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Origin and age of the Cracow Canyon, Western Tatra Mts

ABSTRACT: The Cracow Canyon, one of the largest and most picturesque morphological forms in the Tatra Mountains owes its origin to karst phenomena. Observations on the development of similar forms under polar climatic conditions in Spitsbergen suggest that they originated mainly due to activity of meltwaters derived from perennial snows. The origin of the Cracow Canyon has been initiated at the Tertiary decline, and during the Quaternary the Canyon has been deepened due to the activity of meltwaters coming from the snow deposited on the flat surfaces around its upper part. Numerous caves preserved in the cliffs of the Canyon are remnants of underground tributary flows. The deepest, lower part of the Canyon originated in result of a collapse of a cave collecting the meltwaters.

INTRODUCTION

Field observations of recent karst landforms in Southern Spitsbergen (LINDNER & KŁYSZ 1984) allow to make some comparisons with the Pleistocene forms occurring in the Tatra Mountains which are commonly known from numerous reports (PASSENDORFER 1952, WÓJCIK 1968, KOTARBA 1972, KLIMASZEWSKI 1978). The most striking are similarities of the karst valley developed along the slopes of the Stupryggen massif (Sörkapp Land) in Spitsbergen to those ones exposed along the slopes of the Kościeliska Valley in the Western Tatra Mts.

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SETTING OF THE CRACOW CANYON

The Cracow Canyon, situated in the eastern part of the Kościeliska Valley in the Western Tatra Mts (Text-fig. 1), has developed mainly within the Triassic and Upper Jurassic — Lower Cretaceous limestones and in the Lower Jurassic limestones and calcareous sandstones (Text-fig. 2). The Canyon is about 3.5 km long, 5—30 m wide and ca. 100 m deep in its lower, and about 100 m wide and 20—40 m deep in its upper part.

The caves in the Cracow Canyon were investigated by many authors (ZWOLIŃSKI 1955; WÓJCIK 1960, 1966, 1968; RUDNICKI 1961, 1967), and already ZWOLIŃSKI (1955) concluded that the deepest, lower part of the Canyon (1050—1200 m a.s.l.) has resulted from a collapse of the underground passages. The middle (1200—1500 m a.s.l.) and upper parts (1500—1700 m a.s.l.) of the Cracow Canyon

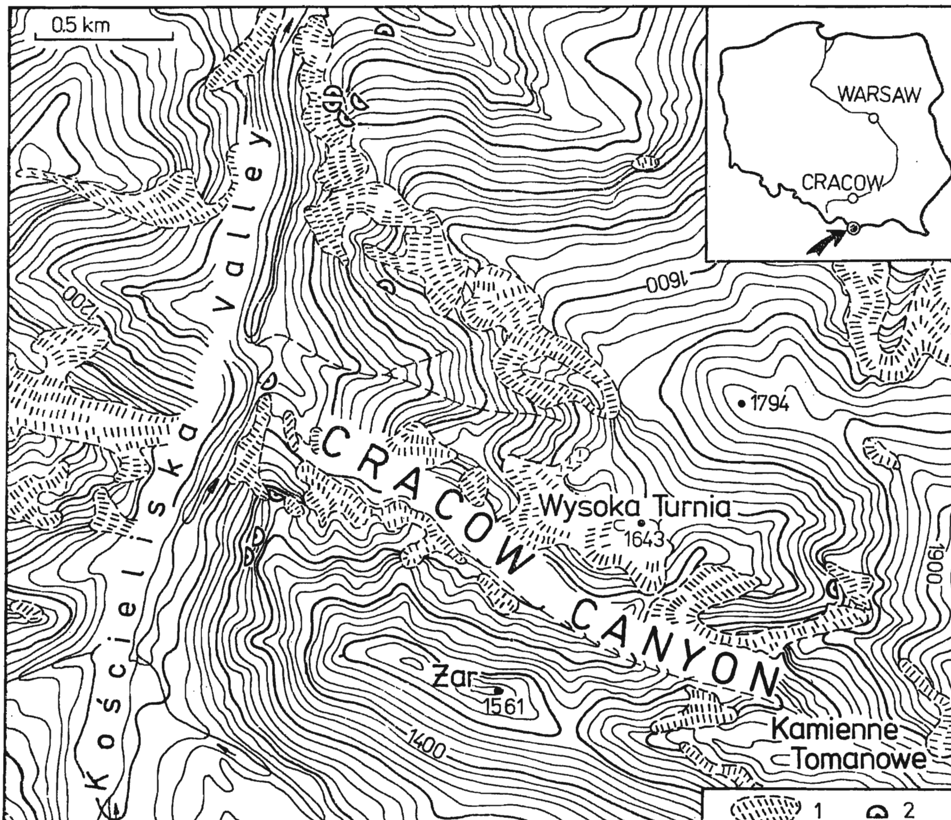

Fig. 1. Morphologic sketch-map of the Cracow Canyon, Western Tatra Mts
1 — crags and cliffs. *2* — larger caves

consist a valley broadening (Pl. 1, Figs 1—3) which in its highest (eastern) sector has originated due to a fusion of several sinkholes (Pl. 2, Figs 1—2). WÓJCIK (1968) regarded the upper part of the Canyon to be the primary form of a marginal polje. At present time the bottom of the Cracow Canyon is dry, and only heavy rains and spring snow melting produce enough water to a temporary flow that disappears in many sinkpoints. Corridors of numerous caves preserved at various heights along the Canyon slopes, mainly in its lower and middle parts, are the traces of ancient flows. In the opinion of WÓJCIK (1968), they make six distinct levels

(Text-fig. 3). The lowest caves (5—9 m over the Canyon bed) are developed as rock niches partly filled with gravel carried from the highest parts of the Canyon. The second level of caves (15—17 m) is relatively weakly developed, whereas the third (38—40 m) and the fourth (57—86 m) ones contain large quantities of allochthonous gravel. The caves of the fifth (96—137 m) and of the sixth levels (155—160 m over the Canyon bed) contain allochthonous material deposited in two sedimentary cycles. Following the accumulation of the first cycle, the gravel has been cemented and then eroded to supply the material to the second cycle.

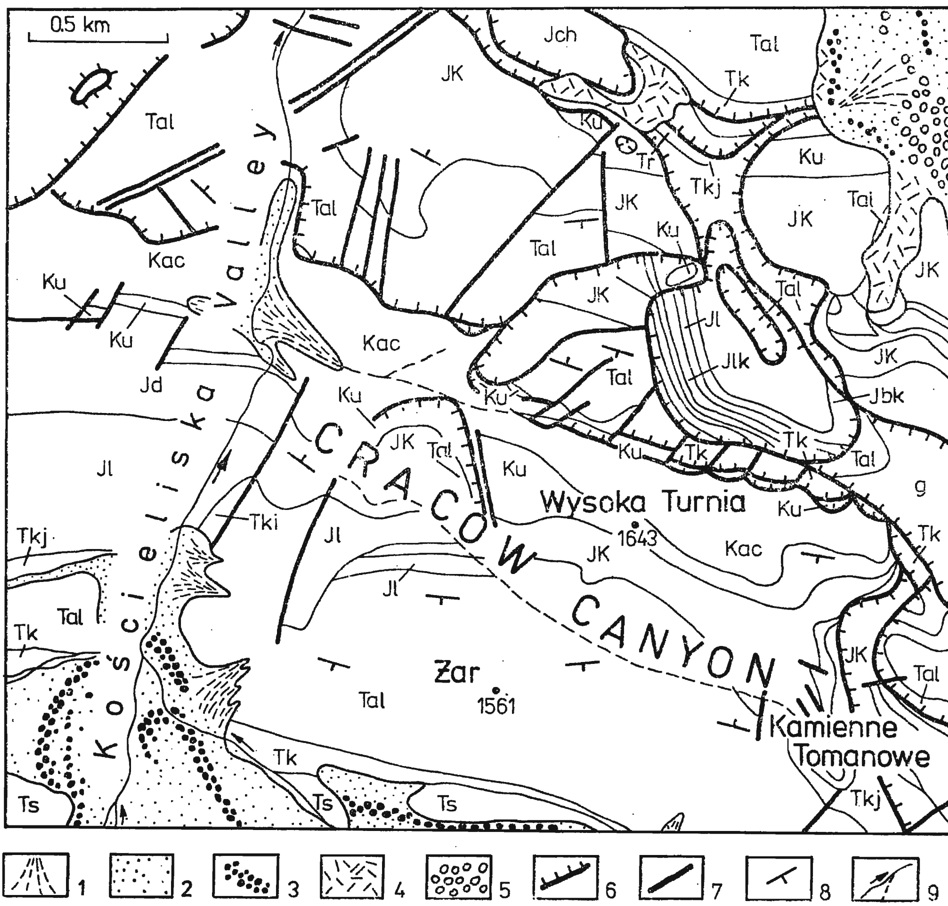

Fig. 2. Geologic sketch-map of the Cracow Canyon (*after* M. BAC-MOSZASZWILI & *al.* 1979; *simplified*)

1 alluvial fans, *2* gravel and glacifluvial sands, *3* boulders, gravel and clays of the front moraines, *4* moraine debris, *5* moraine boulder lags, *6* main overthrusts, *7* main faults, *8* strike and dip of strata, *9* permanent and temporary streams

g Variscan granitoids; TRIASSIC: *Ts* quartzitic sandstones and shales (Seis), *Tk* dolomites, limestones, shales and breccias (Campilian), *Tal* limestones and dolomites (Anisian-Ladinian), *Tkj* shales, conglomerates and dolomites (Keuper), *Tr* shales, sandstones and limestones (Rhaetian), JURASSIC: *Jl* sandstones, limy conglomerates and limestones (Liassic), *Jch* limestones and sandstones (Liassic), *Jd* encrinites (Bajocian, Bathonian), *Kj* limestones (Callovian till Hauterivian), *Jlk* limestones and spongiolites (Liassic), *Jbk* limestones and radiolarites (Bajocian till Lower Tithonian), CRETACEOUS: *Ku* limestones and reef breccias (Urgonian), *Kac* limestones and marls with sandstone interbeds (Albian — Lower Turonian)

WÓJCIK (1968) was of opinion that this deposition has been associated with penetration of the caves by streams at the final stages of the Pleistocene glaciation and the cementation took place under interglacial climatic conditions. Numerous karst clints observable in the higher parts of slopes in the Cracow Canyon prove the existence of intensive processes of superficial denudation in the area. Those are the

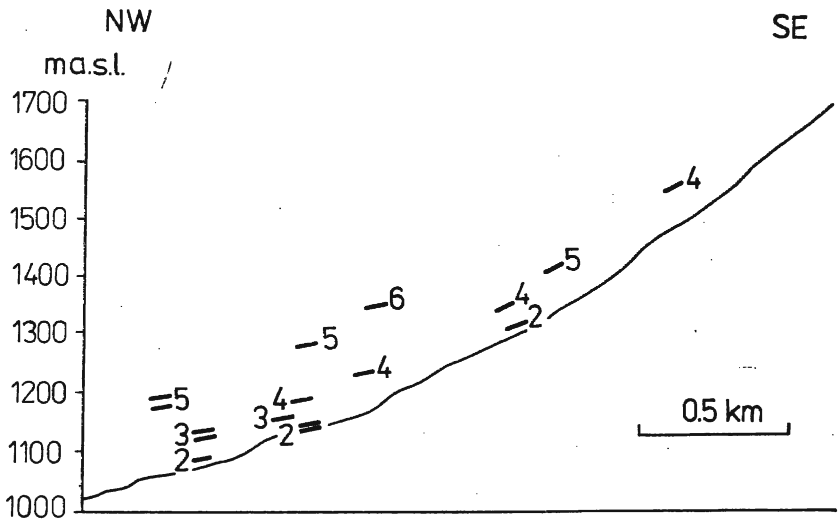

Fig. 3. Cave horizons in the Cracow Canyon (*after* WÓJCIK 1968)

youngest elements of karst morphology in the Canyon. Relatively young are also the speleothems present in the cave, and their age is attributed to the Young Holocene as they cover the remnants of subfossil bats *Myotis mystacinus* (KUHL) representing the fauna of mild climate (*cf.* WOŁOSZYN 1970), presumably of the Holocene climatic optimum (WÓJCIK 1968).

SETTING OF THE JEWTUCHOWICZ CANYON

The Jewtuchowicz Canyon in Southern Spitsbergen is located in the lower part of a vast concave slope of the Stupryggen massif built of the Lower Paleozoic limestones of the Hecla Hoek Formation (Text-fig. 4). It is the most typical karst form in the Sörkapp Land (LINDNER & KŁYSZ 1984). The Canyon, almost 100 m long, 30 m wide and about 20—30 m deep, runs in SE-NW direction along the limestone bedding well discernible on aerial photos (Pl. 3, Figs. 1—2). The mouth of the Canyon is dammed by the Bunge Glacier (Pl. 3, Fig. 1), and its bottom forms an almost flat surface consisting of gravel and sand overlaid by debris at the foot of walls (Pl. 3, Fig. 2).

In the upper part of the Canyon there develops a large waterfall (Pl. 3, Fig. 2), the waters of which are responsible for the leaching of limestones of the Hecla Hoek Formation. These waters are fed by patches of permanent snows that cover the higher slopes of Stupryggen (Text-fig. 4). These patches infill all larger ledges and steps in the slope. The meltwater is very agressive, as it is expressed not only by carving new gullies (in the area north and west from that described by LINDNER & KŁYSZ 1984), but also by an intensive corrosion of limestone blocks and smaller particles along the flow. Erosional furrow located southwest of the Jewtuchowicz Canyon (Text-fig. 4) makes a fragment of a newly formed karst gully with active

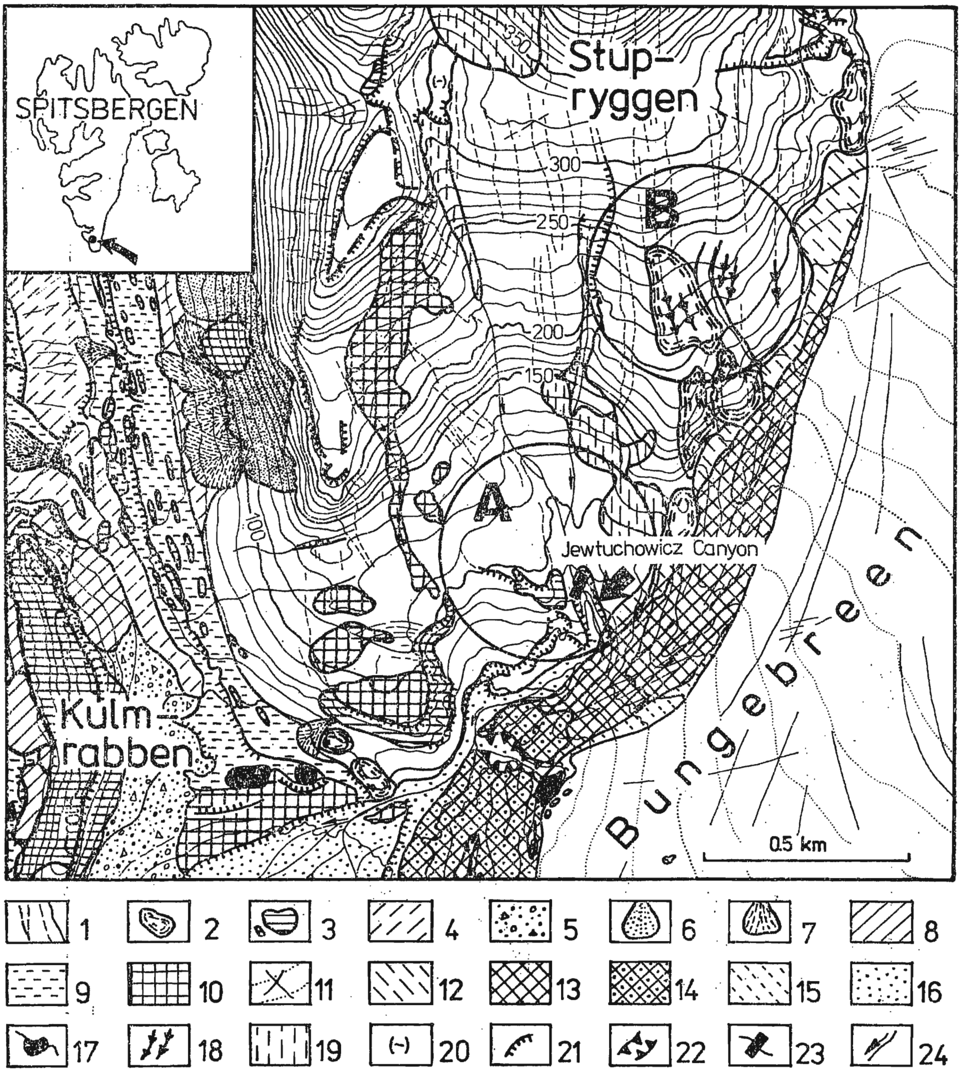

Fig. 4. Photogeologic map of the southern slope of Stupryggen; Sörkapp Land, Southern Spitsbergen (*after* LINDNER & KŁYSZ 1984)
A — area of the Jewtuchowicz Canyon, B — area of karst furrows
1 rock outcrops with structural elements, *2* roches moutonnées, *3* cliffs, *4* deluvial covers, *5* debris covers, *6* debris fans, *7* alluvial fans, *8* nival moraines, *9* marine terraces, *10* old moraine sediments, *11* glacier ice, *12* dead ice, *13* ice-cored moraine, *14* mud covers on ice-cored moraine, *15* ablation moraine, *16* outwash surfaces, *17* lakes, *18* karst furrows, *19* lobes of old snow, *20* undrained depressions, *21* erosional rims, *22* gaps, *23* waterfall, *24* streams

flow in early summer when the meltwater overfills the Canyon. Near the Canyon there appear systems of karren which occur both on the limestone *roches moutonnées* and within their vicinity. The karren have developed along the bedding planes and, regardless of them, on all the surfaces sloping down. These forms should be regarded as a combination of meandering solution runnels (German: *Meanderkarren*) and grikes (German: *Kluftkarren*) on flat, glacially smoothed surfaces developing due to considerable linear corrosion (LINDNER & KŁYSZ 1984).

ORIGIN AND AGE OF THE KARST CANYONS

All the data on the karst phenomena developed under polar climatic conditions (CORBEL 1957; HELLDÉN 1973; PULINA 1974, 1977; SALVIGSEN & *al.* 1983) and in mountainous areas of lower latitudes (BÖGLI 1960; CORBEL 1959,

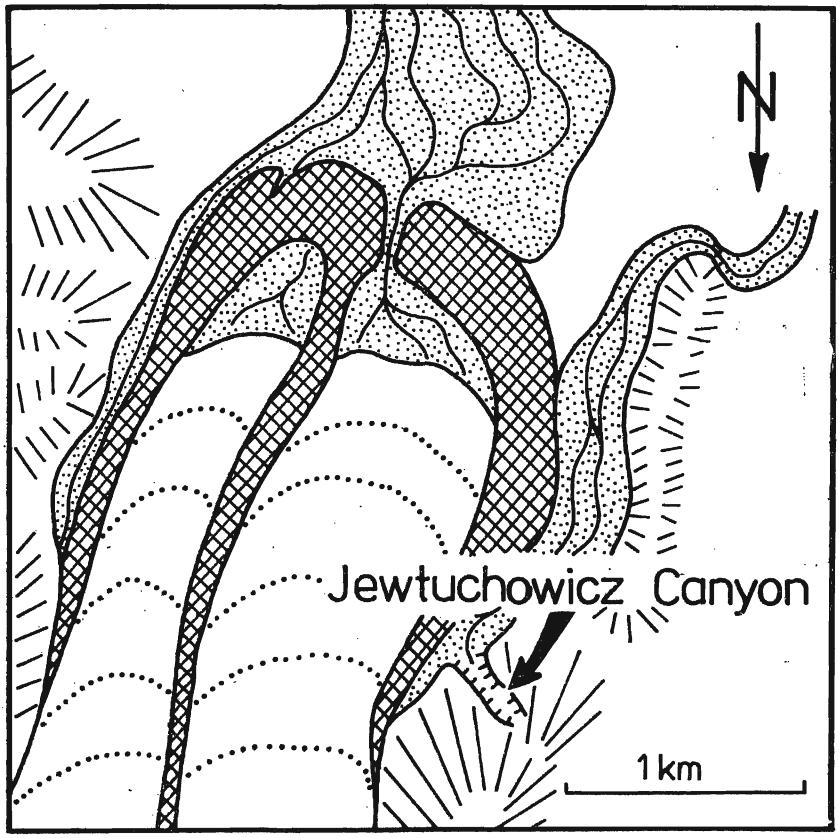

Fig. 5. Location of the Jewtuchowicz Canyon against the present-day range of the Bunge Glacier; Sörkapp Land, Southern Spitsbergen
1 main elevations and their slopes, *2* glacier, *3* ice-cored moraines, *4* surfaces of glacifluvial outflow

1964; EK 1966; EK & PISSART 1965) allow to discuss the problem of the acceleration of karst processes under severe climatic conditions (particularly the superficial phenomena). The problem is apparent when we realize that under cold climatic conditions (polar and mountainous) the dissolving activity of meltwaters is meaningly intensive due to their saturation with great quantities of carbon dioxide (KLIMASZEWSKI 1978). Beside that, one must take into account that under such conditions the crushing of limestone is favored by great thermal contrasts between the rocks relatively quickly warmed by insolation, and the overflowing cold meltwaters. Under favorable morphologic situations meltwaters gather into oriented superficial flows that sculpture furrows and canyons or gorges on steep surfaces. The presence of levelled surfaces covered with long lasting snow in higher parts of slopes enhanced the development of canyons.

In the case of the Jewtuchowicz Canyon, such flat surfaces exist in the higher parts of the Stupryggen slopes (Pl. 4, Fig. 1). They have originated due to exaration

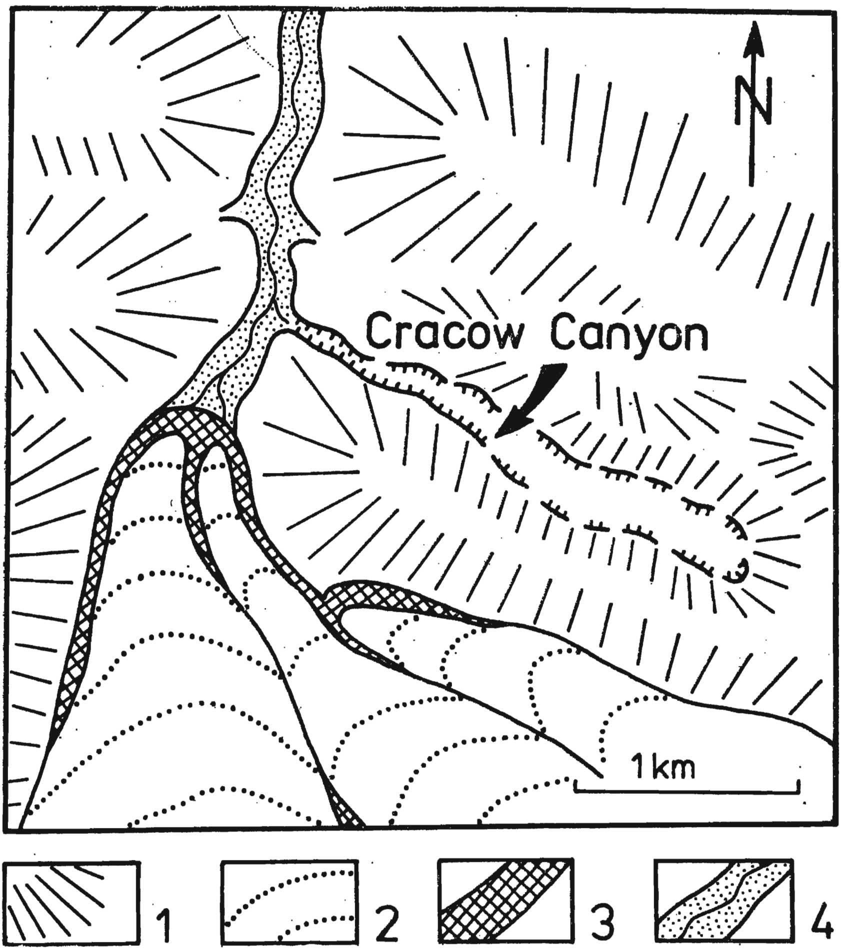

Fig. 6. Location of the Cracow Canyon against the maximal extent of the Pleistocene glaciers in the Kościeliska Valley, Western Tatra Mts

1 main elevations and their slopes, *2* glaciers, *3* ice-cored moraines, *4* surfaces of glacifluvial outflow activity of the Bunge Glacier which reached that part of the Stupryggen (KŁYSZ & LINDNER 1982). In the case of the Cracow Canyon it was a marginal polje that existed over the Kościeliska Valley in the early evolution stage of the Canyon (WÓJCIK 1968). Snow accumulated in this polje could not turn into firn and ice because of relatively low altitude (1500—1700 m a.s.l.). Melting snow was probably a constant source of water that flowed along the shortest way down through the fissured carbonate rocks toward the Kościeliska Valley which was a local drainage base. A greater slope inclination was then a favorable factor in the development of the lower systems of underground flow that have resisted till the present-day in form of caves filled in some places with allochthonous gravels. These caves have attained their greatest dimensions in their mouth parts and this was probably the reason that their roofs collapsed thus leading to the formation of gorge-like shape of the Cracow Canyon (ZWOLIŃSKI 1955, KOTAŃSKI 1963).

Considering the age of the two discussed karst forms, the Jewtuchowicz Canyon might have developed since the exposition of the southern part of the Stupryggen slope after melting of the Bunge Glacier (Text-fig. 5), *i.e.* about 20 000 y. BP (LINDNER & KŁYSZ 1984). The Cracow Canyon which is a form of remodelled valley head and a system of periodically active and collapsing caves, might have developed at the Tertiary decline, and probably it has deeply incised since the time of a more permanent snow coverage of the Tatra Mts. It is thought that the transition periods between the glacials and interglacials reactivating considerable quantities of melt-waters were the most favorable for its incision.

The studies by WÓJCIK (1968) shows that there were presumably at least 11 periods for the development of karst phenomena in the Tatra Mts. The oldest two or three periods were associated with the decline cf the Tertiary and the preglacial time of the Pleistocene. The lower cave horizons, distinguished by WÓJCIK (1968), should be attributed to the 8 main interglacials (*cf.* LINDNER 1984), the climatic conditions of which enhanced the disappearance of ice-snowy covers in the Tatra Mts.

Consequently, it is concluded that the Cracow Canyon located (*cf.* HALICKI 1930) beyond the extent of the Pleistocene glaciers (Text-fig. 6) has recorded at least six of the discussed periods of the disappearance of the glaciers, precisely the beginnings of the interglacials, during which the six successive cave horizons have formed.

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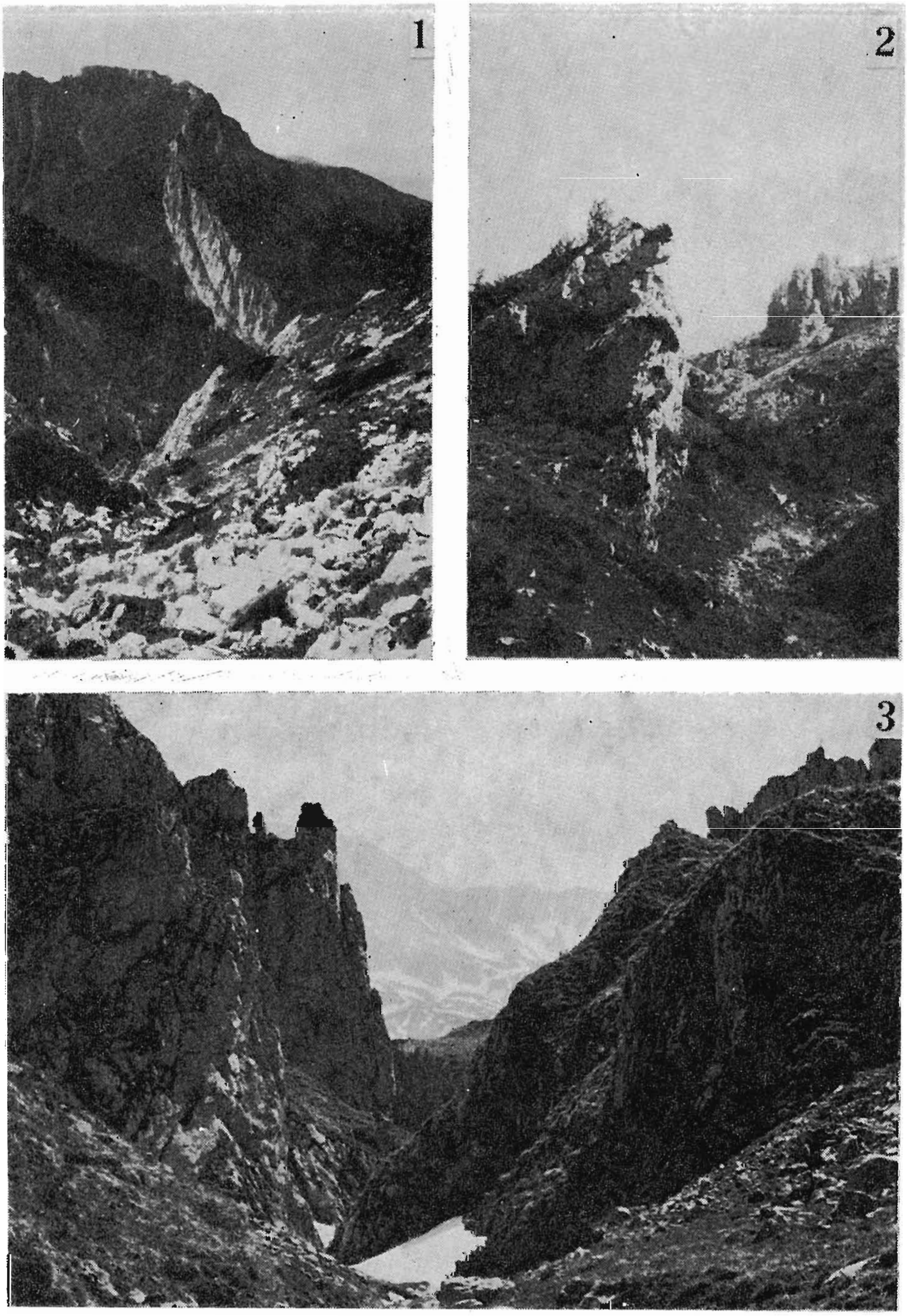
GENEZA I WIEK WĄWOZU KRAKÓW

(Streszczenie)

Wąwóz Kraków, usytuowany na wschodnich stokach Doliny Kościeliskiej w Tatrach Zachodnich, należy tutaj do największych i najpiękniejszych form rzeźby zawdzięczającej swoją genezę procesom krasowym (fig. 1—3 oraz pl. 1—2). Obserwacje poczynione nad rozwojem analogicznych form w warunkach polarnych na Spitsbergenie (fig. 4 oraz pl. 3—4) wykazały, że powstają one na zewnątrz od obecnego zasięgu lodowców (fig. 5), głównie dzięki działalności krasowej wód pochodzących z topnienia wieloletnich śniegów. Rozwój Wąwozu Kraków zapoczątkowany został u schyłku trzeciorzędu przez wody spływające z otaczających grzbietów po powierzchni oraz w podłożu zbudowanym ze skał węglanowych. W czwartorzędzie Wąwóz Kraków znajdował się poza zasięgiem lodowców tatrzańskich (fig. 6) i został rozbudowany dzięki działalności wód roztopowych pochodzących z wieloletnich śniegów pokrywających spłaszczenia wokół górnej partii wąwozu. Liczne jaskinie układające się piętrowo w zboczach wąwozu (*patrz* fig. 3) są śladami podziemnych przepływów krasowych. Ich wiek odnieść należy do okresów interglacjalnych środkowego i młodszego plejstocenu. Dolna, kanionowa część wąwozu powstała w wyniku zapadnięcia się systemu jaskiniowego, które nastąpiło przypuszczalnie w holocenie.



1 — Upper part of the Cracow Canyon, Western Tatra Mts
2 — Limestone crags over the upper part of the Cracow Canyon
3 — Middle part of the Cracow Canyon

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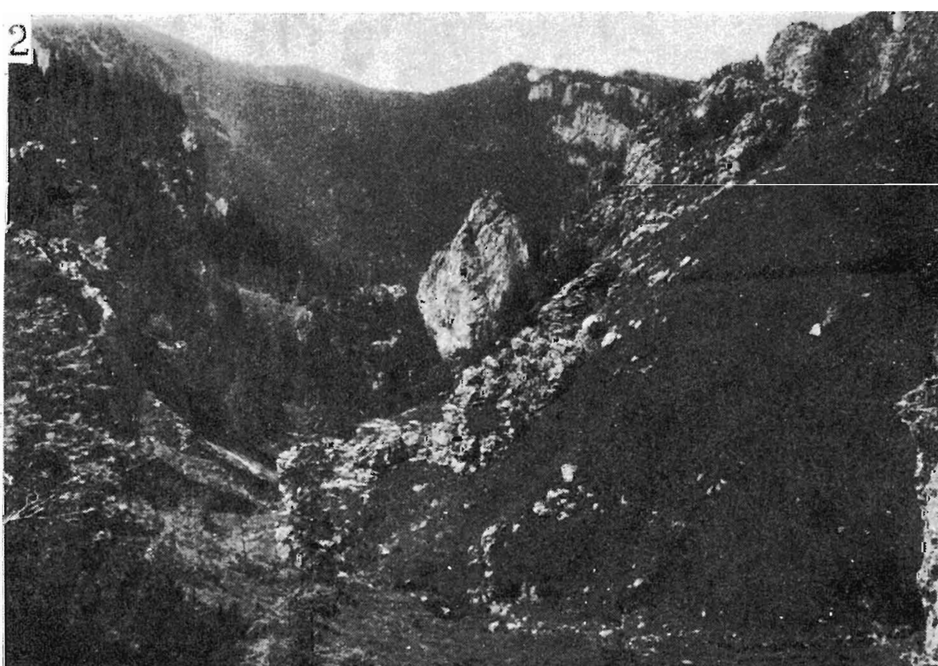
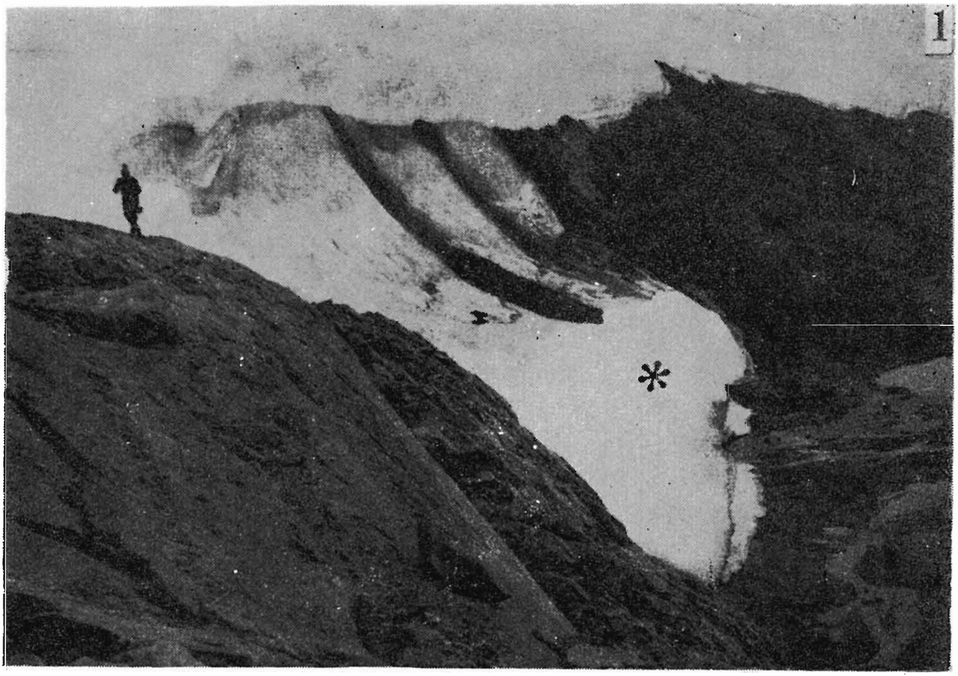
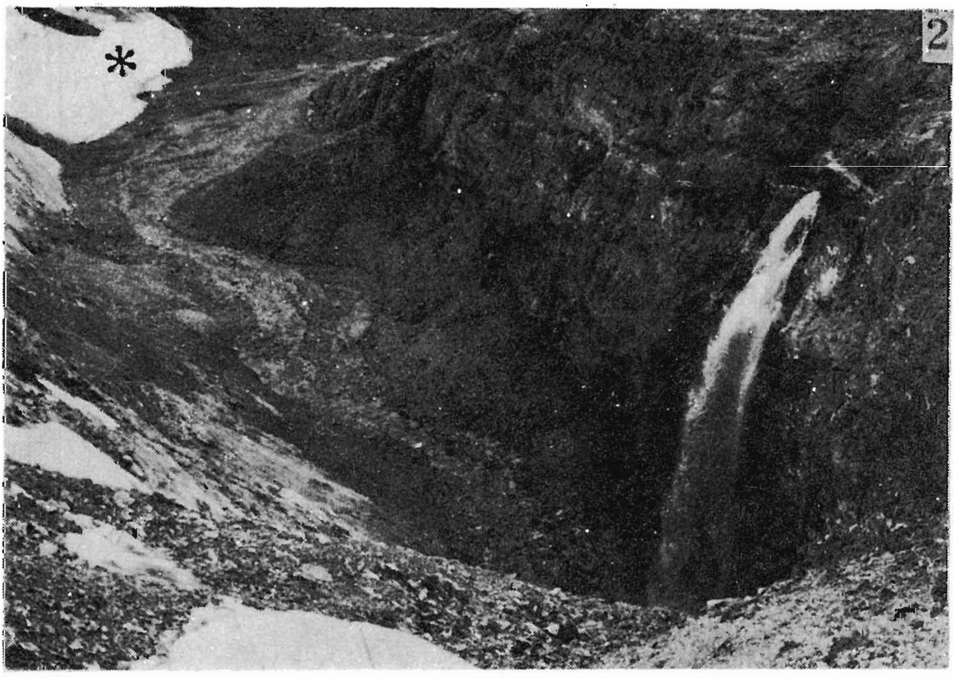


1 — Slopes of the terminal part of the Cracow Canyon, Western Tatra Mts
2 — Limestone cliffs over the middle part of the Cracow Canyon





1 — Ice-cored moraine on the eastern slope of the Jewtuchowicz Canyon (Sörkapp Land, Southern Spitsbergen); July 1980

2 — General view of the Jewtuchowicz Canyon, to show its course (*cf.* Pl. 3, Fig. 1; an asterisk in the same place) and upper part with the waterfall (*cf.* Pl. 4) on its western slope; July 1980

Exaration flats along the slope of Stupryggen (Sörkapp Land, Southern Spitsbergen), above the uppermost part of the Jewtuchowicz Canyon (*cf.* Pl. 3, Fig. 2); July 1980