Geomagnetic measurements of the net of repeat stations in the Republic of Macedonia

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Abstract: After the disintegration of Yugoslavia first geomagnetic measurements of three repeat stations in the Republic of Macedonia were carried out in 2002. Net of 15 repeat stations is set in 2003. Geomagnetic measurements were performed in 2003 and 2004. Republic of Macedonia not possesses Geomagnetic Observatory and the Department of Geology and Geophysics in past few years make efforts to establish it. Because of that, for the reduction of the data are used the data from neighbouring observatories: Panagiurishte - Bulgaria, L'Aquila - Italy, Grocka - Serbia, Penteli - Greece and Tihany - Hungary. The equipment from the Royal Observatory, Dourbes was used. It consists of:

- 1 Diflux/GPS receiver type FLM3/A serial 001
- 1 Proton magnetometer Geometrics G816 (electronics + sensor) serial 1579
- 1 Geodetic Tripod
- 1 Monocular digital compass KVH Data scope II pn#01-0162 Serial 02070033

and the equipment from the Faculty of Mining and Geology, Stip: 1 Diflux type LEMI 203 (from Tempus JEP project "Geomagnetic measurements and quality standards") and proton magnetometers BISON and Geometrics.

Field measurements included observation of the total vector of the geomagnetic field F, declination D and inclination I. On the basis of the measurements all parameters of the geomagnetic field of the Republic of Macedonia for these three years were calculated. Based on the results of the elements of the geomagnetic field geomagnetic maps were compiled.

1. Introduction

Present day geomagnetic measurements in the Republic of Macedonia started in 2002. They were carried out by the Department of Geology and Geophysics at the Faculty of Mining and Geology in Stip in cooperation with Royal Meteorological Institute - Geomagnetic Observatory in Dourbes, Belgium.
Within the Tempus Project IB_JEP-17071-2002 "Geomagnetic measurements and quality standards", during the period from 2003 to 2004, in the Dourbes Observatory training for geomagnetic measurements of 4 trainers was carried out, as well as practical measurements on the territory of the Republic of Macedonia. The Tempus Project made it possible a large number of engineers to learn the issues related to geomagnetic investigations.
In 2002 observing of several repeat stations was carried out in the Republic of Macedonia in order to define the site for the future Geomagnetic Observatory. The repeat stations in Mts. Galicica, Ponikva and Plackovica were studied several times. The analyses of the physical and other parameters indicated that the most appropriate location for the construction of the future Observatory is Mt. Plackovica.

In 2003 complete survey on 15 repeat stations on Macedonia was performed. The same was done in 2004.

2. The first measurement points in the year 2002

In absence of information about past repeat networks, our first repeat measurements network had to be planned from scratch. The focus is put on an optimal geographical distribution of stations and on the necessity to perform magnetic tests in order to find a location for the future magnetic observatory. Latter it is taking into account not only geological and magnetic considerations but also what sites were practical, available, and affordable. The three station network pictured on fig.1, was established.

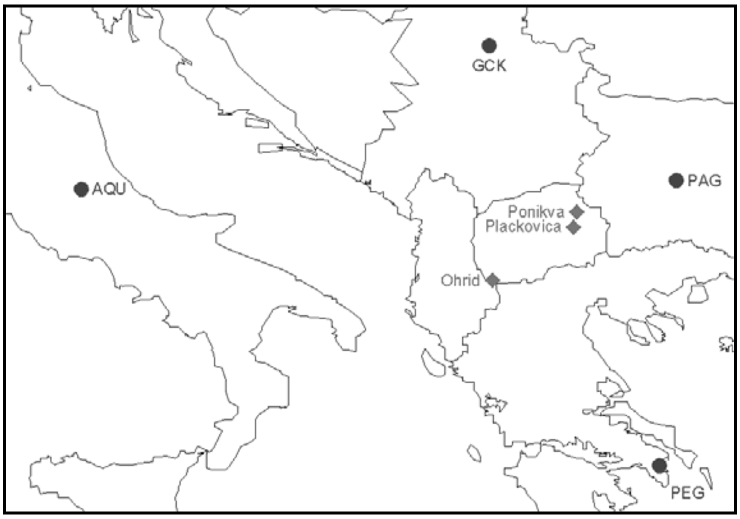

Figure 1. The first repeat stations of the Republic of Macedonia (diamonds), created in 2002. Also represented are nearby magnetic observatories (dots).

3. Measurements in Macedonia in 2003 and 2004

In 2003 and 2004 measurements of D, I and F were carried out on the grid of repeat stations. The names and the geographic coordinates of the 15 repeat stations are given in Table 1, and Fig. 2 show the map of repeat stations. Measured components of the geomagnetic field in 2004 and standard deviations are given in Table 2.

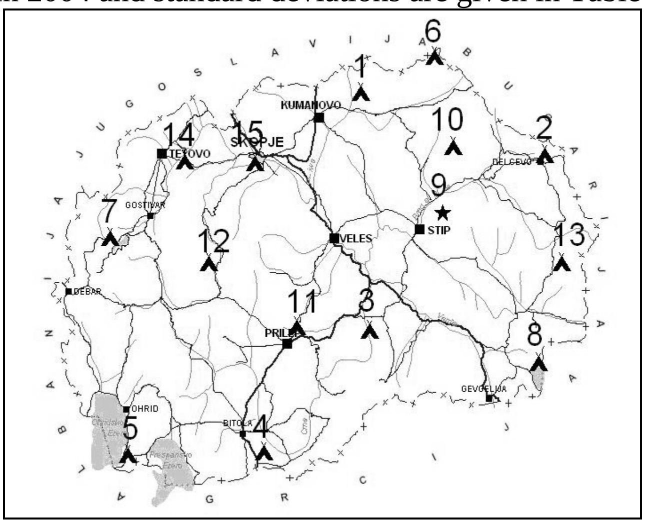

Figure 2. Map of repeat stations in the Republic of Macedonia.

Table 1. Geographic coordinates of repeat stations

Repeat station	Geographic latitude	Geographic longitude	Altitude
"Bajlovce"	42° 13' 16"	21° 55' 17"	592 m
"Crna Skala"	41° 59' 41"	22° 47' 28"	833 m
"Gradot Island	41° 23' 15"	21° 57' 06"	317 m
"Egri"	40° 57' 56"	21° 26' 54"	626 m
"Galicica"	40° 57' 23"	20° 48' 51"	1684 m
"Luke"	42° 20' 39"	22° 16' 29"	1180 m
"Mavrovo"	41° 42' 58"	20° 43' 38"	1418 m
"Nikolic"	41° 15' 54"	22° 44' 36"	300 m
"Plackovica"	41° 47' 41"	22° 18' 13"	677 m
"Ponikva"	42° 01' 35"	22° 21' 29"	1618 m
"Prilep lake"	41° 24' 11"	21° 36' 32"	870 m
"Sv. Marija Precesna"	41° 37' 38"	21° 11' 36"	837 m
"Slivnica"	41° 36' 54"	22° 51' 46"	1252 m
"Tetovo-Zelino"	41° 59' 09"	21° 04' 46"	522 m
"Vodno"	41° 58' 40"	21° 24' 57"	569 m

Table 2. Measured components and standard deviation of the geomagnetic field in 2003.5

Repeat Station 2003.5		Coordinates WGS84		**Total Field** [nT]		**Inclination** [°]		***Declination** [°]*	
Code	Locality	Long	Lat	Mean	st dev	Mean	st dev	Mean	*st dev*
BAI	BAILOVCE	42.221	21.921	**46723.5**	3.2	**59.248**	0.013	**2.918**	*0.026*
CRN	CRNA SKALA	41.995	22.791	**46886.4**	4.8	**58.883**	0.005	**3.188**	*0.017*
EGR	EGRI	40.966	21.448	**46399.2**	7.4	**57.748**	0.014	**3.004**	*0.037*
GAL	GALICICA	40.956	20.814	**46264.7**	2.8	**57.694**	0.005	**2.881**	*0.027*
GRA	GRADOT island	41.388	21.952	**46414.2**	5.0	**58.079**	0.015	**3.535**	*0.025*
LKA	LUKA	42.344	22.275	**47015.4**	4.2	**59.387**	0.006	**3.265**	*0.011*
MVR	MAVROVO	41.716	20.727	**46533.8**	4.2	**58.564**	0.010	**2.977**	*0.015*
NIK	NIKOLIC	41.265	22.743	**46569.5**	3.2	**58.197**	0.002	**3.078**	*0.006*
PLC	PLACKOVICA	41.795	22.304	**46645.9**	3.1	**58.618**	0.004	**3.162**	*0.010*
PON	PONIKVA	42.026	22.358	**46799.8**	1.9	**58.987**	0.003	**2.821**	*0.015*
PRP	PRILEP lake	41.403	21.609	**46634.6**	5.6	**58.275**	0.009	**3.042**	*0.013*
SLI	SLIVNICA	41.615	22.863	**46665.4**	4.7	**58.499**	0.006	**3.381**	*0.008*
SMP	ST MARIA PRE	41.627	21.193	**46532.1**	2.2	**58.444**	0.004	**3.084**	*0.006*
TET	TETOVO	41.986	21.079	**46717.7**	2.4	**58.757**	0.003	**3.109**	*0.005*
VOD	*VODNO*	*41.978*	*21.416*	***46712.3***	*2.6*	***58.789***	*0.002*	**3.199**	*0.009*

4. <u>Instruments for measuring the stations</u>

We used the instruments from the Dourbes Observatory. This is the instrumentation list:

- Proton magnetometer G816. The electrical supply is provided by D-cell batteries which are readily available
- Zeiss 010 Diflux (Mingeo demagnetisation) with Pandect fluxgate sensor
- Zeiss tripod (non-magnetic)
- Telescope with internal compass display (KVH DATASCOPE). This instrument facilitates finding targets when setting up the stations or when revisiting them
- 90° eyepieces for Zeiss 010 Telescope and Microscope (non-magnetic)
- Solar filter for sunshots. This small optical device is needed to make sunshots with the Zeiss 010 theodolite
- FLM3/A fluxgate electronics with GPS receiver and battery

and the equipment from the Faculty of Mining and Geology, Stip: 1 Diflux type LEMI 203 (from Tempus JEP project “Geomagnetic measurements and quality standards”) and proton magnetometers BISON and Geometrics.

5. Observation techniques

- Measurements on 15 repeat stations are made in only 2 weeks with 4 independent sessions for each point.
- Measurements were done in early morning and/or late afternoon, because these times favour elimination of the daily variation differential between the station and observatory used for the reduction.
- A preliminary proton magnetometer survey was performed before occupying each station to check the magnitude of the horizontal and vertical gradients to rule out magnetic pollution at the site.
- The standard DIflux 12 step session (protocol): 2 x target, 4 x D, 2 x targets, 4 x I was used. This protocol is very strict and eliminates almost all DIflux and theodolite dimensional and mechanical errors.
- The selected distance for targets is >5 km. Far away targets provide high accuracy orientation in space for declination measurements.

6. Reduction technique

Magnetic observatories are in operation in neighbouring countries, so we decided to use their data to reduce our field instantaneous data to annual mean data. We had to wait until the observatories published their definitive data, about typically 6 months after the year end. The data reduction procedures and formulae follow:
Given that the repeat survey gives us a measurement of *D* in station *Stat* at the epoch *t*:

$$D_{Stat}(t)$$

and that a nearby Observatory *Obs* supplies us with a measurement in the observatory at the same epoch *t* :

$$D_{Obs}(t)$$

as well as an annual mean in the observatory for epoch *a*:

$$\overline{D_{Obs}}(a)$$

We want to calculate the annual mean in the station *Stat* for epoch *a*:

$$\overline{D_{Stat}}(a)$$

It is postulating that:

$$\overline{D_{Stat}}(a) - \overline{D_{Obs}}(a) = D_{Stat}(t) - D_{Obs}(t) \qquad (1)$$

Hence it finds the annual means at epoch *a* at station *Stat* for the component *D*:

$$\overline{D_{Stat}}(a) = D_{Stat}(t) - D_{Obs}(t) + \overline{D_{Obs}}(a) \qquad (2)$$

The validity of the above postulate (1) depends mainly on the differential in daily variation between *Stat* and *Obs* and hence is influenced by: Distance in longitude and latitude between *Stat* and *Obs*, Geomagnetic Field activity, Time in the day and t – a. We performed this reduction for each measured component. Data from several observatories were used to reduce repeat station measurements: L'Aquila, Italy (AQU), Pedeli, Greece, (PEG), Grocka, Serbia, and Montenegro (we could not get the data for 2003), Tihany, Hungary, (THY), Nagycenk, Hungary (NGC) and Panagyurishte, Bulgaria (PAG). In table 3 and table 4 is given an example for reduction technique for one repeat station and figures 3, 4 and 5 present maps of measured elements in 2003.

Table 3. Summary of the Declination measurements at the repeat station Santa-Maria Precesna on august 9th 2003

Time UTC	Declination measurement at location:						Difference in Declination between *Stat* and Observatory				
	Stat	AQU	PEG	NGC	THY	PAG	Stat-AQU	Stat-PEG	Stat-NGC	Stat-THY	Stat-PAG
13:42		1.784	3.198	2.600	2.779	3.184					
13:43		1.785	3.200	2.602	2.781	3.184					
13:45		1.782	3.198	2.598	2.778	3.184					
13:46		1.782	3.198	2.598	2.777	3.184					
Mean:	3.035	1.783	3.199	2.600	2.779	3.184	1.252	-0.163	0.436	0.257	-0.149
Session #2											
14:18		1.804	3.220	2.637	2.818	3.218					
14:19		1.806	3.222	2.638	2.820	3.218					
14:21		1.806	3.222	2.637	2.819	3.218					
14:22		1.805	3.222	2.637	2.819	3.218					
Mean:	3.062	1.805	3.221	2.637	2.819	3.218	1.257	-0.159	0.425	0.243	-0.155
Session #3											
14:50		1.805	3.220	2.640	2.820	3.218					
14:53		1.809	3.222	2.643	2.824	3.218					
14:58		1.807	3.222	2.643	2.823	3.218					
15:00		1.809	3.223	2.645	2.825	3.218					
Mean:	3.067	1.808	3.222	2.643	2.823	3.218	1.260	-0.155	0.424	0.244	-0.150
Session #4											
15:23		1.814	3.223	2.652	2.831	3.218					
15:25		1.811	3.223	2.647	2.827	3.218					
15:26		1.811	3.223	2.647	2.827	3.218					
15:27		1.812	3.225	2.648	2.829	3.218					
Mean:	3.068	1.812	3.224	2.648	2.828	3.218	1.256	-0.156	0.420	0.240	-0.149
Final result, average of all sessions:							**1.256**	**-0.158**	**0.426**	**0.246**	**-0.151**

Table 4. Final result for the annual mean of magnetic declination at the station Santa-Maria Precesna for epoch 2003.5

At Observatories					At Station by reducing on					***At Station***	
AQU	PEG	NGC	THY	PAG	AQU	PEG	NGC	THY	PAG	**Average**	*StanDev*
1.833	*3.233*	*2.660*	*2.843*	*3.231*	*3.089*	*3.076*	*3.086*	*3.089*	*3.081*	***3.084***	*0.006*

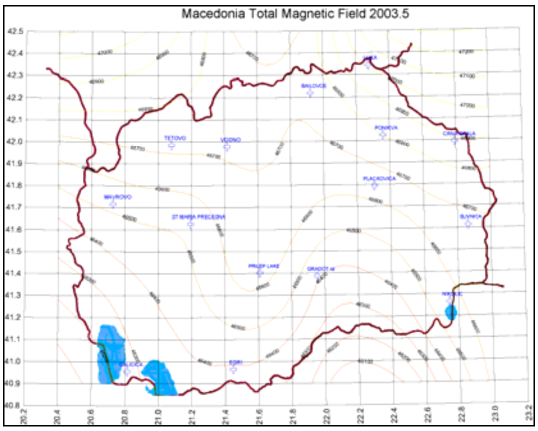

Figure 3. Map of measured values of total vector for epoch 2003.5

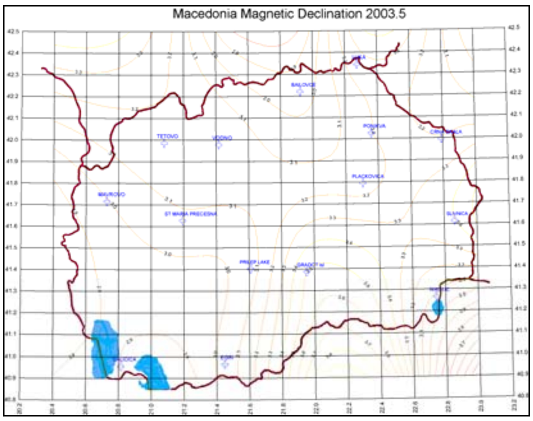

Figure 4. Map of measured values of declination for epoch 2003.5

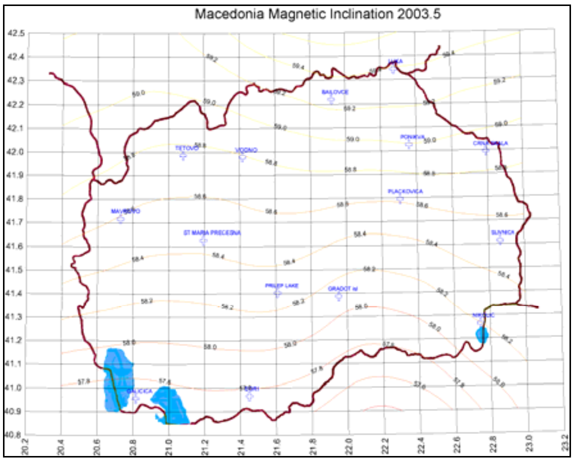

Figure 5. Map of measured values of inclination for epoch 2003.5

7. Geomagnetic Observatory in the Republic Macedonia in Mt. Plackovica

The Republic of Macedonia does not possess an operating Geomagnetic Observatory. It is important to say that over the past years the Faculty of Mining and Geology worked on a project for establishing a geomagnetic observatory with a net of repeat stations. The location for the Geomagnetic Observatory was decided after measurements carried out on the repeat stations network. Detailed geomagnetic map of the terrain was also compiled. Conditions are excellent owing to the fact that the population in the area is not dense and the stable gradient of the geomagnetic field that provide excellent conditions for the operation of the Observatory (Fig. 6). The implementation of Tempus project under the title “Geomagnetic measurements and quality standards” during the period 2003 – 2006 intensified the activities for establishing the Geomagnetic Observatory. The following equipment was purchased within the project: Theodolite Zeiss 010 A, Theodolite Lemi 203 and Variometer Lemi 008. The equipment will be used in the Geomagnetic Observatory and in measurements of the repeat stations network. The equipment is of the highest quality and in accordance with Intermagnet standards.

Parallel to the measurements of the geomagnetic field on the repeat stations network, the following parts of the Geomagnetic Observatory at Plackovica (Fig. 6, 7, 8) were completed:

- The construction site for the Observatory was acquired, the size being 10 hectares. The land was given by the Government of the Republic of Macedonia,
- A proposal plan for the construction of the Geomagnetic Observatory was developed, (see Fig. 9),
- Technical facility for the staff in the Geomagnetic Observatory (offices, living facilities, sanitation) were constructed,
- Power supply was installed to the existing facilities,
- Access road was constructed to the facilities of the Geomagnetic Observatory.

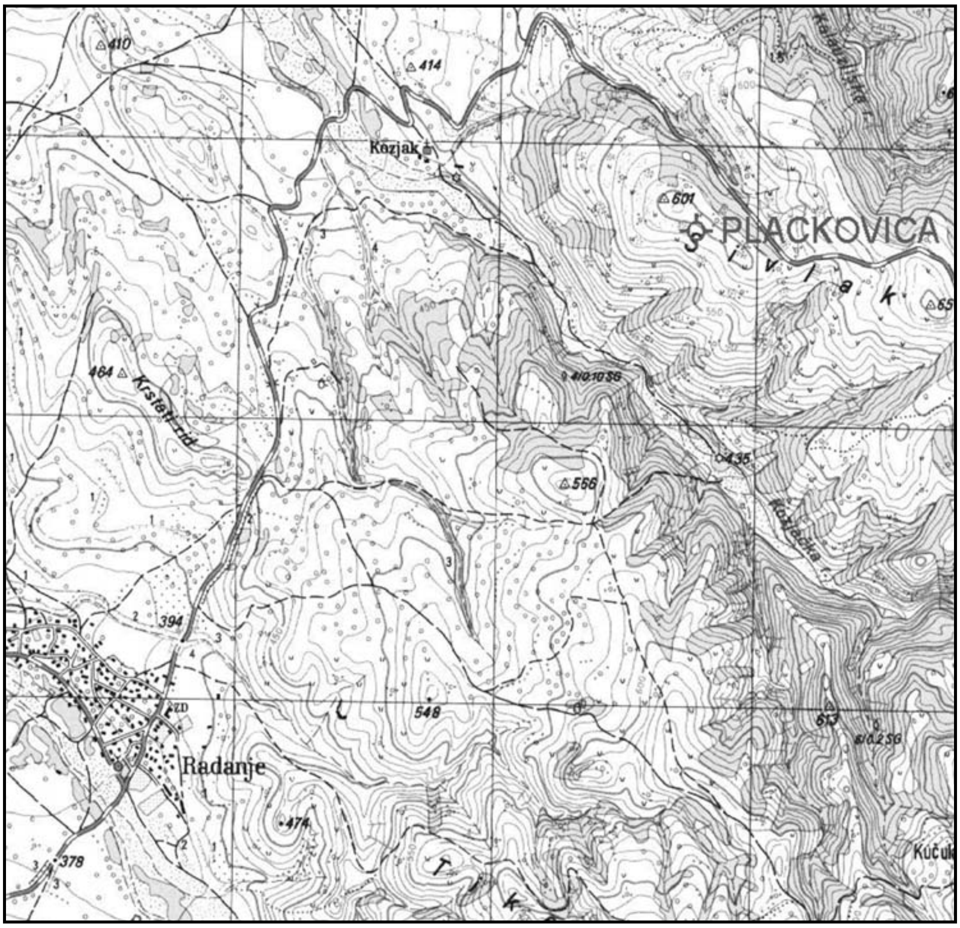

Figure 6. Topography of access road to the Plackovica repeat station

Figure 7. Satellite view and disposition of the proposed geomagnetic observatory

Figure 8. Geomagnetic Observatory, Plackovica - Implementation carried out so far.

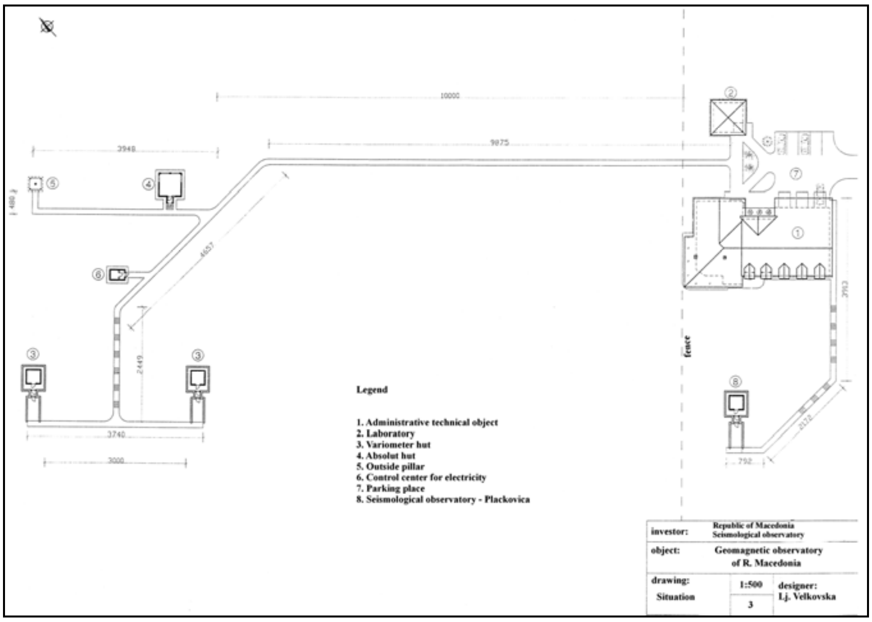

Figure 9. Schematic plan of the Geomagnetic Observatory Plackovica

8. The Future

The repeat station network in Macedonia should be connected to networks in neighbouring countries. The network should be integrated into MagNetE project, which plans the coordination of European magnetic repeat stations and the creation of a European database.

The network data should be used in providing magnetic services and products.

Finally, construction of a Macedonian geomagnetic observatory at the Plackovica repeat station site should improve reduction procedures and provide important geomagnetic data.

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