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NATIONAL SPELEOLOGICAL SOCIETY

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Contents

JANUARY 1969

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NATIONAL SPELEOLOGICAL SOCIETY

Karst and Caves in Poland

By Marian Pulina

ABSTRACT

Karst phenomena including caves are rather well developed in Poland, but carbonate and gypsiferous rocks comprise only about 2000 square kilometers. The largest karst areas lie under thick Pleistocene covers. The three best-known karst areas in Poland are (1) the Cracow-Czestochowa upland of about 1800 square kilometers; (2) the Tatra Mountains of about 50 square kilometers; and (3) the Sudeten Mountains of about 15 square kilometers. These and other minor karst regions differ widely in geomorphic characteristics.

Three main types of karst relief are distinguished in Poland: (1) young Alpine karst in the Tatra Mountains; (2) old karst along bedding planes in the Cracow-Czestochowa upland; and (3) the fossil "island" karst in the Sudeten Mountains. The most intense karst development is in the Tatra Mountains where the quantitative value of chemical denudation reaches 20 to 100 cubic meters per year. Most caves in Poland are not large because of destructive continental glaciation during the Pleistocene.

INTRODUCTION

Carbonate and gypsiferous rocks, the bases for karst development, are not widely found in Poland. They compose only about 2,000 square kilometers, which is 0.6% of the area of this country. The largest karst areas lie under thick Pleistocene covers.

Karst phenomena, especially caves, are rather well developed in Poland. This is the reason that karst problems attract many researchers. The investigations have not only scientific interest, but also practical applications, *e.g.*, to building, water exploration, and the exploitation of raw materials.

The three best known karst regions in Poland (fig. 1) are the Cracow-Czestochowa Upland of 1,800 square kilometers, the Tatra Mountains of more than 50 square kilometers, and the Sudeten Mountains of about 15 square kilometers. Limestone rocks appear also at smaller areas in the Silesian Upland (Gilewska, 1965), the Swietokrzyskie Mountains (Rozycki, 1960), the Lubelska Upland (Malicki, 1946; Marusczak and Wilgat, 1955), the Pieniny Mountains, and in gypsum deposits in the Nida Basin (Flis, 1954). These karst regions differ in the stages of development of karst morphology and caves, the distribution of large forms, and the rate of present denudation processes.

CHARACTERISTIC FEATURES OF KARST REGIONS IN POLAND

The Cracow-Czestochowa Upland is situated in the south of the middle part of Poland. This upland is built of limestones and dolomites which form the thick platform of the Upper Jura (fig. 2). This platform is 20 to 30 kilometers wide and 100 kilometers long, extending from northwest to southeast. It is gradually inclined to the east, and dips below the chalk rocks. The main part of the upland is 500 meters high. Here several steps of karst development are shown. The oldest took place during the Lower Cretaceous when, as the result of early Kimeryd movements, this region became land. Then there was very intensive karst development. Conical holes 30 to 90 meters deep are filled with Upper Cretaceous, Tertiary, and Pleistocene sediments (Gilewska, 1965; Mossoczy, 1959; Rozycki, 1960). The next steps occurred during the long Tertiary period of land

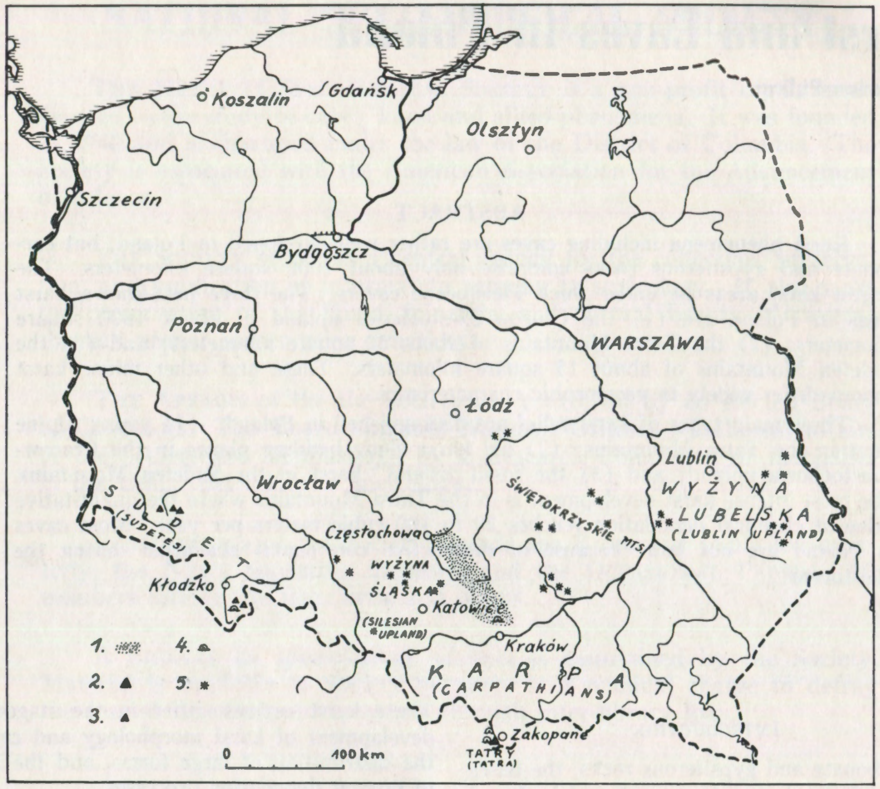


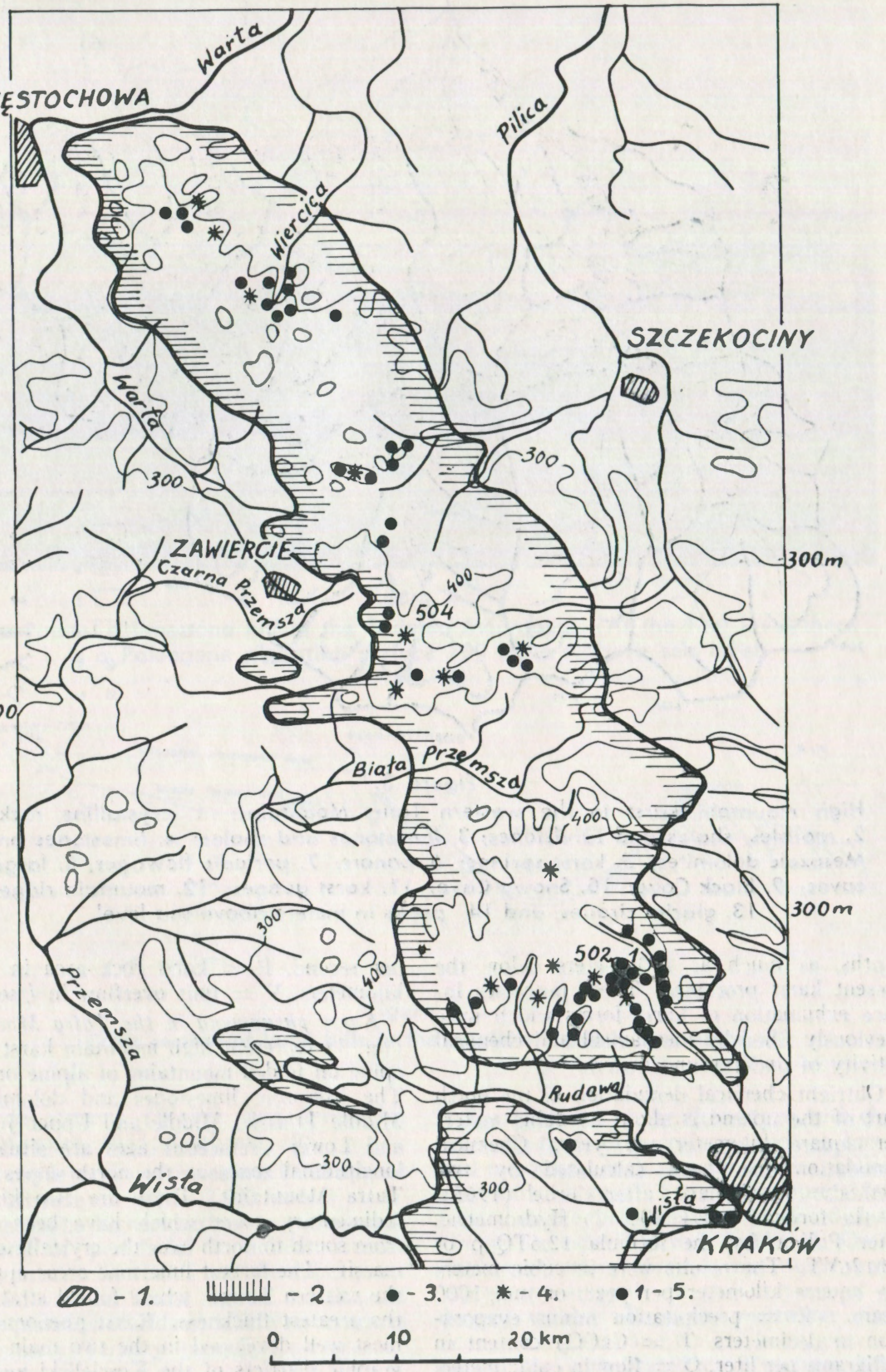
Figure 1.

Karst areas in Poland: 1. The Cracow-Czestochowa upland; platform karst; 2. the western Tatra Mountains; high-mountain karst; 3. the Sudeten Mountains — "island karst"; 4. largest caves described in text; and 5. karst forms in other areas.

exposure under tropical climatic conditions. There is preserved from this age a well-developed karst relief with characteristic karst planation surfaces, hills of *mogotes* (Gradzinski, 1962; Pokorny, 1963; Polichtowna, 1962), and cave systems on several horizons (Mossoczy, 1959; Rozycki, 1960). The Pleistocene appears to have been catastrophic for the karst upland. Periglacial processes caused devastation of microforms, and glacial deposits filled valleys, conical holes, and caves (Dylik, Chmielewska, M., and Chielewski, W., 1954). The Holocene brought partial exhumation of the Tertiary karst forms, and this process has continued to the present. The present underground hydrography is formed with the deepest valley bottoms as base level. This results in the appearance of water only in several of the deepest valleys, the big system of karst springs. On the extensive surfaces between valleys, water can be found only at great

Figure 2. (Opposite page)

Platform karst in the Cracow-Czestochowa upland: 1. towns; 2. Upper Jurassic limestone platform; 3. large caves; 4. monadnocks; and 5. Wierzchowska Cave.



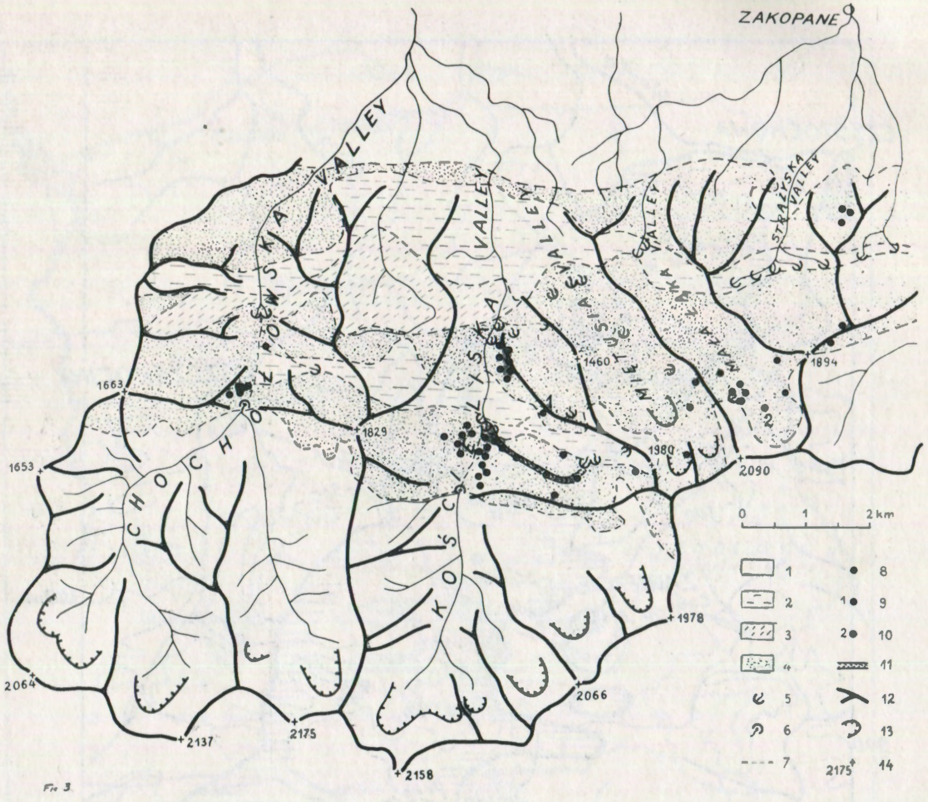


Figure 3.
High mountain karst in the western Tatra Mountains: 1. crystalline rocks; 2. marbles, shales and sandstones; 3. limestones and shales; 4. limestones and Mesozoic dolomites; 5. karst springs; 6. ponors; 7. periodic flowages; 8. larger caves; 9. Black Cave; 10. Snowy Cave; 11. karst guages; 12. mountain ridges; 13. glacial cirques; and 14. peaks in meters above sea level.

depths, as much as 100 meters below the present karst processes. These processes induce exhumation of karst forms which were previously filled by mechanical and chemical activity of underground waters.

Outright chemical denudation in the north part of the upland is about 20 cubic meters per square kilometer per year. Chemical denudation has been calculated by two methods: 1) Climatic, after Corbel (1965), by the formula: 4ET 100. 2) Hydrometric, after Pulina, by the formula 12.6TQ/p or 0.0126VT. The results were in cubic meters per square kilometer per year, or mm/1000 years. (E = precipitation minus evaporation in decimeters, T = $CaCO_3$ content in miligrams per liter, Q = flow in cubic meters per second, P = karst rock area in square kilometers, V = unit overflow in l/sec/m².)

Karst phenomena in the Tatra Mountains (fig. 3) represent high mountain karst developing on folded mountains of alpine orogeny. The Mesozoic limestones and dolomites of Middle Triassic, Middle and Upper Jurassic, and Lower Cretaceous ages are situated in longitudinal zones on the north slopes of the Tatra Mountains. There are two kinds of sedimentary cover which have been moved from south to north over the crystalline Tatra massif. The largest limestone areas appear in the western Tatras, where folded strata have the greatest thickness. Karst phenomena are most well developed in the two main hydrographic districts of the Koscieliski and Cho-

Figure 4.
The Polom, a limestone hill in the Sudeten Mountains. At the first level there is a Paleogene planation surface 700 meters above sea level.

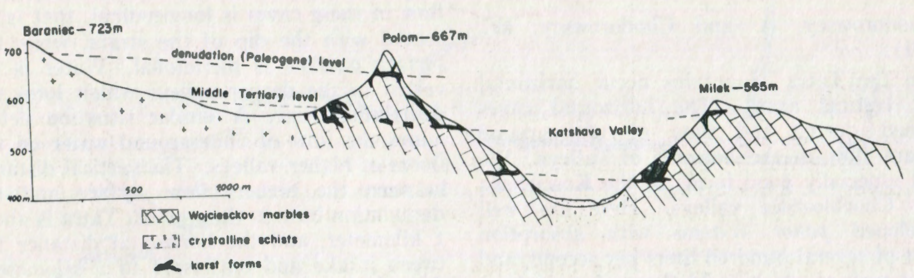


Figure 5.
Cross section of karst hills in the western Sudeten Mountains.

cholowski streams (Wojcik and Zwolinski, 1959; Wrzosek, 1933; Zwolinski, 1955).

Carbonate rocks in the western Tatra appear at the altitude of 900 to 2,000 meters above sea level. The highest carbonate rocks reach the zone of periglacial mountain climate, which contains snowfields and the upper parts of glacial valleys. Large regions are situated on the plateaus of ridges, where some traces of the early Tertiary planation surface are preserved.

Karst relief is of the alpine type with characteristic fields of microforms such as *karren*, and mesoforms such as conical holes, hollows, and karst gorges. Some microform fields located on the rock dumps of the closed glacial cirques are especially well developed. On the limestone surface there is not much water. Water appears only in the bottoms of the deepest valleys. Rain and meltwater disappear in the joints and conical holes, penetrating to the complicated cave systems below

Figure 6.
Calcite dripstone in a cave of the karst hill, Polom, in the Sudeten Mountains.

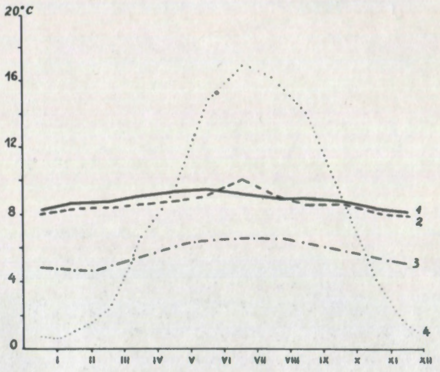


Figure 7.
Thermal regime of karst water in the Sudeten Mountains: 1. Zelazno Spring — 340 m above sea level; 2. Pogwizdow Spring — 380 m above sea level; 3. Kletno Spring — 775 m above sea level; and 4. surface karst water.

(Chodorowscy, A. and Chodorowscy, W., 1959).

In the Tatra Mountains occur horizontal and vertical caves. The horizontal caves formed during the time of underground stream flow in the bottoms of valleys. We find especially good forms in the Koscieliska and Chochlowska valleys. Here are well developed *ponor* systems with absorption rates of several hundred liters per second, and karst springs which yield flows of more than 0.5 cubic meters per second (Dabrowski, 1960; Wit and Ziemonska, 1960). During periods of low water level, parts of the valleys as wide as 2 kilometers between the *ponors* and the karst springs are arid. The horizontal caves are situated on several horizons above the bottoms of the valleys (Rudnicki, 1958). In the Koscieliska valley there are four horizons: 0, 100, 200, and 300-plus meters above the valley floor. Black Cave, Mietuskia Cave, and Cold Cave are the longest, being 4 to 6 kilometers in length.

Vertical caves divert water from the highest karst regions. Shaft systems are located below the conical holes and the highest glacial cirques. The general direction of water outflow in these caves is longitudinal, that is, in accord with the dip of the strata, while the surface outflow is meridional. Water is diverted to the deeper valleys which form the denudation base. A similar situation determines the flow of underground water on the floors of higher valleys. The vertical distance between the highest flow surface and the denudation base in the western Tatra is about 1 kilometer, and the horizontal distance between intake and outflow 4 to 5 kilometers. A typical system of vertical shafts is represented by Snowy Cave which is 640 meters deep.

The circulation of karst water in the Tatra Mountains has many similarities to the scheme of Bretz (1942). The vadose water zone is represented here by Snowy Cave which is more than 800 meters long. The boundary between vadose and phreatic zones is at about 1,000 meters above sea level. The largest horizontal caves and the lower parts of vertical caves are developed at this boundary, which depends on the denudation base.

The evolution of karst phenomena occured after the formation of the Tatra geologic massif during the Neogene. Some Tertiary

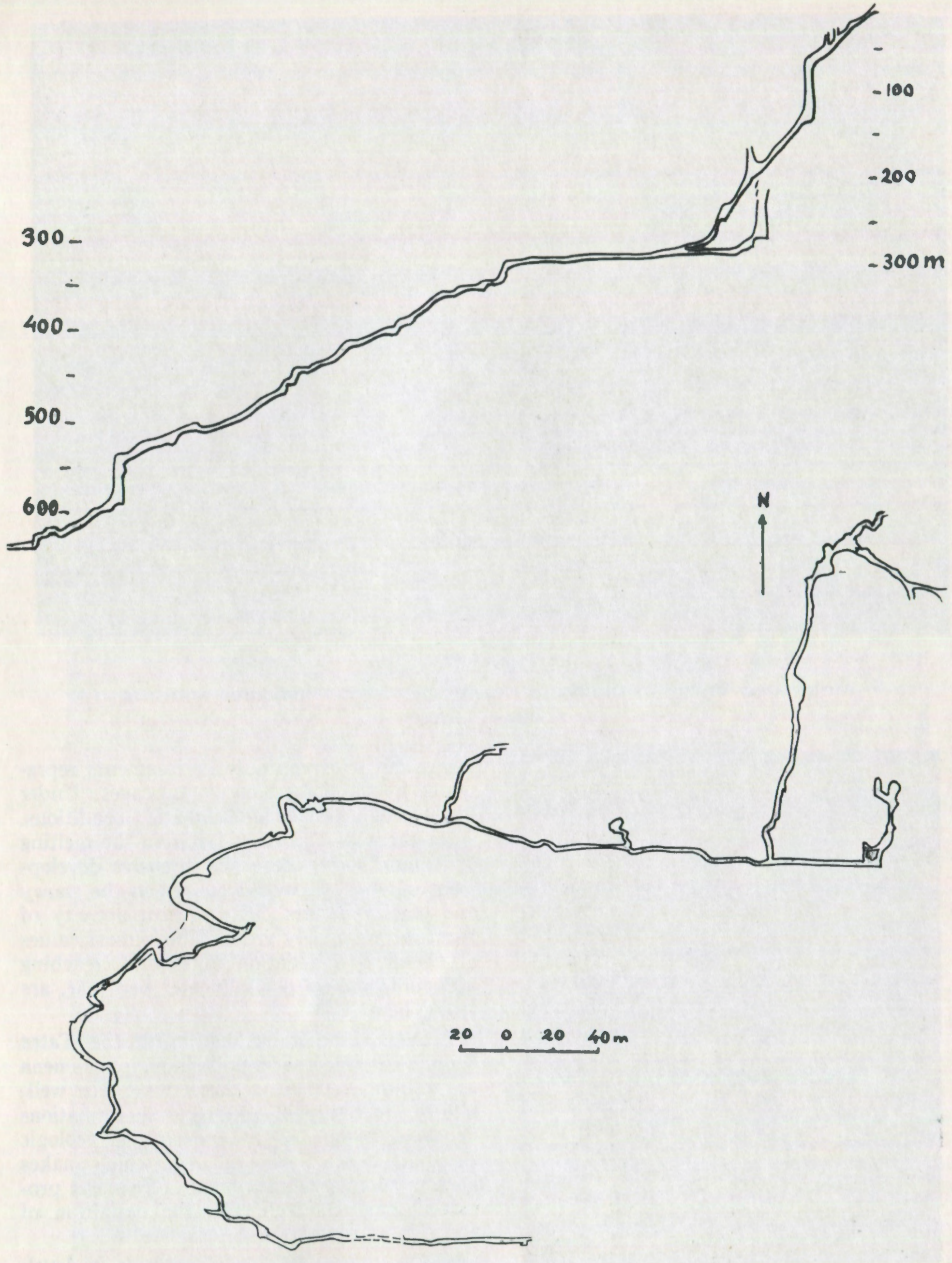


Figure 8.
Map (lower) and cross section (upper) of Snowy Cave.

Figure 9.
Mala Laka Valley in the Tatra Mountains. Arrow indicates entrance of Snowy Cave.

Figure 10.
The fault surface in Snowy Cave, 540 meters below the entrance.

forms are preserved only in fragments represented by the highest horizontal caves. Under Pleistocene periglacial climatic conditions, when there was much water from the melting of ice and snow, there was intensive development of vertical caves localized in the snowy and glacial cirques. The present activity of karst waters is very great. The highest values of chemical denudation in Poland, reaching 100 cubic meters per kilometer per year, are found here.

Although the karst district in the Tatra Mountains is rather small, karst phenomena are well-developed in a classic way. The well-known stratigraphic and tectonic formations in these mountains are shown on geologic maps at a scale of 1:10,000, which makes karst explorations convenient. This has promoted good research, and the definition of the laws of alpine karst evolution.

Karst in the Sudeten Mountains is developed in small outcrops of marbles and dolomites of early Paleozoic and Precambrian age (Walczak, 1958). These are the "islands" or lenses which have individual surface areas

Figure 11.
Passages on a joint 280m below the entrance of Snowy Cave.

Figure 12.
Ice stalagmites in the region of dynamic microclimate in a cave of the Tatra Mountains.

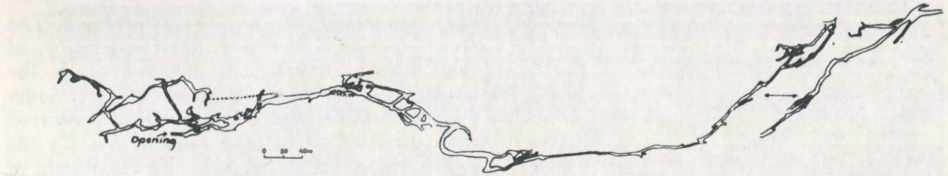


Figure 13.
Map of the Black Cave in the Tatra Mountains.

Figure 14.
Kascieliska Valley in the Tatra Mountains. Arrow indicates entrance of Black Cave.

of about 2 square kilometers. They are surrounded by non-soluble rocks, specifically, crystalline fissles. A characteristic feature of these marbles is their high purity, with $CaCO_3$ content above 95%. Thickness is from several to 500 meters. They have intensive cleavage, and steeply dipping beds. These "islands" are concentrated in two regions: the Kaczawskie Mountains in the western Sudetens, and the Klodzko Basin in the eastern Sudetens. The outcrops of limestone are 400 to 900 meters above sea level. Physiographically, they appear as hills which rise 300 meters above the surrounding country (fig. 4). A cross-section of Polom hill, 667 meters above sea level, is shown in fig. 5. On the walls of a quarry were discovered quantities of conical holes 10 meters deep, located above three cave horizons. Karst evolution arose parallel to planation of the old Paleogene and the second Neogene karst surface. The conical holes were determined

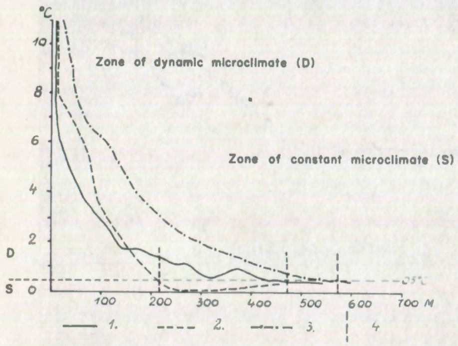


Figure 15.
Yearly amplitude of air temperature in the highest caves in the Tatra Mountains.

to be of Tertiary age on the basis of sediments found in them. They are all filled with sediments, except for some small fragments of caves in the walls of the quarry (fig. 6).

Many of the karst forms in the Sudeten Mountains are in the characteristic hills of Tertiary age. During the Pleistocene, some parts of these forms were devastated and filled with sediments. At present there are active exhumation processes, and chemical activity of allochtonic waters. The main value of chemical denudation is 30 cubic meters per square kilometer per year.

Especially interesting is the karst hydrography of these limestone "islands." On their surface is no water. It flows by underground joint systems localized by the levels of valley bottoms. Springs yield a flow of up to 50 l/sec, and have a special regime with thermal, chemical, and seasonal flow variations (fig. 7).

Sudeten karst can be called "island" karst because of the special geologic conditions. The "islands" have an original karst relief with a net of caves and conical holes, and characteristic present systems of underground drainage.

Caves in Poland

The biggest caves are in the Tatra Mountains, although it is not the largest karst district in Poland (Kowalski, 1951, 1956). The Tatras have ideal geological, morphological, and climatological conditions conducive to karst in alpine folded mountains. The recent age, late Tertiary and Quaternary, of the caves is significant. The caves in the Cracow-Czestochowa Upland and in the Sudeten Mountains were disturbed and covered with deposits during the Pleistocene. So the caves which we know there are fragments of old caves uncovered in the Holocene, or they are the result of karst processes during the Holocene.

Snowy Cave (fig. 8) is 640 meters deep. It is the deepest cave in Eastern Europe and one of the deepest caves in the world. The entrance of Snowy Cave is in the old glacial cirque, Mala Laka Valley, at 1720 meters sea level (figs. 3 and 9). This cave is in Middle Triassic limestone and dolomitic rocks. The passages form along crevices, being extended by gravity, neotectonic movements (fig. 10), and the activity of water. The upper part of Snowy Cave is 300 meters deep and is a system of shafts or very steep passages (fig. 11) which are found on the dolomitic planation surface. The shafts extend below the old glacial cirques and snowy niches which are 2000 meters above sea level. In the lower part is a system of horizontal passages connected by cascades. A stream flows here which has five waterfalls, the largest 40 meters high. The greatest part of the karst forms are erosive and gravity formed. There are no large calc-sinters. The bottom of this cave is a water siphon which is on the boundary between the vadose and phreatic zones. During one of the expeditions there were noted fresh traces of water on the walls 100 meters high around this siphon. Water from the siphon flows 4 kilometers from the entrance of Snowy Cave to Ice Spring in the Koscieliska Valley. Water dyed by urania took seven days to flow this distance.

A comparison of microclimatic conditions in this cave shows two zones, upper and lower. As a criterion for distinguishing microclimatic zones, the yearly middle amplitude of temperature was used according to the formula: $D = A_t \geq 0.5°$ C.; $S = A_t < 0.5°$ C. (D = dynamic zone, S = static zone, and A_t = yearly amplitude of air temperature.) The upper, dynamic zone, 0 to 280 meters deep, has the highest annual amplitude of several meterological elements: temperature, moisture, air movement, and biological cooling. Because this zone has specific circulation, at the top is an underzone

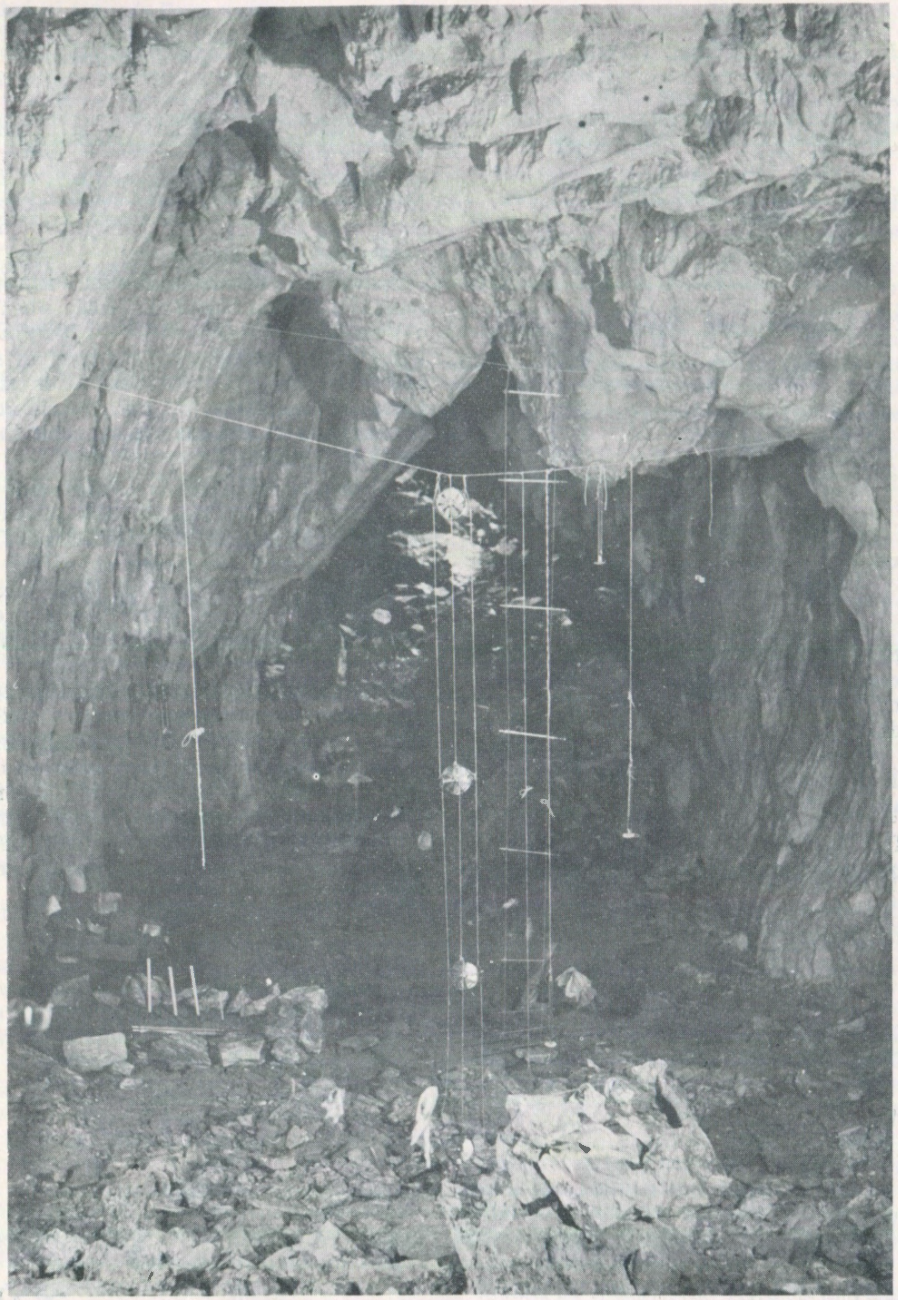


Figure 16.
Meterological station in Black Cave.

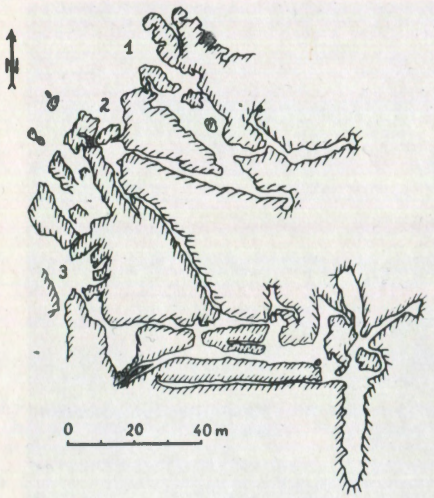


Figure 17
Map of Wierzchowska Cave in Cracow-Czestochowa upland.

with lower temperatures. Such a situation allows for the accumulation of snow over many years, and its change to firn, which leads to the origin of ice caves (fig. 12). In the dynamic zone are periglacial processes such as ice segregation and strong mechanical weathering.

The lower part of the cave is in the static microclimatic zone. Characteristic features of this zone are rather small changes in individual meteorologic elements, *e. g.*, air temperature varies 2.1 to 3.5°C. Increase of temperature is associated with increase of depth with a vertical gradient of 0.5 to 0.6° C. per 100 meters. This gradient is in agreement with the mean annual air temperature gradient outside on the north slopes of the Tatra Mountains (Pulina, 1960). Processes in the static zone are chiefly mechanical and chemical activity of water.

Snowy Cave formed during the Pleistocene, especially during the Postglacial, when the old passages were remodeled by very active water which comes from the melting snow and ice on the alimentation fields above. Chemical denudation by the streams at the present time in the cave is 12 cubic meters per year (Pulina, 1962).

Black Cave (fig. 13) is 6 kilometers long, the longest cave in Poland. The entrance is on the right side of the Koscieliska Valley (fig. 14), about 350 meters above the floor of the valley. This cave has three separate horizons of passages which are connected with vertical shafts. The largest is the middle horizon which has several big chambers (fig. 14) connected by rather narrow passages. Gravitation forms are predominant. Collapse due to rock failure occurs, especially in the lower part of the cave. Here also are devastated remains of huge calcite stalagmites. The reasons for devastation are two: tectonic movements (Wojcik and Zwolinski, 1959) and the climatic conditions of glacial periods.

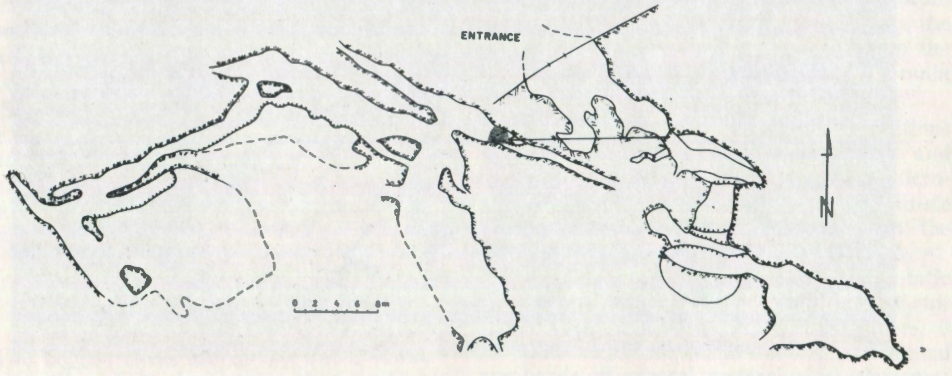


Figure 18.
Map of Bear Cave in the Sudeten Mountains.

All parts of Black Cave are situated in the vadose zone above the level of the local water table. Some periodic gravity water flows here. but there are no streams. Figure 15 shows that the cave has two microclimatic zones: dynamic and static. Annual amplitudes of air temperature (Fig. 16) in Black Cave are like those in other horizontal caves in the Tatra Mountains.

Wierzchowska Gorna Cave (fig. 17) is 640 meters long and is the longest cave in the Cracow-Czestochowa Upland. It is situated in the southern part of this region, at Kluczwoda Valley, 25 kilometers north of Cracow. The lower entrance is at 370 meters above sea level.

The cave has several rooms which are connected with narrow passages. The joint systems NW to SE, N to S, and W to E have determined the development of passages. On the walls are some flutes and flowstone. The most beautiful features are lublinite sheets. At the bottom of the cave there is a thick, sandy mud cover in which are traces of Paleolithic man and bones of Pleistocene animals.

Bear Cave was discovered in November of 1966 and is the largest cave in the Sudeten Mountains (fig. 18). It is about 300 meters in length and 30 meters deep. Bear Cave is situated on the north side of the Snieznik Massif, 800 meters above sea level, 40 kilometers south of the town of Klodzko. It is formed in white marbles of Pre-Cambrian age. It has three horizontal levels of big chambers connected by vertical shafts. Periodic streams flow on the lowest horizon at the level of the outside valley floor. The development of the cave was determined by joints and tectonic movements in NW to SE and W to E directions. In the cave deposits, most of the animal bones are from the Pleistocene. Of special interest are bones of *Ursus spelaeus* and other polar animals.

CONCLUSIONS

Based on research in the regions and caves described above, three main types of karst relief are distinguished in Poland:

1) Young alpine karst in the Tatra Mountains where there are very well-developed micro- and mezo-surface forms and very many caves.
2) Old karst along the bedding planes of the Cracow-Czestochowa Upland, which was strongly disturbed during the Pleistocene. Still preserved are some remnants of the karst planation-surface, hills or *mogotes*, and other mezo- and macroforms (Klimaszewski, 1958).
3) The fossil "island" karst in the Sudeten Mountains with original hills and classic karst hydrography.

The extent of modern processes in Poland may be determined by a quantitative value of chemical denudation (Corbel, 1965) which reaches 20 to 100 cubic meters per kilometer per year, and the chemical activity of water (fig. 19). Research has shown that the most

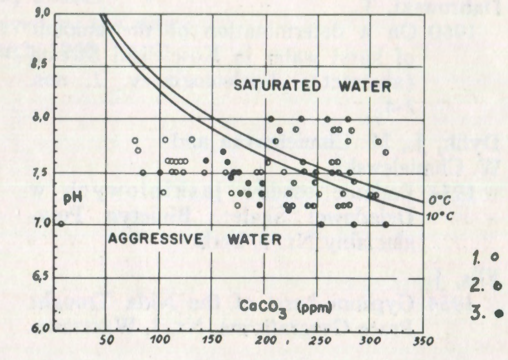


Figure 19.
Chemical activity of karst water in Poland according to Trombe's diagram: 1. Tatra Mountains; 2. Cracow-Czestochowa upland; 3. Sudeten Mountains.

intensive karst development is in the Tatra Mountains where there is the greatest activity of water and denudation processes. In the other karst regions in Poland these values are not so high. because the activity of water is less.

Most caves in Poland are not very large. This is because of the destructive activity of continental glaciation during the Pleistocene. The very recent caves in the Tatra region are the exceptions.

Results of speleological research in Poland also have great meaning for general knowledge of karst development. This continuing research provides data for comparisons with other karst regions.

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Stereographic Cave Mapping

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ABSTRACT

A three-dimensional approach to cave mapping utilizes two projections to give a pair of drawings: these can then be combined in several ways to give a solid picture. The method is illustrated with the surveyed line of the Nakimu caves, and proposals made for further refinement of the techniques.

Many cavern systems, especially those developed in steeply dipping rocks and Alpine environments, present considerable mapping problems. The representation of a complex three-dimensional entity on a two-dimensional plan or elevation is frequently so difficult that the resulting map is unsatisfactory to all but those acquainted with the system.

Model building is technically difficult, and models are not suited to mass reproduction. But it is possible, by the use of optical techniques, to give an impression of depth by combining more than one two-dimensional projection. Figure 1 illustrates a simple stereographic projection.

A plan is conventionally a vertical projection. In this system, two projections are made as illustrated. Both projections are made at an angle α to the vertical in a given plane, in this case the plane containing east, west and the vertical. As shown in figure 1, α is determined by the height of the observer above the plane of projection, and by the distance between the observer's eyes. By assuming that h is much greater than the depths of passages below datum, then α. α_1 and α_2 are approximately equal. This greatly simplifies computation of x_1 and x_2 since

$$x_1 = z_2 \tan \alpha \text{ and } x_2 = z_2 \tan \alpha$$

By providing the eye with the images it would receive if viewing a solid model, the brain is deluded into an impression of depth. The two projections are viewed with a stereoscope (basically a pair of binoculars so arranged that each eye sees only one projection). An impression of solidity is gained: upper passages appear to run over lower passages, and sloping passages appear as such.

As an alternative to the use of a stereoscope, both projections might be overprinted on a single sheet, one in red and one in green. The whole could then be viewed through the familiar red and green three-dimensional spectacles.

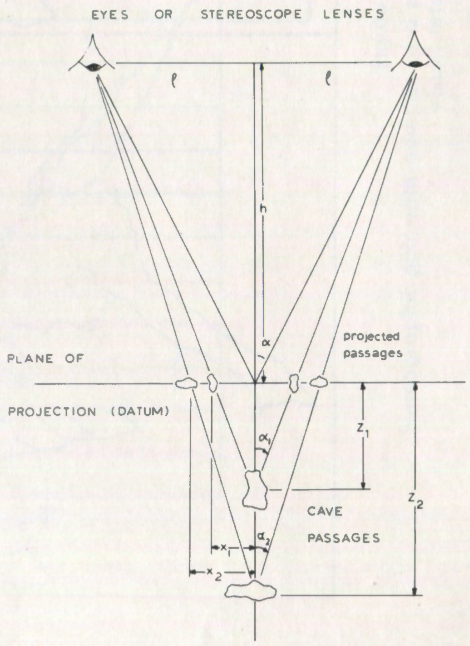

Figure 1.
Projection geometry.

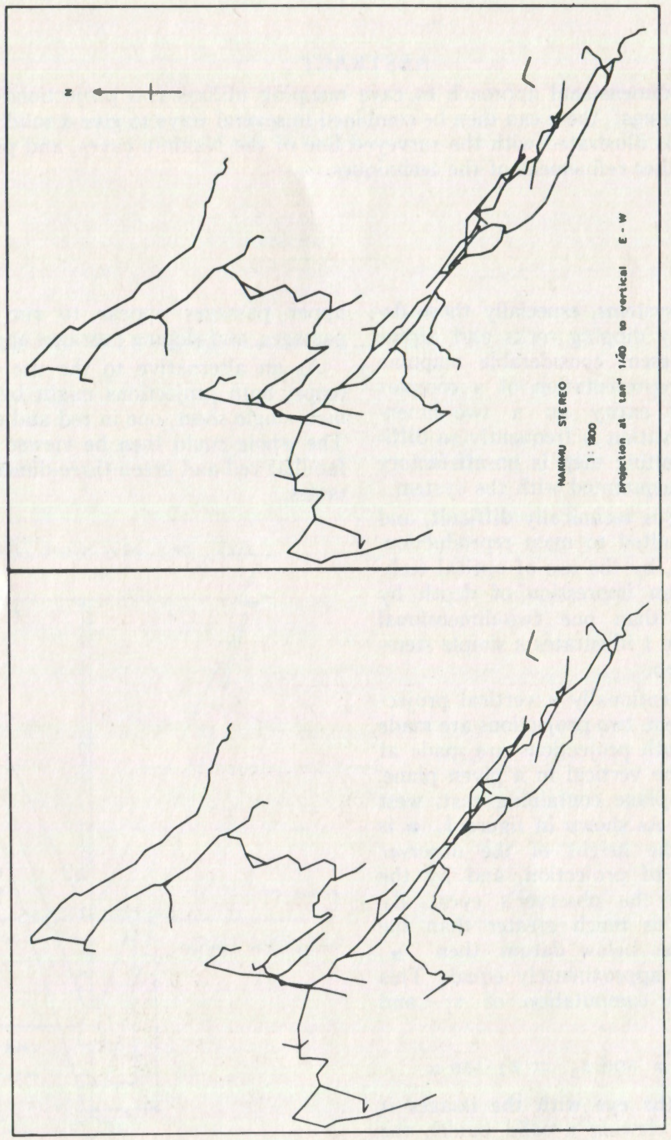

Figure 2.
Stereographic pair of the Nakimu surveyed line.

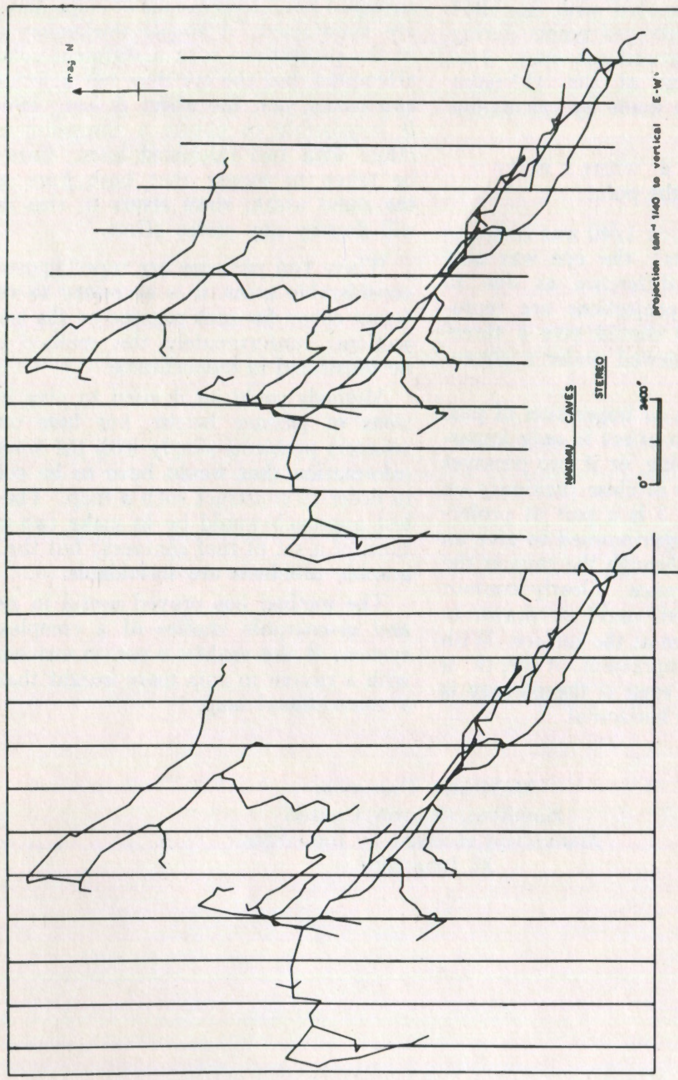

Figure 3.
Stereographic pair with addition of a plane through the main entrance for visual reference.

Monochrome stereographic projection has been extensively tested in studies of the Nakimu Caves, British Columbia, an Alpine system surveyed to CRG Grade 4 with vertical control. Eastings, northings and depths below datum were computed with an IBM 7040 for each of the surveyed points during the plotting of the conventional map. Two stereographic projections of the 412-point surveyed line were then made by calculation of two new eastings

$$x' = x \pm z \tan \alpha$$ where z is the depth of the point

The value of $\tan \alpha = 1/40$ was found to give satisfactory results: the eye was able to accommodate the difference as due to different depts. The projections are reproduced in figure 2 and should give a three-dimensional effect if viewed under a stereoscope.

The projections give no impression of passage depth. The stereo effect is only apparent if a passage is sloping, or if two passages of differing depths are in close proximity on the projection. Figure 3 is a pair of projections with N-S lines superimposed to give an impression of a plane through the cave at the level of the main entrance. Clearly contour lines, suitably projected, could be drawn to give the same impression at the surface. With such a surface, an impression of depth is given to each passage even if the passage is isolated from others, or horizontal.

The next step is to give some impression of width to passages. Where passages are not superimposed over considerable areas, this may readily be achieved by drawing two lines for each projection instead of the one surveyed line. Impressions of slope and depth are maintained. A simple thickening of one of the projections with a different color was attempted, but the eye does not associate the two colors, and the effect is lost. However, it is possible to obtain a three-dimensional effect with two thickened lines. Care must be taken to ensure that both lines are of the same width, since errors in this respect will destroy any stereo effect.

Where two passages are superimposed over considerable areas, it is necessary to use different colors for each passage on the two projections: unfortunately this method cannot be illustrated in monochrome.

Methods could be devised to give impressions of passage height, but here one encounters problems simply with the amount of information that would have to be collected in order to construct such a map. The simplest approach would be to make two projections of a set of roof contours; but the cartographic problems are formidable.

The method has proved useful in geologic and geomorphic studies of a complex cave system; it also enables a person unacquainted with a cavern to gain more insight than with a conventional map.

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