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# TYPES OF CONTACT KARST

ABSTRACT: GAMS I., *Types of contact karst.* (IT ISSN 0391-9838, 1994).

Most of the largest and best-known karst forms in non-tropical climates are bound to litho-hydrologic contacts. The essay presents some evidence for their genetic linkage to horizontal and vertical contacts. At the same time, it explains the conception of contact karst and its main types as a result of selected modifiers.

KEY WORDS: Theoretic karst geomorphology, Speleology, Closed karst depression, Dinaric karst.

RIASSUNTO: GAMS I., *Tipi di carsismo di contatto.* (IT ISSN 0391-9838, 1994).

La maggior parte delle più estese e meglio conosciute forme carsiche, nel regime climatico non-tropicale, sono legate a contatti lito-idrologici. Questa nota presenta prove che evidenziano il legame genetico di tali morfologie carsiche con contatti lito-idrologici orizzontali e verticali. Inoltre, viene spiegato il concetto di «carsismo di contatto», facendo riferimento alle sue principali manifestazioni, condizionate da vari fattori.

TERMINI CHIAVE: Geomorfologia carsica, Speleologia, Depressioni carsiche, Carsismo Dinarico.

## INTRODUCTION

There has been lengthy discussion regarding the depth of the karst at which major corrosion processes by precipitation water occur. It has finally been realized that, as a rule, solution by precipitation water rapidly declines from the surface downwards (see also FORD & WILLIAMS, 1989, ch. 4). In the barren-surfaced Slovenian karst of the high Alps, in which during corrosion by the precipitation water, only the balance between $CO_2$ and the pressure of $CO_2$ in the free atmosphere is established, mineralization of water in karst sources reaches up to 70-80 mg of $CaCO_3$ + $MgCO_3$/l. However, on the lowland karst, where precipitation water percolates through soil, mineralization of source waters in Slovenia is usually 2 to 3 times higher as a result of biological activity in the soil. Precipitation water is most aggressive on its first contact with carbonate rocks, which happens at the base of the soil. If the water drips into a cave after percolating through only 5-10 m of rock thickness, it already deposits calcareous sinter, which is proved by the occurrence of dripstones (GAMS, 1966).

In the Alpine geologic structure with finely ruptured and often also thinly stratified karstic rocks, precipitation water percolates without being previously collected in surface stream. If isotropic conditions of corrosion (homogeneous soil cover, homogeneous vegetation cover, etc.) exist, then the chemical solution of rocks acts with equal intensity to surface lowering throughout the area and thus simultaneously lowers it during a geologic period. The karst of isotropic corrosion conditions is called the «pure karst model» by ŠUŠTERŠIČ (1986). Ridges and valleys, plains levelled by erosion, are inherent in lower altitudes when isotropic corrosion conditions are active in the karst period, as well as after the non-karstic or impermeable rocks are removed from the surface.

With corrosion by precipitation water in such isotropic conditions, bigger closed karst depressions can only be generated by differentiated vertical tectonic movements. Depressions of such origin, if located in humid climates and on impermeable sediments, would be filled with stagnant water or buried beneath alluvial sediments, but they are retained in their rudimentary form in the karst, due to the underground drainage. However it is difficult to prove the tectonic origin of bigger depressions even though this is very probable in the young geotectonic structures of the Alpine system. This kind of origin will be ignored in the current essay.

Perfect isotropic conditions for precipitation water corrosion are rare on the karst. Direct vertical percolation of water is locally prevented either by less permeable soils, seasonally frozen soil, or blocks of impermeable rocks, etc. A more severely weathered rock means that the deepening and the genesis of a depression will potentially progress faster. The soil on the slopes of the depression directs the flow of groundwater towards the bottom of the depression.

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For these reasons, by concentration of precipitation water in the areas of more intense ground drainage, local accelerated solution occurs. Local concentrations of groundwater inflows cause the formation of smaller depressions, no bigger than dolines. Local corrosion is essentially accelerated in the areas where surface rivers from other areas sink, and they will be called allogenic waters in the current paper. This allows the genesis of large underground caves and medium-sized or big karst depressions, which are the greatest karst peculiarities in non-tropical climates. They include blind valleys, canyons, dry valleys, karst poljes, deep shafts, large caves of sinking rivers, and collapse dolines above them.

The forms, resulting from the activity of allogenic waters on the border karst, are called by FORD & WILLIAMS (1989, p. 423) «landforms associated with allogenic inputs», which include, according to them, blind valleys and through valleys. Upon older karst literature, to larger depressions, lying in areas of allogenic water inputs in the border karst, also the border polje (*Randpolje* in German, LEHMANN, 1959) has to be included. Larger depressions and bigger underground caves are often related to vertical alternation of impermeable and permeable rocks. Both the former and the latter forms will be called by the common term of «contact karst» which has already been adopted in the Slovenian geomorphologic literature (Slovene Karst Terminology, 1973; GAMS, 1962, 1974 and 1993; MIHEVC, 1991). Since the forming of contact karst is influenced by flowing waters as well, the term of «contact fluoviokarst» has also been used (GAMS, 1989).

This essay presents evidence to prove that the best known morphology karst phenomena in the world are related to litho-ydrographic contact. The notion of contact karst was formulated and widely accepted when analysing conditions in the Dinaric karst. The forms of contact karst are numerous there but smaller in size, except for the poljes, because there are few allogenic rivers due to minor island of impermeable sediments. Therefore, when supporting our ideas we most often point to large forms and their geologic-morphologic sketch maps as published in the foreign literature quoted, and we can partly rely on our knowledge.

Bigger depression forms generated on the contact of permeable with impermeable rocks are quite various. Among the numerous causes and influences which act upon them during their formation there are also the following.

a) The discharge and chemical characteristics of allogenic waters. Their discharge is conditioned by the extent of impermeable sediments in the point of origin of the water, by precipitations or the climate in general. Chemical characteristics mostly depend on the lithology of the river basin (especially the percentage of silicate and carbonate rocks). A more concentrated and thus bigger influx of water, aggressive water in particular, has a greater capacity for the formation of more extensive forms.

b) The quantity and kind of river transport by an allogenic river. At the contact of the surface with the underground river networks water stagnates at a high level, and alluvium depositing occurs. The increase of discharge through the endokarst stops at certain points, regardless of the subsequent rise of the water level (it is specifically restricted), while the flow of the surface streams is less obstructed and thus faster. At the contact of impermeable and permeable areas water stagnates and accumulates. The deposited sediments seal the ponor crevices. The bigger the grains of transported material, the bigger fissures can be sealed. On the alluvium, the water then prolongs its surface flow until it reaches the rock border of the depression where it initiates so-called border corrosion. However when it percolates through its own alluvium, it carries out underground (suballuvial) corrosion.

c) The degree of permeability of the contact karst. The length of the surface flow of allogenic waters on the border karst is determined by the total sinking capacity of all active open-to-surface aquifers.

d) The altitudinal relation between the landforms of impermeable sediments and the surface of the contact karst. Allogenic waters from the landforms of higher altitudes transport, as a rule, greater quantities of material, which also consists of bigger grains.

e) The depth of the piezometric level. This term, more frequently used on the Continent, defines the so-called «karst water table» in English literature. A deeper piezometric level provides better conditions for the percolation of allogenic water into the ground without its having previously flowed and deposited material on the surface of the border karst, and vice versa.

f) The relation between the size of the area of impermeable and permeable sediments and the location of the latter within the river network system over a larger territory. Greater quantities of allogenic water represent greater potentials of re-forming the contact karst, particularly if the latter is of a smaller size. The «island» karst, surrounded by larger non-karstic areas, which also represents the erosion base level of karst waters, has been given the name of isolated karst in Slovenian karst literature. The name of «overflow karst» is used to denote the karst through which the water from the surrounding areas, i.e. allogenic water, flows, besides autochtonous precipitation water (HABIČ, 1992). The term of «hanging water» denotes the water in the karst which is prevented from vertical percolation to the erosion base level (piezometric level) by impermeable inlayers or an impermeable base. Therefore, hanging water is often drained to the land surface on the slopes of valleys.

g) The size of a contact karst form also depends on the duration on its development.

Combination of the above mentioned seven, favourable or unfavourable, factors are numerous. The current essay will discuss only selected combinations of favourable factors which create the most typical forms of contact karst in the world. They are schematically presented in the illustration as profiles with the same numeration as in the text.

## SCHEMATIC PRESENTATION OF CONTACT KARST TYPES (figs. 1 and 4).

1. Border karst of horizontal contact with the influx of allogenic water;

1.1 with greater flow of aggressive allogenic water in the tectonically rising land;

1.2 with a brook, shallow piezometric level and limited permeability;

1.3 with rivers and long-lasting tectonic stability of the border karst;

1.4 with a brook, deep piezometric level, and high permeability.

2. Isolated karst in the area of concentrated sink of allogenic water.

3. Karst with impermeable layers forming a barrier to concentrated surface flow.

4. Karst with vertical litho-hydrologic contacts;

4.1 Deep endokarst with a river on impermeable base, or with hanging water;

4.2 Subglacier and pro-glacier karst;

4.3 Endokarst under perforated impermeable cover;

4.4 Interstratal endokarst («sandwich karst»).

## 1. BORDER KARST OF HORIZONTAL CONTACT WITH THE INFLUX OF ALLOGENIC WATER

1.1 With greater flow of aggressive allogenic water in the tectonically rising land.

A through valley represents in this case a typical form. It is considered by numerous scientists to be of erosional origin, not a karst form. Nevertheless, a typical karst process, i.e. corrosion, contributes greatly to its genesis.

Corrosion is particularly intensive when allogenic water comes from an area of silicate rocks. Such cases are particularly numerous in the Alpine-type mountain system where the central, i.e. the highest range is mostly composed of silicate rocks (the Alps, partly the Carpathians, the Caucasus), and the lateral belt, which is crossed by river outflows, is composed of carbonate rocks. DROPPA proved, by means of limestones tablets, an intense corrosion activity by the Demaenova river, which flows from silicate rocks of the Carpathians Minor to their border limestones (GAMS, 1985). The streams from the Carpathians Minor have also formed through valleys on the southern side of the range, between the plateaus of the south-Slovakian karst (HERAK & STRINGFIELD, 1972). There are also several well-known through valleys in the Northern and Southern Alps. The through valley between Trento and Verona is also such an example, stretching along the Adige river which mostly drains the Precambric silicious impermeable sediments of its upper basin (SAURO, 1992). There are two valleys of this type in the Dinaric karst: the through valleys of the upper Kolpa and Neretva rivers. Karst springs also occur in lateral parts of through valley bottoms if the piezometric level is shallow, while ponors occur where it is deep; or the karst waters flow under the bottoms (compare the Inn valleys, see PAVUZA & TRIANDL, 1988). Intensive recent tectonic rising of permeable rocks can transform a through valley into a dry valley (see the case of the Bullock Creek on the western coast of South Island, New Zealand; FORD & WILLIAMS, 1989). The section of the Danube river valley between Immedingen and Moehringen in the area of the Swabian Jura periodically dries up, since the low water is completely swallowed by the ponors in the riverbed (ZOETL, 1974). In certain valleys, the type of so-called parallel lateral cave occurs at the side of the periodically dry valley. The most impressive example is represented by the combination of three tourist caves called the Demaenovske jaskyne (SWEETING, 1972; DROPPA, 1957). More rapid tectonic rising of the border karst can cause piracy of an allogenic river before it reaches the karst, resulting, in geological time, in the formation of a hanging dry valley. A nice example of this can be found in the Čepovan dry valley, north of Gorizia, between the Banjšica and Trnovski gozd plateaus in Western Slovenia.

1.2 Border karst of shallow piezometric level, allogenic river, considerable river transport, and lower water permeability.

The following landforms are the most typical: a blind valley, a border karst polje, a ponor allogenic cave, a collapse doline, and a dry valley.

Border corrosion is considered the principal process in the widening of a blind valley or a border karst polje. However, before this process starts, a basin must occur first. It is rendered possible, above all, by sub-alluvial corrosion. The soil is usually thicker on the alluvium, and the production of $CO_2$ in it is greater, which causes local accelerated solution even by the mere percolation of the autochtone precipitation water. Corrosion is additionally accelerated by the percolation of allogenic water. Both types of corrosion are intense if the allogenic brook flows from silicate sediments or some other kind of karstic sediments differing from those at the bottom of the depression. The mineralization of rivers which flow from petrographically diverse carbonate and non-carbonate areas is as a rule greater than of those rivers which only drain pure carbonate rocks. In Slovenia, there is a positive correlation between the allogenic water discharge, its mineralization, and the volume of the dry valley (GAMS, 1962). During speleologic explorations, recent corrosion activity in the caves under alluvium has been discovered (MIHEVC, 1991). Time is undoubtedly important: the older the karst forms, the bigger they are (JENNINGS & *alii*, 1980).

A blind valley is the most typical macro-depression of contact karst in humid climates (SWEETING, 1972). It often occurs together with closed depressions (see the situations near Parnassos — Ghion, Greece, Central Jamaica, the Pennines near Ingelborough in England; SWEETING, 1972).

There is no difference as regards the genesis and often also the spatial extension between a blind valley and a border polje (FORD & WILLIAMS, 1989). Allogenic waterflow and alluvium can be found in both of them. According to MELIK (1955), the alluvia in the Slovenian karst poljes are supposed to have originated, for the most part, in the periglacial climate of the Pleistocene, when rivers used to transport greater quantities of gravel and sand. Due to this, border poljes at the foothills are quite numerous (of the piedmont polje type: GAMS, 1978). Among the 42 most typical karst poljes in the Dinaric mountains, 29 are of the border polje type, or of the border polje type combined with other factors (GAMS, 1978). Among them, there are also poljes with Würmian glacial deposits, which is also the case of the Cetinja polje in

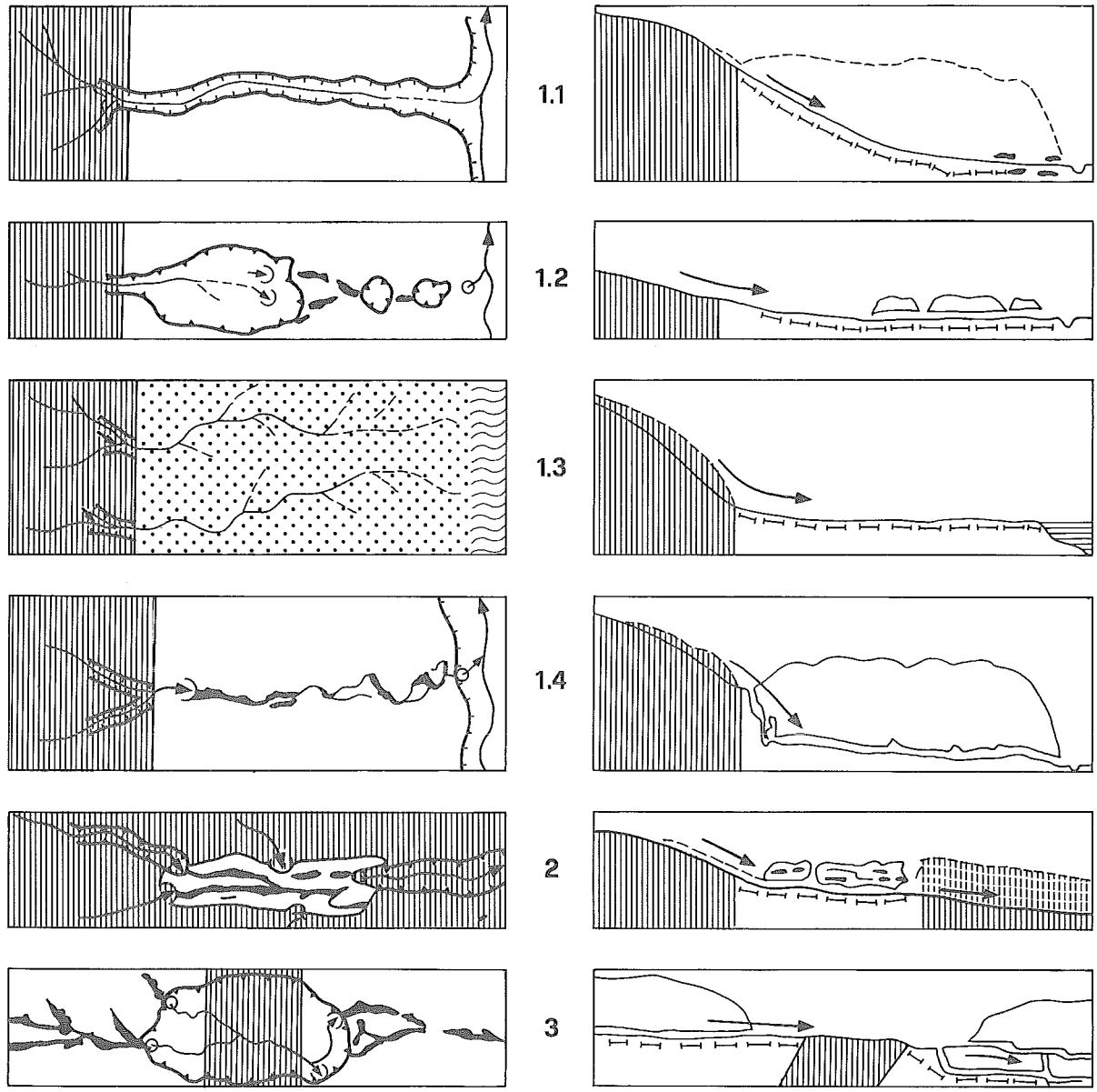


FIG. 1 - Types of contact karst - A scheme
1 - Impermeable sediments, 2 - Permeable soluble sediments, 3 - Alluvium (gravel sand), 4 - Glacier, 5 - Valley, 6 - Closed basin, 7 - Direction of water flow, 8 - Ponor, 9 - Spring, 10 - Piezometric level, 11 - Cave.

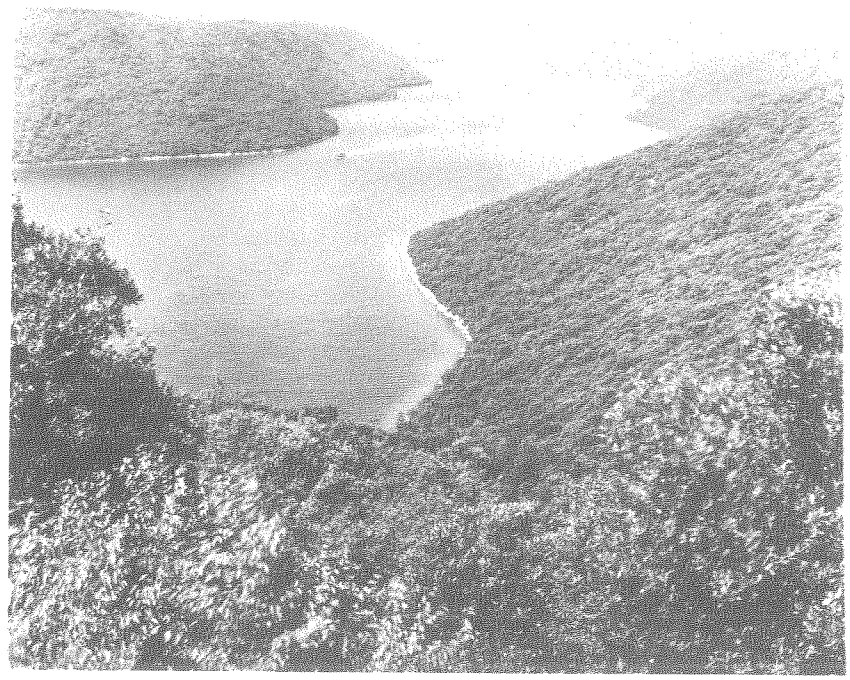

FIG. 2 - The submerged final part of the 36 Km long dry valley in the western border of the Istrian karst plain (above the valley). In the Quaternary, the dry valley had mostly been formed by the river Pazinščica (Foiba) which now sinks at the tower of Pazin and drains the Eocene flysch area.

Montenegro, a dry polje at present. It can be taken as an example for the study of the origin of contact karst. While studying it, we also have to take into consideration other kinds of conditions during the geologic past, such as glaciers or temporary or permanent permafrost in the temperate climate during the Pleistocene. For this reason, there are so many currently dry depressions (basins) on the Dinaric karst at the contact with dolomite, where the soil is continuous, and limestone. Examples of recent influx of allogenic water, flowing from dolomite to limestone, are not so rare either (example: the Grosupeljsko polje).

Particularly the poljes in lowland areas are connected with one another through dry valeys which are located only a few meters or some ten meters higher. Some authors (such as LOUIS, 1956) explain them as being the remnants of the prekarstic, i.e. fluvial phase. They also occur behind numerous blind valleys, as proof of the shortening of allogenic brooks which nowadays sink in the blind valleys (see evidence of the shortening of the Lost River in Indiana near Mallot, JENNINGS, 1985; GAMS, 1962 and 1974; MIHEVC, 1991). They might have also been generated in the Holocene period due to the reduction of river transport or allogenic flow, or tectonic rising of the territory (the case of the dry valley between Pazin and the channel of Limska draga in Istria; GAMS, 1974).

The tiny network of shallow dry valleys which has been reconstructed on the karst plateaus of partially permeable sediments is not included among the relief forms of the contact karst. Local water flows, running on permanently or seasonally frozen ground, might have played their role in the genesis of these valleys, particularly when a shallow piezometric level is in question. Examples of dry valleys in the fluviokarst of the Dinaric Karst and in chalk near the Avon basin in Derbyshire, England, are pointed out by SWEETING (1972); on the plateau of the Swabian Jura/Swabian Alps by PFEFFER (1978) and HERAK & STRINGFIELD (1972). Allogenic caves most frequently occur on the outflow sides of blind valleys and border poljes or other types of karst poljes with periodic or permanent surface waterflows. On the 25 km long, and up to 15 km wide karst area stretching among the Postojnsko, Planinsko, and Loško poljes, the common length of allogenic caves on the outflow sides of the poljes amounts to 50 km, among which the famous 20 km long Postojnska jama is included. A shallow piezometric level is maintained by the dolomite layer of the Notranjsko valley system. In the Dinaric Karst, there are some caves on the outflow sides of the poljes (Vjetrenica in the Popovo polje and Cerovačke pečine above the eastern end of the Liško polje in Croatia). A common feature to all such caves is that they have two or more levels.

Allogenic caves are usually long, they have a more even inclination of the ground and comprise large voids which are the result of erosion and corrosion (KRANJC, 1989). All longer caves in Slovenia are the result of allogenic water activity (GAMS, 1974). Collapse dolines also belong to the characteristics of the contact karst with such caves. There are still the creeks flowing on their bottoms, yet, the collapsed rubble heaps most frequently shift their flows. The caves of Škocjanske Jame in the region of Kras are a classic example, and they have been listed in the register of the World Natural Heritage. The relation between the width of the upper part, and that of the bottom part of these collapse dolines might, provided that other conditions are equal, point to the age of the collapse (GAMS, 1983).

There is an excellent example of contact karst with

combinations, stated under numbers 1.1, 1.2 and 1.3 in Gunong Mulu National Park in Sarawak (Borneo). The mountain range, composed of impermeable sandstone shales of the Mulu Formation, is drained by several rivers and brooks through the 35 km long, and 1-4 km wide ridge of Melinau Limestone formation which runs at a right angle to the drainage direction. Waterflows have created in this limestone ridge several through valleys, blind valleys, karst plains, and caves of enormous sizes; about 100 km of the latter had been explored by 1980. The base level is controlled of the outflow side on the ridge by a plain which is composed of alluvia deposited on limestone near the ridge, and of shales farther on (accordingly to the publication Caves of Mulu 80 and its sketch map of the Caves of Gunong Mulu National Park.

1.3 Border karst with allogenic rivers, shallow piezometric level, lower permeability, and long-lasting tectonic stability.

A karst plain is the most characteristic form of this type of karst. The karst plain of the Dinaric Karst have numerous characteristics in common. A shallow piezometric level is one of them, which is at present based on the rivers crossing a certain plain in shallow canyons. Since the inclination of the surface is usually the same as that of the longitudinal profile of these rivers, and because remnants of former impermeable covers of Tertiary rocks or impermeable island within carbonate rocks can be found, it is quite reasonable to conclude that karst plains were generated in the time when the water level, during a long geologic period, reached the surface of the contact karst at the foothills where rivers still run nowadays. Such is the case of the Kistanje plain in Dalmatia which is crossed by the mountain rivers of Krka and Čikola, and, in the geologic past, it was also crossed by the Zrmanja. The karst plain in the hinterland of Karlovac is even larger; however, it is less levelled. It comprises the Črnomelj plain and the neighbouring low karst in Croatia, including the rivers Kolpa, Dobra, Mrežnica and Korana. Although the west-Istrian plain is no longer crossed by rivers in canyons, certain traces are still evident of the former state, which has only been preserved in the norhthern part of this plain, near Umag (GAMS, 1986). These conditions are similar to those in which some of the karst plains on the coast of Cuba have developed (NUNEZ & *alii*, 1986) and also part of the karst in Florida. Similar conditions of origin are also supposed by FORD & WILLIAMS (1989 (the chapter entitled: Base levelled corrosion plains. In this chapter, the following two terms are also mentioned: lateral solution planation and corrosion planation). In the case of the Karlovac plain the piezometric level is based on Tertiary sediments of the Karlovac basin, and on the sea level in the case of the Kistanje and Umag plains. There is a world-wide-known plain on the western coast of Ireland, in the Gort Lowland, i.e. the Burren Plateau (see the sketch and profile in FORD & WILLIAMS, 1989), onto which streams flow from higher areas in the south and the east, composed of shales (the Slleve Aughty Mts.).

At a vault-like tectonic rising (the West-Istrian plain), or a rise in the form of an anticline (the Kras region), the piezometric level becomes lower, thus causing local surface rivers to start dissecting the surface of the plain.The inflow of allogenic rivers may be interrupted (the Kras region), or the rivers cut deep canyons (example: the high plains between the rivers Piva, Tara and Čeotina in Montenegro). Besides, together with the tectonic rising denivelations occur: the area from where the allogenic rivers used to flow is reduced, and drainage is changed. For this reason, traces of the plains become less and less evident in high karst plateau (example: the plains in the North Limestone Alps in Austria). A similar conclusion was drawn from the study of the plains in Puerto Rico (PFEFFER, 1973).

1.4 The contact karst of very permeable sediments, with a deep piezometric level, and less allogenic water

Bigger closed depressions do not, as a rule, occur around ponors in this type of karst. Typical phenomena are deep shafts which, in their lower parts, pass into more horizontal cave channels. The deepest shafts occur in high mountains or medium-high mountains where the so-called depth potential (i.e. the vertical drop between a ponor and bottom of a nearby valley) is great. In humid and perhumid climates, even smaller areas of impermeable rocks and smaller aggressive streams are sufficient to generate deep shafts.

In Slovenia, the Jazben and the Habečkov brezen are deepest shafts generated in such a way; and in the nearby Čičarija in Istria, there is the Raspor shaft (GAMS, 1974) into which water flows from the surrounding flysch area.

## 2. ISOLATED KARST IN THE AREA OF CONCENTRATED FLOW OF ALLOGENIC WATER

If the non-karstic surroundings are levelled, an isolated karstic elevation is centrifugally drained. Therefore, as a rule, bigger caves do not occur. But there are quite numerous examples with landscapes in deeper permeable sediments. The water from the non-karstic surroundings concentrates its flow through the isolated karst area, which is eventually recognized as overflow karst. There, the carbonatic elevations are usually full of caves. Some good examples of isolated karst can be found in the Australian states of New South Wales and Victoria. «The Wombeyan Caves Areas is as an isle of marble situated between the igneous rocks and is full of gorges and caves» (JENNINGS & *alii*, 1982). The longest caves in Australia, and most frequented by tourists, are situated in the islands of Paleozoic limestones in the middle of non-karstic surroundings (Jenolan, Wombeyan, Yarrangobilly, Cooleman Plains; SPATE, 1988). The isolated karst of the Buchan Caves country in East Gipsland, Victoria, Australia, also abounds with caves, collapsed valleys, blind valleys, etc. (SWEETING, 1972). The isolated limestone elevations in the non-karstic surroundings in the north of Moravia, with well-known caves (the Mladečka, the Javoričke jeskyne, etc.) also belong to this type.

Smaller islands of karst surrounded by non-karstic area

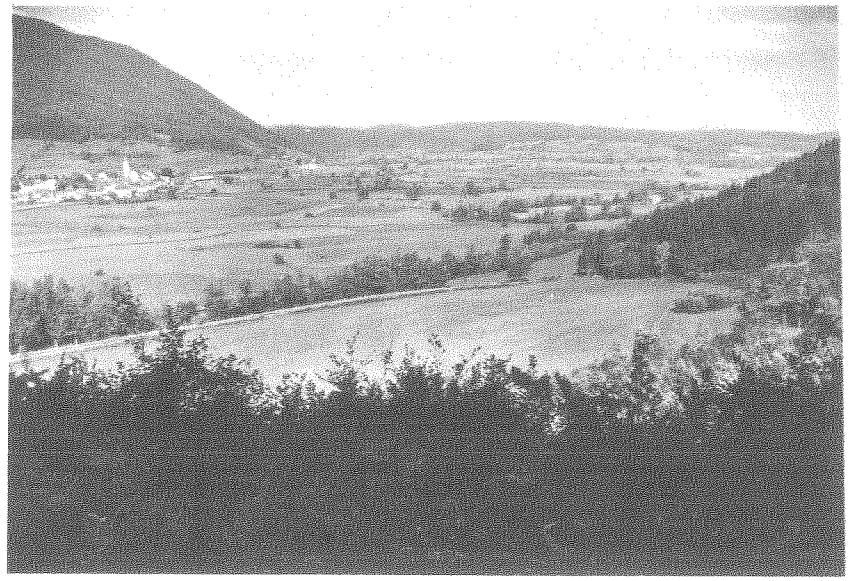

FIG. 3 - The overflow polje of Planina (Slovenia). Between the settlement of Planina on the left and two settlements on the right, there is a belt of semipermeable Triassic dolomite which forces the Unica River (in the belt of bushes) to flow on the surface to the ponors below the forested slopes (background).

which provide aggressive water usually represent a lower surface. The existence of the isolated karst is limited in time due to intensive corrosion. The situation is different if periods of corrosion are interrupted by phases of depositing impermeable sediments. The so-called south-Moravian karst, north of Brno, underwent such a process; namely during the Mezozoic and Tertiary periods, it was alternately fossilized and uncovered several times (PANOŠ, 1964a and 1964b.). This karst of Devonian limestones is crossed by allogenic streams from the hills of Drahanska vrhovina. It is supposed that water from wider surroundings additionally flowed on these limestones in the past (ŠTELCL & ŠTELCL, 1966). The 24 km long and 2-6 km wide outflow and overflow karst with an area of 100 km² abounds with heterogeneous karst forms: about 1100 registered caves (11 caves per sq km) among which many are allogenic caves, a through valley (Luha), blind valleys (udoly), collapse dolines (Macocha), and a relatively levelled surface which is, for the most part, lower than the non-karstic surroundings. Numerous caves in south Kirghizia, having been generated by allogenic waters, are now, after the phases of fossilization and erosion of the covering sediments, uncovered again in the form of towers (BOSAK, 1991).

## 3. CONTACT KARST ALONG THE BARRIER OF IMPERMEABLE SEDIMENTS IN THE AREA OF CONCENTRATED WATERFLOW

The term «overflow polje» had already been established in the Slovenian karst literature (GAMS, 1974) when FORD & WILLIAMS (1989) renamed it as a «structural polje». It is a polje with karst springs on one side, and ponors on the other side of the water barrier which constitutes the bottom of the polje. In the poljes of the northwestern Dinaric Karst, these barriers mostly consist of triassic semipermeable to permeable dolomites while in the rest of the Dinaric Karst, they are, for the most part composed of Tertiary layers, which are up to several hundred meters thick. Among the 42 most typical karst poljes in the Dinaric karst, four belong to the overflow type, and eight are combined with some other types (GAMS, 1978). Most of the poljes in the Notranjsko valley system (Slovenia) also comprise belts of impermeable or semipermeable dolomite which water streams from the karst are forced to cross on the surface. In addition, the bottom of the polje is widened and reaches over the neighbouring permeable rocks. The majority of Tertiary sediments on the poljes of the Dinaric Karst are partially carbonatic. For this reason, both processes, erosion and corrosion, are active in forming the polje bottom of impermeable rocks. Suballuvial and border corrosions caused by the alluvium cover represent the third process; it can also be joined by neotectonic movements (example: the Fucino polje in the Abruzzi).

## 4. KARST WITH VERTICAL LITHO-HYDROLOGIC CONTACT

### 4.1 Deep endokarst with a river on an impermeable base, or with hanging water.

The main impermeable base collects dripping water to form a river flowing on it as a surface spring. The hanging water level is caused by a higher impermeable inlayer. In both cases running water creates large caves. Favourable conditions for the development of endokarst are great quantities of precipitations and run-off, and a widely extended area of impermeable base. Larger caverns enhance

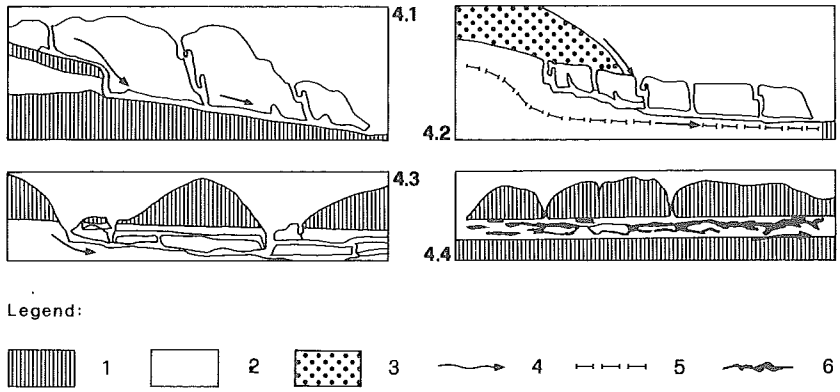


FIG. 4 - Types of contact karst - A scheme. 1 - Impermeable sediments, 2 - Permeable soluble sediments, 3 - Glacier, 4 - Direction of water flow, 5 - Piezometric level, 6 - Cave.

by the collapsing of ceilings the creation of potholes which eventually reach the surface. Some extensive examples: the Reseau de la Pierre St. Martin, 51 km long and 1342 m deep (NICOD, 1972) in the Pyrenees, and the Reseau Berger (1241 m deep: see the skecth in FORD & WILLIAMS, 1989 and MAIRE, 1990), and recently discovered extensive caverns on the island of New Britain. Bases of impermeable rocks played an important role in the development of the caves of Cueva del Agua in Spain and of Selminum tem on Papua-New Guinea (FORD & WILLIAMS, 1989).

### 4.2. Subglacial and pro-glacial karst

Particularly in their lower part, warm glaciers sliding down along uneven ground deep fissures which reach to their bottoms and through which glacier waters can run off into the karst at the glacier base. The total hardness of glacier waters after their contact with carbonate rocks is weak (GAMS, 1967), nevertheless, the capacity for making a shaft is great due to the great quantities of water discharge. The glacier water, running off at the base of the glacier during the ablation season only, prevents the permafrost from being continuous. Among the caves of this type, the channel of the Casteguaard Cave under the Columbia glacier in Canada is best known. A similar role in the formation of the karst is played by the interrupted permafrost cover where the surface water run-off is concentrated only in certain places (for the karst forms generated due to permafrost, or continental or mountain glaciers, see FORD & WILLIAMS, 1989; for glaciers see MAIRE, 1990). The forms which are generated by concentrated water run-off on the end side of a glacier are very close to our type of contact karst with horizontal contact. Since glaciers are typical for their annual change of fronts, the pro-glacier contact karst is often transformed into the subglacier karst, and vice versa.

The great importance of corrosion by subglacial and pro-glacial waters is evident from the great density of shafts and glacio-karstic depression in the once glaciated Alpine karst. In the Kanin Mts., along the border between Slovenia and Italy, there are several up to 1370 m deep shafts supposed being of such an origin; the same applies to the shaft of Medvedova konta in the Julian Alps (KUNAVER, 1960). The shaft of Triglavsko brezno at the lower end of the Triglav glacier is still in such a position and is in a process of development at the present time. As the surface was covered with glaciers in the glacial periods, the glacier water must also have helped to form the two deepest shafts in France, the Gouffre Pierre Saint Martin in the Pyrenees, and the Gouffre Berger in the Alps (MAIRE, 1990), as well as the long caves in the then glaciated plateau of the Northern Limestone Alps (the caves of Eisriesenwelt, Tantalhoehle, Mammuthhoehle, Rieseneishoehle, Frauenmauer-Langenstein Hoele, etc.). The same conditions are supposed to have influenced the formations of the cave maze of Hoelloch in Switzerland, the cave of Pološka jama in the Julian Alps, and the shaft of Duboki do along the lower end of the glacier of Lovčen (Montenegro).

### 4.3 Endokarst under perforated impermeable cover

The cover of impermeable sediments is often cut by the river valley, the bottom of which reaches the karst bedrock. If the cover is composed of silicate rock, the aggressive river water can generate extensive caves in the karst rocks, often in the lateral parts of the valley. Such are the cases of the Friars Hole System (68 km long) in West Virginia, the Caverns of Sonora in Texas, as well as the Cave Creek, Ky, and the Omar Cave in Ethiopia (FORD & WILLIAMS, 1989).

If collapses occur in the impermeable cover and subsequently bigger closed depressions follow them, then the locally accelerated corrosion has the capacity of hollowing deep shafts which can reach down to the caves of the endokarst in the bedrock (the shafts in the longest cave system in the world, the Mammoth-Flint-Ridge cave in Kentucky). Up to several hundred meters deep collapses are known in salt layers which are soluted by water and thus render possible, by the collapsing of ceilings, the formation of potholes or collapse dolines (Germany, USA, etc.).

### 4.4 Interstratal endokarst («sandwich endokarst»)

If easily soluble sediments occur as inlayers within the impermeable or less soluble rocks, and aggressive waters from the surface or uncovered lateral sides can flow on

them, then maze caves are formed in them. Such mazes have been discovered in Norway in carbonate inlayers into which glacier waters have flown or still flow. After the Web river in Ethiopia had cut its way through the basalt rock on the bottom of its valley, it hollowed a cave maze with several kilometers of channels in the meander of lower limestones (FORD & WILLIAM, 1989). The most representative example of the interstratal cave maze is found in the caves of horizontal inlayers of gypsum in Polinija in Ukraina. Here, the second longest cave in the world can be found, i.e. the Optimističeskaja (157 km), and also the Ozernaja (105 km), Zaluška (82 km), Atlantida, Mlinki, etc. In some of them, up to 195 km of channels per sq km of area have developed (DUBLJANSKIJ, 1966). According to the findings of PALMER (1975), 86% of investigated maze caves in the USA have developed directly beneath permeable sandstones. Under them, a dense maze of smaller channels can be hollowed by aggressive water along joints or fissures.

If the karstic zone is thicker, the demarcation is lost between our type of «interstratal endokarst» and the «endokarst under perforated impermeable cover» (types 4.3 and 4.4). This is the base of the majority of the caves in the Mammoth Cave National Park in Kentucky. The karst there is a classical examples of role of litho-hydrologic contact in the development of karst forms. Allogenic waters from the south and southwest (the Penroy Plateaux) have contributed to the formation of the karst plain (the Sink Plain) and hollowed out the caves under the Chester Upland in the limestones beneath the cover of impermeable sediments. In these limestones there are the cave horizons of the Mammoth and Flint Ridge cave systems within a vertical drop of 90 m. The cover, cut through in the valleys, caused locally accelerated corrosion by aggressive waters in the basal limestones (our type 4.3), where shafts and caves eventually appeared (see geologic-morphologic sketches in MIOTKE, 1973; PALMER, 1981). Impermeable silicate cover prevented water falling on the surface from percolating into the caves. In older caves without impermeable cover, such dripping water blocks the channels with speleothems. From this aspect, horizontal litho-hydrologic contacts were favourable for the development of the longest cave system in the world discovered so far, i.e. in Kentucky, while vertical contacts enabled preservation throughout its length until the present day, in spite of its great age.

## CONCLUSION

In karst literature, there is plenty of sporadic information on karst forms which are related to the inflow of allogenic water into the border karst. Certain remarks also occur as regards the links between the caves and the location of karst rocks beneath impermeable cover or inlayers of karst rocks in non-karstic sediments. The aim of the current essay is to systematize these karst forms as a specific type of karst, the contact karst, and classify them in relation to their location along horizontal or vertical contacts of impermeable and permeable rocks. Although different causes and modifiers (lythologic, landforming, hydrographic, situational, etc.) intertwine in various ways in nature, certain types of the contact karst can be defined. In the Dinaric karst, numerous forms of the contact karst occur, but they are, except for the poljes, of minor dimensions. The refore, the majority of proofs quoted in the essay for the relation between these forms and lytho-hydrologic contacts, are taken from the world karst literature if it is provided with geologic-morphologic sketches.

Because the through valleys, blind valleys, dry valleys, different types of poljes, long caves, and deep shafts, as well as collapse dolines above the caves are mostly the result of morpho-hydrological contacts, the contact karst is a special and the most impressive type of the karst.

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