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Sedimentation of clastic strata associated with Miocene salts in Wieliczka (Southern Poland)

KRZYSZTOF BUKOWSKI

Faculty of Geology, Geophysics and Environment Protection, Akademia Górniczo-Hutnicza, al. A. Mickiewicza 30, 30-059 Kraków, Poland

Abstract. The Miocene salt-bearing strata in the Carpathian Foredeep near Cracow in Wieliczka, southern Poland, contain intercalations of conglomerates, sandstones and claystones. These rocks show the facies variability and sedimentary structures characteristic of turbidites. The sediments accumulated near the shores of an evaporite basin and thereafter were transported by turbidity currents into deeper parts in the basin.

Key words: Badenian, Miocene, clastic sediments, evaporites, sedimentology, Wieliczka, Carpathian Foredeep.

Introduction

A Miocene salt-bearing formation, that extends as a narrow strip north of the folded and overthrusted Carpathian massif, was deposited in the Late Badenian, *i.e.* about 12.5-13.5 Ma ago (Fig. 1). Paleobotanical investigations show that the associated climate was characterized by dry and hot summers and rainy winters (Zabłocki, 1930). Evaporites accumulated in the foreland of uplifting mountains which coincided with increasing tectonic activity in the Carpathians. Contemporaneous recurrent volcanic eruptions produced pyroclastic deposits (tuffites) whose thickness is as much as 1,000 m in the Transcarpathian basin of West Ukraine (Kityk *et al.*, 1983). The accompanying earthquakes caused landslides and submarine slumps, and initiated turbidity currents, which formed deposits characterized by rapid facies changes and a relatively small extent.

The evaporation basin of Wieliczka was situated far from eruption centers but it contains traces of volcanic material. Tuffite layers occur in the beds both underlying and overlying the evaporites (Kamieński & Glińska, 1966; Wiewiórka, 1979; Parachoniak, 1954, 1962). These rocks are related to with submarine flows and slides interpreted in the Wieliczka mine (Kolasa & Ślączka, 1985; Ślączka *et al.*, 1986; Ślączka, 1994). Their facies variability indicates substantial changes in the water depth and in the configuration of the shore line (Garlicki, 1979; Bukowski, 1994) which reflect dynamic processes connected with the tectonic remodelling of the Carpathians. The aim of this paper is to consider the deposits from the lower part of the Wieliczka salt series as a source of information on the depositional environment and processes which took place during the early stages of salt sedimentation.

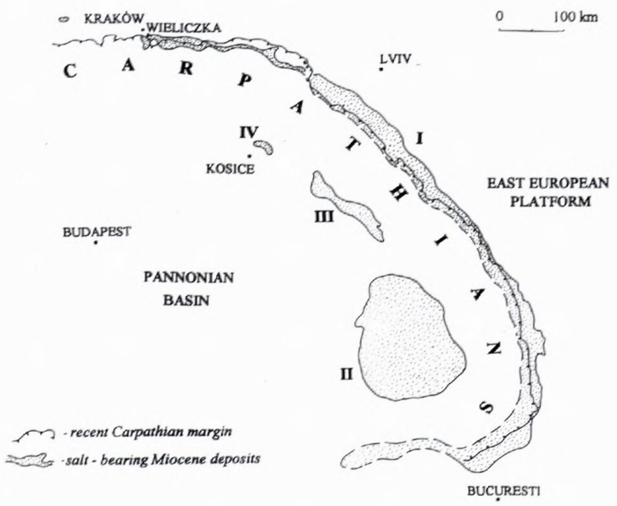

Fig. 1. Distribution of salt-bearing Miocene rocks in the Carpathian zone.
I - Carpathian Foredeep; II - Transylvanian Basin; III - Transcarpathian Basin of West Ukraine; IV - East Slovakian Basin

The mode of development and extent of the clastic rocks

The clastic-pelitic rocks in the lower part of the Wieliczka strata separate two levels of rock salt, the level of the oldest salts from the level of the stratiform "green" salt (see Galamay *et al.*, 1997, Fig. 4). In the literature, these rocks were called the "sub-salt sandstone" as they were considered to be a member that initiated deposition of the salts.

Beds at the base of this series are grey and dark-grey claystones and mudstones containing intercalations of anhydrite 1 mm thick. These rocks represent an extension of the vanishing deposition of the oldest salts and were formed probably as a result of opening a connection with more distant parts of the basin and of an influx of waters undersaturated with NaCl. Overlying the claystones and mudstones are coarse-grained sandstones and conglomerates with a gypsum cement (Charysz & Wiewiórka, 1976) which originated under different conditions. The latter are characterized by abundant carbonized plant fragments, grains of anhydrite, fragments of light-coloured limestones and flysch rocks (light-grey and brown-tan siliceous sandstones and variegated shales). The size of the clasts usually varies from several to twenty centimeters in length but can reach 50 cm. The sorting is relatively poor, and the top and the bottom of the layers are uneven and jagged. If the conglomerates occur only in the central part of the deposit, the overlying coarse-, medium-, and fine-grained sandstones are developed as a regular level, observable over the distance of several kilometers. They are grey-greenish, contain small admixtures of disseminated grains of nodular anhydrite (visible in hand specimens), linear thin layers of plant detritus, and numerous disseminated clay partings. The characteristic features of these rocks include graded bedding, ripplemarks, horizontal bedding and cross-bedding, and complex displacements resembling load casts where coarse- and fine-grained fractions are mingled (Fig. 2, 3). The sequence of these textures corresponds best with the Bouma sequence Tabcde (Bouma, 1962). Such a sequence is repeated several (at least four) times within the series, but is not always fully developed. Away from the axis of the basin, the content of sandstone decreases and the sequen-

Fig. 2.Convolute bedding in coarse-grained sandstones. The Galicja gallery, level IV-V.

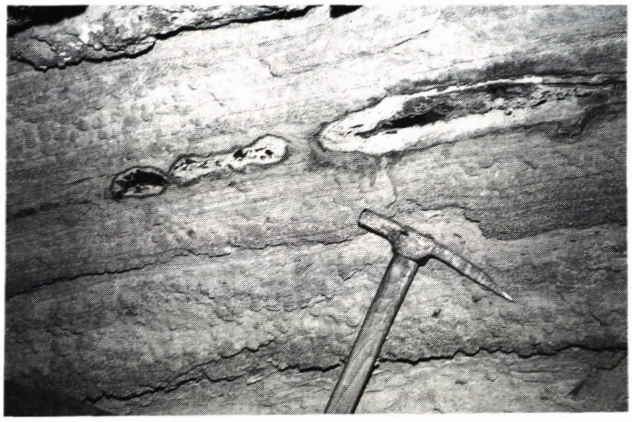

Fig. 3. A fragment of sandstone with a gypsum-halite cement (the graded bedding is visible). The Galicja gallery, level IV-V.

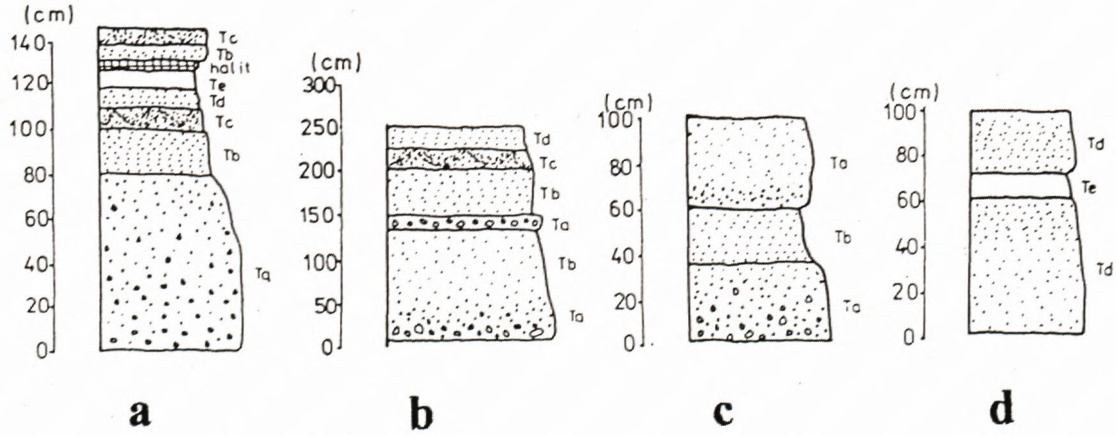

Fig. 4 Examples of Bouma sequences within the "sub-salt" sandstone of the Wieliczka Formation.
a - the modified sequence Tabcde with an additional evaporite layer - the central part of the deposit, the Galicja gallery; b - the Tabcd sequence - the central part of the deposit, the Mina gallery; c - the Tab sequence - the eastern part of the deposit, the F. Miller gallery; d - the Tde sequence - the western part of deposit, borehole no. 962 (Barycz).

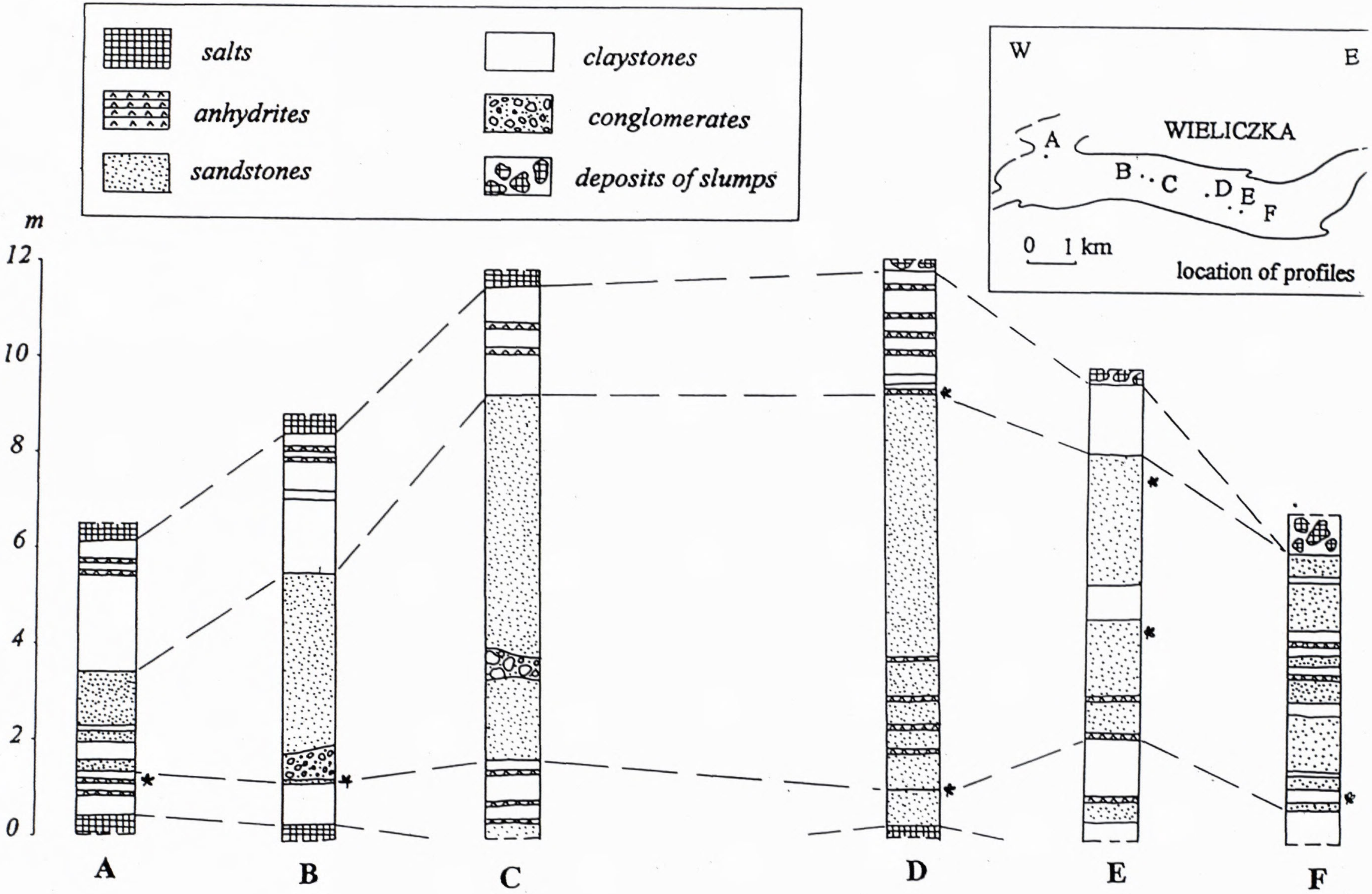

Fig. 5. Lithostratigraphic correlation of "sub-salt" sandstone in the Wieliczka mine.
Location of profiles: A - borehole no. 962 (Barycz); B - Mina gallery; C - Galicja gallery; D - August gallery; E - Ilka gallery; F - F. Miller gallery.

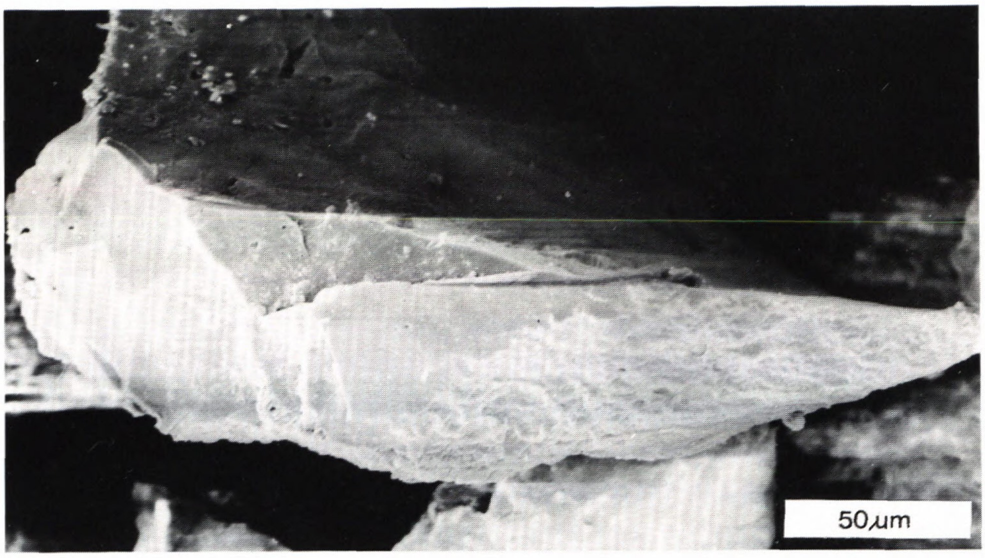

Fig. 6. Angular grain of quartz with a fresh fracture. The sample was taken from sandstone underlying the tuffite insert WT-2. Borehole no. 963.

ces are limited to the Tab (Fig. 4c), Tabcd (Fig. 4b) or Tde (Fig. 4d) members. A modification of the Bouma sequence is caused by the presence of an evaporite layer, tens of centimeters thick, composed of anhydrite or halite. In this case, the sequence takes the form of Tabcdef (Fig. 4a). Plant fragments, which occur most often as a fine dispersed detritus, are sometimes concentrated and include remains of needles, fruits and leaves. The bigger fragments of plants are very rare in the sandstones; they include a carbonized log that was found within the interlevel Kołobrzeg (presently at the collection in the Museum of the Wieliczka Salt Mine).

During geological mapping in the mine, attention was paid to the spatial differentiation of these rocks. Such changes exist west and east of the central part of the deposit and are expressed as the decreasing thickness of the whole series, lower content of coarse-grained deposits, and confining the conglomerate layer only to the center of the basin. Figure 5 illustrates profiles of these sediments at several localities in the basin. The data given by Pawlikowski (1975) to the north seem to confirm this tendency. Simultaneously, towards the top of the whole distinguished series, the coarse-grained sediments disappear and grade into mudstones and claystones, with more abundant intercalations of gypsum and anhydrite. The total thickness of these rocks ranges from 6 m in the marginal parts of the basin to *ca.* 12 m in its center.

Volcanogenic material

In these clastic sedimentary rocks, two layers of tuffites, designated with the symbols WT2 and WT3, were found (Wiewiórka, 1979). They are thin, up to 5 cm, inserts of a pyroclastic material cemented by halite (WT2) or gypsum (WT3) (Pawlikowski, 1975). They were deposited probably in waters with an elevated concentration of NaCl. Such an environment is indicated by weak bentonitization of the volcanic ash; this process must have been slowed by the crystallization of gypsum or halite in intergranular spaces of the rocks (Kamieński & Glińska, 1966; Pawlikowski, 1975).

The volcanogenic material is not confined to the tuffite layers. Observations of the detrital fraction of the clay-sandy rocks underlying the tuffites indicated numerous (up to 40%) angular, transparent quartz grains, often of elongated habit and with fresh fractures (Fig. 6). The lack of rounding and luster in these grains indicate their similarity to pyroclastic quartz, described in many papers (*e.g.* Mišik, 1954; Salat, 1955; Alexandrowicz, 1957). Simultaneously, within the same rocks, the pyroclastic quartz is accompanied by equally numerous quartz grains with leached and corroded surfaces. This advanced corrosion could only be due to the temperature and chemical action of a lava (M. Chandij, pers. com.).

So, the following conclusion can be drawn: the sedimentation of volcanogenic material could have continued for a longer time, also in the clay-sandy deposits, and the tuffite layers were formed only when the volcanogenic material was not diluted by the clastic sediments (comp. Alexandrowicz, 1957). This relationship explains the difficulties faced by some authors during attempts to correlate the tuffite layers. Volcanogenic beds might be continuuous but of variable thicknesses or even discontinuous.

Evaporite minerals

Anhydrite occurs most often in the form of oval aggregates, defined in the literature as nodular anhydrite, and continuous deformed layers, which resemble tectonically folded strata (the so-called enterolithic textures). The nodules (concretions) are usually from several millimeters to several centimeters in diameter. They were formed probably by the alteration (dewatering) of gypsum. Although examples of the primary crystallization of nodular anhydrite from a solution are known, that process is limited to dry and very hot sabkha areas, where the temperature reaches 50°C and concentrated brines tend to rise due to capillary phenomena (Kinsman, 1966; Shearman, 1966). The sabkha environment has not been recognized in the salt-bearing basin of Wieliczka.

The origin of enterolithic textures has not been fully explained. They could have been formed by the sliding of unconsolidated sediment on a slightly inclined sea floor (Garlicki, 1980) or by the deformation of a primary sediment during a post-depositional alteration of gypsum into anhydrite. In the second case, the loss of water and increase in the volume of initially deposited gypsum by *ca.* 38% (Shearman, 1985) could be a major mechanism for these alterations and caused by a rise in temperature during folding of the sediments. Enterolithic anhydrite is commonly found in the described rocks, where it occurs either in form of continuous layers that separate sequences of mudstone and claystone in the uppermost member of the turbidites (Fig. 4a) or as secondary infillings of discordant veins and fractures.

In thinly laminated clay-rocks the anhydrite was formed during diagenesis *in situ.* In coarsely clastic beds, the grains and concretions of anhydrite were brought - similar to other grain components - by currents from other parts of the basin or from the land (Fig. 7, 8).

Fig. 7. A clast of anhydrite with a diameter of 20 cm from within a layer of salt conglomerate. The Lilienbach gallery, level III.

Gypsum occurs with anhydrite in the cement of sandstones and conglomerates, and as fibrous vein fillings.

Halite is less abundant, it occurs in cements mainly in the top and bottom parts of the sequence. The first distinct intercalations of halite herald the onset of the proper chemical sedimentation, *i.e.* the formation of stratified

Fig. 8. A core of sandstone with graded bedding (white grains of anhydrite show the gradation from bigger to smaller ones towards the top of the layer, similar to the other components). Borehole no. 963.

"green" salts. Additionally, redeposited rounded fragments of rock salt and of halite crystals occur in the conglomerate, and locally in coarse-grained sandstone.

Rock fragments

During microscopic investigations, about 10 varieties of rock fragments were distinguished, mainly of sedimentary and metamorphic rocks. The most abundant are fragments of claystone and mudstone with a clay cement, sandstone with a calcareous cement, and marls and variegated shales. These fragments are usually well rounded, with a roundness of 3-4 according to Powers (1953). They are accompanied by less numerous fragments of limestone, most often micritic and finely crystalline, and also by rounded polymorphic clasts composed almost entirely of sutured quartz grains, derived probably from quartzites and gneisses (Pawlikowski, 1975). Single quartz grains show variable rounding and microrelief.

Apart from the angular and corroded quartz grains described above, rounded quartz grains have been distinguished by features pointing to an eolian origin or with evidence of beach abrasion (Fig. 9; also E. Mycielska-Dowgiałło, pers. com.). Numerous mica flakes are disseminated throughout the rocks, particularly in the claystone.

The rock fragments in the detrital sediments were transported from the land surrounding the Wieliczka basin. They were derived partly from the Skawina Beds, as indicated by the microfauna in the accompanying ball clays and sandstones (Pawlikowski, 1975), and from the flysch rocks of the Carpathian land (fragments of sandstones and variegated shales). Clasts of metamorphic

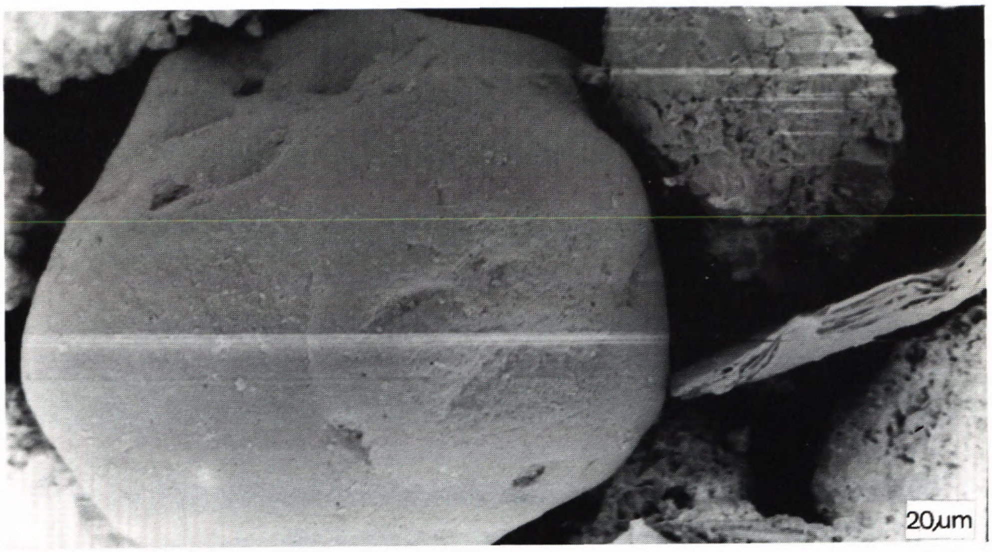

Fig. 9. Quartz grain of beach origin. On the surface of the grain there are half-moon indentations, signs of abrasion. Sandstone sample collected in the Prokopowicz gallery, level III.

rocks (gneisses and quartzites) were probably derived from coarse-grained, older flysch rocks, which had been formed by erosion of the metamorphic cover of a cordillera (Unrug, 1968). The limestone clasts could be derived from both the older rocks of the basement and penecontemporaneous carbonate rocks deposited in marginal parts of the basin.

Sedimentary environment

The clastic sedimentary rocks, deposited between sequences of evaporites, display a fan-like form, a range of thicknesses, and various sizes of detrital grains (Fig. 3). The poor sorting of grains in the coarser fractions, facies variability, grain diameters that decrease with distance from the basin axis, and sedimentary structures indicate that the clastic rocks were deposited by turbidity currents. The currents transported detrital material onto the floor of the basin, where the water was saturated with $CaSO_4$ and almost saturated with NaCl, as indicated by experiments on the crystallization of salts (Jänecke, 1915; Friedrich, 1924). This environment favoured the crystallization of sulfates, either as the cement of sandstones or as regular layers of gypsum. Clasts of rock salt, which occur in conglomerates, were not dissolved under such conditions, and wood fragments have been preserved without signs of decay (Kolasa, 1988). The clastic material accumulated as a vast fan, whose central part is represented by outcrops situated between the "Kościuszko" and "Daniłowicz" shafts. The presence of the submarine alluvial fan in Wieliczka was proved earlier Ślączka *et al.*, 1986).

In the upper part of the profile, a distinct slackening of the sedimentation rate can be interpreted. At this stage, currents were moving slowly and only fine detrital material could be deposited. The presence of pyrite, which occurs within dark-grey claystones, suggests euxinic conditions during deposition. It is probable that such conditions prevailed only in deeper parts of the basin. In shallow waters organisms could proliferate, which is indicated by the fossil fish, found in sandstone (Kolasa, 1981), and by the laminae of fine plant detritus which probably are algal fragments (Kolasa, 1988). The gradually lessening transport of terrigenous material combined with the progressive concentration of stagnant brine resulted in saturation of the water with NaCl, followed by the crystallization of rock salts within clayey sediments. The formation of the regular layers of green salts, which overlie the sequence in question, seems to be complex and its explanation will require separate studies.

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