PRELIMINARY RESULTS OF TIME SERIES ANALYSIS OF EPN STATIONS IN CENTRAL EUROPE REGION[1]

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1. INTRODUCTION AND MOTIVATION

Comprehensive geodynamical researches in the Middle and Eastern Sudety Mts. as well as in the Fore-Sudetic Block started in 1996 as the GEOSUD project (financed by Polish State Committee For Scientific Research) and realised by the Department of Geodesy and Photogrammetry, Agricultural University of Wroclaw. In 1997 as the co-operation with Institute of Rock Structure and Mechanics of Czech Academy of Sciences in Prague, the existing local networks were connected into the one research network SUDETES. Geodynamic research investigations are based on yearly repeated satellite GPS observations of local geodynamic network (LGN) points. Localisation of the observation points, adapted to specific geological and tectonic conditions (Sudety Mts. and Sudety Foreland envelop the area of north-east margin of Bohemia Massif with complicated block-type geological structure), causes large differences of base line lengths. Geometric heterogeneity of the networks requires a specific strategy of data processing (data from various receivers, network construction, ambiguity resolution, ionosphere and troposphere modelling, normal equations solution, connection with EUREF/IGS permanent stations and distribution of results).
The definition of a geodetic reference system by modern techniques (GPS) requires systematic temporal changes of the position of the defining stations.
In this paper authors present the results of time series analysis of EPN stations located no more then 700 km from our LGN in Sudety Mts. And Sudety Foreland (e.g. WTZR, BOR1, GRAZ, PENC, POTS, JOZE, GOPE, BOGO, LAMA, WROC), performed for the selection of the best reference stations. The proposed methods of coordinates time series analysis using Matlab libraries and own Matlab toolboxes are discussed. The results of comparison of analysis results with tectonic background for EPN stations are presented.

2. THE REGIONAL AND LOCAL GPS NETWORKS

Since 1996 at the European Continent the GPS EUREF Permamnent Network supervised by the EUREF-Technical Working Group has been functioned (EUREF TWG).
The EPN network was originally established for serving as an European regional geodetic reference frame. It has been treated as the regional as well as recognised as a part of International GPS Service (IGS). During the meeting in Tromso (21 June 2000) the EUREF TWG have created a new EPN Special Project (SP), charged with the tasks to monitor the EPN weekly combined SNX solutions and to analyse the EPN time series in order to further improve the network performance (*http://www.epncb.oma.be/projects/sp_timeseries.html*).

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Within the above mentioned project the authors of this paper have introduce a time series analysis of the EPN stations located at the one of the six network's regions (fig. 1) - (V. Central Europe STU/AUW).

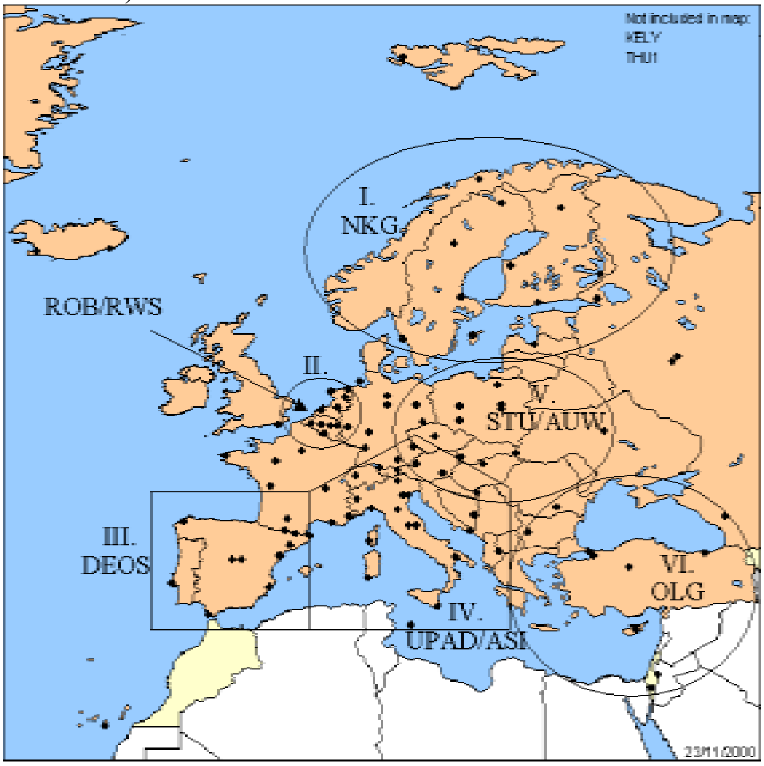

Fig. 1 The EPN subnetworks monitored by the SP groups (http://www.epncb.oma.be/projects/sp_timeseries.html).

In 1992 an investigation of the recent movement of the upper layer of lithosphere of the areas in Eastern Sudety Mts. and Sudety Foreland was begun. The following areas were investigated: Śnieżnik Massif, Paczków Tectonic Trouch and Stołowe Mts. In 1996 these separate projects were included into the GEOSUD project and geodynamical GPS local precise network GEOSUD *(Cacoń S., Kontny B., Bosy J. 1998).*

Fig. 2. The geodynamical local GPS network SUDETES

The geodynamical GPS network SUDETES (Fig. 2) covers the area Middle- and East-Sudeten Mts. and Sudeten Foreland and links together existing Czech and Polish local GPS networks in this area. The Polish part of this network includes selected sites of the network GEOSUD, established by Department of Geodesy and Photogrammetry of Agricultural University of Wrocław in 1996. The Czech part consists mainly of the network SILESIA built in 1997 by the Institute of Rock Structure and Mechanics of the Academy of Science in Prague *(Schenk V., Cacoń S., Bosy J., Kontny B., Kottnauer P., Schenková Z., 1999).*

While the data processing the SUDETES network has been connected with the regional EPN by especially chosen particular permanent stations. The choice has been depended on many factors as: station's location in relation to local network, geological structures existing in the area where stations have been located as well as observation data quality and quantity. The authors have investigated the time series analysis based on the data obtained from stations which are located in the range of 700 km from the area where the local geodynamics network „SUDETES" has been created. Furthermore, the results of analyses have been related to main geological structures of the Central Europe.

3. TIME SERIES ANALYSIS OF SELECTED EPN STATIONS

The input information used for time series of stations' positions summary $X_s(t_i), Y_s(t_i), Z_s(t_i)$ during the particular GPS weeks , $t_i = 860, 861, ..., 1115$, have been obtained from the EUREF network solution (the SINEX files). The geocentric coordinates of the station have been transformed into the geodetic coordinates $\{X_s(t_i), Y_s(t_i), Z_s(t_i)\} \rightarrow \{\varphi_s(t_i), \lambda_s(t_i), h_s(t_i)\}$, by following the algorithm presented in *(Fukushima 1999).* Furthermore, the linear changes of station's position (Fig. 3) in the direction of φ (N-S) and λ (E-W) have been calculated following the formula:

$$\Delta\varphi_s(t_i) = R_s[\varphi_s(t_i) - \varphi_s(t_0)]$$
$$\Delta\lambda_s(t_i) = R_s[\lambda_s(t_i) - \lambda_s(t_0)],$$

where R_s is a average radius of the ellipsoid curvature related to the station *s*, $R_s = \sqrt{M_s N_s} + h_s$, and the mean curvature radiuses M_s and N_s, have been calculated on the basis of the WGS'84 parameters.

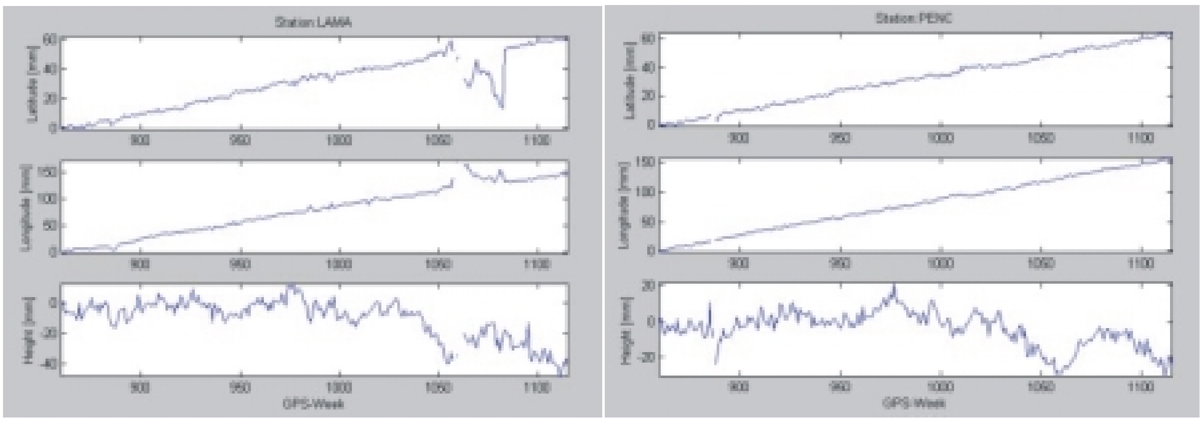

Fig.3. Time series of linear changes of position of the three selected EPN stations' in directions N-S and E-W.

Time series as $\Delta\varphi_s$ and $\Delta\lambda_s$ have been recognised as the base for the quality hierarchy of the station. The mentioned hierarchy has been introduced by following the iteration process where the criteria was discrepancy degree of time series of particular station in relation to the mean trend determined by using the least squares error's method based on the stations. The iteration process may be divided into three steps:

Step 1: Determination of φ and λ change trend (Fig. 4) based on $\Delta\varphi_s$ and $\Delta\lambda_s$ for n chosen stations, assuming the $p_{\varphi,\lambda} = a_0 + a_1 t$ as a model of station's movement, where coefficients a_0 and a_1 are estimated;

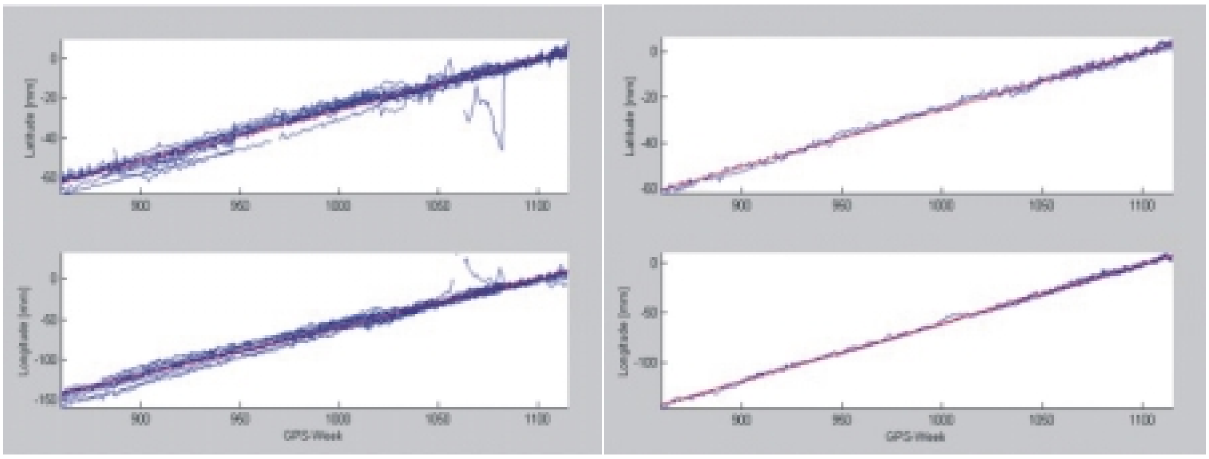

Fig. 4. Determination of φ and λ change trend based on $\Delta\varphi_s$ and $\Delta\lambda_s$ for n chosen stations (iteration No. 1 and 15)

Step 2: Calculation of standard deviation $\sigma_s = \sqrt{\sigma^2_{\varphi_s} + \sigma^2_{\lambda_s}}$, where $\sigma^2_{\varphi_s} = \frac{1}{m}\sum_{i=1}^{m}\left[(p_\varphi - \Delta\varphi_s)\Big|_{t_i}\right]^2$,

$\sigma^2_{\lambda_s} = \frac{1}{m}\sum_{i=1}^{m}\left[(p_\lambda - \Delta\lambda_s)\Big|_{t_i}\right]^2$ and m is observations number done at particular stations;

Step 3: Rejecting the station with the maximal value of σ_s, decrease n value by one and return to Step 1.

Eliminated stations become the position of $n, n-1, n-2, ..., 1$ in hierarchy *(Table 1)*.

Table 1

STATION	No. obs.	Standard deviations for each iteration in mm																						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
BOR1	255	2.3	2.0	2.6	3.3	3.3	2.9	2.4	2.3	1.9	1.8	1.7	1.7	1.7	1.8	1.8	1.8	1.6	1.6	1.6	1.6	1.5	1.5	1.5
PTBB	57	1.9	1.8	1.8	1.8	1.9	1.9	1.8	1.7	1.7	1.6	1.6	1.7	1.6	1.6	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.7	-
UZHL	95	2.4	2.3	2.4	2.5	2.6	2.6	2.4	2.3	2.2	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	-	-
KLOP	81	2.7	2.6	2.6	2.6	2.9	2.7	2.7	2.5	2.6	2.5	2.6	2.5	2.4	2.4	2.4	2.3	2.2	2.2	2.2	2.2	-	-	-
HOBU	50	2.3	2.5	2.4	2.3	2.4	2.4	2.4	2.5	2.5	2.6	2.6	2.4	2.5	2.5	2.4	2.3	2.5	2.6	2.6	-	-	-	-
GSR1	12	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.4	2.4	2.3	2.4	2.4	2.4	2.4	2.5	2.6	-	-	-	-	-
OSJE	32	2.2	2.4	2.3	2.3	2.3	2.3	2.4	2.5	2.5	2.6	2.6	2.4	2.5	2.5	2.3	2.4	2.6	-	-	-	-	-	-
PENC	255	2.4	2.5	2.8	3.2	3.1	2.8	2.6	2.6	2.6	2.7	2.6	2.5	2.6	2.6	2.6	2.4	-	-	-	-	-	-	-
GRAZ	254	3.7	3.8	4.3	5.0	4.9	4.5	4.0	3.9	3.5	3.5	3.0	3.0	3.0	2.8	2.8	-	-	-	-	-	-	-	-
GOPE	255	3.3	3.2	3.7	4.2	4.1	3.8	3.4	3.3	3.1	3.1	2.8	2.9	2.9	2.8	-	-	-	-	-	-	-	-	-
POTS	256	2.9	2.7	2.7	3.0	3.1	2.9	2.8	2.7	2.7	2.7	3.2	3.1	3.1	-	-	-	-	-	-	-	-	-	-
DRES	82	3.8	3.9	3.9	3.9	3.8	3.8	3.9	4.0	4.1	4.2	4.2	4.1	-	-	-	-	-	-	-	-	-	-	-
SBGZ	120	5.3	5.1	5.3	5.4	5.4	5.3	5.1	5.0	4.9	4.9	4.8	-	-	-	-	-	-	-	-	-	-	-	-
WTZR	256	4.8	4.9	4.2	3.8	4.1	4.2	4.5	4.6	4.9	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-
BZRG	125	4.8	5.0	4.8	4.5	4.4	4.6	4.8	4.9	5.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WROC	192	5.5	5.7	5.0	4.3	4.3	4.7	5.2	5.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KARL	136	6.4	6.7	6.3	6.0	5.9	6.1	6.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MOPI	224	6.9	7.2	6.4	5.8	5.8	6.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OBER	229	7.1	7.4	6.7	6.0	5.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PFAN	211	6.8	6.6	6.4	6.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BOGO	256	7.5	7.2	8.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
JOZE	256	10.2	10.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LAMA	253	12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$d\varphi$ [mm/Y]		**13.4**	**13.5**	**13.6**	**13.7**	**13.6**	**13.6**	**13.5**	**13.5**	**13.5**	**13.5**	**13.3**	**13.2**	**13.2**	**13.0**	**13.0**	**13.0**	**13.2**	**13.2**	**13.1**	**13.2**	**13.3**	**13.4**	**13.4**
$d\lambda$ [mm/Y]		**31.0**	**31.0**	**30.6**	**30.3**	**30.3**	**30.5**	**30.7**	**30.7**	**30.8**	**30.8**	**31.1**	**31.2**	**31.1**	**31.2**	**31.3**	**31.1**	**31.1**	**31.0**	**31.0**	**31.0**	**31.0**	**31.0**	**30.8**

As the result of investigated time series analysis the stations hierarchy of 23 has been noticed with the observations quality as the mean point (reliability of correlation of individual station's position with trend). Figure 3 presents the analysed data results (marked red) The following step of analysis was comparison of quality results with length of observation time. (Fig. 3, marked blue).

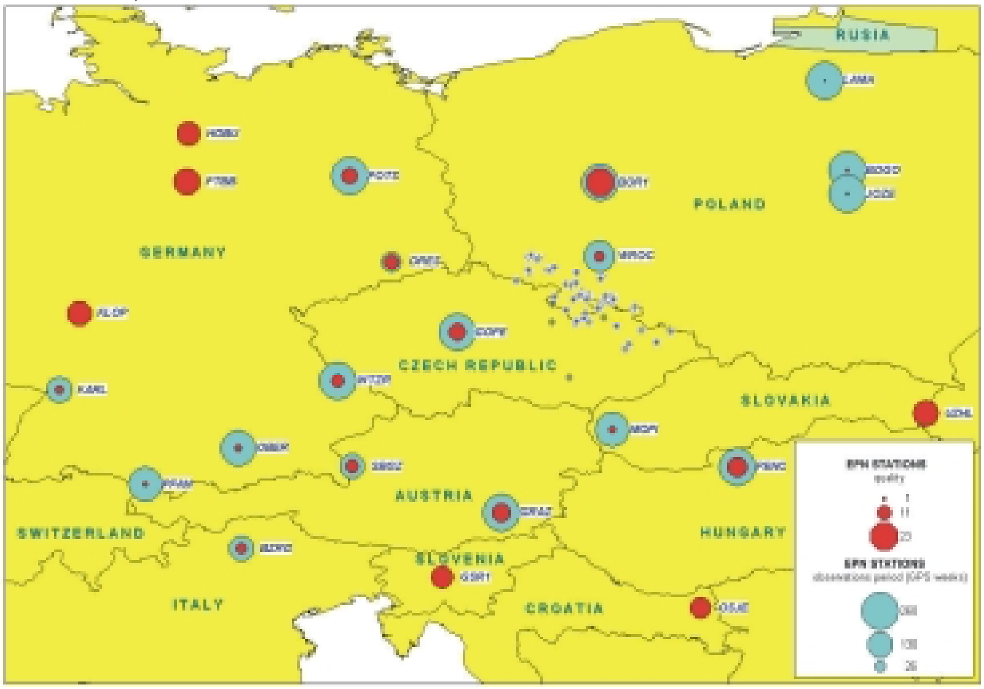

Fig. 3 Quality and quantity data analysis results at the EPN stations (observation time).

The group of 16 stations, observed at least 2 years (120 weeks), have been recognised. Observations have been processed by using the time series analyse and finally the hierarchy has been determined (Fig.4).

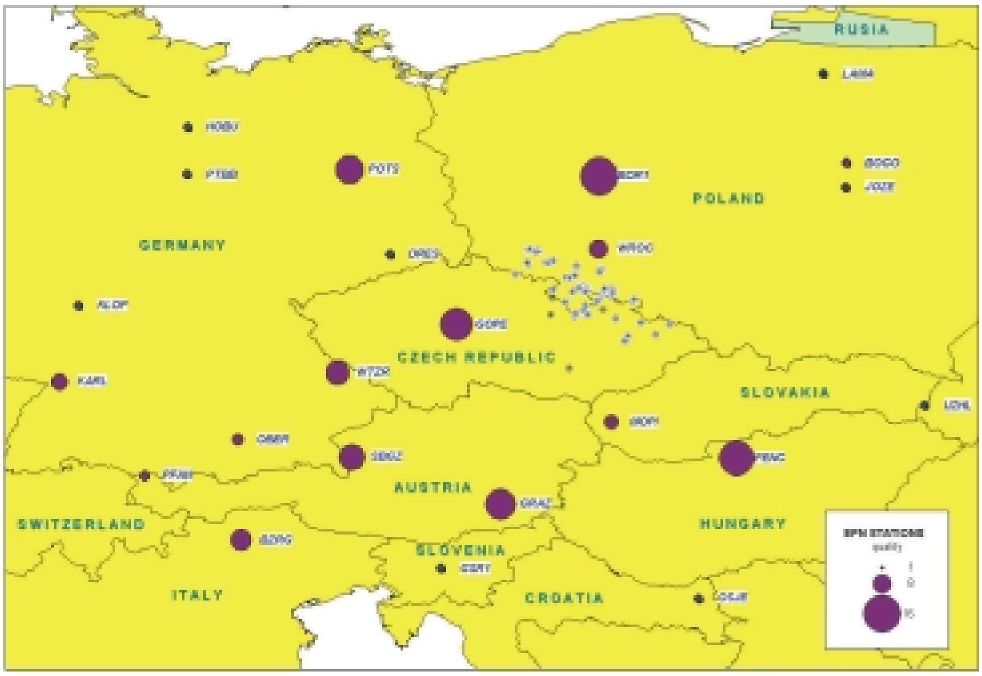

Fig. 4 Results of quality analyse for stations where the observation time was longer than 2 years.

Based on the above mentioned analysis it can be concluded that the qualitative best stations are:

1. BOR1 (Borowiec, Space Research Centre, Poland);
2. PENC (Penc, FOMI Satellite Geodetic Observatory, Hungary);
3. GOPE (Pecny, Research Institute of Geodesy, Czech Republic);
4. GRAZ (Graz-Lustbuehel, Institute for Space Research, Austria);
5. POTS (Potsdam, GeoForschungsZentrum, Germany);
6. SBGZ (Salzburg/Gaisberg, Institute for Space Research, Austria);
7. WTZR (Wettzell, Bundesamt fuer Kartographie, Germany);
8. BZRG (Bolzano, Ufficio Geodetico di Bolzano, Italy);
9. WROC (Wroclaw, Agricultural University of Wroclaw, Poland);
10. KARL (Karlsruhe, Bundesamt fuer Kartographie, , Germany);
11. MOPI (Modra-Piesok, Slovak University of Technology, Slovak Republic);
12. OBER (Oberpfaffenhofen, GeoForschungsZentrum, Germany);
13. PFAN (Pfaender/Moos/Bregenz, Institute for Space Research, Austria);
14. BOGO (Borowa Gora, Institute of Geodesy and Cartography, Poland);
15. JOZE (Jozefoslaw, Warsaw University of Technology, Poland);
16. LAMA (Lamkowko, University of Warmia and Mazury in Olsztyn, Poland).

Results of the analyses are taken as a base for weighting process while the GPS data processing of the local geodynamics network „SUDETES". *(Bosy, Kontny 1998)*.

4. COMPARISON OF ANALYSIS RESULTS WITH TECTONIC BACKGROUND FOR EPN STATIONS

The highest-qualified stations by quality (reliability of correlation of individual station's position with trend), observed at least 2 years (120 weeks), are located within the range of two basic structural units: Varyscides and Alpides, at the western side of the Teissere-Tornquist zone (T-TZ). All analysed stations situated at the eastern side of the T-TZ zone within the range of East European Craton – EEC (BOGO, JOZE, LAMA), are be situated in the presented hierarchy at the latest positions (Fig. 5). The reason of this fact is not explained yet. The stations' location as well as many other reasons would be taken into account. However, it could be emphasised that stations can not be taken as the connection points (reference) for local tectonic movements investigations in the Sudety Mts. and also its foreland.

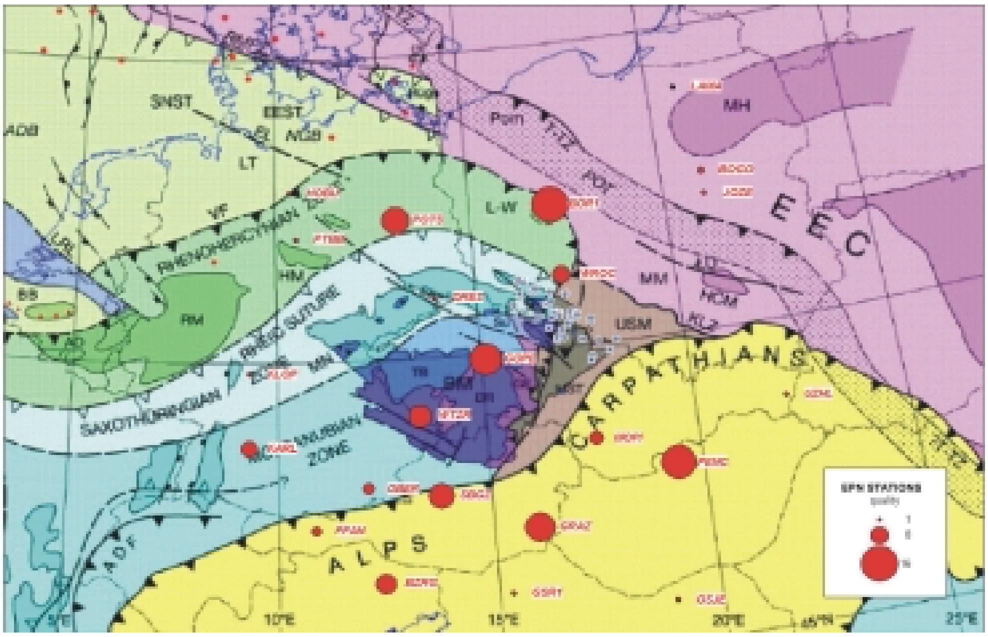

Fig. 5. The quality stations classification related to the mean tectonical units presented on the map (http://www.geofys.uu.se/eprobe).

5. CONCLUSIONS

Taking into account the presented classification as well as the distance between stations and the local research area (Sudety Mts.), the best conditions of connection of local measurements to the European network have been fulfilled for the stations: BOR1, PENC, GOPE, GRAZ and POTS. Stations as WROC, WTZR and MOPI, located also close to the research area possesses significantly worse quality parameters. Presented analysis have been related only to the horizontal coordinates. As the next step, changes of EPN stations' altitude would also be taken into consideration.

6. ACKNOWLEDGMENT

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7. REFERENCES

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