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A STUDY OF SOLUTION PIPES PRESERVED IN THE MIOCENE LIMESTONES (STASZÓW, POLAND)

PREUČEVANJE ZAPOLNJENIH KOROZIJSKIH BREZEN (GEOLOŠKIH ORGEL) V MIOCENSKIH APNENCIH (STASZOW, POLJSKA)

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Izvleček UDK 551.4(438)

Iwona Morawiecka & Peter Walsh: Preučevanje zapolnjenih korozijskih brezen (geoloških orgel) v miocenskih apnencih (Staszów, Poljska)

V sarmatskih karbonatih Jarosławske formacije (miocen) pri Staszówu so stotine korozijskih brezen (geoloških orgel), zapolnjenih s sanskim morenskim gradivom. Volumen brezen je 1 - 15 m^3, povprečna globina 1,9 in premer 0,6 m. V kamnini so vodilne tenzijske razpoke, toda niso vplivale na nastanek in razporeditev brezen. To naj bi bilo odvisno od stika kamnina - pokrov, v kemizmu pokrova in v naravi hidrološkega ali kriološkega režima. Staszówski paleokras predstavlja pokriti kras, nastal zaradi deglaciacije in "depermafrostizacije" konec sanske mrzle dobe.
Ključne besede: speleogeneza, korozijsko brezno, kvartar, Staszow, Poljska.

Abstract UDC 551.4(438)

Iwona Morawiecka & Peter Walsh: A Study of solution pipes preserved in the Miocene limestones (Staszów, Poland)

Hundreds of solution pipes are in quarries near Staszów. The pipes are in Sarmatian carbonates of the Jarosław Formation and are filled with sediment from Sanian till cover. The pipes have the volume of 1 to 15 m^3, the average depth is 1.9 m, the diameter 0.6 m. In the host rock are tensional master joints but the structure of the host rock had no influence in determining pipe locus and form. These has to be in the nature of the interface host - cover, in the chemistry of the cover, and in the nature of the hydrologic or cryologic regime. Staszów piping palaeokarst represents a covered karst system, developed as the product of deglaciation and "depermafrostisation" at the end of the Sanian cold period.
Key words: speleogenesis, corrosion pipe, Quaternary, Staszów, Poland.

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INTRODUCTION

A solution pipe may be defined as a cylindrical, vertical, suberosional landform produced by the removal of a soluble host beneath an insoluble cover. Most often, pipes are exposed only in profile, such as in quarry walls (Harasimiuk *et al.* 1975) or in natural cliffs (Coetzee 1975; Morawiecka 1993), where they are often difficult to access. Occasionally, they are visible in plan on erosional features such as intertidal beach platforms (Kaye 1959; Baughen, Walsh 1980; Morawiecka *et al.* 1996). If they are developed at all, it is uncommon to find them as isolated forms and their occurrence in large pipe populations is very characteristic. At Staszów, in SE Poland, the large pipe population contained in a Miocene limestone host is well exposed in low quarry walls and also on near-horizontal quarry floors. In these respects, the Staszów area must represent one of the most favourable situations in the world in which to study this little-understood karstic phenomenon.

FIELD SETTING AND GEOLOGY

The pipes of the Staszów system are exposed in about 15 small limestone quarries situated N and NE of the town (Fig. 1) near Podmaleniec, Kopanina, Dobra, Sztombergi, Karolinów and Smerdyna. Only some of the quarries are currently worked; about half are disused. The quarries are situated within the outcrop of Sarmatian limestones known as the Jarosław Formation (Jurkiewicz, Woliński 1981) which outcrop in an E-W band along the southern borders of the Holy Cross Moun-

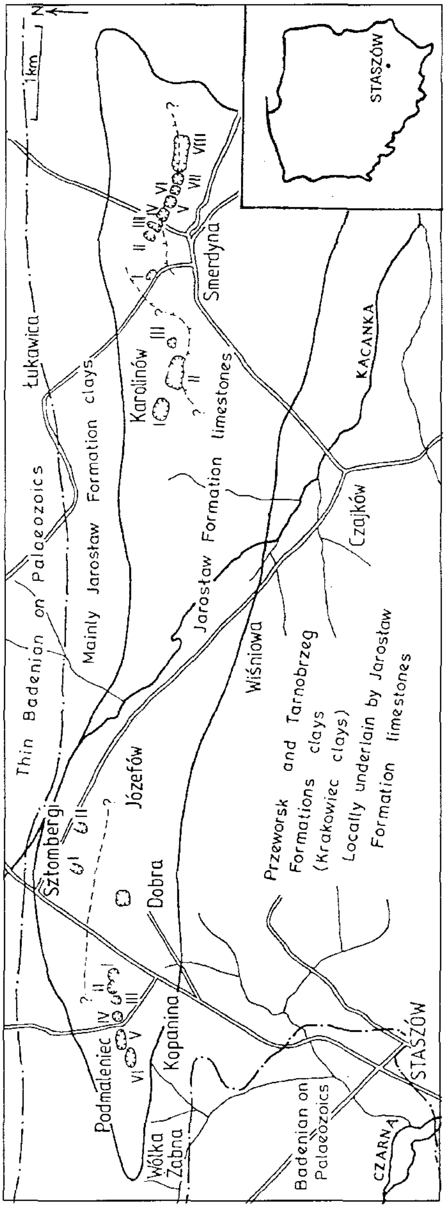

Fig. 1: Map of the study area to show the outcrop of the Jarosław Formation reef limestones (after Jurkiewicz and Woliński 1981) and the location of the quarries which display pipes.

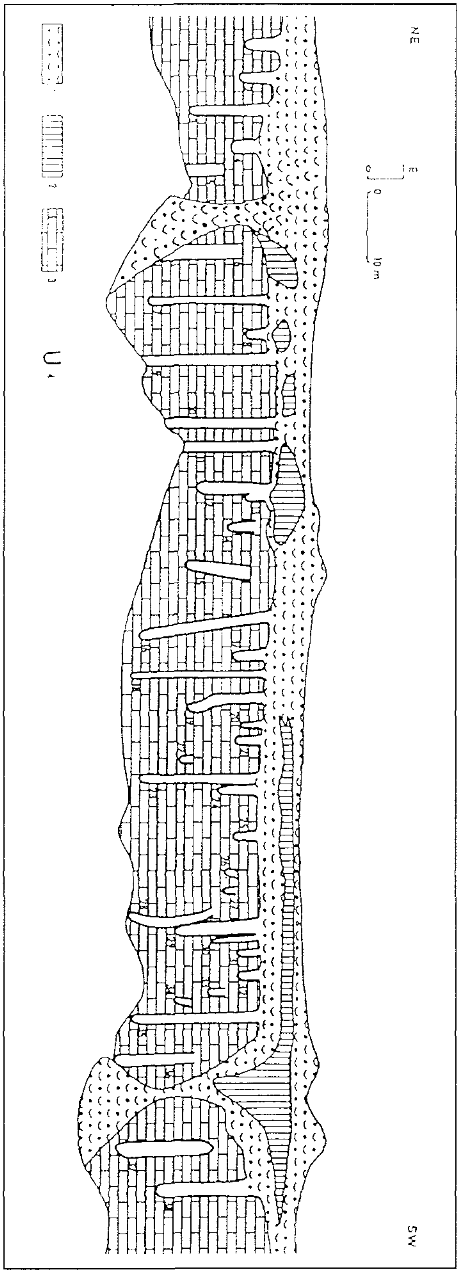

Fig. 2: Geomorphological sketch of the north-western wall of the Podmaleniec II Quarry.

tains of SE Poland. The general elevation of this piped, plateau-like area is c. 230-240 m a.s.l.

The thickness of the host limestone is up to 40 m. It is a cross-bedded, bioclastic forereef limestone, constructed mostly from *Lithothamnium* (Rutkowski 1969). The $CaCO_3$ content of the hostrock is 93% and the porosity is about 35% (Bugajska-Pajak 1974).

The Sarmatian limestone is riven by numerous sets of tensional master joints. Two sets are usually dominant, the one close to regional strike and the other, the dip. The open master joints are seldom wider than 2 cm or so. Many are iron-stained; however, very few of them show any evidence of solution widening by karstic fluids or infilling with insoluble residue from above.

The limestone is overlain by a till of the Sanian (Mindel) glaciation (Różycki 1980). The till is up to 4 m thick locally and is formed by a sandy-clay diamict containing a suit of far-travelled erratics. No pipe so far surveyed was observed to have any surface expression, whether topographical, pedological or vegetational. In this respect, we presume that piping was an event which took place before the Holocene erosion cycle was instituted; the Staszów piping karst may thus reasonably be regarded as a covered (or subjacent) palaeokarst system.

THE NATURE OF THE PIPES

About 300 pipes have been mapped so far in the quarries studied. Most are exposed only in the quarry walls, where they occur as vertical or near-vertical funnel-shaped hollows (Fig. 2).

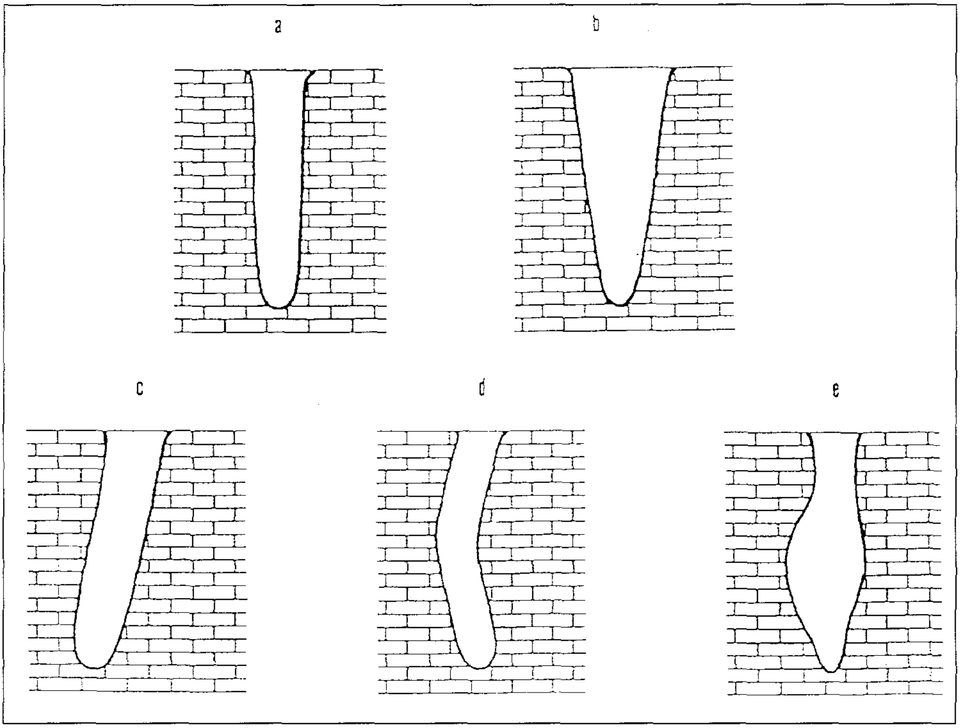

Fig. 3: Types of the Staszów pipes according to their shape. 1 - vertical-cylindrical, 2 - inverted conical, 3 - inclined, 4 - doubly inclined, 5 - bulbous.

The largest pipe so far observed is about 8.2 m deep and has a diameter of about 1.5 m (Photo 1). On average, however, pipes are about 1.5 m deep and 0.5 m in diameter.

The walls of the pipes are generally smooth and laminations of the hostrock are not usually visible. Sometimes, a well-developed crust about 2 cm thick is present on the pipe walls.

In terms of their shape, 5 types of pipe have been distinguished: vertical-cylindrical, inclined, doubly inclined, inverted conical and bulbous (Fig 3); however, the three first predominate.

Additionally, about 170 pipes have been mapped in cross-section. These were exposed in a scraped surface of about 700 m^2 in one of the quarries studied, Smerdyna I (Fig. 4). The pipes here were revealed to be both circular and ovate in plan and appeared to be quite randomly distributed. Preliminary analysis to try to determine whether there is any positive relationship between the alignments of nearby vertical joints and the long-axes of ovate pipes (Fig. 4) indicated that this is not possible, because the master joint systems

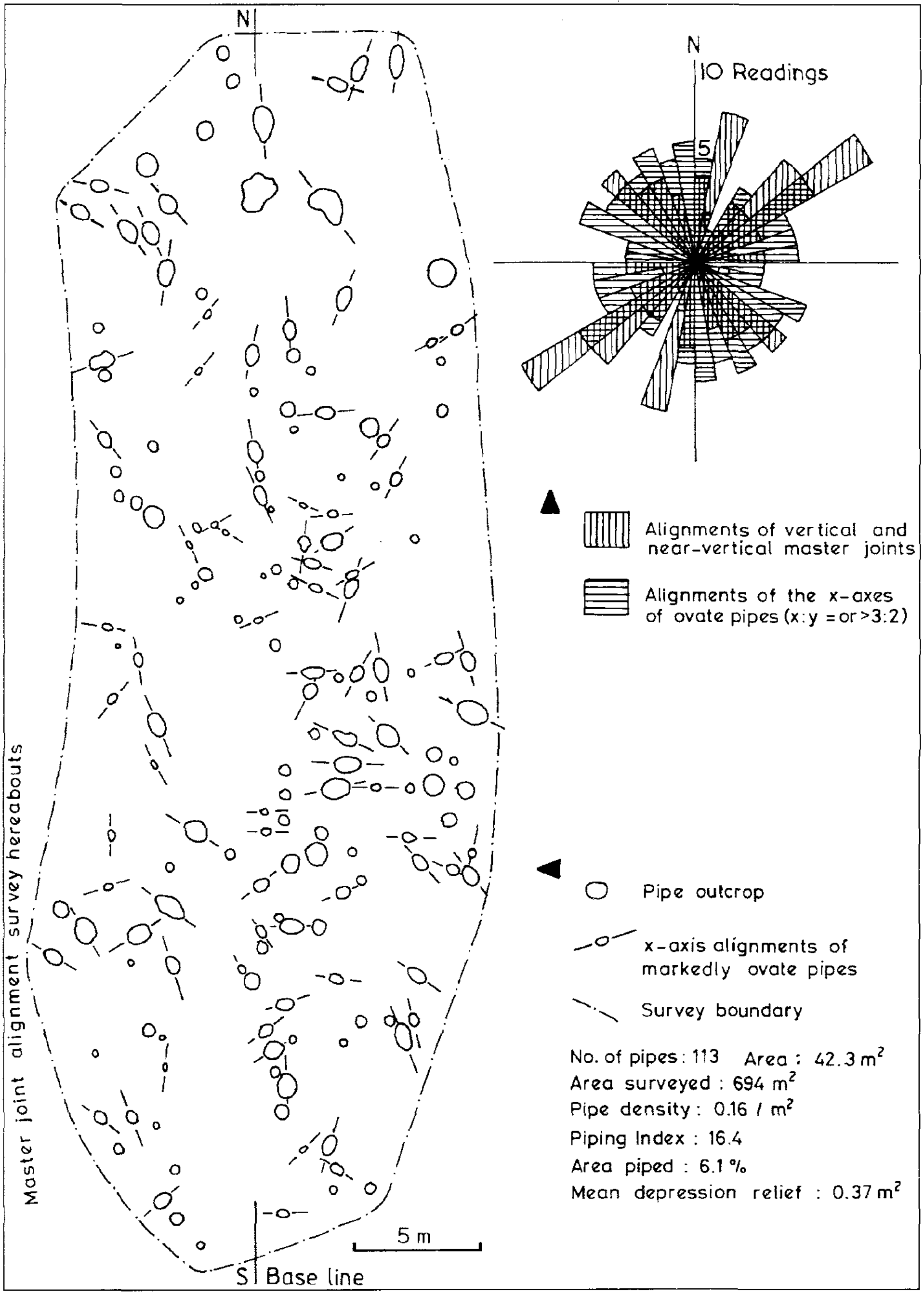

Fig. 4: Survey of a selected area of Smerdyna I Quarry.

(as revealed on Fig. 4) are themselves fairly evenly distributed at this particular locality.

The field evidence is unequivocal that pipes are not usually associated with master joints. Certainly, less than 10% of the pipe population showed any coincidence with joints, when seen in profile. In many instances, it was noted that a pipe had developed in "solid" limestone only a few centimetres away from an open master joint (Photo 2). It is, therefore, very difficult to avoid the conclusion that the locus of master joints at the interface with the till cover was not one of the major controls which determined the locus of pipe development.

Only some of the pipes at Staszów now contain fills. It is presumed, however, that all the pipes once contained a fill, and, in most cases, the fill has been removed as a result of quarrying. In all pipes where the fill has been preserved, two components are easily recognized (Photo 3): a cortex, forming the lining, which consists of brown silty clay, and a central core which consists of sandy-clayey-stony material, megascopically identical to the till overlying the limestone. In case of the larger pipes, the brown clay is up to 30 cm thick and it is presumed to be a mixture of both a solutional residue and illuviated fine-grained till sediment. Diffractometric analysis showed that it comprises 87% quartz, 9.5% illite and 3.5% montmorillonite. The core matrix comprises 90% quartz, 7% illite and 3% montmorillonite (Morawiecka 1994).

Piping is certainly not evenly developed across the outcrop of the limestone hostrock. In the study area, some of the quarries display hundreds of pipes; in others there is no trace of piping whatever. Where piping is present, it seems to be fairly evenly developed. Morawiecka (1994) demonstrated that, in one section, Podmaleniec II, which exposes 37 pipes (Fig. 2), the linear density of piping is about 1 pipe/2.5m.

Field mapping reveals a marked relationship between the piping and the cover sediment: (1) piping is very closely coterminous with the existing till cover; (2) piping is only very rarely found without a cover of till being present; (3) whenever a till cover is present, some degree of piping is usually evident.

THE ORIGIN OF THE STASZÓW PIPES

There is no evidence that piping ever took place in the Staszów area more than once, i.e. during or after the Sanian tills were deposited. There is no trace whatever of pre-Sanian solution subsidence (though, of course, it is possible that this was once present and evidence for it has been entirely removed by the Sanian ice); nor is there any evidence to hand to indicate that the same source sediment (the Sanian till) was involved in two or more phases of piping (it is acknowledged that it might be difficult to establish criteria on which to recognize separate phases of piping). But the exact relationship between piping and the Sanian till is by no means obvious; in our present state of knowledge, two hypotheses must be considered: firstly, that the piping was a Neopleistocene event and developed only at a time when the Sanian till cover was worn back more or less to its present limits. Alternatively, the piping is a process contemporaneous or penecontemporaneous with deglaciation and that the present-day limits of the Sanian till sheets are, therefore, little different from those resulting from deglaciation of the area.

With respect to the first alternative, there is no positive evidence to support this view, which is based solely on an intuition that, after 500 ka, it would be extremely unlikely for the Sanian tills to have exactly the same distribution as that in which they were originally formed. Certainly, if the piping at Staszów was exclusively a Neopleistocene event, this then begs the question why hundreds of cubic meters of rather cold meltwater per square metre of host limestone surface failed to produce some piping effect here at the end of the Sanian cold period. For the present, we have not rejected either of these working hypotheses.

That the pipe-forming fluids have "ignored" the multiplicity of open master joints during pipe formation is a feature of the Staszów palaeokarst which, at present, is not easy to explain. The most obvious explanation for this is that the master joints (or at least their openness) were formed after the pipe-forming processes had ended. However, given the antiquity of the host and the youthfulness of the till cover, such a notion seems very unlikely.

Another explanation we are at present considering is that, at the time when the piping was initiated, the joints existed in much their present form, but were then filled with something which precluded their utilisation by groundwater fluids; in which respect, sealing of the joints by ground ice seems to be the only realistic possibility. Because the rock cover in this karst system is clearly a cold-climate sediment, this notion seems to be quite reasonable. Moreover, it is well known that water which has a temperature only a little above freezing point is a much more effective solvent of carbonates than one of temperate nature (Pulina 1974). Indeed, it is hard to see how any attempt to explain the development of the Staszów piping karst can avoid considering the possible effects of climatic amelioration at the end of Sanian period, which certainly produced a deglaciation, and, probably, a concomitant "depermafrostisation", as a likely major influence.

Therefore the following working hypothesis concerning the origin of the Staszów piping system and the sequence of subsequent events in this area has been formulated:

During the Pliocene, the area of Staszów was uplifted above sea level. Denudational processes of various kinds affected the area but no pipes developed in the Sarmatian limestones for no insoluble cover was yet present (Fig. 5A). Towards the end of the Sanian cold period, the area studied was overwhelmed by a continental glacier. It is envisaged that, at the time it was overridden by the ice, the permafrost zone extended down to below the

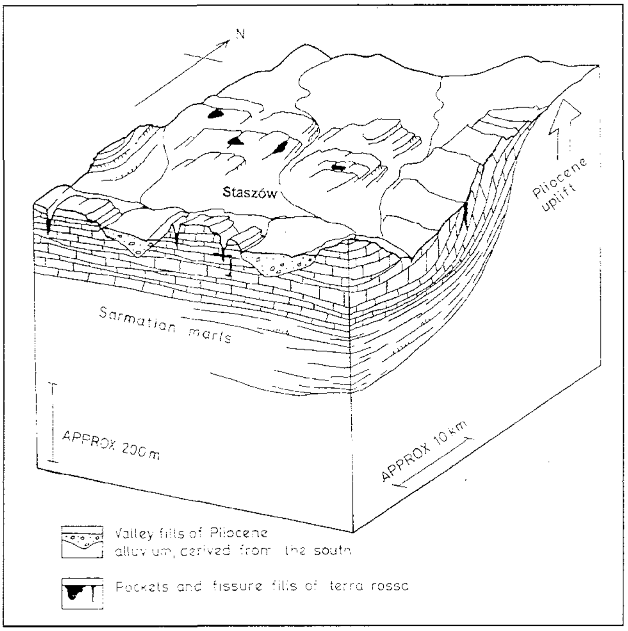

Fig. 5A: The Staszów area in the Pliocene.

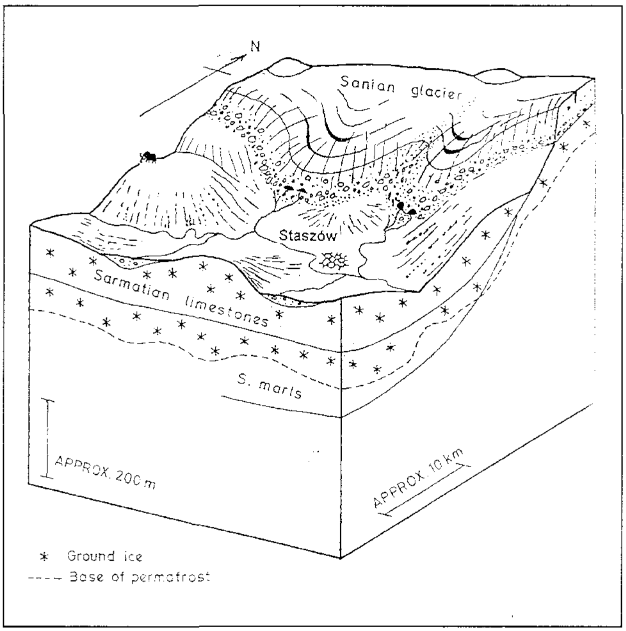

Fig. 5B: The Staszów area near the end of the Sanian cold period.

Sarmatian limestone (Fig. 5B). As a consequence, any open joints present in the host limestone were sealed up by ground ice, both before and during the glaciation. At the end of the Sanian cold period, possibly about 5 ka later, the decay of the ice sheet began, consequent upon the climatic amelioration. Within the decaying glacier body and associated tills, zones of local vertical percolation developed, possibly associated with zones of relatively coarse and relatively permeable moraine material (Fig. 5C). In our provisional model, at the beginning of the post-Sanian warm period the glacier decay left behind rafts of dead ice, themselves underlain by local blocks of discontinuous permafrost. We envisage that piping was controlled initially by combinations of relatively permeable till above, with avenues of first-to-decay permafrost below, and that, once started, the piping process was extremely rapid, piping outlets in the subglacial drainage system capturing the percolation selectively (Fig. 5D). We speculate that piping may have been enhanced by the presence of any depressions in the limestone surface, such as kamenitzas, which may have survived the initial glacial advance over the area (these would presumably have been destroyed by the piping process); we also speculate that piping may have been enhanced by the former presence in the local moraines of organic material such as frozen peat, which, during deglaciation, for a time released aggressive acid radicals into descending meltwater. In our provisional model of pipe development, piping would have ceased (or at least very much diminished) when either the flush of meltwater had ceased or when the acid radicals in the till had all been leached out. It must be stressed, however, that there is not, so far, any positive evidence for the former existence of either organic material in the till cover, significant depressions in the surface of the limesone host, or selectively permeable zones in the till sediment. On the other hand, our

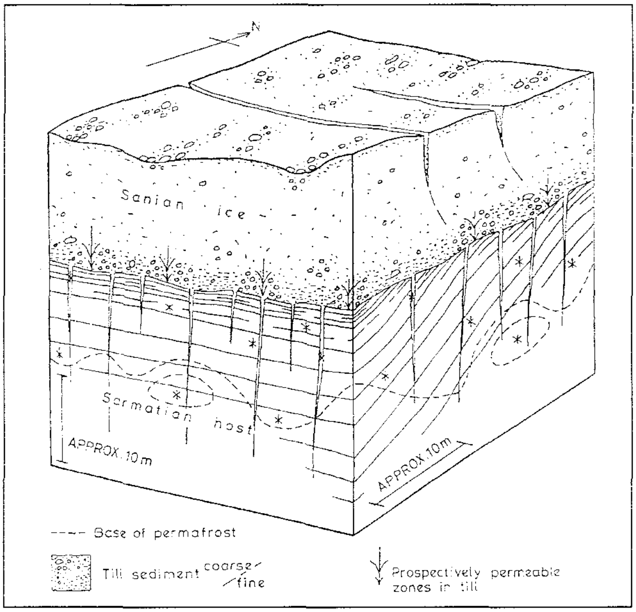

Fig. 5C: The Staszów area when covered by the Sanian ice sheet.

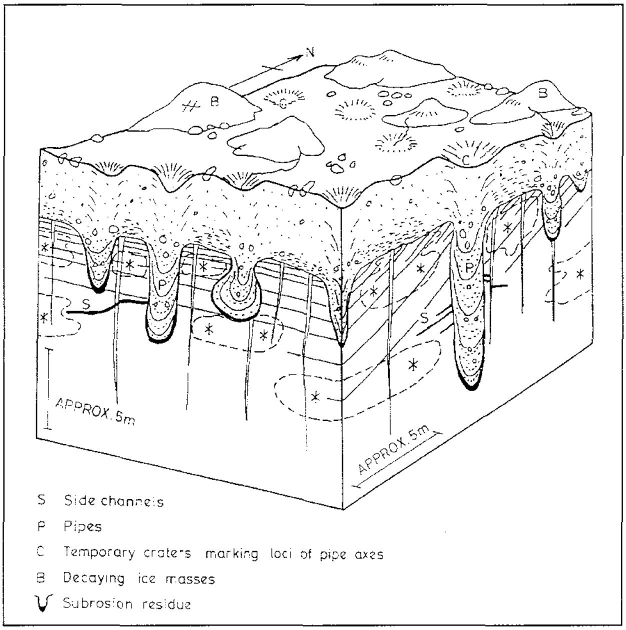

Fig. 5D: The Staszów area at the beginning of the post-Sanian warm period.

"depermafrostisation" model does, at least, have the advantage of explaining why some pipes are non-vertical or doubly-inclined - these features are neatly explained by the presence of permafrost blockages to vertical percolation, any development out of the vertical denoting the former presence of a lens of ground ice which acted as an umbrella to the percolation which created the pipes (Fig. 5D).

PROVISIONAL CONCLUSIONS

At present, we consider that the piping karst at Staszów has been produced by quasi-catastrophic geomorphic agencies, clearly related to deglaciation and probably also to "depermafrostisation" at the end of the Sanian cold period. In our view, the whole of the piping karst development probably took place in not more than a few hundred, and certainly not more than a thousand years. The field and laboratory programmes in this study are to continue. Work in the immediate future will concentrate on gathering data about the nature of the interface between the till cover and limestone host, the brown clay lining of the pipes and about pebble fabrics in the till cover and pipe cores.

ACKNOWLEDGEMENTS

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PREUČEVANJE ZAPOLNJENIH KOROZIJSKIH BREZEN (GEOLOŠKIH ORGEL) V MIOCENSKIH APNENCIH PRI STASZÓWU NA POLJSKEM: PREDHODNI IZSLEDKI

Povzetek

V sarmatskih karbonatnih kamninah Jarosławske formacije (zgornji miocen) pri Staszowu na osrednjem Poljskem so v kamnolomu prerezane stotine korozijskih brezen (geoloških orgel), zapolnjenih s sanskim (srednjepleistocenskim) morenskim gradivom. Volumen brezen znaša povprečno 1 m^3, vendar dosežejo največja 15 m^3. Povprečno globino teh brezen je 1,9 m, povprečni premer pa 0,6 m. V matični kamnini so gosto razporejene vodilne tenzijske razpoke, toda terenske raziskave jasno kažejo, da je igrala struktura matične kamnine zelo majhno ali sploh nobene vloge pri nastanku in razporeditev teh brezen. To naj bi bilo odvisno od stika matične kamnine in morenskega pokrova, v kemizmu pokrova in oziroma ali v naravi hidrološkega ali kriološkega režima, ki je vladal takrat, ko so ta brezna nastajala. Staszówska paleokraška brezna predstavljajo pokriti kras. Ta naj bi predvidoma nastal "nenadoma" zaradi taljenja ledu oziroma izginotja permafrosta konec sanske mrzle dobe.

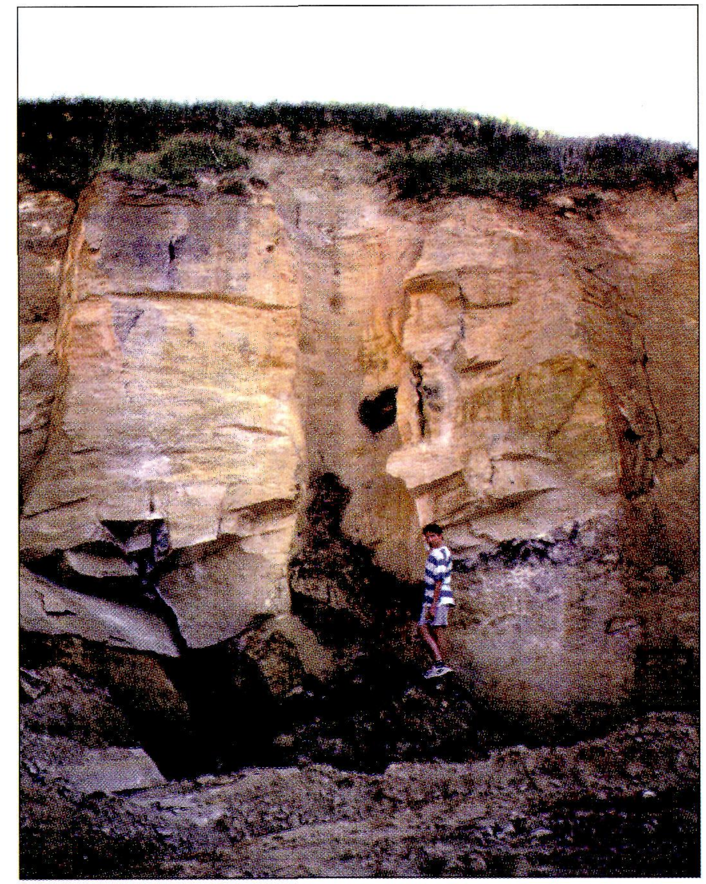
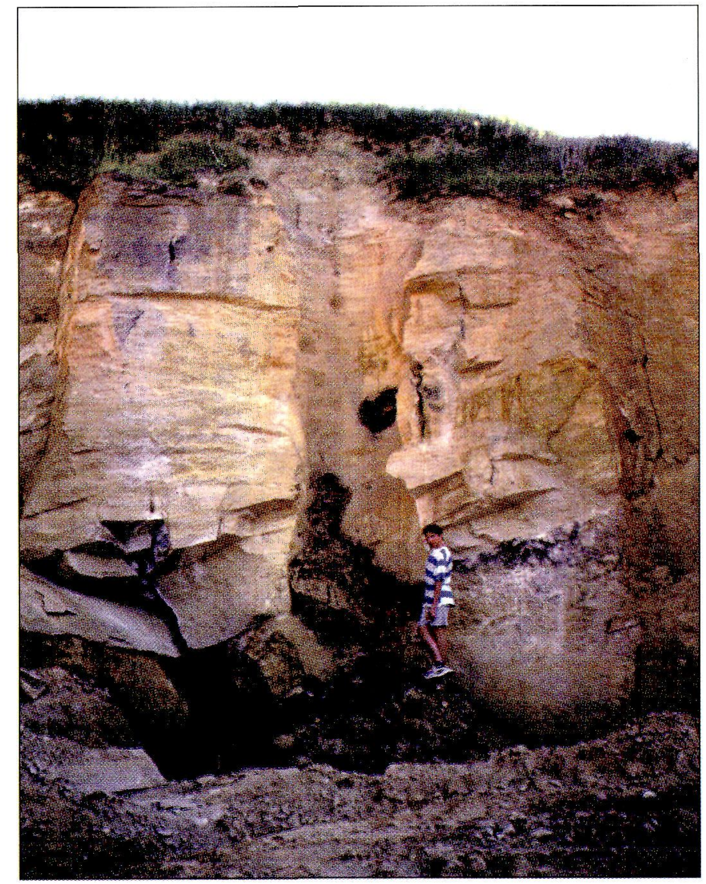


Photo 1: One of the largest pipes recorded in the quarries studied. Podmaleniec V Quarry.



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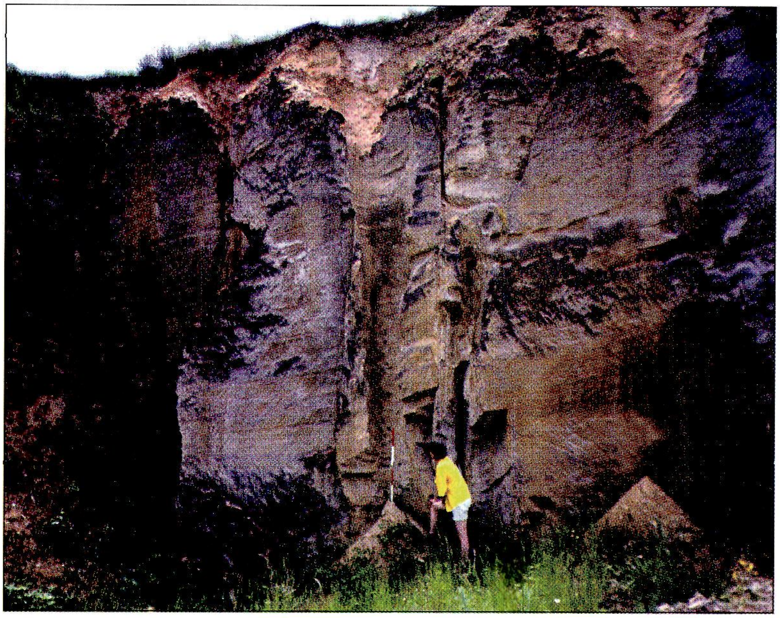

Photo 2: An example of a pipe developed about 0.5 m to the left of a master joint. Podmaleniec IV Quarry.

Photo 3: An example of a pipe with the fill still preserved. Smerdyna I Quarry.