The geo-analyses of the horizontal movement tendencies in the Eastern Slovakia

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Abstract: Constraining the present day strain rate in Central Europe is crucial for reconstructing the tectonic evolution of this area. Accurate time series of (possibly) permanent GPS stations are required to infer the local velocity and the associated strain rate field. This requirement is especially recognized within the CERGOP project, where several Research Groups from Central Europe Institutions co-operate in GPS based research.

The contribution from the Institutes of Geodesy (FCE BUT and FCE SUT) results not only in supplying of the GPS Data but in Structural evaluation of these data, too. The Example of Complex analyses and interpretation of horizontal deviation tendencies measured through GPS campaigns *(Mojzeš and Papčo, 2004)* with the set of Geo-Data information from the Eastern part of the Western Carpathians (Eastern Slovakia) is presented.

This article demonstrates the possibilities of geophysical data in the process of verification and evaluation of horizontal movement tendencies, gathered during three GPS observation "campaigns", in the area of the West and the High Tatra Mountains *(Mojzeš and Papčo, 2004; Czarnecki et al., 2002).*

On example of Muráň – Malcov transcurrent tectonic system it is possible to find components explaining the different orientation of horizontal movement vectors at GANO GPS Station. The Results of analyses of Complex Geo-Data set offer detail and regional structural model explaining the micro-structural deformation in Gánovce block, located between the Kežmarok - Malcov, Vikartovce and Vrbov faults. This hypothetical kinematical and structural-tectonic model can be tested in next periods.

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1. Introduction

In the Central European region, GPS permanent network CERGOP (Central Europe Research Geodynamic Project) is available. The GPS measured geodynamic deformation respective motion tendency on the ground has been monitored.

The network gaps are supplied by regional campaigns that are focused on monitoring and motion tendency in kinematical and dynamic most active region of Bohemian Massif and Western Carpathians.

Even though the measured movement tendencies gained from GPS results reach in order millimeters to centimeters deformation per year, the permanent monitoring and followed detail analyses of the interdisciplinary geo-data in given region, processed on the base of GIS technologies, can be used for monitoring the neotectonic movements, changes and deformations on the Earth surface.

The aim of this contribution is to verify the results of regional measurements gained at stations of GPS network located in the High Tatras and the Levočské vrchy Mts. on the basis of complex analyses of wide set of geophysical and geological data and information.

Our analysis focuses on anomalous data on horizontal motion tendency at GANO (Gánovce village) reference point, which is located in the area separated by several regional and local tectonic systems. At most of the faults the strike slip character was found during Tertiary period.

The tectonic systems - Muráň – Malcov *(Pospíšil et al., 1989)* and Sub-Tatra *(Pospíšil et al., 1986)* finally known as Ružbachy *(Sperner et al., 2002)*, which belong to distinguished transcurrent systems in Western Carpathian area, are mostly dominated in the whole interested area.

Finally we have tried to compile a theoretical kinematic model of the area, on a basis on which we could explain the horizontal changes of GANO GPS point position in recent time period.

2. GPS data

GPS data, for analysis of horizontal movements in the area between High Tatras and Levočské vrchy Mts., were obtained from 5 observation regional campaigns, which were realized annually from year 1998 to 2002 *(Mojzeš and Papčo, 2004)*. These regional campaigns were performed within international project CERGOP. The main task of this project is international cooperation to the intent of geodynamic research in Central Europe. There was established a special network of permanent and epoch GPS sites for monitoring geodynamic deformations. The CEGRN network is created since year 1993 and up to this time it includes 80 points. In Slovak Republic are 3 permanent stations (Modra – Piesok – MOPI, Lomnický štít – LOMS, Rimavská Sobota – RISO) and 4 epoch stations (Partizánske – PART, Kamenica nad Cirochou – KAME, Skalnaté pleso – SKPL, Strážna hora – STHO). Point GANO is component of special GPS network for monitoring tectonic movements of the High Tatras.

All the GPS campaigns were processed with two different processing strategies. The first solution named STU-FIX uses only one fixed point ROHA with one set of fixed coordinates for each epoch. The second solution named STU-IGS uses IGS permanent stations with changing coordinates in time. The differences in variation of horizontal position are not significant between STU-FIX and STU-IGS solutions. In this analysis only STU-IGS solution was used, because it is fixed to reliable and stable stations of the EUREF Permanent Network.

All data from the performed GPS campaigns were processed in 2 steps. In the first step all GPS measurements were processed using the Bernesse Software 4.2 *(Beutler et al., 2000)*, where the default method of processing for epoch measurement was used. Input parameters, such as precise ephemeris's and information about the phase center of the GPS antennas were obtained from an International GNNS Service (`http://igscb.jpl.nasa.gov/`). The total troposphere effect was reduced using a-priori Saastamoinen model. For the supplement troposphere effect estimation a special mapping function ($1/\cos z$) was used. Every GPS campaign was processed as a free network for each day and each observation campaign.

In this strategy we used five permanent IGS stations: BOR1, GOPE, GRAZ, PENC, JOZE and the coordinates and velocities of permanent stations were derived from reference frame ITRF2000, epoch 1997.0 for each epoch. The analysis was performed with a specific mathematical model and realized using the WIGS and SONET program system. With the inconsistency of spatial coordinates X, Y, Z with the first year's solution we obtained the coordinate differences $\delta X, \delta Y, \delta Z$. The coordinate differences were consequently transformed to the local horizontal coordinate system. At last step velocities of interesting points were computed.

3. Tectonic and structural conditions

The tested area between the High Tatras and the Levočské vrchy Mts. gives complete information about the structure and the record of tectonic processes connected with the collision area between the Eurasian and the African plate. This deformation zone, which is part of collision system between Eurasian and African plate, is in the tested area represented by the peri-Klippen Belt zone and outer accretion prism represented by the outer flysch belt.

To observe and understand the function of tectonic systems and the movements connected with them, knowledge of structural, kinematic and geomorphologic characteristics connected with the main fault systems and dislocations in the studied area is required. There are 3 regional fault zones visible even from satellite images of the area. Two of them the Myjava – Sub-Tatra boundary (Ružbachy fault – after *Sperner et al., 2002* - MPTS) and the Muráň – Malcov tectonic system (*Pospíšil et al., 1989* - MMTS) have ENE – WSW or NE - JZ direction, respectively. The third North-Tatras lineament (boundaries) which is reaching to the Bohemian Massif is running north from surface termination of crystalline complex of the Eastern High Tatras and has E-W direction and also is crossing the two mentioned lineaments in the area of Stará Lubovňa town. This boundary is interpreted based only on the data from Remote Sensing *(Potfaj et al., 1995)*. There are also other regional faults in the area, confirmed by seismic research. The Kežmarok fault (in literature also called as Poprad fault – *Pospíšil and Hrušecký, 2001*) and faults crossing in the direction of NW-SE the whole Levočské vrchy Mts. (Kluknov fault). For further study, dominant significance have the first two mentioned fault systems-MMTS and MPTS.

The MMTS can be understood as a fault system composed of two or three main parallel faults with direction NE-SW. This system is not faulted until Tisovce, where lateral faults occur in direction WNW-ESE accompanied by an effusion of young andesites.

Horizontal displacement about 40 km, which is estimated for the period of young Tertiary *(Pospíšil et al., 1989)*, is hidden by significant vertical movement in single branches of the fault belt. Since the formation until now, there has been dominant sinistral component of the movements *(Bezák,*

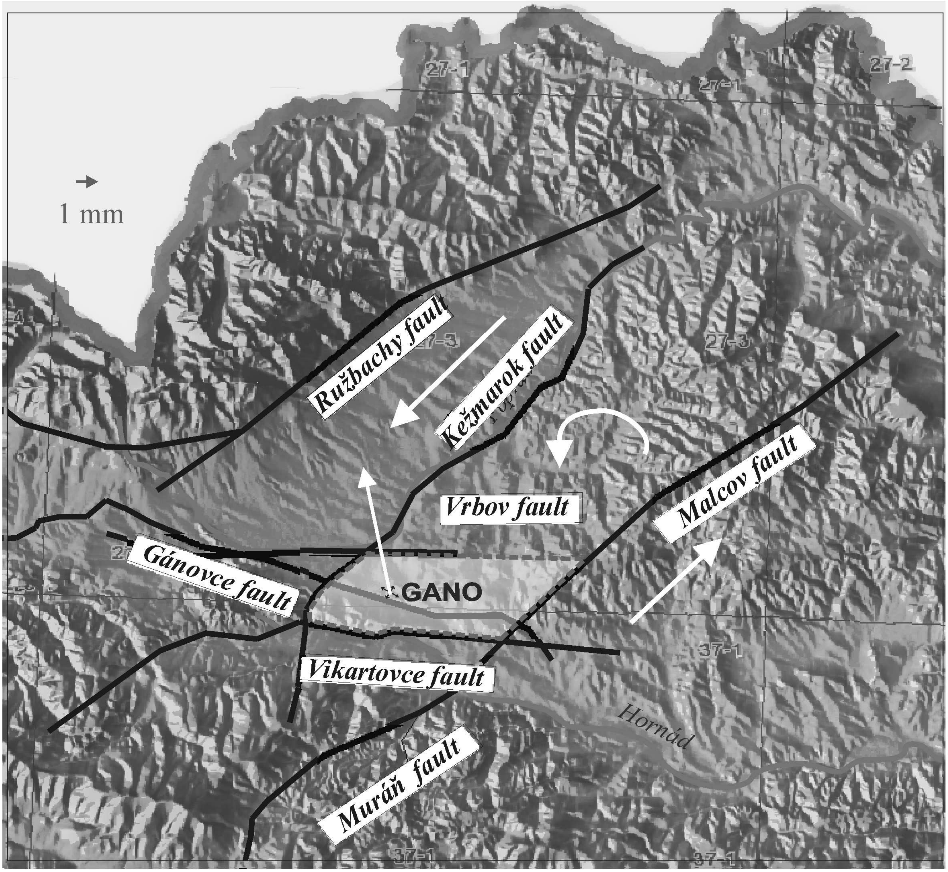

Fig. 1. Position of GPS point GANO in area of Muráň – Malcov tectonic zone *(Pospíšil and Hotovcová, 2003)* .

1988).

As the NE follow-up of the Muráň fault system is considered the Malcov fault system which was analyzed in detail by *Nemčok (1978).* The Malcov fault system is active as tectonic system, originating between two blocks in underlying rocks of Central-Carpathian Paleogene of Levočské vrchy Mts. and the edge of flysch belt. The two blocks move unevenly, each block has different speed of the movement.

Tectonic character of overlaid complexes above Muráň fault system in the area of the Central-Carpathian Paleogene (Levočské vrchy Mts. area) has sigmoid arrangement of flysch sequences. The Flysch sediments were in the Tertiary rotated, which confirms not only the attitude of sand bars, but also the measured paleocurrent vectors *(Nemčok, 1978).* It is visible near the Ujak village and in the Šambron horst, where flysch layers are rotated into the direction of the Muráň tectonic zone (NE–SW).

In the area of the Klippen Belt zone the Muráň tectonic zone shows on the surface by faulting the Klippen belt, in the area of the Ujak-Plavec, and also by forming direction depressions, where lower the Malcov formation occurs, also called the Strihov formation.

4. Geological-geophysical characteristics

The MMTS zone is significant not only in geomorphology data but also in geophysical data. For example in gravity and magnetic maps it creates 10-20 km wide zone of anomalies oriented in the direction of NE–SW. The Similar record is visible in geological and Remote Sensing data, too. The mentioned zone has a character of classic transcurrent fault system (horizontal movement of Earth crustal blocks along the system occurs) accompanied with all extensive and compressive elements.

The Maps of the Complete Bouguer and Magnetic anomalies belong to basic integrating geophysical data *(Kubeš et al., 2001).* The Airborne magnetic anomalies were gained from aerial geophysical mapping of the Levočské vrchy Mts. *(Gnojek et al., 1992).* For our aim, we used maps of contour lines delta T. Even though the gamma spectrometric data of the Levočské vrchy Mts. (K, Th, U, total) were available, too *(Gnojek et al., 1992; Kubeš*

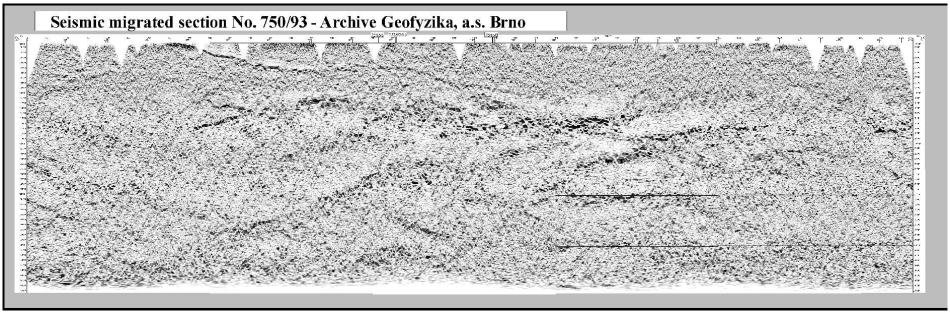

Fig. 2. The Reflection seismic profile No. 750/93 gives clears idea about structure and tectonic relations in perpendicular direction to geological structures (direction SW-NE-N). (Archive of Geofyzika a.s., Brno – arranged by *Pospíšil and Hrušecký, 2001*).

et al., 2001), for shallow character of information this data has not been used.

In the area of the Levočské vrchy Mts., at the beginning of 90-tees, a net of reflection seismic profiles was realized for hydrocarbon exploration. Four profiles are situated in our defined area. On two profiles of W–E direction structural relations are demonstrated and an image of the Muráň - Malcov fault and Ružbachy and Kežmarok transcurrent systems. In the rest of the profiles of NE–SW direction relation of sedimentary complex formed by Central-Carpathian Paleogene with the units of pre-Tertiary basement (Fig. 2) is detected.

For the analyses, we used a map of earthquake focuses and seismotectonic map supplemented with the solution of focal mechanisms in selected areas of the Western Carpathians *(Pospíšil et al., 1993)*, too. Unfortunately, the data did not give us distinct information about kinematics in the tested area. We can only suppose that all main faults are proving to be seismo-active in the recent period. The proof is the presence of few earthquake focuses with intensity from 4° to 5° MSK in the proximity of each fault (web – Geophysical Institute of the Slovak Academy of Sciences, Bratislava). For the analyses of tectonic relations in the tested area analysis of Remote Sensing data was very important. Analysis from very good quality LANDSAT TM and SPOT satellite images (*Pospíšil et al., 1985; Šutora et al., 1993*) showed that MMTS is very significant in several parallel boundaries. The course, by itself, of the faults is very non-continuous and faulted by series of transverse boundaries. Because of this, the course of two single tectonic lines (Divín and Muráň) in the southwest and Malcov, Kežmarok and Ružbachy boundaries in the northeast has been defined *(Pospíšil et al., 1989).* The more accurate and detail position and course of all interpreted boundaries were gained by the use of digital model of terrain. On the basis of the correlation of the Remote Sensed, gravity, magnetic data, and geomorphology analysis has been showed that fault systems and interpreted boundaries (photolineations) have significant geomorphology record and geophysical evidence which can be verified by the geophysical data to the level of 10 km.

For the whole Slovakia a map of recent vertical movement tendencies was constructed from very precise leveling *(Vanko and Kvitkovič, 1982).* Although it is only a regional view and tendencies of vertical movements, the importance of MMTS in geological structure of the Western Carpathians is obvious. MMTS divide the Western Carpathians into two parts – east, relatively stable with no significant movements in the proximity of tectonic zone and west part with relatively great dynamics of movements – area of the Lower Tatras. This area has uplift tendencies up to 2,5 mm/year, while the area of High Tatras and Danube basin is sagging from 0,5 up to 2,5 mm/year.

5. Results

Kinematic evaluation of Muráň - Malcov tectonic system – detail model

From geophysical and geologic information and interpretations *(Pospíšil et al., 1989; Pospíšil et al., 1985; Šutora et al., 1993)* it is evident that in the surroundings of point GANO exists important Muráň – Malcov fault system (MMFS), which is in the area between High Tatras and Levočské vrchy Mts. represented by considerable Malcov, Kežmarok, Muráň faults. Point GANO is located between Malcov and Kežmarok fault. From geophysical (e.g. gravity - *Pospíšil et al., 1989)* and geologic information (e.g. structural data - *Marko, 1993, 2002)* it can be deduced and interpreted that at both faults sinistral component of movement prevails. From next geologic information and interpretations is evident, that there is a series of faults

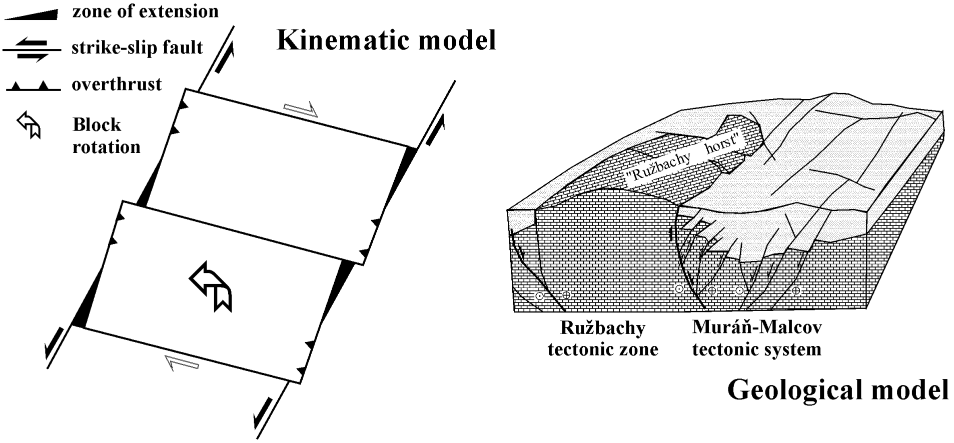

Fig. 3. Model of rotation of micro blocks with geological background.

in W–E direction (Vrbov, Gánovce and Vikartovce faults). These faults influence the flow of two rivers in the area, Poprad and Hornád river, which respect orientation of these faults in some parts of their flows. These faults (Kežmarok – western, Malcov – eastern, Vrbov – northern and Vikartovce – south) define "Gánovce micro block" (Fig. 1).

GPS interpretation gives evidence that the vector calculated from GPS data during the campaigns realized in 1998–2002 has a NNW direction (about 14° from north to west). The question is what causes the "Gánovce micro-block" to move to north-west direction? As a solution a model of rotating micro-blocks is offered. In our case a model of rotating micro-blocks between the Kežmarok and Muráň - Malcov sinistral transcurrent faults (Fig. 3) is chosen. The block is characterized by the two main parallel faults where sinistral movement component prevails. Affected by this movement, a left sided rotation is generated between these two main parallel faults of the block thereby the main block is broken into several partial micro-blocks. The total movement vector of GANO point (Fig. 4), determined by GPS measuring reflects deformations and motion tendencies during 1998–2002. If we looked into details, how the particular vectors were calculated between the campaigns *(Mojzeš and Papčo, 2004)*, we would find out that the GANO site movement between various campaigns realized during 1998–2002 was a little more complicated. The drift vector of GANO point, between

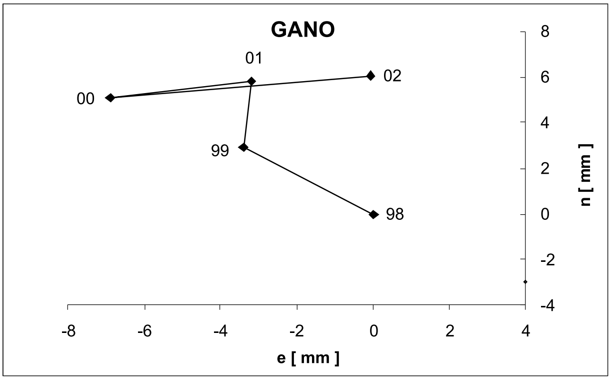

Fig. 4. Movement of GANO GPS point estimated from GPS measurement with STU – IGS solution.

campaigns in 1998 and 1999 (calculated from STU-IGS solutions) having approximately a NW direction, changes its orientation to NNW direction in the following period (1999–2000). Afterwards, during the third period between campaigns in 2000–2001 it has already a SW direction and during the forth period between campaigns in 2001–2002 the shift vector of the observed site directs to SE. It looks like there is a precessional motion performed.

The block rotation was divided to four phases that make possible to explain how could the individual movement phases of faults between various campaigns be in progress. During the particular phases, the pairs of faults were obviously dominating in horizontal displacements. One of this pair would move to the left and the other to the right.

During the first phase, i.e. period of 1998–1999, the observed site moved to NE. This movement can be interpreted as a result of horizontal movements, mostly on the Malcov fault, which indicates the left side motion and on the Vrbov fault the right side motion. We can't say that the movements are not realized also on the other faults, but probably the above mentioned faults have the major intensity (Fig. 5).

The site movement during the second phase (1999–2000) can be mostly influenced by the same faults when the Malcov fault has presently more

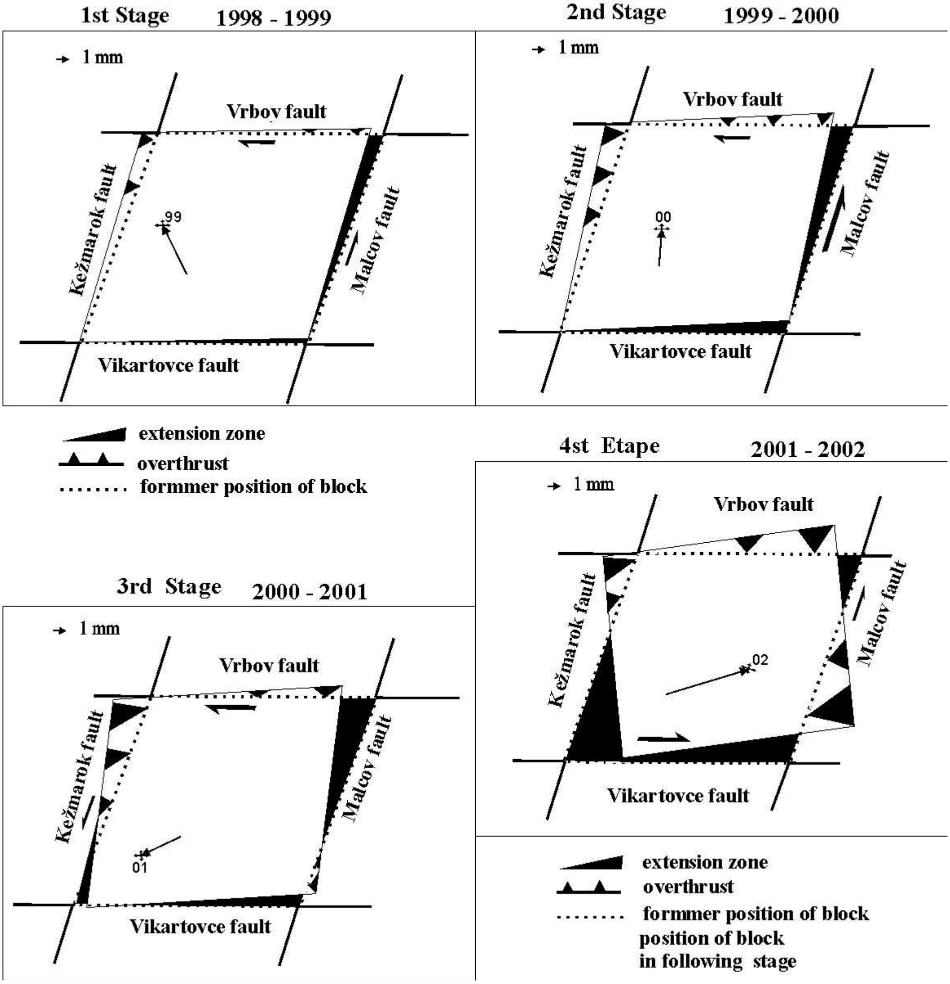

Fig. 5. Final kinematical movement's model of "Gánovce micro block" obtained from recent geological and geophysical information.

intensive motion then during the previous phase. Thanks to these prevailing motion tendencies on the faults, the tension on the west part of "Gánovce block" is generated (Fig. 5)

In the third motion phase the GANO site (2000–2002) leads prevailing fault motion influenced by accumulated tension in Gánovce block in western part move to Kežmarok fault. The dominance here has the Vrbov fault with dextral shift. This movement drift tendency from Malcov to Kežmarok fault can be caused by the above-mentioned tension. The tension in the west part of the block was increasing during these two periods. Horizontal motion on the faults is break-like, where shear tension in fault (Kežmarok fault in this case) is reaching critical value. After that, fault system will start to move (Fig. 5).

Shear tension replacing from west part to south-west part "Gánovce micro-block" is affected by dominant tension. In this phase GANO site motion vector changes from N–E to S–W direction due to tension conditions change in Gánovce block boundaries.

In 4th phase (last phase – years 2001–2002) the accumulated tension in the SW block exceeded critical value. As a result of this tension the prevailing motion has been compensated on the Malcov and Vikartovce faults. Probably it caused the change of GANO point movement and its orientation from previous orientation S–W to N–E.

Precession motion can be explained by "Gánovce micro-block" rotation model – "returning" of GANO point in period 2001–2002. We are aware, that finite amount of observations does not enable us to present unique solution and conclusions. The submitted model we consider as a first iteration of movement tendencies solved in the Levočské vrchy Mts. and High Tatras areas. Next observation will be step by step supplied and specified in future period.

6. Conclusion

In this contribution kinematic analyses of horizontal deviations of GANO GPS point was demonstrated. Although this solution was demonstrated only for one point of special GPS site (network), presented interpretation shows the procedure and possibility of complex geophysical and geological analyses in the study area. In this area, we can find series of parallel tectonic boundaries of NE–SW direction, which are components of important transcurrent system of the Western Carpathians – Muráň - Malcov tectonic system.

The analyses of results proved that the tested area is very complicated, concerning the tectonics, and is deformed not only by the net of faults with horizontal movement tendencies but also by numerous normal and listric faults.

Particularly dominant is a display of detachment which is connected with the function of the Ružbachy fault. The Ružbachy fault also evidently and strongly affects the area between the High Tatras and the Levočské Mts. *(Pospíšil and Hrušecký, 2001; Sperner et al., 2002).* Already existing network of GPS points is registering movement tendencies in the surroundings of Poprad – Kežmarok towns. Because the lack of GPS data north of Kežmarok town, the strain condition and movement tendencies cannot be determined. The next more detailed analyses require to spread and extend the recent GPS network to the area between the High Tatra Mountains and the Levočské Vrchy Mts. in order to verify or refute the correctness of the used kinematic model solution.

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