through marine erosion, and, finally, the remaining parts of the plateaux were inundated. Lower lying places, e.g. valley bottoms, were covered by water earlier. Sites where the till which is older than 20-15 ka BP (such as the till of Pre-Grudziądz stadial, e.g. profile W4 on the Odra Bank, acc. to Jurowska and Kramarska - Geological Map..., 1995, or of Warta age, e.g. profile 14097 B, acc. to Uścinowicz & Zachowicz - Geological Map..., 1995) is overlain by organic, or organic-mineral deposits of lacustrine origin which still formed in Late Glacial times are the evidence of destruction processes. Profiles in which marine *Litorina* deposits rest on the eroded surface of peat and lacustrine deposits are another example (e.g. profile R74 on the Odra Bank; Jurowska & Kramarska - Geological Map..., 1995). The youngest dates from these last profiles therefore indicate the lower age limit for the beginning of the transgression.

It should also be noted that there is a distinct differentiation in the age of the youngest glacigenic forms which remained after periods of shallow plain destruction. Over most of the Słupsk Bank, both glacial horizons of the last glaciation were destroyed, i.e. of the Wisła stage, and, because of this, the near-surface till still present there is of the Warta stage age, i.e. 17-11.5 ka BP. On the South Central Bank, the youngest till was formed during the last advance of the Vistulian ice-sheet, because its age is 25-10 ka BP (Fig. 1). The question then arises as to why there is such a large difference in the age of tills comprising the surface of the two banks. The answer should be sought in a possible glacio-isostatic rising of the South Central Bank. During the development of the *Litorina* transgression, that bank was at first in a much lower position than the Słupsk Bank. Therefore it became inundated earlier and during a shorter time than the surface of the Słupsk Bank.

When the Southern Baltic area became inudated by the *Litorina* transgression, the process of destruction of the bottom became slower, and gradually an increasing role in that process was taken over by near-bottom currents. However, we do not know enough about them to be able to evaluate quantitatively their influence on the shaping of the bottom relief. Assessments by Uścinowicz (Geological Atlas..., 1995) indicate that, at present, in the shallow plain area redeposition of sand and sand-gravel sediments prevails. Such processes are not favourable to the survival of forms of the older relief. Much of the shallow plain surface has become covered with fine sand, and, in effect, the older relief gradually disappears. On the Słupsk Bank and along the coast, an eastward direction of sand transport predominates. In places on the deep plain, clay and silt are deposited at a rate of 0.15 to 2.04 mma^{-1} (Pempkowiak, 1991; Szczepańska & Uścinowicz, 1994). This has lead to a further smoothing of the seabed.

The whole complex of morphogenetic processes, all active at present on the seabed, leads to the generation of increasingly distinctive small forms of underwater relief in the littoral zone, shaped in the environment of the very shallow non-tidal basin of the Baltic Sea.

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Karst areas in Poland and their changes by human impact

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Abstract: The karst areas of Poland occur mainly in the uplands of the southern parts of the country. The karst is evidently polygenetic, with forms produced in the tropical climates of the Tertiary, side by side with those produced in the Pleistocene cold periods. The karstified limestones are often mineralised and they produce large amounts of reliable drinking water and other resources which are extensively exploited (mineral mining, rock quarrying, groundwater abstraction, etc.) Many of Poland's karsts lie within or adjacent to the large industrial conurbations; in such regions, the karsts are under constant anthropogenic pressure. This paper discusses the effects of this human impact on the present evolution of the karst systems.

Key words: cave, harst, human impact

Introduction

The karst areas of Poland have formed in various limestone formations. Precambrian and Palaeozoic marbles are karstified in the Sudety and Holy Cross Mountains, Mesozoic limestones and dolomites in the Cracow-Częstochowa Upland, Tatra and Pieniny Mountains, Mesozoic chalk in the Lublin Upland and Tertiary halite and gypsum in the Nida Basin and the Wieliczka and Bohnia areas of the Carpathian Foreland. The outcrops of these formations are not collectively very large (about 3% of the total area of Poland), but those areas where carbonates are covered by only thin unconsolidated sediments of Tertiary or Quaternary are much more important in respect of the preservation of karstic features (20%). Moreover, the same formations have formed the foundation for palaeokarst developments at other times when a continental regime affected Poland, in the Upper Keuper and Upper Cretaceous, for example. There is no doubt that much of the modern karst

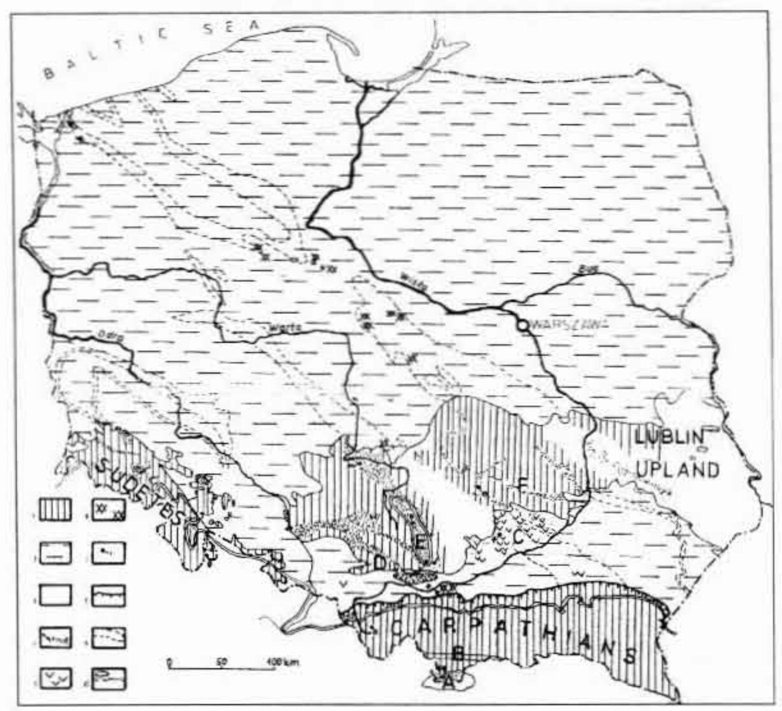


Fig. 1. Karst phenomena in Poland (after Głazek, *et al.*, 1982).
A - Tatra Mountains, B - Pieniny Mountains, C - Nida Basin, D - Silesian Upland, E - Cracow-Wieluń Upland, F - Holy Cross Mountains. 1 - Pre-Neogene non-karst areas, 2 - Neogene clay-sand deposits overlying karst rocks and other rocks, 3 - karst rocks, 4 - surface carbonate karst, 5 - surface gypsum karst, 6 - gypsum-salt diapirs, 7 - the more important caves: in the West Tatras: Śnieżna, Miętusia, Mroźna and Mylna (both opened for tourists); in Beskidy Mountains: W Trzech Kopcach (flysch cave); in the East Carpathian Foreland: Kryształowa in Wieliczka (developed in rock-salt); in Nida Basin: Skorocicka (in gypsum); in Sudety Mountains: Niedźwiedzia in Kletno (open for tourists), Radochowska, Jasna in Wojcieszów; in Cracow-Wieluń Upland: Wierzchowska Górna (open for tourists), Łokietka (open for tourists), Głęboka, Ewy (open for tourists); in Holy Cross Mountains: Raj (open for tourists), 8 - boundary of Carpathian overthrust, 9 - outline of karst rock limits under Neogene sediments, 10 - maximal extent of Pleistocene glaciation.

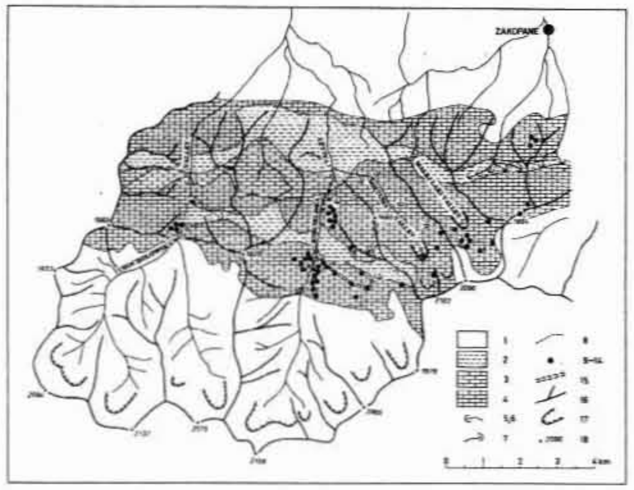
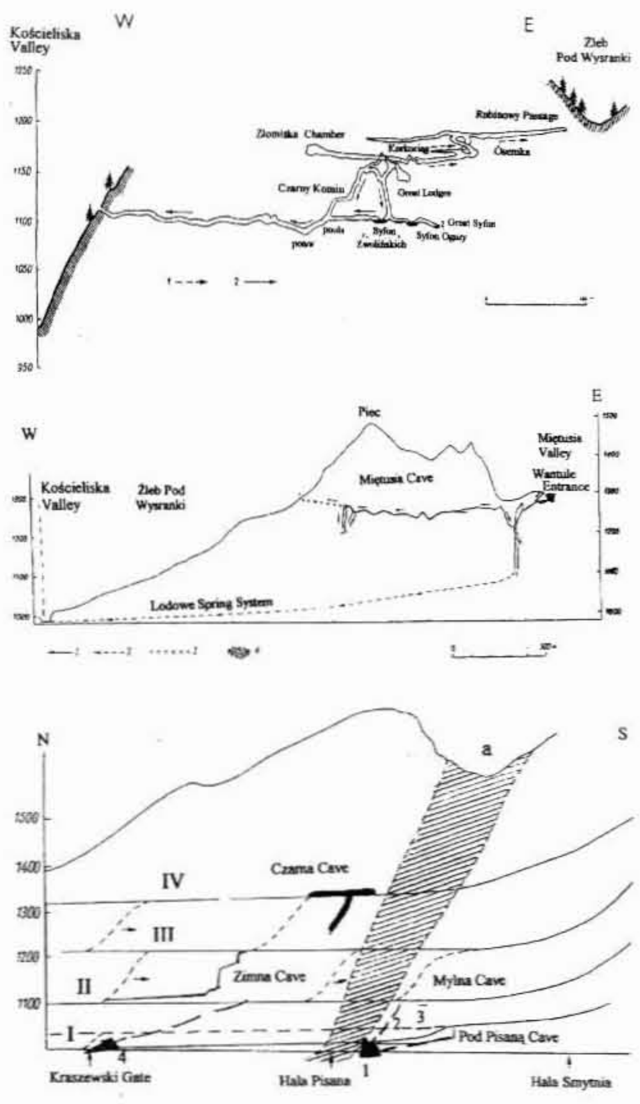
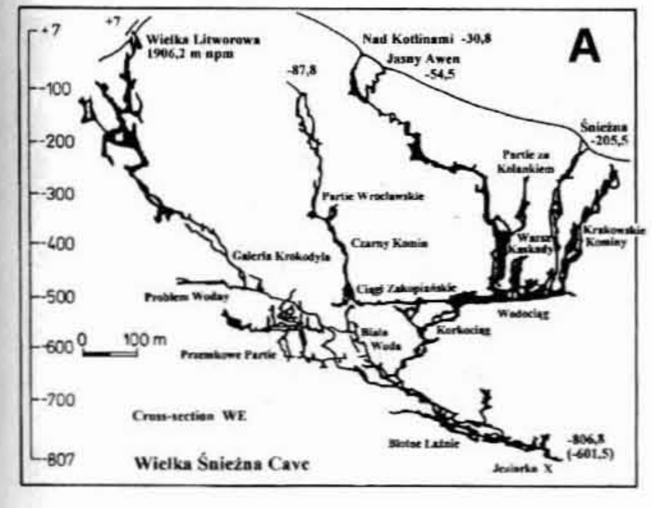


Fig. 2. Karst phenomena in West Tatras (Pulina, 1974).
1- zones of crystalline rocks; Mesozoic terrestrial rocks: 2 - marls and slates, 3 - limestones and slates, 4 - limestones and dolomites, 5 - karst springs, 6 - Lodowe spring karst system, 7 - flows of periodic streams, 8 - underground flows. The larger caves: 9 - Śnieżna, 10 - Czarna, 11 - Miętusia, 12 - Zimna and Mroźna (open for tourists), 13 - Szczelina Chochołowska, 14 - Wodna Pod Pisaną, 15 - karst gorges, 16 - mountain ridges, 17 - glacial cirques, 18 - peaks and their altitudes.

relief represents a landscape greatly modified by the glaciokarst processes which were operative when the Scandinavian ice sheets at least twice crossed what is now southern Poland; in these events, much of the older tropical karst scenery was destroyed and much of the area was covered by fluvio-glacial deposits. However, in the Tatra Mountains, for example, the karst forms are wholly those of a glaciokarst nature, the characteristic networks of deep cave systems having been formed at times of deglaciation in these areas. Even so, much of Poland's karst is polygenetic, with remnants of tropical karsts, mogotes and ridges, now deeply fretted by solutional forms and riven by deep gorges. The interiors of these karst massifs are perforated by extensive networks of galleries, most of which contain rich infills of secondary limestone forms. They also contain thick aquifers which usually provide reliable potable water. This type of karst finds a classic expression in both the Silesian and, especially, the Cracow-Częstochowa Upland. In the Sudety and Holy Cross Mountains, limestones and dolomites became preferentially eroded into positive landforms and are now found to have developed "insular" or "isolated" karsts. Quite different karstic landforms occur in the chalk of the Lublin Upland. A relatively subdued relief here is accompanied by numerous large karst depressions called

Fig. 3. Cave horizons and stages of evolution of Kościeliska Valley in the West Tatras (after Rudnicki, 1967; modyfied).
Cave horizons:
I - contemporary valley floor (Wodna Pod Pisaną Cave, exit of Lodowe źródło),
II - the level of about 100 m above Kościeliska Valley floor (lower parts of Zimna Cave and also Mroźna and Mylna),
III - the level about 200 m above valley floor (upper parts of Zimna Cave),
IV - the level more then 300 m above valley floor (Czarna Cave); karst springs:
1 - from Wodna Pod Pisaną Cave and from Mylna Cave (water flows from Kościeliski stream which disappears below Smytnia Meadow and at Pol Gate),
2- from Cracow Gorge,
3 - from Kominy Tylkowe (springs in Pisana Polana of increased temperature and increased mineralization),
4 - Lodowe spring at the exit of Kraszewski Gate (underground drainage of Czerwone Wierchy including Śnieżna Cave system and Miętusia Cave); a - Albian marls and slates which separate limestone series of Kominy Tylkowe (at Pol Gate) and Czerwone Wierchy (at Kraszewski Gate).
A - cross-section through the Zimna Cave which represents II and III cave levels in Kościeliska Valley.
1 - directions of water flow in the upper level of caves,
2 - directions of water flow in the lower level of caves.
B - cross section through Miętusia Cave and its relation to the system of underground drainage of Lodowe spring (results of fluorescence method).
1- directions of water flow at the time when the cave originated,
2 - contemporary water flow to Lodowe spring,
3 - presumed further part of the cave,
4 - Wantule rock collapse rubble.





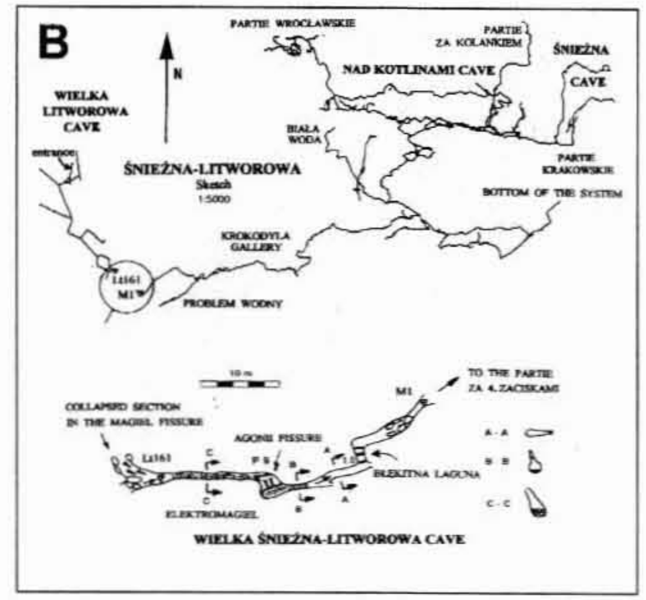


Fig. 4. Wielka Śnieżna cave system in the West Tatras (after Bolek, 1996).
A - a vertical cross-section W-E, B - map.

"popławy", which have been interpreted as modified poljes, and numerous karst dolines called "werteby". These negative landforms are often infilled by later sediments, usually Holocene deposits, including bog lime. Where the water table is high, some are flooded and give rise to picturesque lakes.

Both surface and subsurface karst forms are found on a large scale in areas where evaporite deposits are present, e.g. the Eocene halite of Wieliczka and the Tertiary gypsum of the Nida Basin. Salt diapirs of Zechstein age are also known from the Silesian-Pomeranian Anticlinorium. Zechstein salt is exploited at Kujawy, near Inowrocław and Kłodawa. It is also present beneath the brown coal depsoits in the huge karst-related depressions in the Jurassic limestones at Bełchatów and Starczynów.

Many of the older karst landscapes have extensive cave systems but it is known that erosion in recent times has destroyed many of them, while many others are infilled with clastic sediments. Of course, these infills enable us to date the cycles of Tertiary relief development and the changing palaeogeographic conditions during the Pleistocene in these areas. The largest cave systems in Poland occur in the Tatra Mountains; most of these originated in the Quaternary, and usually in glaciokarst conditions. Some of the larger caves are open to tourists, though inevitably this causes a great many changes to both the caves and their surroundings.

Some of the older karst areas in Poland are situated in areas which have been considerably urbanised. Indeed, the outcrops coincide with some of the largest population densities in the country. In these areas, there has been much exploitation of the karst systems (lead, zinc and silver mining, opencast brown coal mining, aggregate quarrying and abstraction of groundwater for both industrial and domestic requirements). The karst areas have also been used as repositories for much industrial waste, both of a solid and fluid nature. The human impact in these areas has been enormous, and this is nowhere more evident than in the areas adjacent to the regions of "black" metallurgical and mining industries in Silesia, Cracow and Częstochowa and the "white" (cement-producing) industries in the Holy Cross Mountains and the Lublin Upland. In terms of the changes which may directly be attributable to human impact, the Polish karsts may bę considered to be among the most affected anywhere in Europe.

Karst areas in Poland

Four major karst areas are present in Poland (Fig. 1) These are as follows:

- large-scale mountain and alpine karst in the West Tatras,
- medium-scale mountain karst in the Sudety Mountains, associated with small outcrops of marble (isolated or "insular" karst) (Fig. 5) and in the Holy Cross Mountains (Fig. 16),

Fig. 5. Location of karst and pseudokarst forms in Polish Sudety Mountains (after Pulina, 1977).
I - karst areas: I Kaczawa Mountains, II - Kaczawa Plain, III - Krowiarki, IV - Śnieżnik Kłodzki Massif, 2 - Pseudokarst areas: V - Kaczawa Plain, VI - Zawory (Kamienna Góra Basin), VII - Stołowe Mountains, 3 - karst domes, 4 - caves known in 1985, 5 - destroyed caves (the number stands for the number of the cave, see Pulina 1977), 6 - Niedźwiedzia Cave in Kletno.

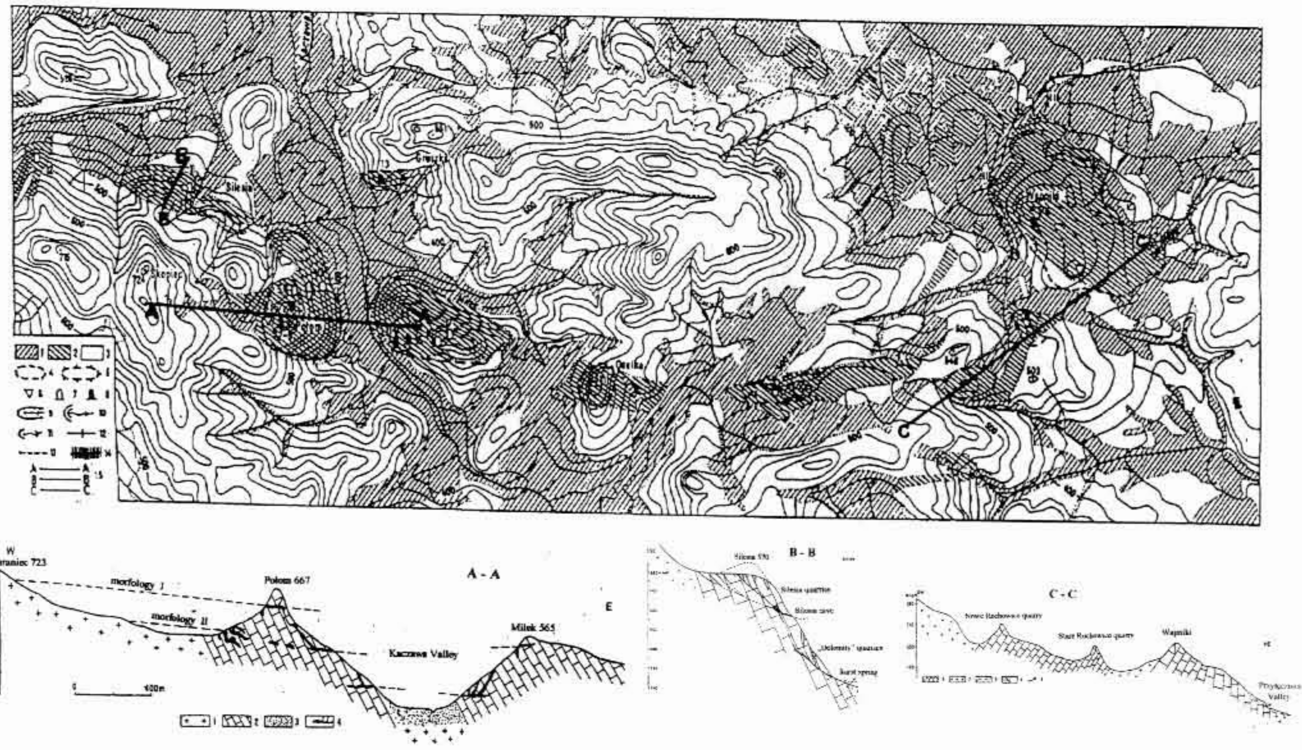


Fig. 6. Karst phenomena in the Kaczawa Mountains - the West Sudety, (after Pulina, 1977).
1 - loose Quaternary deposits, 2 - marbles and dolomites, 3 - non-karst metamorphic rocks Karst macro-forms: 4 - karst domes (hills), 5 - karst shelves. Karst macro-forms: 6 - karst dolines, 7 - caves known in 1975, 8 - caves destroyed in the quarries, 9 - karst spring valley. Karst hydrography: 10 - sinkhole ("ponor"), 11 - karst spring, 12 - hydrometric gates, 13 - periodical flow, 14 - travertine, 15 - morphological cross sections.
I - profile through the karst hills Połom (667 m a.s.l.) and Miłek (565 m a.s.l.). 1 - crystalline slates, 2 - Wojcieszów marbles, 3 - alluvia and glacial deposits in the Kaczawa Valley, 4 - caves.
II - profiles through the karst shelf on the northern slopes of Skopiec hill in the Kaczawa Mountains.
III- profile through the karst hill Wapniki (506 m a.s.l.).

- the Cracow-Czestochowa Upland karst, which is the largest in the country (Fig. 12),
- the karst of the Rotocze area of the Lublin Upland.

Some small-scale developments in areas of gypsum outcrops in the Nida Basin and halite in the Wieliczka area and also, locally, on carbonate rocks are present.

There are three large areas currently being karstified in the area of the Czech Republic and Slovakia, in both cases close to the Polish border:

- the alpine karst in the Slovakian Tatras and the Low Tatras (Demanovska and Świętojańska Valleys),
- numerous karstic massifs in Middle Slovakia and the Moravian Karst in the Czech Republic,
- the Sudety karst, such as that of the Śnieżnik Massif (Fig. 8).

There is also a large area of karst close to the Polish border in the Ukraine.

The alpine karst in the Tatra Mountains

The Tatra karst (Fig. 2) has many cave systems but only weakly developed surface karst forms. Although the oldest karst developments yet to be recognised clearly relate to the formation of at least two widespread planation surfaces of Tertiary age, their trace on the modern landscape is far from obvious. In contrast, there are many well-preserved caves, which contain significant cave infill sediments which may be related to the old planation surfaces and old valley floors. The pre-glacial relief was doubtless largely destroyed when the landscape was redeveloped by glaciokarst and nivalokarst processes during the Pleistocene (the best preserved remnants of the preglacial forms probably occur on the ridges of the West Tatras, e.g. under Małołączniak summit). The karst landforms were obliterated in the new landscape of cirques and nival alcoves.

In the West Tatras, old horizontal cave systems occur at several levels above the floors of the larger valleys (Kowalski, 1951,1953,1954; Zwoliński, 1955, 1987; Rudnicki, 1967; Grodzicki, 1996). It is possible to correlate the uppermost of these cave systems with the pre-glacial evolution of the Tatra relief (Wójcik, 1960). The highest levels of the caves occur in the ridge of Organy between the Kościeliska and Miętusia Valleys (Fig. 3) and in the Kominy Tylkowe between the Kościeliska and Chochołowska Valleys. Not only the highest, but also the largest caves occur there (Tables 1 and 2). The largest of all, the Śnieżna, is 18 km long and 807 m deep. In the Organy and Twardy Upłaz Massifs, a large composite system, formed from three intersecting caves (Miętusia, Czarna and Zimna) is over 20 km long.

The most characteristic caves in the alpine Tatra Massif are vertical. These are located in the glacial cirques and nival alcoves of the Czerwone Wierchy ridge. They originated during the melting of the Pleistocene glaciers in this area (Pulina, 1962). Śnieżna Cave is the deepest of them.

The Tatra karst has a distinctive groundwater hydrography

Table 1. The longest karst caves discovered in Poland [1/]

	Name of cave	Length (km)	Location
	WESTERN TATRAS		
1.	Wielka Śnieżna	11.7	Małołączniak Valley Mała Łąka Valley
2.	Wysoka za Siedmioma Progami	11.7	Ciemniak Massif, Wąwóz Kraków
3.	Miętusia	10	Twardy Upłaz, Miętusia Valley
4.	Bandzioch Kominiarski	9.3	Kominy Tylkowe, Kościeliska Valley
5.	Czarna	6	Organy, Kościeliska Valley, Czerwone Wierchy
6.	Ptasia Studnia - Lodowa Litworowa	5.5	Miętusia Valley
7.	Sniężna Studnia	5.3	Czerwone Wierchy Krzesanica Massif
8.	Wielka Litworowa	4.6	Kocioł Litworowy, Miętusia Valley
9.	Zimna	3.6	Organy
10.	Kozia	3.3	Kościeliska Valley
	CRACOW-WIELUŃ UPLAND [2/]		
1.	Wierna	1.03	Wiercica Valley
2.	Wierzchowska Górna	0.95	Kluczwoda Valley
3.	Szachownica I	0.60 [3/]	Krzemienna Hill
	SUDETY MOUNTAINS		
1.	Niedźwiedzia in Kletno	2.0	Śnieżnik Massif
2.	Gwiaździsta in Połom	0.56	Kaczawa Mountains - Połom
3.	Szczelina Wojcieszowska	0.44	Kaczawa Mountains - Połom
	HOLY CROSS MOUNTAINS		
1.	Chelosiowa Jama	3.7 [4/]	Kopaczowa Mountain near Kielce

[1/] Measurements taken in the early 1990s, according to PTPNoZ archives. The length of Śnieżna Cave system (Wielka Śnieżna, Nad Kotłami, Jasny Awen, Wielka Litworowa) according to the measurements taken in 1996.
[2/] 14 caves longer than 200 m are reported in Cracow-Wieluń Upland.
[3/] Including 0.35 km of natural passages.
[4/] The length of Chelosiowa Jama - Jaworznicka Cave according to the measurements taken in 1996.

Table 2. The deepest karst caves discovered in Poland [1/]

	Name of cave	Depth (m)	Location
	WESTERN TATRAS [2/]		
1.	Wielka Śnieżna	783	Małołączniak Massif, Mała Łąka Valley
2.	Śnieżna Studnia	752	Małołączniak Massif
3.	Bandzioch Kominiarski	562	Kominy Tylkowe, Kościeliska Valley
4.	Wysoka za Siedmioma Progami	466	Ciemniak Valley, Wąwóz Kraków
5.	Kozia	389	
6.	Wielka Litworowa	361	Krzesanica Massif, Kocioł Litworowy in Miętusia Valley
7.	Ptasia Studnia - Lodowa Litworowa	356	Wielka Świstówka Miętusia Valley
8.	Czarna	288	Organy, Kościeliska Valley
9.	Miętusia	263	Twardy Upłaz, Miętusia Valley
10.	Małołądzka	166	Mała Łąka Valley
	CRACOW-WIELUŃ UPLAND [3/]		
1.	Studnisko	75	Sokole Hills
2.	Januszkowa Szczelina	56	Olkusz area
3.	Piętrowa Szczelina	45	Niegowa area
	SUDETY MOUNTAINS		
1.	Szczelina Wojcieszowska	113	Połom
2.	Jasna	95	Kaczawa Mountains
3.	Gwiaździsta	65	

[1/] Measurements taken in the early 1990s.
[2/] Measurements taken in 1994, according to PTPNoZ archives. Śnieżna Cave is 807 m deep according to the measurements taken in 1996.
[3/] 10 caves deeper than 30 m are reported in the Cracow-Wieluń Upland.

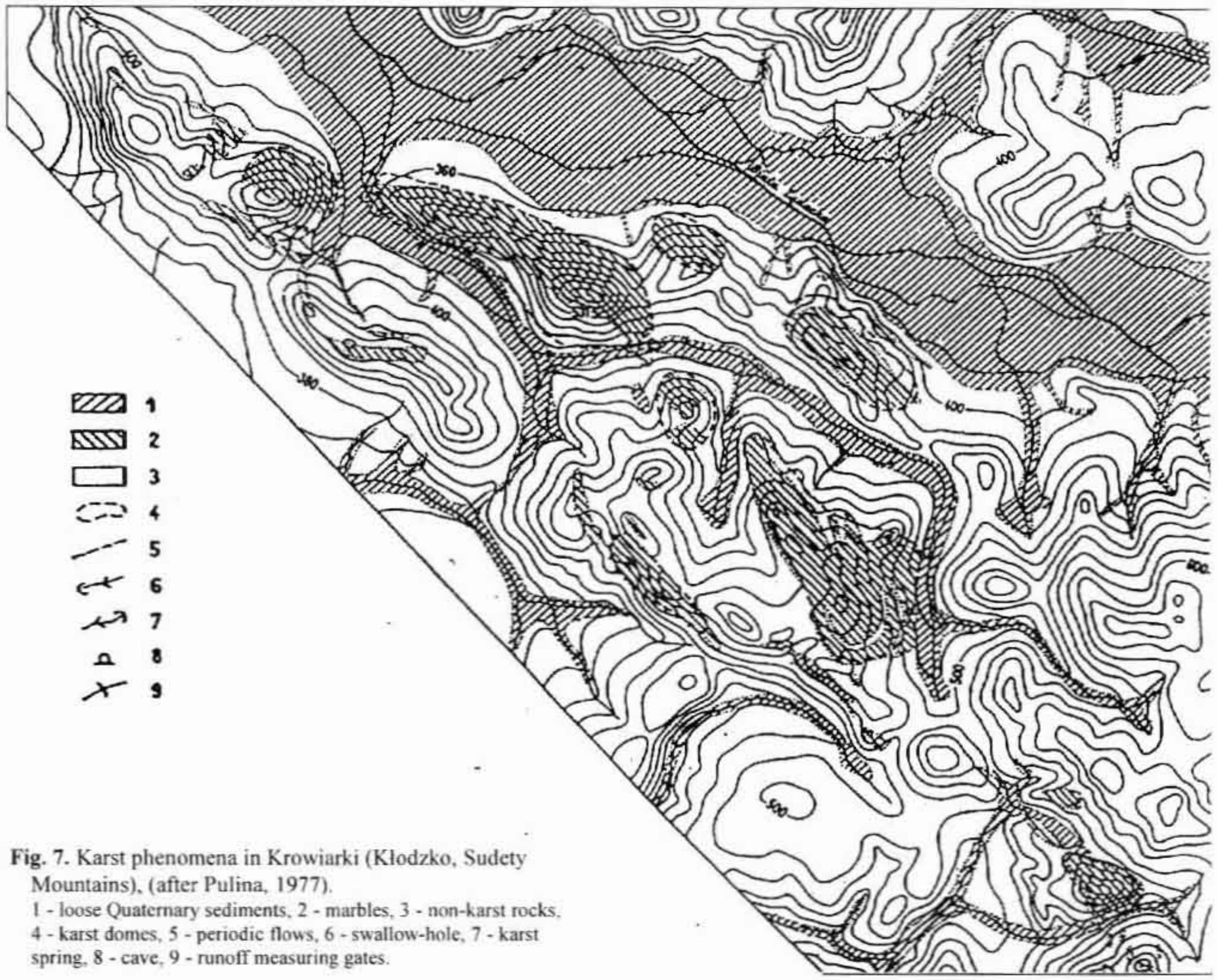


Fig. 7. Karst phenomena in Krowiarki (Kłodzko, Sudety Mountains), (after Pulina, 1977).
1 - loose Quaternary sediments, 2 - marbles, 3 - non-karst rocks, 4 - karst domes, 5 - periodic flows, 6 - swallow-hole, 7 - karst spring, 8 - cave, 9 - runoff measuring gates.

(Małecka, 1989). Water circulates in a highly compartmentalised series of subsurface canals which appear to be totally independent of the surface courses. The large springs, normally situated in the floors of the deeper valleys, are often recharged by water from adjacent valleys. For example, the Lodowe Spring, situated at the Kraszewski Gate in the Kościeliska Valley has its source in the upper parts of the Mała Łąka and Miętusia Valleys (Dąbrowski & Rudnicki, 1967).

Karst phenomena in the Sudety Mountains

The Sudety karst represents a specific type of isolated karst which has developed in Palaeozoic and Precambrian marble blocks. Their outcrops cover only about 1 km². The isolated domes, karst crests and rock shelves are perforated by networks of both vertical and horizontal caves. The largest development occurs in the Kaczawa Mountains in the western Sudety (Figs. 5 and 6) and in the Kłodzko Basin, mainly in the ridge of Wapniarka (518 m a.s.l.) and Słupiec (531) and in the Śnieżnik Massif on both sides of the Polish-Czech border (Fig. 8).

The karst of the Kaczawa Mountains has developed on outcrops of Cambrian carbonates. It forms high, isolated hills (Połom - 667 m a.s.l.; Miłek - 565m a.s.l.) and rock shelves (Fig. 6). The complex of karst hills near Wapniki Hill is drained

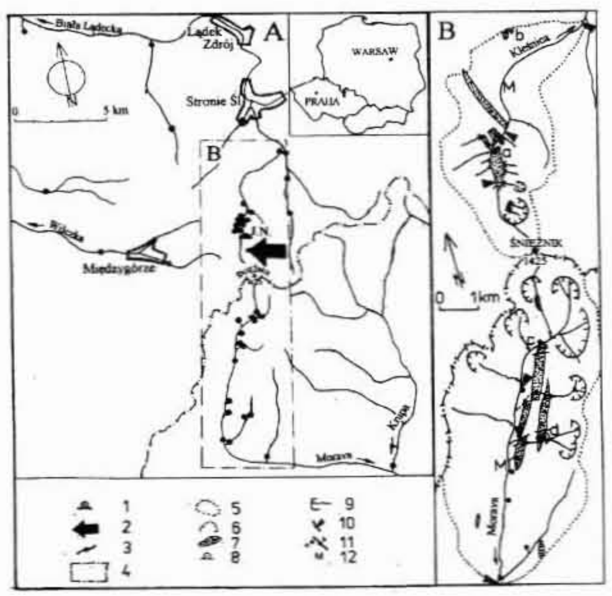


Fig. 8. Karst phenomena in the Śnieżnik Kłodzki Massif in the Sudety Mountains (after Ciężkowski *et al.*, 1986).
A - sketch of the Śnieżnik Kłodzki Massif: 1 - the cave, 2 - Biały Kamień karst swallow-hole, place where fluorescein was introduced, 3 - place where fluorescein flowed out, 4 - the detailed place of investigation shown on the Figure 8.25B.
B - Geomorphological map of the Kleśnica and Morawa catchments: 1 - catchment limits, 2 - nival cirques, 3 - marbles and erlans, 4 - more important caves: a - Niedźwiedzia, b - Kontaktowa, c - Tvarožne Diry, d - Paceltova; 5 - more important swallow-holes, 6 - water gauge, 7 - sites of water investigations: a - karst water from karst springs, b - surface water ; 8 - meteorological and monitoring stations.

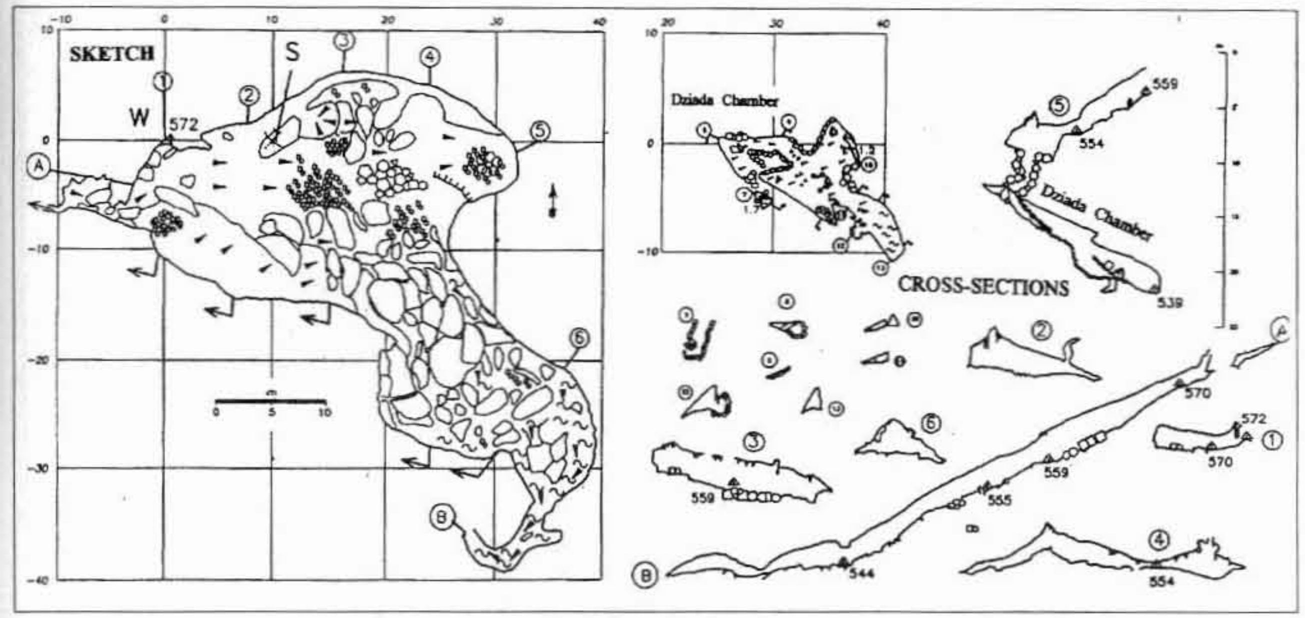


Fig. 9. Północna Duża Cave in Połom Hill in the Kaczawa Mountains (after Pulina, 1996).
S - archaeological site studied by Zotz (1939), W - artificial entrance to the cave.

by a large karst spring, below which an enormous travertine cone has formed. Several quarries are located here (the largest are in the Połom and Miłek area) which supply the base for the manufacture of industrial lime. Some quarrying dates from the 19th century. Numerous caverns and infilled dolines are visible from time to time in the quarry walls, thereby revealing the honeycombed nature of these carbonate massifs. Some of the large numbers of caves which are also present here may represent fragments of horizontal passages formed by underground rivers which relate to the cutting of the Tertiary planation surfaces. Others form deep vertical shafts which interconnect the various levels of cave systems. The Północna Duża Cave is an example of the former type (Fig. 9); in this cave, a large number of artefacts were discovered in the inter-War period (Zotz, 1939); Nowa Cave, which is notable for the presence of Scandinavian glacial debris (Pulina, 1977) and which was not discovered until after the Second World War (Kowalski, 1954), is another. The Jasna Cave (Fig. 10) is a good example of the second type. This is 95 m deep and is located in the southern slopes of Połom Hill in the so-called "Royal Quarries"; it was not discovered until quarrying started in the early 1970s (Pulina, 1997). The deepest of the Kaczawska Mountains caves is 113 m deep. Dating the cave sediments here has enabled us to determine the age of the planation surfaces and also to delimit the earlier catchments of these karst areas.

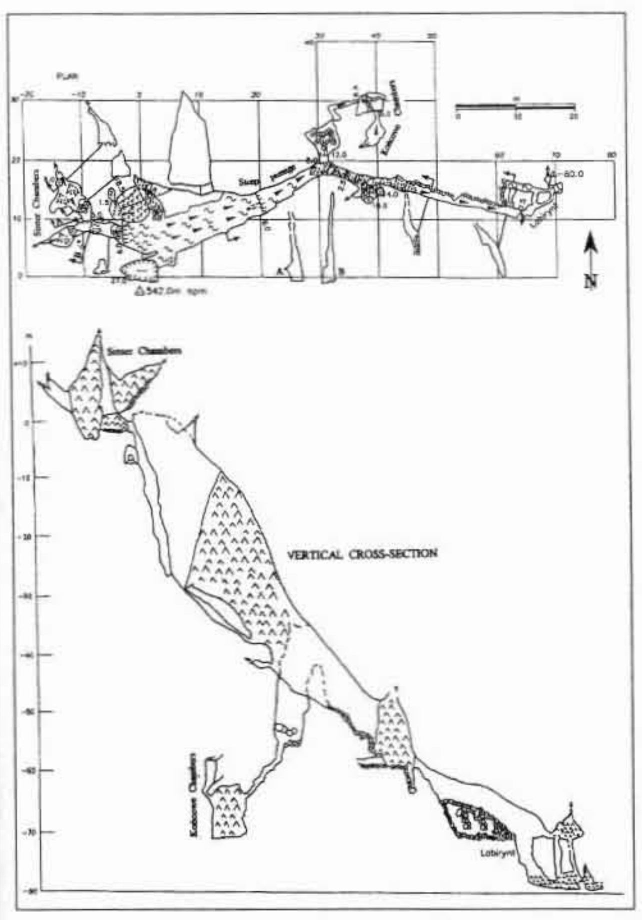


Fig. 10. Jasna Cave in Połom Hill in the Kaczawskie Mountains according to Rojek (from Pulina, 1996).

The second largest karst system in the Sudety Mountains is situated in the Krowiarki and Złote Mountains area of the Kłodzko Basin (Walczak, 1958). The source area for this karstification originally lay in the Romanowa Valley (Fig. 7) The Romanowski Stream, which issues there, loses itself in the complex of sinkholes ("ponors") which are located in the upper part of Romanowo village. The discharge of this water is via a large spring near the village of Żelazno in the lower part of this valley. Many caves, including the well-known Radochowska Cave, also occur in the Złote Mountains.

The Śnieżnik Massif is a very distinctive karst region. The karst is developed here in Precambrian marbles which occur as part of a disrupted fold which pierces the Śnieżnik Dome. The marbles are preserved as detached blocks, which form both isolated hills, such as Krzyżnik, 710 m a.s.l., and the valley slopes on the northern sides of the Kleśnica and Kamienica Valleys and the southern sides of the Śnieżnik

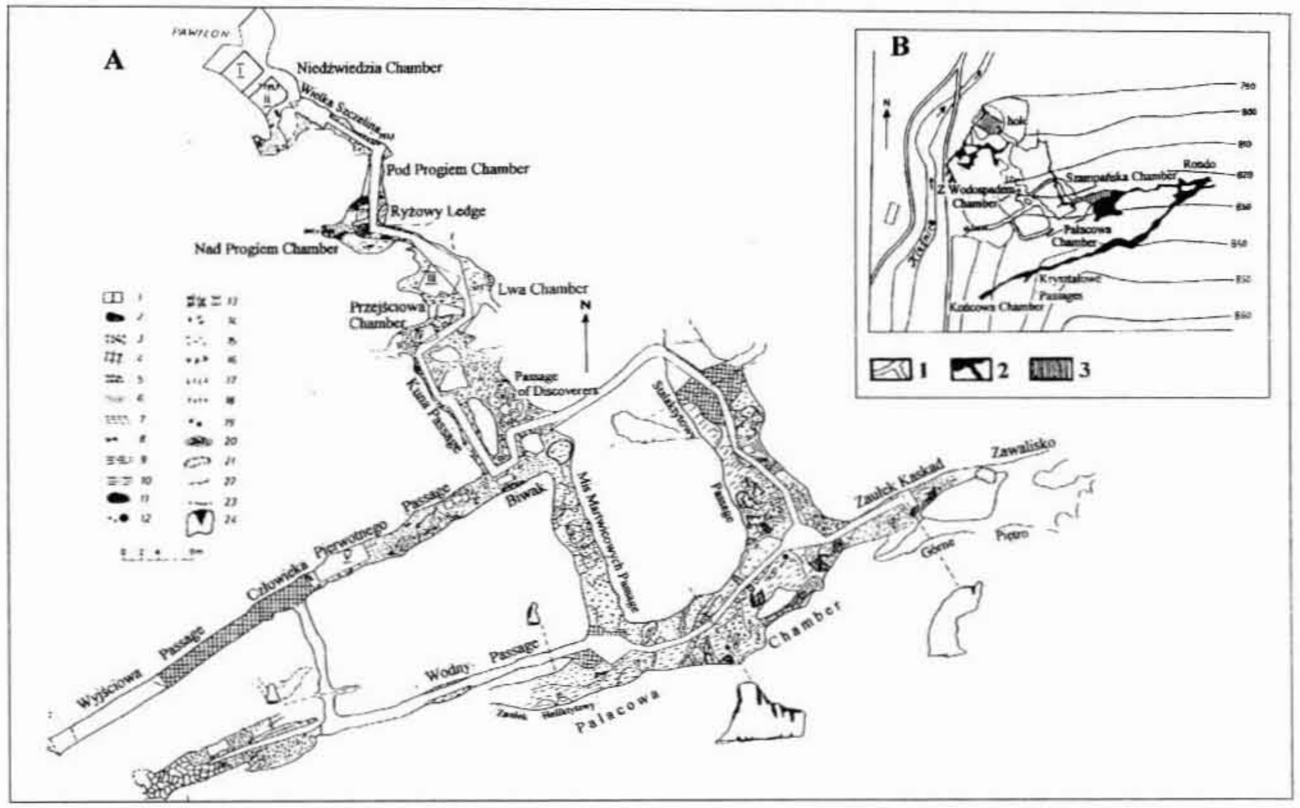


Fig. 11. Niedźwiedzia Cave in Kletno in Śnieżnik Kłodzki Massif (after Pulina, from Jahn *et al.*, 1989).
A - map of the passages of the middle level, open for tourists: 1 - research diggings, 2 - rock blocks, 3 - sharp marble rubble, 4 - collapse rubble, 5 - marble roundstones, 6 - sand deposits, 7 - clay, 8 - bones of the Pleistocene mammals, 9 - covers of the calcite sinters, 10 - "mont milk" type sinters, 11 - marble blocks covered by calcite sinters, 12 - stalagmites, 13 - travertine bowls, 14 - places of "cave pearls" occurrence, 15 - calcite kidneys in the bottom of travertine bowls; 16 - "flowing flowers" on the surface of pools, 17 - crystals of fibrous calcite in the bottom of travertine bowls, 18 - "calcite brushes", 19 - "calcite hedgehog", 20 - pools permanently filled with water, 21 - periodic pools, 22 - limits of sinter covers, 23 - rock sills, 24 - vertical profiles cross-sections of the passages.
B - map of main passages of the Niedźwiedzia Cave on the slope of Stroma Hill: 1- passages of the middle level, 2 - passages of lower level, 3 - artificial passages.

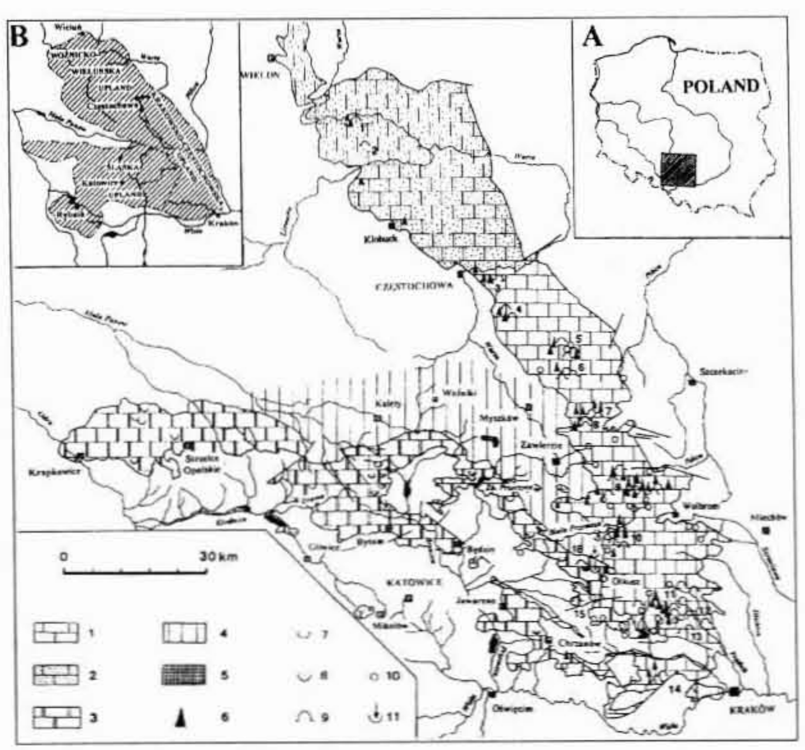


Fig. 12. Karst phenomena in the Silesia-Cracow Upland (after Tyc, 1997).
A - geographical setting;
B - physico-geographical division: 1 - Upper Jurassic carbonate series - outcrops or thin cover of permeable deposits, 2 -Uupper Jurassic carbonate series - thick cover of Pleistocene deposits, 3 - Triassic carbonate series - outcrops or thin cover of permeable deposits, 4 - Triassic carbonate series - cover of impermeable Rheatic-Liassic sediments, 5 - outcrops of Devonian carbonate rocks; 6 - groups of karst rocks and haystack hills, 7 - groups of karst dolines, 8 - groups of large filled karst depressions (fossil karst), 9 - caves or underground karst form groups: 1 - Zelce Hill: Niespodzianka C., Stalagmitowa C.; 2 - Krzemienna Hill: Szachownica I,II; 3 - Towarne Hills: Cabanowa, Towarna C., Dzwonnica; 4 - Sokole Hills: Maurycy C., Olsztyn and Wszystkich Świętych C., Koralowa C., Urwista C., Studnisko C.; 5 - Ostrężnik: Wierna C., Wiercica C., Ostrężnicka C.; 6 - Mirów Hill: Kamienny Grad C., Piętrowa Szczelina C.; 7 - Kroczyce Rocks: Głęboka C.; 8 - Podlesice Rocks: Szpatowców C., Żabia C., Wielkanocna C.; 9 - Smoleń-Niegowonice area: Na Świniuszce C., W Straszykowej Górze C, Na Biśniku C., Psia C., Zegar C., Jasna w Strzegowej C.; 10 - Klucze-Jaroszowiec area: Mąciwoda C., Januszkowa Szczelina C.; 11 - Sąspówka Valley and Jamki Gorge: Łokietka C., Sąspowska C., Koziarna C., Sadlana C., Zbójecka C, Krakowska C., Biała C.; 12 - Prądnik Valley: Ciemna C., Okopy; 13 - Sub-Cracow Valleys: Wierzchowska Górna, Mamutowa, Nad źródłem I, Nietoperzowa C., Na Tomaszówkach Dolnych C., Racławicka C., Ciasny Aven; 14 - Vistula Valley: Smocza Jama C., Twardowski C., Kryspinowska C., W Diablej Górze C.; 16 - Olkusz area: Pomorzany; 10 - karst springs, 11 - groups of induced dolines and anthropogenic depressions.

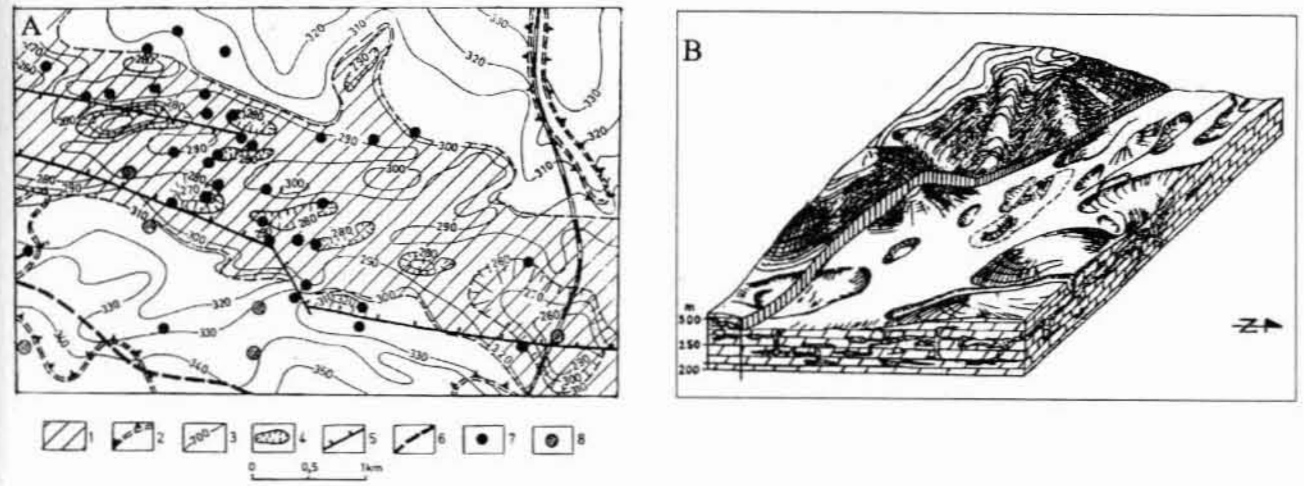


Fig. 13. Palaeomorphology of Keuper karst in middle Triassic limestones and dolomites in the Silesian Upland (after Wilk *et al.*, 1989).
A - structural map of the Muschelkalk roof deposits: 1 - regional morphological depression, 2 - limit of Keuper deposits, 3 - contours of the height of the Muschelkalk roof deposits (in m a.s.l.). 4 - funnel-shaped depression, 5 - fault, 6 - course of Ponikowska Gallery, 7 - the opening where open karst canals were found, 8 - the opening where breccia was found.
B - the morphology of the roof of Muschelkalk sediments.

Massif, in the Morava Valley. The karst drainage is very distinctive in the Kleśnica Valley (Ciężkowski *et al.*, 1986) with much subsurface water flow, including some directed northwards to below the European watershed (Ciężkowski, 1989). Several major caves have been discovered in the Śnieżnik Massif, including the Niedźwiedzia Cave at Kletno, which represents part of both the ancient and the modern course of the Kleśnica (Fig. 11).

Silesia-Cracow Upland karst

The most extensive karst area in Poland is that of the Silesia-Cracow Upland, where karst processes have affected Triassic limestones and dolomites and Jurassic limestones (Fig. 12). These formations are monoclinally disposed and divided tectonically into separate blocks. The karst relief, which exhibits well-preserved traces of tropical karst, is superimposed

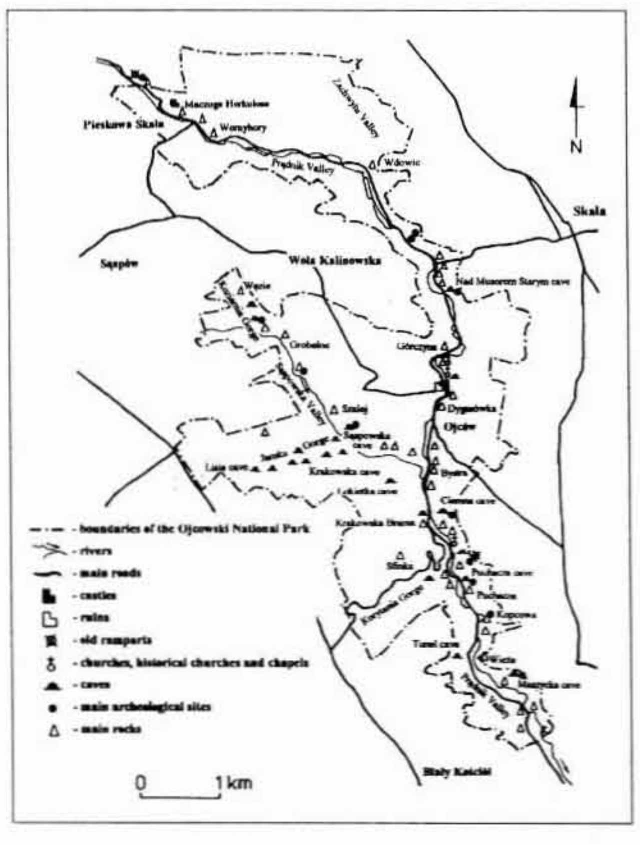


Fig. 14. Caves and historical monuments in the Prądnik Valley in the Cracow Upland (after Partyka, unpublished).

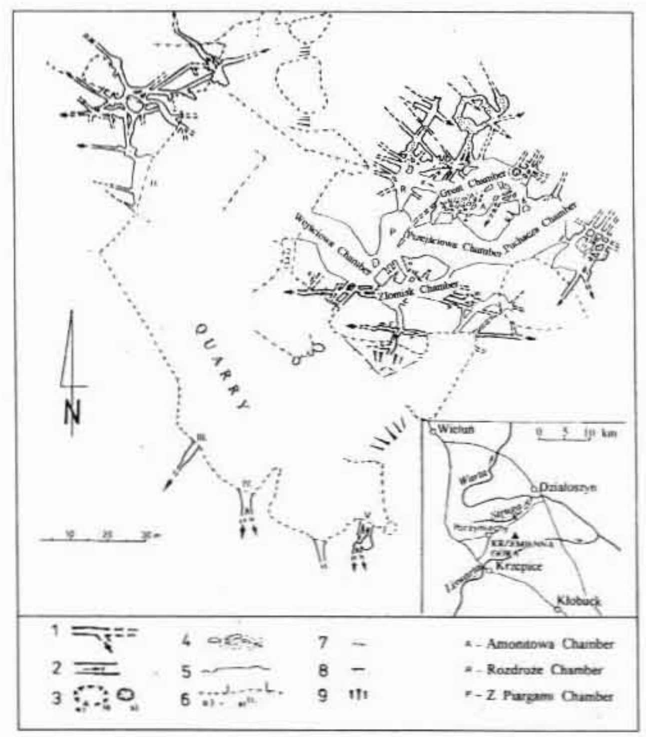


Fig. 15. Szachownica Cave in the Krzemienna Hill in the Cracow-Wieluń Upland (after Głazek *et al.*, 1978).
1- natural passages, 2- directions of water flow, 3 - shafts (a - in the bottom of the cave, b - open to the surface), 4 - collapse rubble blocks, 5 - cave walls enlarged by limestone exploitation, 6 - sketch of the quarry (a - walls, b - overlaps and the numbers of the cave fragments), 7 - steep sections 8 - sills, 9 - escarpments.

on a scarp-and-vale topography (where the cuestas are formed from limestone). Two separate regions may be distinguished here: the karst of the Silesian Upland, which is preserved as a fossil covered karst and the karst of the Cracow-Wieluń Upland, which has a relief of relict tropical karst (albeit one much modified by Pleistocene cold period processes) which must date from the Tertiary. The former is developed in the Muschelkalk limestones and dolomites and also, locally, in Devonian limestones. It contains abundant mineral resources and produces copious supplies of potable water. In the landscape of limestone scarps and ridges, there is evidence that at least some of this is an exhumed karst of Keuper age. The depressions between the ridges are largely filled with glacigenic deposits from the Cracow and Middle-Polish glaciations. The latter, which borders the former along the prominent cuesta of Jurassic limestones, forms the meridional upland belt, a part of the Silesian/Pomeranian Anticlinorium. The southern part of the Cracow-Wielun Upland is cut by the tectonically-induced Krzeszowice Depression which has isolated the Tęczyn Ridge and several smaller hills, including those at Wawel and Skałki. The northern part of the Depression is cut by numerous so-called "Cracow little valleys", including the deep gorge of the Prądnik. (Fig. 14) The slopes of these valleys contain numerous cave entrances (Gradziński, 1962; Szelerewicz & Górny, 1986; Gradzinski *et al.*, 1995) and there are numerous karst springs in the floors of the valleys. The central part of the Upland consists of picturesque limestone hills (those situated between Wawel Hill and Jasna Góra in Czestochowa are surmounted by old castles, called "eagle nests") and irregular limestone ridges. Between these, traces of large karst depressions (e.g. the Ryczówek Depression) which have been much dissected by tectonic movements, have been preserved. This relief is a remnant of a well-developed tropical karst which was largely destroyed in the Pleistocene (Klimaszewski, 1958).

Numerous karst springs, probably parts of the original karst drainage network occur in the central part of the Upland. The most interesting of these drains to the Wiercica valley via the large Zygmunt and Elżbieta Springs and temporary springs in Ostrężnik. Another example is the karst spring system in Julianka These karst springs are the sources of some quite large rivers, including the Przemsza, Pilica and Warta.

The northern part of the limestone upland is not so prominent in the landscape for much of it hereabouts is covered by unconsolidated covers of Tertiary and Pleistocene sediment. But limestone hills rise from beneath the glacial cover in the Warta valley in the area of the Załęczański Landscape park (Szynkiewicz, 1977), as well as an older generation of caves which are preserved in, for example, Zelce Hill, the Szachownica Cave, which was discovered in a small quarry in Kamienna Góra, near Działoszyn (Fig. 15); these were evidently formed by meltwater from the Scandinavian ice sheet (Głazek *et al.*, 1978). In the Bełchatów area, brown coal deposits fill large depressions which owe their form at least partly to fossil tropical karst of Tertiary age.

Karst in the Holy Cross Mountains

A further large karst region was established on the Devonian limestones and dolomites of the Holy Cross Mountains (Fig. 16). This is a Tertiary karst, somewhat modified in the Quaternary. As in the case of the Sudety karst, it forms a landscape dominated by karst domes (as at Zelejowa Hill, near Chęciny) and ridges (e.g. the nature sanctuary at Miedzianka Hill). The numerous quarries in this area often expose cave systems, many of which are rich in cave deposits. Otherwise, there is little evidence of their existence (Urban, 1997). Some of the caves were discovered during mining operations for silver ores, which have been carried out here since Medieval times (e.g. at Miedzianka, near Chciny). The Raj Cave, near Kielce is open to tourists (Fig. 17).

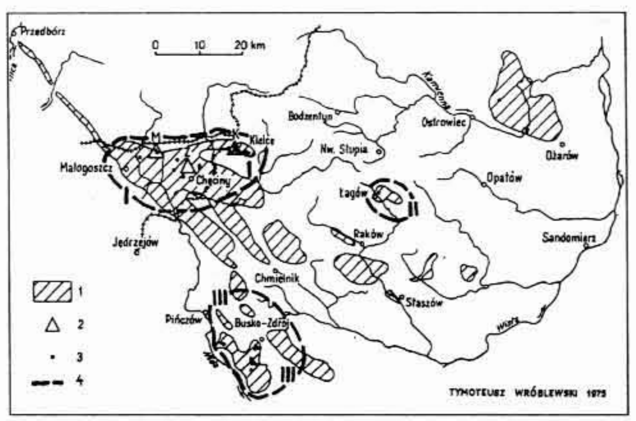


Fig. 16. Karst in the Holy Cross Mountains according to Wróblewski (after Rubinowski, 1975).
1 - outcrops of the karst rocks, 2 - limestone mogotes under protection:
M. - Miedzianka, Z - Zelejowa, K - Kadzielnia,
3 - caves, 4 - karst areas:
I - Kielce-Chęciny, II - Łagów, III - Nida (gypsym karst).

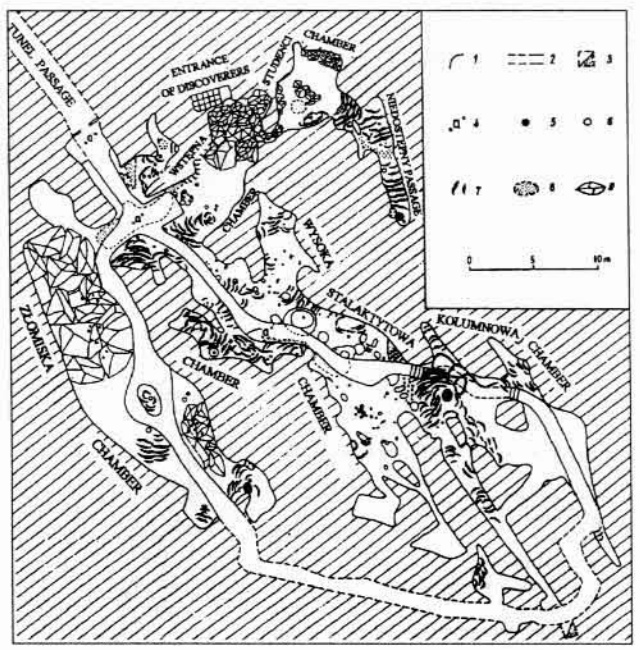


Fig. 17. Raj Cave near Kielce according to Wróblewski (after Rubinowski, 1974).
1 - sketch of the cave natural passages, 2 - artificial parts of the passages, 3 - ventilation shaft, 4 - archaeological research pits, 5-8 - main elements of sinters in the cave bottom: 5 - sinter columns, 6 - larger stalagmites, 7 - fields of travertine bowls, 8 - fields of cave pearls, 9 - rock blocks.

(called "werteby") and large ones (called "popławy") are the most characteristic karst forms here. Many of these are filled with peat deposits and some are flooded, to form attractive lakeland scenery (e.g. Łęczyn-Włodawa Lakes - Wilgat, 1953). In the south-western part of the Lublin Upland, the karst hydrography has numerous karst springs (e.g. those at Wierzchowiska, the discharge of which is as much as 100 dm^3s^{-1} - Janiec, 1984). However, none of the larger karst landforms nor caves have been located to date.

The evidence of karst in gypsum and halite

Karst processes have been effective on outcrops of gypsum and halite in some parts of Poland but the developments are on a relatively small scale. However, gypsum karst is quite well developed in the Nida Basin where it was investigated by Sawicki (1919), Malicki (1947) and Flis (1954). In this area, numerous karst meso- and microforms and small caves are present (the length of passages in the Skorocice Cave totals 280 m). Halite- and gypsum-karst occur in the Wieliczka area, where deformations of the ground surface are principally the results of salt-mining (Garlicki *et al.*, 1996), in particular the collapse of small cavities both near the surface and deep within the mines. The Kryształowe Caves appear to be natural forms; here the caves walls are covered with fine displays of large halite crystals.

The karst areas in Poland under human impact

The karst areas of Poland, especially the cave systems, have been much influenced by humans since the end of the Pleistocene when Humans settled in the caves consequent upon the retreat of the Vistulian glacier. Middle Palaeolithic artefacts (dating to the end of the Middle-Polish glaciation and the Eemian interglacial) have been discovered in several caves in the Cracow-Częstochowa Upland (Nietoperzowa Cave in the Będkowska Valley, Ciemna Cave in Prądnik, Koziarnia Cave in Sąspowska and Biśnik Cave in Wodąca - Fig. 19). By the middle of the last glaciation, cave-dwellers of the so-called Jerzmanowice Culture made use of the caves in the Cracow Upland, i.e. 30-40,000 years BP Palaeolithic people also settled in the Sudety caves. In the Połom area, flint tools and a cave bear skull with filed teeth (the teeth appear to have been filed when the bear was alive) were found in the Północna Duża Cave (Fig. 9). This seems to be evidence in support of the supposition that Palaeolithic Man practiced a bear-worshipping culture hereabouts. In the Niedźwiedza Cave at Kletno, a large store of bear bones was found (Wiszniowska, 1976), suggesting that Palaeolithic Man was a hunter of bears in this district.

During the numerous wars in Medieval Europe, the precious belongings of the persecuted were often hidden in caves and it is probably the search for this buried treasure, more so than anything else which has stimulated the growth of both modern speleology and ore prospecting. Moreover, the presence of the isolated limestone hills, and easy access to the building stones there, favoured the construction of the numerous hill fortresses, castles and fortified churches which are still to be found in these regions. Practically all of the major

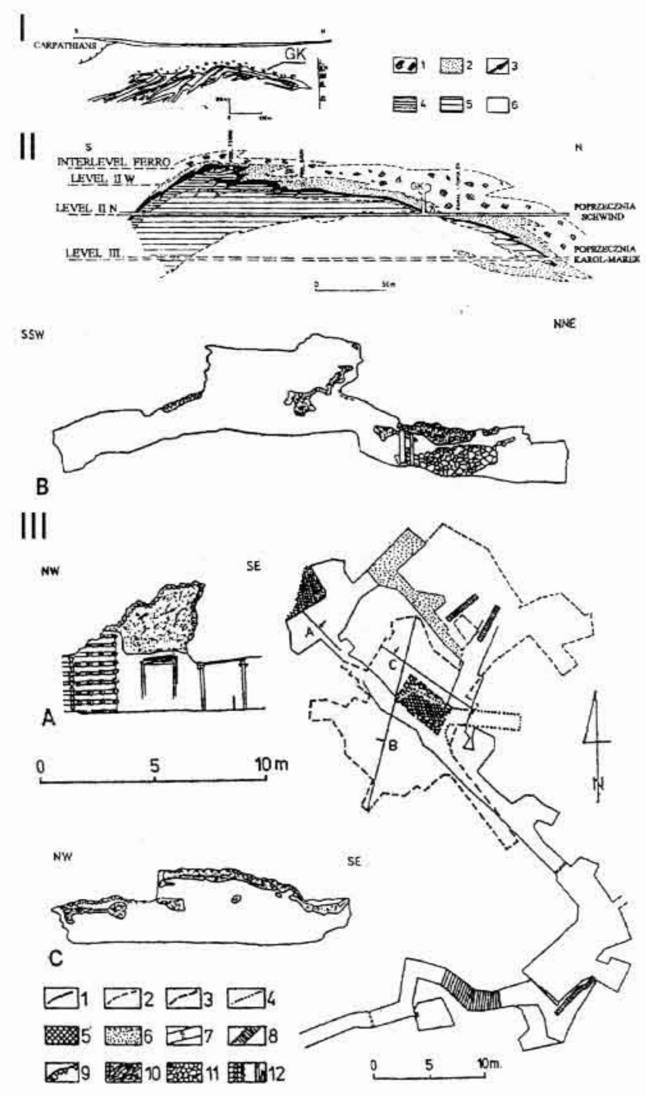
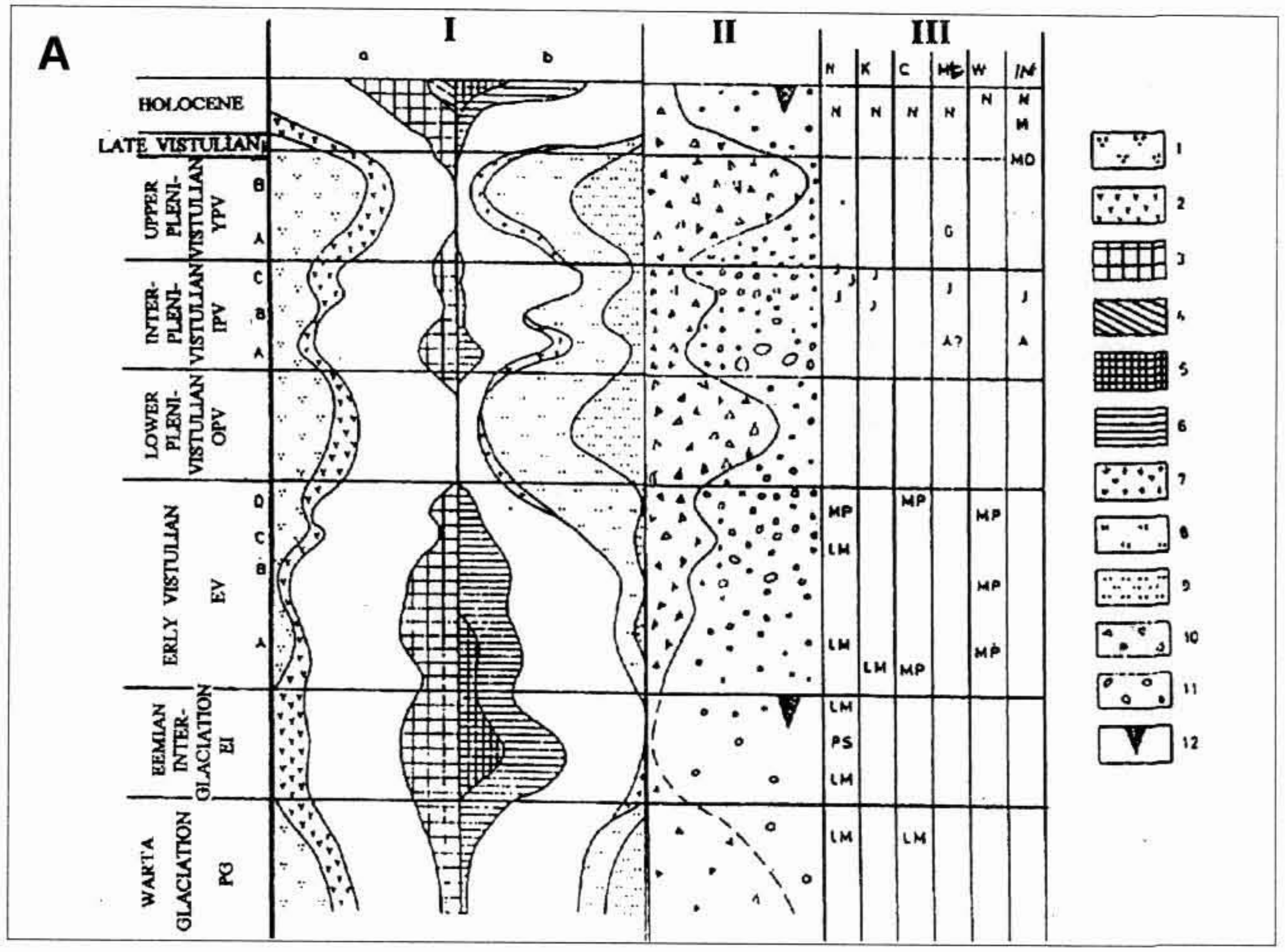


Fig. 18. Kryształowe Caves in the salt mine in Wieliczka (after Aleksandrowicz, 1994).
I - geological cross-section through the Miocene formations (GK - location of Kryształowe Caves);
II - cross-section through the "dome of Kryształowe Caves":
1 - megabreccia deposit ("zuber" with green salt blocks; stratum resource: 2 - "spiza" salt, 3 - "shaft" salt, 4 - green salt, 5 - the oldest salt, 6 - Miocene deposits in the floor and roof of salt bed (clay with gypsum and anhydrite, clay and sand),
III - map of Kryształowe Caves and entrance passage: - 1 - sketch of the floor of the lower cave, 2 - sketch of the excavation between the caves, 3 - limits of the upper caves, 4 - the uppermost level of the upper cave, 5 - crib protecting the roof, 6 - filling, 7 - closing, 8 - stairs, 9 - halite crystals in the cross-sections, 10 - crystalline erratic covers on the walls along the cross-sections, 11 - filling, 12 - crib and wooden casing .
A, B, C - vertical cross-sections.

Chalk karst in the Lublin Upland

In terms of its area, the interfluve between the Vistula and the Bug (which includes a considerable part of the Lublin Upland) is, theoretically, a large area of karst, but the classic karst landforms are largely absent (Maruszczak, 1966). This nevertheless distinctive landscape has a subdued karst expression, which relates directly to its foundation of Cretaceous chalk, lime-silicate rocks and marls and Miocene limestones (Harasimiuk, 1975). Numerous small depressions



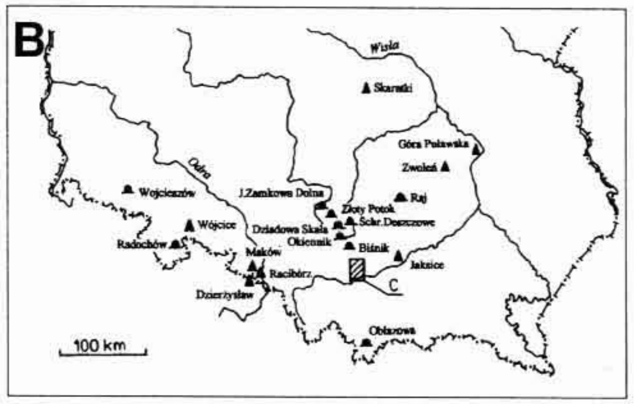


Fig. 19. Geological, faunistic and archaeological data from Palaeolithic sites in the Cracow Upland (after Madeyska, 1982).
A - geological time-scale. I - percentage of mammal remnants: a - percentage of mammal species in the ecological groups, b - percentage of rodents in the same ecological groups: 1 - tundra, 2 - steppe, 3 - wood, 4 - domestic, 5 - wood mouse - *Apodemus silvaticus* and *Apodemus* distinguished from wood rodents, 6 - other wood rodents, 7 - steppe rodents; 8 - tundra rodents, 9 - lemmings - *Dicrostonyx torquatus* and *Lemmus lemmus* distinguished from tundra rodents, the places without hachure - eurotopic elements. II - main lithological features of cave deposits: 10 - coarse limestone rubble, 11- rounded limestone rubble, 12 - horizon of calcite sinter. III - culture horizons in deposists of the following caves: N - Nietoperzowa, K - Koziarnia, C - Ciemna, Mt- Mamutowa, W - in Wylotne rock shelter, In - in other caves and rock shelters; Archaeological cultures: N - Neolithic age, M. - Mesolithic age, MD - Magdalenian age.
B - Location of Palaeolithic sites in the Southern Poland.
C - Location of Palaeolithic sites in the Cracow Upland.
1 - open sites, 2 - cave sites.

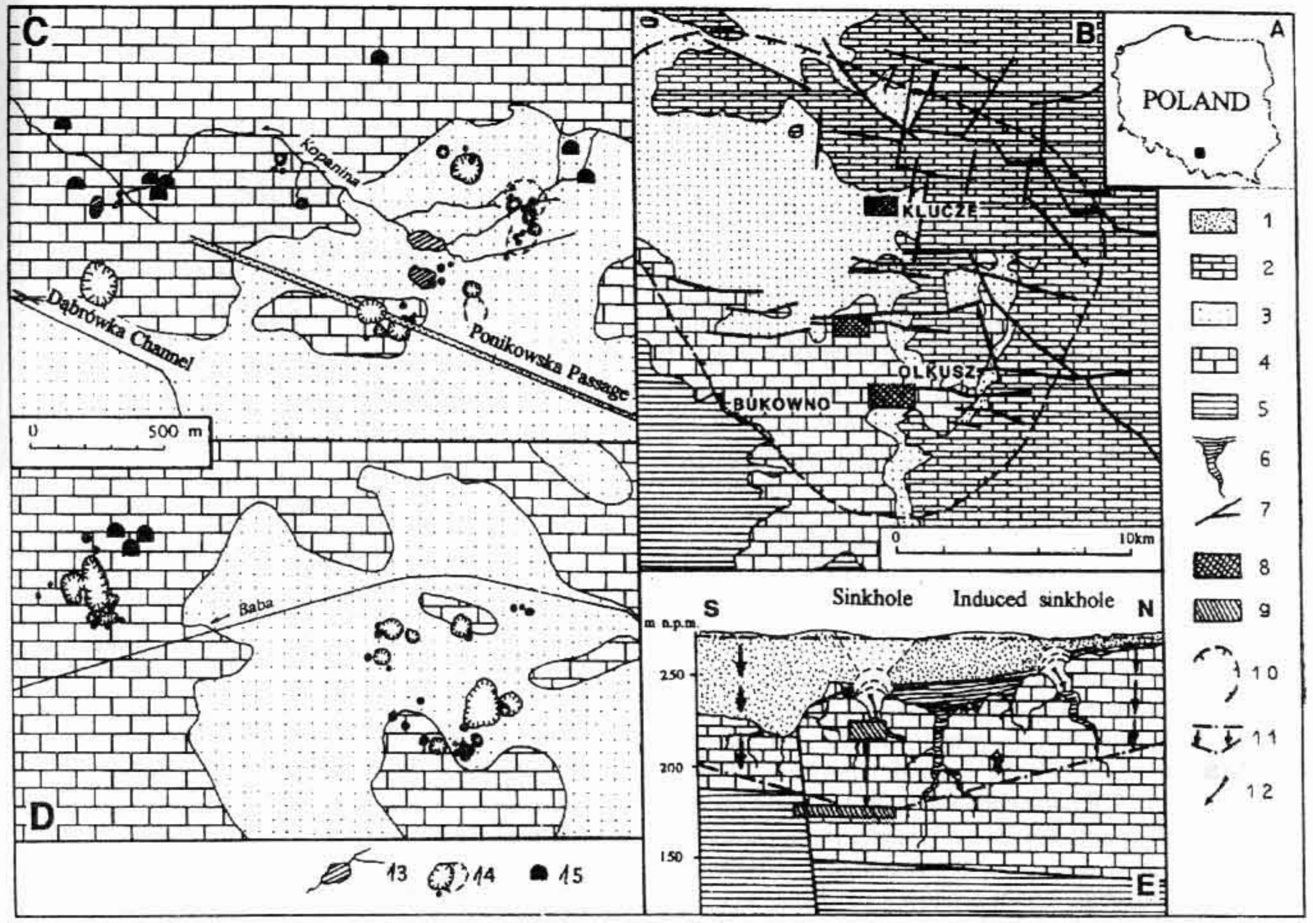


Fig. 20. Subsidence forms in the Olkusz Ore Region and their relationship to the geology and palaeokarst (after Tyc, 1997).
A - location of the Olkusz Ore Region, B - geology (without Quaternary cover) and location of the areas with subsidences, C - location of the subsidence forms in the area of Hutki - Dąbrówka, Pomorzany Mine, D - location of the subsidences in the area of Baba - Olkusz Mine, E - outline of the origin of subsidence forms in the area of Olkusz and Klucze.
1 - Quaternary sediments (sand and clay), 2 - Jurassic carbonate rocks, 3 - Upper Triassic and Lower Jurassic impermeable sediments, 4 - Triassic carbonate rocks, 5 - rocks of the Palaeozoic basement, 6 - deposits which fill karst forms, 7 - main faults, 8 - places where subsidence forms occur, 9 - mine excavations, 10 - the limits of the hydraulic depression in the Triassic carbonate rocks; 11 - modern circulation of groundwater caused by the lowering of karst water horizon due to mine water pumping, 12 - direction of migration of deposits which fill karst forms, influenced by lowering of groundwater horizon, 13- elements of the hydrographic network (rivers, dry water aquifers, canals of mine water), 14 - subsidence forms and sinking basins, 15 - larger underground voids found in mine excavations.

karst massifs of Poland were so occupied in Medieval times, nowhere moreso than in southern Poland.

However, these early contacts of man with the karst environment caused few, if any negative effects. Until recently, Human use of the karst environment was minimal as a landscape-changing element and pollutant. By contrast, in the last 150 years or so, Man has become the most important agent of change in these respects. Caves have been devastated and, as a result of deforestation, the karst massifs have been robbed of much of the thin soil cover they once had. The karst aquifers have been depleted and what were once rich natural areas have become stripped of their environmental values. The fortification and home construction, and the change of forested land into ploughland began to pressure the karst areas in a serious manner. The karst environment in Poland has never been under a greater pressure than at the present time; much of this is due to the sheer incompetency of Human management of these areas and, in turn, this is fundamentally due to Human ignorance of karst materials and processes. The results of the ignorance become manifest principally when municipal infrastructures are located in these areas, roads and reservoirs which are either badly planned or badly constructed and do not take heed of the special requirements of engineering on these soluble and sensitive foundations, and when traditional water supplies from these areas are depleted to the point of exhaustion or are poisoned (Różkowski, 1989, 1990, 1996; Różkowski *et al.*, 1985). All the karst areas of Poland are affected, without exception, though admittedly to different degrees. Many of the most important effects have been associated with the construction of large-scale industrial plants and mines; as these involve huge capital sums, there is always a tendency to try to cut environmental corners and the result is not always without severe consequence. Probably the worst changes have taken place in the Silesia-Częstochowa Upland, where deterioration of surface flows and springs, the product of artificial lowering of the water table by creating large cones of depression in the water table around Zn-Pb mines and wells for both industrial and domestic usage have occurred. (Fig. 20).There is also a considerable pollution of those supplies traditionally used for domestic outlets; this arises from the improper disposal of sewage, the untreated waste water being allowed to drain directly into the karst aquifers. Solid domestic wastes are freely disposed of in old limestone and dolomite quarries. Agricultural sewage and incomptent use of chemical fertilisers also poison the karst aquifers, thereby further degrading the karst environment.

Selected examples of the effects of human impact on the karst environment of Poland

Probably one of, if not the most extensive human impacts on the karst environment in Europe is that affecting the Silesia-Cracow Upland. Prolonged karstification of the local middle Triassic carbonates took place both in the Keuper (Wilk *et al.*, 1989) and the Tertiary (including the formation of poljes, large karst depressions and cave systems). In the latter, several phases of karstification are recognised, certainly in the Palaeocene and especially in the Neogene, the latter a consequence of the regeneration of karstification by the orogenesis in the Carpathian area to the south. The Neogene karst developed under a humid subtropical climate and much of it took the form of a littoral karst (Gilewska, 1964; Pulina & Tyc, 1987). The remnants of this relief are still to be discerned in the modern landscape, with domes and karst ridges very similar in aspect to those of modern littoral tropical karsts in such as the Caribbean Islands (Pulina & Fagundo, 1992) or China (Klimaszewski, 1958; Kozarski, 1964). In the Pleistocene, much of this area was covered by fluvioglacial and aeolian sediments which, in the large valleys, cut through the Triassic outcrop, attaining a thickness of as much as 90 m. Below these sheets, therefore, the karst has been fossilised (Głazek, 1989). In the eastern part of this Upland, the several large aquifers present in the Triassic carbonate formations are normally separated by aquicludes of Keuper clay, but, owing to the presence of several erosional "windows", they are locally in direct contact and, in such situations, the aquifers are in hydraulic continuity (Fig. 21). In both the eastern and northern parts of the Upland, the aquifers are separated by tectonic and hydrodynamic boundaries which are associated with the morphology of the Middle Triassic karst. Perched water tables also occur in these areas in the widespread fluvioglacial deposits. Extensive resources of zinc and lead ores are to be found in the Triassic aquifers (Dżułyński & Sas-Gustkiewicz, 1982).

The karst areas of the Silesia-Cracow Upland are not only heavily urbanised, they are also the site of large metallurgical processing plants and opencast mining (Upper Silesian Industrial Region - USIR). Zinc and lead ores are mined in the eastern part of the Upland, near Olkusz, whereas the Triassic aquifers are heavily exploited in the northern and eastern parts of the USIR. The Jurassic aquifer supplies many rivers in the region, including the left bank tributaries of the Vistula, the Przemsza, the Pilica and the Upper Warta. It is also exploited for domestic water supplies in the Częstochowa region.

Important changes have resulted from exploitation of the Zn-Pb ores in relatively recent times; these effects are superimposed on long-term wasting effects of Ag-Fe mining which dates back to Medieval times. Human activity from before the Industrial Age, such activities as charcoal-based metal refining, deforestation and agricultural improvements, have all played a part in the karst degradation, but the mining

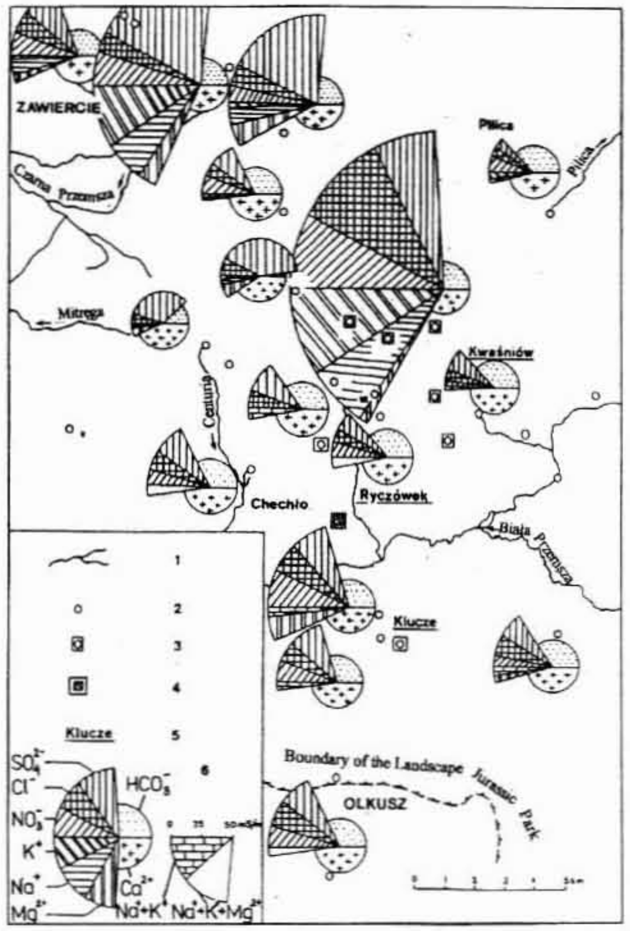


Fig. 22. Ionic composition of karst springs on the boundary of Triassic and Jurassic outcrops in the Silesia-Cracow Upland (after Krawczyk *et al.*, 1990).
1 - water flows, 2 - karst springs, 3 - investigated domestic wells, 4 - well in Chechło observed by Institute of Meteorology and Water Management, 5 - spring groups investigated in details in the period 1983-1989, 6 - circle diagrams of ionic composition of selected karst springs (the longer radius shows the value of water specific conductivity in μs/cm).

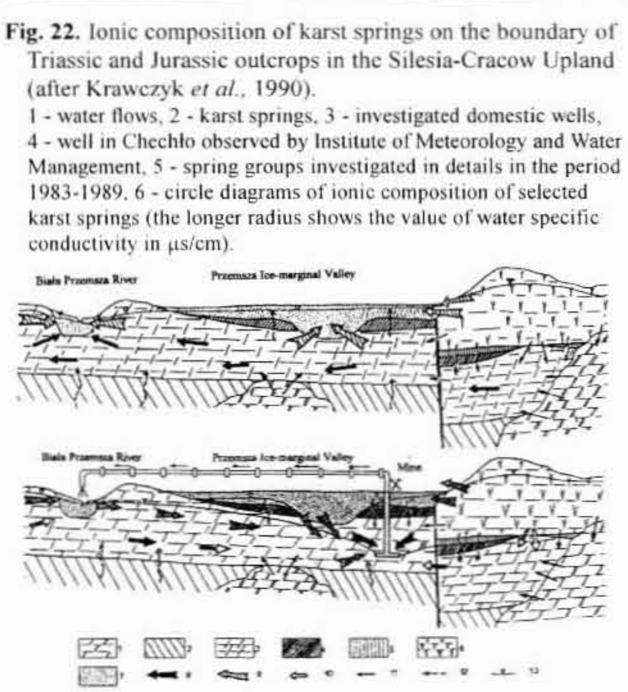


Fig. 21. Sketch of groundwater circulation in the Olkusz area according to Motyka and Wilk (after Różkowski & Wilk, 1980).
A - natural conditions, B - conditions influenced by mining and groundwater intakes.
1 - Devonian carbonate rocks, 2 - Permian and Triassic conglomerates, 3 - Roethian and Muschelkalk carbonate rocks, 4 - Keuper and Jurassic clays, 5 - marls, 6 - limestones, 7 - Quaternary sand and rubble, 8 - very easy and intensive water exchange, 9 - easy water exchange, 10 - moderate water exchange, 11 - difficult water exchange, 12 - very difficult water exchange, 13 - groundwater horizon.

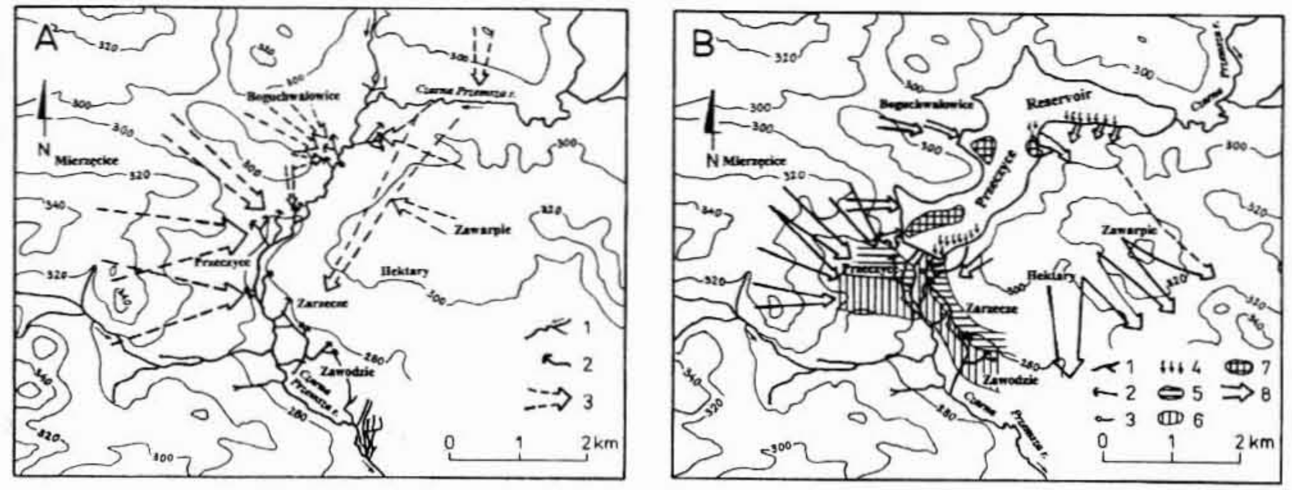


Fig. 23. Water relations in the dam section of Czarna Przemsza river in Przeczyce (after Jankowski, 1983).
A - before the dam was built: 1 - river, 2 - karst springs, 3 - direction of groundwater circulation, B - after the dam was built: river, 2 - new karst springs (called "vampires"), 3 - old karst springs, 4 - zones of water escape within the artificial aquifer, 5 - zone of new karst springs, 6 - zone of old karst springs, 7 - zone of underground water, direction of groundwater circulation, 8 - line of the direct drainage of groundwater.

in the Olkusz district has totally depleted the karst aquifer there; the phreatic zone now lies in the lowermost possible level, the Permian Sandstone, which lies not less than 150 m below ground level. As a result, the cone of depression, coupled with smaller cones associated with wells for domestic abstraction, covers an area of 350 km^2 (Motyka, 1989). If the mining development takes place in the Zawiercie area, as planned, this cone of depression will extend as far as the Częstochowa area and its area will then reach over 1000 km^2 (Pacholewski & Różkowski, 1989). Twenty large springs have disappeared from the Upland and several of the larger rivers (e.g. the Baba, Biała, Sztoła, Biała Przemsza) have either dried up completely or have changed in character from drainage to infiltration rivers (Adamczyk, 1990). In its eastern part, the cone of depression reaches under the Jurassic aquifer, drainage taking place here through the erosional windows in the Keuper clays. The local perched water tables in the fluvio-glacial sediments which overlie the Triassic aquifers have also drained away. The easy infiltration into the karst aquifers has allowed ready penetration by sewage, toxic wastes from settling ponds and industrial effluents. Possibly the most dangerous example is the penetration of toxic liquid wastes from a paper-making factory in Klucze, which seep through the sands of the Błędowska Desert directly into the galleries of the Pomorzany Mine (part of this goes directly to an abstraction well for domestic use). This causes not only a degradation of the karst environment, it actually threatens the principal conurbation.

A vast karst aquifer is present in Triassic rocks in the northern part of the Upland. In contrast to that in the eastern part, the damage is not so great. Only around Tarnowskie Góry, in the southern part, has there been much mining activity and, indeed, one of the local mines, where the water table is still quite high, has become a tourist attraction (the Tarnowskie Góry Mine with its historic Pstrąg Gallery) (Figs. 4 and 5). In this part of the aquifer, water is abstracted on a large scale for domestic supply. But the inflow of pollutants from the urbanised areas above and the industry of the Tarnogórski Ridge (the main recharge area for the northern aquifer) is readily observed. An excessive exploitation of water and pollutants have both caused severe damage, not only to this northern aquifer but also the Triassic aquifer of the Bytom Basin to the south. In contrast, the northern part of the aquifer contains water which has not been changed by human impact and which, in the phreatic zone, comes from 20 000-50 000 years ago, i.e. associated with the last glaciation (Różkowski, 1993).

The Jurassic karst aquifers, especially those in the western part of the Silesia-Krakow Monocline are much polluted. Most of this pollution comes from surface infiltration of chemical fertilisers used in agriculture and acid rain. As a result, much of the water shows a high level of NO_3^-, SO_4^{2-} and Cl^-.

The Przeczyce Dam is a good example of a construction scheme which did not adequately account for the local karst conditions. The dam is located in the gap where the Czarna Przemsza traverses the Triassic Tarnowskie Góry - Siewierz Ridge. (Fig. 23) Here, the river partly followed an underground course across the neck of a meander. When the reservoir behind the dam filled to a critical level, many more subsurface routes through the Triassic carbonates became utilised and the subsurface flow of the Czarna Przemsza increased enormously.

Downstream from the dam, building foundations in the village of Przeczyce became flooded and many new springs originated (local inhabitants termed these "vampires"). One of the larger "vampires" inundated the basement of the Dam Management building. The structural integrity of the dam became compromised by an obvious suffosion of its foundations and, on safety grounds, it has never been possible to allow the reservoir to become more than half full in terms of its design capacity (Jankowski, 1983; Pulina & Tyc, 1987)

Subsurface mineral exploitation frequently leads to the deformation of the surface of the karst areas. Dozens of subsidence depressions occur in the Olkusz Ore Region (Tyc, 1990, 1997). The largest of these is associated with cones of depression, which reach more than 100 m in diameter and are several decametres deep.

Their genesis is linked to large karstic palaeodolines, under which former mining levels have been left without support sufficient to prevent eventual roof subsidence (Fig. 20). There are also numerous instances connected with human impact where surface basins and craters have been formed simply by the loss of hydraulic support through overpumping of water supply wells. In many areas of the Upland, there has been much surface mineral exploitation, especially of limestones and dolomites, but also, locally, of the fills of fossil karst dolines (especially moulding sands and kaolinite).

This industry has developed on a large scale in the central and eastern parts of the Upland. The largest quarries occur in the area of Tarnowskie Gory and Bytom (e.g. Bytom Dolomite Works). Moulding sands are exploited in the Czestochowa area. Some quite large scale landscape changes are caused by the excavations of Middle Triassic limestone, especially in the Opole-Strerzelce Plain. Likewise, large scale changes have also taken place in the Sudety Mountains, the Holy Cross Mountains, in the Lublin Plain and in Kujawy and western Pomerania through the exploitation of limestones and marbles (Kozlowski, 1986).

Significant changes to the interiors of the limestone massifs are, perhaps surprisingly, caused by the opening of some large caves to the touring public. Fortunately in this respect, there are only a few which have been opened up to tourism. Research into the changes caused by tourism have been the subject of several reports (Rubinowski, 1974; Jahn *et al.*, 1989). These found that changes were due to several factors: mechanical damage, changes of microclimate in the inner part of the cave and changes in the chemical composition of the air and water in the cave systems. An increase in the content of CO_2 in condensation water, which comes mainly from tourist activity, leads to erosion of the cave sinters. An increase in the air temperature causes an increase of evaporation and drainage from the caves and also the growth of a flora in areas illuminated by artificial light (the so-called "lampenoflora").

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