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Geomagnetism in Croatia – A Historical Overview

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ABSTRACT. A historical overview of almost 200 years of the geomagnetism in Croatia is given.

Keywords: geomagnetic surveys, geomagnetic observatory, geomagnetic network.

The oldest geomagnetic measurements on Croatian territory date from 1806 – 1823, when J. Marieni carried out a magnetic declination survey on the Adriatic coast. This is quite a remarkable fact if we bear in mind that C. F. Gauss started to consider the Earth's magnetic field in 1803 (Mokrović 1955a). However, one shouldn't be very surprised at the vast interest in magnetic mapping of the territory of Croatia. Being a military strategic information for centuries, the knowledge of the magnetic declination is still particularly important in the region where diverse cultures and interests meet. Futhermore, Croatian territory reveals many interesting magnetic features, as we shall soon see.

The second set of measurements dates back to years 1847 and 1854. In the 1847, K. Kreil measured declination, inclination and horizontal intensity on the land, and in 1854 at 30 points of the Adriatic coast. From 1867 to 1870 G. Schellander carried out measurements on 14 points situated on the islands of the eastern coast of the Adriatic sea. With support of the *Viennese Academy of Science*, E. Gelcić performed measurements on 9 stations in the 1886 and 1887. Supported by the *Austria-Hungarian Navy*, F. Laschober and V. Kesslitz surveyed Istria and Dalmatia on 14 sites during 1889 to 1890. With the intention to find out the secular variation of the dec-

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lination, V. Kesslitz completed survey on the Adriatic sea in 1907. From 1902 to 1904, R. Eötvös measured all three rectangular components of the geomagnetic field at Fruška gora and further to the north, but these data were never released. Following gravity variation measurements during 1911 and 1912 in Srijem, Gavazzi calculated declination at 51 points using his own and previous Eötvös data along with time variation registrations in Pula.

During the World War I, Germany and Austria-Hungary took on the task of geomagnetic survey of the territory of Croatia. These measurements relied on Potsdam, and the time variations registrations of the geomagnetic observatory in Pula were taken into account (Mokrović 1928).

Geomagnetic measurements on the Đurđevac – Bjelovar – Zagreb – Karlovac – Bubnjarci – North, and North-West border stretch, started in 1915 (Kugler 1916).

During 1916 these were continued east of the Koprivnica – Zagreb to Vukovar – Županja stretch. Horizontal intensity was measured at 54, and declination at 41 spot (Kugler 1922). Based on the measurements from both years, a relatively small geomagnetic anomaly near Lepavina between Križevci and Koprivnica was found (Fig. 1).

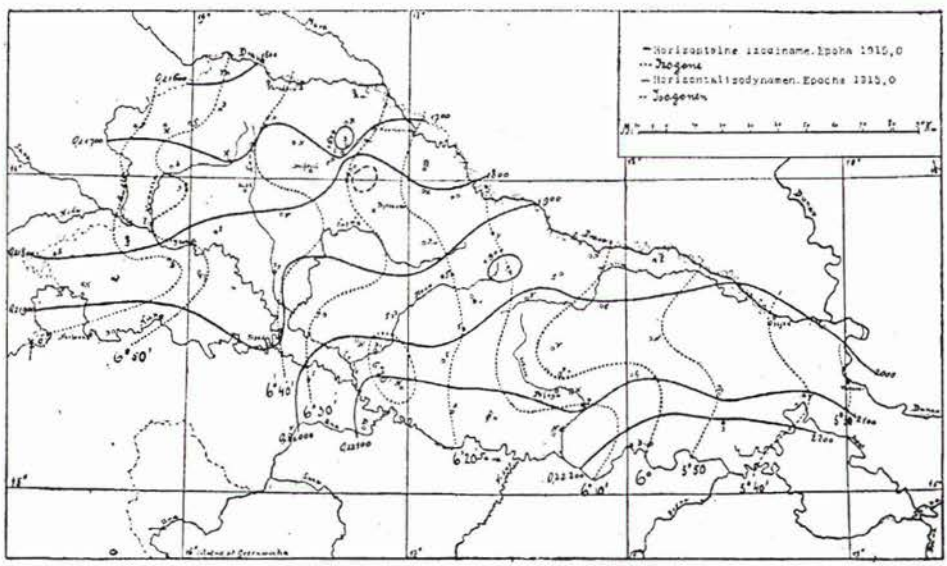

Fig. 1. *Izodynamic and Isogonal Map, Epoch 1915.0 (Kugler 1922).*

Mokrović in 1928 put together all the surveys as well as derived data relating to the epochs of 1806 – 1918 (Tab. 1) and used them in the calculation of the geomagnetic elements for the epoch 1927.5 (Fig. 2).

In 1929 Mokrović wrote on the subject of normal and anomal declination and horizontal intensity. Processing Kugler's 1915.0 epoch data, which at the time was the most homogeneous, and complete, because of the network stations density, Mokrović advised on the significance of the position of the geomagnetic observa-

Mjesto	Vrijeme	Geografske koordinate: dužina λ	Geografske koordinate: širina φ	t. god.	Deklinacija D	Inklinacija I	Horiz. jakost H_T	Opažač	Izvor
		° ′	° ′		° ′	° ′			
Ston Veliki	1890,0	17 42	42 50	9	3,2	58 35,6	23185	L-K	15
Strijevolna	1915,0	18 25	43 18	31	5 41,9	—	22272	Kg	5
Slubica	1915,0	15 58	45 58	52	6 51,2	—	21723	Kg	4
Subotište	1912,0	19 56	44 51	4	5 35	—	—	E	2
Sulet (Šulet)	VII. 1818	16 15	43 23	—	16 —	—	—	M	6
Sunja	1915,0	16 33	45 21	21	6 30,2	—	21052	Kg	5
Supetar	VII. 1818	16 33	43 22	—	16 18	—	—	M	6
Surdin	1912,0	20 16	44 47	8	5 23	—	—	E	2
Svelac	1907,0	15 45,8	44 1,4	—	7 48,9	—	—	K	7
Sv. Ivan	1915,0	16 14	39 45 57	35	6 43,0	—	21733	Kg	4
Šabac	1887,0	19 42,0	44 45,5	—	8 10,7	60 4,6	23256	Cj	12
Šumevec	1915,0	16 26	23 46 18	12	6 37,8	59 46,7	22410	Shd	13
Šupetar	VIII. 1847	15 59	43 44	—	14 0,8	61 2,6	21674	Kr	6
Šibenik	1860,0	15 59	43 44	—	13 37,1	60 58	21793	Kr	1
	1870,0	15 59	43 44	—	11 31,8	—	—	Sch	6
	1890,0	15 53,4	43 44,4	—	9 47,9	59 46,4	22538	L-K	15
	1907,0	15 53,4	43 44,4	—	8 18,1	—	—	K	7
Šimanovci	1912,0	20 4 47	44 52 33		5 30	—	—	E	2
Tajer	1905,0	15 11,5	43 51,9	—	8 20,0	—	—	K	7
Tkalčić	1850,0	18 42	42 25	—	8 29,9	—	—	L-K	15
Ton veliki	1907,0	14 56,0	44 10,4	—	8 35,4	—	—	K	7
Travnik	1890,0	17 39	44 14	—	8 43,7	59 43,1	22591	K-S	3
	1907,0	17 39	44 14	—	7 20	—	22773	K	11
Trebinje	1890,0	18 21	42 43	—	8 37,0	58 23,3	23240	K-S	3
	1907,0	18 21	42 43	—	7 14	57 49	23512	K	11
Trpanj	1890,0	17 17	43 1	—	9 3,8	58 47,3	23019	L-K	15
Ugrinovci	1912,0	20 11	1 44 52	18	5 26	—	—	E	2
Ušice	1918,0	19 34,0	43 51,9	—	7 25,9	58 57,1	22819	Shd	13
Valjevo	1918,0	19 52,6	44 16,6	—	4 42,0	59 21,0	22629	Shd	13
	1850,0	18 18	45 18	—	—	62 49	20363	Kr	1
Varaždin	1915,0	16 19	52 46 18	29	6 45,0	—	21644	Kg	4
Velika	1915,0	17 39	49 45 27	47	5 56,2	—	22023	Kg	5
Velika Gorica	1915,0	16 2	56 45 42	25	6 51,5	—	21877	Kg	5
Velika Mučna	1915,0	16 45	24 46 7	22	—	—	21700	Kg	5
Vel. Pisanica	1915,0	17 2	41 45 47	53	5 25,0	—	21876	Kg	5
Vinica	1915,0	16 9	12 46 20	20	—	—	21576	Kg	4
Vinkovci	1915,0	18 49	15 45 16	37	5 41,4	—	22139	Kg	5
Vir	VII. 1852	15 3	— 44 18	—	16 45	—	—	M	6
Virovitica	1915,0	17 25	20 45 50	00	6 9,6	—	21935	Kg	5
	VII. 1818	—	—	—	14 —	—	—	M	6
	1850,0	16 11	— 45 5	—	13 8,4	59 44	22420	Kr	1
	VII. 1854	15 4	— 43 5	—	12 32,0	59 31,9	22517	Kr	6
Vis	V. 1869	15 12	3 43 4	15	10 58,4	59 12,6	22653	Sch	6
	1870,0	16 12	3 45 4	15	10 54,9	—	—	Sch	6
	1890,0	16 11,2	— 43 3,5	—	9 3,7	58 40,6	23138	L-K	15
	1907,0	16 11,8	— 43 3,5	—	7 42,0	—	—	K	7
	1890,0	19 18	— 43 47	—	7 50,2	59 2,7	22943	K-S	3
	1907,0	19 18	— 43 47	—	6 27	58 58	23185	K	11
Višegrad	1918,0	19 17,8	— 43 47,3	—	—	58 55,9	22834	Shd	13
Vlasenica	1890,0	18 57	— 44 11	—	8 13,9	59 31,3	22644	K-S	3
Vočin	1915,0	17 32	31 45 27	9	6 1,5	—	22064	Kg	5
Vrsa	1912,0	20 9	32 44 56	42	5 27	—	—	E	2

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		° ′	° ′	° ′	° ′			
Volinja	1915,0	16 29	10 45 12	1	—	—	21984	Kg	5
	1915,0	16 28	43 45 12	15	—	—	21978	Kg	5
Vranje	1918,0	21 55,9	— 42 33,0	—	3 58,2	57 32,4	23387	V	8
Vrbovec	1915,0	16 24	54 45 52	35	6 48,7	—	21810	Kg	4
Vukovar	1915,0	18 59	54 45 21	13	5 30,2	—	23048	Kg	5
Zabok	1915,0	15 54	52 46 1	50	6 44,9	—	21741	Kg	4
	29. 1850,0	15 59	— 45 49	—	13 58,8	62 33	20909	Kr	1
Zagreb	1887,0	15 59,1	— 45 48,8	—	9 59,1	61 18,7	21906	Cj	12
	1907,0	15 59	— 45 49	—	8 3	60 39	22063	K	11
Zaječar	1918,0	22 16,2	— 43 54,4	—	4 7,4	59 4,7	22928	N	8
Zaprešić	1915,0	15 49	28 45 50	19	6 50,1	—	21745	Kg	4
Zemun	1850,0	20 24	— 44 50	—	11 26,5	61 13	21568	Kr	1
	1907,0	20 26	— 44 50	—	5 52	59 28	22088	K	11
	1912,0	20 23	22 44 51	20	5 15	—	—	E	2
Zenica	1887,0	17 55,2	— 44 11,8	—	8 30,1	59 54,7	22679	Cj	12
	1890,0	17 54	— 44 12	—	8 39,4	59 57,3	22577	K-S	3
Zvornik	1890,0	19 7	— 44 23	—	8 17,6	59 33,4	22932	K-S	3
Žepče	1887,0	18 2,5	— 44 25,7	—	8 56,2	59 47,0	22616	Cj	12
	VII. 1818	—	—	—	14 36	—	—	M	6
	VII. 1819	—	—	—	14 19	—	—	M	6
Žirje	VI. 1821	—	—	—	16 12	—	—	M	6
	VI. 1868	15 37	55 43 49	8	11 29,6	60 14,7	21725	Sch	6
	1870,0	15 37	55 43 49	8	11 29,6	—	—	Sch	6
Žirovac	1912,0	19 48	6 44 58	29	5 41	—	—	E	2
Žut	1907,0	15 22,7	— 43 48,1	—	8 17,9	—	—	K	7

[a] Srednja iz dvije nesuglasnih redukcija na epohu 1850,0 dobivenih iz mjerenja od 1847,8 ($D = 13° 31{,}0'$) i 1851,6 ($D = 13° 42{,}7'$).

Tab. 1. *A Part of 1806 – 1918 Geomagnetic Elements (Mokrović 1928).*

tory, as the basis for time reductions of the data. In conclusion, Mokrović pointed out the relationship between horizontal intensity anomaly and geological structure of the Earth's crust in Croatia.

It should be highlighted that in 1938 and 1939 the *Vojno-geografski institut* (*Military-Geographical Institute*) from Belgrade, in agreement with the *Geofizički zavod* (*Geophysical Institute*) from Zagreb was preparing the establishment of the geomagnetic observatory. On that occasion the *Geophysical Institute* proposed the area between Slavonski Brod and Vinkovci. However, the observatory wasn't set there, essentially because of the political directive: "*the observatory should not be placed on this* (i.e. Croatian) *side of so-called amputation line, but has to be close to Belgrade*" (Mokrović 1948).

However, the observatory failed to be established at that time. In 1938 the *Military-Geographical Institute* completed the determination of the magnetic declination in 22 stations from all over the contemporary Yugoslavia.

As far back as 1947, the *Expert geodetic council* concluded that it was necessary to undertake a magnetic survey of the country, but it "*would not satisfy because of the lack of the geomagnetic observatory on our territory.*"

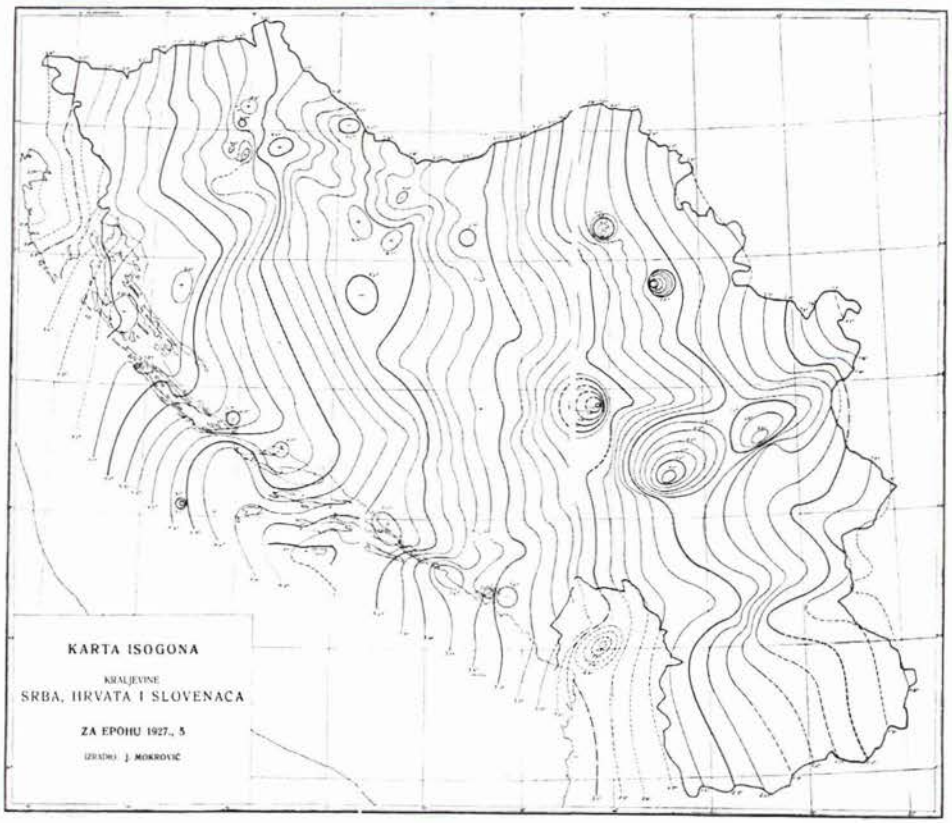

Fig. 2. *Isogonal Map, Epoch 1927.5 (Mokrović 1928).*

In 1948 Mokrović gave a speech regarding the development of geomagnetism, the location of the geomagnetic observatory, and the organization of surveys. Since all the previous surveys may be characterized as unsystematic and inhomogeneous, and the *Federative National Republic of Yugoslavia* did not have a geomagnetic observatory, Mokrović set the fundamental goals as follows: "*(1) to set-up of the observatory, (2) to perform geomagnetic survey, (3) to make use of the geomagnetic methods of applied geophysics in the geology and mining, and (4) to start with the scientific research of the Earth's magnetic field.*"

While all the neighboring countries completed geomagnetic surveys, there were no surveys in Croatia in the years between the two World Wars. One of these, accomplished by the Italian *Istituto geografico militare* from 1933 to 1937 contains the data which relate to Istria, Zadar and Lastovo for the 1935.0 epoch, and few more data for the 1939.5 and 1943.5 epochs (Goldberg et al. 1952).

During the summer of 1949 the magnetic declination survey took place at 62 points along the Adriatic coast and islands (Goldberg et al. 1952). Despite the fact that synchronous registrations of the observatories Fürstenfeldbruck near München and Castellacci near Genova were at disposal for the reduction of measurements, a

variometer station was set-up on the island Čiovo, in the middle of the survey area. In order to determine possible inhomogeneities of the magnetic field, the vertical intensity was measured in the vicinity of each point. It was shown that the vertical field component increases in the northern part at first, reaches maximum near the latitude 44E15', and decreases in the south. Such a behavior points to the eruptive anticlinal in the northern basin of the Adriatic sea. Declinations reduced to 1950.0 epoch were charted (Fig. 3). The isogones that begin on Istria, and on the island Rab to Zadar channel, across islands Dugi otok and Pašman along to Biograd, show maximum of large western declination on Maunski channel. Relative western declination minimum was observed on islands of Škarda, Premuda and Tovarnjak to Mali Lošinj. On the other side, on the south, starting at Dubrovnik, and following across the islands Mljet, Lastovo, Sušac, Vis, Biševo, Brusnik, Svetac, and Jabuka, one can find an area of too small western declination with a strong local minimum (eastern declination) on Brusnik and Jabuka islands. These two anomalies are due to considerable containment of the magnetite in dark gray eruptive diabase rocks, from which the islands blocks are made. The secular variation decrease from North to the South of the Adriatic sea, was confirmed. In addition, the set-up of the two geomagnetic observatories was proposed: the main one near Podgorač on Đakovo plateau, and for the purposes of navigation, an auxiliary observatory near Metković.

Using the previous data, along with Niemegk and Fürstenfeldbruck recordings, in 1955 Mokrović determined approximate values of magnetic declination for the be-

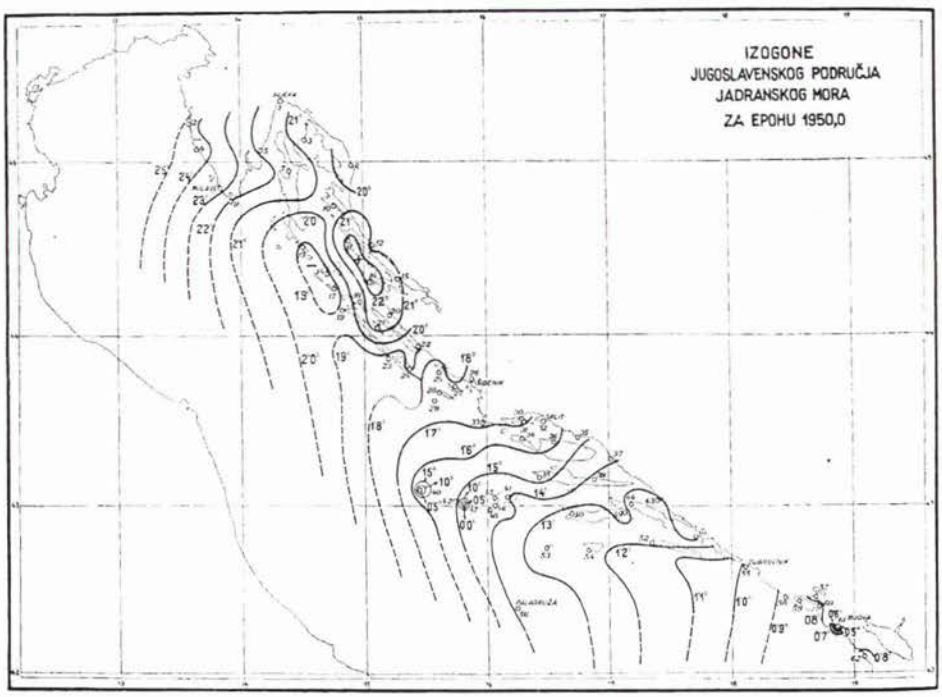

Fig. 3. *Adriatic Area Isogonal Map, Epoch 1950.0 (Goldberg et al. 1952).*

ginning of that year. Once again, he stressed that the gross errors will be avoided only by establishment of an observatory and by measurement of the all the geomagnetic elements.

Despite Mokrović's claim in 1948 that *"the most convenient location of a future observatory is between Slavonski Brod across Đakovo to Vinkovci"*, the observatory was situated in Grocka (Serbia). It should be noted that this decision had crucial effect on the development of the geomagnetism as a science in Croatia. Thus prior to the proclamation of the Republic of Croatia in 1991, the geomagnetic observatory in Grocka was in charge of the geomagnetic surveying and mapping. Let us point out that all the survey data and geomagnetic maps relevant to the territory of Croatia are still unavailable. The only trace left was the 1:1000000 paper map with former geomagnetic points' marks, printed by *Geomagnetic Institute* Grocka in 1962.

In the last 50 years the geomagnetic activities in Croatia were narrowed to the field of geophysical exploration (e.g. Zagorac 1974, Zagorac 1975, Zagorac 1981, Zagorac and Šumanovac 1990, Gregl and Zagorac 1993, Gregl 1997, Gregl 1998, Gregl and Brzica 1999, Gregl 2000) and paleomagnetism (for e.g. Kissel et al. 1995). Besides, more then a hundred of magnetometry projects were carried out by the firm *Geofizika d.d.* for the needs of the oil and gas industry *INA*.

In the last year, a preliminary study "Basic Geomagnetic Declination Network of the Republic of Croatia" has been prepared at the *Faculty of Geodesy* as part of the contract signed with the *Institute for Defense Studies, Research and Development* of the *Croatian Ministry of Defense* (Bašić et al. 2002).

To get an idea about the normal field, the *International/Definitive Geomagnetic Reference Field* (IGRF/DGRF) and *World Magnetic Model* (WMM) magnetic declination and its secular variation were computed for the territory of Croatia.

Then, according to *International Association of Geomagnetism and Aeronomy* (IAGA) recommendations for magnetic repeat station surveys, the requirements needed in the design of the geomagnetic network were recognized.

In the network design, it is of interest to exclude the part of anomal geomagnetic field that originates in magnetic rocks of the crust and upper mantle. Thus, the knowledge of the spots where the mineralization with ferrous ore occur (Fig. 4), as well as the rock types present in some parts of Croatia (Fig. 5), may help to roughly identify places which should be avoided. Besides that, the nearest known geological locality, map and description of the former geomagnetic network points was assessed.

After that, in accordance with the available NATO, STANAG, NIMA and DIGEST cartography and GIS standards, the *Geomagnetic Geographical Information System* intended to facilitate planning of the survey campaigns, storing, check and charting of the results was conceptualized.

One important criterion in choosing the repeat station site is the absence of noise that is the result of human activities. Unfortunately, the obstacle to *a priori* evaluation of civilization noise comes from incompleteness and obsoleteness of the available cartographic and GIS materials, not to mention difficulties in obtaining very detailed electrification, traffic, natural resources, and other GIS layers. It should be mentioned that some parts of Croatia are still not accessible because of mine

Fig. 4. *Geological Noise – Mineralization with Ferrous Ore in Croatia (Bašić et al. 2002).*

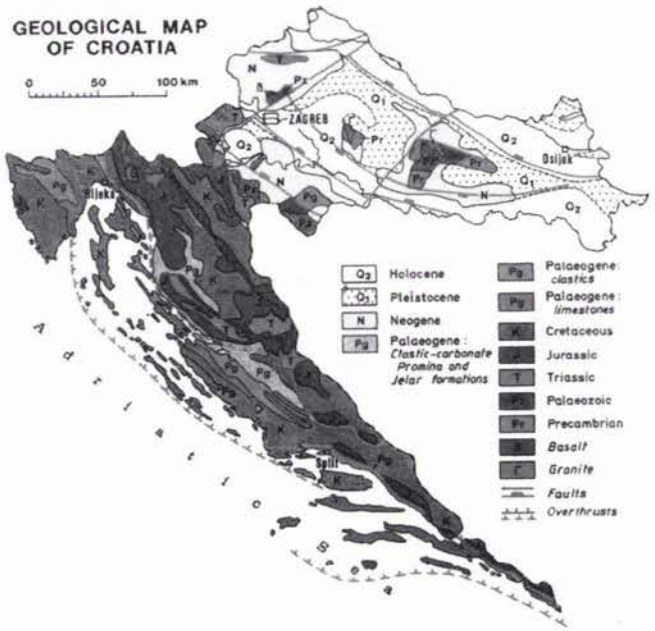

Fig. 5. *Geological Noise – Geological Map (Bašić et al. 2002).*

fields. Anyway, each former geomagnetic point was reviewed by inspection of the 1:25000 topographic maps.

In the study, the proposed geomagnetic network design primarily relies on the former (Yugoslav) geomagnetic network (Fig. 6), which consisted of approximately 150 ground survey points, separated 25 to 30 km in average. On figure, the triangles show the position of the 5 secular stations.

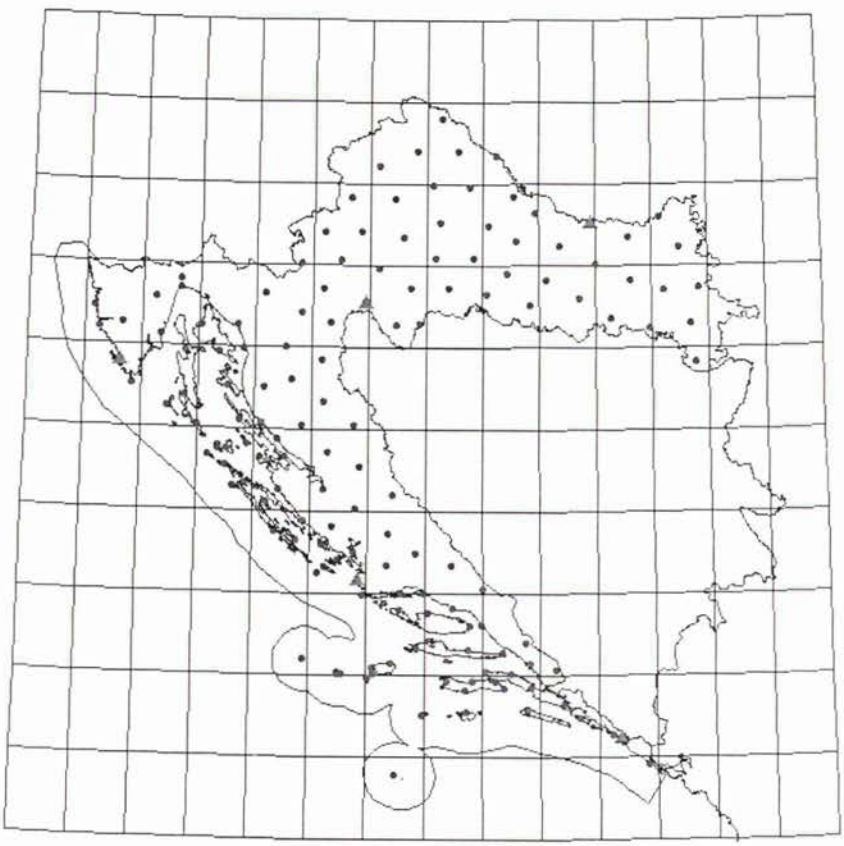

Fig. 6. *Former Geomagnetic Network:* ● *ground survey points;* ▲ *secular points (Bašić et al. 2002).*

Yet, the exact positions and descriptions of these former points are not known, and this is the one of the reasons to rely on the old trigonometric, and modern gravimetric, and GPS networks as well (Fig. 7).

For this purpose the digitized map of the former geomagnetic points, basic gravimetric points, so-called '10-km GPS network' points, trigonometric points, and raster topographic maps 1:25000 were on hand. In addition to other conditions, the points of the new geomagnetic network should match with either triangulation or GPS points which fulfill line-of-site visibility and GPS position accuracy.

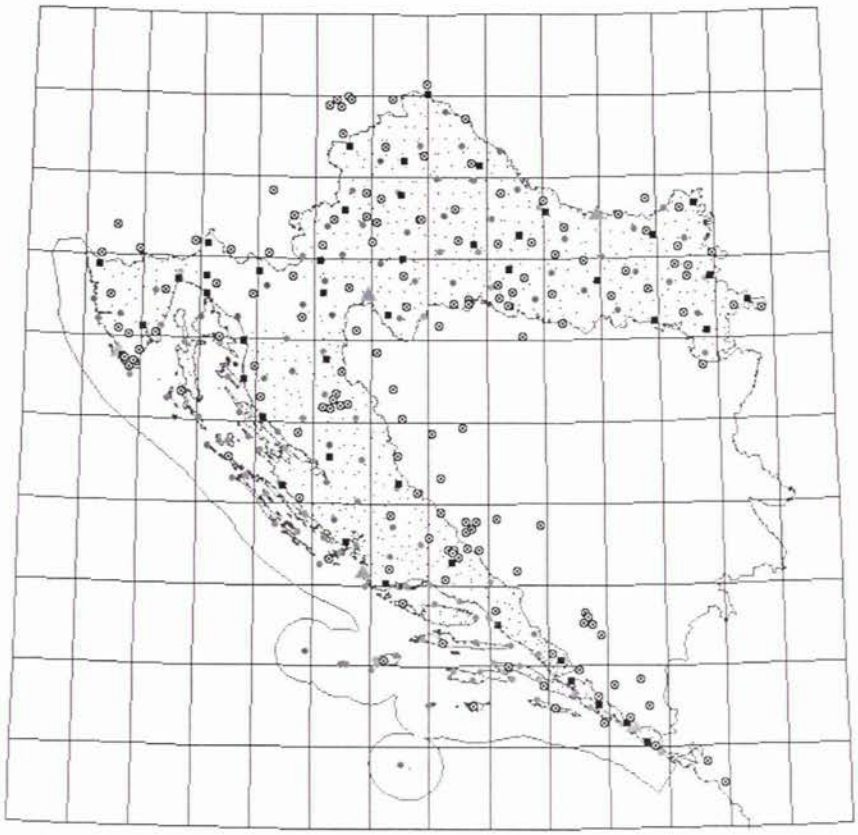

Fig. 7. *Former Geomagnetic* ● *&* ▲, *Gravimetric* ■, *Trigonometric* ⊙ *and GPS Network* • *(Bašić et al. 2002).*

The ultimate decision regarding the new network points' locations will be made following to the field evaluation of the all obligatory criteria. In order to be prepared each former geomagnetic point has been reviewed.

This year in Niemegk the European 'geomagnetic' community was briefed on the recent efforts in Croatia (Brkić et al. 2003). In 2002 the Croatian *Ministry of Science and Technology* launched two projects and funded the purchase of the instruments at the *Faculty of Geodesy*, and *Faculty of Science*.

In order to stress that the understanding of the Earth's magnetic field, and its use in cartography, geophysical exploration, oil prospecting, and military could be possible only by continuous observatory measurements and periodic terrestrial surveys of the geomagnetic elements, IGRF/DGRF and WMM declination models for the all available epochs were compared (Brkić et al. 2003a). The obvious necessity of measurements follows from significant and unpredictable time and spatial variation of geomagnetic elements and their secular variations. For instance, global models' declinations in Croatia for the 1900.0 epoch have a negative sign! Extreme differences of the IGRF1900 and IGRF2000 models on the Croatian territory are

found to be more than 11°. On the other hand, the regularly obtained data will enable an improvement not only of the local but regional and global geomagnetic models as well.

While reading Prof. J. Mokrović's 1948 paper 'Geomagnetism Problem in FNRJ', one cannot escape the impression how current the issues older more than a half of a century seem. There he stated that historically the geomagnetism was the first branch of geophysics in Croatia (!). However, today, as well as then, the Croatian geomagnetism stands at the last place in respect to other branches of geophysical science. Moreover, the following can be literally quoted: *"Croatia is today almost the only European country without the geomagnetic survey and has no observatory as a precondition for the survey".*

With the hope that the lessons from the past have been learnt, let us conclude with the following Mokrović's words: "*... nautical and air traffic call for the knowledge of the geomagnetic elements, especially the magnetic declination; besides, the geomagnetic elements' variations are close related to the phenomena in Earth's atmosphere, so their understanding plays a significant role in the research of the ionosphere. Consequently, in addition to the pure scientific cooperation we are forced to the research of our geomagnetic circumstances by our maritime and air traffic, our economy and industry, we are obliged by our mineral deposits and our defense.*"

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Geomagnetizam u Hrvatskoj – povijesni pregled

SAŽETAK. Dan je povijesni pregled skoro 200 godina geomagnetizma u Hrvatskoj.

Ključne riječi: geomagnetska izmjera, geomagnetski opservatorij, geomagnetska mreža.

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