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THE USE OF GNSS TECHNOLOGIES FOR APPLICATION IN MINING, GEOLOGY AND GEODESY IN BULGARIA

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Abstract: A review on the use of GPS technologies for application in mining and geology on territory of Bulgaria is presented in this paper. Some particular results concerning the application of GPS in opencast mining in Bulgaria are presented and analyzed. The essentials of them are periodical survey of mine working; investigation of slope strain; management of output and transportation of mining mass. In the area of geology and geophysics are discussed some results on application of GPS on: geological mapping and assaying; gravity investigations; deformation of earth's crust; investigation of landslide processes; coordination of platforms for oil and gas production etc. Plans for future work on the above issues are discussed too. The problem of the combined processing of GPS and other types of classical geodetic measurements concerning the higher accuracy of the result is still topical. In the proposed paper a better accuracy in the vertical component of the GPS-networks has been sought. It is suggested that the results from the spirit levelling expressed by heights should be used. Observation equations of heights (orthometric or normal) can be included in the mathematical model for processing of GPS measurements. In these equations a simplified model of geoid (quasigeoid) is involved. A numerical example for the combined processing of GPS measurements with EDM and spirit levelling heights has been presented. The results confirm the expected higher accuracy of the height component.

Keywords: GNSS Technologies Application

1. GPS application for geological targets on the Bulgarian territory

1.1. Introduction (history)

Computer systems application for representation of geographically related geological information during the geological investigations on Bulgarian territory was initiated in 1995 by the experts of the Derectorate "Geology and subsurface protection" of the Ministry of Environment and Waters (MEW) by means of purchase of the program product MapInfo. Later MEW introdused the requirenment all map materials to be submited by application of MapInfo, ArcView or AutoCad both from the state and private (including foreign) firms fulfiling geoprospecting on the territory of Bulgaria. The usage of GIS is the main reason for introduction of the Global Positioning System (GIS) in geological practice. The first attempt was done in 1995 by the Irish company of "Navan" completing prospecting works on several licenced area in Bulgaria. The supplied Trimble GPS receptors turn to be difficult to carry and useless in the daily field work of the geologists.

In the period of 1998-2001 MEW bought the software products of ESRI ArcViewGIS and ArcVewInfo, necessary for the processing of the immense geological information preserved in the National Geofund. Several GPS receptors was bought as well.

In the period of 1999-2000, in the frames of projects financed by the European Community (Phare Program), two GIS laboratories was equiped in the departments "Geology and prospecting of mineral resources" and "Geology and paleontology" of the University of Mining and Geology "St. Ivan Rilski" – Sofia. Software product ArcView 3.1 of ESRI was purchased. In addition three GPS receptors of Garmin were supplied. Up to date these laboratories have been applied mainly for research work. In the nearest future they will be incorporated in the frames of the courses of "Field geology (geological mapping)" and "Prospecting of mineral resources". At the moment the students get some ideas about the Global Positioning System and GPS receptors during the practice of "Field geology".

- protected areas and objects in the frame of task financed by the Ministry of Environment and Waters related to the completion of register and cadastre of the Bulgarian geological phenomena and so on.

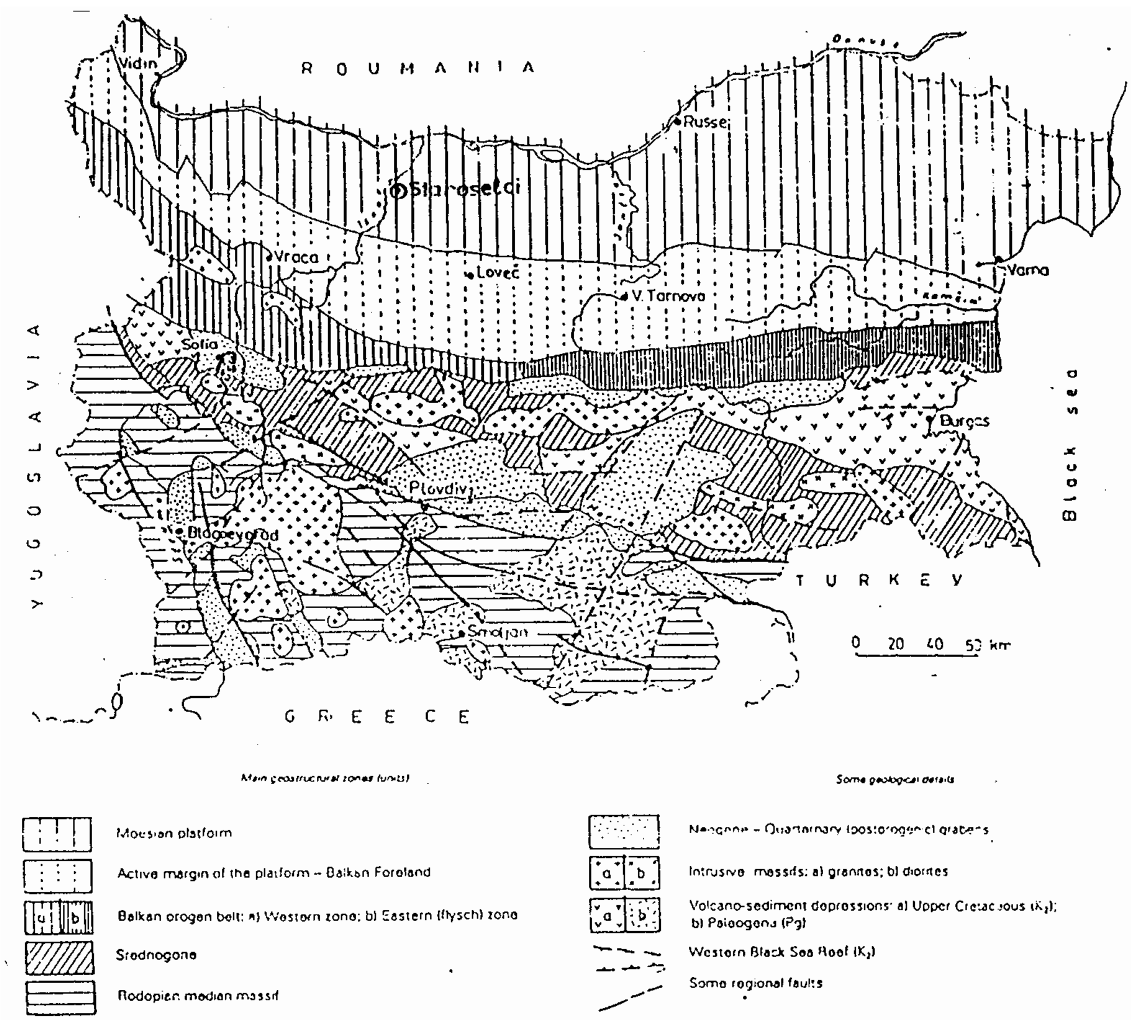

Fig.1.Geostructural scheme of Bulgaria.

1.2. Application

GPS is applied in the field of geology to receive coordinated relations of objects as follows:

- outcrops of the geological mapping;
- profile lines and pickets of the reconnaissance geoprospecting as well as of the preliminary prospecting (e.g. in the soil and rock sampling);
- lithogeochemical samples in the stream-sediment sampling, used for searching of goldbearing areas and structures as well as for environmental tasks;
- boreholes, trenches and prospecting shafts during the detailed exploration of industrial minerals and most of the types of ore deposits (excluding the vein type that reqiures higher accuracy);

1.3. Scales

The requirement for accuracy of the geological maps of Bulgaria is 1 mm independantly of the map scale (Bairaktarov et al., 1995). The conditional state geological mapping on the territory of Bulgaria fulfills in scale 1:25 000 i.e. the admissible mistake is up to 25 m. Maps in scale of 1:10 000 and 1:5 000 are used in the reconnaissance geoprospecting as well as in the preliminary exploration. The admissible errors are accordingly 10 and 5 m. GPS receptors of Garmin (e.g. GPS 12, GPS 12 CX, eTrex, eTrex Summit etc.) are oftenly used in the field works due to their low price. In favorable conditions (good constellation of the visible satellites) their accuracy drop down below 5 m. It satisfies entirely the needs of the field geoprospecting works mentioned above.

1.4. Problems

The principal problem is the discrepancy between the GPS coordinates and the coordinates of the topographic maps of Bulgaria elaborated for industrial application. In practice this problem is resolved by GPS coordinate determination of several characteristic objects (topographic repers) existing on the maps followed by a computer correction of the rest map data using some of the GIS products (e.g. the extention of ArcViewGIS, Spatial analyst).

Another problem is the level inaccuracy (so called Z coordinate). In some of the recent models of Garmin GPS receptors (e.g. eTrexSummit) this problem is resolved by means of an additional build in barometric altimeter. The rest of receptors require field calibration using a topographic reper of known level.

1.5. Perspectives

The world process of globalisation as well as the pre-accession strategy of Bulgaia urges an integrated aproach to the collection and application of geographically related information. In the field of geology this process of unification is traditional. But the new technologies have elaborated a number of more rapid and more effective methods to do this. The Global Positioning System (GPS) improves permenantly. Permanently improve and GPS receptors and their accuracy increases. Electronic notebooks are elaborated (e.g. palmtop type) with interface both to GPS receptors and mobile phones. Moreover, there are laptops which work do not depend on the weather. They possess installed software ArcViewGIS that apart from the integration of all field documentation allows both geological maps compilation and decission making in real time (in the field). In fact, the dream of the field geologist is reached. But for the Bulgarian geologists it is still unreal due to its very high price.

2. GPS application in the open pits

Recently, GPS-technologies have often been used in the open pits in Bulgaria. This fact is due to a number of circumstances as follows:

- GPS-measurements do not depend on the visibility between the points as well as on the presence of points of higher class;
- GPS allows the measurements of the three coordinates;
- Many receivers with different class of accuracy existed.

The receivers of higher class are mainly used in inventing and supporting of mine surveying models of the open pits. The most important applications are as follow:

2.1. Establishing of local geodetic networks

The advantages of GPS technologies are very clearly expressed in pits, which embrace significant areas, situated in plain relief (e.g. Maritsa-East pit in Bulgaria) and isolated small pits (e.g. numerous quarries for building materials and facing rocks in Bulgaria).

Maritsa-East lignite deposit is situated in the southeastern part of the Upper-Thracian lowland. The minefield embraces a territory of 250 km2 between the villages of Aprilovo, Rassimanovo, Gledachevo, Kovachevo, Gradets, Mednikarovo and Obruchishte (Fig. 2). The proven coal reserves are 3,5 milliard tons. Two open pits are exploited in the Maritsa-East basin: “Troyanovo-North” and “Troyanovo-3” (Fig. 3, Fig. 4) which feed three electric power stations. This complex produces 30% of the total electrical energy of Bulgaria.

Maritsa-East is e complicated industrial object with entirely completed energical cycle: from the coal mining to the production of electrical energy and briquettes. Production related technological processes cause versatile impact on the environment. This impact is expressed mainly in destruction of the relief forms, soil and vegetation overburden, alienation of fertile lands etc. Large areas have been affected by significant deformations, which make the classical methods for development of stable networks inefficient.

2.2. Development of surveying base and detail surveying

GPS advantages are significant in surveying of underwater mining (aquatorial surveying works). In Bulgaria it is applied for surveying of dam bottoms (of course, in combination with echo sounding.

It is useful to apply GPS for studying of deformational processes especially in large mine fields.

Larger GPS-technology application in open pits is impeded by factors, which are not inherent to the system, but to the Bulgarian conditions as follows:

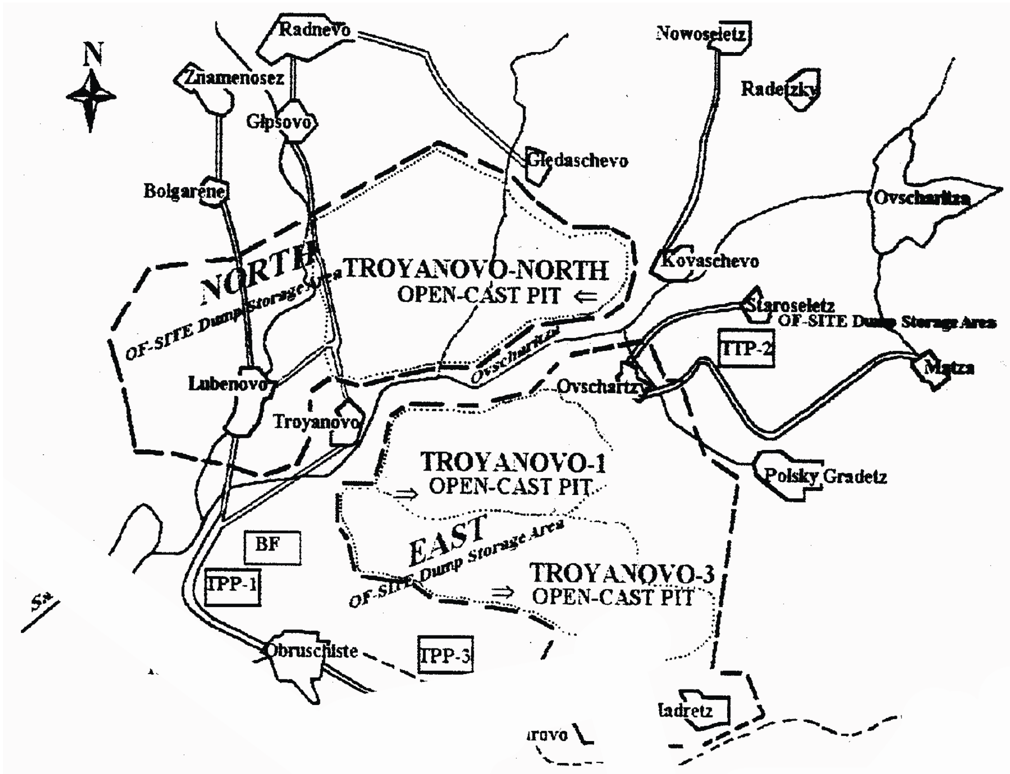

Fig.2.Schematic map of Maritsa-East lignite deposit region.

2.2.1. The high price of the receptors especially of these ones working in real time. This problem could be resolved by a relevant policy: leasing, attraction of sub-executors etc.

2.2.2. GPS determines the coordinates in projections and on ellipsoids, which are different from Bulgarian ones. That is why a transformation of the obtained data is required. In the future with the implementation of the new coordinate system BGS 2000 and the ellipsoid WGS84 it could be expected direct receiving of the coordinates.

The receptors of low class of accuracy (1-5 m) are used in the open pits for operative management of the autotransport (e.g. in the "Assarel" open pit). It

Fig.3.Open pit "Troyanovo-North".

is perspective these systems to be included in the totally automized systems for management both the quality and quantity of the production in real time.

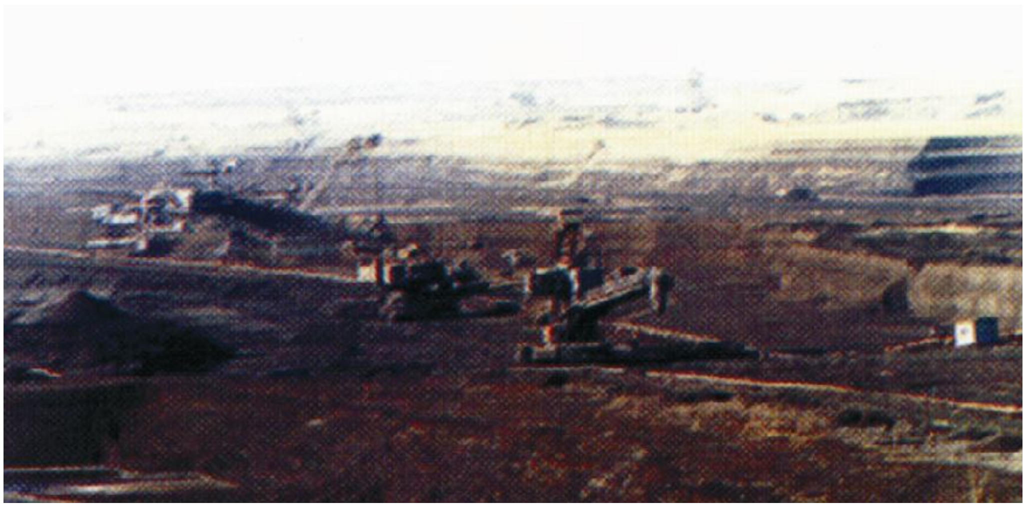

Fig.4.Open pit "Troyanovo-3".

By introduction of differential corrections, GPS-receptors of low accuracy could be used for current surveying of the situation of the mine workings in unfavorable weather conditions (fog, rain etc.), for coordination of geological samples and so on.

3. Some geodetic application of the GPS in Bulgaria

3.1. Combined processing of the GPS measurements with classical geodetic measurements

There are many publications on the problem of the combined processing of different types of measurements (classical and from space techniques), (Hein, 1981; Valev and Minchev, 1989; 1994; 1995; Valev et al., 1997) and others.

In the mentioned papers, the problem about the combined processing of GPS measurements (baselines) with results from different classical geodetic measurements: horizontal directions, zenith distances, slope distances, astronomical coordinates, astronomical azimuths, height differences are discussed. There are also program realisations of different algorithms on this problem.

In the case of a combined adjustment of GPS data with some of the classical geodetic measurements, the best way is to use slope distances, measured with EDM. But the inclusion of distances despite their high precision leads to the increasing only of the accuracy of the horizontal component. The accuracy of the vertical component is unchanged. And this is namely the weak point of the GPS measurements. The vertical accuracy neither of the horizontal angles nor the astronomic azimuths increases. The accuracy increases when zenith distances, heights or height differences from spirit levelling are included in the adjustment model of GPS measurements. It is known that the zenith distances are measured with a low accuracy because of the vertical refraction and we have to accept some hypothesis about the atmospheric pressure. The use of zenith distances also requires an introduction to the astronomic coordinates of the points. But when we use height differences from spirit levelling the main problem is that we have to introduce some hypothesis for the geoid and to accept the stipulation that the adjacent points between which height differences are measured are situated not far from each other. Depending on the complexity of the gravity field as well as on the complexity of the geoid that distance can be restricted to 3- 4km. Besides that the use of the height differences requires the introduction of astronomic coordinates. The problem in combining of GPS measurements with zenith distances and height differences rises with the difference between the astronomic system and WGS84.

The problem of the use of results from spirit levelling expressed in heights in some height system is not discussed very detailed and in our opinion is not enough developed. However, if heights from sprit levelling and gravimetric data are used the accuracy of height component will increase considerably.

The heights h can be obtained from levelling and gravimetric measurements through the gravitational potential W

$$h(orth) = (Wo - W)/gm$$

or

$$h(norm) = (Wo - W)/\gamma m$$

Geopotential difference (Wo - W) has been obtained as follows

$$Wo - Wa = \int_0^a g.dh = \sum_0^a gi.hi$$

The weak point of the problem is that we have to know the undulation. However, we have the possibility of dividing the territory in small regions and of applying some simplified suitable model of geoid (quasigeoid), for example

$$dh = C0 + C1.\varphi + C2.\lambda,$$

where φ and λ are geodetic coordinates of the point, belonging to the same region and Co, C1, C2 are coefficients specific for the region. Instead of geodetic coordinates λ and λ we can replace them with the linear quantities B and L calculated from the formulae

$$B = M.(\varphi - \varphi o); \quad L = N.\cos(\varphi).(\lambda - \lambda o),$$

where φo and λo are the geographic coordinates of some central point of the territory, and M, N - main radii of curvature.

It is possible to introduce more complicated models of geoid (quasigeoid), for example

$$H – h = Co + C1.B + C2.L + C3.B2 + C4.B.L + C5.L2 + \dots$$

Whereas in the classical 3D adjustment it is supposed the level surfaces were concentric spheres in the proposed method the level surfaces are not parallel and a deviation along the parallel and the meridian is supposed.

On the base of the above presented method algorithms for combined adjustment of GPS measurements, slope distances and orthometric (normal) heights are written as well as their computer realization. An experience is performed and from the results it is obvious that the accuracy of the coordinates increases. However, the familiar problem which heights are more convenient to be for use is still under discussion.

Numerical example

67 GPS baselines with Leica System 200 receivers, 89 slope distances with Mecometre 5000 and heights of 25 points by spirit levelling have been measured in the network, shown on the Figure 6. Using the above described procedure the network has been adjusted once - as a pure GPS network, second - as a GPS network, combined with slope distances and several combinations of GPS data with slope distances and heights. In the last case, with three types of data, several combinations with different a priori standards for the adjustment have been performed. For each variant, a posteriori standards for each type of measurements have been derived.

Coefficients of the Geoid Model are derived

Co = 35.4543 m ±0.0032 (m),

C1 = -6.251319356 (mm/km) ± 0.000395920 (mm/km),

C2 = 41.759181949 (mm/km) ± 0.000659620 (mm/km).

Estimations for whole (entire) network

Mean square error of the space position
Mp = ± 3.18 mm

Mean square error of the horizontal position
Mxy = ± 1.05 mm

Mean square error of the height position
Mh = ± 2.99 mm

3.2. A new Reference System and its introducing in Bulgaria

A new geodetic projectional coordinate system has suggested to be distributed on the territory of Bulgaria. It is a conformal conic projection with two standard parallels and a basic meridian. It is uniform for the whole country and calculated with the parameters of the ellipsoid of WGS84. The most appropriate parameters and formulae for calculation have been chosen. The orientation of the ellipsoid will be carried out on the basic of the points, defined on the territory of Bulgaria as a result of the performed EUREF campaigns. This system is named SYSTEM 2000. It is planned to build a fundamental GPS networks, consisting of about 400 basic points. Requirements and a technology for measuring and adjustment of the network have been worked out. There is planned a further densifying of this network so that the new coordinate system is used effectually.

3.3. Geodynamic research of the Mirovo Salt Deposit, NE Bulgaria

The Mirovo salt deposit is located approximately

5km southeast of the town of Provadija, in the Varna province, Bulgaria. That is a unique natural phenomenon with its origin, composition, location and geophysical characteristics. The Mirovo salt diapir has a depth of approximately 4 000 m and its top is 15 to 20 m deep. The diaper has a base area of the order of 200 km2 and generally has the shape of a truncated cone. Approximately 73% of the diapir are Sodium Chlorid, the remainders comprising insoluble elements and other evaporites, irregularly distributed through the salt mass. It was excavated in 1919. The method of boring is applied at present in the salt pits (more than 30 utilized bore-holes) and more specifically the method of underground salt leaching through which one major raw material for the Devnya chemical plants is produced – brine.

It is a geodynamic project, which was attracting researcher's interest. A dense network (Fig. 5) of 26 stable pillars and many leveling benchmarks is designed and built-up especially to monitor movements and deformations in the deposit area using precise angular and distance measurements, spirit leveling and GPS. Part of the pillars– outside the central zone – control the detailed over the salt body. Twenty campaigns, after the initial observations in 1990, were taking place. The aim is to examine how far exploration of rock salt is connected to local seismic activity because recently earthquakes occur here more frequently and with increasing strength. To give an idea what the magnitude of the deformations is, these solutions are compared also to the campaign, accomplished in June 1990.

The general trend of terrain deformations is subsidence of the central zone (Fig. 6) and, as a by-product, shortening of the distance between the center and the outer margin. Increasing residuals with time span is due to the time-dependent components, whereas the constant part gives an accuracy estimate.

The components of the isotropic plane deformations of earth blocks in the region of the geodynamic polygon are calculated by the final element method and by the relative linear deformations at suitable sides of the network. The calculation results are the base for a variable analysis of deformation processes in the investigated region.

It is necessary to point out that the deformation intensity for the period investigated is higher than the average critical values of the earth crust. Taking into consideration the shortness of the temporary interval, for which research has been done, the received extreme values of deformations should

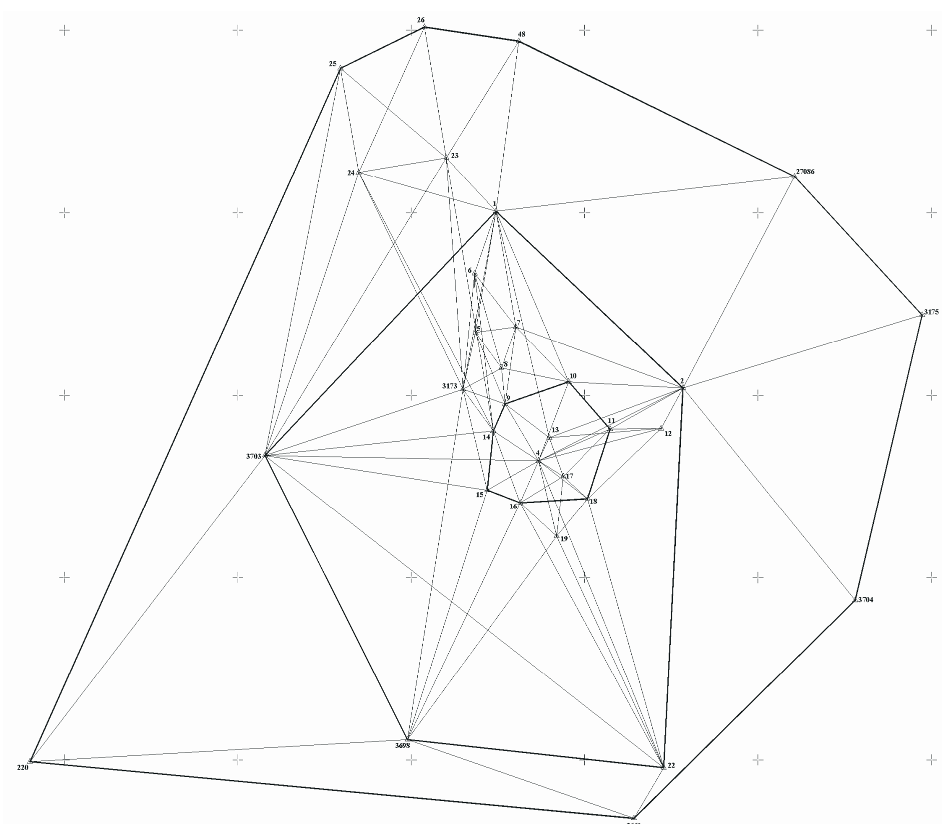

Fig.5.Geodynamic Network.

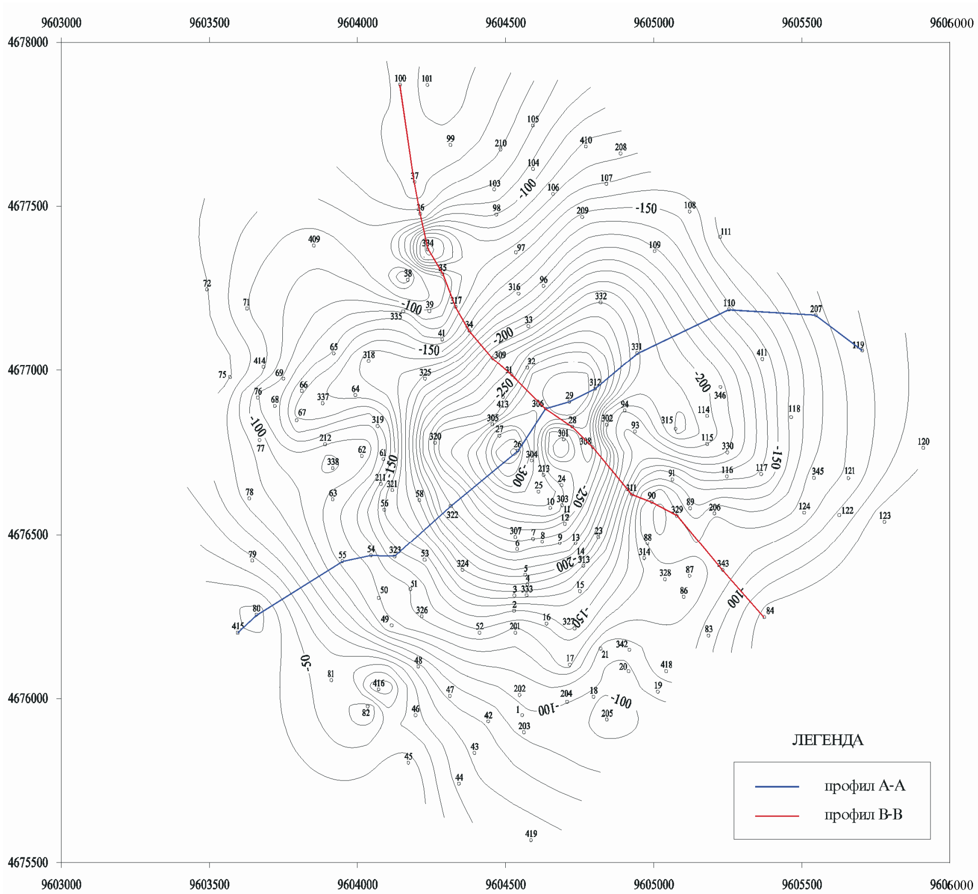

Fig.6.Subsidence in the Mirovo Salt Deposit.

not ease us, especially in the salt mirror. However, it is necessary to determine what part of the total value of deformation is the one of technogenetic character and what is the part, which is of tectonic origin. The necessity of such determination in the near future is supported by the fact that a great part of the axes of deformation sections are in NW-SE direction, a direction characteristic of the whole country. Additional specifications are necessary to the activity and the territory detachment of the tectonic processes in the region, and especially to those, which could become generators of seismic occurrences. A final and definite answer to these questions could not be given for the time. The reason for this opinion is the relatively small amount of information, which prevents us from creating a full concept on the mechanism and the genetic peculiarities of dynamic and deformation processes in the region.

3.4. GPS technology application in monitoring of landslides

We have successfully applied GPS technology in monitoring of landslides on the entire territory of North Bulgaria. These are the regions of Orjahovo, Orsoja, Gabrovo, Cibar, Somovit, Kneja, Lom, and Varna.

3.5. Application of new technology in the surveying and mapping of the Danube River

According to the PHARE-project „Morphological Changes and Abatement of Negative Effects on a Selected Part of the Danube River", a surveying experiment has been carried out. The task of the experiment includes surveying and mapping of a selected reach of the river applying new technologies including GPS use. Many scientists and specialists from Austria, Bulgaria and Romania have participated in the project. The team leader has been the Institute of Hydrology and Water Resource Management, University of Technology, Vienna.

The project's aim is to establish the preconditions for remedial actions. This includes the following tasks:

Development and application of modern methodology and technology including GPS use for surveying and mapping of the Danube River.

Generation of precise maps of the riverbed from historical and current measurements.

Assessment of morphological and hydrological situation and its development for planning of remedial actions, based on a common view and perception of the major processes.

It is proposed, that all Danube countries should use a uniform co-ordinate and height systems for all control points, benchmarks and gauges, situated along the river banks and on the islands. The bases of these systems are EUREF and UELN. Results, such as maps of the River Danube, GIS-applications, etc. have to be prepared in Lambert conic map projection.

More details and some other applications in geodesy are given it the paper "Some aspects of GNSS applications in Bulgaria" by Dr Milev, prof. Valev at all.

4. Conclusions

The using of the Global Navigation Satellite System in Bulgaria has been started since 1980. Numerous established surveying and other firms are equipped with modern GPS hard and software. Presently nearly fifty geodetic receivers are in use in Bulgaria. The scope of its application is increasing continuously. Many scientists, engineers and specialists are applying this technology for different purposes. The GPS technology is studied by the students from the Universities. Several conferences, workshops and symposiums on this topic have carried out in Bulgaria. A lot of papers and theoretical works have presented from Bulgarian autors.

Acknowledgements

Without the assistance and cooperation of Bulgarian mining & geological exploration company personel in the allowing access to geological and GPS data this work would have been impossible. Thanks to all of them. A part of these results are debated with colleagues in United Nations/United States of America workshop on "The use and application of global navigation satellite systems". Thanks to all of them. The development and application of modern methodology and technology including GPS used for surveying and mapping of Danube river successful can be used and for surveying of Black sea coast. Just such problems are working in 7FP project "Up-grade Black sea scientific network", N226592, who financed this investigation. Thanks.

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