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MONITORING OF THE CRACKS AFFECTING THE "MADARA HORSEMAN" ROCK BAS-RELIEF, NORTH-EAST BULGARIA

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ABSTRACT. The "Madara Horseman" rock bas-relief (VIII c. AD) is carved in the Madara Plateau scarp and is protected by the World Heritage List of UNESCO. Rock destructive processes have threatened the monument by the disintegration of the Madara Plateau edge and cracking and erosion of the rock face where the bas-relief is situated. Three cracks cut through the monument forming two rock prisms. One of them forms a thin rock "flake" that endangers the front part of the bas-relief. These cracks allow water percolation, front effects and deeper disintegration behind the rock face. Three 3D extensometers TM71 and five benchmarks for monitoring rock deformations were installed. The obtained data show some trends of movements and a relation between the dynamics of displacements and some factors such as temperature, stress condition and seismic events that have happened during the period of observation (1990-2007). The necessity of a longer period of permanent monitoring of the main cracks, dangerous for the stability of the monument, is emphasized.

Introduction

The "Madara Horseman" is a historical bas-relief carved on the NW rock scarp of the Madara Plateau. It is situated about 10 km to the East of the town of Shumen, NE Bulgaria. The bas-relief was created in the VIII c. AC during the time of the First Bulgarian Kingdom. The rock composition represents a scene of a horseman, who is said to be the Bulgarian Khan Tervel (701-717) on his horse, piercing a lion with a spear and followed by a dog (Fig. 1). The monument is cut to a rock scarp at a height of 23 m above the basic terrain and together with the cut inscriptions is 7.2 m wide, and 6.5 m high. The Madara Horseman monument is included in the World Heritage List of UNESCO.

Several characteristic rock blocks in the form of rock slices of different profiles have developed at the NW periphery of the Madara Plateau. The present state is a result of different conditions and factors like geology, lithology, fissuring, physical and deformational parameters, tectonic activity, seismicity, erosion, climatic conditions, and human activity. The stability of the block with the bas-relief presents a major problem. To solve it, there is a call for researching into the failure mechanism of the wall as well as of the block behind it, and of interrelations between rock blocks from the edge of the plateau above the monument.

Fig. 1. The "Madara Horseman" bas-relief

Relief and geological setting

The Northwestern part of the Madara plateau is characterized by 80-120 m vertical scarp, with 1 km strip of slope deposits (deluvium) dipping from 10 to 20° (Fig. 2). The morphology of the slope is determined by a two layer model of its structure (Fig. 3). The rock massif consists of two complexes (Venkov, Kossev, 1974; Frangov et al., 1992; Anguelov et al., 1993): the upper one comprises limy-sandy sediments of the Upper Cretaceous – Cenomanian Age; the lower one is marly of the Lower Cretaceous – Hauterivian Age (Tzankov, 1943) (Fig. 3). There are no sharp lithological boundaries between the individual units. Yet, it can be recognized that individual layers are characteristic of either high or low carbonate contents, which will result in variation of physical-mechanical rock properties. This variation is highly reflected in all strength properties of this rock (Frangov et al., 1992). A borehole carried out in 1990, and located into the bas-relief profile of the plateau, found 137.50 m of the Cenomanian rock complex showing several lithological grades. Originally, it had been described as characteristic of a lower one – conglomeratic, and an upper one – fine-grained, which is generally in accord with the drilling investigations (Frangov et al., 1992). The bas-relief has been carved out of yellowish limy sandstones, spanning in height between 17 and 100 m (Fig. 3).

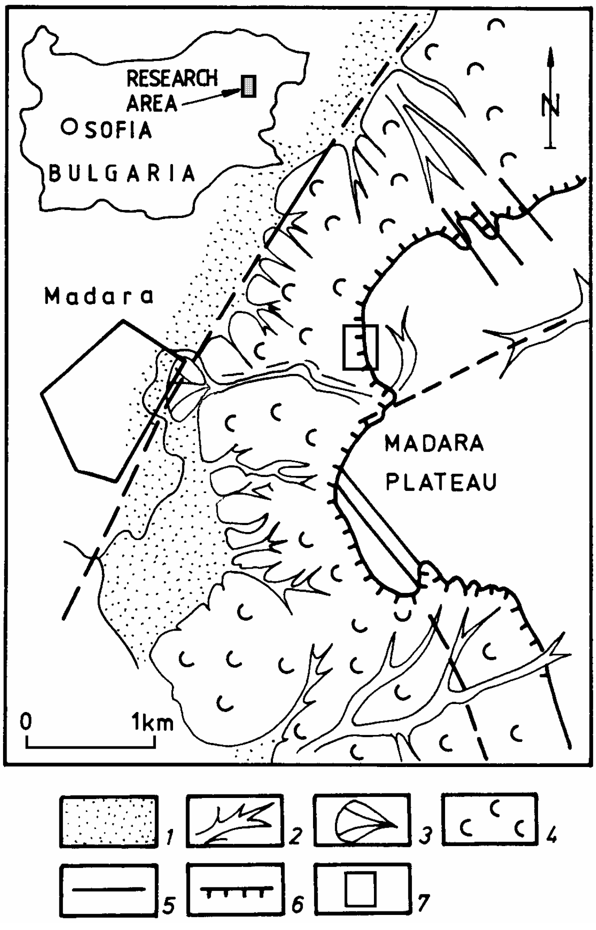

Fig. 2. Geomorphological map of the NW part of the Madara Plateau (modified after Angelova, 1995): 1 – Alluvial deposits; 2 – Gully or ravine; 3 – Alluvial fan; 4 – Creeping and sliding deposits; 5 – Fault (the supposed fault is with a dashed line); 6 – Plateau edge; 7 – the Madara Horseman locality

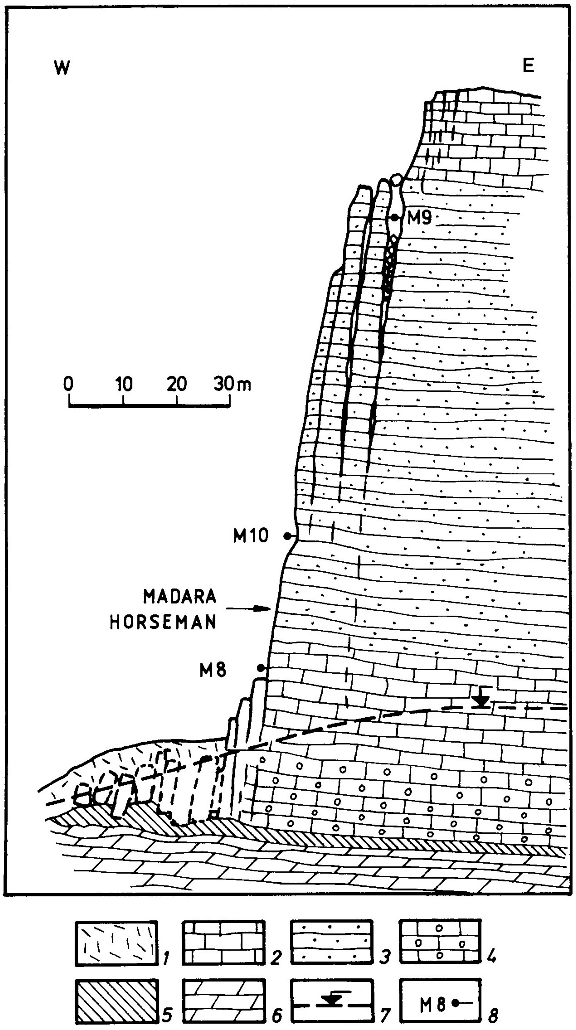

Fig. 3. Engineeried-geological profile of the Madara Plateau (modified after Frangov et al., 1992): 1 – slope deposits; 2 – whitish sandy limestone; 3 – yellowish calcareous sandstone; 4 – conglomerated limestone; 5 – yellow montmorillonite clay; 6 – grey marl; 7 – groundwater table; 8 – extensometer for 3D monitoring

A second lower complex is marly, and consists of grey-bluish layered marlstones, creeping if heavily loaded. Between the Hauterivian and the Cenomanian complexes a layer of yellow plastic montmorillonite clay has been discovered. The thickness of this particular layer varies between 0.4 and 6.5 m (average 1.5 m). The underground water table was found at depth of 110 m from the plateau surface.

The rock wall is almost vertically built by limy-sandy complex. Down the slope, the deposits (deluvium) are affected by creep. Traces of relic and recent landslides are visible.

Geological hazards

Different types of destructive geological processes have threatened the rock monument. There are 7 cracks cutting the rock face that bears the bas-relief (Fig. 4), and 3 of them are dangerous. The cracks allow water percolation, front effects, and deeper rock disintegration behind the rock wall. The earthquake impact can accelerate the process of disintegration of the rock, including opening the cracks, rock-falling and rock-toppling.

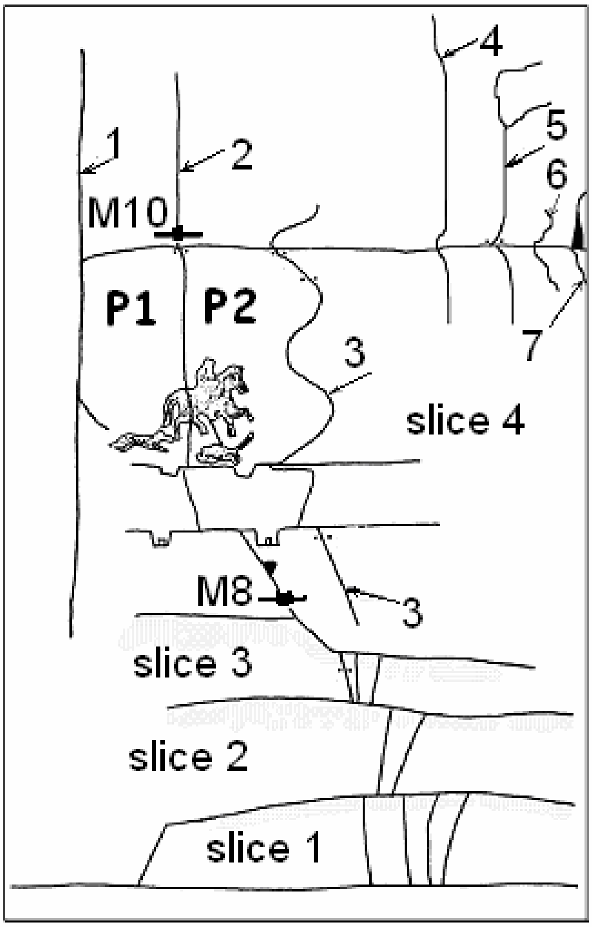

Fig. 4. The main cracks (1-7), slices (1-4), rock prisms (P1 and P2), and monitoring sites (M8 and M10) at the rock monument

Seismicity

According to the seismotectonic prognostication of NE Bulgaria, the Madara Plateau and its wider region has the characteristic of a high potential seismicity where earthquakes with magnitudes of more than 5 could be generated (Kostadinov et al., 1992). The nearest focal zone that could influence the rock monument is the Provadia area, located at 25 km SE of Madara. During the last decades several earthquakes with magnitude up to 4.0 were registered there. At the same time, the region was under seismic effect coming from outside.

This may be exemplified by Vrancea earthquakes in Romania – May 30 and 31, 1990, M=6.8 and 5.7, respectively, and the Izmit earthquake in Turkey – August 17, 1999, M=7.4.

Other potential epicentre areas are the Shabla-Kaliakra (110 km ENE of Madara) and the Gorna Oryahovitza-Strazhitza (75-100 km W of Madara) (Shebalin et al., 1974; Solakov, Simeonova, 1993). The last strong earthquakes after 1900, that came from outside of the investigated area, are those of Shabla 1901, M=7.2; Gorna Oryahovitza 1913, M=7.0; Vrancea 1940, M=7.3; Shabla 1956, M=5.5; Vrancea 1977, M=7.2; Strazhitza 1986, M=5.7 (Shebalin et al., 1974; Ranguelov, Ivanov, 1994).

Local earthquakes occurring during the observation period can be localized as several active tectonic faults, e.g. the Novi Pazar and the Sub-Balkan Faults. Local earthquakes are in majority here. Having experienced disruptive effects to Madara Plateau rock walls due to Vrancea and Izmit earthquakes (May 1990 and August 1999), we can try to make an assessment of the possible effects due to other earthquakes, coming from other nearby epicentres. One can see that the seismicity is a factor that should be always involved into consideration when studying rock slope stability.

Cracking

The cracks have a different origin. The large cracks are developed as a result of gravitational extension of the rock massif. These fissures are parallel to the plateau scarp and separate rock slices form the edge (Fig. 3). The rock slices are 1-3 m wide and more than 80 m high. The slices are instable – they subside into the plastic lower layer and topple due to large oscillation of the upper parts.

Transverse cracks cut the rock slices (see Fig. 4, cracks 1 and 2). They are a result from internal stresses into the rock slices during the subsiding or strike slip movements. A third kind of cracks forms thin rock shapes – “flakes” (see Fig. 4, crack 3). They affect the central parts of the rock slices. They are a result from the tensile stresses due to bending under a heavy load of the rock slice.

The main cracks located at the rock face form two rock prisms (Fig. 3) known as prism N1 (P1) between the cracks 1 and 2, and prism N2 (P2) between the cracks 2 and 3 (Venkov, Kossev, 1974). For our study, the behavior of prism P2 is the most important. This prism is more unstable than P1 because it forms a “rock flake” carrying the front part of the bas-relief.

Monitoring results and interpretation

The monitoring system was created in the period 1990-1993 with use of three 3D extensometers TM71 called M8, M9 and M10 (Kostak, 1991; 1993) and five benchmarks for caliper measuring. Two extensometers follow the movements along crack no. 2 and the third one is installed within the fissure below the plateau edge (Kostak et al., 1998). The accuracy of a TM-71 extensometer is 0.01 mm and the same one of the measurement of benchmarks, carried out by Mututoyo caliper, is 0.05 mm. The obtained information from the regular measurements permits to compose an adequate model of the dynamics of the rock blocks at the peripheral zone of the Madara Plateau and a prognostication of expected deformations and movements to be made (Dobrev, Avramova-Tacheva, 1997).

Movements at the plateau edge

The movements observed at the plateau edge passed through four stages (Fig. 5). The first stage starts from April 1990 (the beginning of the monitoring) till May 1994. This period is characterized by a stable trend of subsidence of the rock slice (axis Z) into the plastic lower layer with 0.91 mm/y. The second stage (1994-1999) is unclear due to 2 years disruption of the monitoring.

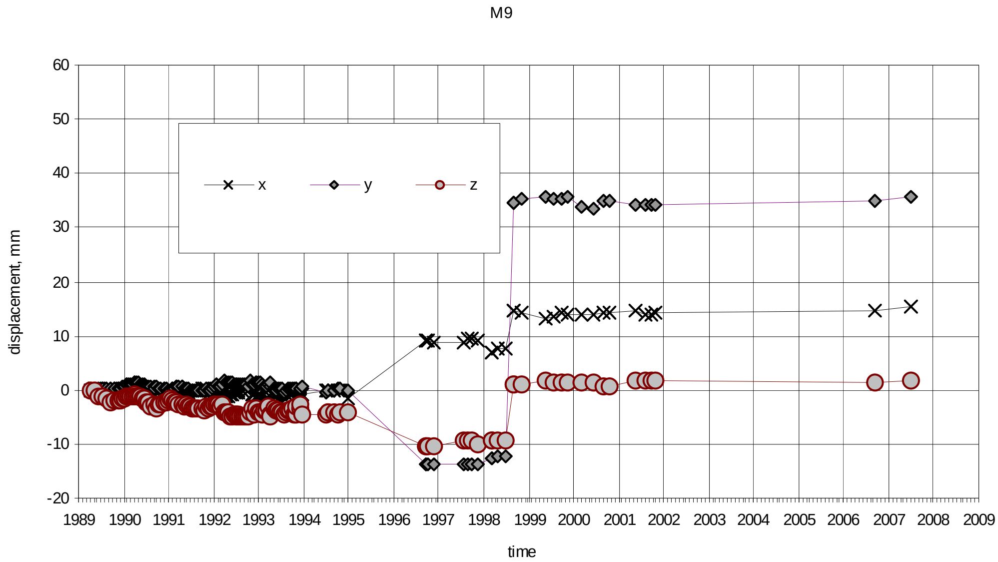

Fig. 5. Diagram of displacements established at monitoring point M9 for the period 1990-2008: +X – compression of the crack; +Y – the rock slice to SSE; +Z – uprising of the rock slice

Probably, a sharp displacement of unknown origin occurred in 1996-1997. At the end of June 1999, the fissure was shortened approximately by 7.6 mm, slipped to NNW by 12.2 mm, and subsidence of the rock slice with 9.5 mm at the spot of M9 (Fig. 3).

The third stage is the period during the Izmit earthquake, 17 August 1999. During the seismic event the rock slice was shaking according to some local evidence. Unstable rock pieces were toppled from the plateau edge. The monitoring point M9 recorded sharp displacements as the following:

ΔX = +6.91 mm compression of the monitored fissure;

ΔY = +46.78 mm horizontal slip of the rock slice to SSE;

ΔZ = +10.43 mm vertical movement (uprising) of the rock slice.

The fourth stage includes the period after the Izmit earthquake and continues till present. The movements have strongly decreased. Just before the Izmit eartquake some preventive works were impemented at the plateau edge. They included the creation of a concrete cover over the main fissure. The aim was to prevent deep water percolation after rainfalls. Unfortnately, the monitoring was disrupted from 2002 to 2007. Despite that the final results show very low values of displacements.

After 4 years of disruption of the observation, we can compare only the values before and after that disruption. At axis X the results show slight shortening of the fissure with 0.9 mm for the period from November 2002 to June 2008. The strike slip movements (axis Y) reveal sliding of the rock slice to the South with 1.4 mm for the same period. The vertical position of the rock slice (axis Z) shows almost stable state. These results can be interpreted as a process of formation of a new rock slice behind the plateau edge and a possible tectonic movement as well.

Movements at the bas-relief

The monitoring of cracks N2 and N3 aims: 1 – to establish the rate and the tendency of the movements along the monitored cracks; 2 – to take the best engineering decision for monument protection, including sites of anchors, etc.

The observation of crack N2 is performed by 2 gauges: M8 (below the monument) and M10 (above the monument). Till now the results show only light shortening of crack N2. There is no impact established by the local and regional earthquakes.

The results established at point M8 are highly influenced by the seasonal temperature influence (Fig. 6). The amplitude at axis X exceeds 1 mm, and it is approximately 0.5 mm at axis Y. Despite the high temperature impact, we observe slow tendency of compression of the crack N2 (axis X). The state at June 2008 shows 0.96 mm shortening of the crack from the start of the monitoring (April 1990). The axis Y shows a negligible trend of movement of the rock prism outwards. The axis Z shows a slow trend of subsiding of the rock prism summary - 1 mm for the last 18 years.

The movements at point M10 are strongly influenced by the daily and seasonal temperature fluctuations (Fig. 7). The yearly amplitude along axis X can exceed 2 mm. Despite of the large values of fluctuations we can assess that the movements along axis X express slight compression of the crack N2. At axis Y, the monitoring shows a movement of the rock prism outside the massif by 1.37 mm. The amplitude fluctuations are also with large values – approximately 1 mm. Despite that the positions of the values of axis Y were at the positive part of the diagram till year 2002. The movements along axis Z show a sharp subsidence by 2.7 mm within the period from September 2007 to June 2008.

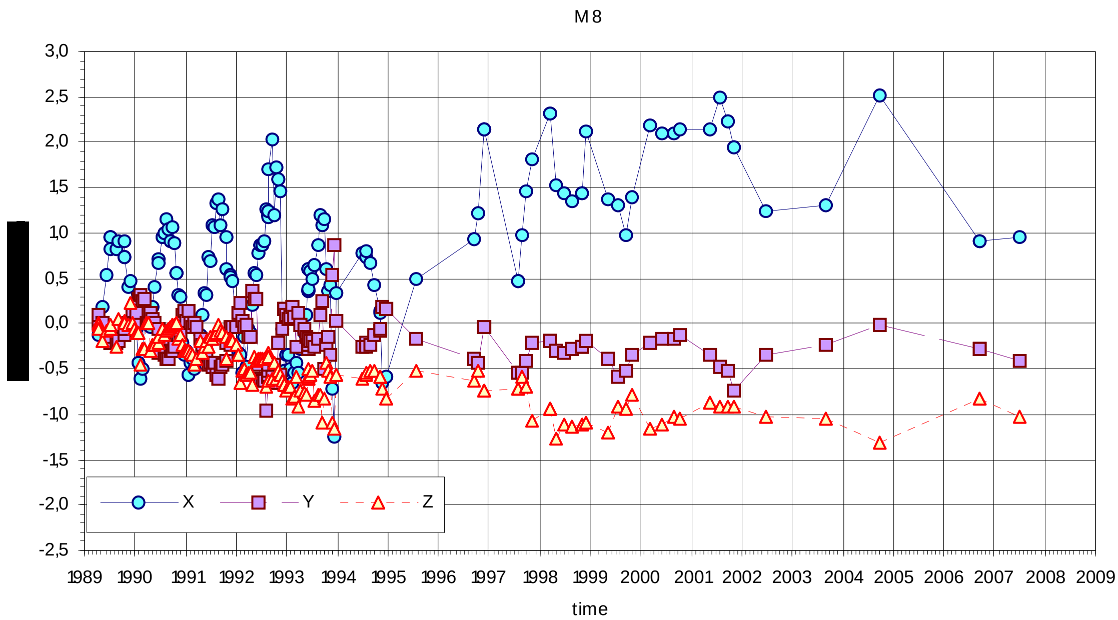

Fig. 6. Diagram of displacements established at monitoring point M8 for the period 1990-2008: +X – compression of the crack; +Y – moving of the rock prism P2 inside the massif; +Z – uprising of the rock prism

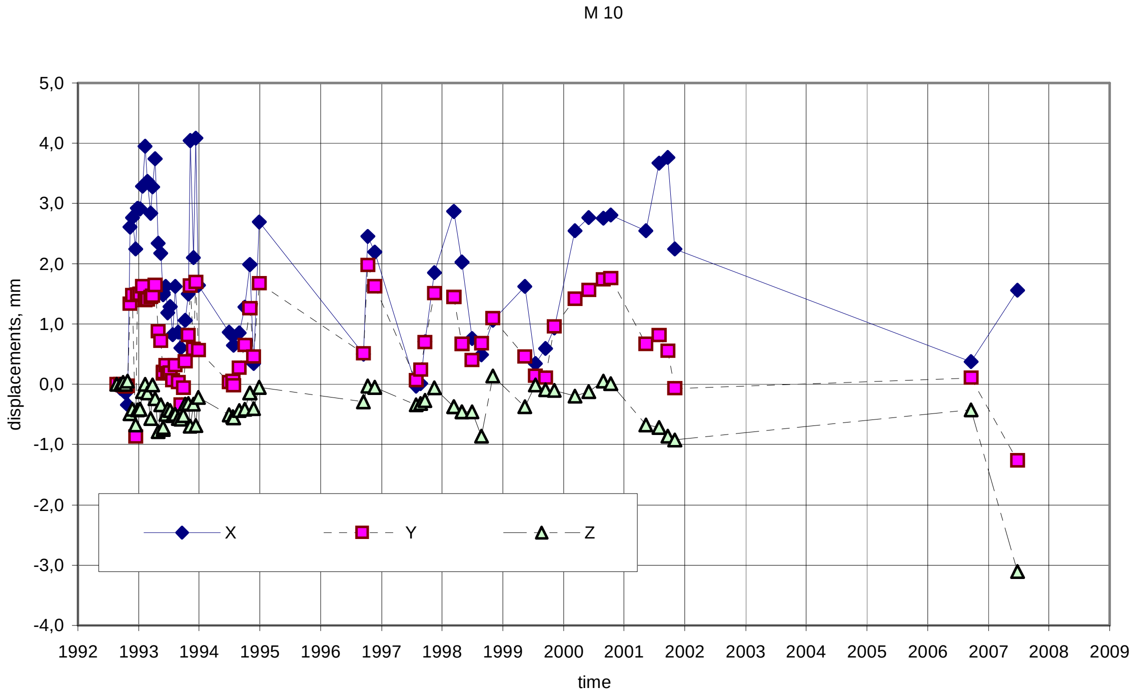

Fig. 7. Diagram of displacements established at monitoring point M10 for the period 1993-2008: +X – extension of the crack; +Y – moving of the rock prism P2 inside the massif; +Z – uprising of the rock prism

The behavior of crack N3 is observed by caliper measurements of 2 benchmarks. The monitoring began in 1993 but it was disrupted two times (in 1995-1997 and in 2002-2007). So far large displacements were recorded that can be explained by huge temperature fluctuation. Slow relation between movements along cracks N2 and N3 was found meaning compression of crack N2 correlates with opening of crack N3, and on the contrary.

Discussion

There is no doubt that the rock monument was carved into a good rock face without any cracks. During the last twelve centuries, the geological processes have deteriorated slowly and ruthlessly the condition of the rock wall by cracks, erosion, and, probably, earthquake tremors. The monitoring that is carried out from 1990 onwards shows few conclusions that can be outlined as follows:

▪ The movements found at the periphery of the plateau have higher velocities. They are very sensitive to local and regional earthquake impacts that can produce falling and toppling of large blocks at the footwall of the plateau. However, there is no evidence for direct impact of seismic events on the crack deformations at the monument.
▪ The movements along the cracks at the rock face are a result of stress conditions into the rock slices. Their velocities are very low, with high influence of seasonal and daily temperature fluctuations. Due to this reason these velocities are difficult to establish. So far, we detect only a slow subsidence of P2 by 0.07 mm/y.
▪ The compression of the crack N2 is in relation to the opening of crack N3. This behavior is strongly connected to the temperature fluctuations of the rock massif.
▪ The creation of preventive works requires a longer period and a permanent monitoring of the main cracks. Only then, the most appropriate countermeasure could be chosen. Probably, it will be this part of P2 that is less influenced by the various movements. This could avoid the risk of appearance of additional stress fields into the rock flake, which could worsen the stability of the monument.

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