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Research Paper

The evolution of Holocene Transgression in Drini Bay. Northewstern Albania

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Abstract: This paper presents for the first time data regarding the evolution of Drini Bay (Adriatic Sea) coastal plain since LGM (20 Ka BP). This area is very poorly studied by both Albanian and foreign researchers. A database including data from 200 borehole logs performed during different field campaigns undertaken in this area since 1953 was created with the purpose to determine the lowest sea level reached during LGM. The field observation helped us to evidence the presence of sea level indicators on the slopes of the carbonate hills surrounding the coastal plain. Two indicators represented by “wave cuts” or “tidal notched” were distinguished. The first one at an altitude 30-40 m, which probably belongs to the higher sea level reached during MIS5.5 and a second one, at an altitude of 9-10 m, which probably belongs to the Maximum Flooding Surface of the last transgression. The position of MIS5.5 sea level indicator suggests that the area was under the conditions of a tectonic uplift. Based on data at our disposal, we have calculated that the contribute of glacio-isostatic and hydro-isostatic components in this area during last 20 ka varies between 1.05 and 1.35 mm y^{-1}

Keywords: *Drini Bay, coastal plain, MIS5.5, LGM, MFS.*

Introduction

The relative sea level changes (RSL) were a major focus of several multiproxy investigations during the last 20 years (Lambeck *et al.*, 2004; Pirazzoli 2005; Dutton &Lambeck 2012; Lambeck *et al*. 2014; Vacchi et al. 2016; Benlamin et al. 2017). In the Adriatic Sea area, the large majority of studies were performed along the Italian coastline, notably in the north-eastern part. None of the above mentioned studies was based on data provided for the Albanian Adriatic coast plain, but this fact certainly does not exclude this area from the general history of sea level changes in the Mediterranean.

The most well determined principal sea level positions in the scientific literature are the sea level of MIS 5.5 or 5.5e (Eeminian stage) of approximately 125 ka BP, the sea level during the Last Glacial Maximum (LGM) approximately 20-19 ka BP and the actual sea level. Regarding the higher sea level reached during the Eeminian, it was estimated generally slightly higher than the present (in emerged position) (Pirazzoli 2005) estimated by several authors at an elevation from the present sea levelof 8 m by Ku *et al*. (1974), About 7.2 m above the present mean sea level (MSL) (Kopp et al., 2009) and + 5.5 to 9 meter above the present sea level (Dutton &Lambeck, 2012).The sea level during LGM was estimated to be 120±5m below the present sea level (Lambeck *et al*., 2004; Lambeck & Purcell, 2005).

Sea level rise from 20 ka BP to present was characterized by a continuously rise during the Holocene with a sudden slowdown at ~7.5 ka BP and a further deceleration during the last ~4.0 ka BP according to (Vacchi *et al.* 2016). Lambeck et al. (2014) divided the rise of the eustatic sea level into several phases: (1) a short rapid rise and a short interval of near-constant sea level, between 20 ka BP and 16.5 ka BP (2), a main phase of deglaciation, a fast sea level rise that occurred from ∼16.5 ka BP to ∼8.2 ka BP (3), a progressive decrease in the sea level rise from 8.2 ka to ∼2.5 ka BP, (4) nearly constant sea level until 100–150 y ago.

Regarding Albania, only very few data were available, the study of the Quaternary deposits being reported only in the explanatory notes of the geological maps at 1: 200.000 scale published in 1929 (Nowack 1929), 1957 (Mishunina 1957), 1967 (Biçoku et al., 1970) Vranai, et al., 1997& 2002; Xhomo*et al*., 2010). The used scheme for the description of these deposits was the genetic classification of sediments.

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Mathers et al. (1990) performed a remote sensing study based on data from Landsat TM images and aerial photographs obtained in 1943, in order to decipher the sedimentary architecture and the evolution of the Late Holocene coastal plain deposits. They concluded that the coastal plain has prograded up to 40 km since the sea level rise slowed down, according to Mathers et al., (1990), 6ka Fouache et al. (2003) through an interdisciplinary approach along the Albanian shore inferred that two-thirds of the deltaic progradation occurred over the last 500 years, starting in the 15th century.

Durmishi et al. (2008) recognised two clearly identified regional cycles (mega-sequences) along the entire Adriatic coastline, a first cycle of sedimentation formed during the Pleistocene and a second one formed during the Holocene. The lower (first) cycle is composed of intercalations of alluvial gravel or sand and marine clay facies, while the upper (second) cycle is mainly built of intercalations of gravely-sand, sand, silty-sand, clay and peaty clay facies formed on deltaic, fluvial, lagoonal, marshland and littoral environments.

The most detailed study was carried out by Unclu (2011) in a geographic area that is part of our study area. Among others, Unclu (2011) tried to draw some possible coastline positions from 6ka BP (4th millennium BC, Middle Neolithic) until 10th century AD (Early Medieval times). The results achieved by Unclu (2011) were based on the interpretation of 53 vibracore data. According to Unclu (2011), in the upper part of the vibracore logs, the sediments belong to the prograding phase and are of alluvial origin. The sediments belonging to this phase overlay the shallow marine deposits showing that during the Late Holocene, the sea progressed about 13 km toward east flooding the investigated area. From the material of those vibracores was measured 57 radiocarbon dating.

Although didn't aimed the study of Quaternary deposits, during the second half of 20th century, in the area, a considerable number of boreholes for structural geology, hydrogeology, geo-engineering, deep seismic profiles for petroleum studies, SEV for road and railway infrastructure purposes were performed, most of them logs being used by us to create our data base.

Materials and Methods

Study area.

The area of Drini Bay belongs to Tirana-Lezha field, part of the Western Albanian Lowland (WAL). The entire WAL is a flat area which extends along the Adriatic coastline, the Drini Bay being the most northern part of this coastline in the Albanian territory. The studied area has a trapezoidal shape with a north – south axis 23 km long and a maximal width about 11 km in south and 5-6 km in north. The alluvial fields of rivers Drin and Mat, the torrents of Manatia and Droja and also Ishmi River which flow in the most southern angle of this area, are the main physical-geographical elements. A chain of mountains and hills with a southeast – northwest direction surrounds the eastern and northern boundary of the area. In Lezha, the mountain chain is crossed by Drini River which crosses the coastal plain, thus linking the coastal plain with Mërçia field. North of Lezha follows two anticline structures of Renci Mountain and Kakarriqi Mountain, separated from each other by the synclinal of Torovica (Figure 1).

The Ishmi River became part of this coastal plain since the17th century, meaning that besides the maritime activity, a leading role in the formation of this coastal plain has been played by Mati and Drin rivers, the most important ones in Albania. The coastal plain is underlain by Quaternary sediments with a maximum thickness of 180 to 200 meters. This coastal plain lies above the Quaternary deposits reaching depths of 180 to 200m.In their formation, an important role has played by the process of sea level change caused by climatic changes (Durmishi *et al*., 2008).

Methods

The used method aims to study the morphology of the studied area, in order to find a connection between the sea level indicators (SLIn) of MIS5.5, the Last Glacial Maximum (LGM) and the Maximum Flooding Surface (MFS), making possible the geochronological interpretation based on geomorphological data, a method classified as correlative (Noller et al., 2000).

Following this goal, we collected two types of data. The first type is the group of data obtained during our field observations on the slopes of the hills surrounding the study area in order to evidence the possible presence of the"tidal notches" or "wave cuts" in the Upper Cretaceous carbonate deposits. The second type of details obtained from a data base containing lithological records of boreholes drilled in this area in 1953. These records, excluding the records obtained by Unclu (2011), were also used for building this database and are unpublished and archived in the Central Technical Geological Archives at the Albanian Geological Survey. The geographic position of all boreholes included in this research is presented in Figure 2.

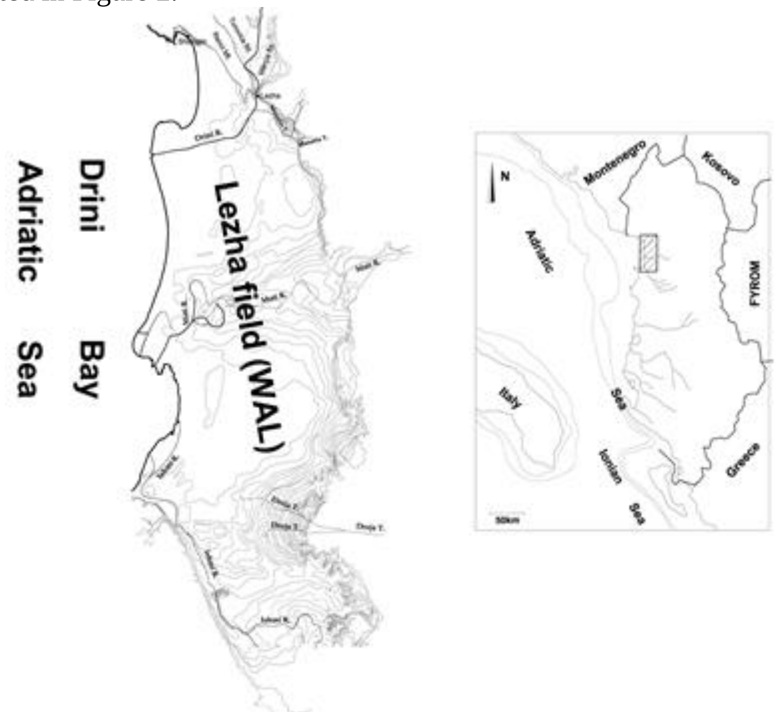

Figure 1. Presentation of area and of it position related to South Adriatic Basin

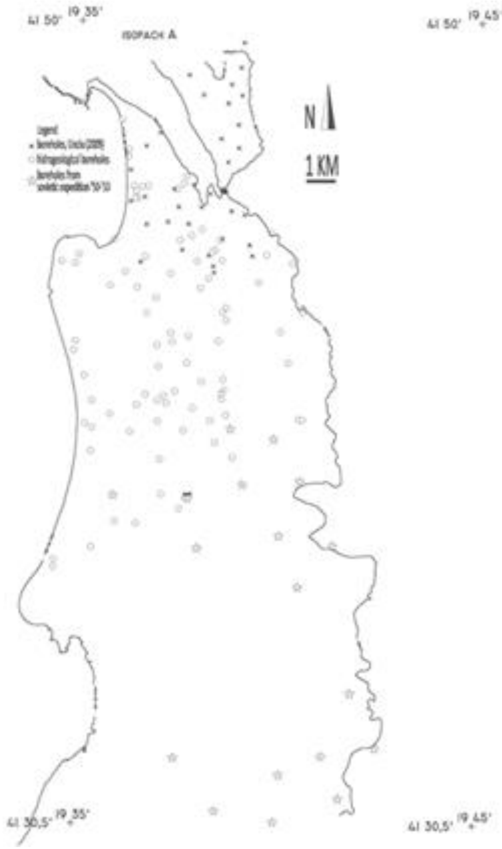

Figure 2. The map of borehole position

The second type of data was obtained from a unique database consisting of all records of drilling logs performed in this area in 1953 and was used to draw the isopach surfaces. The analysis of the boreholes lithological records shows a cyclicity of the gravel layers covering the peaty clays. Among them, the most upper gravel layer, which according to Durmishi et al. (2008) is the boundary between the upper and lower cycles, was used as basis to draw the upper surface of the peaty clays covered by this gravel layer.

In total, three isopach surfaces were drawn: two for the lower and the upper (Isopach A and B) bounding surfaces of the most upper gravel layer and another (Isopach C) for the contact between the shallow marine sediments and those of progradation pattern defined by Unclu (2011). The isopach A is shown in Figure 3.

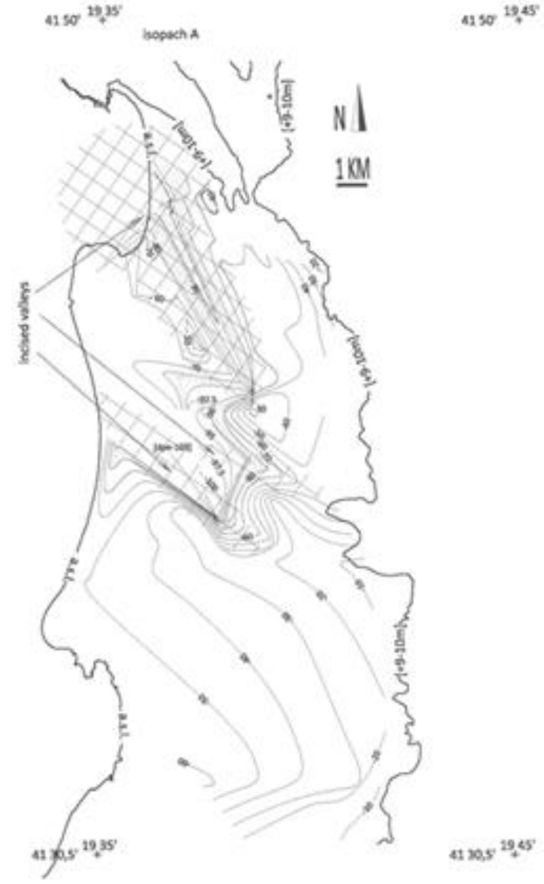

Figure 3. The map of isopach A (lower bounding surface of gravels).

Results

On the slopes of Renci and Shelbunit hills, two levels of traces similar to “tidal notches” or “wave cuts” were identified during the field campaigns. The trace of highest level stays between 30 and 40 meters above sea level and shows a stepped look which referring to Evelpidou N. and Pirazzoli P.A. (2015) should be a marker for “tidal notches” or “wave cuts” created under the action of waves and tides during the conditions of a tectonic uplift (Figures4, 5).

The trace of lowest level stays at a height of 9-10 meters above sea level and stretches from Shengjini to Zejmen (a village located approximately 8 km south of Lezha) as an almost vertical escarpment at the base of the contact between the Upper Cretaceous limestone with the overlaying Quaternary formationsand, and leaving the aforementioned contact it creates a half-arch with the convex part in the direction of the coastline. The perimeter of this arch serves as a cutting line between the surface of the Isopach B and the coastal plain surface. The interpretation of SLIn for LMG is done through the study of the isopachs more precisely the Isopach A. This isopach shows the upper surface of the peaty clay covered by the upper layer of gravel. In this area, we clearly distinguish some of the channels we treated as channels created by the progress of the rivers toward west during the regression that took place between MIS5.5 and LGM. The lowest quota is -103m below the current sea level and is considered to be the lowest rate of sea level during LGM.

Figure 4. View of SLIn MIS5.5 "wave notches" in Mali i Rencit, Shëngjin (photo S. Marku)

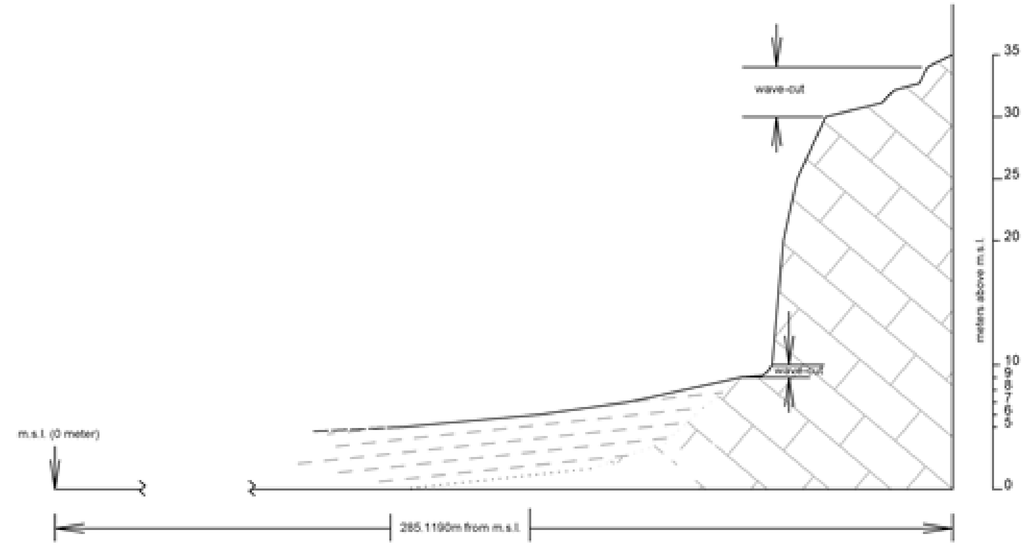

Figure 5. Skematic presentation of SLIn MIS5.5 "wave notches" presented in fig. 4

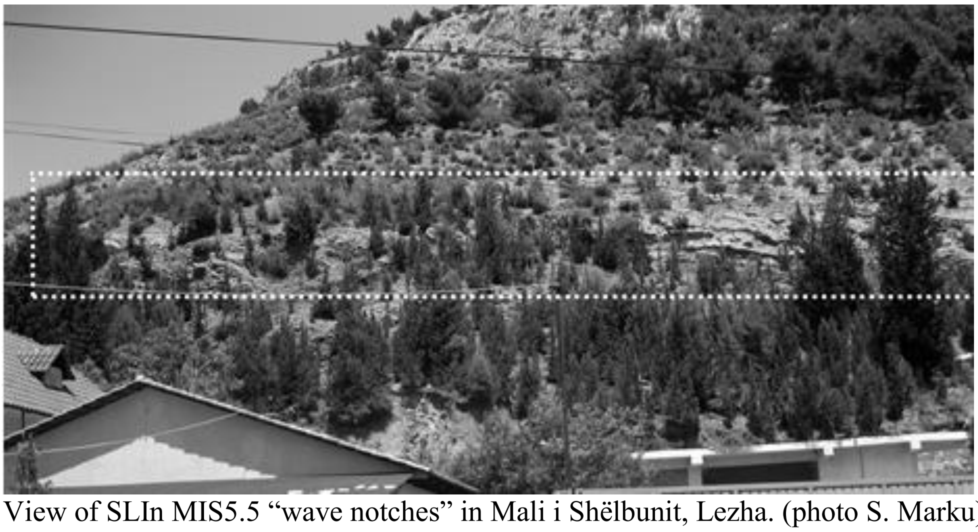

Figure 6. View of SLIn MIS5.5 "wave notches" in Mali i Shëlbunit, Lezha. (photo S. Marku)

Discussion

Following the methodology that attempts to establish a connection among the known facts regarding the sea level fluctuations between MIS5.5, approximately 125ka BP and those of today, we treat the results obtained from the studies of the coastal plain facing Drini Bay.

In the aforementioned period, they can be distinguished four stations for the positioning of the coastline, 1) the maximum level during MIS5.5 called by us SLIn-MIS5.5 at altitudes between 30 and 40 meters above the actual sea level, 2) the minimum level during LGM, determinate by us through the DPE-103 point, at a depth of -103 meters below sea level and covered by younger deposits, 3) the maximum flooding surface (MFS) reached during transgression that accompanied the current interglacial of 20ka BP up today and called SLIn-MFS, which is situated 9-10 meters above the actual sea level and 4) the current sea level, considered as absolute quota0 meters.

The SLIn-5.5 shape is characteristic for "tidal notches" or "wave cut", developed in the rock formation, whose beds dip on the opposite direction of the slope inclination. In the presented cases, the limestone dip angle is downward the slope of the hills, respectively 51 degrees in the Renci Mountain (Shengjin) and 42 degrees in Shelbuni Mountain (Lezhe). The position SLIn-5.5, is more than 20 meters above sea level. In such cases, when the position of this shoreline is situated higher than+20m, Antonioli et al., (2002) suggest that the tectonic factor has to be considered.

According to Ormeni et al. (2013), the studied area is situated in a seismic active region. Shëngjini-Lezha region is situated in the forehead of the Adriatic collision, in front of Shkodër-Peja lineament (Scutari – Peć) and stands on the Drini Bay – Lezha strike – slip fault. All faults have a high contribute to the total number of seismic events in Albania, the region constituing the connecting node joining these faults. The Shëngjini-Lezha area is part of Lezha – Ulqin area, where the seismic events with M>4.0 registered, represent 14% of total events, making it the most active area of Albania.

The difference measured between the maximum height of the position of SLIn-MIS5, 5and dpe-103, is close to the maximum level of -134 meters given by Dutton& Lambeck. (2012). The same is the position of dpe-103 which shows a tectonic uplift of the studied area during the transgressive period that affected the LMG. This uplift was considered constant over the LGM period.

In the moment of climate warming, just after the LGM, 20ka BP, the sea level begun to rise. The total of this rise in the Adriatic Sea is evaluated to be 120±5 m during the current interglacial period, which means an average rate of about 6.25 m ky-1. The rise wasn't constant. Lambeck *et al.* (2014) gave a model of multispeed rates of sea level rise during the last 20ka. According to this model, a progressive decrease in the rate of rise from 6.7 ka to recent time has occurred. On this basis, we have to calculate a sea level rise of ~3-4 during last 6 ka and a rise of ~ 120-121 m from 20 – 6 ka BP, with a respective average rate of 0.7 m ky-1 and 8.6 m ky-1.

Taking in consideration that the average difference in altitude between SLIn-MIS5,5 and dpe-103 is ~ 134m, it can be accepted the hypothesis that those are the two indicators of the sea level oscillation during the last glacial period. Taking this into account, the dpe-103 is the indicator of sea level during LGM, 20ka BP. at this time point, i.e. 20 ka BP, point dpe-103 considered as sea level at LGM peak and was positioned 125 meters below the current global sea level.

Considering that the difference in altitude between SLIn-MIS5.5 and actual sea level is at least 30m, deduced from Lambeck, et al. (2004), the area can be considered as an uplifting area.

Pirazzoli (2005) suggests the following equation to calculate the elevation of past coast line:

$$ps = eu+te+ gi+hi, \qquad (\mathbf{1})$$

where *ps* is the elevation of the past shoreline, *eu* the eustatic position, *te* the tectonic (other than isostatic) component, *gi* the glacio-isostatic component and *hi* the hydro-isostatic component.

Based on this the contribution of *te*, *eu* and *hi* can be expressed by the following equation:

$$Ut = te+gi+hi, \qquad (\mathbf{2})$$

Considering that in case of "normal" sea level rise, the MIS 5.5 should have been positioned 6±3 m above the present sea level, it can be deduced that our SLIn-MIS5.5 stays 24±3 m higher. The contribution of Ut rate in last 20 ka can be calculated as follow:

1. For normal MIS 5.5 situated 6 m above present sea level, the average Ut rate for our case is ~1.2 mm y^{-1}. This means that the relative sea level reached its maximal quote in SLIn-MFS between 8.3 ka Bp and 7.5 ka BP;

2. For normal MIS 5.5 situated 9 m above present sea level, the average Ut rate for our case is ~1.05 mm y^{-1}. This means that the relative sea level reached its maximal quote in SLIn-MFS between 9.5 ka Bp and 8.6 ka BP;
3. For normal MIS 5.5 situated 3 m above present sea level, the average Ut rate for our case is ~1.35 mm y^{-1}. This means that the relative sea level reached its maximal quote in SLIn-MFS between 7.4 ka Bp and 6.6 ka BP;
4. The area studied in this paper belongs to the coastal plain situated in the front of Drini Bay. It covers the Quaternary deposits that reach a depth of 180 to 200 meters and transgressively overlies the Neogene deposits.
5. Until today in Albania, the studies of the Quaternary deposits have been limited to the genetic classification of deposits. This paper is the first attempt to discuss the history of the region's evolution during the last 20,000 years.
6. Our results show that theeustatic sea level changes since the MIS5.5, (approximately 125ka BP) are similar with those that occurred in the whole area of the Mediterranean. Over the last 20,000 years, even in the studied region, the eustatic level change is distinguished from a first phase with a highest rise that lasted until 8.2 ka Lambeck *et al*. (2014) or 7.5 BP according to Vacchi et al. (2016) and a second phase characterized by a decrease of the eustatic sea level rate.
7. In the area there were distinguished 2 distinct levels of sea waves or tides abrasion activity. One, (SLIn-MIS5.5) at an altitude of 30-40 m above sea level, which seems to belong the maximum level obtained during MIS5.5and the other, (SLIn-MFS) located at an altitude 9-10 m above sea level, belonging to the MFS reached during the last transgression.
8. Also, by analyzing the borehole logs performed over the years, we distinguished the lowest sea level reached during LGM (20ka BP).This level being called by us dpe-103 is situated at a depth of -103, and is covered by younger deposits.
9. The altitudeof SLIn-MIS5.5 indicates an area that has been under the conditionsof a tectonic uplift over the last 20,000 years.
10. From the calculations based on the Pirazzoli equation (2005), it results that the contribute of tectonic (other than isostatic), glacio-isostatic and hydro-isostatic components in this region were between 1.05 and 1.35 mm y^{-1}over the last 20ka.

Conclusions

The area studied in this article belongs to the coastal plain situated in the front of Drini Bay. It covers the Quaternary deposits that reach a depth of 180 to 200 meters and transgressively overlies the Neogene deposits. Until today in Albania, the studies of the Quaternary deposits have been limited to the genetic classification of deposits. This paper is the first attempt to discuss the history of the region's evolution during the last 20,000 years. Our study reaches the conclusion that the eustatic sea level changes since the MIS5.5, (approximately 125ka BP) are similar with those that occurred in the whole area of the Mediterranean. Over the last 20,000 years, even in the studied region, the eustatic level change is distinguished from a first phase with a highest rise that lasted until 8.2 ka Lambeck BP *et al*. (2014) or 7.5 BP according to Vacchi *et al*. (2016) and a second phase characterized by a decrease of the eustatic sea level rate. In the area there were distinguished 2 distinct levels of sea waves or tides abrasion activity. One, (SLIn-MIS5.5), in altitude of 30-40 mabove sea level, which seems to belong the maximum level obtained during MIS5.5and the other, (SLIn-MFS) located at an altitude 9-10 m above sea level, belonging to the MFS reached during the last transgression. Also, by analyzing the borehole logs performed over the years, we distinguished the lowest sea level reached during LGM (20ka BP).This level being called by us dpe-103 is situated at a depth of -103, and is covered by younger deposits. The altitude of SLIn-MIS5.5 indicates an area that has been under the conditions of a tectonic uplift over the last 20,000 years. From the calculations based on the Pirazzoli equation (2005), it results that the contribute of tectonic (other than isostatic), glacio-isostatic and hydro-isostatic components in this region were between 1.05 and 1.35 mm y^{-1}over the last 20ka.

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