ATLAS OF GEOTHERMAL ENERGY IN SLOVAKIA

Ondrej Franko

Dionýz Štúr Institute of Geology, Bratislava

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Abstract. In Slovakia, which is an area of 49 035 km^2 and has 533 mil. inhabitants, the reserves of geothermal energy to the end of the year 1990 are valuated at 5800 MW,. Spatial distribution of this potential is represented in maps, sections and diagrams and mentioned in the legend, tables and explanations. The geothermality of the atias is expressed by areal application of colours for representation of the temperature field in plane maps from 500 m to 6 km with the step of 500 and 1000 m below surface. In the atlas are thematic maps, maps of the temperature and heat field, of delimited geothermal areas, saturation indices, technological properties of geothermal waters (GTW) and disposal of waste waters and maps of the reserves.

1. INTRODUCTION

The compiled atlas (about 30 specialists took part in expanding it) represents a summarization of nearly 30 years GE research. The basis of this research has become knowledge obtained until the year 1970. In the first place geological knowledge of the Tertiary filling of the Pannonian basin and intramontane depressions as well as of the pre-Tertiary basement of the Inner West Carpathians southern part was applied in GE research. In the second there was knowledge of favourable geothermal activity, mainly of oil-bearing areas, which was obtained from oil wells. In the third place as to the order but in the first place in relation to concrete natural manifestations of geothermal activity of the Inner West Carpathians there was knowledge of natural areas of issues. In the fourth place were wells, which proved the possibility to drill GTW outside natural discharge areas. Essentially indirect geothermal boreholes are concerned. On the basis of the mentioned knowledge in the years 1970 and 1974 the project of GE research was established for the years 1971 - 1980 with prospect until 2000.

In the years 1971 - 1991 geological knowledge of the Tertiary filling of basins and intramontane depressions and of the pre-Tertiary basement of the whole Inner West Carpathians essentially extended (Fusán et al., 1987). Data on temperatures from 376 boreholes and heat flow from 136 boreholes were obtained (Čermák et al. 1992). Gradually 25 geothermal areas (Franko, 1980) were delimited, from 14 of the 61 boreholes drilled (Franko, 1995). From them the fundamental data about hydraulic properties of GTW aquifers, debit of wells, temperature of waters, their T.D.S., chemical composition and heat power of wells were obtained. All the obtained knowledge and data for the compiled hydrogeothermal maps and sections, profiles, diagrams and tables. Besides these data the hydrogeothermal data from natural GTW issues and boreholes realized in areas of issues as well as outside them were used.

2. CONCEPTION AND METHODS OF ATLAS COMPILATION

The compiled maps and sections are schematic representation of geothermal activity of the region. The methods of compilation and arrangement of the atlas are similar to thbse applied for the Atlas of Geothermal Resources in the European Community (EC), Austria and Switzerland (Haenel et al., 1988). This way both atlases are comparable. The base line however, the Atlas of Slovakia is different from the Atlas of the EC. EC Atlas with regard to the predominating platform structure of the region is based on representation of depth of the GTW aquifers from the sea level with temperature isolines at their top (their spatial extension at depth is known). The Atlas of Slovakia, because of the folded - nappe structure of its territory is based on areal representation of the lithostratigraphic and tectonic units in plane maps (spatial extension of the aquifers at depth is not known) and in maps of the pre-Tertiary basement. The maps of the pre-Tertiary basement are only compiled from those areas, in which the basement is formed by the Mesozoic (where there are GTW aquifers - Triassic dolomites and limestones). The fundamental purpose of the Atlas is colour depiction of the temperature and heat field and individual plane in maps from the field surface. Areal application of colour takes into account "geothermality" of the Atlas and the levels below the field, direct knowledge of temperature at corresponding depths. Geothermal activity of the territory is represented in maps of 6 kinds:

- thematic geothermal map
- maps of heat flow at surface
- maps of heat flow at Moho-discontinuity
- geothermal maps of Slovakia
- geothermal activity maps of delimited areas
- hydrogeothermal maps of delimited areas.

The hydrogeothermal content of hydrogeothermal plane maps and maps of the pre-Tertiary basement consists of expressing of geothermal installations (existing, planned), of boreholes with geothermic measurings with and without data of chemical properties of waters, of geological boreholes with data of chemical properties of waters (mainly oil wells are concerned) and of hydrogeological objects. All objects are plotted in competent maps and a part of them also in sections. In maps of the pre-Tertiary basement mainly natural GTW issues are plotted (in absolute majority intercepted by boreholes). In maps with the step of 500 m to 3000 m (e.g. the Danube basin) the data established in the section of 250-750 m

are plotted at the level of 500 m and the data in the section of 750 - 1250 m at the level of 1000 m etc. In maps with the step of 1000 m the data established in the section of 500 - 1500 m are plotted at the level of 1000 m and the data in the section of 1500 - 2500 m at the level of 2000 m etc. This different step (500m, 1000 m) is given by the amount of well data. With their sufficient amount the step is shorter and vice versa. It results from the former that also in vertical scale more or less schemes are concerned. In construction of maps and sections planar, line point and numeral characteristics were used.

In plane maps and sections the temperature field and heat field are represented by coloured surfaces. The lithostratigraphical and tectonic units are depicted by screen.

By line characteristics the boundaries between the lithostratigraphical and tectonic units, tectonic lines, isotherms, isolines of heat flow, isobaths of the Tertiary and boreholes in sections are represented.

By point marks geothermal installations, boreholes with geothermic measurings, geological boreholes and hydrogeological objects are represented. In them one or more objects, their debit and water temperature are distinguished by various marks.

By numerical marks or combination of numerical and point marks the debit of geothermal installations, temperature and T.D.S. of GTW are expressed. The presence of CO_2 and H_2S and chemical properties of waters are indicated by point marks.

The territory of Slovakia is on principle represented in maps of two different scales. In the map 1:1000 000 geothermal activity of the whole territory is shown synoptically. In maps with scale 1:200 000 and less detailed scales geothermal activity of delimited geothermal areas is shown (maps of scales more detailed than 1:200 000 have the preciseness of this scale). This combination of the individual delimited areas and the whole territory provides a picture of geothermal activity also of territories without suitable GTW aquifers or territories suitable to exploitation of heat from dry rocks. This combination also provides information on areas suitable to vertical dumps or harmful refuse. The total spatial idea of geothermal activity of the territory is shown by combination of plane maps, maps of the pre-Tertiary basement and heat flow maps. The thematical geothermal map shows that geothermal resources are bound to the Inner West Carpathians only. Similar information is provided by the map with delimited geothermal areas.

3. CONTENT OF THE ATLAS

The Atlas contains the text, tables, diagrams, profiles and maps (with sections).

The text part includes besides the foreword and introduction, mainly the purpose of the Atlas and compilation methods of the individual kinds of maps, hydrogeothermal characterization of the territory of Slovakia and of the individual delimited areas. Further more, it provides the commentary on the technological properties of GTW and the possibility for waste water disposal. Lastly is a commentary on the valuated GE reserves.

The tables contain data about temperatures of GTW springs and geothermal installations, data about temperatures in boreholes and heat flow. Further data about waters and aquifers are in the text for the whole territory of Slovakia and for individually delimited areas.

In the diagrams the chemical properties of GTW and spatial distribution of the temperature of the Outer West Carpathians, Inner West Carpathians and some delimited areas are presented.

Lithology of boreholes and its properties are depicted by well log profiles. There are several profiles with typical aquifers of GTW from various delimited areas.

The map part contains maps of various kinds and scales. Maps scaled 1:1000 000 include an average annual air temperature map, thematic geothermal map, map of heat flow (surficial), map of. heat flow at the Moho-discontinuity, plane temperature maps with lithological and tectonic content at depth of 1 - 6 km below surface with the step of 1 km, temperature map of the pre-Tertiary basement, map of delimited geothermal areas with GTW aquifers and isotherms at depth of 2 km below surface (Fig. 1), map of saturation indices, map of technological properties of GTW and disposal of waste water and map of GE reserves (Fig. 2).

Maps with a scale of 1:200 000 and less detailed include plane (from the surface) temperature or hydrogeothermal maps at depths of 500 - 1000 m to 6000 m with the step of 500 m, 1000 to 2000 m of the individual delimited areas. They also include maps of the pre-Tertiary basement from those areas, where there are GTW aquifers. I mention that maps with scale less than 1:200 000 have the preciseness of this scale. The different less scales are depending on the surface of delimited areas. With regard to their uniform preciseness (1:200 000) the maps of all areas are comparable.

All Slovak maps as well as maps from the individual delimited areas are accompanied by sections with areal coloured representation of the temperature field.

4. ASSESSMENT OF GE PROBABLE RENEWABLE RESERVES

As it is possible to dispose of waste water into surface streams, is preferred exploitation of the renewable (dynamic) reserves (Franko, 1995). From the chemical composition of the GTW and their T.D.S. it is obvious that they are waters of atmospheric origin, with petrogenic mineralization. In such a case the specific yield (runoff) of GTW is assessed on the basis of general knowledge of hydrogeothermal activity in delimited areas by means of geothermic balance (balance method) expressed by the equation (Lizoň and Marušiak, 1977):

$$V = \frac{q}{(T_H - T_o).\, c \,.\, \varrho} \qquad (1)$$

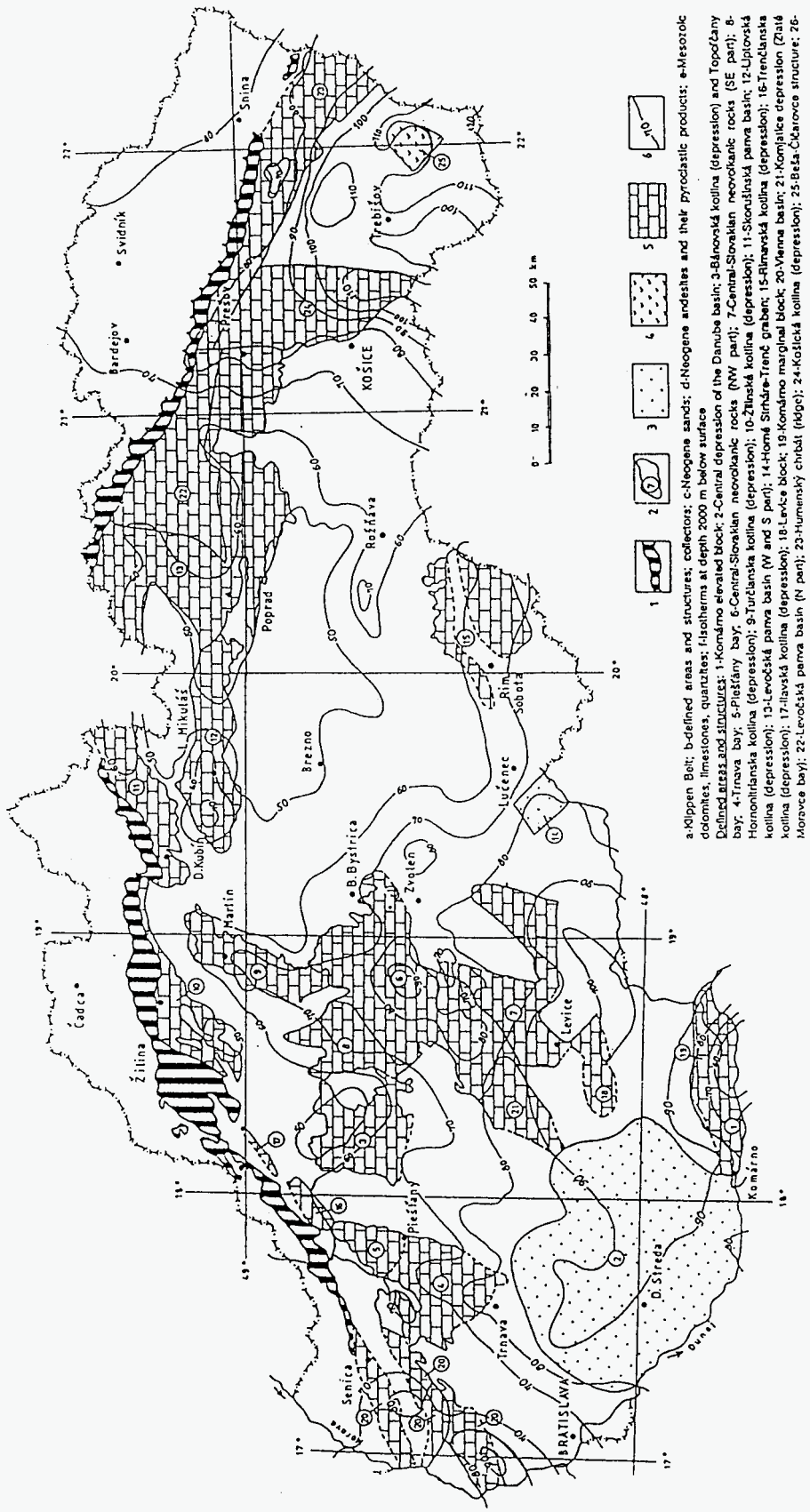
where
V - specific yield ($m^3.s^{-1}.m^{-2}$),
q - mean heat flow ($W.m^{-2}$),
T_H - mean aquifer temperature at depth H (°C),
T_o - mean temperature of indifferent zone, represented by average temperature of air (°C),
c - specific heat capacity of the water ($J.kg^{-1}.K^{-1}$),
ϱ - specific density of the water ($kg.m^{-3}$).

The quantity of water that can be exploited from a region is assessed according to equation:

$$Q = F \,.\, V \qquad (2)$$

where
Q - yield of region ($m^3.s^{-1}$),
F - area of region (m^2).

Probable heat power of the region is assessed according to equation:



a-Klippen Belt; b-defined areas and structures; collectors: c-Neogene sands; d-Neogene andesites and their pyroclastic products; e-Mesozoic dolomites, limestones, quartzites; f-isotherms at depth 2000 m below surface

Defined areas and structures: 1-Komárno elevated block; 2-Central depression of the Danube basin; 3-Bánovská kotlina (depression) and Topoľčany bay; 4-Trnava bay; 5-Piešťany bay; 6-Central-Slovakian neovolkanic rocks (NW part); 7-Central-Slovakian neovolkanic rocks (SE part); 8-Hornonitrianska kotlina (depression); 9-Turčianska kotlina (depression); 10-Žilinská kotlina (depression); 11-Skorušinská panva basin; 12-Liptovská kotlina (depression); 13-Levočská panva basin (W and S part); 14-Horné Strháre-Trenč graben; 15-Rimavská kotlina (depression); 16-Trenčianska kotlina (depression); 17-Ilavská kotlina (depression); 18-Levice block; 19-Komárno marginal block; 20-Vienna basin; 21-Komjatice depression (Zlatá Morava bay); 22-Levočská panva basin (N part); 23-Humenský chrbát (ridge); 24-Košická kotlina (depression); 25-Beša-Čičarovce structure; 26-Dubnica depression; 27-East Slovakian basin

Fig 1 MAP OF DELIMITED GEOTHERMAL AREAS (O. Franko - M. Král, 1994)

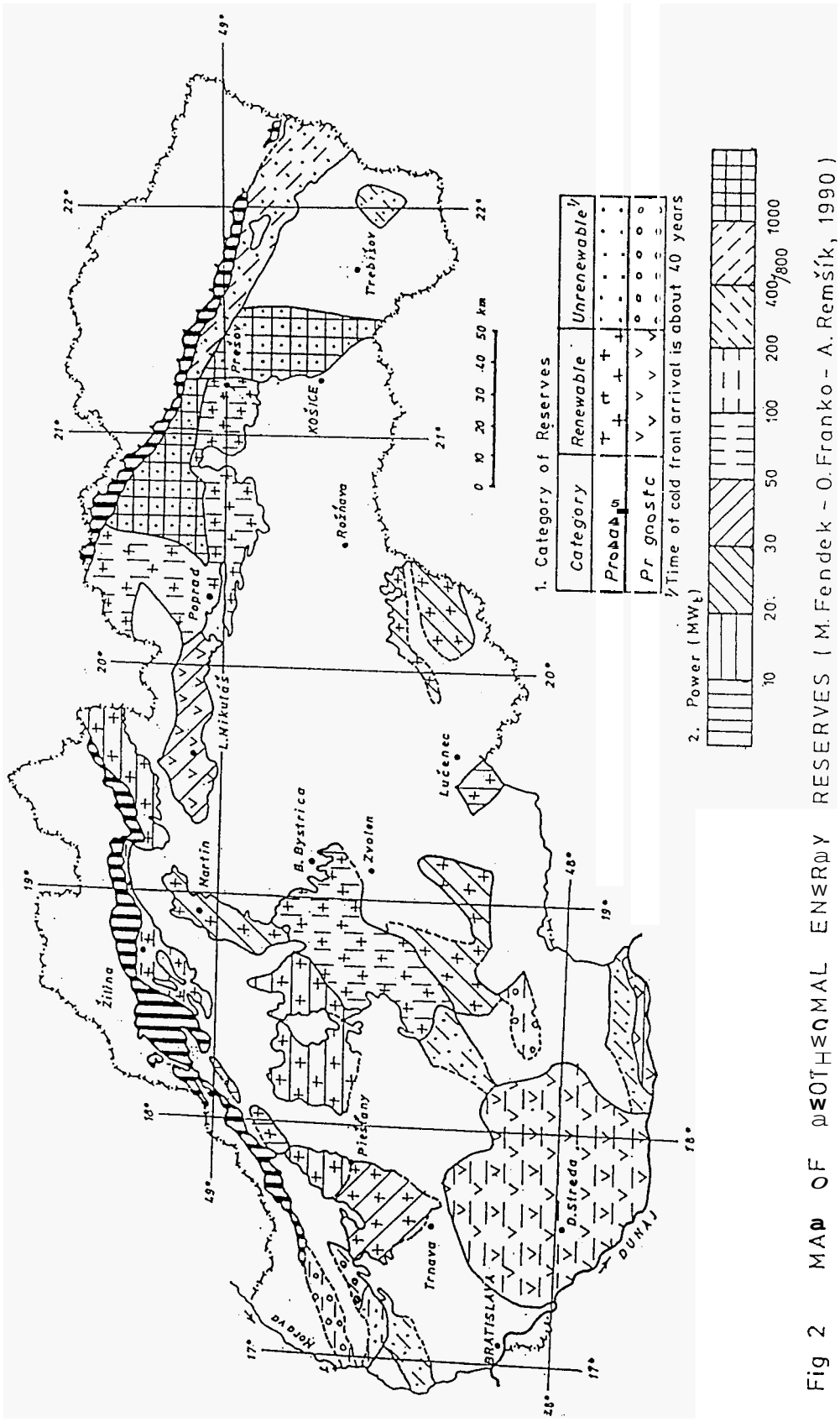


Fig 2 MAP OF GEOTHERMAL ENERGY RESERVES (M.Fendek - O.Franko - A.Remšík, 1990)

$$P_t = Q \cdot (T_u - T_r) \cdot c \cdot \varrho \quad (3)$$

where

P_t - heat power of the region (W),

T_u - water temperature at the well head, the value of which was taken as 7 °C less than T_H (°C),

T_r - reference temperature, the value of which is 15 "C.

Valuation of probable renewed GE reserves by geothermic balance method has provided very good results. We applied this method for intramontane depressions of the West Carpathians. They are folded hydrogeothermal structures, in which the aquifers are formed by Triassic limestones and dolomites. The structures have intake transitional and discharge areas or are without discharge area. The minimum value of heat flow in these depressions is about 53 $mW.m^{-2}$, the maximum value about 109 $mW.m^{-2}$ and the average value about 68 $mW.m^{-2}$. T.D.S. of GTW vary within the range of about 0,7-5 $g.l^{-1}$. Specific discharge or outflow of GTW from these depressions varies within the range of about 0,2-0,35 $l.s^{-1}.km^{-2}$. The results achieved by this method are, for instance, comparable with the results obtained with valuation of natural dynamic flow rate through the structure. In the Komhrno high block (Fig. 1, delimited area No. 1) the geothermic method provides the value of about 9,75 MW_t and the hydraulic method about 11,3 MW_t (Remšík-Franko-Bodiš, 1992). With geothermic balance we used the following values: q = $64,5.10^{-3}$ $W.m^{-2}$, T_H = 32,5 °C, T_o = 10 °C, c = 4186,8 $J.kg^{-1}.K^{-1}$, ϱ = 995,5 $kg.m^{-3}$, F = $224,6.10^6$ m^2. With hydraulic method (Q = KIA, where Q = dynamic flow rate, K = hydraulic conductivity coefficient, I = hydraulic gradient, A = cross-sectional area) we used the following values: K = $1,13.10^{-5}$ $m.s^{-1}$, I = 3907.10^{-4}, A = 3.10^7 m^2).

Similar results achieved by geothermic balance method in the Liptovskh kotlina depression (about 32 MW_t; Fig. 1 - delimited area No. 12) are comparable with the results (34,3 MW,) achieved by 2-D numerical model according to the AQUA - Vatnaskil Consulting Engineers Programme 1992 (RemSik et al. 1994).

The probable unrenewable (static) reserves is at least 10 times higher than renewable one. It is estimated by the volume geothermal method (Muffler and Cataldi, 1978). With regard to decreasing aquifer pressure, and consequently the debit of the well, it is necessary to reinject of waste water. As reinjection cools the aquifer, model solutions point to about 40 years of unchanged GTW temperatures; after this time the temperature of the GTW begins to decrease slowly but permanently. Therefore the question is: WHAT IS MORE DESIRABLE FROM THE POINT OF VIEW OF AQUIFER PROTECTION "PERMANENT EXPLOITATION OF THE RENEWABLE RESERVES OR UNRENEWABLE ONE DURING A DEFINITE PERIOD".

5. CONCLUSION

The Atlas of geothermal energy of Slovakia as well as atlases of other countries will fulfil 3 mainly functions:

- general-educational or cultural,
- practical or national-economic-ecological,
- supernational or integrating.

The general character of the Atlas lies in providing a complete idea of spatial geothermal activity of the area. The practical side is in giving an idea of the geothermal resources and reserves of GE, of the possibility of saving classical fuels and of reduction of emissions to the atmosphere. The practical side is also reflected in higher quality contribution to the environment and health of the population, which includes exploitation of GTW at recreational and health centers (bathing, swimming, rehabilitation). As the Atlas is bilingual (Slovak-English). it will be available to specialists from all over the world, althoughly mainly for Europeans where it will fill the supernational or integrating function.

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