Palaeoseismic event in the Bronze Age in northern Sardinia (Italy) evidences from megalithic monuments

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ABSTRACT

Megalithic monuments of northern Sardinia, referable to the Copper and Bronze age, are used to test the hypothesis that the observed building damage is of seismogenic nature. For this purpose have been analysed 100 megalithic sites covering an area of about 500 Km^2 occurring in an area geologically characterized by very low seismic activity and located in the horst shoulders made up of Palaeozoic basement at the edge of Oligo-Miocene Logudoro basin. Observed monuments show structural damage including torsion of top block in rock-cut tombs (the so called "Domus de Janas"), horizontal displacement of ashlars and collapse orientation in nuraghs. Observed collapses of nuraghs show a maximum of frequency around N, indicating a possible palaeosismicity activity. The proposed interpretation is in agreement with the occurrence of recentmost volcanic activity of Plio-Pleistocene anorogenic cycle ending at about 0.5 Ka as well as the distribution of seismic events in historical times.

Keywords: recentmost volcanism, palaeosismicity, megalithic monuments, Sardinia

1. INTRODUCTION

Sardinia Island is commonly considered a non seismic region. In the seismic map of Italy, however, is reported a low value of seismic hazard for northern side of the island. Consequently, studies devoted to seismic or palaeoseimic events are lacking. The investigated area is located in the northern Sardinia and has been chosen because of the contemporaneous occurrence of important nuragic remains as well as the presence of the recentmost volcanic products belonging to the Plio-Pleistocene anorogenic volcanic cycle. In addition, the chosen area represent a good deal to investigate a possible palaeoseismic activity. Indeed, the focus of a historical seismic event was recorded on the up mentioned recent volcanic products (Ittireddu, 1870). Ar/Ar published data, indicate for these basaltic rocks, a radiometric age of about 50000 years for at the western edge of the investigated area (Cheremule; Sias *et al*., 2002)

In the present paper we investigate megalithic monuments referable to the Copper and Bronze Age occurring in northern Sardinia and covering an area of about 500 Km^2. The main goal of the present research was to focus on a possible seismic activity referable to prehistoric age as argued for Oschiri and Ittireddu areas (Ginesu & Sias 1993; 2003).

The selected area shows a high incidence of megalithic buildings and occur at the edge of tectonic thoughs in which outcrop the recentmost volcanic activity of the Island.

In order to verify a possible role of the seismic activity in this period, have been chosen monuments located in the Palaeozoic basement because of a more favourable elastic behaviour of rocks in comparison to the volcano-sedimentary sequence of Logudoro basin. It has been measured the orientation of collapse materials observed at the bottom of the monuments by modelling the statistic data finalized to the recognition of a common seismic event (Fig. 1).

Investigated megalithic monuments of Copper Age are represented by rock-cut tombs (the so called "Domus de Janas") obtained on granitic rocks whose of Bronze Age are represented by towerlike *tholos* building (the so called nuraghs). Recognized nuraghs exceed the 8000 in the whole Sardinia island. The several copper

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and bronze cultures recognized in Sardinia, are commonly indicated in literature as pre-nuragic and nuragic cultures respectively and outlined by several Authors (Contu, 1981; Nicosia & Basoli, 2002; Lilliu, 2003; Ugas, 2005 and reference therein).

In the chosen area, the investigated monuments show evidence of collapse or horizontal displacement of ashlars (Fig. 2). The elaboration of collected the data, indicate a preferential orientation of the collapses of such monuments in good agreement with the distribution of recent-most volcanic apparatus and tectonic lines of northern Sardinia.

The aim of the present research is the realization of proper sheets for 100 monuments to insert in a GIS that can allow the easy and direct comparison among the territorial, geomorphologic and archaeological data to identify the connected aspects with the structural damage of the monuments. The present survey has, at the moment, offered the position of the collapses and the palaeoseismic deformations; the conclusive result of the note could add a new wedge of knowledge of the geo-environmental crisis that has competed to the decline of the nuragic civilization.

2. GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The chosen area is schematically made up of Palaeozoic basement and locally (Oschiri) by Oligo Miocene covers (Fig. 3). Palaeozoic basement is mainly represented by calcalkaline

Figure 1: Examples of oriented collapses in nuraghs from northern Sardinia (Norchetta, Pattada)

Figure 2: Examples of horizontal displacement in the walls of nuraghs form northern Sardinia (Sos Tittinosos, Pattada)

granitoid plutons ranging in composition from leucogranites to granodiorites emplaced at the end of Variscan orogenesis. These plutons contacts at the western edge of investigated area with low grade metamorphic rocks (metalimestones and phyllites). Oligo-Miocene covers are mainly represented by densely welded ignimbrites. The selected area reveal a quite complex sequence of morphogenetic phases of Miocene to Holocene times. The observed area is dominated by Gocèano and Alà ridge and the Limbara relief, which represent an ancient landscape dismembered by several tectonic phases and finally redefined by different uplifting of blocks during Plio-Pleistocene events. These events, caused the redefinition of drainage network (Sias, 2002) and produced embanked forms, as the Mesu e'Rios cañon. Fluvial terraces are well developed in the eastern side of Chilivani plain and testify the progressive change from north-westward to northward direction due to the early-middle Pleistocene (Sias et al., 2002). Particularly, the Plio-Pleistocene deposits are locally constituted by conglomerates with clay matrix and silica or carbonate cement. Recent covers of fluvial environment are widespread in the Oschiri plain and represented by Holocene and Plio-Pleistocene alluvial and colluvial deposits (Fig. 3). At regional scale it should be emphasized the occurrence of selected area at the eastern edge of Oligo-Miocene Logudoro basin. This basin outcrops largely outside the investigated area and is infilled by thick volcano-sedimentary covers ar-

ranged in several sub basin outlined by Sau et al. (2005) and aged about 20 Ma according to K/Ar radiometric ages (Lecca et al., 1997). The sub-basin are redefined during Plio-Pleistocene times marked by the emission of anorogenic volcanics of broadly basaltic composition, commonly linked in literature to the opening of Thyrrenian basin (Beccaluva et al., 1987.). The recentmost activity of this volcanic cycle is related to NNW tending faults. It ranges from 0.8 to 0.05 Ma on the basis of K/Ar and Ar/Ar radiometric data set collected on small detritus cones associated with lava-flows (Beccaluva *et al*., 1985; Sias *et al*., 2002) observed in the Logudoro basin. The alignment of emission apparates indicate the reactivation of pre-existing fracture systems in a NE/SW and NS trending in Plio-Pleistocene times (Beccaluva *et al.* 1976; 1981). Morphological characters of investigated area suffered the high inversion of relief linked to the recent uplift of western sectors. Westwards landscape is dominated by plateau whereas in the studied area flatirons and fluvial to erosional terraces likely referable to the uplift are commonly observed.

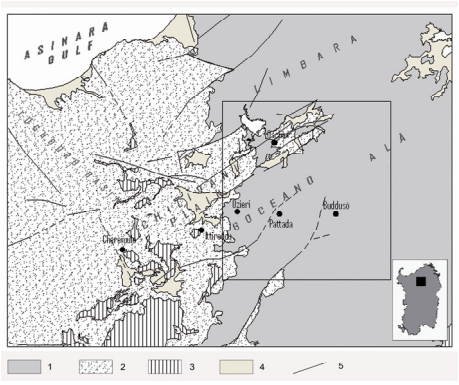

Figure 3: Simplified geological map of northern Sardinia and localization of investigated area. (1) Palaeozoic basement. (2) Oligo-Miocene covers. (orogenic volcanic rocks and sedimentary sequences) (3) Plio-Pleistocene anorogenic volcanic cycle; (4) Plio-Pleistocene alluvial and colluvial deposits. Other symbols: (5) main regional faults. Geological data simplified and modified after Sau *et al*. 2005 and Lecca *et al*., 1997

3. METHODOLOGY AND RESULTS

In order to investigate a possible palaeoseismic activity in northern Sardinia, we report the first data on 100 megalithic monumenths located in the Palaeozoic basement in order to obtain a homogenous answer to the seismic stress.

Nuraghs and rock-cut burials are investigated for several aspects as structural damages (e.g. collapses, block torsion, ashlars horizontal displacement), used rock-types, altitude as well as lithological and geomorphological characters of surrounding areas. Survey criteria of monuments included also the distribution of the monuments entrances and the illumination conditions of every single structure. Obtained field data, are reported in a data base projected for GIS analyses.The best examples of ashlars horizontal displacement are shown in the Fig. 2.

Figure 4: Examples of displacement along subhorizontal fracture system observed in a rock-cut tombs (Malghesi, Oschiri)). Note the occurrence of a quite pronounced dislocation along the vertical surface in the right side of entrance.

Figure 5: Examples of titling of rock-cut burials (Borucca near Buddusò area)

As regards structural damages, rock-cut tombs show locally (Oschiri) torsion of the block top along a sub-horizontal fracture systems of the hosting rocks (Fig. 4).

In Buddusò area a rock-cut tomb shows a glide of the hosting granite block of around 50°, with a dip of the axe that exceeds in some places the 40°. (Fig. 5)

Nuraghs show structural damages dominated by oriented collapses and horizontal displacement of ashlars. Style and typology of collapses are reported in Fig. 1. From a architectural point of view, nuraghs are towerlikes tholos structures made by overlapping big rock ashlars without using any kind of cement (Fig. 6). Such spectacular megalithic monuments are more than 20 m in height and have one to three storeys, linked by a spiral staircase. In detail nuraghes are single or complexes (up to five towers) of many towers. Almost of nuraghs stand without foundations only by virtue of the weight of its big rock ashlars.

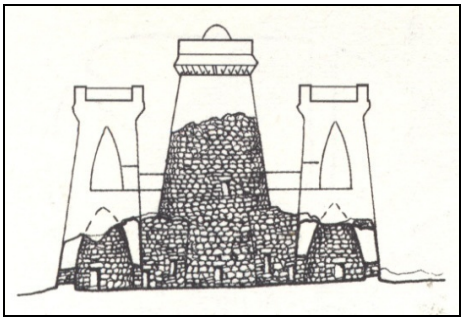

Figure 6: Schematic reconstruction of complex nuraghe made up by three towers. After Ugas 2005) modified

In the investigated area, ashlars are quite exclusively represented by granitoid rocks, which may exceed several tons. Almost of nuraghs occurring in areas with strategic significance, in the range of 300-660 m of altitude. Oriented collapses observed in nuraghs are measured in the field by compass. measured collapses in the complexes nuraghs do not show a clear collapses orientation, consequently significant data are provided by single tower nuraghs. 42 nuraghs show significant oriented collapses being those showing a simple relationships with slope discarded. A sub set of 30 nuraghs show a trend of collapse orientation ranging from WNW to N as indicate by data plotted in polar and cumulative diagrams (Fig. 7). Remarkably, oriented collapses are observed in nuraghs locate at the western edges of Palaeozoic basement, near to the up mentioned NNW trending fault bordering the basement in this region favoring the emission of Plio-Pleistocene recentmost volcanic events (Fig. 8).

A possible relationship between nuraghs collapse and seismic events is provide by plotting the subset of 30 studied nuraghs on DTM image. Best results are obtained on nuraghs occurring mainly along a narrow elongated band.

The behaviour of such megalithic structures during seismic stress, should be in agreement with the no random orientation of observed collapses. In this perspective, chaotic collapses observed in complexes nuraghs, may be explained with a domino-like effect commonly observed during seismic events.

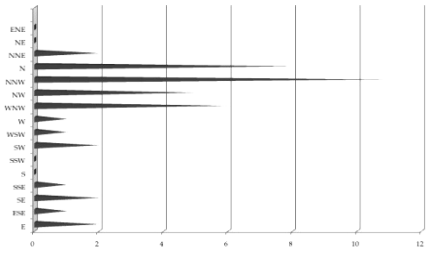

Figure 7: Cumulative diagram for oriented collapses observed in the nuraghs of investigated area

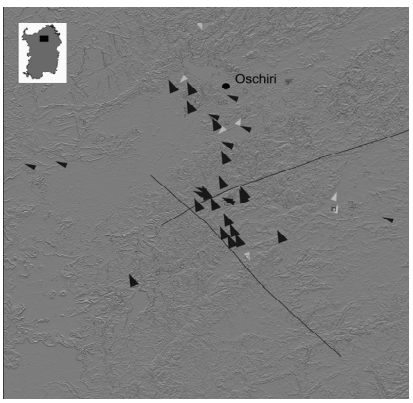

Figure 8: GIS analyses for oriented collapses in nuraghs of investigated area. Symbols are oriented according to measured collapses

Taking into account of geological context and assuming a homogeneous behavior of damaged nuraghs during the seismic stress, the possibility that the maximum frequency of observed collapses was linked to the seismic activity, cannot be excluded. As mentioned in the geological section, along the Logudoro basin occur the recentmost volcanic activity of the Sardinia. On the other hand, on the basis of historical seismic events in the seismic risk map historical seismic events in the seismic risk map of Italy, the Sardinia show a low values in the northern part of the island. Historical seismic events refer to the 1870 until spring 2008. Remarkably, seismic event of 1870 has a focus in the Ittireddu village locate in turn in the up mentioned recentmost volcanic products.

4. CONCLUSIONS

In summary, megalithic monuments as rock cut tombs and towerlike tholos structures (nuraghs), show evidences of structural damages which can be linked to palaeosismicity activity. Several lines of evidences agree with the proposed interpretation as well as the occurrence of recentmost volcanic focus of Plio-Pleistocene anorogenic cycle of Sardinia for which K/Ar and Ar/Ar radiometric ages suggest values reaching 0.5 Ka (Sias et al., 2002). On the other hand, the occurrence of seismic focus (e. g. Ittireddu 1870) in the up mentioned recentmost volcanic. Moreover, the whole data suggest to consider observed damages in the studied monuments as linked to seismic events. As expected, an high number of investigated megalithic monuments was necessary to obtain a realistic answer of the proposed method (100 sites over 500 Km^2). The maximum of frequency around NNW and N however is difficult to explain in the lack of an engineering seismological model. Published papers commonly refer the parallel collapse orientation of architectonic vertical elements, e. g. Selinunte colonnade (Guidoboni et al., 2001). A key aspect is the sinchroneity of the seismic event throughout a large area due to the areal effects of a strong earthquake.

Assuming a similar coseismic behaviour for nuragic towers, in which the statics is dominated by vertical (gravitational) component, we cannot exclude a single seismic event to explain the relatively high percentage of collapse orientation around NNW and N.

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