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Relationship of linear remote sensing data and springs in epimetamorphic late paleozoic rocks

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Abstract:

In the basin of the Eastern Slovak river Hnilec the location of natural groundwater outflows has been correlated with the course of lineaments identified on multispectral, foto-grammetric panchromatic and 2.5 cm "SLAR" radar pictures and by geologic mapping determined fault zones. The relationship between the lineaments and springs was investigated using the geographic information system IDRISI, creating envelope surfaces around the lineaments, with boundaries at the distance of 50, 100 and 150 m. Afterwards, cumulated spring capacity inside the envelope surface of lineament groups, distinguished on panchromatic, multispectral, radar images was compared as well as their number. Direction intervals of lineament divided into 10 ° were compared in the same way.

It has been found that direction interval of 51–60° and 151–160° had the highest "absolute" values of cumulated capacity and spring number, however, after division with the envelope area, aimed at obtaining "relative" values, lineaments of the direction intervals 71–120° appeared in foreground. These are, as it appears, the most open ways for the circulation of groundwater. The west-east direction of these, from hydrogeologic viewpoint well opened lineaments, is consistent with the direction perpendicular to the last regional extension field connected with the subduction of the flysch belt basement under the Western Carpathians during Upper Sarmatian – Pliocene.

Key words: remote sensing - hydrogeology - groundwater - springs - faults - radar - multispectral , panchromatic, images

(2 Figs., 5 Tabs.)

Introduction

Water-bearing fractured rock environment is from hydrogeologic viewpoint, due to its discretion, anisotropy and heterogeneity, a complicated system. Fracture systems and tectonic predisposition of transmissivity play an important role in massifs formed of rocks, as well as in the case of semi-rock Paleogene sediments. Tectonic predisposition of transmissivity often even covers the differences in hydraulic conductivity expected with regard to lithologic types of aquifers. In the first stage of obtaining and capturing groundwater by drilling, the faulting of the massif becomes a factor increasing the risk in successful capture of the sources and complicating representative calculations of filtration characteristics.

Remote sensing became in the last decades an important part of the investigation of fractured environment on regional scale. Recording compact regions, using various apparatus in different spectral ranges of electromagnetic radiation, provides regional information on the position of important fault lines, as well as about the character of the fracturing. Fractured water-bearing environment has so far been investigated by remote sensing especially with the aim to locate hydrogeologic exploitation drillholes, or to evaluate the relationship between the capacity of existing hydrogeologic drillholes and the location, number and orientation of photolineaments in their immediate surroundings (SIDDIQUI – PARIZEK, 1971, GERLACH, 1977, KRUCK, 1977 and 1979, MOORE, 1976, PARRY – PIPPER 1979, TARANIK 1976, HRKAL 1989).

Our attempt at finding statistical correlation relationships between natural groundwater outflows in water-bearing fractured environment of Lower Paleozoic epimetamorphic flysch rocks and the position of photolineaments is, more or less, an inverse task.

Geological characterisation of the studied region

The area of the Spišsko-gemerské rudohorie Mts., within which the studied regionof Volovské vrchy Hills is situated, is the southernmost tectonic unit of the Inner Western Carpathians, termed "gemericum". This tectonic unit is lying in a nappe position on the tectonic unit of the more to the north lying veporicum. The thrust boundary corresponds to the course of the Ľubeník-Margecany line. Gemericum consists of rock complexes from three evolution cycles: Early Paleozoic, Late Paleozoic and Mesozoic. Rock complexes of the Early Paleozoic form almost all of the Hnilec drainage basin, within which there are 510 km^2 of the studied territory. It is a flysch meso-rhythmic sedimentation of sandstones and claystones, with alternating flysch subformations, accompanied by synchronic acid, to a lesser extent also basic volcanism. In the upper part the sedimentation is more varied due to carbonates and lydites. The age of the lower unit – the Gelnica Group - has an estimated stratigraphic span of Upper Cambrian to Lower Devonian (BAJANÍK — VOZÁROVÁ 1982). The result of Hercynian regional epimetamorphism of the above rock complexes are then alternating layers of phyllites and quartzites, metarhyolites and metarhyolite tuffs, in an estimated thickness of 4500 – 8000m.

The above lying Rakovec Group is then a volcanogenic formation characterised by extensively developed subaquatic basic volcanism. Besides phyllites and quartzites, there are mostly metabasalts and metabasalt tuffs. The thickness of the Rakovec Group is estimated in the range of 1500 to 2500 m.

Most important for the formaiton of fragile deformations in rocks of the epimetamorphic Paleozoic of the Spišsko-gemerské rudohorie Mts. was the post-Paleogene stage of geological history of the territory. The formation, course and importance of rupture faults were however controlled by the existence of a basic inhomogeneity - cleavage. The direction of cleavage is almost in all of the territory east-west, only in the area of Smolník-Úhorná it turns to NE-SW (SNOPKO, 1971). This marked, but very isotropic inhomogeneity then determined the character of fragile-deformation effects of later stress fields. Regional deformation field rotated from the Oligocene to the Sarmatian gradually in clockwise direction, from stress direction NW-SE to NE-SW (KOVÁČ et al., 1992, NEMČOK et al., 1993). The resulting extension directions - the direction of pull-apart fractures - are parallel with stress direction and they may be thus assumed in the ranges 141–150°(or 151–160°) to 41–50°. However, this rotation of stress field from NW-SE to NE-SW does not end the evolution of tectonic stress in this territory. In the period from the Sarmatian to the Pliocene, the territory was affected by extension forces related to the development of the Carpathian arc - subduction of the flysch belt basement beneath the Western Carpathian block (RATSCHBACHER, 1991, RATSCHBACHER et al., 1991). The extension has the direction NNE–SSW to NE–SW (20 to 40°), so that open fracture system perpendicular to this system is lying in the direction range 110–130°.

Circulation pathways of groundwater in the studied territory

The ways of groundwater circulation in the hydrogeologic massif of epimetamorphic Paleozoic rocks of the Volovské vrchy Hills is in its basic features determined by the interrelation of water-bearing Quaternary sediments (alluvia, elluvia and delluvial slope debris) and underlying rock basement. While Quaternary sediments are generally ascribed by an order higher transmissivity and pore permeability, Paleozoic rocks are considerably less transmissive with fracture type of permeability. From the results of hydrogeologic survey carried out in this region in 1986–1990 (P. MALÍK – K. VRANA – J. IVANIČKA, 1990) it follows that lithologic differences in the basement rocks do not play an important role in the way of groundwater circulation. The generally accepted assumption of a circulation pathway being predisposed by the interaction of rock environment type and tectonic stress should however reflect better the effects of the plasticity of epimetamorphosed flyschoid sediments, especially phyllites. These rocks should have, in comparison with the more rigid quartzites, more packed fracture systems and thus lower transmissivity. The results of hydrological observations, hydrogeologic drilling and evaluation of spring documentation however do not indicate lower water-bearing capacity of phyllites (maybe with the exception of graphitic phyllites), to the contrary, they indicate 2–8 times higher transmissivity, determined in hydrogeologic drillholes situated in phyllites.

1761 springs and mine waters were documented in the drainage basin of Hnilec in the Volovské vrchy Hills. It is interesting that quartzites, porphyroids as well as non-mine water of the metabasalts have very similar distribution of spring numbers as well as capacities between different spring types, which would indicate relative similarity of circulation conditions in these rock types, forming the drainage basin, as well as the fact that circulation pathways are probably controlled by the direction of tectonic faults in all rock types.

However, since there is the generally accepted opinion of higher water-bearing capacity of quartzites in comparison with phyllites, there was an attempt to quantify this ratio in the case of springs (MALÍK et al., 1990). The ratio the occurrence of quartzites vs. phyllites determined by planimetric analysis is approximately 40% : 60%. If we take into consideration the number of all documented springs and the capacity of all springs, this ratio is 30 : 70%, or 31 : 69%, respectively. After excluding debris springs we obtain for the number and capacity of springs the ratios 36 : 64%, or 33 : 67%, respectively, again not in favour of quartzites. If we exclude also mine water, which can unfavourably affect the statistics by drainage of large mixed units, we obtain the ratios 35 : 65% for the number and 32 : 68% for the capacity of springs, again unfavourable for quartzites. The ratio is also similar for springs exceeding 1.0 $l.s^{-1}$ - 34 : 66%. Generally we may thus state that quartzites display lesser hydrogeologic effects than it would correspond to their ratio to phyllites and we could deduce that their hydrogeologic productivity may be even lower than that of phyllites. However, since these considerations are loaded by imprecision in the determination of relative occurrence of quartzites and phyllites, as well as problematic accurate specification of rock types in the documentation of springs, we conclude than the most important factors of water-bearing capacity are here rather the cover formations and tectonics.

Based on these results, we may evaluate the pre-Quaternary rocks of the Volovské vrchy Hills as a relatively uniform hydrogeologic massif, in which, independently of rock composition, tectonic faults of rupture character produce the decisive and determinative effects on water-bearing capacity. We may thus state that the whole massif is a strongly discretised body with substantially aquiferous fractures and tectonic faults and low-aquiferous rock blocks, which occur among them.

EVALUATED REMOTE SENSING MATERIAL

We consider the circulation of groundwater in Volovské vrchy Hills to be controlled to a greater extent by tectonic predisposition than by lithologic properties of the evaluated territory. From this fact then followed our attempt to find preferred ways of water issue with the help of remote sensing using several types of material.

Air panchromatic images

Classical black-and-white (panchromatic) air images, with an approximate scale of 1 : 30 000, allow a relatively simple identification of basic geodynamic elements. The stereoscopic analysis itself was focused on the study of faults and fractures, slide areas and conspicuous approximate relicts of original levelled surfaces. To ensure greater objectivity, stereoscopic interpretation was based on two independent evaluations and comparison of the results. The results were documented on map appendices, on the scale 1 : 25 000 (POSPÍŠIL, 1992)

Radar images

Radar images were taken by a Soviet radar, with the wave length 2.5 cm, on the principle of SLAR (Side Looking Airborne Radar) - "radar bokovogo obzora". During the evaluation of the radar images the absence of complementary data - situation of the air course in terrain - became evident, presenting, due to the applied method of side radar orientation and subsequent progressive distortion of images, considerable difficulties for the location of interpreted results in maps.

Multispectral air images:

Multispectral air images were made by an air multispectral chamber MKF-6M in six spectral ranges:

Channel 1: 460 – 500 nm
Channel 2: 520 – 560 nm
Channel 3: 580 – 620 nm
Channel 4: 640 – 680 nm
Channel 5: 700 – 740 nm
Channel 6: 780 – 860 nm

Air courses during the scanning were approximately parallel in east-west and west-east direction, with appropriate overlapping of the images, allowing stereoscopic evaluation.

From multispectral air images of the Hnilec river basin in the Volovské vrchy Hills, pseudo-coloured multispectral syntheses have been prepared for further interpretation, using electronic mixer and image analyser NAC MCDS 4200F. According to original intents, negative and positive images of the Channel 2, 4 and 6 of MKF-6 should have been used for syntheses, in the following colour combinations:

Channel 2: positive blue

Channel 4: negative green

Channel 6: negative red

When preparing syntheses according to this scheme it became evident that the quality of existing negatives would not yield required results. These technical reasons led to a change in the colour and channel combination in multispectral synthesis: to ensure that the synthesis would not be too dark in the final appearance, positive version of the channels were preferred and the synthesis scheme was as follows:

Channel 2: positive blue

Channel 3: positive green

Channel 6: positive red

Thus, a pseudo-natural colour combination was selected, preserving the succession of colours in spectrum (blue-green-red) and simultaneously shifting them into higher wave lengths (red colour was attached to the infra-red range invisible to the human eye). Therefore, the resulting colour appearance of the synthesis corresponds approximately to colour spectrozonal images.

Another source of adverse effects in the syntheses, besides the above mentioned difficulties with the too high optical density of negatives, was also too high optical steepness (contrast) of negatives of channels 2, 3 and 4. Too contrasting negatives did not allow to create a full range of colour shades for the synthesis (Pospíšil, 1992)

Evaluation and analysis of linear remote sensing data and method of their correlation with groundwater issues

Using the module DIGITIZE of the software package ROCKWARE, rivers, spring co-ordinates and fault lines were digitised from the geological map, panchromatic images and radar images. Digitised data were then transferred for the purpose of drawing into the software SURFER and transformed into the analytical program IDRISI, producing **raster** maps of springs and lineaments from each basic material. The lineament maps were further divided to obtain 18 maps for each method of lineament determination - separately for panchromatic, multispectral, radar images or faults from geological map. Individual maps always showed lineaments in a direction range. The ranges were divided at 10° from the range 1°– 10° to the range 171°– 180°. For each of these maps, envelope curve maps about relevant lineaments were created, limiting an area of up to 50 m, up to 100 m and up to 150 m about the lineament. From thus prepared material, an intersection has been made with the map showing the distribution of springs, obtaining the numbers of springs and later on cumulated spring capacities within the surfaces of up to 50 m , 100 m and 150 m from the lineaments or fault lines. Since surfaces about the lineaments with different directions overlapped at certain places, some springs were recorded in both surfaces and thus may have been counted several times into the total number of springs and their capacities summed into cumulated capacity. Since the aim was not to determine accurately the boundaries between the surfaces about lineaments with different directions, and the number of double-counted springs was not significant, this fact should not affect the general conclusions. From the above description of the construction of maps it follows that the surfaces and thus also the numbers of springs are more accurate at a distance of up to 50 m from the lineament and with increasing distance they become more cumulated.

Relationship between the occurrence and capacity of natural groundwater issues and their position in relation to the interpreted lineaments

We based our investigation of the assumed relationship of groundwater issues to zones of more intensive faulting of the rock massif, which from the bird's eye perspective may appear as lineaments identifiable on air images of the territory, on the following premises:

1. if the groundwater issues were not associated with preferred zones, the total number of 1761 springs would be distributed more or less uniformly

on the whole area of the Hnilec river basin in the Volovské vrchy Hills (510.0 km^2)

2. if the spring issues were not associated with fault zones, the total spring capacity in the river basin (845.85 $l.s^{-1}$) would be more or less uniformly distributed on the whole area of the river basin.

On the surface limited by the distance of up to 50 m from faults determined by geological mapping (this surface is 51.03 km^2, which is 10.00% of the total area) there are 337 springs, which is 19.13% of the total number of springs in the river basin. Assuming homogeneous distribution of springs, the relative parts of surface and spring number should be approximately the same in value. The determined 1.913 times higher relative number of springs near fault lines determined from the geological map indicates certain relationship of spring occurrences to faults. Similar is the case of the comparison of spring capacities at the distance of up to 50 m from fault lines of the geological map. Total capacity of these springs (200.29 l.s-1) represents 23.67% of the total capacity of all springs in the river basin, and it is thus 2.36 times higher than it should be at uniform distribution of spring capacities on the whole studied territory.

The surface of up to 50 m from lineaments interpreted from panchromatic materials represents 30.92 km^2, and thus 6.06% of the Hnilec river basin surface in the Volovské vrchy Hills. 219 springs are flowing off on this area, with a total capacity of 128.4 $l.s^{-1}$, i.e. 12.43% of the number of springs and 15.18% of the total capacity of all springs on the studied territory. In the case of number of springs the real number vs. expected numbers at uniform distribution is 2.05 and in the case of spring capacities it is 2.50.

Multispectral images are, due to the total length of lineaments identifiable from them (and by the surface limited by 50 m distance from them), together with radar images, the most important ones. In contrast to radar images - and, of course, also panchromatic images and geological map - the determined ratios of expected (at uniform distribution) and real number of springs - 2.52, and of the expected and real capacity - 2.75 - are however somewhat higher than these ratios at lineaments determined from other materials. On a surface of 70.91 km^2 (13.90% of the investigated area) there are 617 springs (35.03% of the total number), with a total capacity of 323.4 $l.s^{-1}$ (38.23 % of the total capacity).

In the case of radar images these ratios have the values of 2.02 for the number of springs and 2.38 for their total capacity. Lineaments interpreted from radar images have the area of up to 50 m distance largest of all (86.22 km^2 or 16.90%), but the number of springs is here a little lower than at lineaments from multispectral images (602 springs, i.e. 34.18%) and their total capacity (341.3 $l.s^{-1}$, or 40.35%) is only a little higher.

We may thus generally state that for surface boundaries at the distance of 50 m from lineaments identified from various materials, the ratios of the real number of springs vs. the number of springs expected according to the size of area at assumed uniform spring distribution on the whole surface of the studied territory is about the double (in average 2.12) and the ratio of the real total capacity of these springs and total capacity expected according to the surface size of the area at their uniform distribution on the whole studied territory vary about two-and-a-half multiple (in average 2.50). This indicates thus a relationship between the location and capacity of the spring issues and the location of the lineaments. At first comparison of the successfulness of different methods or materials for the identification of lineaments for the areas of up to 50 m from lineaments, the best appears to be the relationship to lineaments interpreted from multispectral images. The ratio of real and expected numbers of spring on these areas is 2.52 (arithmetic mean of the other three identification materials is 1.995) and for the capacity of these springs 2.75 (other three methods – 2.15).

From the obtained results it may be inferred that with increasing distance of area boundaries from the lineaments the total number of springs as well as total capacity increases, but generally not as rapidly as the surface of the areas. From this it follows that the ratio comparing real and expected values of these quantities with increasing distance from the lineament (fault) decreases. This means that spring issues are probably mostly related to narrow zones which could be identified with relatively high precision. For the comparison of successfulness of each lineament identification from different materials there were compiled tables 1 and 2, eliminating the differences in length and thus also in the surface of areas about identified lineaments by introducing average number of springs and average spring capacity on 1 km^2 of the area about the lineaments.

When comparing average number of springs and average spring capacity on 1 km^2 of the area about lineaments (from tables 1 and 2) we may again observe the above mentioned fact that average number as well as capacity of springs decreases with increasing size of the area. We assume that this confirmed the consistence of the pathways of preferred groundwater circulation and issue with the course of identified lineaments, while considerable precision of their localisation has been shown as well. When comparing the capacity to record the most of groundwater issues with highest capacity according to tables 1 and 2 the best appear to be again lineaments from multispectral images. Since from the above said it may be inferred that the most significant is the distance range of up to 50 m from a lineament, in the following we shall also deal with the comparison of values obtained from various

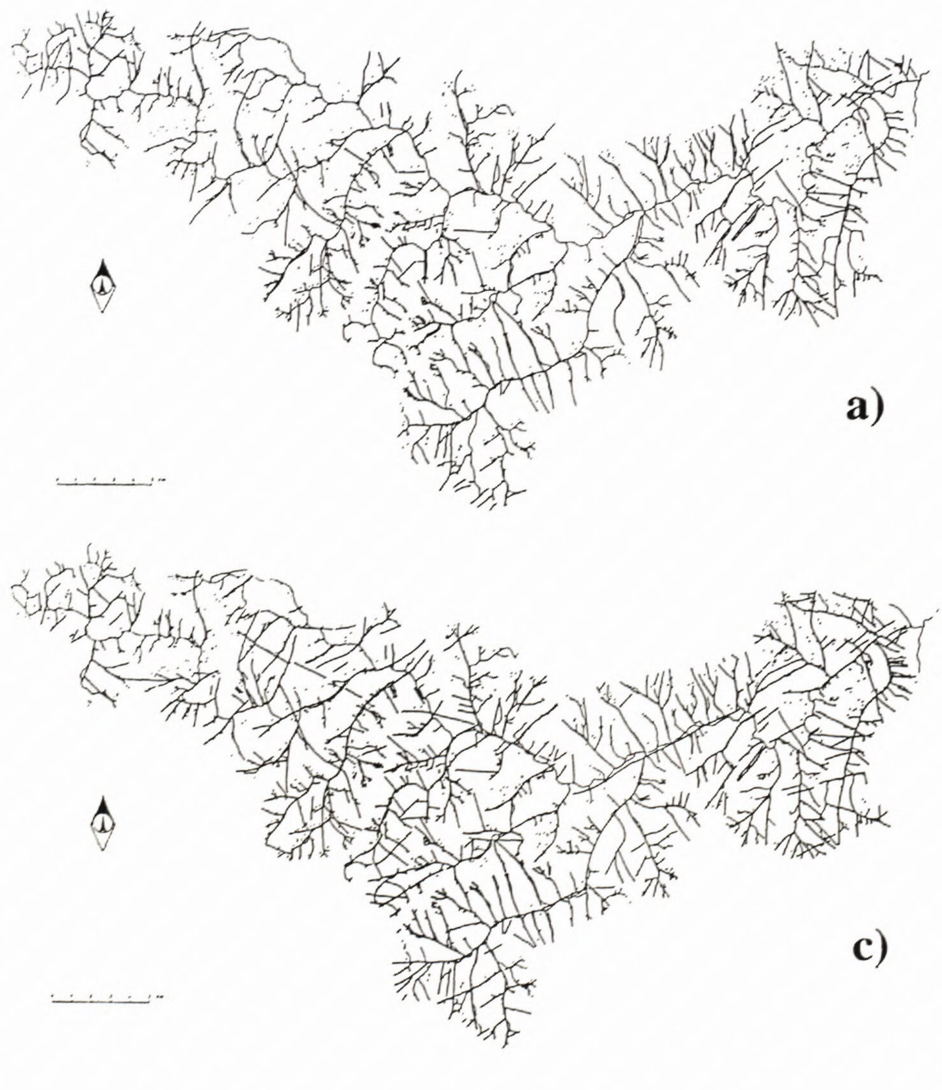
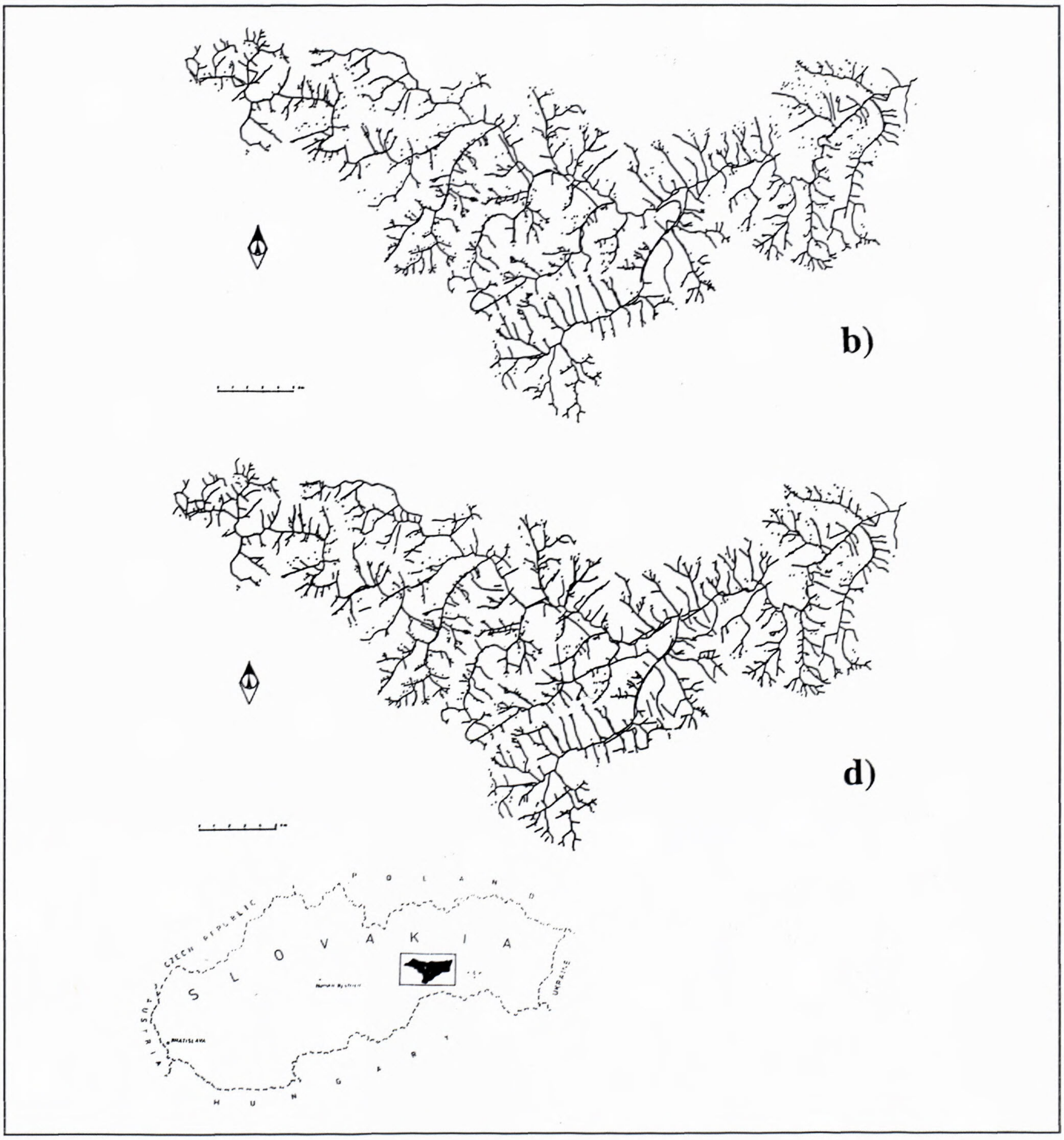


Fig. 1 Investigated area of the river Hnilec basin, position of surface streams, springs and: a) fault lines according to geological map in 1:50 000 scale, b) lineaments derived from panchromatic images, c) lineaments derived from multispectral images, d) lineaments derived from radar (SLAR) images

identification material for this range: total number of spring on the surface of 1 km^2 of the area is for all materials 7.34, for "multispectral lineaments" it is 8.70 and for lineaments from other materials 6.89.

Average spring capacity sum from 1 km^2 of the "50 m area" for lineaments of all materials is in average 4.15 $l.s^{-1}$, for lineaments obtained by the interpretation of multispectral images 4.56 $l.s.^{-1}$ and for other lineaments is the average 4.01 $l.s^{-1}$. Multispectral images, or from them interpreted lineaments, do not display length dominance (lineaments from radar images are by almost 20% longer) nor preference of lineament directions, which would be neglected by lineaments from other materials (see previous part). Multispectral lineaments are rather characterised by uniform distribution of lineaments into direction ranges. We thus assume that their relatively higher effectiveness is a result especially of the precision of localisation of



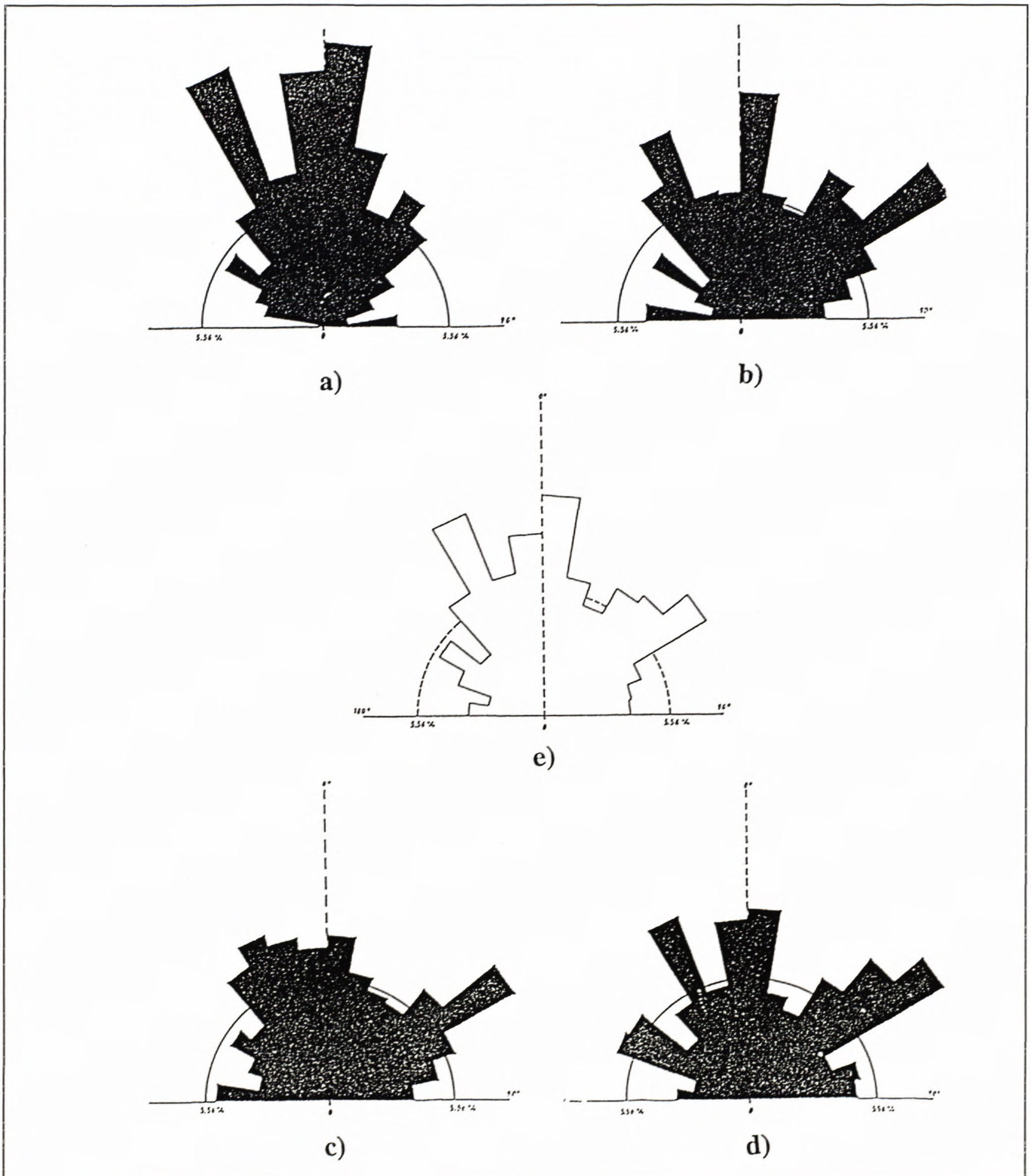


Fig. 2: Preferences in direction of lineaments, derived from: a) fault lines according to geological map in 1:50 000 scale, b) lineaments derived from panchromatic images, c) lineaments derived from multispectral images, d) lineaments derived from radar (SLAR) images, e) average values of all methods. Interval of lineament directions are divided in 10° intervals (0°– north, 90°– east, 180°– south),figures are made to compare relative values of cumulated lengths of lineaments belonging to separate direction intervals. Semicircle represents average value, which can be expected in the isotropic case - equal preferences of all direction intervals.

lineaments and of not loading of the lineament network with lineaments having little or no relevance as preferred groundwater circulation ways (which probably happened in the case of radar images).

RELATIONSHIP BETWEEN LINEAMENT DIRECTION AND OCCURRENCE AND CAPACITY OF GROUNDWATER ISSUES

When comparing the hydrogeologic significance (openness for groundwater circulation) of different direction ranges of lineaments determined by the interpretation of different materials, we also used the original premise of homogeneity – uniform distribution of the number of total capacity in relevant areas for all lineament direction ranges. Since direction ranges were divided at 10°, the respective percentage of number or capacity of springs at their uniform distribution in all ranges would be 1/18, i.e. 5.56% for each range.

Since total spring capacities as well as numbers within the 50, 100 and 150 m areas in general follow the relative area surface within the ranges (1–10° to 171–180°), in view of the considerably variable surface of the areas it was necessary to evaluate the hydrogeologic significance, i.e. the probable openness of various lineament directions for groundwater circulation by relative quantities - ratios of the percentage of the spring numbers or capacities and the percentage of the relevant area surface.

This evaluation of the ratio of spring number percentage and relevant area surface percentage yielded quite different preferences for different direction ranges than those recorded in the evaluation of "absolute numbers". The highest values of the above ratio are obtained from relative spring occurrences about faults determined by geological mapping. Tab.4 shows that the succession of first three direction ranges is constant for all area sizes: 1. 91–100°, 2. 11–120°, 3. 161 – 170°, 4. 121–130° and 5. 171–180°

The value of relative spring occurrence attains here 1.85 and the first three ranges have the highest average values from all evaluated direction ranges at all lineaments. Lineaments identified from panchromatic images show significant changes in

Tab. 1 Comparison of the number of springs in a 1 km^2 area limited by various distances from a lineament (fault) for different identification methods of lineaments

Area at a distance - " -	Number of springs on 1 km^2 area in relevant distance from a lineament identified from:			
	geologic map	panchromatic images	multispectral images	radar images
up to 50 m	6,604	7,080	8,701	6,982
up to 100 m	6,066	5,932	7,060	5,939
up to 150 m	4,847	5,052	5,828	5,230

Tab. 2 Comparison of average spring capacities on 1 km^2 area limited by various distances from a lineament (fault) for different lineament identification methods.

Area at a distance from lineament of:	Spring capacity on 1 km^2 of the area in relevant distance from lineament identified from:			
	geological map	panchromatic images	multispectral images	radar images
up to 50 m	3,925	4,154	4,561	3,959
up to 100 m	3,441	3,063	3,521	3,389
up to 150	2,691	2,792	2,864	2,810

the succession of direction ranges with changing area boundary distances from the lineaments. The leading position in the succession according to the relative occurrence is relatively constant with direction intervals of 21–30°and 51–60°, relatively significant are perhaps also the ranges 51–60°and 91–100°.

Lineaments identified from multispectral images in relation to the value of relative spring number occurrence show clear preference of the direction range 121–130°. Second place is then occupied by the direction 81-90° and other preferences are more ore less dispersed, or there are preferred secondarily the ranges 41–50° and 171–180°.

The direction range 121–130° is clearly leading also in the case of lineaments identified from radar images. At a distance then follows the preference of the direction 101–110° and we may also mention secondary preferences of direction ranges 171–180°, 131–140° and 61–70°. The results of the evaluation of the spring occurrence percentage and relevant area surface percentage ratio are listed for all lineament types in Tab.3.

In general we may thus evaluate as most occupied by springs the direction range 121–130°, taking the first place in multispectral as well as radar lineaments and having a firm leading position also among tectonic lines determined by geological mapping. With the exception of lineaments derived from panchromatic images, the direction 171–180° has also considerable common preference, other ranges of direction do not have many simultaneous preferences at various lineament types.

If we evaluate the ratio of total spring capacity percentage and relevant area surface percentage in the areas of up to 50, 100 and 150 m about faults from geological map as well as lineaments identified from panchromatic images, we obtain, in comparison with lineaments from multispectral and radar images, higher numerical values of this ratio. Fault lines have besides this a clearly determined preferential relation to specific direction ranges, which does not change even with increasing area. In the first place they are faults in the direction range 61–70°, then 111–120° and third is the direction 31–40°. Secondary are preferential orientations in direction ranges 151–160° and 171–180° (see also Fig. 2).

Lineaments from panchromatic images have with fault lines in common only the preferential orientation to the direction range 111–120°, besides this preferred directions are 51–60° and 91–100°. Less preferred is the orientation in the range 101–110°and, similarly as in the case of fault lines, the preference of the direction 151-160° is here less significant - it is one of the few direction ranges which - with their significantly preferred "absolute values" of spring numbers and capacities - did not get lost among sub-average values after the introduction of relative capacities.

The values of relative total capacities of springs occurring in relevant areas about lineaments interpreted from multispectral images and their differences are lower than in the above mentioned cases. A significantly preferred range is 41–50°, followed by 101–110°. Complementary to the clearly preferred direction 101–110° are preferences of the ranges 81–90° and 111–120°, along with 121–130°.

The main direction ranges of "radar lineaments", on the surface of which there is relatively highest total spring issue capacity, are 71–80° and 101–110°. Secondarily preferred are then the directions 121–130° and 61–70°. These results can be found in Tab. 4.

Along with the evaluation of the ratio of total spring capacity percentage and relevant surface percentage, useful for the determination of hydrogeologic significance of different direction ranges may be also the value of median for the capacity of springs occurring in relevant area of the direction range. A common feature of the evaluation of hydrogeologic significance of different direction ranges using median of the capacity of springs occurring within areas up to 50, 100 and 150 m is the common preference of the range 151–160°. Even though this direction does not always appear on leading preferential places, it is nevertheless present in preferences of all lineament types according to material from which they were identified. Besides this it may be stated that "multispectral" and "panchromatic" lineaments have a common feature in their preference of the range 81–90°. Considering that the median of the set of all 1761 documented spring in the Hnilec river basin in the Volovské vrchy Hills is 0.235 $l.s^{-1}$, we may state that springs related to the most preferred direction intervals in Tab.5 really indicate the presence of more open circulation ways of groundwater.

Tab. 3 First 7 lineament direction ranges (identified by various methods) with greatest values of the ratio of relative spring occurrence number percentage vs. area surface percentage at a distance of up to 50, 100 and 150 m from the lineament - first datum in the column shows the value of this ratio in the area of up to 50 (100, 150) m for the relevant direction range, the second datum shows the order of precedence of the range in the relevant range (50, 100 or 150) of the area

Direction ranges of lineaments	Faults from geological map			Panchromatic images			Multispectral images			Radar images		
	50 m	100 m	150 m	50 m	100 m	150 m	50 m	100 m	150 m	50 m	100 m	150 m
1-10°												
11-20°							1,059 7	1,091 5				
21-30°		1,010 6		1,426 1	1,321 2	1,155 5			1,025 7			
31-40°												1,078 7
41-50°			1,090 6	1,384 2	1,422 1	1,160 4	1,075 5	1,189 2	1,128 4			
51-60°				1,146 6	1,225 3	1,170 3		1,059 7				
61-70°	1,122 6									1,249 4	1,314 2	1,343 3
71-80°										1,049 7	1,029 7	
81-90°							1,150 2	1,165 3	1,192 2			
91-100°	1,854 1	1,515 1	1,552 1	1,269 3	1.223 4	1,279 1		1,129 4	1,137 3			
101-110°						1,146 6	1,069 6			1,282 2	1,158 5	1,149 5
111-120°	1,618 2	1,467 2	1,517 2	1,191 4	1,206 5	1,180 2	1,088 4		1,099 5			
121-130°	1,372 4	1,250 4	1,185 4		1,193 6		1,398 1	1,432 1	1,388 1	1,433 1	1,577 1	1,512 2
131-140°										1,203 5	1,208 3	1,189 4
141-150°												
151-160°				1,160 5	1,141 7	1,131 7						
161-170°	1,560 3	1,302 3	1,279 3							1,197 6	1,086 6	1,575 1
171-180°	1,288 5	1,088 5	1,127 5				1,131 3	1,066 6	1,039 6	1,262 3	1,181 4	1,135 6

Tab. 4 First 7 lineament direction ranges (identified by various methods) with greatest values of the ratio of total spring capacity percentage vs. area surface percentage in the area of up to 50, 100 and 150 m from the lineament - first datum in the column shows the value of this ratio in the area of up to 50 (100, 150) m for the relevant direction range, the second datum shows the order of precedence of the range in the relevant range (50, 100 or 150) of the area.

Direction ranges of lineaments	Faults from geological map			Panchromatic images			Multispectral images			Radar images		
	50 m	100 m	150 m	50 m	100 m	150 m	50 m	100 m	150 m	50 m	100 m	150 m
1-10°	1,116 6	1,072 6										1,128 7
11-20°							1,112 6					
21-30°												
31-40°	1,822 3	1,610 3	1,335 4							1,109 6		
41-50°				1,141 6	1,154 7	1,073 6	1,913 1	1,765 1	1,684 2		1,161 6	
51-60°			1,192 7	2,491 2	2,168 3	2,530 1		1,533 3	1,336 6			
61-70°	5,013 1	3,381 1	2,870 1							1,039 7	1,922 2	1,685 3
71-80°										2,621 1	1,960 1	1,716 2
81-90°							1,202 5	1,256 7	1,553 3			
91-100°				2,410 3	2,263 2	1,766 4		1,330 6	1,225 7			
101-110°				1,796 4	1,430 4	2,223 2	1,660 3	1,751 2	1,906 1	1,896 2	1,777 3	1,831 1
111-120°	2,376 2	2,011 2	2,291 2	3,078 1	2,457 1	1,900 3	1,680 2	1,430 4	1,353 5			
121-130°							1,110 7	1,346 5	1,371 4	1,660 3	1,588 4	1,551 5
131-140°											1,164 5	1,243 6
141-150°			1,135 6		1,230 5							
151-160°	1,346 5	1,308 4	1,449 3	1,202 5	1,217 6	1,180 5				1,197 4	1,067 7	
161-170°												1,589 4
171-180°	1,420 4	1,122 5	1,253 5				1,212 4			1,175 5		

Tab. 5 First 7 lineament direction ranges (identified by various methods) with greatest median of spring capacity in the area of up to 50, 100 and 150 m from the lineament - first datum in the column shows the value of the spring capacity median ($l.s^{-1}$) in the area of up to 50 (100, 150) m, the second datum shows the order of precedence of the range in the relevant range (50, 100 or 150) of the area.

Direction ranges of lineaments	Faults from geological map			Panchromatic images			Multispectral images			Radar images		
	50 m	100 m	150 m	50 m	100 m	150 m	50 m	100 m	150 m	50 m	100 m	150 m
1-10°	0,290 6	0,280 5	0,265 5		0,250 4	0,250 5-7						0,275 7
11-20°	0,270 7											
21-30°												
31-40°							0,230 6		0,230 7			
41-50°				0,260 5		0,250 5-7						
51-60°			0,260 6	0,250 6	0,240 5	0,250 5-7		0,250 6	0,250 6	0,350 4	0,350 2-3	
61-70°	0,950 1	0,805 1	0,550 2							0,440 2	0,320 5	
71-80°						0,380 1						
81-90°	0,325 5			0,380 2	0,380 1-2	0,325 3	0,320 2	0,350 2	0,340 1		0,290 7	0,280 5-6
91-100°				0,620 1	0,380 1-2	0,330 2						
101-110°			0,220 7				0,300 3	0,590 1	0,300 3	0,615 1	0,350 2-3	0,520 1
111-120°	0,445 3	0,460 2	0,585 1				0,335 1	0,335 3	0,295 4			
121-130°					0,230 6			0,310 4	0,310 2	0,300 7	0,300 6	0,305 4
131-140°		0,240 6										0,280 5-6
141-150°				0,365 3		0,305 4				0,345 5	0,335 4	0,350 3
151-160°	0,500 2	0,420 3	0,480 3	0,330 4	0,320 3		0,280 4-5	0,280 5	0,280 5	0,420 3	0,420 1	0,380 2
161-170°		0,210 7		0,225 7	0,225 7							
171-180°	0,435 4	0,300 4	0,295 4				0,280 4-5			0,330 6		

CONCLUSION

When averaging the percentages of length preferences of lineaments identified from all four materials, we obtain a dominance of direction intervals 151–160°, further the directions north-south (1–10° and 171–180°) and the range 51–60°. From average values of the per cent occupation of total lengths in the different direction ranges there is also inferred an absence of a greater number or of longer lineament sections in the direction ranges 61–110°. However, it must be stressed that in any of the materials from which the position of the lineaments was determined these are narrow direction zones, in which there are lineaments, while these direction zones are, when comparing the sums of the lengths of in a direction zone present lineaments, sharply separated from neighbouring direction zones.

The relationship of the position and capacities of spring issues to the position of lineament is supported by the fact that for boundaries of studied areas of up to 50 m from lineaments identified from various materials, the ratios of real number of springs vs. number of springs expected according to relevant size of area surface, assuming uniform distribution of springs on the whole surface of the studied territory, vary approximately about the double (in average 2.126) and the ratios of the real total capacity of these springs and total capacity expected according to the size of relevant area surface at the assumption of uniform spring distribution on the whole surface of the studied territory, vary approximately about two-and-a-half multiple (in average 2.502).

Comparing the successfulness of different methods, or materials for the identification of lineaments in areas of up to 50 m from lineaments, the most frequent appears to be the relationship to photolineaments interpreted from multispectral images. For the number of springs in these areas the ratio of real and expected value is 2.520 (arithmetic mean of the other three identification materials is 1.995) and for the capacities of these springs it is 2.750 (other three methods - 2.149-multiple). With increasing distance of area boundaries from the lineaments the total number as well as total capacity of springs occurring inside the areas increase, but in general not as rapidly as the surface of the areas. The ratio comparing real and expected values of these quantities with increasing distance from the lineament (fault) decreases. Spring issues are therefore probably mostly related to narrow zones, which could be identified with great precision, depending from the used image material. The most successful interpretation material - multispectral images, or lineaments interpreted from them, do not show length dominance (lineaments from radar images are almost by 20% longer) nor preference of lineament directions, which would have been neglected by lineaments from other materials (see previous part)."Multispectral lineaments" are rather characterised by uniformity of the distribution of lineaments into direction ranges. We thus conclude that their relatively higher effectivity is a result of the precision of lineament localisation and of the lineament network not being loaded by lineaments which have little or no significance as preferred groundwater circulation pathways.

In the case of multispectral images the interpreters declared a number of technical errors (too high optical steepness (contrast), too high optical density, damage by colour), making the interpretation more difficult. In spite of this we value multispectral images as material capable of providing the most comprehensive and from the hydrogeologic viewpoint most reliable information on the course of lineaments indicating fault zones, to which groundwater issues could be related. This means that these materials, or this method of scannig of the territory, using suitable air carrier, at suitable distribution of air courses and taking into consideration all technical faults, especially in regard to the quality of recorded material, is the most suitable for solving equivalent problems.

"Relative" values of the evaluation of hydrogeologic preference of different direction ranges force into background the directions NE-SW, NW-SE, as well as N-S, and bring into foreground in length (or area) little represented lineaments of east-west direction, especially the ranges 101–110°and 11–120°, less 91–100° and 81–90°. However, even at "relative values" some in length more frequently represented directions do not fall into background: in preferences according to the ratio of total spring capacity percentage and relevant area surface percentage, at lineaments identified from multispectral and panchromatic images, the ranges 41–50° and 51–60° appear as well. In the evaluation of lineaments according to median of the capacity of springs occurring in relevant areas about the springs, there is a common, even though not the most significant preference of the direction range 151-160° for all lineament types. The decreased median value of water temperature for all lineament types in this direction range indicates also deeper circulation of groundwater in fault zones of this direction.

We assume that the majority of other identified lineaments has its geological-tectonic basis in fragile stress strike-slip deformations. These are connected with significant deformation faults, manifested in the surroundings of faults and "making visible" especially lineations of the "Carpathian" NE-SW direction. Besides this, east-west extension zone directions are not only parallel with the air courses during scanning of the territory, but they are parallel also with the general direction of lithological boundaries in the epimetamorphic massif. Therefore we assume that the determined lineaments in the direction ranges of 101-120° (81-100°) have not been exhaustively documented on the studied territory and for their identification it would be necessary to interpret images (especially radar) obtained by scanning in several, preferably perpendicular flying directions. These lineaments, indicated by increased median of the capacity of springs occurring in their immediate surroundings as well as increased values of the ratio of total spring capacity from relevant areas vs. surfaces of these areas represent an important anisotropy and groundwater circulation direction. We may however state that preferred west-east direction of open groundwater circulation pathways is consistent with pull-apart rupture faults, formed due to effect of extension forces related to the development of the Carpathian arc - subduction of the flysch belt basement under the Western Carpathian block (RATSCHBACHER 1991, RATSCHBACHER et al. 1991) in the time of Sarmatian to Pliocene.

In the relevant Hnilec river basin in Volovské vrchy Hills, built predominantly of epimetamorphic Paleozoic rock with fracture permeability the identification of preferred lineament directions (fault and fractures) with higher permeability is an important piece of knowledge for the prospection for groundwater bound to this rock environment. Situating hydrogeologic drilling to the immediate surroundings of such zones results in increased probability of obtaining higher exploitable quantities of groundwater. It is also important to consider increased risk of encountering a permeable tectonic fault with highly confined groundwater table of east-west direction, or in the direction range 151–160° and 41–50° during mining and tunnelling works in this region. To the contrary, when making underground galleries with the aim of capturing the greatest possible quantity of groundwater for supplying drinking water at lowest costs, is the optimum way to situate the gallery perpendicularly to the identified lineaments of above mentioned directions.

The method applied in the presented work may be used on any territory. As it is inferred by the comparison of materials for the interpretation of photolineaments, the most suitable for the interpretation of lineaments with hydrogeologic significance appear to be multispectral images.

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