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# ACTIVE TECTONIC STRUCTURES IN THE W PART OF SLOVENIA – SETTING OF MICRO-DEFORMATION MONITORING NET

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**ABSTRACT**
Basic information is given about the installation of monitoring instrumentation in W part of Slovenia where measurements started at the beginning of 2004. The measurement is carried out with the use of a verified, very stable and sensitive deformeter TM71. Four instruments were installed either directly in or in the close vicinity of major Dinaric faults in karst cave or on the surface. The place for the fifth instrument is selected on the Kneža fault, south of the Ravne fault, where the measurements will start in 2005. Introductory monitoring shows displacements within 0,04 mm. Both devices in Postojna cave system recorded the same reaction on the July 12, 2004 earthquake. These were movements changing the trend in strike slip (y-axis) with magnitude around 0,03 mm and angular deviation in horizontal plane xy within 0,02 □/200 that occurred before or during the earthquake.

**KEYWORDS:** tectonic movements, monitoring, Dinaric fault system, Slovenia

## 1. INTRODUCTION

A survey of principal active faults in W part of Slovenia adopted movement monitoring between separate fault walls on some specific structural outcrops. This research was initiated within COST 625 European project "3D monitoring of active tectonic structures" and organized in close co-operation between Slovenian and Czech partners.

The regions under investigation are Postojna cave system, Idrija fault, Raša fault and Ravne fault. The research is directed to improve our knowledge of the movement reactions that accompany present tectonic development on the fault structures. Field investigations were carried out to find suitable points representative for tectonic development and, at the same time, acceptable technically for the adjustment of the field monitoring equipment. Two instruments TM71 were installed at the beginning of 2004 and other two instruments in November 2004. Then regular data readings of the instruments were organized.

## 2. METHODOLOGY OF MONITORING

It is evident that a long-term underground measurement in caves calls for special equipment, stable in hard outdoor conditions. Besides, to detect low order movements with an acceptable accuracy is essential. Crack gauge TM71 produced by GESTRA, Sedloňov, represents a device, tested under field conditions to suit such special demands (Košťák 1991). It works on a mechanical optical principle (moiré), results being independent of any electrical transmission. Due to that, and due to very stable indicator elements made of glass and chromium, and due to anticorrosive materials of the indicator body, the equipment is extremely stable in nature, and can survive years of hard outdoor and aggressive conditions with almost no maintenance except some cleaning. The instrumentation is produced also to survive current seismic events and to show resulting permanent deformations. It counts to indicate spatial displacements in three co-ordinates between two walls or discontinuity faces.

The deformeter is usually mounted on steel holders anchored to the two opposite rock faces of a joint, up to about 2 m apart (see Figs. 1 and 2). This was the case in the caves. It represents a combined moiré indicator equipped with 20 to 70 m lines/mm circular grids for indication of displacements and 100 lines/mm linear grids to indicate angular deviations in two planes. Thus, under conditions of minimum interference of exogene processes, the gauge can demonstrate relative spatial movements between two adjacent crack faces as low as 0.01 mm/year and relative angular deviations of up to 0.00032 rad. It was tested for block type slope movement detection, as well as for complex measurements on geological structures. The gauge bears Czechoslovak Patents Nos 131631 and 246454.

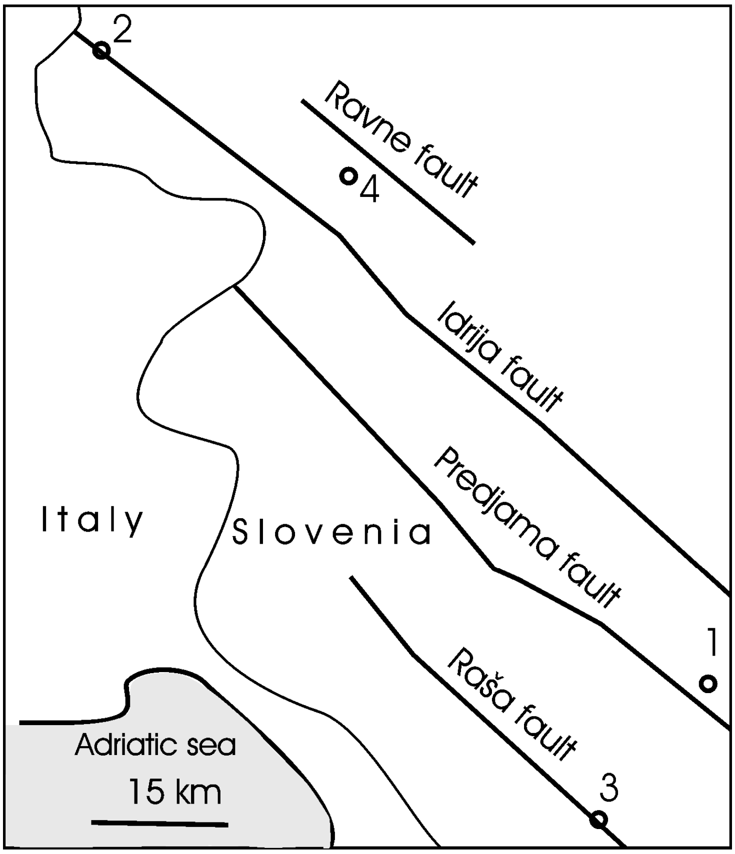


**Fig. 4** Important faults in W Slovenia and TM71 sites. 1-Postojna cave system, 2-Idrija fault, Učja location, 3-Raša Fault, Vremščica Mountain, 4-Kneža fault, Zadlaz, Čadrg. Based on digital cartography Perko & Orožen Adamič (1995)

Underground installations are preferential because climatically conditioned processes (temperature, precipitation, etc.) are limited, and, at the same time, even superficial deformations, like slope deformations etc. are of limited influence. A similar type of monitoring in cave structures is organized in the Czech Republic, along Sudetic border fault (Na Pomezí Cave or Na Špičáku Cave) from 2001 (Stemberk & Štěpančíková 2003).

## 3. TECTONIC SETTING OF SELECTED INSTALLED SITES

Slovenia lies at the NE boundary of the Adratic microplate. Its northern tectonic units (Southern Alps, Internal and External Dinarides) are highly deformed and backthrusted to the south onto undeformed segment of the Adriatic plate called Adriatic tectonic unit. Collision of European and African (Adriatic) plates results in predominantly N-S oriented recent principal stress direction in the region of Slovenia. This causes a system of conjugate strike slip faults. In Western Slovenia a right-lateral NW-SE oriented strike strip faults and in Eastern Slovenia a left lateral NE-SW oriented strike slip faults (Buser & Draksler 1993) prevail. In addition there are several W-E oriented reverse faults and north vergent trusts.

The External Dinarides occupy the SW part of Slovenia. Its basic structural characteristic is a dense pattern of faults in NW-SE (Dinaric) direction and a series of thrusts with SW direction of thrusting. The most important Dinaric faults, listed from SW to NE are: Palmanova, Divača, Raša, Predjama, Idrija and Žužemberk faults (Placer 1981). External Dinarides are characterized by moderate historic and recent seismicity (Fig. 3). Relocations of the hypocentres in the last ten years have delineated their alignments along the Raša and Idrija faults (Michelini et al. 1998). Fault plane solutions of the majority of these events indicate right lateral strike slip mechanism. In 1511 the earthquake with magnitude 6,9-7,2 and intensity 10 shook the W part of Slovenia. The researches show that the possible seismic activity was along Idrija, Raša or Ravne fault lines. The strongest earthquake in recent 100 years with a magnitude 5,8 occurred in 1916 to the SE of Rijeka (Poljak et al. 2000). The last strongest earthquake in Slovenia occurred on 12th April 1998 in upper Soča valley in NW Slovenia. The earthquake had the magnitude Ms = 5,7 and hypocenter at 7,5 km. Aftershocks are suggesting the seismic activity of NW-SE oriented Ravne fault (see Fig. 4) with horizontal dextral movement.

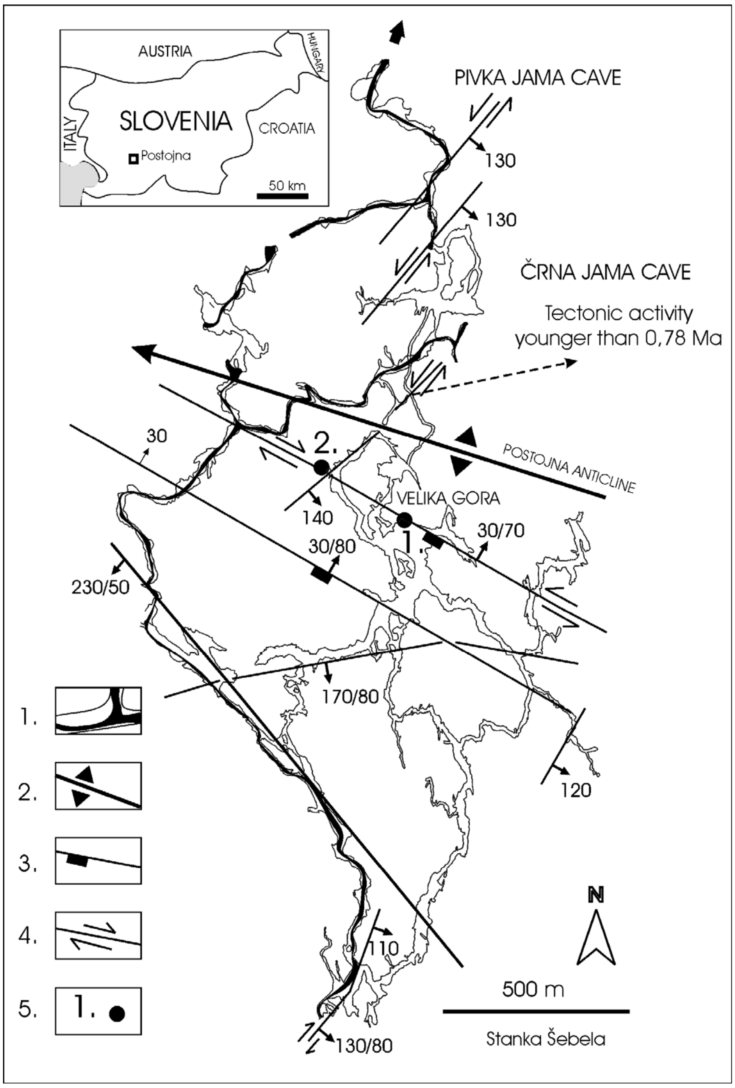


**Fig. 5** General structural geology of Postojna cave system (after Šebela 1998) with TM71 sites.
1-underground water flow, 2-anticline, 3-fault with vertical movement, 4-fault with horizontal movement, 5-TM71 sites, 1=Postojna 1, 2=Postojna 2

### *3.1. POSTOJNA CAVE SYSTEM*

The area of Postojna cave system (SW Slovenia) is a part of Outer Dinarides, which belonged to Adriatic - Dinaric platform. Due to the Adriatic plate movements towards N (where it collided with the Eurasian plate) the Eastern Alps come into existence and the Northern Limestone Alps were overthrusted from the S to the N. Due to rotation of Adriatic plate in anticlockwise direction it collided with the Eurasian plate and caused the uplifting and thus giving rise to the Western Alps. In the late Cretaceous the Slovene Littoral was influenced by a Laramide folding. After the regression in the Paleocene, the transgression and deposition of flysch started. At the end of Eocene the Illyrian uplift and general sea regression followed. When in the Pyrenean phase the Eocene flysch was deposited the rocks were folded in NW-SE direction. Later the folds were deformed by thrusts, normal or longitudinal faults. Due to the pressure of the Adriatic plate movement towards N a regional tension field with the highest pressure state in the axis N-S and tension strain E-W occurred.

Postojna cave system is with its 20.000 m the longest known cave in Slovenia. From impermeable flysch of Pivka basin the river Pivka sinks at 511 m to the cave and comes out as a spring of Unica River in Planina cave. The main drainage of Pivka belongs to Black Sea watershed, but bifurcation of Pivka (Habič 1989) proved that Pivka also belongs to Adriatic Sea watershed.

Postojna cave system is developed in 2 principal levels. Higher level starts at the altitude of 529 m and represents actual dry passages which are filled with cave sediments, flowstone and collapse blocks. Lower level represents actual underground channels of the river Pivka, which are situated more to SW or NW regarding higher levels. Both levels are connected with side passages.

The passages of Postojna cave system are developed in Upper Cretaceous limestones (Cenomanian, Turonian and Senonian) mostly bedded limestones. Cenomanian and Turonian limestones are more thin bedded and can include chert lenses or layers. Senonian limestones are thick bedded to massive. Cave passages are developed through about 800 m thick lithological column (Šebela 1998).

Postojna cave system is situated between 2 regionally important faults, Idrija fault on the north and Predjama fault on the south. Tectonic structure of the area between those two faults has all the characteristics of inner zone between two dextral strike-slip faults. In the Postojna cave system we distinguish older overthrusting and folding deformations and younger faulting deformations. Overthrusting took place after the deposition of Eocene flysch. During the Miocene and Pliocene, the overthrusting was accompanied by folding. Principal folding deformation in Postojna cave system is Postojna anticline (Fig. 5). The cave passages are developed in both flanks of anticline. Cave passages follow strike and dip of the bedding-planes, especially those with interbedded slips. Passages of the underground river Pivka between Otok cave and Pivka cave follow the dip of bedding-planes and cross-dinaric (NE-SW) oriented fault zone.

The biggest collapse chamber in the cave called Velika Gora shows that final breakdown occurred when the room wasn't exposed to river floods any more. The northern edge of Velika Gora collapse chamber is developed inside dinaric oriented (NW-SE) fault zone with vertical displacement for some meters (site Postojna 1). The reactivation of the tectonic zone through different time periods enlarged the collapse chamber to actual size. Occasional river floods helped to carry the collapse blocks away. The same fault zone from Velika Gora can be found in other parts of the cave. But in other parts it doesn't have the same tectonic characteristics. In Pisani Rov we can observe horizontal movements with $60^0$ of the dip angle for fault zone, in Lepe Jame the same fault zone has vertical and horizontal displacements (site Postojna 2) and is cut by relatively younger cross-dinaric fault zone, which is younger than 780 000 years (Sasowsky et al. 2003). On the same tectonic zone we observe different tectonic activities, sometimes even 4 different tectonic events.

One of the principal questions for speleologists and karstologists is how old is the karst cave they explore. And the next question for structural geologist would be "Are there still active tectonic deformations in the cave system that influence the cave formation?" In the Postojna cave we found many broken stalagmites. One of the causes for flowstone damage could be an earthquake. In this sense we selected two locations for TM71 installation. Two devices are installed on the same fault zone NW-SE direction (see Fig. 5). Postojna 1 represents the contact between fault plane and collapse block. The TM71 device Postojna 2 is installed between two fault planes, which are about half a meter apart. The observed fault is situated about 1 000 m north from the inner zone of Predjama fault. The eventual tectonic deformations detected by TM71 devices can give important information about recent tectonic activity in the wider zone between Idrija and Predjama faults.

### *3.2. IDRIJA FAULT*

The best morphologically expressed fault in the region is the Idrija fault, which is clearly visible in topography and in aerial or satellite images. It extends from the Italian border near Bovec to the Croatia in Gorski Kotar (N of Rijeka), having a total length of more than 120 km. The strongest historical earthquake in the region (the »Idrija« earthquake in 1511 with estimated magnitude of 6,8 and max. intensity 10) is usually related to this fault (Ribarič 1979), but its exact location and relation to the faults in the region is still not clear. The second strongest known event with magnitude 5.6 happened in 1926 at the SE end of the Idrija fault. However, recent seismicity in the vicinity of this fault is rather low (Poljak et al. 2000). In November 2004 we installed a TM71 crack gauge in the NW part of Idrija fault, where good exposures of the main fault zone were found in the Učja valley near Bovec.

### *3.3. RAŠA FAULT*

The second important fault located approximately 25 km SW from the Idrija fault is the Raša fault, which can be clearly traced in a length of 50 km from Anhovo (N of Nova Gorica) in the Soča valley to the Snežnik thrust at Ilirska Bistrica. Most impressive features related to this fault are: almost straight flow of the Raša River between Kobdilj and Štorje and its clear expression in topography around Vremščica Mountain. A cross-section of this fault is well exposed near Senožeče where the highway crosses the fault trace. Otherwise there are only few good exposures of the fault. The seismicity in the vicinity of the Raša fault is concentrated mainly in the Snežnik Mt. area (see Fig. 3) at its SE termination. Hypocenters of the earthquakes in this area define a steeply NE dipping fault plane (Michelini et al. 1998).

We explored the whole trace of the Raša fault to find a suitable location for installation of TM71 crack gauge. We recognized that in spite of its clear expression in the topography, there are very few good exposures. The best location was found at the foot of Vremščica Mountain, on its SE side, near Košana. There are two abandoned quarries in the Upper Cretaceous limestone situated exactly at the fault trace. There is a plan to put the upper quarry again in operation, but the lower one is abandoned for more than 15 years and will remain closed. Therefore, it provides a suitable place for crack gauge measurements. The contact between Upper Cretaceous limestone to the NE and Palaeocene Kozina limestone to the SE (Buser et al. 1967) is exposed in this quarry, separated by the main fault zone, which is approximately 10 m wide. Therefore, it was not possible to install the instrument in the main fault plane, but we selected a parallel crack in the exposed wall of the quarry built of Cretaceous limestone (Fig. 6). The measurements started in November 2004.

## 4. INTRODUCTORY MEASUREMENTS

Monitoring on TM71 locations in Slovenia started in February 2004 (site Postojna 1) and in May 2004 (site Postojna 2). First results show very small displacements along all three axes. It is important, that the temperature in the cave is very stable, around 10°C, therefore the temperature effect in data record can be excluded.

On 12th July 2004 the NW part of Slovenia was affected by moderate earthquake with epicenter close to Bovec and with magnitude M = 4,9. Data from both devices were recorded one day after the earthquake, on July 13. Preliminary results show the same character of changes (direction and magnitude) along the axis y on both devices. Before the earthquake, trend of displacement along axis y has corresponded to right lateral movement. Just before or during the earthquake the trend changed to left lateral with a step about 0,03 mm recorded on both devices (see Figs. 7 and 8).

## 5. CONCLUSIONS

Monitoring network has been established in W part of Slovenia along a possible seismoactive fault of Dinaric fault system. The first two devices were activated during February and May of 2004 in the Postojna cave system. Introductory monitoring shows displacements within 0,04 mm. Both devices recorded the same reaction on the July 12, 2004 earthquake. These were movements changing the trend in strike slip (y-axis) with magnitude around 0,03 mm and angular deviation in horizontal plane xy within 0,02 π/200 that occurred before or during the earthquake.

The location of TM71 Postojna 1 shows the same movement characteristic as Postojna 2. In fact this proves we are observing the same fault zone. The results obtained from TM71 device Postojna 1, which is located between the fault plane and collapse block show strike slip movement what excludes the activity of the collapse in Velika Gora of Postojna cave system. The registered displacements in the period of some months should be assigned to tectonic deformations.

Monitoring of displacements on Raša and Idrija faults started in November of 2004. The installation on the fifth instrument situated south of Ravne fault on the Kneža fault (Fig. 4) will be completed in 2005.

**ACKNOWLEDGEMENT**

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**Fig. 1** TM71 device installed across the fault in Postojna cave system (Postojna 1)

**Fig. 2** TM71 device installed across the fault in Postojna cave system (Postojna 2)

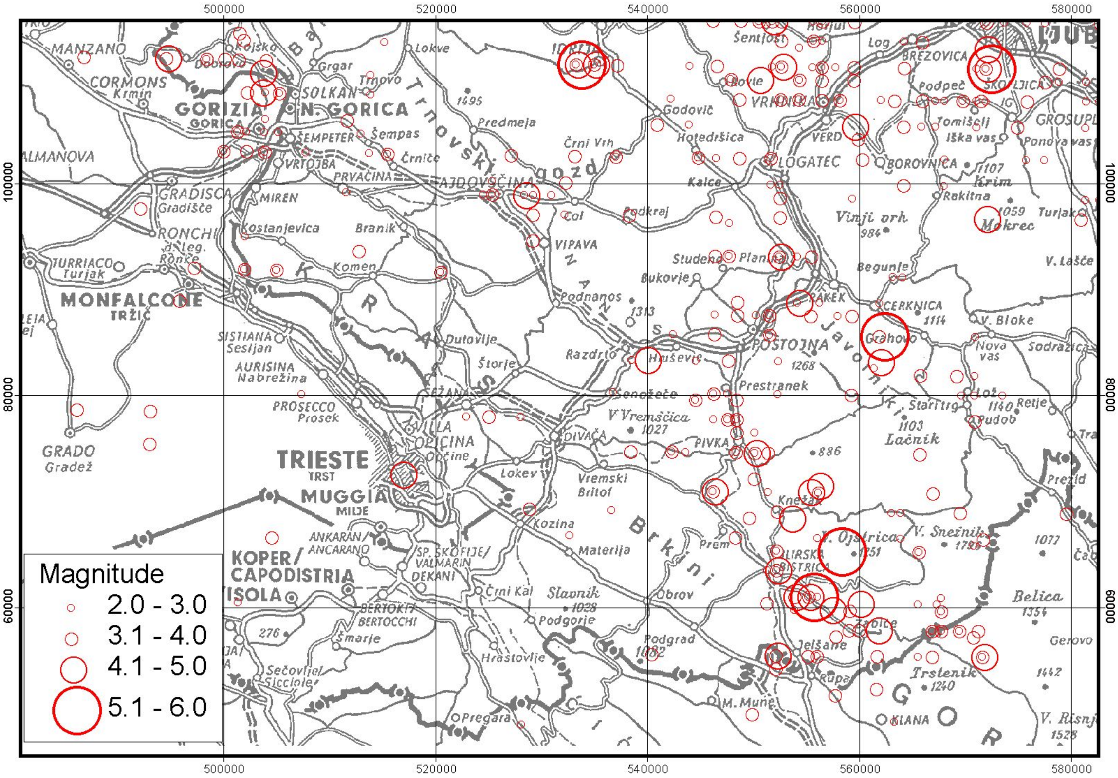



**Fig. 3** Seismicity map of SW Slovenia

**Fig. 6** Installation of TM71 crack gauge on the Raša fault in the quarry at the foot of Vremščica mountain

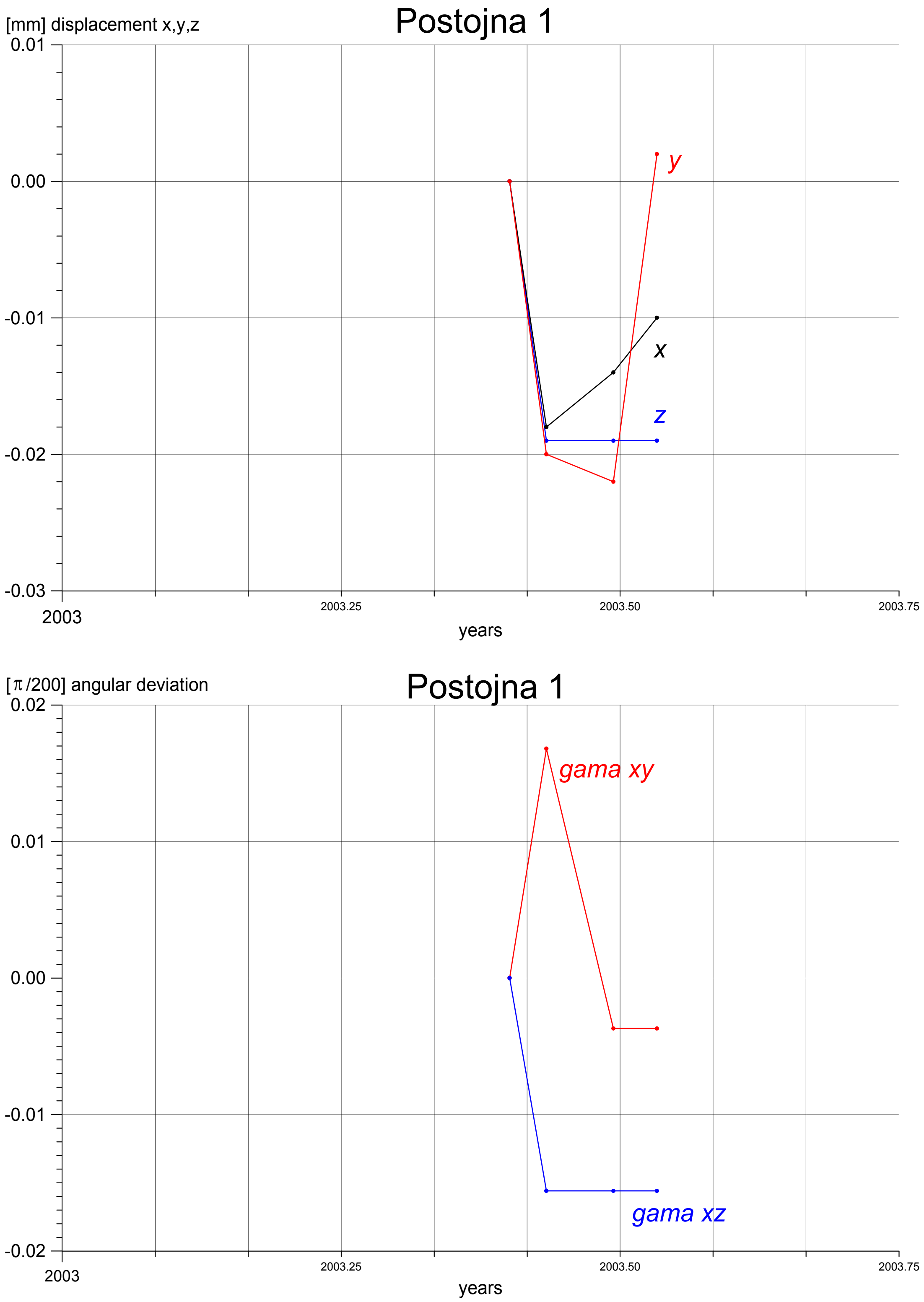
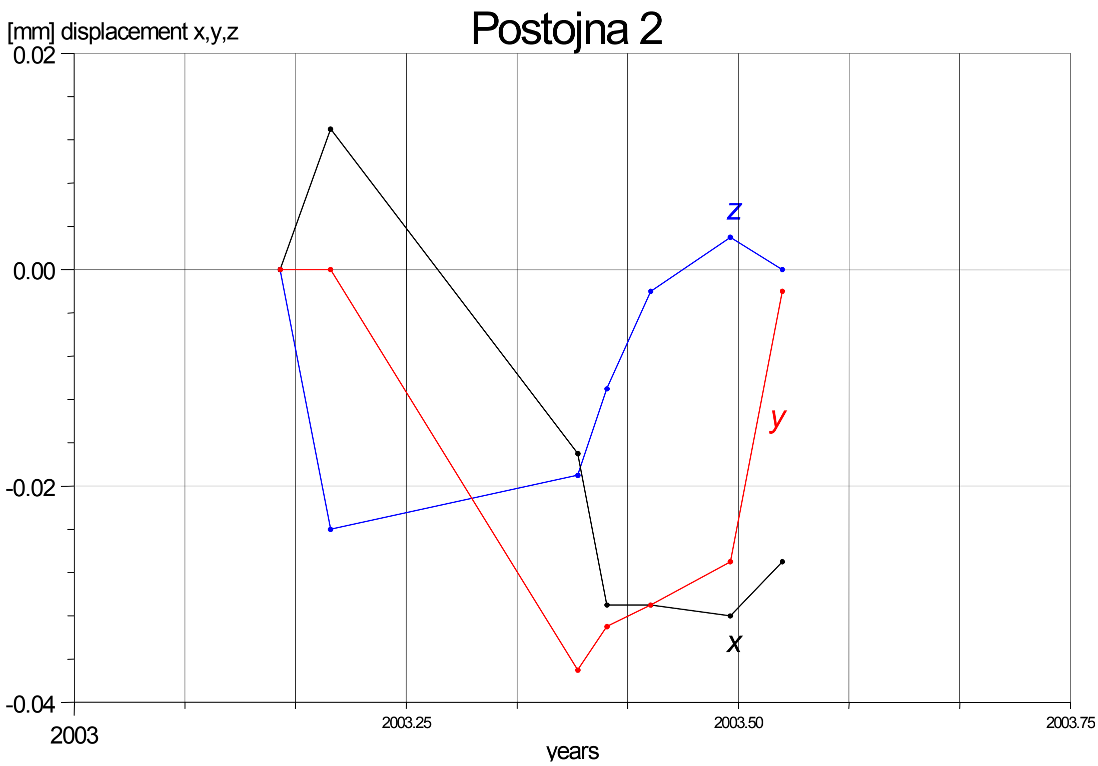



**Fig. 7** Displacements recorded at the monitoring site Postojna 1 in Velika Gora



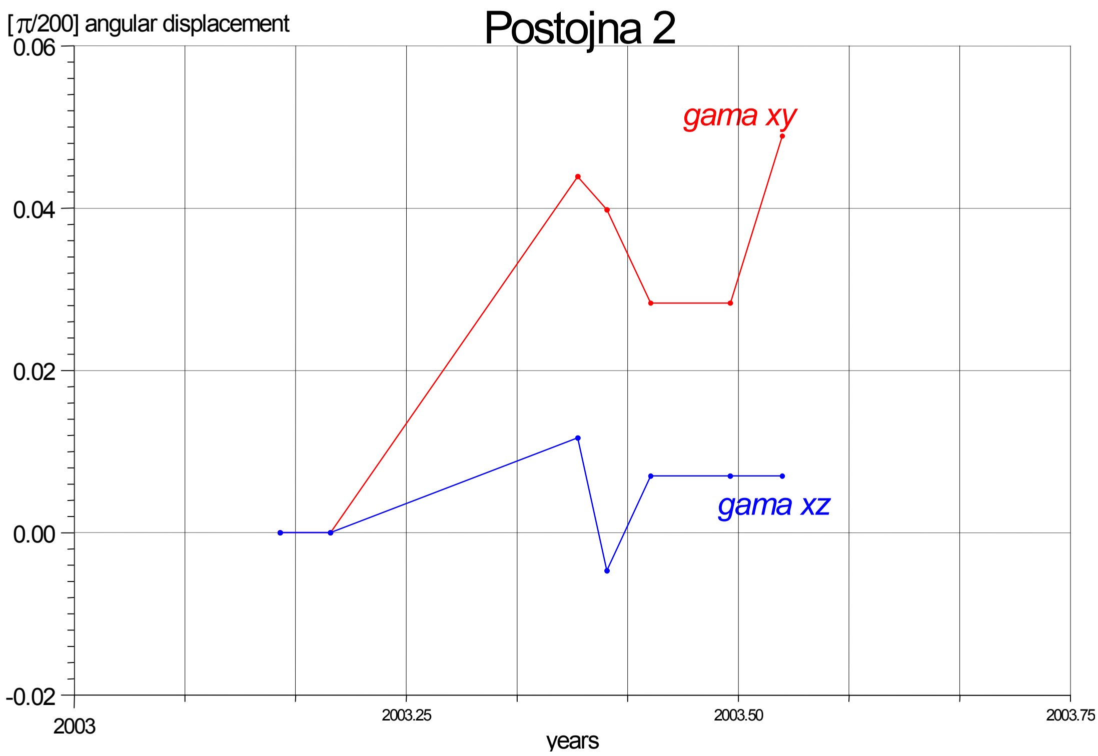




**Fig. 8** Displacements recorded at the monitoring site Postojna 2 in Lepe Jame