

Space, ground-based and model investigations of lithospheric movements of Balkan peninsula and Bulgaria within the framework of the EUROPROBE project

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High accuracy of space technology, the development of space methods and the resolution of remote sensing imagery, providing possibility to define the boundaries (faults) of the lithospheric plates and blocks revealed large perspectives for the different geosciences.

Many projects have been developed giving answers to series of problems related with global, regional and local geodynamics and the correlation of these phenomena with the natural ones (seismicity, volcanic activity, etc.). Recently the possibility to establish close relation between international projects is available. For example the joint project VEGENER-IDEAL is a combination between the VEGENER Project (of the European Space Agency) and IDEAL (of the Eastern Space Council) [12—16].

Together with the European Project, aiming at the investigation of the regional dynamics of the Eurasian plate versus African, Arabian and Indian plates, there was initiated another Project EUROPROBE on the territory of the Eastern Space Council countries as well for the detailed investigation of the local and microlocal dynamics with the aid of complex scientific and experimental classical and space methods, providing qualitative and quantitative data on European and Asian platforms. Our attention is firmly directed towards the investigation of one of the most seismically active regions, i. e. the Balkan peninsula and Bulgaria in particular with the help of available data from classical measurements and future space GPS measurements and remote sensing imagery. In order to realize these investigations on the Balkan region we have made proposals and would like to consolidate the opinion of the specialists in the region for the future objectives in studying the geodynamic processes.

1. Geotectonic and geodynamic situation of Bulgaria and Balkans

The investigation of the geotectonics and geodynamics of the Bulgarian territory — part of the Balkan segment of the Eurasian continental region is closely related with the structure and the development of the Alpine-Himalayan orogen. With Vardar-Izmir-Ankara ophiolitic suture of the southern orogenic border northward close to the stable continental part Moesian platform it embraces southern and eastern Karpathians, the Balkanides, Serbian-Macedonian and Rhodopean massives, Strandja Mountain and the Pontides. Southward the suture fragments of the passive African edge are revealed represented by the Dinarides, Hellenides, Anatolides and Tavrides [1, 3, 11, 17].

The separate tectonic zones along Bulgarian territory are clearly distinguished with manifested fault ruptures some of them seismogenic. In order to investigate the geodynamics on regional scale and the separate neotectonic structures within the different tectonic zones, a geodynamic test site was selected (which we named Balkanprobe) along the Bulgarian territory which crosses transversely the mentioned tectonic structures. The test site embraces the central inland parts of 150-200 km width starting northward from Danube and ending southward with the Bulgarian-Greek border. This provides for continuation along Greek territory and encompass the European continent till the Vardar suture southward also encompassing the tectonic zones which are part of the African continent. Thus the main fault ruptures, crossing the crust and separating the tectonic zones are adjusted. In some fragments of the fault structures we define clearly expressed seismogenic effects and this is very typical for the southern Misian and Maritsa deep fault.

Linear and concentric formations obtained via aerospace imagery are marked on the neotectonic map. They reveal substantially new information which enriches our knowledge on the neotectonic structure of the Bulgarian territory. Some of them transect the entire Bulgarian territory and continue along the adjacent regions of the other Balkan countries. They are identified with dashed and dotted lines on the map.

Recent geodynamics of the Bulgarian territory is relatively well studied and is manifested with vertical movements mainly [3, 5, 6, 10]. The maximum values (up to 5,9 mm/year) of vertical movement velocity are expressed in tectonic zones with most thick crust. Such are the tectonic regions of the Rhodopean and Serbo-Macedonian massives, individual Balkan segments (the Balkan range). Large areas of the Misian platform, the front Balkan range, Srednogie, Kraiste, and Strandja are featured with average uplift values (up to 2 mm/year). In contrast with the general uplift of the Balkan peninsula there are some regions with relative sinking that embrace part of the Moesian platform and Sredna Gora, as well as the eastern Rhodopes [10]. The levelling lines cross the main fault ruptures of the Bulgarian territory which follow north-south-ward: Southmoesian, Breznik-Prezlav, the Balkan range, Cis-Balkan range and Maritsa. The elongated zones of the first and last fault comprise the most active well studied regions: Gorna Oryachovitsa and Plovdiv. They are featured with great frequency and high magnitude earthquakes $M=7,0$.

The complex implementation of remote sensing, geological, tectonic, geophysical and geodetic information which is realized along the suggested test site (Balkanprobe) will enable the investigation of the regional geodyna-

mics of the conflict area between the Eurasian and the African plates within the Alpine-Himalayan orogen.

2. Scientific goals and expected results

The suggested program (**BALKANPROBE**) may be considered as a continuation of the meridional profile of the **EUROPROBE** Program along the Balkans up to the Mediterranean sea. The **EUROPROBE** Project itself may be considered as a supplement of detailed local and micro-local information to the VEGENER — IDEAL Project. Using various ground-based and space methods this project will apply laser satellite observations.

The fundamental scientific purposes of the **BALKANPROBE** Project are:

a) determination of the recent joint movements of local and microlocal blocks along the Balkan and Bulgarian transect and namely: between different geostructural elements in the Balkans — Dinarides, Balkanides, Serbian-Macedonian and Rhodopean massives, which are distinguished by fault ruptures;

b) investigation of the neotectonic structures and the geodynamic processes along the Balkans which embrace large sectors of the Alpine-Himalayan orogen and the Bulgarian territory along the transect starting north-southward and encompassing the tectonic zone of the Misian platform, the PreBalkan range, the Balkan range, Sredna Gora mountain and the Rhodopean massive;

c) control of the inner stability of the regional and local lithospheric blocks of the Balkan peninsula and Bulgaria;

d) determination of the peripheral deformations of the Balkanides, Serbian-Macedonian and Rhodopean massives;

e) contribution via the local **BALKANPROBE** Project to the regional VEGENER — IDEAL for the investigation of the dynamic processes in the Alpine-Himalayan orogenic belt.

The scientific and applicable purposes embrace the following important tasks:

a) evaluation of seismic danger and prediction of deep focal earthquakes, applying subductive and slip-collision seismic models via empirical climatic verification;

b) determination of the relative movements of the large crustal blocks in great rifts and fault zones of the orogenic belt which are interesting for the prediction of shallow focal earthquakes and for the construction and exploration of important structures and complexes.

3. Methodical, technical patterns and scientific strategy

Europrobe to a great extent embraces considerable territory of the European continent. Combining the Europrobe transect with the VEGENER — IDEAL project this areal is further extended encompassing the Karpathian-Balkan region. Based on this large scale we clearly may group into two groups the investigated objects by areal coverage:

a) investigation of the continental (for distances 10^3 - 10^4 km) and regional (10^2 - 10^3 km) dynamics (plate, intraplate and block) with the help of space techniques;

b) investigation of the local (10² km) and microlocal (up to 10 km) dynamics (between the blocks) in order to reveal the recent differentiated movements of the crust and the corresponding variations of physical and other fields in the vicinity of the observation station.

The survey of regions marked by *a* on the site are realized mainly within the framework of the VEGENER—IDEAL Project with the aid of third generation laser equipment and the investigation in point *b* is made with the Europrobe project using GPS system and ground-based laser equipment.

Considering the extensive theoretical and model studies made with IDEAL Project [14, 15, 16] and some results obtained with the VEGENER Project [12, 13] we shall concentrate mainly on the transect projected over the Bulgarian territory in order to discuss the suggested goals for joint theoretical and experimental investigation.

3.1. On the possibilities of contemporary remote sensing applications

Large resolution capacity provided by remote sensing imagery ensures supplementary reliable information on the geological structures, the neotectonic formations and the fault zones. Considering these facts after the complete investigation of the available geological structures and in particular the faults on the Bulgarian territory, maps and schemes have been drawn in the Remote Sensing Department of the Space Research Institute in Bulgaria.

Thus available data were analysed with respect to levelling and gravimetric information and four profiles were projected crossing through I and II class levelling points and transecting the main fault zones (Fig. 1). We proceed in a similar way determining the triangular chains selected in a way as to start in the area of Belene and to encompass the region around Strazhitsa town and Chirpan where two immediate measurements of the reference network are available (Fig. 1). After analysing the networks a transect of 21 chords was identified. The latter will be determined with GPS measurements. Fig. 2 represents the available geomagnetic anomalies and the geophysical stations and seismic epicenters.

3.2. On using available groundbased data based on defined geodynamic test sites

As we mentioned before, the determination of the profile direction of the reference networks are selected in a way as to follow the direction of the meridional beam of the Europrobe transect in order to obtain natural inclusion of the Balkan profile into the European Project.

The vertical measurements on the Bulgarian territory started in 1928 and the first investigations of the vertical crust movements were made since 1929-1932. Particularly interesting results were obtained after the Chirpan earthquake when another measurement of the state levelling network was made and the results were used to analyse the vertical shifts of the fault zone regions [5, 6]. Recently these analyses resulted in mapping the vertical movement velocity both for the Bulgarian territory and the Karpathian-Balkan region.

Initially four levelling courses were identified No 1, 2, 3, 4 (Fig. 1) which comprize the levelling points of the I and II rank of the state levelling network. Throughout the selected courses there are two to four epochs, where high precision measurements are made and namely: 1924-1929, 1956-1960, 1975-1976,

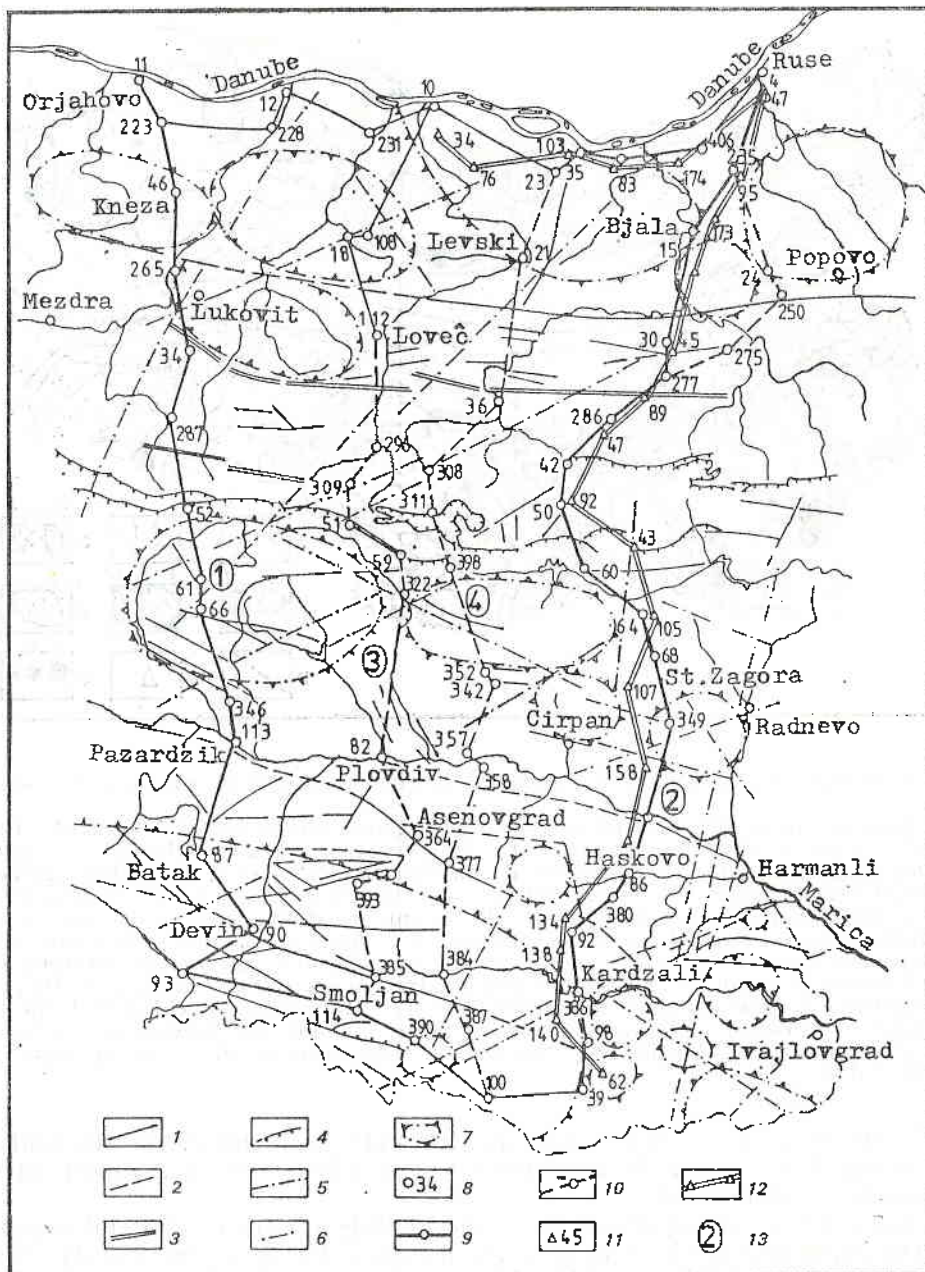


Fig. 1. Neotectonic map and triangulation network with plotted levelling lines
 1 — faults, 2 — suggested faults, 3 — flexures, 4 — overthrust, 5 — space geological lineament, 6 — suggested space lineament, 7 — ring structures, 8 — number of the levelling reference, 9 — first class levelling line, 10 — second class levelling line, 11 — triangular point, 12 — distance between triangular points, 13 — number of the levelling line

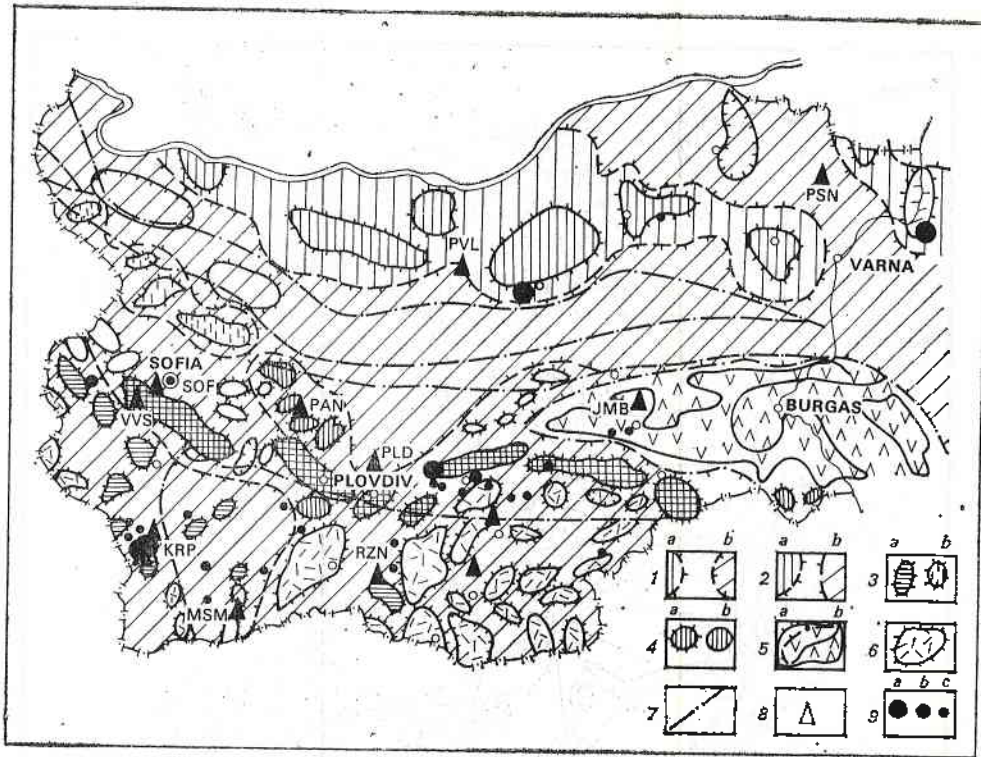


Fig. 2. Map of the magnetic field of Bulgaria and the location of the geophysical observatories

1 — zones of the positive field (a) and the total negative background of the magnetic field (b); 2—7 regioning of the magnetic anomalies by magmatic age and metamorphism: 2 — maxima (a) and minima (b) reflecting differently magnetized rock types in the Balkan basement of the Misian platform; 3 — maxima related with the magnetized rock formation distribution in the Wallachian and other metamorphic complexes (a) Struma dioritic formation and (b) Balkan range metamorphites and magmatites; 4 — magnetic maxima related with belts of upper cretaceous intrusions of Central Sredna Gora Mountain (a) and the southern belt of the Sredna Gora (b); 5 — positive (a) and negative (b) magnetic anomalies reflecting the distribution of paleogenic and neogenic volcanites; 6 — magnetic anomalies related with the distribution of paleogenic and neogenic volcanitic types; 7 — boundary between structural zones; 8 — seismological stations; 9 — earthquake magnitude: a) $M=7$, b) $M=6,0 \div 7,0$, c) $M=5,0 \div 6,0$

1987. The majority of data refer to transects No 1 and 2, the substantial fact being that transect No 2 is within regions where recently the most active seismicity is manifested.

Gravimetric measurements are made in Bulgaria since 1960 and in general the determination is made into the points of the levelling network. This far two cycles are realized and the third is not yet completed for the entire territory of the country. With the help of these data complex analysis will be made for the vertical and gravity anomalies for the present period and the attention will be mainly concentrated on regions where the transects cross the fault lineaments.

While vertical movements are subject to detailed studies in Bulgaria, the horizontal ones due to labour consuming procedures and the specifics of of the performance of high accuracy angular geodetic measurements just re-

cently entered our practice. This is due to the fact that there are no secondary measurements of the triangular network along the entire territory, as well as the fact that the accuracies we obtain with angular measurements only cannot satisfy the accuracy requirements for the investigation of the horizontal measurements. Considering this it was agreed to accept one chain of triangles, starting from Nikopol town (l. p. 34) parallel to Danube river up to l. p. 96 which is located between Russe and Byala (Fig. 1) following afterwards southern direction close to levelling chain No 2. We have immediate repetitive measurements for the regions of Strazhitsa and Chirpan and the areal networks will be processed. In [9] using data from 1921-1933 and secondary determinations made in 1956, the first measurements of the horizontal movements in Chirpan region were made and the results obtained show an explicit trend in north-western direction. We dispose of secondary measurements made in 1987 in Strazhitsa which also provide ground to start analysis and supplementary interpretation of horizontal movements in this region as well. Undoubtedly these studies with the aid of information obtained with classical measurements will provide for an approximate a priori estimation of the planned GPS measurements of the Balkans as a part of the Europrobe Project.

During the first stage of the measurements for a given region we shall use not only the mentioned data but also the available geophysical information. In order to determine the general nature of the epoch 1986 and the determination of the century course during the last 50 years by geomagnetic field elements, the computation of "normal" and "abnormal" fields and the unification of all absolute measurements made this far a general absolute geomagnetic picture of Bulgaria was made for the period 1978-1980 [4]. These data provide grounds to make the respective analyses and to search for the dependence between the movement of the lithospheric blocks and the anomalies in the geomagnetic field on the research site, i. e. to investigate one of the criteria for short term earthquake prediction.

The seismicity in Bulgaria is a part of the Alpine-Himalayan Belt seismicity. We have observed for the territory of Bulgaria a series of strong seismic events and only during this century five macroseismic events occurred with magnitude of $M=7,0$ [18].

With respect to former and future strong earthquakes the most interesting are the following seismic zones: Krcsna, Plovdiv, Shabla and Gorna Oryahovitsa [2].

3.3. On the possibility of applying modern available space techniques, classical equipment and the methods of the geodynamic investigations

Recent space technology — laser equipment and GPS systems reveal great possibilities to the high precision determination of point location and distance on the earth surface. This could be used in the determination of the lithospheric horizontal movements. The results from GPS measurements made in Bulgaria during the last two years explicitly show the possibility to determine the joint location of points on the earth surface with a relative error of the limits of 10^{-6} - 10^{-7} . With an appropriately selected program giving observational conditions and the methods of mathematical processing, the single frequency GPS receivers we dispose of can provide this accuracy at distance between the points of the order of 25-30 km. This allows to control the geodynamic networks or the basic lines, as well as to investigate

the changes in the network point location due to tectonic or technogenic factors [7]. In theoretical aspect the methods for the kinematic parameter estimation are defined, based on plate tectonic models developed with GPS measurement data on different epochs [7].

These accuracies allow to apply the GPS systems for measurements August-September 1991 along the transect over the Bulgarian territory. After these initial measurements with GPS instruments the results of previous triangular determination and the new spaceborne ones will be compared in order to provide initial estimation of the shift vectors for the selected points. This will enable the obtaining of quantitative estimates reflecting the local and micro-local geodynamics within the limits of the surveyed region for the period between triangulation and the measurements in 1991. Afterwards we shall make the following GPS measurements along determined transect. It may be reasonable to change the transect configuration in order to embrace regions where higher seismic activity was recorded. Further studies will be done based on comparison between GPS measurement results of former cycles. The high accuracy of these measurements especially if double frequency GPS receivers will be used allows to trace the geodynamics of the studied geotectonic structures with time discretion of 2-3 years.

The first instrumental registration of crust movement in Bulgaria was made in 1905. Nowadays 14 seismological stations operate in the country [2]. Since 1980 the National Express Telemetric System for Seismological Information operates in Bulgaria.

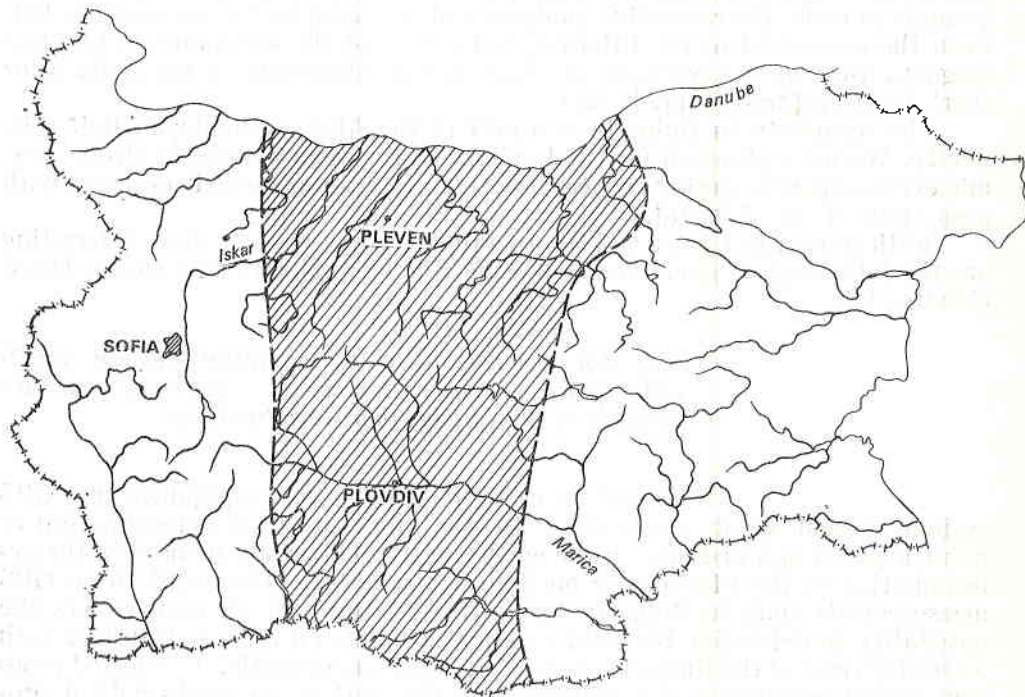


Fig. 3. Location of the test site on Bulgarian territory

4. Conclusion

We may consider that the complex of methodological, technical and organizational support is a serious background to start initially on the Bulgarian territory and afterwards on the Balkans a research activities within the coming 5-10 years based on the Europrobe Project. It is expected that during the research process large amount and various in type information will be stored: spaceborne (laser distance meters, GPS-measurements), geophysical (seismic, gravimetric, geomagnetic, meteorologic, geodetic), electrooptical and laser ground-based measurements, classical angular, levelling, gravimetric. The processing and the analysis of all the data requires for the establishment of advanced informational system, allowing for the rational selection, the systematization and the storage of the received information.

We should mention that the data from the both large projects VEGENER - IDEAL and EUROPROBE may provide a complex information on the regional, local and microlocal geodynamics.

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Космически, наземни и моделни изследвания на литосферните движения на Балканския полуостров и в България в рамките на проекта „Европроб“

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(Резюме)

В статията се обсъждат целите, перспективите и методите на изследване на движенията на литосферата на Балканите и България в съответствие с проекта „Балканпроб“, който е южно отклонение на европейския геодинамичен проект „Европроб“.

За решаване на тези задачи комплексно се използват аерокосмически, геодезични, геофизични и геолого-тектонски материали, измервания и наблюдения.

Комплексните изследвания се провеждат по дължината на геодинамичен траверс, който пресича напречно основните тектонски зони от територията на България, а така също и разделящите ги разломни нарушения. Някои от тези дислокации имат и сеизмогенен характер.

Крайната цел на проекта „Балканпроб“ е изучаването на геодинамиката на територията на Балканите и задачата ще се осъществява през настоящото последно десетилетие на XX век.