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ARHAEOLOGICAL EVIDENCE FOR SEISMIC ACTIVITY IN BUTRINTI (SW ALBANIA) AND NEOTECTONICS OF THE AREA.

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ABSTRACT

This is a preliminary study of the neotectonics and the historical seismic destruction imprinted on the archaeological site of Butrinti (SW Albania). Two fault sets surround and intersect both the limestone hill with the archaeological site and the area around it. A normal N-S trending fault is located along the NW of Butrinti hill with an observable length of 1 km and a maximum vertical displacement of 3-4m. The southern part of the hill is confined by a steep tectonic scarp, trending E-W to NE-SW, which represent the continuity of the transcurrent (right-lateral strike-slip) fault of Northern Corfu. Fault planes parallel to this fault have been observed inside the archaeological site. The continuous subsidence of part the ancient city, the presence of evaporates diapirs and their continuous vertical movement allows us to conclude that these faults are still active. Cracks crossing special foundation stone elements of archaeological buildings and other types of dislocation were the main criteria to evident seismic damage in this study. The catastrophes of the Hellenistic-Roman theatre of Butrinti and the surrounding monuments dated to the 3^{rd}-4^{th} century AD should be attributed to the seismic activity triggered by the reactivation of these faults during late Roman-early Byzantine time (358 AD). Another seismic event affecting Byzantine monuments is also probable (1153).

KEY WORDS: Archaeoseismology, Seismotectonics, Butrinti, Neotectonics, Albania, Earthquakes.

INTRODUCTION

In the framework of "Neotectonic mapping of Albania" have been examined critically evidence of supposed earthquakes at the site of Butrinti, or Buthroto, situated in the southern coast of Albania (Corfu strait), close to Greek-Albanian border (fig.1). This site is located in an area of intense seismic activity, where the historical

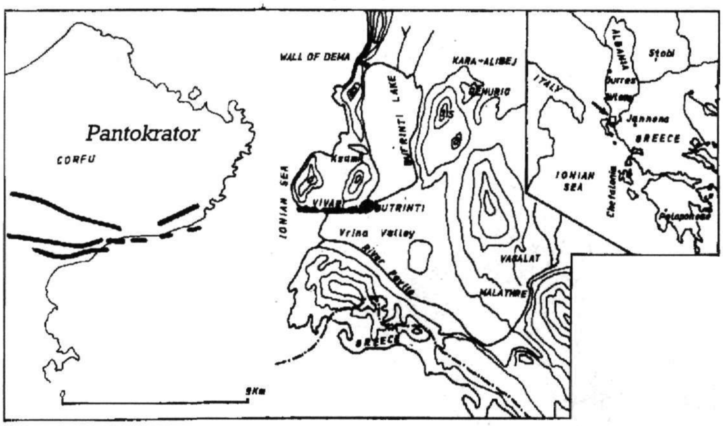

Fig. 1. Topographic map of Butrinti and the adjacent area (Ksamil peninsula, Butrint lake, Dema wall of classical times, river Pavlo which indicates the Quaternary asymmetric Vrina depression and N. Corfu island). The main oblique-slip (right lateral) fault of Corfu, which bounds northern "Pantokrator limestone" mountain with the Neogene-Quaternary southern part of the island, is shown. It possibly extents to Ksamil peninsula (Butrinti area). Black arrow at the top right corner map shows the position of the Butrinti area in relation to Albania, Greece and Ionian sea.

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seismicity is imperfectly known (Sulstarova and Kociaj 1975/1989; Guidoboni 1989; Papazachos & Papazachou 1997). Albania is mostly characterised by the occurrence of moderate size earthquakes, according to the instrumental data (Muco 1998; Louvari et al, 2000).

Butrinti archaeological site (fig. 1) lies at the south western of Albania at the southern edge of the peninsula Ksamil. A long narrow, rocky ridge which links it with the mainland to the north (Saranda district). The hill on which the city was built and developed (altitude 50m) is composed of Jurassic crystalline limestone covered with a hard layer of soil. To the south the Vivary channel separates the hill from the land beyond; thus the town occupies a position naturally well protected. It also enabled Butrinti to function as a port, as it is mentioned in the maritime itineraries of the 3rd century BC (Ugolini 1942). On the west side alone, a narrow strip of land, which broadens into a flat, links the hill with the remainder of the peninsula. Butrinti is identified as city for the first time in written sources by Hecataeus, a geographer of the 6th century BC and later by Strabo (1st c. BC-1st c AD) as well as by archaeological excavations (Ugolini 1942; Bace & Condi 1990 Butrinti guidebook; Condi and Chatzi personal communication).

THE GEOLOGY OF THE REGION

The Butrinti broader region (fig. 2), which is located on the western part of the *Ionian Geological Zone*, occupies the southern part of the *Cika* anticlinal belt. The new Geological map of the Butrinti area (fig. 2) was based on the Geological Map of Albania (1983), Tectonic Map of Albania (1983), Pirrenjasi et al. (1985), Vaso et al. (1990), Neotectonic map of Albania (in press) and our new field data.

The Meso-Cenozoic stratigraphic sequence, consists of Lower Triassic evaporates, Upper Triassic-Lower Liassic platform carbonates (which grade upwards into Liassic to Lower-Middle Paleogene pelagic carbonates), Eocene flysch (clay-silt-sand) and Oligocene flysch (sand-silt-clay). The Late Miocene deposits represented by the Tortonian sandstones are placed transgressively on the older deposits. The basal transgressive deposits consists of coarse sandstones and conglomerate lenses that are followed by grey, compact, medium to small grain sandstones with rare pebbles. Pliocene deposits are placed transgressively above the Tortonian and older deposits. The Pliocene deposits are composed of grey to dark green silt and clay, rarely interbeded with thin beds of fine sandstones covered by massive sandstones with crossbedding and underwater slidings. The Quaternary deposits fill the lowest part of the region and have different origins:

- reddish conglomerates, non compact conglomerates with coarse grain yellow to brown sandstones lenses,
- the slope cones and breccia slopes cover the mountain piedmonts,
- lagoonal deposits are represented by turf and are common around Butrint lake,
- alluvial and proluvial deposits, formed by the rivers of Pavlo, Bistrica and Kalasa, cover the fields and are composed of grey to dark green alluvial clay and sand, This so called *Vrina* valley represent a typical active asymmetric subsidence. *Pavlo* river has chanced its flow during historical times.

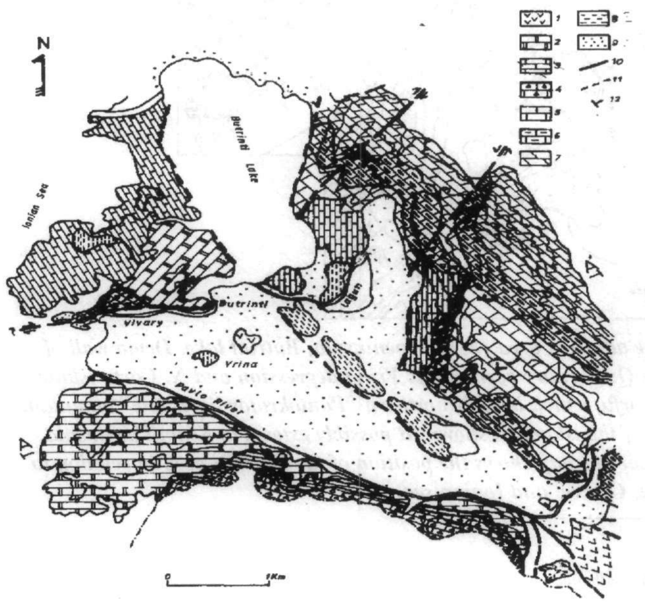


Fig. 2. Geological map of Butrinti area;
1:Lower Triassic evaporates,
2: Upper Triassic - Lower Liassic platform carbonates (Pantokrator),
3: Jurasic limestone,
4: Cretacius conglomerates,
5: Paleogene,
6: Eocene flysh,
7: Oligocene flysh,
8: Neogene (Pliocene mainly),
9: Quaternary (Holocene deposits mainly).

• beach deposits are located along the sea coast and are formed by coarse sand and pebbles

The sedimentary cover, which was detached from the underlying basement along a Lower Triassic horizon has been deformed by thrust and related folds. This horizon outcrops in the forms of diapiric hills. As a result of the "eruption" of the evaporitic diapirs near the hinge, the Butrinti anticline was divided into two parts (fig. 3): to the east the Bogazi anticline and to the west the Karafi monoclinal. The dip of the east flank deposits is 25^0-30^0E and the dip of the deposits of the Karafi monoclinal is 15-20° W. The *Bogazi anticline* continues northwards to the Saranda anticline, the eastern flank of which was complicated by a tectonic fault dipping west, resulting an eastern asymmetry.

The superposed molassic deposits form the upper unit and overlie unconformably the Mesozoic one. The presence of the evaporates in the basement and their continued vertical movement have been the main factors driving the structural and paleogeographical changes during Neogene and Quaternary, especially during Holocene times. These deposits form the Xara-Mursi synclinals that generally strike NW-SE. Southwards, the syncline is divided into two synclines, dipping towards Butrinti Lake (Prrenjasi E. 1985; Geological map of Butrinti-Xara region), by a fault that defines the tectonic contact between the limestones on the east and evaporates on the west. The NW part of these synclinals was moved eastward by a transcurrent fault, which also affects the carbonate rocks. A representative simplified geological cross section of the Butrinri area (Vrina) is shown on figure 3.

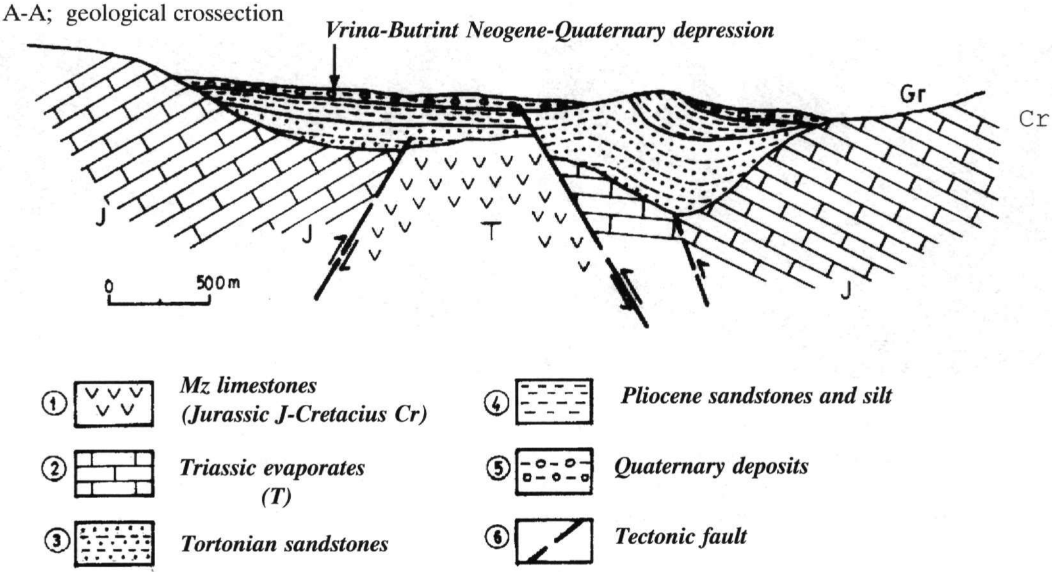


Fig. 3. A simplified geological cross-section across the fold of Vrina (Butrinti area). (AA′ site at figure 2). A core of evaporates is shown, carbonates as a unit (Mesozoic limestone) and Neogene as Tortonian (Miocene) and Pliocene sandstones-silts. Although the area is dominated by compressional tectonics (anticlines, reverse faults etc) the surface features (Butrinti fault, Vrina-Pavlo depression) show extensional characteristics. Subsidence seems probable (Plio-quaternary sediments). Buried reverse faults have been drown on the basis of some unpublished seismic profiles, folded or tilting of the overlying sedimentary rocks, as well as on the fault plane solutions of surface earthquakes of the broader region.

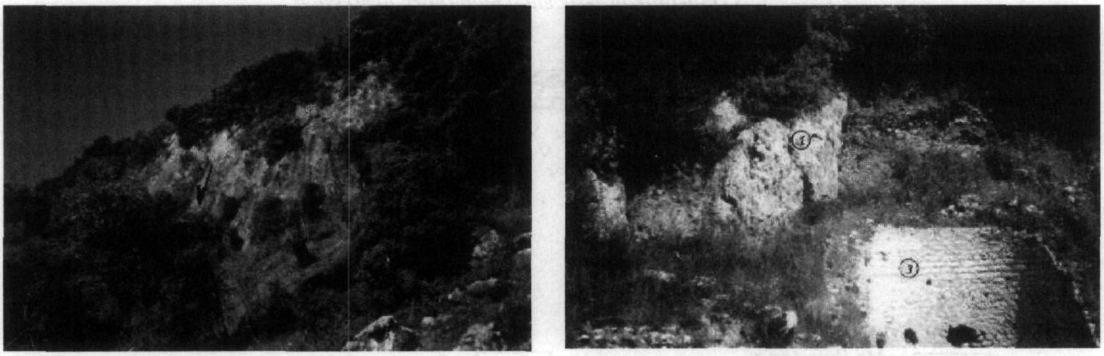
The hill where the Acropolis of Butrinti was built consists of Jurassic "*Pantocrator limestones*", while the town was developed on the soft Holocene sediments on the southern and southeastern side of the hill. This side is bordered by an E-W to ENE-WSW trending trancurrent fault, which is the extension of a greater strike-slip right-lateral structure of northern Corfu Island (fig. 1). The recent movements of this fault have been identified as normal to oblique-slip structures. It affects basement limestone and molassic deposits, and as expressed on the topography by a steep scarp. NE-SW fault directions (fig. 4) have been observed inside the archaeological site.

The most significant faults strike N-S, delineating the western and eastern sides of the lake (fig. 2). A characteristic fault of this group is located on the N-NW of the Butrinti hill. This is a NNE-SSW trending oblique-normal fault dipping 75^0 E. It also defines the contact of "*Pantocrator*" limestone with Tortonian limestone and forms a continuous fault scarp about 400 m long at least. The observed maximum throw at the fault scarp is around 4 m. The upper part of the scarp is intensively eroded while the lower part is still fresh and remnants of fault breccia are observed there.

Representative striated faults (as curves with arrows) of the broader Butrinti region are shown on figure 5. In our analysis the "the best mean tensor" (Carey & Brunier 1974) and "conditioned square minima" (Caputo & Caputo 1988) methods have been applied. They give the three principal axes of the stress (or strain) field, as well as some index with the mean standard deviation or angular deviations, which indicate the reliability of the results. The few analysed measurements from the Butrint E-W to ENE-WSW striking normal fault inside the archaeological site indicate a NNW-SSE trending horizontal σ_3 (minimum) stress axis (local extensional regime), while the representative data from the broader area (regional stress regime) show typical strike-slip domain, where: σ_1 : Az 224^0 / Dip 100^0; σ_2 : Az 92^0 / Dip 75^0; σ_3 : Az 316^0/ Dip 11^0.

These results are consistent with the North Corfu and Vlora-Elbasan right lateral strike-slip faults and especially with the stress field derived from focal mechanism. Representative data from N. Corfu strike slip fault are as follows:

Strike N 90°	Dip 86° S;	Pitch (striation)	27° E right lateral
Strike N 80°	Dip 90° S;	Pitch (striation)	26° E right lateral
Strike N 50°	Dip 85° S;	Pitch (striation)	30° E right lateral



(a) (b)

Fig. 4. Left (a) : ENE-WSW striking fault surfaces (contact between basement limestone and recent deposits) inside the archaeological site, that is the eastward extension of the fault scarp of figure 6. Arrows indicate the slip vector (striae direction of dip-slip to oblique-slip fault). Right (b) : The same fault surface some meters eastward : 1, fault plane; 2, historical (post-Roman) scree; 3, ruins of a Roman building.

Seismicity in the region is almost entirely shallow, but evaporate halokinisis is dominant, and fault plane solutions predominantly indicate compression. The seismicity and fault plane solutions of small and moderate earthquakes reveal complicated deformation. Stronger earthquakes along the Albania coast and NW Greece are associated with horizontal compressional stresses (NE-SW) mainly, and secondly with NW-SE trending extension (Muco 1998; Louvari et al, 2000). The most of the activity is probably below the Mesozoic and Cenozoic cover and it is detached rather from the underlying older sedimentary rocks and basement, e.g. Triassic evaporates. So, seismic activity is not associated with surface faults.

ARCHAEOLOGICAL EVIDENCE

Historical record of the southern Albania - Epirus (Greece) and Ionian sea coast is simply not complete. Among the great earthquakes (Ms>6.0) of the region are the 358 AD event, which affected the broader area and destroyed many cities of Epirus (Michailovic 1951; Sulstarova and Kociaj 1975/1989; Albanian Earthquake Catalogue; Papazachos & Papazachou 1989/1997). From all the data, including the catalogue of the Balkan Region (Shebalin et al. 1974) and the recent European Catalogue of Earthquakes of CNR Milan (see Stucchi et al., 1991), it is resulted that the 358 AD earthquake was a very strong event, which occurred somewhere in Northern Epirus (Southern Albania, Northwestern Greece). The location of the epicenter is not well known. Argyrokastro (or Gyrokastr), a town lying 30 km NE of Butrinti is referred as macroseismic epicenter for this event by Papazachos & Papazachou 1997. Maximum Intensity estimated for Argyrokastro is VIII (MM scale),

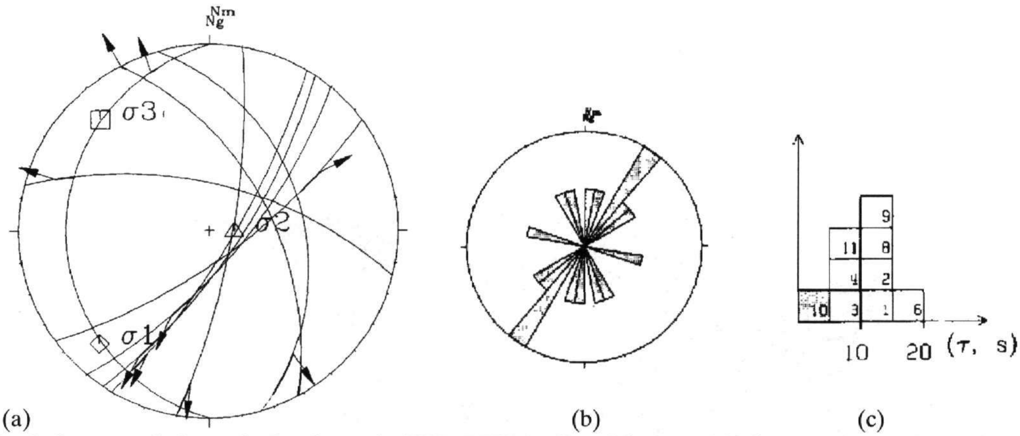


Fig. 5. Stress analysis on the Butrint main NNE-SSW trending right-lateral fault. a) stereographic projection (lower hemisphere) of the measured striated fault planes (as curves) and slip-vectors (striae) as arrows; b) rose diagram of the measured faults. c) histogram of the measured striation.

while the shock was also felt strongly in Ioannina (60 km ESE of Butrinti).

For none earthquake Butrinti or the nearest towns and villages are referred in original sources. With the exception of the Corfu earthquakes of the 17th century, with epicenters close to Butrinti coastal area, no other event can be directly associated the Butrinti, unless they were missed events. The 358 and 1153 shocks are located very close to study area.

The building or re-building phases show that economical, trading and cultural development of the city suffered two important declines, among others, the first, in the later part of the 4th century AD and the second during the 12th century AD. The foundations of the 3rd century AD buildings, including the orchestra of the theatre, the temple of Aesculapius (1st and 2nd centuries AD) and Roman baths, are today flooded with fresh water 10 to 60 cm deep. Analysis of subsidence on the basis of the archaeological remains is complicated by a variety of factors, and these difficulties must be acknowledged. Most serious is the inability to identify the position of features in relation to sea level at the time of their usage. This of course depends on the tide (maximum observed 40 cm) and season, but it generally indicates a post Roman subsidence of the area, either due to compaction or tectonic movements. But the present day water quantities covering the whole theater orchestra and surrounding areas staying today under see level, suggest the idea of subsidence. The hydrological data from the Hydrometeological Institute of Albania are fragmented and unavailable. The subsidence of the area is connected with the tectonic movements, that is possibly coseismic displacement of the Butrint fault or aseismic creep.

The main issue addressed in this study was the cause of destractive event which affected Roman building firstly and Byzantine secondly. In most of the Roman buildings there are observable fissures of possible earthquake origin. These are : Diagonal shear fissures (joints), opening cracks, inclination of wall blocks, displacements of foundation stones (offsets). The most characteristic are those of the theater (fig. 6) and the foundation offset of the eastern wall. The terraced seating (auditorium) and the area around the theatre is a typical example of earthquake damage. Terraced seating and the avenue aged to the 3rd century BC, while the stage is of the 2nd century BC. Shear diagonal fissures have been found on the terraced seating on both sides and on their support walls. Photograph of the figure 7 and the corresponding diagram is from the western side of the theater, while such joints passing through two or more adjacent blocks (troughgoing joints) and in infrastructure lying on the ground mainly as an old Greek theater is, could be formed only under high strain. Such joints require energy released from an earthquake event than to be related to weathering process or simply compaction. Numerous other examples of dislocated stones (joints) were observed. Some are also clearly visible on the Tower Gate (2nd century BC) and Lake Gate (4thcentury BC) (fig. 7). Within the walls shear diagonal fissures are orientated N60^0 E. Most of these monuments were built before the 4thcentury AD. Fissures have found also in two dwelling houses, close to the Amphitheater, Nympheum of 1st-2nd century AD, not so clear in Roman Baths, 4th to 2nd century BC, and in a Roman house of the 1st to 2nd century AD. On the later some vertical open cracks on the walls are probably due to seismic vibration or seismic fault activation.

To avoid the features of destruction caused by nonseismic forces, such as climate and static loading, we have conducted of the ground deformational features, the most probable due to earthquake shaking or seismic fault primary effects, that is 15 cases out of about 30. They were compared to similar seismic phenomena from the broader area and from global experience as well (e.g. Guidoboni 1989; Stiros & Jones 1996; Galadini & Galli 1999; Korjenkov & Mazor 1999). There are also many other cases in Albania, during the 20th century, that strong or either moderate earthquake, followed by liquefactions, cracks on grounds or on foundations, falls of river banks and subsidence in unconsolidated alluvial deposits, soil cracking and sinking were observed, especially in the Periadriatic coastal area (Kociu et al.,1996; Kociu 1997).

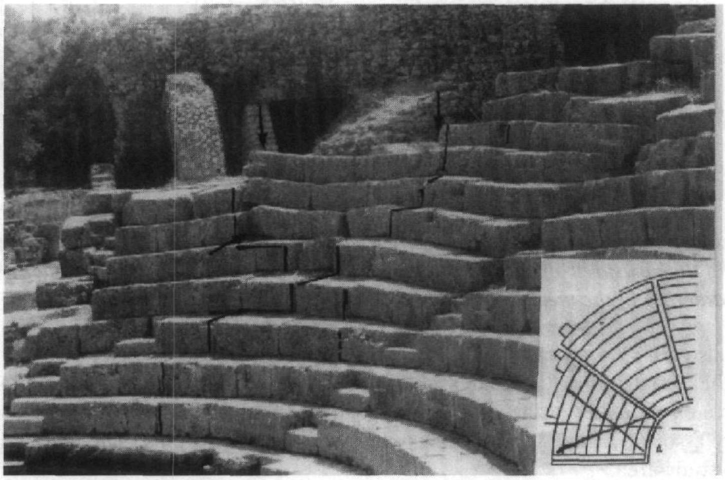


Fig. 6. Photograph of the 3rd century BC terraced seating (auditorium) of Butrinti Theatre. Deformed construction and especially open fissures are shown by arrows at the western side of the auditorium. Right down corner: the sketch of the diagonal shear cracks.

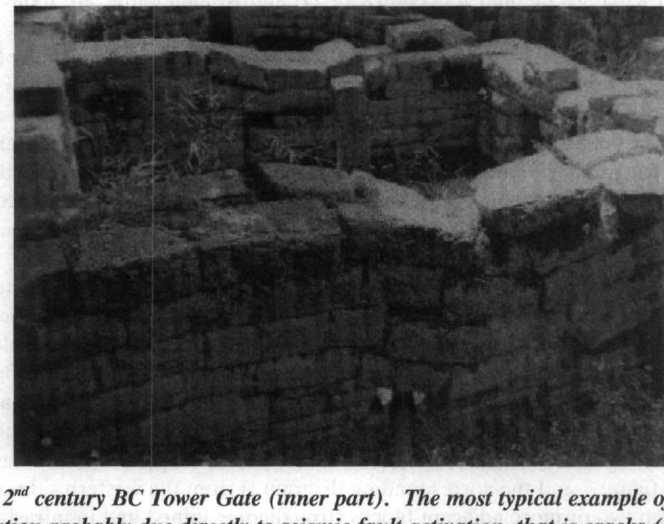


Fig. 7. The 4th to 2nd century BC Tower Gate (inner part). The most typical example of earthquake destroyed walls and foundation probably due directly to seismic fault activation, that is cracks (arrows) and tilted side (right) of the foundation.

Mapping observed earthquake damage in the city (fig. 8) highlighted two sets of fissure orientations. The older set, trending NE-SW, occurs throughout the site and is concentrated on the NE and SW sides of the monuments. These are generally diagonal shear fissures (striking 60^0 N) and, occasionally, open cracks. The majority of the monuments displaying this type of damage were built before 4th century AD, for example the terraced seating of the theatre (3rd century BC), Tower Gate (2nd century BC) and the Lion Gate (2nd century BC). Therefore, this damage is restricted to the western part of the town mainly and around the wall, that is the Hellenistic-Roman area, and remained un-repaired until they were excavated by archaeologists (second quarter of 20th century). In conclusion this evidence infers that all these observed phenomena in the Butrinti artchaeological site are probably the result of fault activity, either co-seismic or sympathetic. They probably relate to the little known 358 AD earthquake.

A second set, comprising only shear diagonal fissures, strike 0° N, and occur on the N and S walls of the younger Christian basilica (5^{th}-11^{th} century AD) (Hasani, Xh. 1990), which was built in the 5^{th} to 6^{th} century AD and reconstructed twice, in the 9^{th} and 13^{th} century AD. Therefore, this damage is only in the eastern northeastern part of the town where the Byzantine monuments extent. These can probably be related to a possible seismic destruction of the 1153 earthquake, a poorly documented event, as it is also referred in the Albanian earthquake catalogues (Sulstarova 1975; Muco 1996).

Fissures are also present in many other of the structural remains and were probably created by strong earthquakes of static origin of dislocation or weathering. However, dating the fissures is difficult due to: subseguent earthquakes in the active zone, the destruction of the fissures in monuments as a result of wars, archaeological reconstruction and natural erosion; the fragmented character of the fissures as a result of the destruction of the foundations of the monuments, lack of historical macroseismic evidence for the area.

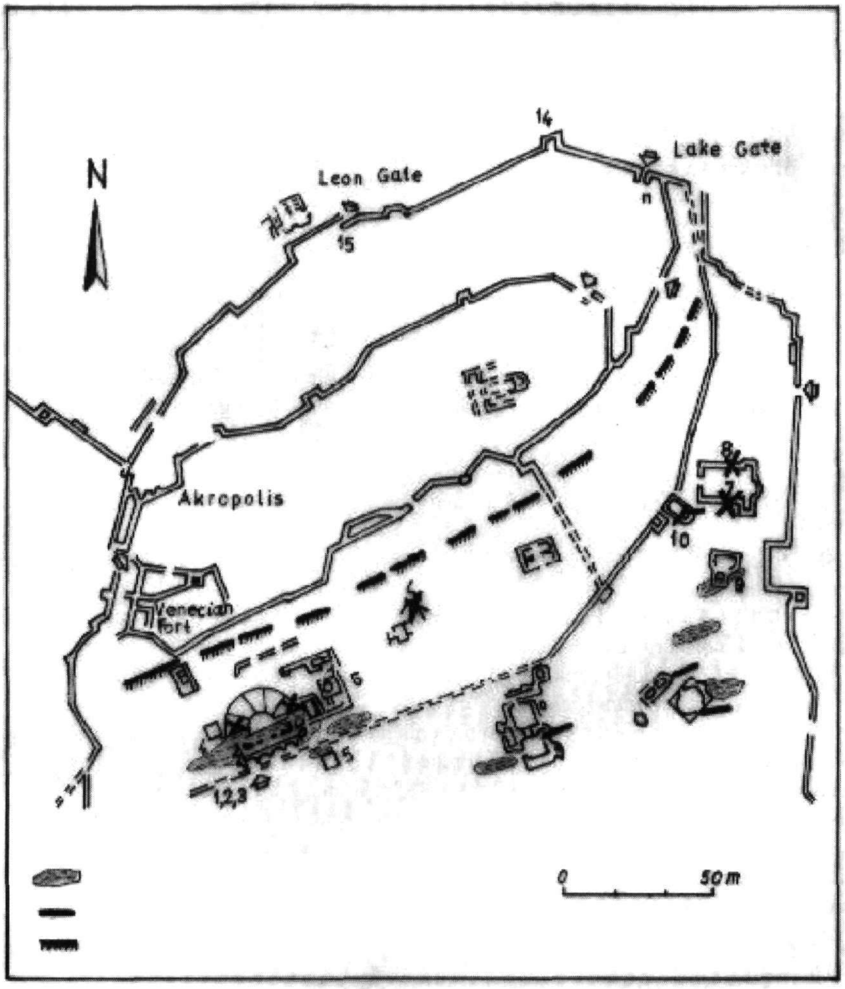


Fig. 8. Map of earthquake damages observed inside the archaeological site. Numbers indicate the places of observed "seismic" fractures and shadow areas covered by water (under see level). 1,2,3, Amphitheater (3rd-2nd c. BC) and surrounding Hellenistic (?) and Roman walls. 4, Small Temple of Esculap (Aesculapius). 5, Roman house. 6, Greek house foundation. 7,8, Palaeochristian Basilica (Cathedral). 9, Nympheum. 10, Tower Gate. 11, Lake Gate. 12, Foundation. 13, Church. 14, Wall. 15, Leon Gate.

PRELIMINARY CONCLUSIONS

The destruction is widespread in the archaeological site of Butrinti especially on the flat lowland, but it cannot be correlated to similar findings over the broader area. On the other hand the broader area was affected by many seismic events, and a hypothesis of seismic damage in the archaeological site as mentioned above, is very probable. But it does not agree satisfactory with the few historical data, because the historical seismicity of Albania is imperfectly known. Large magnitude events can be inferred, which created shear diagonal fissures with a NE-SW direction and is probably related to the activation of the known NE-SW trending active fault. The observable subsidence and dislocation could be considered as a reasonable consequence of seismic activity, as well as "aseismic" creep and geomorphologic changes.

A first hypothesis could suggest that cracks surrounding the Acropolis along the margins of the basement with the soft Holocene sediments, where the Hellenistic, Roman and Byzantine towns mainly developed, they are due to creeping and other natural processes, e.g weathering, compaction, underground water fluctuation.

A second hypothesis suggests that observed damages due to a long or short distance shock shake. So, they are the result of seismic shaking and not of primary fault activity, although it is clear that they systematically follow, more or less, pre-existing tectonic structures. A hypothesis of blind reverse fault (fig. 4) is also probable. The oldest known event occurred around the late 3rd and 4th centuries is that of 358 AD. In this case the Butrinti can be considered the macroseismic epicenter of the 358 AD strong earthquake, where primary destruction due to seismic fault damages are evident. The maximum Intensity of this event can then be considered as IX to X, because of the seismic cracks affecting foundation mainly and the theater terraced seating on the ground. The epicenter of the poorly known seismic event of the 1153 AD could also can be considered in Butrintri, with a degree of uncertainty.

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