us to assess some stratigraphic and tectonostructural characteristics, which were never described in the few geological reports available in accessible literature.

Velika Palagruža is composed of four main sedimentary units. However, evidence that these units are in stratigraphic continuity is lacking, as they are all bounded by faults and discordances.
The oldest unit recognized is formed of highly deformed siliciclastic (silt and clay) deposits containing gypsum and thin layers of stromatolitic limestones capped by a package of thin-bedded dolomite layers. Palynomorphs contained in the clay at the base of this succession indicate a Middle Triassic age (Ladinian). This unit, named Žalo, represents a transitional fluvial-to-shallow marine, occasionally evaporitic environment, typical of the Middle Triassic rifting phase of the Adriatic microplate.

The Žalo unit is in discordant relationship with the younger Lanterna unit of thick to medium-thick bedded dolomite and dolomite breccia, with or without chert. Palynomorphs in a sample from the Lanterna unit indicate a Late Triassic age. The Lanterna unit is actually made up of two subunits recognizable for their different bedding thickness and style. Unit A is characterized by thick and medium-thick layers of dolomite with chert, and unit B is characterized by massive dolomite breccia and thin- to medium-thick dolomite layers devoid of chert. These two subunits are separated by a WNW–ESE striking, subvertical, oblique-slip fault, which crosses the entire length of the island. The presence of well-bedded dolomite with chert and massive bodies of dolomite breccia suggests a transitional platform-to-basin depositional setting of an evolving Adriatic Basin domain.

The Lanterna unit dolomites are capped by biocalcarenites of the Salamandrija unit, containing abundant microfossils, which, along with strontium isotope data, indicate a broadly Miocene age. The biocalcarenites bedding alignment is highly discordant in respect to the underlying Lanterna unit, although the actual contact between the two units is not visible because it is covered by talus. Talus, landslide deposits, and humic soil make up the cover of the bedrock sedimentary succession of the island, and they represent the ultimate phase of emergence of the island, which probably occurred during Pliocene? to Quaternary times.

The bedrock units of Velika Palagruža, each one displaced by faults and/or in diapiric contact to each other, and therefore not in stratigraphic continuity, represent just a few pieces of a large and complicated puzzle depicting the tectono-sedimentary evolution of the central Adriatic basin. The almost perpendicular discordance (unconformity?) separating the Salamandrija unit from the underlying Triassic dolomites suggests a deformational phase preceding Miocene marine deposition, perhaps a marine transgression over an already deformed and eroded dolomite massif. The WNW–ESE striking subvertical oblique-slip fault that crosses the entire length of the island is probably still active. Soft and strongly deformed Ladinian siliciclastic-evaporitic Žalo unit deposits occur along the fault, and may be related to diapirism.

The central Adriatic area is under an active seismic regime. Recent uplifting of Velika Palagruža is shown by remnants of pebbly palaeobeach deposits, marine (erosional)

Figure 15: A) Pelagosite encrustations on the cliff near Picokare at about 4 m above sea level; B) polished section of a pelagosite crust; C) thin section microphotograph (transmitted plain light) of a pelagosite crust from Picokare showing a rhythmic microlaminar arrangement; D) a cell of cyanobacterium *Xenococcus* extracted from pelagosite.
straths, and cyanobacterial supratidal encrustations (pelagosite) today found at various elevations above mean sea level. Further detailed research on the structural geology, stratigraphy, micropaleontology, and radiisotope geochronology will hopefully add detailed constraints in a more accurate reconstruction of the geologic and tectonic history of the Palagruža archipelago.

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APPENDIX 1.

LIST OF AUTOCHTHONOUS LADINIAN PALYNOMORPHS FROM THE ŽALO UNIT CLAYSTONES (SAMPLE PAL–6, LOCATION 1 ON FIG. 2)

Spores

- Calamospora tener (LESCHIK, 1955) MÄDLER, 1964a – 0.6%
- Calamospora keuperiana MÄDLER, 1964a – 0.6%
- Todisporites minor COUPER, 1958 – 0.2%
- Todisporites major COUPER, 1958 – 0.2%
- Todisporites cinctus (MALJAWKINA, 1964) ORŁOWSKA-ZWOLIŃSKA, 1971 – 0.4%
- Deltoidospora minor (COUPER, 1953) POCOCK, 1970 – 0.2%
- Concavisporites toralis (LESCHIK, 1955) NILSSON, 1958 – 0.8%
- Concavisporites crassexinius NILSSON, 1958 – 0.4%
- Osmundacidites wellmanii COUPER, 1953 – 0.2%
- Verrucosisporites morulae KLAUS, 1960 – 0.2%
- Uvaesporites gadensis PRAEHAUSER-ENZENBERG, 1970 – 1.2% (Fig. 7/1)
- Aratrisporites fimbriatus (KLAUS, 1960) MÄDLER, 1964a – 0.4%
- Leschikisporis aduncus (LESCHIK, 1955) POTONIÉ, 1958 emend. BHARADWAJ & SINGH, 1964 – 0.4%

Pollen

- Enzonalasporites sp.
- Patinaeasporites sp.
- Heliosaccus dimorphus MÄDLER, 1964a – 0.4% (Fig. 7/4)
- Cannanoropollis scheuringii BRUGMAN, 1986 – 1.4% (Fig. 7/3)
- Kulgeria meieri SCHEURING, 1978 – 0.8%
- Doubingerispora filamentosa SCHEURING, 1978 – 0.2% (Fig. 7/2)
- Infernopollenites sulcatus (PAUTSCH, 1958), SCHEURING, 1970 – 0.4%
- Lunatisporites acutus LESCHIK, 1955 emend. SCHEURING, 1970 – 4.2% (Fig. 7/5)
- Striatodiasporites griseus VISSCHER, 1966 emend. SCHEURING, 1970 – 0.8% (Fig. 7/6)
- Striatodiasporites balsami KLAUS, 1964 emend. SCHEURING, 1978 – 4.6%
- Triadispora plicata KLAUS, 1964 – 0.4% (Fig. 7/7)
- Triadispora crassa KLAUS, 1964 – 0.4%
- Triadispora stabilis SCHEURING, 1970 emend. SCHEURING, 1978 – 0.4%
- Triadispora verrucata (SCHULZ, 1966) SCHEURING, 1970 – 1.2%
- Podosporites amicus SCHEURING, 1970 emend. SCHEURING, 1978 – 1.2%
- Brachystaccus remsdorfius MÄDLER, 1964a – 3.8%
- Samaropollenites speciosus GOUBIN, 1965 – 3.8%
- Ovalpollis pseudokostia (THIERGART, 1949) SCHUURMAN, 1976 – 24.8% (Fig. 7/8)
- Staurosaccites quadridens DOLBY, 1976 in DOLBY & BALME, 1976 – 1.8% (Fig. 7/9)
- Vireisporites palais (REISSINGER, 1950) NILSSON, 1958 – 1.2%
- Alisporites opti DAUGHERTY, 1941 emend. JANSONIUS, 1971 – 2.4%
- Falcisporites stabilis BALME, 1970 – 0.8%
- Sulcatasporites braunsd MÄDLER, 1964a – 1.8%
- Microcachryidites fastioides (JANSONIUS, 1962) KLAUS, 1964 – 7.4%
- Haberkornia gyladi SCHEURING, 1978 – 0.4% (Fig. 7/10)
- Haberkornia parva SCHEURING, 1978 – 0.4%
- Partitispores verrucosus (PRAEHAUSER-ENZENBERG, 1970) VAN DER EEM, 1983 – 0.8%
- Duplicisporites granulatus LESCHIK, 1955 – 0.4%
- Duplicisporites verrucosus LESCHIK, 1955 – 0.4% (Fig. 7/11)
- Camerospores secatus LESCHIK, 1955 emend. SCHEURING, 1978 – 15.8% (Fig. 7/12)
- Ephedripites primus KLAUS, 1963 – 0.4%
- Cycadopites follicularis WILSON & WEBSTER, 1946 – 0.8%
- Aulisporites astigmosus (LESCHIK, 1955) KLAUS, 1960 – 1.4% (Fig. 7/13)

Prasinophycean algae

- Leiosphaeria sp. div. – 3.6%

Acritarcha

- Veryhachium sp. 0.4% (Fig. 7/14)
- Microystis sp. 0.4%
- Dictyotidium tenuinotum EISENACK, 1955 – 1.2%

Coenobial chlorophycean alga (Chlorococcales)

- Plaeisiodictyon mosellatum WILLE, 1970 – 0.2%
- Botryococcus sp. 0.2%
APPENDIX 2.
LIST OF REWORKED PERMIAN AND LOWER TRIASSIC PALYNOMORPHS FROM THE ŽALO UNIT CLAYSTONES
(SAMPLE PAL–6, LOCATION 1 ON FIG. 2)

Spores
- Cyclotriletes sp.
- Endosporites papillatus JANSONIUS, 1962 (Fig. 7/17)
- Densoisporites nejburgii (SCHULZ, 1964) BALME, 1970 (Fig. 7/16)
- Lundbladispora sp.
- Kraeuselisporites sp.

Pollen
- cf. Nuskoisporites sp.
- Limitisporites sp.
- cf. Lueckisporites virrkiae

Acritarcha
- Micrhystridium sp.

APPENDIX 3.
LIST OF PALYNOMORPH GROUPS ACCORDING TO THEIR BOTANICAL AFFINITY AND ECOLOGICAL SENSITIVITY

A Leschikisporis aduncus
B Calamospora spp., Todisporites spp.
C Deltoispora spp., Concavisporites spp.
D Osmundacidites spp., Verrucosisporites spp., Amagiculatisporites spp.
E Uvaesporites spp., Sellaspora spp.
F Kyrtomisporis ervei
G Aratisporites spp.
H Cycadopites spp., Aulisporites astigmosus, Ephedrites primus
I Porcellispora longdonensis
J Vireisporites pallidus, Alisporites spp.
K Brachysaccus neomundanus, Falcoisporites stabilis, Sulcatisporites kraeuseli, Microcachryidites fastidioides, Podosporites amicus, Samaropollenites speciosus
L Ovalipollis pseudovalatus, Stanosaccites quadrifidas
M Infernopollenites spp., Lunatisporites spp., Striatobalitites spp.
N Triadispora spp.
O Heliosaccus dimorphus, Cannaoropollis scheuringii, Kuglerina meieri, Dauingerispora filamentosa
P Haberkornia gadati, Haberkornia parva, Praecirculina granifer, Partitisporites spp., Duplicisporites spp., Camerosporites secatus
Q Leiosphaeridia spp.,
R Plaeosdictyon mosellanum, Botryococcus spp.
S Veryhachium spp., Micrhystridium spp., Dicyotidium teniornatum

APPENDIX 2.
LIST OF REWORKED PERMIAN AND LOWER TRIASSIC PALYNOMORPHS FROM THE ŽALO UNIT CLAYSTONES
(SAMPLE PAL–6, LOCATION 1 ON FIG. 2)

Spores
- Cyclotriletes sp.
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- Lundbladispora sp.
- Kraeuselisporites sp.

Pollen
- cf. Nuskoisporites sp.
- Limitisporites sp.
- cf. Lueckisporites virrkiae

Acritarcha
- Micrhystridium sp.