APPLICATION OF THE DIRECTIONAL PREDICTION METHOD TO THE DRAINAGE OF THE REKA - TIMAVO UNDERGROUND RIVER

UPORABA METODE PREDVIDEVANJA NAJPOGOSTEJŠIH SMERI ODTOKA V KAMNINI NA PRIMERU PODZEMELJSKE REKE REKE - TIMAVA

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Adolfo Eraso & Franco Cucchi & Joaquin Fernandez & Jose Antonio de la Orden & Louis Torelli: Uporaba metode predvidevanja najpogostejših smeri odtoka v kamnini na primeru podzemeljske reke Reke - Timava

Metoda predvidevanja najpogostejših smeri odtoka v kamnini se je izkazala kot pravo orodje za študij karbonatnih ali drugih anizotropnih kamnin. Metodo, podprto z računalniškim programom, so uporabili na več kot 50 različnih primerih, od Arktike do Antarktike. Tudi rezultati 265 terenskih meritev tektoglifov na področju podzemeljskega toka Reke, so se izkazali kot zelo dobri. Raziskovalne metode, prikazane v tem prispevku, so prvi koraki k uporabi omenjene metode na Krasu.

Ključne besede: strukturna geologija, tektonika, metoda predvidevanja, podzemeljski pretok, Italija, Slovenija, Kras, sistem Reka-Timavo

Abstract UDC 556.38(450)

Adolfo Eraso & Franco Cucchi & Joaquin Fernandez & Jose Antonio de la Orden & Louis Torelli: Application of the Directional Prediction Method to the drainage of the Reka - Timavo underground river

The Prediction Method of the water drainage in karst regions has proved to be a genuine tool for study of karst massif anisotropy. The Method, supported by three computing programmes, has been applied in more than 50 examples all over the world from Artic to Antartic. The results of realized 265 field work measurements of tectoglyphs or tectoglyphs conjunctions in the Reka-Timavo Region were again very successful. Investigations mentioned in this text are the first steps for the application of the "Prediction Method of the underground drainage main directions" to the Reka -Timavo Karst Region.

Key words: structural geology, tectonics, prediction method, underground drainage, Italia, Slovenia, Kras, Reka-Timavo system

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INTRODUCTION

During the last decade, the Prediction Method of the drainage main directions in karst has proved to be a genuine tool for the study of karst and/or the quantification of a rocky massif anisotropy.

Applied yet in more than 50 different examples all over Europe, Asia, America, Oceania, the Arctic and Antarctica, from which the balance has been made in 1990 of the 33 first cases with excellent results, we think it is time now to apply it in the Kras-Carso-Karst region, where the history of this part of science started last century.

The Reka-Timavo underground river traject seemed to be, for us, the appropriate place to initiate the application of the Prediction Method in this interesting region, due to its historical importance.

GEOLOGICAL AND STRUCTURAL CHARACTERISTICS

The underground karst system of the REKA-TIMAVO river develops in a 50 km long, 12 km wide and several thousands meters thick carbonatic massif, with a SE-NW direction.

The massif consists, from a morphological point of view, in a rather ondulated platform extending in a NW direction, with levels going from 450 m (in Škocjan) to 100 m (in Isonzo), (Habič, 1984).

From a geological point of view, the massif belongs to the denominated Komen platform (Comeno), strong Cretacious-Tertiary series, mainly of limestone, on which overthrusts the Trnovo, Hrušica and Snežnik tectonic shield in its NE part. In the SW part, the referred platform also overfolds through the Ćićerija overlapped structure, over the Capodistria area, one of the southern Dinaric linements which features the south-west Slovenia and the north-east Adriatic area (Placer, 1981).

During the alpine orogenesis, this structure was dislocated as a consequence of the N-S oriented stresses (Alpine thrusts) and NE-SE ones (Dinaric thrusts).

The mentioned Komen platform is characterized, from a structural point of view, by a wide anticlinal with a NW-SE axis, complicated by a series of subparallel folds and some faults. The main ones of them are parallel to the main structure, dislocating it partially into small subparallel graben and horst. Other minor faults perpendicularly intersect the structure generating movements with strike slip components within parts of the anticlinal flank (Fig. 2.-1).

The anticlinal axis is ondulated and imerses both at the SW (under the Friulian plain) and at the SE (within the Illirska Bistrica underground).

The lithotypes which form the Komen platform are from the Lower Cretaceous to the Eocene ages, with a global thickness of almost 4000 m of carbonatic sequences and nearly 2000 m of **flysch** sandy-marly levels (Pleničar, 1960).

The Reka-Timavo karstical system develops within limestones, dolomitical limestones and Cretaceous-Tertiary dolomites which are very pure, intensively karstified (probably during the Pliocene age), limited on the sides by the non-karstified lithotypes of the flysch formation.

More in detail, we would say that the karst of the region is characterized by a monoclinal vergence - with a NW-SE direction and a 5° to 50° imersion southwards - complicated on the SE by a series of inverted ondulations and faults which are subparallel to the main structure axis and on the NW by a series of differently oriented faults which give origin to some small graben (Cucchi et al. 1987).

Only a few parts of the Reka-Timavo underground course are known: the Škocjan ponor, the spring near San Giovanni al Timavo, with medium range flows of 30 m^3/s, which comes from the three existing gaps and the shorts parts of the course which can be reached both at the Abisso serpenti (Kačna jama) and the Abisso di Trebiciano, the last one has been the world record of deepness, with 327 m, from its exploration in the XIX century until fairly late in the XX century.

The Reka-Timavo underground course develops in a NE direction during at least 40 km according to a hipsographic curve which has a more than 50‰ slope during the first 4 km (from the 323 m a.s.l. in Škocjanska jama-caverna Michelangelo, to the 88 m a.s.l. in Abisso dei serpenti - Kačna jama). The following 11 km part of the course has a 7‰ slope (from Kačna jama to Trebiciano) and the rest of the course, until the San Giovanni al Timavo spring, only has a 0,5 ‰ slope (Cucchi, Forti, 1981).

THE PREDICTION METHOD OF THE MAIN UNDERGROUND DRAINAGE DIRECTIONS IN KARST (ERASO, A., 1985/86)

The underground aquifer circulation within rock massif is established due to the interconnection of weakness plans systems or privileged fissures, within a discrete tridimensional net of conducts.

We have got to take into account that in these preferential channels genesis, stresses operate on the lithologic material, as a consequence of the

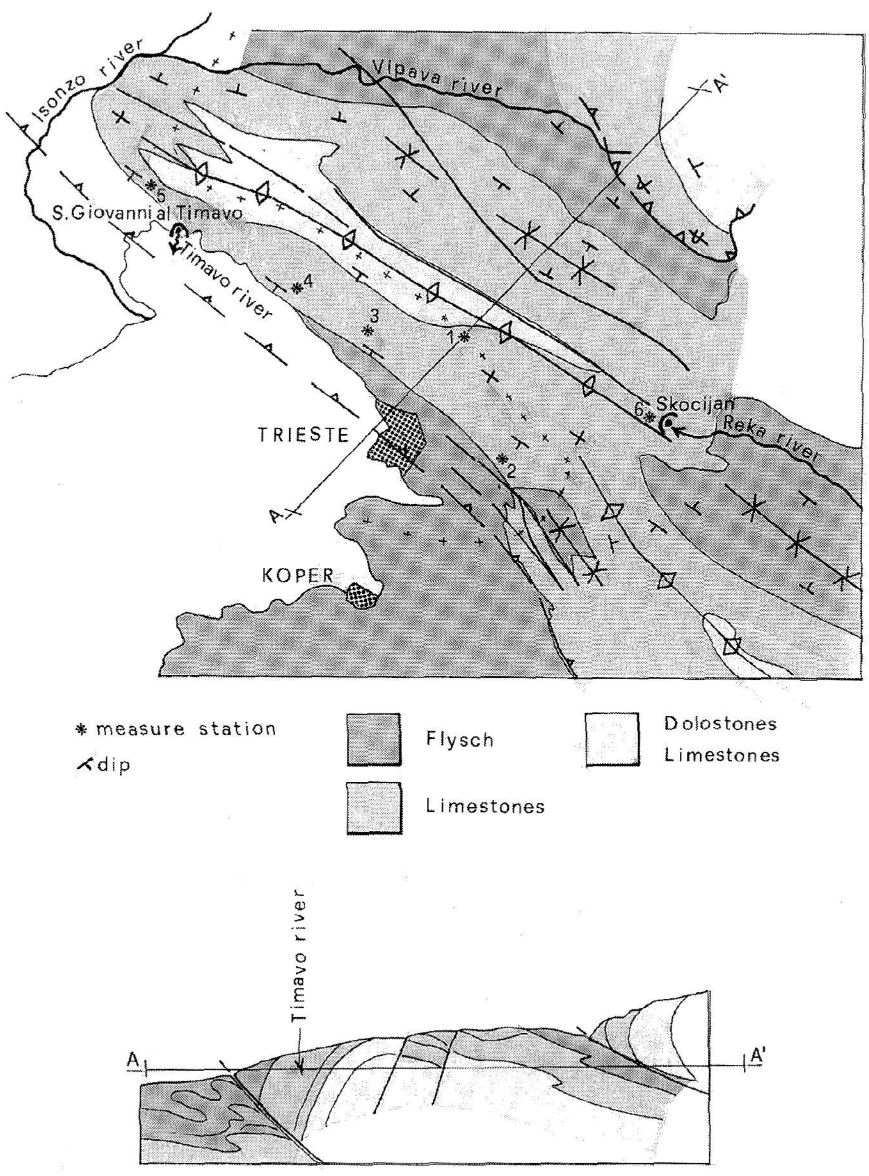

Isonzo river
Vipava river
A'
S.Giovanni al Timavo
Timavo river
1
2
3
4
5
6
Skocijan
Reka river
TRIESTE
A
KOPER
measure station
dip
Flysch
Limestones
Dolostones
Limestones
Timavo river
A
A'

Fig 2.1

orogenic processes, responsible of the variation of the tensional state.

The stresses are of two types:

- normal or direct (σ), which, in its turn, can be a textensional or a compressive one, and
- scissors type (τ), which, in its turn, can be a dextral or a senistral one.

If we consider the efforts which act on the unitary cubic element, orientated according to the three cartesian axis, we can distinguish nine components. Three of them constitute the normal stress and are respectively parallel to the cartesian axis; the other six correspond to the scissors stress and each two of them are orthogonal to a main stress.

The action of these stresses permits different reactions which produce elastic, plastic or fragile deformations of the rock.

Anyway, an efforts tensor can be established, as a result of the joint three components: hydrostatic effort, deflecting effort and unbalance component, as well as a deformation tensor, composed by three diferent effects: dilatation, distorsion and rigid rotation.

Through the study of folds and faults, structural geology permits to establish the orientation and disposition, in the space, of the three principal components of the deformation ellipsoid: $\sigma 1$ (major), $\sigma 2$ (medium) and $\sigma 3$ (minor).

Now, on a detailed scale, the possibilities of these components definition increase in a significant way, analysing the micro-structures and specially the tectoglyphs which are some traces of the permanent deformation, printed in the rock, as a consequence of the tectonic efforts.

Among these tectoglyphs point up, due to its interest, the following types:

- stylolites joints,
- veins or mineral dykes, and
- frictional striation in the fault planes.

Each of them has got a genetic significance which makes it usefull to define the ellipsoid.

The stylolites constitute junctions of the rock discontinuity, where the material situated on both sides has come closer and has got interpenetrated, part of it disappearing due to the under pression dissolution mechanism.

Its form, in peaks of parallel orientation, which can be seen when the junction is open, indicates the direction of shortening. This direction is statistically orientated, in a coincident way, with the component of the major axis of the deformation ellipsoid (σ_1) or, what is the same, the stylolitic junction is statistically orientated in an orthogonal way to this component.

The limestone veins, quartz dykes or other mineral, constitute discontinuity junctions/unions in the rock, in which the material situated on both sides got separated at the same time that the gap got filled, generally, with the predominant recrystallized material of the rock.

The veins have got a planar morphology, resulting of a traction effort, and are statistically orientated, in a coincident way, with the minor component of the deformation ellipsoid (σ_3) or, what is the same, the plan of the vein is statistically ortogonal to the mentioned component.

So we can say that the mineral gets dissolved on the sides when the main compression effort takes place, and is depositated again in the sides where the main traction effort takes place. Thus, stylolitic plans and recrystallization veins are perceptibly orthogonal (when they correspond to the same tectonic phase).

The friction striations, in the plans of fault, indicate the displacement suffered by both sides of the referred plan, as a consequence of some particular scissors type components.

The plan of the fault forms a certain θ angle with the major component of the deformation elipsoid (σ_1). The value of θ, which is generally 30°, really depends on the angle of the rock internal friction, on the massif scale, according to the relation:

$$\varphi = 90° \equiv - 2.\theta$$

Practically, although the plans of the fault present a major continuity in the space than the stylolites and veins, they don't constitute true geometric plans, due to the rock anisotropy and heterogeneity, what produces fluctuations in the average orientation of the referred fault. This is why we need a major number of observations in order to get reliable statistical values.

Fig. 3.-1, by Arthaud & Mattauer (1969), represents the mentioned tectoglyphs and their meaning.

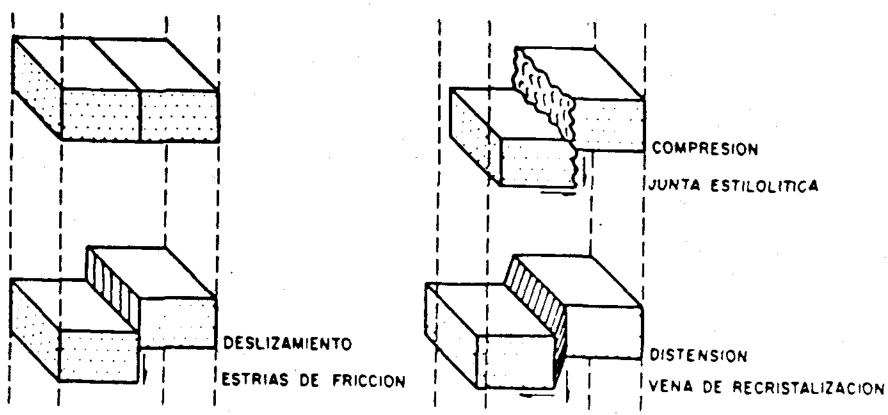


Figure 3.-1 Tectoglyphs genesis.

These tectoglyphs appear interconnected in the nature, and each of them can follow any direction with regard to the stratification plan.

We'll have the more favourable situation to define the deformation ellipsoid when two or more different tectoglyphs are combined, as we define with them the main efforts components. The more suitable combinations (Fig. 3.-2) are the following ones:

a) combined faults,
b) fault- vein,
c) stylolite - vein, and
d) fault - stylolite.

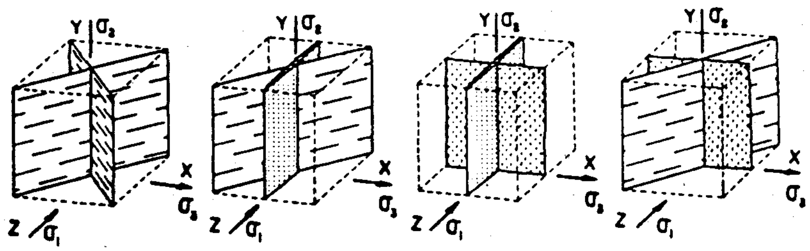


Figure 3.-2 Main tensions in combined tectoglyphs.

Thus, since as a massif gets older, the possibility of its having undergone a large number and variety of stresses increases, the probability to find different families of tectoglyphs, which present different orientations and makes it possible to identify their corresponding stresses ellipsoids.

The method needs to know the succession of the tectonic phases and assign them to different tectoglyphs families which will be used to identify each and every ellipsoid.

This way, in order to know the relative ages of the tectonic phases, we havet to find pairs of homogeneous conjunctions, preferably of vein-vein or stylolite-stylolite types, with the criteria that, in them, the displaced plans are older than the displacing ones.

As, in a tectoglyphs singenetic family, the ellipsoid components are orthogonal ones, we'll be able to identify each tectonic phase, if we've got the sufficient number of conjunctions.

As for the distensive, elapsing or compressing characteristic of the referred tectonic phase, we can determine it according to which is the main ellipsoid component, with the more vertical orientation.

The field work consists in locating the major number of the formerly mentioned tectoglyphs conjunctions and to measure in them the plan orientation and the dip with its vergence.

Thus, as there is a fifth possibility to define the ellipsoid, the localization of a fault where we can determine the "pitch" and the displacement orientation, in this case the following parameters have to be registered:

- orientation of the fault plan,
- dip with vergence sense,
- pitch with vergence orientation, and
- displacement orientation of the fault.

In order to identify the tectonic phases, through the normal efforts directions in the ellipsoids, we will have to make also an inventory of the homogeneous conjunctions connecting:

- its type (preferably the vein-vein and stylolite-stylolite conjunctions),
- the discontinuity orientation,
- the dip with vergence sense, and
- its relative age (the more modern one is the displacing one).

The more appropriate sites to locate tectoglyphs are the recent anthropic excavations and, of course, the natural cavities.

The data obtained in the field are computed, in the laboratory, with the tool which gives the stereographic projections, taking into account that, for each conjunction, the normal efforts are oriented in a different way.

The stereographic projection is used, for this analysis, using the representation in the Wulff's equiangular net and the Schmidt's equiareal net.

The measured plans are reflected in these nets by a maximum circle or by a pole. When we operate with statistically representative data, we can define, in the space, the existing modes, according to the poles density, quantified through the Kalsbeek's net.

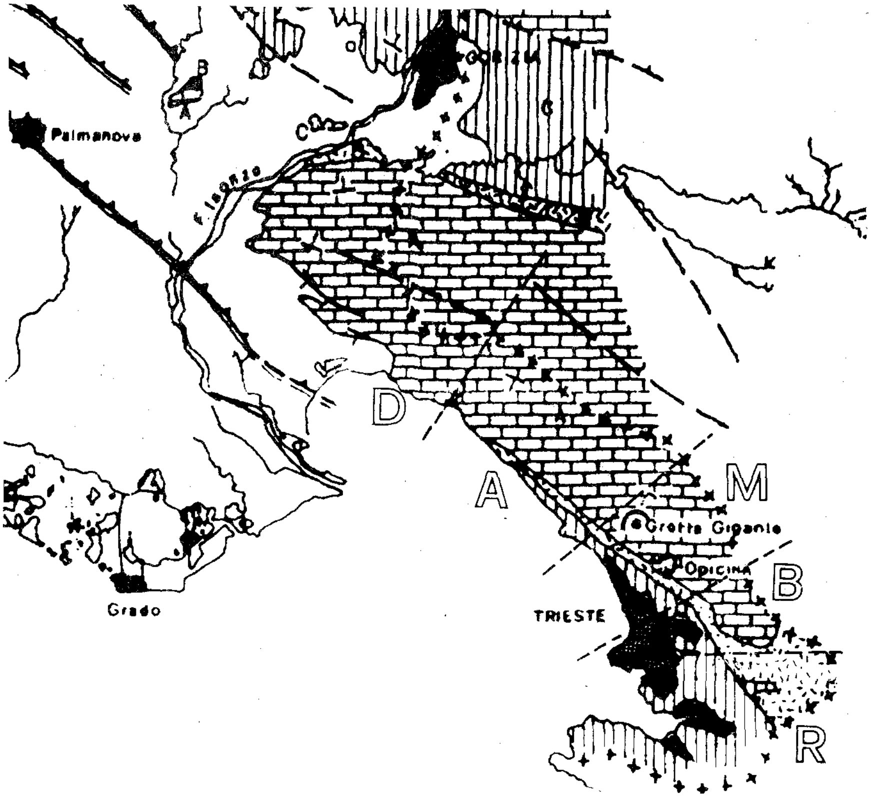
To make easier the work, the method has got three computing programmes (Eraso A., Fernandez Rubio, R., 1990):

- **GEORED**, which draws the equiareal (Schmidt) and equiangular (Wulff) stereographic nets, for any inclination angle of the reference sphere axis, between 0° and 90°.
- **GEODRE**, which computes and draws the position of the elipsoid components (σ_1, σ_2 and σ_3), for the tectoglyphs conjunctions and for the unique fault. This programme gives us the drainage plans, and
- **GEOPOL**, which calculates and draws, for a determined population of plans and/or the areas with the same poles concentration, according to the established percentage chart.

From all the gathered and computed information, the Method (we expose) determines the threedimensional components of the net of underground aquifer three circulation channels, applying two hypothesis:

The first, qualitative one:

- the tectonic efforts have shaped both the net of drainage preferential channels, and the anisotropy of the drainage directions, and



TOTAL CAVES LENGTH			21.689	KM
D	AREA	DUINO	2.8	»
A	»	AURISINA	7.4	»
M	»	MONRUPINO	1.6	»
B	»	BASOVIZZA	6.5	»
R	»	VAL ROSANDRA	3.2	»

Fig 5.-2

The second, quantitative one:

- the more probable directions of this drainage are located within the defined plans, by the

directions of the normal efforts σ_1 and σ_2 of each ellipsoid.

With regard to them, the drainage preferential directions are statistically defined.

APPLICATION OF THE METHOD TO THE REKA-TIMAVO REGION

The result of the realized field works was 265 measurements of tectoglyphs or tectoglyphs conjunctions made in 6 different stations:

- Station n° 1: Monrupino with 41 measurements,
- Station n° 2: Basovizza with 48 measurements,
- Station n° 3: Aurisina with 28 measurements,
- Station n° 4: S. Pelagio with 55 measurements,
- Station n° 5: Sorgenti di Duino with 41 measurements,
- Station n° 6: Škocjan with 42 measurements,

The results obtained as a consequence of the application of the programmes of the method has got are expressed in the following steps:

1. the prediction given by the method, in three dimensions (6 spheric gaussians) for each of the 6 stations.
2. the prediction given by the method, in three dimensions, (spheric gaussian) for the measurements global, with specification of the poles of drainage plans in each station.
3. 6 histogrammes of the prediction given by the method (in two dimensions) for each station.
4. Global histogramme (in two dimensions) of the prediction.
5. 3 spheric gaussians (in three dimensions) with indication of the poles density modes of each principal components (σ_1, σ_2, σ_3) of the ellipsoids.

The analysis of the whole results leads us to do the following interpretation:

1. The existence of four directional modes of the drainage plans with the following characteristics:

- a main mode according to N135° to N150° with a 15,5 % associated probability;
- two secondary modes: one according to N60° to N75° with a 12,8 % probability, another one according to N0° to N15° with a 11,3 % probability;
- a (minor) mode according to N90° to N105° with a 5,3 % probability.

2. The existence of thrusts according to:

- NE-SW, fluctuating from both sides with a 45° inclination, generating overthrusts,
- N150° (of minor importance) with low angle,

- vertical one, (vertical σ_1) gravitational, generating normal faults,
- vertical σ_2 generating strike slip faults.

DIRECTIONS OF THE CAVES ACCORDING TO TOPOGRAPHIES

The results of the conducts and caves directions, topographied in the Carso Triestino, and kept in the archives of "Commissione Grotte E. BOEGAN" were realized in two dimensions, in 15° to 15° statistical classes. They were represented in 360° radial histogrammes, having computed a total of 21.689 km underground course, with the following distribution of stations:

- Station R: Valrosandra area with 3.2 km,
- Station B: Basovizza area with 6.5 km,
- Station M: Monrupino area with 1.6 km,
- Station A: Aurisina area with 7.4 km,
- Station D: Duino area with 2.8 km,
- Global station : with the before mentioned total: 21.689 km,

whose localization appears in Fig.- 5.-2.

COMPARISON OF THE RESULTS

The objective consists, due to the whole available data and results, in comparing, in a quantified way, the prediction given by the applied method and the known reality of the topographied karst conducts.

As the correspondence between the tectoglyphs measurement stations (from 1 to 6) and the topographies ones (from A to Global) do not correspond exactly:

. Station 2 partially covers R and B stations,
. Station A partially covers 3 and 4 stations,
. Station 6 has no correspondence, at the moment, we only made the comparison between both global histogrammes:

- one corresponding to the global tectoglyphs with 265 measurements, and
- the last box of Fig. 5.-1, with the whole 21.689 km underground conducts. The process we followed is:
- homogenize the radial histogramme of all the caves (box n° 6) from 0° to 360° at 0° to 180°,
- compare it (from 0° to 180°, yet) with the global tectoglyphs histogramme,
- draw, in two dimensions, from both polimodals, the corresponding cumulative curve, according to the 12 used statistic classes (from 0° to 180°), every 15°,
- superpose the figures of both cumulative curves in order to find the maximum difference between both of them:

. this one belongs to the class 9 (120° to 135° interval) with a 10.1% absolute value;

- apply the Kolmogorov statistical test, in order to calculate the maximum error in the comparison:

$$\sum \max. \leq \frac{10.1\%}{\sqrt{12}} \leq 2.92\%$$

- and finally, quantify the statistical accuracy between the prediction given by the applied method and the known reality:

$$ACCURACY\,GRADE \geq 100 - \sum \max \geq 100 - 2.92 \geq 97.08\%$$

These results are quantified in Table 6.-1.

COMPLEMENTARY COMMENTS

The investigations made in order to write the present work contains the first steps for the application to the Carso Triestino of the "Prediction method of the underground drainage main directions", and were completed by authors who belong mainly to the Trieste University and the Polytechnical University of Madrid.

We wish to extend its application on the investigations on the whole Kras-Carso-Karst region, so we need the participation of scientists from Slovenia specialized in the study of karst, as the main area belongs to this country.

The first steps were already taken with the monographic workshop held in Postojna May 31th and June 1st, 1993, organized by the Institut za raziskovanje krasa ZRC SAZU.

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CLASS	INTERVAL	CONDUCTS L = 21.7 km %	Σ_C	TECTOGLYPHS N = 265 %	Σ_T	DIFFERENCE $\lvert\Sigma_C - \Sigma_T\rvert$
1	0° - 15°	8,5	8,5	11,3	11,3	2,8
2	15° - 30°	9,8	18,3	8,7	20,0	1,7
3	30° - 45°	7,8	26,1	7,5	27,5	1,4
4	45° - 60°	10,5	36,6	7,5	35,0	1,6
5	60° - 75°	7,5	44,1	12,8	47,8	3,7
6	75° - 90°	7,8	51,9	3,4	51,2	0,7
7	90° - 105°	8,4	60,3	5,3	56,5	3,8
8	105° - 120°	6,7	67,0	3,0	59,5	7,5
9	120° - 135°	10,5	77,5	7,9	67,4	10,1
10	135° - 150°	8,4	85,9	15,5	82,9	3,0
11	150° - 165°	8,6	94,5	9,1	92,0	2,5
12	165° - 180°	5,3	99,8	7,9	99,9	0,1

MAXIMUM ERROR:

$$\Sigma_{max} \leq \frac{\lvert\Sigma_C - \Sigma_T\rvert}{\sqrt{\phi}}$$

ACCURACY GRADE:

$$100 - \Sigma_{MAX} \geq 100 - 2.92 = 97.08\%$$

Table 6.-1

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UPORABA METODE PREDVIDEVANJA NAJPOGOSTEJŠIH SMERI ODTOKA V KAMNINI NA PRIMERU PODZEMELJSKE REKE REKE - TIMAVA

Povzetek

V zadnjem desetletju se je "Metoda predvidevanja najpogostejših smeri odtoka v kamnini" izkazala kot pravo orodje za študij karbonatnih ali drugih anizotropnih kamnin. Metodo so uporabili na več kot 50 različnih primerih po vsej Evropi, v Aziji, Ameriki, Oceaniji, Arktiki in Antarktiki. Z "Metodo predvidevanja" so raziskovalci v večini primerov dosegli uspeh, v zadnjem času pa tudi potrditev pričakovanih razmer v naravnem okolju. Za preizkus metode so si avtorji izbrali tudi področje podzemeljskega toka reke Reke med Škocjanom in Devinom v Italiji.

Raziskovano ozemlje je pretežno karbonatni masiv, ki pripada Tržaško-Komenski planoti, ki jo karakterizira široka antiklinala z osjo v smeri NW-SE. Apnenci so tam večinoma kredne in terciarne starosti. Med alpidsko orogenezo so bile osnovne strukture premaknjene glede na pritiske, ki so delovali v smeri N-S (alpski narivi) in NE-SW (dinarski narivi).

Tridimenzionalni splet kanalov se v podzemnem vodonosniku oblikuje s povezovanjem za vodo lažje prehodnih ravnin oziroma pomembnejših razpok. Tvorba kanalov ob ugodnih razmerah je posledica litološkega stanja, orogenetskih procesov in tenzijskega stanja kamnine.

Avtorji obravnavajo dva tipa pritiskov:
-normalne ali direktne in
-strižne.

Vhodni podatki za "Metodo predvidevanja" so elementi vpada mikrostruktur (tektoglifov), med katere uvrščajo
-stilolitne šive,
-kalcitne žile ali mineralne dajke,
-strije na prelomnih ravninah.

Vsak od navedenih tektoglifov vsebuje namreč značilnosti, s katerimi si pomagamo izdelati elipsoid.

Na terenu pridobljene podatke obdelajo naslednji računalniški programi:

-GEORED, ki rezultate izriše na Schmidt-ovi ali Wulff-ovi mreži.

-GEODRE, ki izračuna in izriše komponentne elipsoida. Rezultat so ravnine drenaže.

-GEOPOL izračuna in izriše pole vnešenih ravnin drenaže.

Analiza vseh podatkov, pridobljenih z raziskavo, je pokazala naslednjo sliko:

1. Prisotnost štirih smeri ravnin drenaže:
   - -glavna smer s karakteristikami N 135^0 do N 150^0 ;
   - -dve sekundarni smeri s karakteristikami od N 60^0 do N 75^{0}in od N 0^0 do N 15^0;
   - -manj pomembna smer s karakteristikami od N 90^{0}do N 105^0.
2. Prisotnost narivov z značilnostmi:
   - -NE-SW, nagnjen z obeh strani za 45^0;
   - -N 105^0 (manjše pomembnosti);
   - -navpičen, ki je povzročil normalne prelome;
   - -navpičen, ki je povzročil drsne prelome.

Pričujoča raziskava, ki je nastala v sodelovanju med Univerzo iz Trsta in Politehnično univerzo iz Madrida, je prvi poizkus "Metode predvidevanja najpogostejših smeri drenaže v kamnini" na Tržaškem krasu.