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UTILIZATION OF HEAT ENERGY FROM GROUND WATER INTAKES

PhD.eng. Barbara Uliasz - Misiak
Polish Academy of Sciences Mineral and Energy Economy Research Institute Geothermal Laboratory
Wybickiego 7 St, 30-950 Cracow 65, Box49, Poland,
Fax: (+48 12) 632-67-17, Phone: (+48 12) 632-33-00 ext.131, e-mail:umb@min-pan.krakow.pl

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ABSTRACT

The hard coal, a traditional fuel in households is the main source of air pollution by low emission in Poland, so that development of alternative sources of clean energy is needed. A potential resource of geothermal energy in Poland was estimated at about 4 mld ton of coal equivalent (Ney.R., 1997).
Utilisation of geothermal waters is costly, therefore we propose that thermal energy should be drawn out from intakes of drinking water from shallow horizons. Technically, using heat pumps one can extract heat energy from shallow groundwater's of temperatures less than 20^0C. In the presented paper is considered a possibility of utilising heat from potable water intakes in the Nowy Sacz environs, a region of good environmental setting in the Carpathians in southern of Poland. Utilisation of heat energy from shallow horizons of groundwater will reduce amount of coal burned in open furnaces, therefore, will reduce air pollution in this region.

1. INTRODUCTION

Geothermal waters as potential heat source for economy in Poland usually have temperatures below 100^{O}C. Water-bearing levels existing at 100 - 4000 m depth can be used as heat source practically all over Poland. Their use is technologically possible while it needs miscellaneous possibly high financial support.

Nowadays geothermal energy is extracted from 1600 - 2600 m deep-water layers (Geothermal Laboratory in Bańska-Biały Dunajec, Pyrzyce, Mszczonów). The waters' exploitation is combined with high financial expenses necessary when heat extracting from such depth is concerned. Deep wells that supply hot water induce the expenses and their exploitation needs support devices as deep-well pumps. Profound originated heat energy cannot be used unless well effective heat power is high enough. Such energy exploitation requires expensive geothermal installation construction dedicated to heat engineering purposes. That kind of installation construction is justifiable only if there are big heat consumers (housing estates, industrial plants et cetera).

Heat energy received from shallow water intakes is cheaper than geothermal energy obtained from deep wells. However, warmth energy extent obtained with warmness pump from such source is less than the other one; it depends on geological conditions and amounts several up to dozen or so kilowatts. A usage of low-temperature geothermal energy intakes needs no geothermal heating network because they can be used to warm individual items.

2. NOWY SĄCZ REGION TRAITS

Area of former Nowy Sącz province is placed in Southern Poland. It was consisted of afforested Beskidy terrains, divided into separated ridges by river valley system (Beskid Żywiecki, Beskid Wyspowy, Gorce, Beskid Sądecki, Beskid Niski). To the South there is wide Podhale depression with Pieniny ridge. There is a massive Tatra ridge too. The northwestern part consists of Middle-Beskid Plateau, Rożnów Plateu and Gorlice depression (Fig.1).

This region is barely industrialized, the economy is recreation and treatment in a health resort. Following towns are local industrial centers: Nowy Sącz, Gorlice, Nowy Targ and Limanowa. There are many little plants being installed now, handicraft is developing. It is combined with recreation and treatment in a health resort dominating service there. Sightseeing background is well developed (e.g., Zakopane, Szczawnica, Krynica).

The region is totally mountainous, it has gotten 67.2 % of surface 500 m above sea level, unique landscape, natural and bioclimatic assets, relatively hardly devastated environment comparing to the rest of Poland.
Nowy Sącz region is excessively afforested. There are following areas protected by law, of outstanding natural attraction: Tatrzański National Park, Gorczański National Park, Pieniński National Park, Magurski National Park, Babiogórski National Park, Popradzki Landscape Park and 32 sanctuaries.

The region is a well-head of upper Vistula tributaries: Skawa, Raba, Dunajec and contains considerable fresh water ratio in Poland. There are natural highland lakes in Tatra Mountains (e.g., Morskie Oko, Czarny Staw Gąsienicowy). Following artificial water reservoirs were built in the region: Rożnowski, Klimkówka and Czorsztyn. There are the most significant mineral water and well-documented geothermal water resources in the Podhale basin.

2.1.Geological conditions

Area of former Nowy Sącz province is placed in the region of Western Carpathians, Southern Poland. It is placed in the region of Inner Carpathians consisting of Tatras, Podhale basin, Pieniny Klippen Belt, and Outer Flysch Carpathians built of several nappes. Outer and Inner Carpathians differentiate in interior structure, they are split by a brake under Pieniny Klippen Belt that is concerned as limit ridge between them (Fig.1).
Outer Carpathians are exclusively composed of flysh sediments. Detritic rocks dominate among them (claystone, mudstone, sandstone, conglomerates) (E.Stupnicka, 1989).
Flysh sediments are bent into a cover between Inner Carpathians and lowland area structures of Middle Poland. Their primary location is not well determined. On Neogene they were forged off and transferred northward for tens of

kilometres. The folded or flaked flysch sediment lies now over Miocene sediments of Carpathian Foredeep.

Flysch basin sedimentation ran in miscellaneous conditions and in miscellaneous distance from alimentation areas. In the Outer Carpathians flysch basin (R. Unrug, 1979) distinguished following items: in the North the edge ridge, southwards next basins: Sub-Silesian and Skole split by central northern ridge. Southwards there was Silesian basin split off the Sub-Silesian basin by Inwałd ridge. It was separated from Skole basin by central ridge. Silesian and Magura basins that are placed in the South were split by Silesian cordillera (M. Książkiewicz, 1972).

Outer Carpathians basin differentiation caused lithofacial dissimilar main series: Sub-Silesian, Skole, Silesian and Magura to rise. Between them rose transient series including main series components.

2.2. Environment condition

Nowy Sącz province hosts many health resorts and recreation villages (Krynica, Rabka, Szczawnica, etc.) because of mountainousness, a multitude of mineral water springs and landscape assets.
Air sanitary condition is affected much external and internal pollution (as industrial plants, housing estate boiler-rooms, individual furnaces and traffic) factors. A pollution influx from neighbouring, much more industrialized areas and from Slovakia plays an important role in atmosphere contamination. Anyhow majority of atmosphere pollutants originates from traffic and low emission of individual furnace.

Within environment state investigation in Nowy Sącz province constant atmosphere pollution monitoring is being run. Research is held in following towns: Nowy Sącz, Nowy Targ, Zakopane, Gorlice, Rabka, Piwniczna, Żegiestów, Muszyna, Złocko and Wysowa. Most of them are a health resort. Dustiness extent (dust precipitation and suspended dust), sulphur dioxide and nitrogen dioxide concentrations are measured. The research does not display full atmosphere contamination due to limited quantity of determined components and low number of measurement points as well as concerned area vastness (Raport o stanie..., 1995).

In Nowy Targ downtown, among other towns, the highest suspended dust concentration excessively transgressing authorized year and twenty-four hours average amount was registered according to the research run in 1995. In Zakopane those values were significantly lower however they still went beyond the authorized limits. In other towns year average concentration level stayed in the permitted range however twenty-four hours limitations were passed over (e.g., in Rabka). Coarse-grained dust accumulation level in "normal" areas trended at 30 - 40% of limitations. On the other hand in protected regions (due to lower limits) transgressions were registered e.g. in Krynica shopping centers and along traffic arteries (Raport o stanie..., 1996).

Sulphur dioxide aggregation measurements displayed the transgressions only in Rabka and Krynica. In spite of more severe limitations SO_2 year concentration did not go beyond permitted limits. Authorized concentration was passed over neither in Nowy Targ nor in Zakopane (it was approximate to the permitted value). However in Nowy Sącz and Gorlice region year concentrations trended below the limits.

According to the research results it was found out that Podhale region had the worst status, nevertheless the cleanest part was the East of the region. It is an incomplete description yet. It concerns only estimated typical fuel combustion products and it is strictly correlated with used fuel class.

In the Nowy Sącz province many towns only lay in the valley bottom. It makes local atmosphere hard to be clean due to weak ventilation and temperature inversion phenomenon. Concerning remarks mentioned above and considering assumed recreation and treatment function of the region it is hard to set up the aerosanitary status as favorable. Anyhow, the environment has not been yet much destroyed in the area so it is recommended to preserve the status as it is as well as to steer to improve it. Employment of clean geothermal energy derived from subterranean water intakes would enable low emission cutback as well as atmosphere condition improvement in this area.

3. RESEARCH METHODOLOGY - UNDERGROUND WATER INTAKES TRAITS

There were thousands of drinkable water intakes of different temperature, depth and efficacy built in Poland. Some of those intakes are not classed usable as heat energy source. It is necessary to detail what kinds of intakes are fit to the goal.

The basic criterion deciding whether particular water intake is usable or not is a supposed gained heat power. Water temperature and a water output determine it.
Water temperature correlates with an intake depth. As we know lithosphere temperature increases with depth but in irregularly way. It depends on a rock type that set up particular area. However downward to 10 m depth season temperature fluctuations influence a rock and water temperature. The effect vanishes below.
Another factor determining an intake heat power is its output. It depends on parameters of hydrogeologic layers that deliver water.

Geological and hydrogeological structure literacy and exploitation parameter knowledge (depth, output, and water temperature) are essential to estimate existing drinkable water intake exploitation possibilities. Among the exploitation parameters there are two of known value in the mentioned area. Water temperature has to be approximated. To do it we can use the following formula (Z. Pazdro, 1983):

$$T = t_{śr} + A + \frac{H - h}{g}$$

where: T - water temperature at H depth in ^{0}C;
$t_{śr}$ - year average air temperature in particular village in ^{0}C;
A - constant depending on above sea level elevation in ^{0}C;
H - water occurrence depth in m,
h - stable temperature zone deepness in m,
g - geothermal grade in m.

In the above formula we assume following particular factor values:

- average year temperature in the referred area oscillates between 5^0C in the South (Tatra Mts., part of Podhale) and 7^0C in the North.
- stable temperature zone deepness - the depth where vanish temperature fluctuations due to air temperature changes. According to the literature we assumed that the value equals to 10 m;
- geothermal grade amounts over 50 m in the South up to 40 m in the north.
- temperature emendation reflecting particular point elevation above sea level ranges from 0.8 (0 m above sea level) up to 3.0 (2500 m above sea level).

Geothermal grade value varies along depth and depends on a class of rocks and its thermal properties (especially heat conduction). The cited formula presents only approximate values - water temperature estimation error increases with deepness enlargement.

Next step to valuate an intake heating capacity is calculating supposed effective heat power (Ocena poprawy..., 1998).

$$Q_{geot} = Q_W \cdot {}^{1}/_{3600} \cdot 1000\, {}^{kg}/_{m^3} \cdot 4{,}19\,(T_W - T_S)$$

where: Q_{geot} - well heat power, kW
Q_W - intake outlet, m^3/h
T_W - water temperature
T_S - chilled water temperature 5^0C (water chilling down to 5^0C was accorded after heat pump producer (SeCePol)).

3.1. Nowy Sącz province intakes

In the area of former Nowy Sącz province there are 768 underground water intakes of different depth and outlet. They pipe water coming from flysch formation. Ability to obtain water from flysch formation depends on sandstone and shale rates. The bigger sandstone ratio is the better container parameters are. Flysch water-bearing ability is not exclusively combined with intergranular porosity but also with fractures and slots of tectonic and erosional origin. In the flysch we cannot distinguish water-bearing bed correlated with stratigraphically determined rocks. It is just correlated with surficial zone, fractured and eroded. On the base of research it was found that fraction zone ranges down to 60 m on the average or e.g. in Magura sandstone reaches 80 m. A layer down to mentioned deepness is regarded as water-supply prospecting one (Budowa Geologiczna Polski, 1991 r.).

The most promising as water supply sources in the area are: the Magura beds (thick-bedded sandstones of thickness up to 1400 m) in the Magura nappe, spread in the south of the region, and Inoceramus layers (marl and sandstone middle- and thin-bedded of thickness about 300 - 500 m); Silesia nappe: - Wierzchów sandstones (sandstone that occurs in Sub-Silesian unit), Lgota sandstones (thick- and thin-bedded sandstones widely spread between Skawa and Dunajec rivers), Ciężkowice sandstones (high and middle granulation class thick-bedded sandstones of thickness up to 500 m) widespread in the Ciężkowice region. Hieroglyphic and Krosno sandstones (an aggregate that presents different granularity and reveals thickness up to 1000 m) widespread in the zone eastern part, Inner Carpathians (Podhale) - Quaternary formations (alluvial or fluvioglacial), Tertiary structures (Podhale flysch and numulithe Eocene) and Mesozoic formations (mainly Triassic).

Potable water intake deepness in Nowy Sącz province oscillates between 0.1 m (superficial sources) and 948 m. Among them there are 269 superficial sources, 339 intakes of depth up to 10 m, 90 well holes of depth between 10 and 100 m and 70 ones deeper than 100 m.

Their outlets are different and oscillate between less than 1 m^3/h up to tens of cubic meters per hour. There are 282 intakes of efficacy less than 1 m^3/h, 243 ones of efficacy up to 4 m^3/h and 243 of efficacy higher than 4 m^3/h. Low intake effectiveness is implicated by flysch structure origin of water.

Only determined depth parameter intakes of proper efficacy can be used for geothermal purposes. In order to obtain minimal assumed heat power we presumed 4 m^3/h as minimal efficacy and 10 m as minimal well deepness. Those conditions assured water temperature about 7^0C. Among total number (768) of intakes 136 fulfill conditions mentioned above with regard to such criteria. Particular intakes deliver a heat power ranging between 9 and 600 kW. Among 136 intakes there were 6 of a heat power greater than 10 kW, 45 varied between 10 and 20 kW, 34 oscillated between 20 and 30 kW, 19 varied between 30 and 40 kW, 10 oscillated between 40 and 50 kW, 9 varied between 50 and 100 kW, 8 oscillated between 100 and 200 kW, finally 5 transgressed 200 kW of heat power. Their heat power was set approximately. The evaluation based on temperature data found in literature. It was not found out by measurement. The mentioned intake heat power values do not consider heat pumping.

In the region one can propose areas due to their ability to be warmed by low intake geothermal energy, where it seems to be the most reasonable because of a local intake possible power and due to particular needs.

We propose following towns in the former Nowy Sącz province: Gródek n/Dunajcem, Kościelisko, Krynica, Szczawa, Tylicz, Wysowa.

4. ENVIRONMENTAL EFFECTS

Analysis of environmental result in the above region that will appear if we use geothermal energy coming from already existing underground water intakes was completed.

Mainly coal and coke, less electricity and natural gas, are used as energy carrier in the mentioned area. We assumed in calculations that the whole necessary energy is obtained by coal combustion. We did make no allowances for using electricity to set up central heating and heat usage water.

Coal is composed of organic substances that contain following base elements: carbon, hydrogen, nitrogen, sulphur and oxygen. Coal also contains mineral substances as silicon oxides, iron oxides, other metaloxides, calcium and magnesium sulfates, calcium and magnesium carbonates, silicates and aluminosilicates, sulfides.
Organic components that originate during coal combustion form the emitted air pollutants. Mineral component contents predispose an amount of ash originating in combustion process.

Due to measurement data shortage atmosphere condition in the above towns was characterized according to estimated pollution quantity that is emitted while required coal amount, covering particular town heating needs, burns. The data is shown in Tab.2. The above towns environment condition was based on:

- particular town heating demands (according to heating needs of 1 sq. m of inhabitable surface and the heat required to obtain usable warm water for 1 inhabitant),
- inhabitant amount
- inhabitable surface
- under condition that real air pollution discharge evaluation is based on particular house heating needs fulfilled by coal burning in stable grid, flame furnace device.
- a mid-quality coal (calorific value of 22 MJ/kg, ash contents 18%, sulphur contents 1%, combustion efficiency 60%).

On the base of the above conditions particular town needs were estimated first, where existing underground water intakes were recommended for heat engineering purposes. The data is set up in Tab. 1. The mentioned table contains values of coal amount required to fulfill those needs.
The heat calculations concerned constant outlet. That means a postulate that consumption of potable water, which is simultaneously an energy source, is unchangeable. Potable water maximum demand arises during the day however heat energy maximum demand arises during the night. Constant outlet condition cannot be fulfilled unless all exploited water is or totally consumed or an overflow is pumped down to the water-bearing bed through another intake or accumulated in proper containers and used during the maximum demand time. Seasonal energy demand increase was neither concerned. Especially in winter-time, when many tourists arrive, the heating needs augment.

Foreseen ecological result to be obtained by geothermal energy use will be expressed by pollution amount being not emitted to the atmosphere. To estimate the result a simulation was run that evaluated geothermal energy quantity possible to obtain from underground water intakes in all mentioned towns and coal amount released off being burnt. Next a pollution amount freed off being dispersed in atmosphere owing to geothermal energy use was assessed. The data corresponding to particular towns is shown in Tab. 3.

In Gródek area 19 water intakes were made. All of them exploit 18 Tertiary flysch structure waters and one Cretaceous. Eight intakes were recommended for heat energy exploitation. They pipe water coming from Ciężkowice formation (Przewodnik Geologiczny. ., 1979).
Single intake supposed heat power scales from 14 kW to 42.6 kW. They can deliver 166.8 kW that enable to reduce local coal combustion of 914.2 t per year.
As run simulation proves usage of already existing underground water intakes would allow to reduce significantly pollution discharge into atmosphere and to improve Gródek n/D environment. Usage of geothermal energy would allow to reduce pollution discharge into atmosphere of about 30%.

Kościelisko area intakes display totally different traits. In the above area 3 wells were made that exploit underground water of Podhale flysch and Triassic sediments. Heat quantity possible to obtain from single water intake ranges from 53.9 kW to 636 kW.
Kościelisko heating needs were evaluated to 5.3 MW that equals to coal combustion of 12.553,2 t per year. The three proposed underground water intakes are able to deliver 1.4 MW of power that will enable local coal combustion reducing of 9384.5 t per year.
In the Kościelisko region pollution amount discharged into atmosphere is significant so geothermal energy usage would allow to lessen it. Usage of already existing underground water intakes would allow to reduce pollution discharge for about 25%.

In the Krynica area 36 mineral and potable water intakes were made. They exploit water coming from flysch structures. The water intakes recommended for geothermal energy exploitation in the Krynica region place in the frontier zone between Krynica and Sącz zone (Chrząstowski J., Reskowa D. , et.al. 1992).
There were 12 intakes proposed to obtain heat energy. Heat quantity possible to obtain from single water intake ranges from 12.4 kW to 156 kW. Krynica heating needs were evaluated to 13 519 MW, that equals to coal combustion of 32.320,2 t per year.
The 12 proposed underground water intakes are able to deliver 680.2 MW of power that will enable local coal combustion reducing of 30694.3 t per year. Because of unique Krynica assets an air condition improvement is a very important question. Usage of already existing underground water intakes would allow to reduce pollution discharge for about 5%.

In the Szczawa area 15 underground water intakes were made. All of them exploit 13 Tertiary flysch structure waters and second Cretaceous. Two intakes were recommended for heat energy exploitation. The intake supposed heat power equals respectively 176.1 kW and 181.8 kW. In the Szczawa area water intakes recommended for geothermal energy exploitation pipe water originating from Krosno sandstone (Chrząstowski J. , 1992).
Szczawa heating needs were evaluated to 1.8 MW, that equals to coal combustion of 4236.3 t per year. The 2 proposed underground water intakes are able to deliver 358.1 MW of power that will enable local coal combustion reducing of 3380.3 t per year.
Atmosphere pollutants discharge in Szczawa originates from solid fuel combustion in individual furnace. Usage of already existing underground water intakes would allow to reduce pollution discharge for about 20%.

In the Tylicz area 18 underground water intakes were made. All of them exploit Tertiary flysch structure waters (Węcławik S. and Wójcik S., 1993). Seven intakes were recommended for heat energy exploitation. Heat quantity possible to obtain from single water intake ranges from 10 kW to 49.3 kW.
Tylicz heating needs were evaluated to 1.8 MW, that equals to coal combustion of 4201.6 t per year. The 7 proposed underground water intakes are able to deliver 189.2 MW of power that will enable local coal combustion reducing of 3749.6 t per year.
Atmosphere pollutant discharge in Tylicz originates from solid fuel combustion in individual furnace. Usage of already existing underground water intakes would allow to reduce pollution discharge for about 10%.

In the Wysowa area 13 underground water intakes were made. All of them exploit flysch structure waters. Underground waters are combined with variegated shale or Inoceramus layers of the Magura unit (Węcławik S., 1969). Four intakes were recommended for heat energy exploitation. Heat quantity possible to obtain from single water intake ranges from 20.2 kW to 39.5 kW.
Wysowa heating needs were evaluated to 682.2 MW that equals to coal combustion of 1630.8 t per year. The 4 proposed underground water intakes are able to deliver 129.1 MW of power that will enable local coal combustion reducing of 1322.1t/year. Atmosphere pollutants discharge in Wysowa originates from solid fuel combustion in individual furnace. Usage of already existing underground water intakes would allow to reduce pollution discharge for 19%.

Deliberations presented in this paper are theoretical and relative. Data about intakes comes from hydrogeological data bank and is not locally verified. Due to the above the results might be born with some incertitude.

CONCLUSION

Shallow underground water intake exploitation with heat pumps as heat energy source is much cheaper than geothermal energy usage with deep bore-wholes.
There is no need to build new intakes because existing ones were proposed to recuperate low-temperature geothermal energy. Among total number of intakes, 136 were recommended for heat energy exploitation. Some areas with greater intake number were proposed to widen their usage.

Nowy Sącz province hosts many health resorts and recreation villages because of mountainousness, a multitude of mineral water springs and landscape assets. The environment has not been yet much destroyed in the area.

Atmosphere pollutants discharge in the proposed areas originates from coal combustion. Usage of geothermal energy would scale pollution discharge cutback from 0.7% up to 30%. The quantity depends on particular village inhabitant number and used intake amount. The greatest reduction will occur in Gródek n/D.

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Table1
Heating needs and coal combustion in selected towns

Town	*Inhabitant amount*	***Inhabitable surface m^2***	***Heating needs MW***	***Coal combustion t/year***
Gródek n/D	535	7 885	0,549	1 312,768
Kościelisko	4 376	79 099	5,251	12 553,221
Krynica	13 100	194 486	13,519	32 320,202
Szczawa	1 781	25 172	1,772	4 236,288
Tylicz	1 527	26 165	1,758	4 201,835
Wysowa	669	9 773	0,682	1 630,766

Table 2

Present emission pollutions in atmosphere in selected towns

Pollution	*Present emission t/year*					
	Gródek n/D	*Kościelisko*	*Krynica*	*Szczawa*	*Tylicz*	*Wysowa*
Benzo(α)piren	0,026	0,251	0,646	0,085	0,084	0,033
Smoke-black	11,815	112,979	290,882	38,127	37,817	14,677
Dust	35,445	338,937	872,645	114,380	113,450	44,031
CO_2	2428,621	23223,459	59792,374	78837,132	7773,427	3016,918
CO	131,277	1255,322	3232,020	423,629	420,185	163,077
NOx	1,313	12,553	32,320	4,236	4,202	1,631
SO_2	21,004	200,852	517,123	67,781	67,230	26,092
Aliphatic hydrocarbons	6,564	62,766	161,601	21,181	21,009	8,154
Aromatic hydrocarbons	6,564	62,766	161,601	21,181	21,009	8,154

Table 3.

Planned emission pollutions in atmosphere in selected towns

Pollution	*Reduction emission t/year*					
	Gródek n/D	*Kościelisko*	*Krynica*	*Szczawa*	*Tylicz*	*Wysowa*
Benzo(α)piren	0,018	0,188	0,614	0,068	0,075	0,026
Smoke-black	8,227	84,461	276,248	30,423	33,746	11,898
Dust	24,682	253,382	828,745	91,269	101,239	35,695
CO_2	1691,177	17361,382	56784,379	6253,631	6936,738	2445,792
CO	91,415	938,453	3069,426	338,034	374,959	132,205
NOx	0,914	9,385	30,694	3,380	3,750	1,322
SO_2	14,626	150,152	491,108	54,085	59,993	21,153
Aliphatic hydrocarbons	4,571	46,923	153,471	16,902	18,748	6,610
Aromatic hydrocarbons	4,571	46,923	153,471	16,902	18,748	6,610

Inner Carpathian: 1-deposits older than Paleogene, 2-Paleogene, 3-Neogene, 4-Pieniny Klippen Belt.
Magura nappe: 5-Inoceramian beds and older rocks, 6a-Paleogene deposit of Sacz zone, 6b-Paleogene deposit of Krynica zone, 6c-Paleogene deposit of Tylicz zone, 7-Bystrzyca zone, 8-Paleogene deposit of Gorlice zone, 9-tectonic windows and scales, 10-Rychwald and Malcowa series, 11-tectonic scales. Dukla folds: 12- Cretaceous, 13-Paleogene.
Outer zone:14-lower Cretaceous, 15-upper Cretaceous, 16-Paleogene, 17-folds zone, 18-Miocene, 19-effusive rocks, 20-margin of the Outer Carpathian, 21-faults, 22-margin of the Carpathian's nappe, 23-klippe.

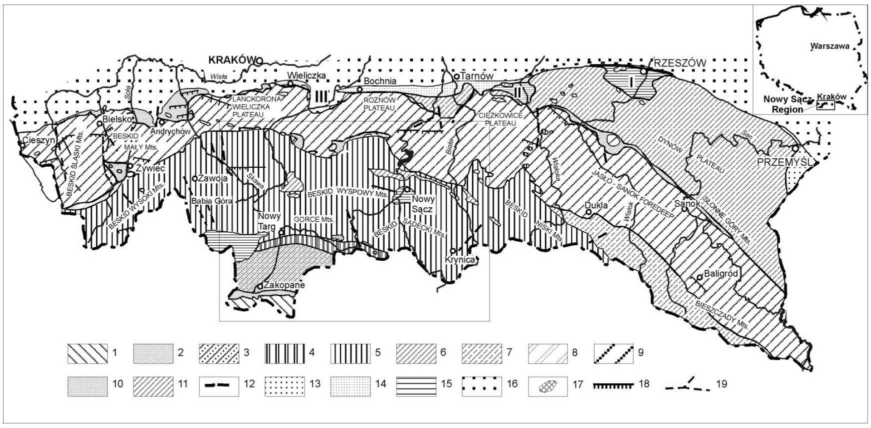

Fig.1.Review tectonic map of the Polish Carpathian
(E.Stupnicka, 1989 by M.Książkiewicz et al, 1972)

1-cristallinic of the Tatra Mts and Sub-Tatric nappe, 2-Sub-Tatric nappe, 3- Pieniny Klippen Belt, 4- Magura nappe, 5-Grybów nappe, 6-Dukla nappe, 7- Fore-Magura unit, 8- Silesian nappe, 9-Sub-Silesian nappe, 10-Andrychów Rocks, 11- Stebnik nappe, 12-Wieliczka-Bochnia folds, 13-folded Miocene over-lying flysch deposit and overthrust with them on north, 14-autochthonous Miocene, 15–Miocen of Nowy Sącz zone, 16-margin of the Carpathian's nappe, 17-more important faults, 18-border I-Rzeszów gulf, II-Pilzno gulf, III- Gdów gulf.

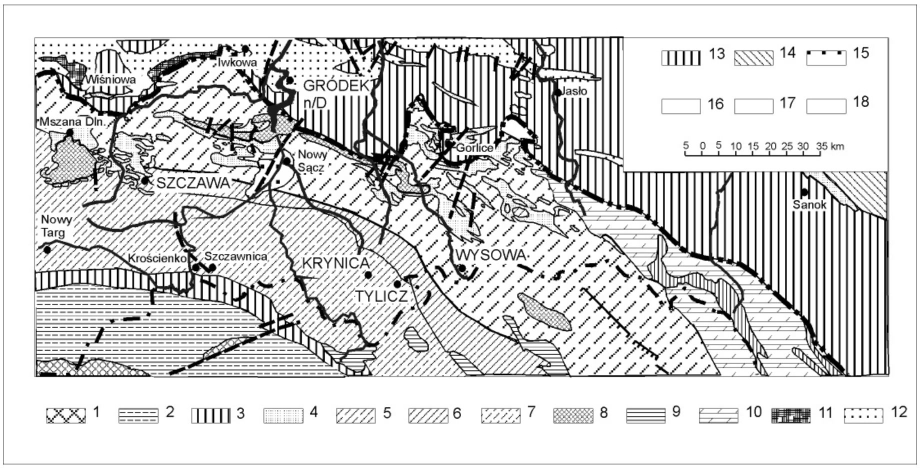

Fig.2. Tectonical sketch of the south-east part Magura nappe and part of the Outer Carpathian
(Weclawik S., 1969 et al.)