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POSITION AND AGE OF CONGLOMERATES IN CAVES NEAR KRAKÓW (POLISH JURA)

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Abstract: Fine-grained conglomerates have been found in five caves in the southern part of Polish Jura: Wierzchowska Górna, Nad Źródłem V, Bez Nazwy, Jama Ani, Schronisko ze Żwirem. The conglomerates are matrix-supported and are composed of dark grains, quartz grains, clasts of Upper Jurassic limestones, ferruginous clay matrix and carbonate cement. The dark grains, characteristic of the conglomerates, formed in Oxisols in tropical or subtropical climate. The soils formed in Palaeogene, probably in Eocene time. They were eroded in Oligocene or Miocene time and their physically resistant components were redeposited into caves, forming the conglomerates. Pliocene erosion removed the conglomerates nearly completely, so that only small fragments of them are preserved until now.

Abstrakt: W pięciu jaskiniach południowej części Jury Polskiej (Jaskinia Wierzchowska Górna, Jaskinia nad Źródłem V, Jaskinia bez Nazwy, Jama, Ani, Schronisko ze Żwirem) stwierdzono występowanie żwirowców. Żwirowce o rozproszonym szkielecie ziarnowym składają się z: ciemnych ziarn, ziarn kwarcu, fragmentów wapieni górnej jury i ilasto-żelazistego matriks. Żwirowce spojone są węglanowym cementem. Charakterystyczne dla żwirowców ciemne ziarna są pochodzenia pedogenicznego i powstały w glebach typu Oxisol w warunkach klimatu tropikalnego lub subtropikalnego. Gleby te rozwijały się w paleogenie, zapewne w eocenie. W oligocenie lub miocenie były one rozmywane, a ich mechanicznie odporne komponenty były redeponowane w jaskiniach tworząc żwirowce. Większa część tych żwirowców uległa następnie erozji w pliocenie tak, że do dzisiaj zachowały się jedynie ich niewielkie fragmenty.

Key words: cave evolution, paleosoils, Tertiary, Polish Jura.

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INTRODUCTION

Age of the caves in the southern part of Polish Jura is determined by most authors at Late Miocene–Quaternary (R. Gradziński, 1962; Madeyska, 1977). The last, Late Quaternary, stage of the cave evolution is well documented by analysis of faunal remains, archaeological material and lithology of cave sediments (Madeyska-Niklewska, 1969; Madeyska, 1981, 1988). A detailed restoration of the earlier phases of cave filling and origin is precluded by the lack palaeontologically dated sediments older than Early Pleistocene.

Fine-grained conglomerates, recently found in five caves in the southern part of Polish Jura (M. Gradziński *et al.*, 1994, 1995; M. Gradziński, 1998), seem to shed a new light on the origin and early evolution of the caves in this area. The origin of the clastic material in the conglomerates, the conglomerates' stratigraphic position, age and significance are the topic of this paper.

MATERIAL AND METHODS

The studied conglomerates have been found in five caves in the southern part of Polish Jura: Wierzchowska Górna, Nad Źródłem V, Bez Nazwy, Jama Ani and Schronisko ze Żwirem (Fig. 1, Table 1). The specimens from the caves Nad Źródłem V and Bez Nazwy were from Andrzej Górny's collection and the specimen from Wierz- chowska Górna – from Lubomir Zawierucha's. The specimens have been collected in caves during exploration by digging. The conglomerates in these three caves are no more exposed.

Specimens were studied by observation of polished sections; polished thin sections made from selected portions were studied under binocular biological microscope, petrographical microscope and scanning electron microscope (SEM) JEOL 5410 equipped with energy dispersive spectrometer (EDS) Voyager 3100. Sediment colour was determined using GSA Color Chart (Goddard *et al.*, 1970).

Table 1

Location and basic morphometric characteristics of the studied caves

Name of cave	Location	Altitude	Length	Source
Wierzchow-ska Górna	Kluczwoda Valley	ca 400 m	960 m	Szelerewicz & Górny, 1986
Nad Źródłem V	Będkowska Valley	405 m	22 m	Szelerewicz, 1996
Bez Nazwy	Żarski Ravine	410 m	60 m	Górny & Kurek, 1996
Jama Ani	Jamki Ravine	418 m	158 m	Gradziński *et al.*, 1995
Schronisko ze Żwirem	Januszkowa Góra hill	417 m	4 m	Górny & Szelerewicz, 1990

THE OCCURRENCE OF CONGLOMERATES

All caves with conglomerate sediments occur in so called rocky facies of Upper Jurassic limestones (cf. Dżułyński, 1952). The caves are now inactive and are fragments of greater ancient systems of underground water circulation, now largely filled with sediments. Wierzchowska Górna, Nad Źródłem V, Jaskinia Bez Nazwy, and Jama Ani lie on valley slopes within the Ojców Upland; the Schronisko ze Żwirem is within an isolated hill of Upper Jurassic limestone, surrounded by Pleistocene sands.

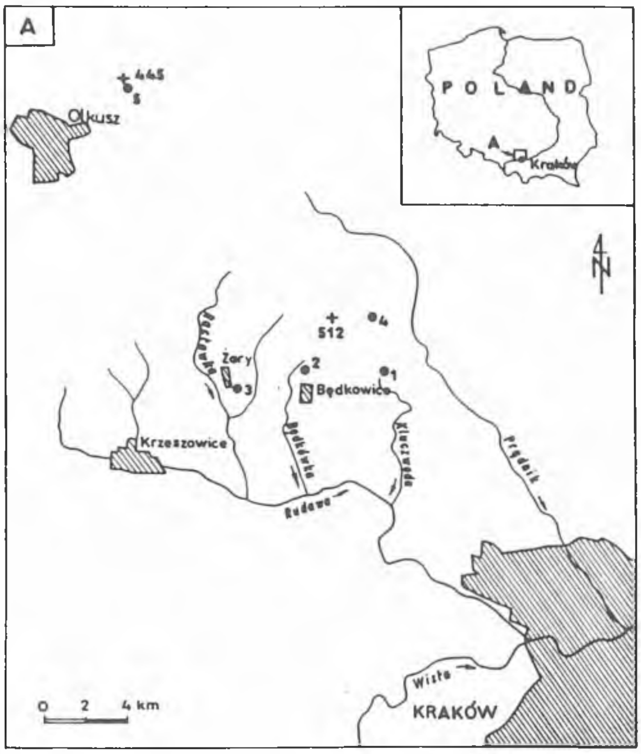

Fig. 1. Location of studied caves: 1. Wierzchowska Górna, 2. Nad Źródłem V, 3. Bez Nazwy, 4. Jama Ani, 5. Schronisko ze Żwirem

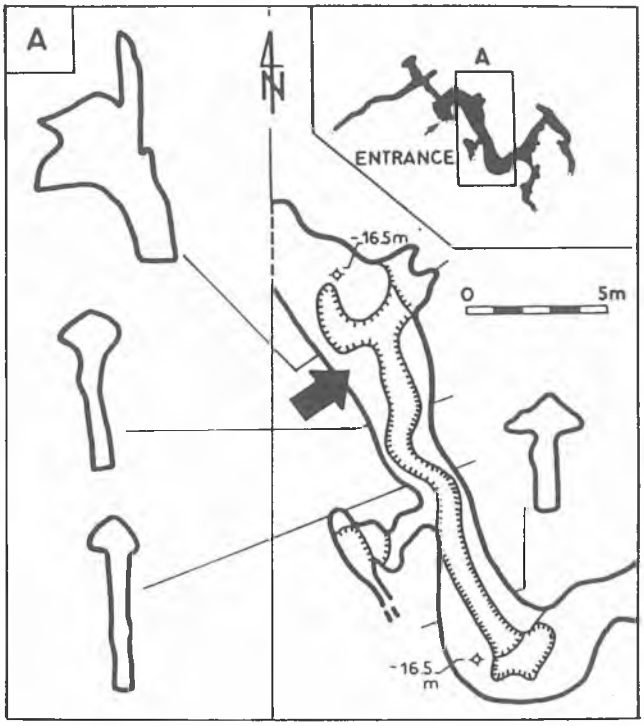

Fig. 2. Cave map and cross-sections through meandering gallery in the central part of Jama Ani; arrow points to location of conglomerate patch on a ledge in the galler

POSITION OF CONGLOMERATES IN SEQUENCES OF CAVE SEDIMENTS

The Wierzchowska Górna cave lies in the Kluczwoda Valley northwest of Kraków (Fig. 1; Szelerewicz & Górny, 1986). Conglomerates were found in this cave in a dig behind Sala Balowa chamber, at altitude of ca 400 m. They occur in the lower part of sediments that completely fill a gallery ca 1.8 m high (personal information by Lubomir Zawierucha). They are directly underlain by red, cemented clays with well rounded gravel of Jurassic limestone (see also Fig. 4) and overlain by brown clays described by Felisiak (1997) and including remains of *Glis sackdilligensis* (Heller 1930) dating the clays at Biharian. The brown clays include also clasts of dark-red clays for which Felisiak (1997) suggests an older, even Pliocene age.

Nad Źródłem V lies on the slope of Będkowska Valley northwest of Kraków (Fig. 1; Szelerewicz, 1996). The conglomerates occur in this cave ca 8 m from the entrance under a thick cover of flowstone and stalagmites. The speleothems are radiocarbon dated as older than 40,000 (Pazdur *et al.*, 1994). The conglomerates lie directly on the limestone floor of the cave (personal information by Andrzej Górny).

Jaskinia Bez Nazwy lies in Żarski Ravine – the right-side lateral branch of Racławka Valley (Fig. 1; Górny & Kurek, 1996). It entrance was excavated by teams led by

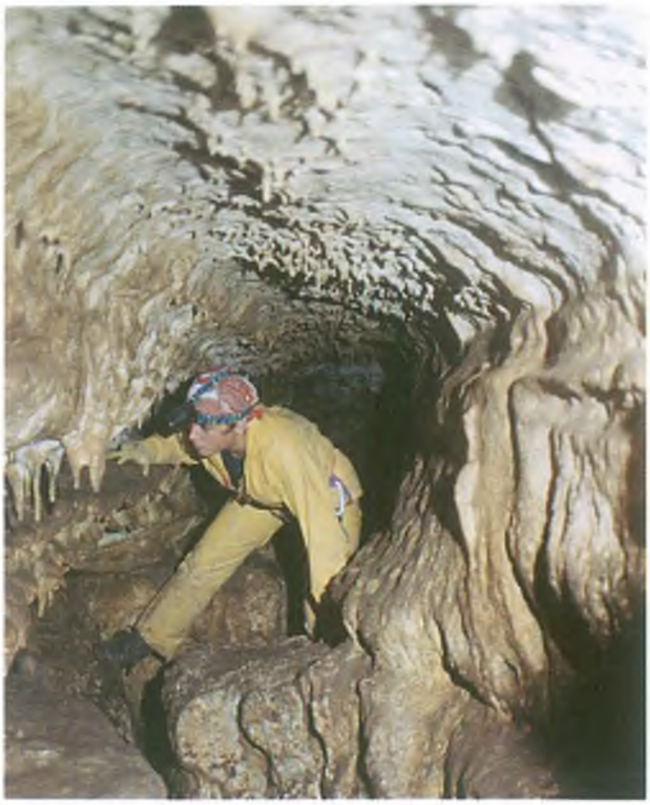

Fig. 3. Jama Ani, ledge in upper part of meandering gallery; conglemarate lies on it behind the person

Andrzej Górny in the eighties. A lens of cemented gravel was found during digging in the bottom of a small pothole situated a few metres behind the cave entrance (personal information by Andrzej Górny).

Jama Ani lies in Jamki Ravine – a side gorge of Sąspowska Valley (Fig. 1; M. Gradziński *et al.*, 1994, 1995). Its entrance lies at altitude of 418 m. The cave is 158 m long and 30.5 m deep. The main gallery of this cave is a meander up to 6 m high. The meander has ovate cross-section in its upper part, with a narrower canyon entrenched into the floor so that the overall cross-section is of "keyhole" type (cf. Ford & Williams, 1989). The conglomerate was found on a ledge in the meander at the depth of 16.5 m below the entrance level, i.e. at altitude of ca 402 m (Fig. 2). They form a lens of 12 cm maximum thickness. The ledge is situated ca. 0.7 m below the ceiling of the meander and it is a fragment of the ancient floor of the ovate gallery (Fig. 3). The sediments probably covered the floor of the gallery or even filled it completely. The preserved patch of conglomerate is a remnant left by erosion that removed the conglomerate from the gallery floor and created the downcut canyon.

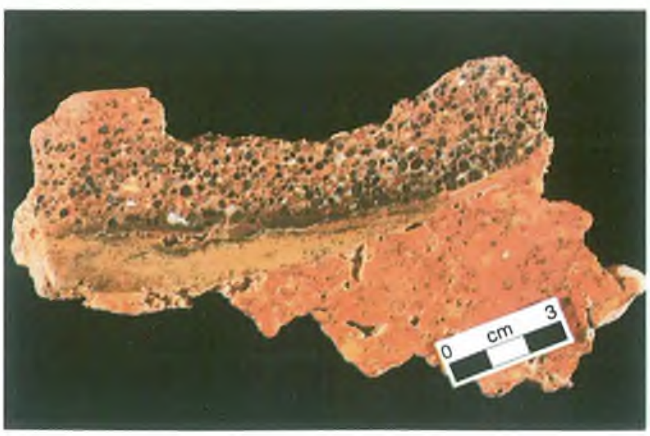

Fig. 4. Fine-grained conglomerate underlain by red cemented clays, Wierzchowska Górna

Schronisko ze Żwirem lies on the southern slope of the Januszkowa Góra hill northwest of Olkusz (Fig. 1; Górny & Szelerowicz, 1990). It is probably a fragment of a larger destroyed karst cave. The described conglomerates form a continuous layer, up to about 20 cm, on top of cave sediments, only fragmentarily covered with a thin layer of humus.

LITHOLOGY OF CONGLOMERATES

The studied conglomerates are matrix-supported (Figs 4, 5). The clasts are usually chaotically arranged. In two cases – in Wierzchowska Górna and Jama Ani – the conglomerates display coarse-tail normal grading.

The described conglomerates are composed of: (i) dark grains of variable roundness, (ii) quartz grains, (iii) angular fragments of Jurassic limestones and (iv) ferruginous clay matrix. The conglomerate has carbonate cement. Proportions of the components vary between the studied localities. Quartz grains dominate in conglomerates from Nad Źródłem V and Schronisko ze Żwirem, while the dark grains dominate in conglomerate from Wierzchowska Górna (Figs. 4, 5). The least numerous were angular fragments of Jurassic limestones.

Among the gravel components, the dark grains are the most differentiated category. Some of them are very well

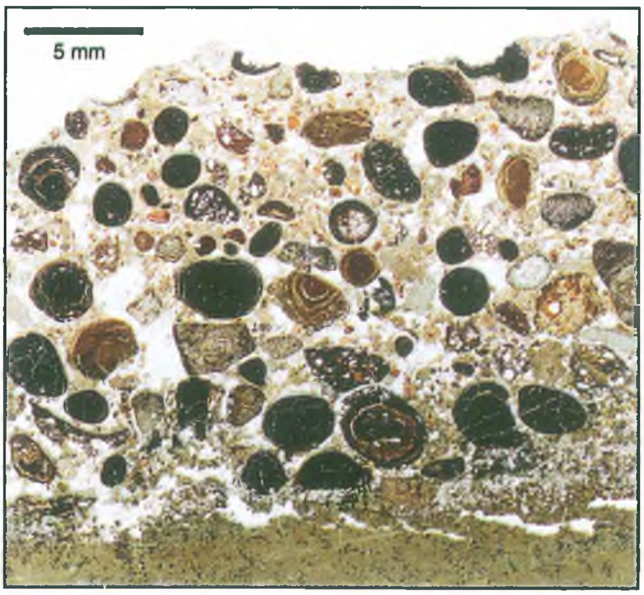

Fig. 5. Rounded dark grains, some of them broken; Wierzchowska Górna; transmitted light

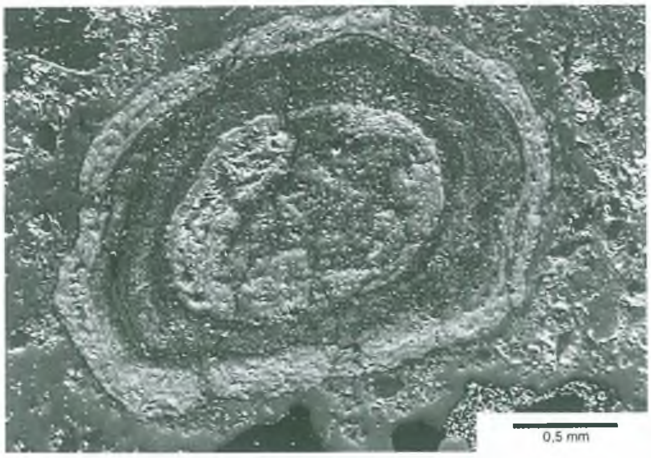

Fig. 6. Dark grain with concentrically laminated structure (concretion); SEM image in back-scattered electrons; Jama Ani

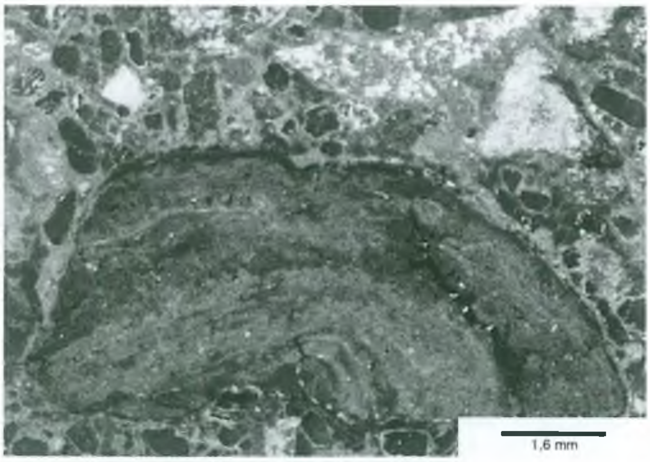

Fig. 7. Fragment of broken, concentrically laminated dark grain (concretion), image from binocular microscope, Wierzchowska Górna

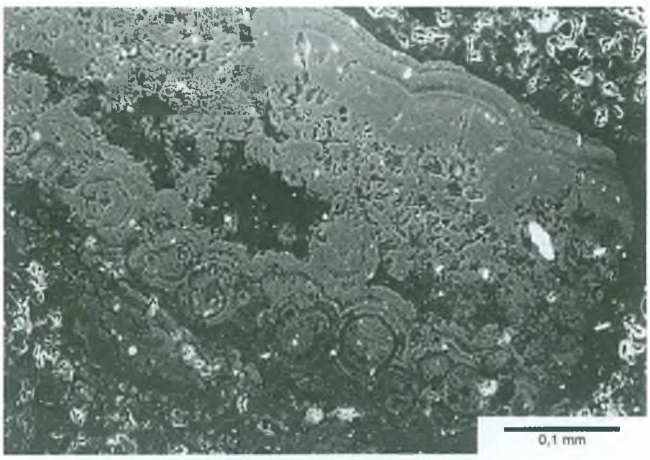

Fig. 8. Agglomerate composed of concentrically laminated dark grains covered with laminated crust (fragment of ferricrete), SEM image in back-scattered electrons; Jama Ani

rounded, spheroidal and discoidal with smooth outer surfaces. The size of the well rounded grains varies between 0,5 and 10 mm. A part of these grains are brownish black (5 YR 2/1), other are from dark yellowish orange (10 YR 6/6) to moderate reddish brown (10R 4/6). The subangular dark grains are mostly from moderate reddish brown (10R 4/6) to dark reddish brown (10R 3/4), though much lighter grains also occur – moderate orange pink (10R 7/4) and darker – olive black (5 Y 2/1). The shape of the subangular grains is discoidal and their size attains 15 mm.

The quartz grains in the conglomerates are all well rounded; some of them are coated with black crusts up to 0.2 mm thick. The quartz grains are up to 15 mm in diameter. The angular grains of Jurassic limestones do not exceed 20 mm in size. The matrix of the conglomerates is light brown (5 YR 5/6) in Wierzchowska Górna, Nad Źródłem V and Schronisko ze Żwirem. The matrix of conglomerates from Jaskinia Bez Nazwy and Jama Ani is slightly darker (moderate brown – 5 YR 4/4).

DARK GRAINS

MICROSCOPIC CHARACTERISTICS OF THE DARK GRAINS

A vast majority of the well rounded dark grains have distinct concentric laminae typical of coated grains (Fig. 6; cf. Peryt, 1983), hence their regular shape is better explained by their mode of growth than by abrasion. Some of the coated grains are broken, but traces of recoating are scarce (Fig. 7). A vast majority of these grains lack nuclei. Sporadically dark grains are aggregates of several grains cemented together and coated with a common laminated crust (Fig. 8).

Most of the well rounded grains are opaque, while some are dark red in transmitted light. It is a rule that grains that are macroscopically brownish-black are opaque. EDS analyses have shown that the opaque grains are mostly built of manganese oxides, while the grains macroscopically red are built of iron oxides (Table 2).

A separate group are well rounded grains lacking con-

Table 2

Main elements (weight percent) of dark grains of concentrically laminated struçture

Element	Laminated opaque grins	Laminated grains red in transmitted light
Al	8.87	9.83
Si	10.12	10.82
Mn	24.12	4.70
Fe	10.40	39.48
Mn/Fe	2.85	0.17

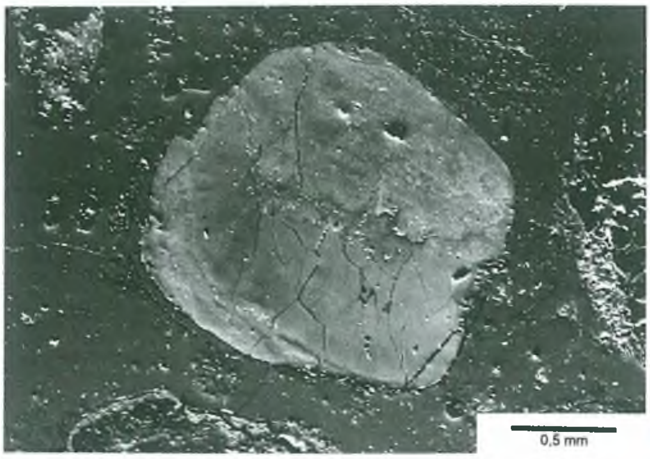

Fig. 9. Dark grain of homogenous structure (fragment of ferricrete ?); SEM image in back-scattered electrons; Wierzchowska Górna

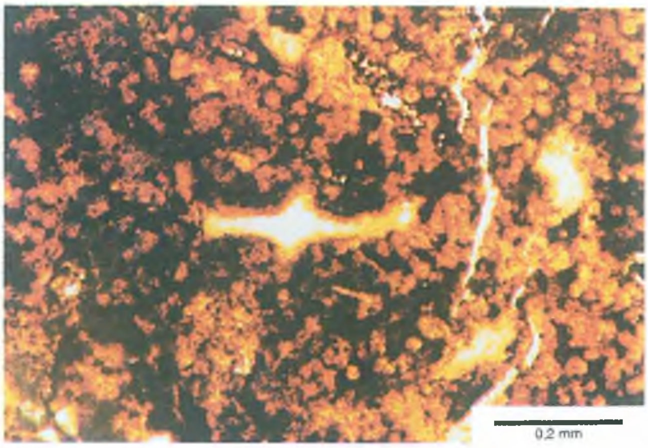

Fig. 11. Sponge spicule in central part of an angular dark grain – (core-stone); transmitted light; Jama Ani

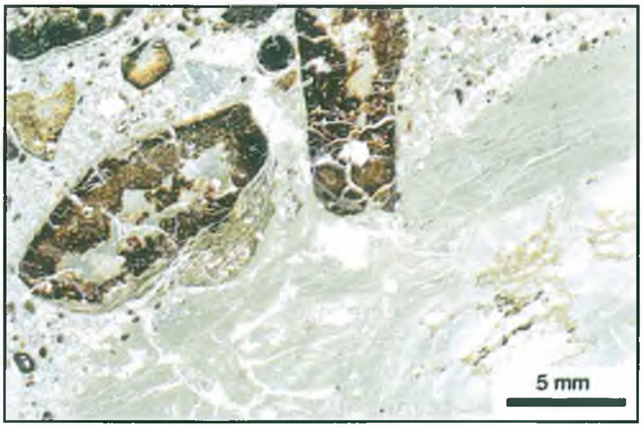

Fig. 10. Angular dark grains (core-stones), alteration is more intense in the outer parts of grains; transmitted light, Jama Ani

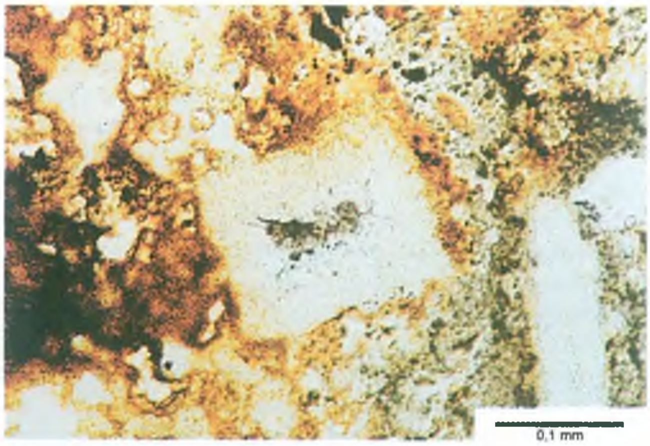

Fig. 12. Silicified fragment of echinoderm calcite in central part of angular grain (core-stone); transmitted light, Jama Ani

centric lamination. They have homogenous internal structure or have parallel lamination, discordant with their outline (Fig. 9). These grains consist of iron oxides. The rounded forms of the grains that lack concentric lamination seem related to abrasion.

The laminated dark grains include embedded clastic components. Observation under petrographic microscope and EDS analyses revealed the presence of quartz and a TiO_2 mineral – probably rutile or anatase. The detrital admixture is small in most of the dark grains. Only a few grains contain significant amounts of detrital elements. In those grains, the detrital components are concentrated mainly in the central parts of the grains, where lamination is obscure or absent. In the outer parts, the lamination becomes more regular with the decrease in the content of the detrital elements. In one case (Schronisko ze Żwirem) a thin crust of iron oxides covers a broken fragment of a vertebrate bone.

The internal structure of the angular dark grains differs from that described above. Their shapes are irregular and the grains are built of iron and manganese oxides, calcium carbonate and locally silica (Fig. 10). These grains lack detrital quartz grains. Oxides, mainly iron oxides, predominate in the outer parts of grains and their content gradually decreases towards the grain centres. The outer parts reveal also the presence of rhizoids and fractures, partly filled with calcite cement and partly with silica. Impregnation by silica occurs also in form of irregular concentrations in outer fragments of some grains. The internal parts of these grains include various bioclasts such as sponge spicules, echinoderm fragments and foraminifers (Figs 11–13). This structure indicates that the described clasts are fragments of altered carbonate rocks.

The alteration consisting in impregnation, mostly by iron oxides, progressed from outside towards the centres of grains.

THE ORIGIN OF THE DARK GRAINS

The sedimentary features of the conglomerates indicate that they are clastic sediments laid down by running water. The dark grains could be thus formed either in caves or outside them and brought in caves as allochthonous grains.

The origin of the described dark grains within caves seems unlikely. Modern analogues of the angular dark grains have not been found in caves and the rhizoids visible

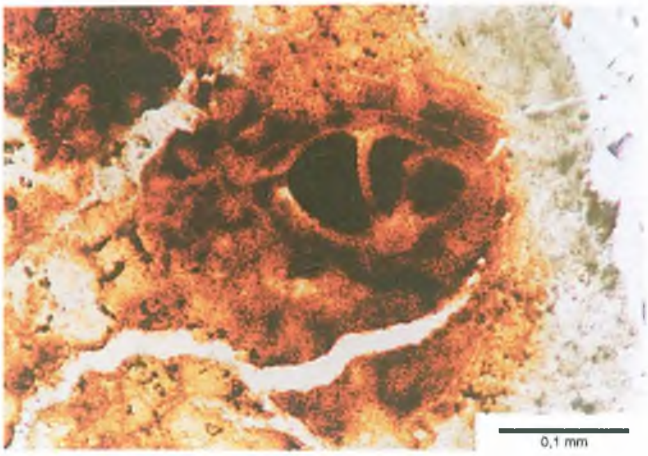

Fig. 13. Foraminiferal test in central part of angular grain (core-stone), transmitted light, Jama Ani

within these grains are more likely to form outside the caves. Coated grains built of manganese oxides were found to be forming in caves, but this is an exceptional situation, described hitherto from Lyon Cave in Philippines only (Hill & Forti, 1997).

Similarly, lakes may be excluded as the sites of origin of the dark grains. Though coated grains built of iron and manganese oxides are known to be forming in lacustrine environment, but those grains always have nuclei (Harris &Troup, 1970; Lemoalle & Dupont, 1972), in contrast to the grains in the conglomerates described here. Such features as agglomeration of grains, growth of laminated crusts composed of iron oxides and impregnation of older rocks with iron and manganese oxides, resulting in formation of grains similar to the described here angular dark grains, have not been observed in lakes.

Nevertheless, equivalents of all the types of dark grains described from the conglomerates are known from various types of soils. The grains equivalent to the described here laminated dark grains form in soils and are described as concretions (Brewer, 1964; Retallack, 1990). Adjacent concretions in the top part of soil may be cemented together and form a crust resistant to erosion. Such crusts are named dependent of their mineral composition. Those built of iron oxides are called ferricrete. Among the components of the studied conglomerates, the dark grains built of iron oxides and having parallel lamination or homogenous structure, agglomerates of laminated concretions, and possibly also a part of single laminated concretions are fragments of ferricrete crusts. On the other hand, the angular dark grains which are fragments of carbonate rocks altered by propagating inwards impregnation with iron and manganese oxides, display characteristics of the so called core-stones. Core-stones are fragments of partly altered parent rocks and occur in basal parts of soil profiles (Ollier, 1969).

Taking into account the presented facts, one can conclude that the described dark grains in the studied conglomerates had been formed in soils and were later transported into caves. Consequently, all grains described above as the dark grains will be farther referred to as.

CONDITIONS OF DARK GRAINS FORMATION

Constituents similar to those described above may form in various types of soils (Ollier, 1969; Retallack, 1990; Zhang & Karathanasis, 1997). The determination of the types of soils in which the described grains formed may contribute to the restoration of climatic conditions of the grains origin.

The ferruginous concretions form the upper layer in Oxisols and in related lateritic mantles (McFarlane, 1976; Nahon *et al.*, 1980; Tardy & Nahon, 1985; Retallack, 1990; Taylor *et al.*, 1992). Concretions built of manganese oxides occur also in Oxisols, but are reported much less frequently (Glasby *et al.*, 1979; Pracejus & Bolton, 1992). The concretions form by reprecipitation of iron or manganese oxides. The parent material are natural soil aggregates, known as peds, covered with a mineral ferruginous or manganiferous crust, called cutan (cf. Brewer, 1964). During further evolution peds are transformed into laminated concretions (Nahon *et al*, 1980; Clarke & Chenoweth, 1995). Such concretions form a ferricrete crust in upper part of a mature lateritic mantle. It is noteworthy, that in the Oxisol profiles and in concretions formed in these soils, detrital components occur only as refractory minerals, and this is one of diagnostic characteristics of this type of soils (Mack *et al.*, 1993).

Manganiferous and ferruginous concretions are also known from other types of soils, mainly of Spodosols but also from Alfisols (see Ollier, 1969; Retallack, 1990; Zhang & Karathanasis, 1997). In the case of Spodosols they are related with the so-called spodic horizon, where oxides, mostly iron oxides, precipitate (Retallack, 1990). The oxides in the spodic horizon occur usually as cement binding various grains, and only subordinately as concretions (cf. Ollier, 1969; Retallack, 1990, 1993).

Ferruginous core-stones are typical of advanced chemical weathering (Ollier, 1969). They occur at the contact of soil with parent rocks, which is known as petroferric contact. Characteristic of it is enrichment of the parent rock in iron oxides and it may contain more than 30% Fe_2O_3. Petroferric contacts are typical of tropical and subtropical climate (Retallack, 1990).

The above discussion indicates that the dark grains in the conglomerates are most likely derived from Oxisols. This is suggested by: (i) the presence of ferruginous core-stones in the conglomerates, (ii) the presence of quartz grains and TiO_2 as the only clastic admixture in the studied concretions combined with the lack of chemically labile components, (iii) the occurrence of ferricrete crust fragments, (iv) the lack of clasts eroded from spodic horizon, which should be expected were the discussed pedogenic components derived from Spodosols.

The above conclusion constrains the conditions of origin of the dark grains. Oxisols and genetically related lateritic mantles form by advanced weathering in tropical or subtropical climate. They are forming nowadays e. g. in equatorial Africa and in equatorial America (McFarlane, 1976; Nahon *et al.*, 1980; Brady & Weil, 1999). Climatic conditions necessary for their development include high humidity and high mean annual temperature, predominating for prolonged period. Retallack (1990) estimates the time necessary for the formation of mature Oxisol profiles at ca. one million years. Recently Taylor *et al.*, (1992) and Chivas & Bird (1995) have demonstrated that weathering resulting in formation of lateritic mantles may also occur in cold climate but at a much slower rate.

Concretions and core-stones are, apart from ferricrete crusts, the mechanically most resistant components of Oxisols and lateritic crusts. In the course of soil erosion they are not destroyed, but are transported and redeposited as grains (McFarlane, 1976; Clarke & Chenoweth, 1995; Bestland *et al.*, 1996). This phenomenon is common and occurs on different scales. In some cases it results in deposition of the so-called detrital laterites (McFarlane, 1976; Bestland *et al.*, 1996).

Summing up, the facts presented above suggest that the dark grains present in the conglomerates had formed in soils in tropical and subtropical climate as a result of advanced chemical weathering. They were then eroded, transported and deposited in caves.

AGE OF THE DARK GRAINS

The dark grains are a component of conglomerates that occur as internal sediment in caves in Jurassic limestones. The conglomerates are covered with sediments dated palaeontologically at Biharian (Wierzchowska Górna cave) or older than 40,000 BP (Nad Źródłem V). Moreover, it is characteristic that no fragments of rocks of Scandinavian origin have been found in the conglomerates. Such rock fragments are common Pleistocene sediments in this area, described by Walczak (1956). This suggests that the conglomerates, and consequently the grains of which they are built, are older than Pleistocene. Taking into account this age constraint, the proposed conditions of origin of the dark grains and the known geological history of the Kraków area (cf. R. Gradziński, 1972; Rutkowski, 1989) one can conclude that the grains under discussion could form in Palaeogene–Early Miocene or Late Miocene–Pliocene times.

A dramatic change in global climate occurred in Tertiary. At the Eocene–Oligocene break there was an important cooling of climate. The change is marked in isotope curves based on foraminifers and molluscs from marine sediments (e.g. Buchardt, 1978; Miller, *et al.*, 1987). Though the curves register a couple of later warmer periods, e.g. in the middle Miocene, the optimum climatic conditions, such as those prevailing in pre-Oligocene time, especially in Eocene, have not been restored since. This change was also manifest in continental climate as is shown by the studies of the fossil floras (Wolfe, 1980). The warm and humid climate in Palaeogene time is also evidenced by the formation at that time of thick bauxite mantles. Bauxites of this age are known, among others, from Hungary, Istria and Dalmatia (e.g. D'Argenio & Midszenty, 1995).

In addition, the palaeoclimatic reconstructions for the area of Poland point to a tropical climate in Palaeogene (see reviews by Tyczyńska, 1957; Klimaszewski, 1958a, 1958b). This climate was favourable for advanced chemical weathering, as is shown by Paleogene deposits found in Poland. Kaoline mantles are known from the Sudetes (Kościówka, *et al.*, 1978; Dyjor, 1978). So called moulding sands were laid down in other areas of Poland (see R. Gradziński, 1977; Bosak *et al.*, 1979; Głazek & Szynkiewicz, 1980). These deposits, occurring in the central and northern part of Polish Jura, are the result of advanced chemical weathering of Cretaceous rocks as is shown by the assemblage of refractory heavy minerals found in them (Bosak *et al.*, 1979). These sediments were later redeposited into vast karst depressions (R. Gradziński, 1977). In the moulding sands from Okrąglik (central part of Polish Jura), Krysowska-Iwaszkiewicz (1974) found dark brown spherolitic aggregates of clay minerals, whose origin may be similar to that of the concretions described here. Krysowska-Iwaszkiewicz (1974) assigns also a Palaeogene age to kaolinitic weathering mantles that fill fossil depressions and karst conduits in the central and northern parts of Polish Jura. Conditions favourable for the development of tropical karst prevailed thus in the southern part of Polish Jura, where the studied caves are situated, and the so called Palaeogene planation surface was formed then (Klimaszewski, 1958a, 1958b; Pokorny, 1963). It may be thus accepted that conditions especially favourable for the origin of the described dark grains prevailed in Palaeogene, especially Eocene times.

This conclusion is corroborated by the relatively common occurrence of similar ferruginous concretions in Palaeogene palaeokarst sediments in Europe. Such concretions have been described from France, Belgium, Germany and Switzerland (Schwarzbach, 1975; Groschopf, 1980; Bárdossy *et al.*, 1989). Their concentration had been so high in some areas that they had economical importance (Bárdossy *et al.*, 1989).

Concretion similar to those described here have been found at many localities in southern Poland, especially in the southern part of Polish Jura. Concretions described as "ruda bobowa" (pellet ore) were first found in Polish Jura by Samsonowicz (1934) in sediments filling a fossil karst cave at Węże near Działoszyn. The concretions were "limonitic-argillaceous, of very small size (poppy seed-size)" (Samsonowicz, 1934, p. 156). Różycki (1960) described "lumps of ochreous limonite" from Błeszno near Częstochowa. The lumps, together with quartz conglomerate redeposited from Cenomanian sediments and fragments of Jurassic limestones, built conglomerates that partly filled a cave exposed by a quarry. The occurrence of similar concretions has been reported by Gilewska (1963) from a filling of a fossil karst form on Silesian Upland. Pokorny (1963, p. 172) notes "tiny ferric-manganese concretions, also siliceous concretions with a ferric coating" in reddish-brown clays directly overlying the Jurassic limestones near Jerzmanowice (southern part of Polish Jura). Kowalski (1971) found similar concretions in sediments in Jaskinia Ciemna cave (Prądnik Valley, southern part of Polish Jura). Głazek *et al.* (1976, 1977) described similar concretions from sediments filling fossil caves on the Draby hill in the northern part of Polish Jura, Madeyska (1977, 1988) from sediments of Schronisko Bramka (Sąspowska Valley), and Bednarek & Liszkowski (1982) from fossil weathering mantles at Dzibice. Joachim Szulc (personal information, 1998) found ferruginous concretions in fills of karst dolinas near Opole.

The age of the concretions-bearing sediments has been variously estimated by various authors at Palaeogene, Miocene, Pliocene and Pleistocene. The main reason for the age estimate was in most cases the lithology of sediments. The only exception is the locality Węże (known as Węże-1) which has rich palaeontological evidence. The age of vertebrate bones in successive layers with concretions has been determined at Biharian, Lower Villafranchian and Ruscinian, respectively (Głazek *et al.*, 1975 and references therein). The small sizes of concretions found at Węże-1 differ them from those described here and may suggest that the weathering mantles in which they formed could be immature. It should also be noted that the age of the bones is not conclusive for the age of the concretions as the latter could be redeposited from older sediments. For the reasons presented above the age accepted for the earlier known sediments with ferruginous or manganiferous concretions, described from the area of southern Poland can not be applied to the conglomerates described in this paper. Consequently, for the present author this age is not the base for the determination of the age of the dark grains described here. Moreover, the often imprecise descriptions of the dark concretions, found in the literature, preclude their precise comparison to the dark grains described here.

All the presented facts seem to corroborate Palaeogene, most likely Eocene, age of the dark grains in the described conglomerates. A younger age of these grains can not be, however, excluded. Nevertheless their formation in Miocene time seems impossible because of the tectonic activity in the area and related intense denudation after the regression of the Miocene sea, and also because of relatively dry climate in early Miocene time (cf. Hsü *et al.*, 1977; Hsü & Giovanolli, 1979) not favourable for intense chemical weathering. More favourable conditions prevailed instead in Pliocene time, but even than climate was less warm and drier, at least temporarily, than in Palaeogene and Eocene.

THE AGE AND ORIGIN OF CONGLOMERATES

The described conglomerates were laid down by subterranean streams. As the conglomerates at all the described localities are similar, they are probably deposits of the same stage of cave filling. All the studied conglomerate occurrences are remnants left after removal of once more abundant sediments that filled the caves. Taking into account the postulated age of the dark grains and the geological history of the Polish Jura area, two hypotheses may be proposed: (i) that the conglomerates formed in Oligocene-Miocene time and were removed in Pliocene or Early Pleistocene (before glaciation) and (ii) deposition of conglomerates in Pliocene and their removal also in Pliocene or Early Pleistocene (before glaciation). The differences in published opinions on the Tertiary evolution of the southern part of Polish Jura, especially on the age of faults, age and evolution of relief, the extent of the Miocene transgression and the degree of Pliocene–Quaternary erosion, preclude a precise verification of these hypotheses. The second hypothesis conforms the hitherto accepted opinions on the age of caves in the southern part of Polish Jura (R. Gradziński, 1962) and on the age of the oldest sediments filling those caves (Madeyska, 1977) so it will be not discussed here in detail. The present author is inclined to accept the first hypothesis and this is discussed below.

A planation surface, truncating sediments, from Palaeozoic in the west through Cretaceous in the east, developed in the southern part of Polish Jura in Palaeocene or Eocene times (Dżułyński, 1953; Klimaszewski, 1958a, 1958b; Pokorny, 1963; Gilewska, 1972). Oxisols with the dark grains, found in conglomerates described here, were most likely formed on this surface. The admixture of quartz grains in the conglomerates might come from Cretaceous sediments eroded at the same time. It may be supposed that the dissection of the planation surface began in Oligocene. Głazek and Szynkiewicz (1980, 1987) link this process with the initial phase of the Meta-Carpathian Rise uplift. It was probably at that time when valleys began to form in this area. This is suggested by the fossil valleys near Rudawa (Alexandrowicz, 1969), a fossil valley near Chrzanów (Panek & Szuwarzyński, 1976), palaeovalleys preserved at the base of Miocene sediments of the Carpathian Foreland (Oszczypko & Tomaś, 1976) and fossil valleys found near Zabierzów (Felisiak, 1992). The existence of a marked relief before the Badenian transgression is indirectly indicated by the results of studies on the Miocene littoral sediments (Radwański, 1968).

Coeval with the evolution of relief was probably the formation of an underground water circulation system, which probably partly used an earlier karst system. Fragments of such old, now completely filled, channels near Kraków have been described by R. Gradziński (1962). Głazek and Szynkiewicz (1980) postulate Miocene age of some now accessible caves in Polish Jura. The Oligocene channels of underground circulation were being filled with various clastic sediments. It was at that, Oligocene, time when conditions were favourable for deposition of conglomerates including material from removal of Oxisols.

The upper time limit of the cave filling is difficult to ascertain. These processes could cease at the beginning of the Badenian age with the onset of Miocene transgression (cf. Ney *et al.*, 1974). They could, however, continue through Badenian and Sarmatian times if the area under discussion was not inundated by the sea. This is still a point of debate. Some authors accept the northern boundary of the Miocene sea at the line of the Kraków Będzin Fault, i.e. roughly at northern margin of the Krzeszowice Graben (Bogacz, 1967; Ney *et al.*, 1974), while others suggest a farther extent of the Miocene transgression (Dżułyński *et al.*, 1966; Głazek & Szynkiewicz, 1987). The northernmost locality with marine Miocene sediments is at Wielka Wieś, at altitude of 360 m (Friedberg, 1933). If the area where the studied caves occur was not covered by the Badenian transgression, the development of caves and their filling could last longer, until drying of climate in the early Pannonian (cf. Hsü & Giovanolli, 1979).

Conditions favourable for cave rejuvenation, that is erosion and removal of earlier deposited sediments and inclusion of older caves into the active system of karst water circulation (Bosák *et al.*, 1989), were established in Dacian time. The cave rejuvenation was related to intense erosion caused by lowering of regional base of erosion (Głazek & Szynkiewicz, 1987). For the southern part of Polish Jura the regional base of erosion was the Black Sea since the beginning of Pleistocene (cf. Lewandowski, 1993). The lowering of the base of erosion may be related to the Messinian crisis, lasting from the Pannonian through Dacian stage, when the level of the Black Sea dropped by ca. 1,600 m (Hsü & Giovanolli, 1979). The effect of the Messinian crisis was additionally augmented by the uplift of the Meta-Carpathian Rise (Głazek & Szynkiewicz, 1987). It should also be noted that the termination of the Messinian crisis was connected with humidification of climate, which additionally favoured processes of erosion and cave rejuvenation. It was then when the described conglomerates have been removed, leaving only scarce remnants. The older caves, cleared of sediments, were incorporated into a new system of underground circulation, related to the new network of valleys in the southern part of Polish Jura (cf. R. Gradziński, 1962; Dżułyński *et al.*, 1966; Głazek, 1989). The caves were then filled with sands and clay-rich debris in Pleistocene time (cf. Madeyska-Niklewska, 1969; Madeyska, 1981).

It can not be excluded, however, that non-fossiliferous sediments that occur at the base of the clastic sediments in caves in the southern part of Polish Jura (cf. Madeyska-Niklewska, 1969; Kowalski, 1971; Madeyska, 1977, 1988; Mirosław-Grabowska, 1997) are coeval with the conglomerates described here. This seems especially likely for the sediments that include dark mineral concretions, described from the Schronisko Ciasne and Ciemna caves (Kowalski, 1971; Madeyska, 1977, 1988). As for now, the opinions expressed above can not be fully verified. This would require additional studies, based on a richer material. Such studies seem to be important because the acceptance of an Oligocene–Miocene age of the studied conglomerates requires a revision of the views on the age of caves in the southern part of Polish Jura and indirectly confirms the existence of a differentiated relief in the studied area before the onset of the Miocene transgression.

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REFERENCES

Alexandrowicz, S., 1969. Couches du Paléogène de la partie méridionale du Plateau de Cracovie. *Rocznik Polskiego Towarzystwa Geologicznego*, 39: 680–696.

Bárdossy, G., Fuchs, Y. & Głazek, J., 1989. Iron ore deposits in paleokarst. In: Bosák, P., Ford, D. C., Głazek, J. & Horáček, I. (eds.), *Paleokarst, A Systematic and Regional Review*. Academia, Prague, pp. 419–429.

Bednarek, J. & Liszkowski, J., 1982. Profil kopalnych pokryw wietrzeniowych w Dzibicach (Jura Polska). (In Polish only). *Biuletyn Geologiczny*, 26: 89–103.

Bestland, E. A., Retallack, G. J., Rice, A. E. & Mindszenty, A., 1996. Late Eocene detrital laterites in central Oregon: Mass balance geochemistry, depositional setting, and landscape evolution. *Geological Society of America Bulletin*, 108: 285–302.

Bogacz, K., 1967. The geological structure of the northern border of the Krzeszowice Graben. (In Polish, English summary). *Prace Geologiczne, Polska Akademia Nauk, Oddział w Krakowie, Komisja Nauk Geologicznych*, 41: 1–89.

Bosák, P., Ford, D. C., Głazek, J., 1989. Terminology. In: Bosák, P., Ford, D. C., Głazek, J. & Horáček, I. (eds.), *Paleokarst, A Systematic and Regional Review*. Academia, Prague, pp. 25–32.

Bosák, P., Głazek, J., Gradziński, R., Wójcik, Z., 1979. Origin and type of the Rudice type of pocket deposits. (In Polish, English summary). *Kras i Speleologia*, 2: 11–16.

Brady, N. C. & Weil, R. R., 1999. *The Nature and Properties of Soils*. Prentice Hall, New Jersey, 881 pp.

Brewer, R., 1964. *Fabric and Mineral Analysis of Soil*. John Wiley & Sons, New York, 470 pp.

Buchardt, B., 1978. Oxygen isotope palaeotemperatures from Tertiary period in the North Sea area. *Nature*, 275: 121–123.

Chivas, A. R. & Bird, M. I., 1995. Paleoclimate from Gondwanaland clays. In: *Proceedings of 10th International Clay Conference, Adelaide, 1993*. pp. 333–338.

Clarke, J. D. A. & Chenoweth, L., 1995. Classification, genesis and evolution of ferruginous surface grains. *AGSO Journal of Geology & Geophysics*, 16: 213–221.

D'Argenio, B. & Mindszenty, A., 1995. Bauxites and related paleokarst: tectonic and climatic event markers at regional unconformities. *Eclogae Geologiae Helvetiae*, 88: 453–499.

Dyjor, S., 1978. Rozwój pokryw zwietrzelinowych i serii ilastych w trzeciorzędzie południowo-zachodniej Polski. (In Polish only). In: *I Konferencja minerały i surowce ilaste, Bolesławiec 25-28 kwietnia 1978*. Polska Akademia Nauk Komitet Nauk Geologicznych, Polskie Towarzystwo Mineralogiczne Sekcja Minerałów Ilastych, Warszawa, pp. 269–290.

Dżułyński, S., 1952. The origin of the Upper Jurassic limestones in the Cracow area. (In Polish, English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 21: 125–180.

Dżułyński, S., 1953. Tectonics of the southern part of the Cracovian Upland. (In Polish, English summary). *Acta Geologica Polonica*, 3: 325–440.

Dżułyński, S., Henkiel, A., Klimek, K. & Pokorny, J., 1966. The developmenty of valleys in the southern part of the Cracow Upland. (In Polish, English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 36: 329–343.

Felisiak, I., 1992. Oligocene–Early Miocene karst deposits and their importance for recognition of the development of tectonics and relief in the Carpathian Foreland, Kraków region, Southern Poland. (In Polish, English summary). *Annales Societatis Geologorum Poloniae*, 62: 173–207.

Felisiak, I., 1997. Age and distribution of some karstic sediments from the Polish Jura and their implications for the age of the relief. In: Jeannin, P. Y. (ed.), *Proceedings of the 12th International Congress of Speleology*, vol 1. Swiss Speleological

Society. La Chaux-de-Fonds, pp. 17–21.
Ford, D. C. & Williams, P. W., 1989. *Karst Geomorphology and Hydrology*. Unwin Hyman, Boston, 601 pp.
Friedberg, W., 1933. Beiträge zur Kenntniss des Miocäns von Polen. I Teil. (In Polish, German summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 9: 50–56.
Gilewska, S., 1963. Relief of the Mid-Triassic escarpment in the vicinity of Będzin. (In Polish, English summary). *Prace Geograficzne, Polska Akademia Nauk, Instytut Geografii*, 41: 1–135.
Gilewska, S., 1972. Wyżyny Śląsko-Małopolskie. (In Polish only). In: Klimaszewski, M. (ed.), *Geomorfologia Polski*, vol. 1, Państwowe Wydawnictwo Naukowe, Warszawa, pp. 232–339.
Glasby, G. P., Rankin, P. C. & Meylan, M. A., 1979. Manganiferous soil concretion from Hawaii. *Pacific Science*, 33: 103–115.
Głazek, J., 1989. Paleokarst of Poland. In: Bosák, P., Ford, D. C., Głazek, J. & Horáček, I. (eds.), *Paleokarst, A Systematic and Regional Review*. Academia, Prague, pp. 77–105.
Głazek, J., Sulimski, A., Szynkiewicz, A. & Wysoczański-Minkowicz, T., 1976. Middle Pleistocene karst deposits with *Ursus spelaeus* at Draby near działoszyn, Central Poland. *Acta Geologica Polonica*, 26: 451–466.
Głazek, J., Sulimski, A., Szynkiewicz, A. & Wysoczański-Minkowicz, T., 1977. Fossil karst with Middle Pleistocene vertebrates at Draby near działoszyn (Central Poland). (In Polish, English summary). *Kras i Speleologia*, 1: 42–58.
Głazek, J., Sulimski, A. & Wysoczański-Minkowicz, T., 1975. On the stratigrapohiuc position of the Węże-1 locality (Middle Poland). In: Panoš, V. (ed.), *Proceedings of the 6th International Congress of Speleology, Olomous - ČSSR*. Academia, Praha, pp. 435–442.
Głazek, J. & Szynkiewicz, A., 1980. Kras między Pilicą a Wartą i jego praktyczne znaczenie. (In Polish only). In: Barczyk, W. (ed.), *Przewodnik LII Zjazdu Polskiego Towarzystwa Geologicznego, Bełchatów 11-14 września 1980*. Wydawnictwa Geologiczne, Warszawa, pp. 84–99.
Głazek, J. & Szynkiewicz, A., 1987. Stratigraphy of the Late Tertiary and Early Quaternary karst deposits in Poland and their paleogeographic implications. (In Polsih, English summary). In: Jahn, A. & Dyjor, S. (eds.), *Problemy młodszego neogenu i eoplejstoceny w Polsce*. Ossolineum, Wrocław, pp. 111–130.
Goddard, G. M., Trask, P. D., DeFord, R. K., Rove,. O. N., Singewald, J. T. Jr. & Overbeck, R. M., 1970. *Rock-color chart*. Geological Society of America. Boulder.
Górny, A. & Kurek, A., 1996. Jaskinia bez Nazwy. (In Polish only). *Jaskinie Wyżyny, Informator*, 8: 5–7.
Górny, A. & Szelerewicz, M., 1990. *Inwentarz jaskiń i schronisk Januszkowej Góry i okolic*. (In Polish only). Unpublished – Archiwum Zarządu Zespołu Jurajskich Parków Krajobrazowych Województwea Katowickiego, 93 pp.
Gradziński, M., 1998. Pedogeniczne komponenty w jaskiniach okolic Krakowa – charakterystyka, pochodzenie, wiek. (In Polish only). In: Szynkiewicz, A. (ed.), *Materiały XXXII Sympozjum Speleologicznego*. Sekcja Speleologiczna PTP, pp. 44–45.
Gradziński, M., Górny, A. & Szelerewicz, M., 1995. *Jaskinie Ojcowskiego Parku Narodowego. Dolina Sąspowska, Wąwóz Jamki*. (In Polish only). Ojcowski Park Narodowy, Muzeum im. prof. Władysława Szafera, Ojców, 92 pp.
Gradziński, M., Szelerewicz, M. & Górny, A., 1994. New caves in the Cracow–Wieluń Upland deserving of protection. (In Polish, English summary). *Przegląd Geologiczny*, 42: 205–208.
Gradziński, R., 1962. Origin and development of subterranean karst in the Southern part of the Cracow Upland. (In Polish, English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 32: 429–492.
Gradziński, R., 1972. *Przewodnik geologiczny po okolicach Krakowa*. (In Polish only). Wydawnictwa Geologiczne, Warszawa, 335 pp.
Gradziński, R., 1977. Sedimentation of "moulding sands" on karstified limestone surface in the middle part of Kraków–Wieluń Upland. (In Polish, English summary). *Kras i Speleologia*, 1: 59–70.
Groschopf, P., 1980. Die Eisenertze der Ostalb – Entstehung und Vorkommen. *Aalener Jahrbuch 1980*: 13–25.
Harris, R. C. & Troup, A. G., 1970. Chemistry and origin of freshwater ferromanganese concretions. *Limnology and Oceanography*, 15: 702–712.
Hill, C. & Forti, P., 1997. *Cave Minerals of the World*. National Speleological Society, Huntsville, 463 pp.
Hsü, K. J. & Giovanolli, F., 1979. Mesinian event in the black Sea. *Paleogeography Paleoclimatology, Paleoecology*, 29: 75–93.
Hsü, K. J., Montadert, L., Bernoulli, D., Cita, M. B., Erickson, A., Garisson, R. E., Kidd, R. B., Mèlierès, R., Müller, C. & Wright, R., 1977. History of the Mediterranean salinity crisis. *Nature*, 267: 399–403.
Klimaszewski, M., 1958a. The geomorphological development of Poland's teritory in the pre-quaternary period. (In Polish, English summary). *Czasopismo Geograficzne*, 30: 2–43.
Klimaszewski, M., 1958b. Modern views on the development of the karstic relief. (In Polish, English summary). *Przegląd Geograficzny*, 30: 425–438.
Kościówko, H., Kural, S. & Milewicz, J., 1978. Problemy genezy i wieku kaolinów Dolnego Śląska. (In Polish only). In: *I Konferencja minerały i surowce ilaste, Bolesławiec 25-28 kwietnia 1978*. Polska Akademia Nauk Komitet Nauk Geologicznych, Polskie Towarzystwo Mineralogiczne Sekcja Minerałów Ilastych, Warszawa, pp. 247–255.
Kowalski, S., 1971. Wyniki najnowszych badań archeologicznych w jaskini Ciemnej w Ojcowie. In: Skalski, A. W. (ed.), *Materiały z III i IV Sympozjum Speleologicznego*. Muzeum w Częstochowie, Częstochowa, pp. 63–67.
Krysowska-Iwaszkiewicz, M., 1974. Mineralogical and petrographical study of Cenozoic continental deposits of the Cracovian Upland. (In Polish, English summary). *Prace Mineralogiczne, Komisja Nauk Mineralogcznych PAN, Oddział w Krakowie*, 35: 1–69.
Lemoalle, J. & Dupont, B., 1973. Iron-bearing oolite and the present conditions of iron sedimentation in Lake Chad (Africa). In: Amstutz, G. C. & Bernard, A. J. (eds.), *Ores in Sediments*. Springer-Verlag, Berlin, pp. 187–178.
Lewandowski, J., 1993. Sub-Quaternary morphology of the Silesian–Cracow region, South Poland, and its morphogenetic evolution. (In Polish, English summary). *Folia Quaternaria*, 64: 101–121.
Mack, G. H., James, W. C. & Monger, C. H., 1993. Classification of paleosols. *Geological Society of America Bulletin*, 105: 129–136.
Madeyska, T., 1977. The age and differentiation of caves and their sediments of the Sąspowska Valley. (In Polish, English summary). *Kras i Speleologia*, 1: 71–80.
Madeyska, T., 1981. Le milieu naturel de l'homme du Paleolithique Moyen et Superieur en Pologne a la lumiere des recherches geologiques. *Studia Geologica Polonica*, 69: 1–125.
Madeyska, T., 1988. The deposits of caves and rock-shelters situated in Sąspowska Valley. (In Polish, English summary). In: Chmielewski W. (ed.), *Jaskinie Doliny Sąspowskiej. Tło przy-*

rodnicze osadnictwa pradziejowego. Prace Instytutu Archeologii UW, 1: 77–173.

Madeyska-Niklewska, T., 1969. Upper Pleistocene deposits in caves of the Cracow Upland. (In Polish, English summary). *Acta Geologica Polonica*, 19: 341–392.

McFarlane, M. J., 1976. *Laterite and Landscape*. Academic Press, London, 151 pp.

Miller, K. G., Fairbanks, R. G. & Mountain, G. S., 1987. Tertiary oxygen isotope synthesis: sea level history and continental margin erosion. *Paleoceanography*, 2: 1–19.

Mirosław-Grabowska, J., 1998. Quaternary stratigraphy in the eastern part of Smoleń–Niegowonice Range (Kraków–Częstochowa Upland). (In Polish, English summary). *Studia Geologica Polonica*, 113: 105–119.

Nahon, D., Carozzi, A. V. & Parron, C., 1980. Lateritic weathering as a mechanism for the generation of ferruginous ooids. *Journal of Sedimentary Petrology*, 50: 1287–1298.

Ney, R., Burzewski, W., Bachleda, T., Górecki, W., Jakóbczyk, K. & Słupczyński, K., 1974. Zarys paleogeografii i rozwoju litologiczno-facjalnego zapadliska przedkarpackiego. (In Polish only). *Prace Geologiczne, Polska Akademia Nauk, Oddział w Krakowie, Komisja Nauk Geologicznych*, 82: 7–51.

Ollier, C. D., 1969. *Weathering*. Oliver & Boyd, Edinburgh, 304 pp.

Oszczypko, N. & Tomas, A., 1976. Pre-Tortonian relief of the Carpathian Foreland between Kraków and Dębica and its effect on Miocene sedimentation. (In Polish, English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 46: 525–548.

Panek, S. & Szuwarzyński, M., 1976. Pre-Tortonian valley with Tertiary fill near Chrzanów (Cracow Upland, Poland). (In Polish, English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 46: 503–523.

Pazdur, A., Pazdur, M., Hercman, H., Górny, A. & Olszewski, M., 1994. Preliminary results of the studies on the chronology of speleothem deposition in selected caves of the Cracow–Wieluń Upland. (In Polish, English summary). *Zeszyty Naukowe Politechniki Śląskiej, Matematyka-Fizyka*, 71, *Geochronometria*, 10: 61–79.

Peryt, T. M., 1983. Classification of coated grain. In: Peryt, T. M. (ed.), *Coated Grains*. Springer-Verlag, Berlin, pp. 3–6.

Pokorny, J., 1963. The development of mogotes in the southern Part of the Cracow Upland. *Bulletin de l'Academie Polonaise des Sciences, Série des Sciences Géologiques et Géographiques*, 11: 169–175.

Pracejus, B. & Bolton, B. R., 1992. Independence of Mn, Fe, and clay mineral formation on Groote Eylandt, Australia: A model for modern and ancient weathering environments. In: Skinner, H. C. W. & Fitzpatrick, R. W. (eds.), *Biomineralization, Processes of Iron and Manganese – Modern and Ancient Environments. Catena Supplement*, 21, Catena Verlag, Cremlingen, pp. 371–397.

Radwański, A., 1968. Lower Tortonian transgression onto the Miechów and Cracow Uplands. (In Polish, English summary). *Acta Geologica Polonica*, 18: 387–445.

Retallack, G. J., 1990. *Soils of the Past. An Introduction to Paleopedology*. Harper Collins Academic, London, 520 pp.

Retallack, G. J., 1993. Classification of paleosols: Disussion. *Geological Society of America Bulletin*, 105: 1635–1636.

Różycki, S. Z., 1960. Jura górna i kreda oraz zjawiska krasowe w północnej części Wyżyny Krakowsko-Częstochowskiej. (In Polish only). In: Różycki, S. Z. (ed.), *Przewodnik XXXIII Zjazdu Polskiego Towarzystwa Geologicznego, częstocvhowa 4-6 września 1960*. Wydawnictwa Geologiczne, Warszawa, pp. 28–50.

Rutkowski, J., 1989. Geological structure of the Cracow region, South Poland. (In Polish, English summary). *Przegląd Geologiczny*, 37: 302–308.

Samsonowicz, J., 1934. Sur les phénomènes karstiques et la breche de Węże prés de Działoszyn sur la Warta. (In Polish, French summary). *Zabytki Przyrody Nieożywionej Ziem Rzeczypospolitej Polskiej*, 3: 151–162.

Schwarzbach, M., 1975. *Climates of the Past. An Introduction to Paleoclimatology*. D. Van Nostrand Company, London, 325 pp.

Szelerewicz, M., 1996. Jaskinia nad Źródłem V. (In Polish only). *Jaskinie Wyżyny, Informator*, 11: 3–6.

Szelerewicz, M. & Górny, A., 1986. *Jaskinie Wyżyny Krakowsko-Wieluńskiej*. (In Polish only). Wydawnictwo PTTK "Kraj", Kraków, 200 pp.

Tardy, Y. & Nahon, D., 1985. Geochemistry of laterites, stability of Al-goethite, Al-hematite, and Fe^{3+}-kaolinite in bauxites and ferricretes: An approach to the mechanism of concretion formation. *American Journal of Science*, 285: 865–903.

Taylor, G., Eggleton, R. A., Holzhauer, C. C., Maconachie, L. A., Gordon, M., Brown, M. C. & McQueen, K. G., 1992. Cool climate lateritic and bauxitic weathering. *Journal of Geology*, 100: 669–677.

Tyczyńska, M., 1957. Climate de Pologne au tertiaire et au Quaternaire. (In Polish, French summary). *Czasopismo Geograficzne*, 28: 131–167.

Walczak, W., 1956. Quatrenary deposits and morphology of the southern part of the Cracow Jura in the Będkówka and Kobylanka basin. (In Polish, English summary). *Instytut Geologiczny, Biuletyn*, 100: 461.

Wolfe, J. A., 1978. A paleobotanical interpertation of Tertiary climates in the northern hemisphere. *American Scientist*, 66: 694–703.

Zhang, M. & Karathansis, A. D., 1997. Characterization of iron-manganese concretions in Kentucky Alfisols with perched water tables. *Clays and Clay Minerals*, 45: 428–439.

Streszczenie

WIEK I ZNACZENIE ŻWIROWCÓW W JASKINIACH OKOLIC KRAKOWA (JURA POLSKA)

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Brak w jaskiniach południowej części Jury Polskiej datowanych paleontologicznie osadów starszych od wczesnego plejstocenu uniemożliwia dokonanie precyzyjnej rekonstrukcji wcześniejszych etapów rozwoju tych jaskiń. W ostatnich latach w pięciu jaskiniach tego rejonu stwierdzono występowanie żwirowców, które zdają się rzucać nowe światło na kwestie powstania i wczesnych etapów rozwoju jaskiń tego obszaru. Pochodzenie materiału budującego żwirowce, ich pozycja stratygraficzna, wiek i znaczenie jest przedmiotem niniejszej pracy.

Badane żwirowce zostały stwierdzone w pięciu jaskiniach południowej części Jury Polskiej: Jaskini Wierzchowskiej Górnej, Jaskini nad Źródłem V, Jaskini bez Nazwy, Jamie Ani i Schronisku ze Żwirem (Fig. 1, 2, 3; Tabela 1). Płytki cienkie ze żwirowców były analizowane w mikroskopie petrograficznymi i w skaningowym mikroskopie elektronowym z przystawką EDS.

Wszystkie jaskinie, w których występują żwirowce są rozwinięte w wapieniach górnej jury. Obecnie jaskinie te są niektywne i stanowią fragmenty większych, częściowo zapełnionych osadami systemów odwodnienia krasowego. Żwirowce stwierdzono w spągowej części profili osadów wypełniających jaskinie lub bezpośrednio na skalnym dnie tych jaskiń. Żwirowce są pozostałością po większej ilości osadów wypełniających jaskinie i wyprzątniętych przez erozję.

Badane żwirowce mają rozproszony szkielet ziarnowy (Fig. 4, 5). Ułożenie komponentów frakcji żwirowej zazwyczaj jest chaotyczne. W dwóch przypadkach – Jaskinia Wierzchowska Górna, Jama Ani – dyskutowane żwirowce cechują się uziarnieniem frakcjonalnym normalnym typu *coarse-tail grading*. Dyskutowane żwirowce złożone są z: (i) ciemnych ziarn o różnym stopniu obtoczenia, (ii) ziarn kwarcu, (iii) ostrokrawędzistych fragmentów wapieni jurajskich i (iv) matrix ilasto-żelazistego. Żwirowce są spojone węglanowym cementem.

Spośród komponentów budujących żwirowce najbardziej zróżnicowane są ciemne ziarna. Część z nich cechuje się bardzo dobrym obtoczeniem, kształtami okrągłymi do dyskoidalnych i gładką zewnętrzną powierzchnią. Wielkość dobrze obtoczonych ciemnych ziarn waha się od 0.5 mm do 10 mm. Natomiast ciemne ziarna źle obtoczone mają kształt dyskoidalny, a ich wielkość sięga 15 mm.

W obrazie mikrokopowym zdecydowana większość dobrze obtoczonych ciemnych ziarn wykazuje wyraźną koncentryczną laminację typową dla ziarn obleczonych (Fig. 6). Część z nich jest pokruszona (Fig. 7). Zdecydowana większość tych ziarn jest pozbawiona jąder. Sporadycznie ciemne ziarna tworzą aglomeraty złożone z kilku scementowanych ziarn i często pokryte są laminowaną krustą (Fig. 8). Spośród dobrze obtoczonych ciemnych ziarn część jest nieprzeźroczysta w świetle przechodzącym, natomiast część ma ciemnoczerwone barwy w świetle przechodzącym. Analiza EDS wykazała, że ziarna nieprzeźroczyste zbudowane są głównie z tlenków manganu, natomiast ziarna o makroskopowej barwie czerwonej zbudowane są z tlenków żelaza (Tabela 2). Znikoma ilość ciemnych ziarn ma homogeniczną budowę wewnętrzną lub posiada laminację płaską, nie nawiązującą do powierzchni ziarn (Fig. 9).

Odmienną budową wewnętrzną w stosunku do opisanych powyżej ziarn charakteryzują się nieobtoczone ciemne ziarna. Są one zbudowane z tlenków żelaza i manganu, węglanu wapnia oraz lokalnie z krzemionki (Fig. 10). Tlenki, głównie żelaza, dominują w zewnętrznej części ziarn, a ich ilość maleje stopniowo w stronę środka ziarn. W zewnętrznej części czytelne są również rizoidy i spękania, wypełnione częściowo cementem kalcytowym, a częściowo krzemionką. W wewnętrznej części tych ziarn zachowane są różnorodne bioklasty jak: igły gąbek, fragmenty szkarłupni i otwornice (Fig. 11, 12, 13). Taka budowa wskazuje, że opisane klasty są fragmentami zmienionych skał węglanowych. Zmiany polegające na przesyceniu głównie tlenkami żelaza, postępowały od zewnętrznej części w kierunku środka ziarn.

Odpowiedniki wszystkich ciemnych ziarn występujących w żwirowcach znane są z różnego typu gleb. Są to konkrecje, skorupy *ferricrete* i klasty typu *core-stone*. Wszystkie powyższe komponenty powstają w glebach typu *oxisol* i związanych z nimi pokrywach laterytowych (McFarlane, 1976; Nahon *et al.*, 1980; Tardy & Nahon, 1985; Retallack, 1990; Taylor *et al.*, 1992). Dowodzi to, że występujące w żwirowcach ciemne ziarna powstały w warunkach sprzyjających rozwojowi gleb *oxisol*, czyli w klimacie tropikalnym lub subtropikalnym. Biorąc pod uwagę proponowane warunki powstania ziarn pedogenicznych, historię geologiczną obszaru krakowskiego (cf. R. Gradziński, 1972; Rutkowski, 1989) a także zmiany klimatyczne zachodzące w trzeciorzędzie (cf. Buchardt, 1978; Hsü & Giovanolli, 1979; Miller *et al.*, 1987) można stwierdzić, że dyskutowane ziarna najprawdopodobniej powstały w czasie paleogen–wczesny miocen, a zwlaszcza w czasie eocenu. Paleogeński wiek ziarn budujących żwirowce i pozycja stratygraficzna żwirowców pozwala na postawienie dwóch hipotez: (i) żwirowce były zdeponowane w czasie oligocenu–miocenu i w znacznej części usunięte w pliocenie lub we wczesnym plejstocenie (przed zlodowaceniami) i (ii) żwirowce były zdeponowane w pliocenie i w znacznej części usunięte również w pliocenie lub we wczesnym plejstocenie (przed zlodowaceniami). Autor przychyla się do pierwszej hipotezy, która stoi w sprzeczności z dotychczas przyjętymi koncepcjami dotyczącymi wieku jaskiń południowej części Jury Polskiej (R. Gradziński, 1962) jak i wieku najstarszych osadów te jaskinie wypełniających (Madeyska, 1977). W obecnej chwili nie można jednak ostatecznie zweryfikować postawionych powyżej hipotez.