ABSTRACT:


The Middle Miocene (Badenian) evaporites of the northern Carpathian Foredeep were deposited in a salina-type basin. Calcium sulphate sediments were deposited mainly on the broad northern margins of the basin, on vast evaporite shoals (mainly as fine-grained microbialite gypsum) and in large shallow saline pans (as coarse-crystalline selenites). 125 sections of these primary deposits, exposed from Moldova, Ukraine, Poland to the Czech Republic, were subjected to stratigraphic analysis based principally on the methodology of event and high-resolution stratigraphy. Due to an extremely gentle relief and a predominantly aggradational type of deposition, typical of a salina basin, the environmental changes or events were recorded nearly instantaneously in the whole area. Some events, such as water-level or brine-level fluctuations (emersions and floods, which can be very rapid in a salina basin), fluctuations in the average pycnocline level, aeolian dust or ash falls, accretion of specific gypsum microbialites, produced sets of marker beds which are perfectly correlated over distances of tens to hundreds of kilometres. Some thin grass-like selenite beds, representing deposits of shallow flat-bottomed saline pans, were correlated precisely over such great distances and are interpreted as isochronous or near-isochronous. Each bed was presumably deposited during the average pycnocline level highstands in the saline pan. The thick-bedded selenite units do not show long-distance bed-by-bed correlation, presumably because they were deposited in deeper pans in which the pycnocline fluctuations were recorded by bedding planes (i.e. by intercalations of fine-grained gypsum or dissolution surfaces) only on the shallow slopes or swells. However some apparent growth zones in the gypsum crystals from such selenite units were correlated throughout the basin, proving that the selenite growth was isochronous.

Key words: Event stratigraphy, High-resolution stratigraphy, Evaporites, Gypsum, Marker bed, Isochronous correlation, Selenite crystals, Growth zoning, Badenian, Carpathian Foredeep.

INTRODUCTION

The Middle Miocene (Badenian) evaporite basin of the northern Carpathian Foredeep (Text-fig. 1) is one of the largest evaporite basins with preserved diagenetically unaltered gypsum deposits which include differentiated and spectacular primary selenite (coarse-crystalline gypsum) facies. The gypsum deposits are well exposed and undisturbed horizontal layers can be traced for tens of kilometres through a belt of outcrops along the whole northern periphery of the Foredeep from Moldova, Ukraine, through Poland, to the Czech Republic (Text-fig. 2). This makes this selenite-evaporite basin unique for sedimentologic and stratigraphic studies.
A correct reconstruction of the depositional history and palaeogeography of sedimentary basins is not possible without stratigraphic analysis. In bedded sequences of sedimentary rocks the best stratigraphic solution is to find as many as possible isochronous surfaces ('time lines') representing the floor of a basin evolving through time during sediment accumulation, erosion and/or non-deposition. The documentation of such isochronous surfaces in the Badenian evaporites of the northern Carpathian Foredeep and the establishment of a stratigraphic framework for gypsum basin analysis is the main aim of this paper.

The palaeogeography and geology of the Badenian evaporites studied were reviewed by BABEL (2004b). The evaporite basin, at least at its northern sulphate margin (Text-figs 1-2), was a salina-type basin (PERTY 2001), which showed water level fluctuations that did not coincide with the world sea level and apparently was supplied with marine water by seepage or occasional inflows through some morphologic barriers.

The analytic basis for this study consists of sedimentologic observations collected by the author during fieldwork on Badenian evaporites in Ukraine, Poland and the Czech Republic in 1992-2002. 125 gypsum sections were measured along the entire margin of the northern Carpathian Foredeep (see Appendix; available only in electronic version attached to the main paper, at the journal website: www.geo.uw.edu.pl/agp), of which 52 were selected as the most representative and shown on the summary scheme (Text-figs 2, 4). The other well documented gypsum and anhydrite sections, especially from outcrops in the Nida area (BABEL 1996, 1999b) and borehole cores from the northern part of the Polish Carpathian Foredeep (KUBICA 1992, KASPRZYK 1993), can be easily correlated and compared with the stratigraphic scheme presented.

The present paper supplements the previous stratigraphic studies in the Badenian evaporite basin (KUBICA 1992, PERTY & al. 1998, PERTY 2001), particularly those in the Nida area in Poland (WALA 1980; BABEL 1996, 1999b). Detailed observation and the large number of the gypsum sections studied enabled the identification and long-distance correlation of a more complete set of marker beds than previously recognised. Isochronous correlation was achieved by applying event and high-resolution stratigraphic methodology. Specific processes and depositional events characteristic of evaporite and selenite deposition were recognised and selected as the most useful for basin isochronous correlation. Some new concepts for high-resolution correlation of selenite beds (see BABEL 2004a) were applied. The results obtained and ideas developed in this regional study can be useful for stratigraphic analyses of similar selenite dominated ancient evaporite basins.

Fig. 1. Palaeogeography and distribution of Badenian evaporite basins. A) Palaeogeography of Paratethys and Mediterranean in the Middle Miocene and location of the Badenian evaporite basin studied (after RÖGL 1999). B) Present distribution of the Badenian evaporites in the Carpathian area (after KHRUSHCHOV & PETRICHENKO 1979, GARLICKI 1979, modified)
Fig. 2. Distribution of the gypsum sections studied in the Badenian (Middle Miocene) evaporite basin in the northern Carpathian Foredeep in Ukraine, Poland, Czech Republic and Moldova; after various sources cited in BÁBEL 2004b and Appendix; A-B - Maps of the study area and correlation line for Text-figs 3-4.
PREVIOUS STRATIGRAPHIC STUDIES

The Badenian gypsum deposits in the northern Carpathian Foredeep were roughly subdivided into two main stratigraphic units: the lower autochthonous and the upper allochthonous unit (Text-fig. 3; PERYT 1996, ROSELL & al. 1998, KASPRZYK 2003). The lower unit is up to 25 m thick and contains widespread layers of coarse-crystalline bottom-grown gypsum crystals and therefore is also called the selenite unit. The upper unit, which locally attains 35 m in thickness, is composed of clastic or micro-crystalline gypsum but also contains thin selenite beds. The lower unit is better exposed and the present study concerns mainly this lower part of the succession. Sections in Ukraine are commonly dominated by thick gypsum micro-bialite layers which, near the Zbruch River and the Ukraine–Moldova border, make up the entire 20 m thick section (PERYT 2001). The central areas of the basin, hidden in the subsurface near the Carpathian overthrusts, contain laminated anhydrite deposits, commonly with clay and halite intercalations (POLTOWICZ 1993, PERYT 2000, KASPRZYK 2003). Thicker halite deposits are present in several subbasins identified from borehole cores (Text-figs 1B, 2). Stratigraphic correlation between these halite deposits in Poland and Ukraine, and between them and the marginal gypsum deposits analysed in this paper are still controversial (compare correlations by LADYZHENSKIY 1997). The stratigraphic methodology applied required detailed recognition of sedimentary environments. These environments are well known from many previous studies (KWIATKOWSKI 1972; KASPRZYK 1993, 2003; PERYT 1996, 2000, 2001; PETRICHENKO & al. 1997; KASPRZYK & ORI 1998; PRYSZAJNIAK 1998; BABEL 1999; NOWAK & POLTOWICZ 2000, p. 385; POBREZGINSKY 2000; ANDREYEVA-GRIGOROVICH & al. 2003).


Recently, a more precise and formal event stratigraphic approach, based on selected thin marker beds unequivocally interpreted as isochronous, was applied to the Badenian gypsum evaporites by PERYT (1996, 2001), BABEL (1996, 1999b), BABEL & al. (1998) and BABEL & BOGUCKI (1999). KUBICA (1992) previously attempted isochronous correlation of some tuffite marker beds in gypsum cores and BABEL (1987) noted isochronous correlation of some growth zones in selenites.

METHODS OF STRATIGRAPHIC ANALYSIS

The event stratigraphic methodology used in this paper is supplemented by lithostratigraphy and elements of high-resolution stratigraphy and cyclostratigraphy. The high-resolution approach (cf. KAUFFMAN 1988) was used only for parts of the measured sections and was limited by the fact that the method of investigation was macroscopic. Correlation was made by a simple optic ‘best fit correlation’ (cf. STRASSER 1994, PITTEL & STRASSER 1998).

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Sedimentary or depositional events are a crucial concept in event stratigraphy. They are commonly defined as very short (hours to days), usually rare intervals of rapid deposition within a system of relatively slow background sediment accumulation (EINSELE & al. 1996). Some authors suggested that events less than 100 ky in duration could have lasted only 20-40 ky (KUDRIN 1955, GARLICKI 1979). However, these definitions are applied mostly to clastic and carbonate deposits and are unsuited to high-resolution stratigraphic studies of evaporites. Evaporite deposition rate is very rapid in comparison with average sedimentation rates of clastic, carbonate or other sediments, hence evaporites are commonly treated as a single event bed. The Badenian evaporites of the Carpathian Foredeep were commonly considered as a single chemical sedimentation event which could have lasted only 20-40 ky (KUDRIN 1955, GARLICKI 1968, TRASHLIEV 1969, NIEMCZYK 1995, PETRICHENKO & al. 1997, cf. KREUTZ 1925). Events useful for high-resolution stratigraphy of evaporite deposits should be significantly shorter than this period.

The following terminology is used in this paper. The term event is used in a broad sense. It is defined as a basin-
scale depositional process, or sequence of processes, which produced a well recognisable record in sediments. Non-deposition and erosion are included in these processes (cf. KAUFFMAN 1988, EINSELE 1998). This record is represented by a stratum or bundle of strata described as an event bed. Extremely thin event beds or discontinuity surfaces are distinguished as event horizons (EINSELE 1998).

The process or processes defining the events should be of relatively short duration, but not necessarily shorter than that of the background sediment accumulation (cf. ERNST & al. 1983). Such a definition is chosen for practical reasons, taking into account the stratigraphic importance of some otherwise relatively short-term events in evaporite basins, like e.g. basin wide refreshments and/or dissolution; these events could be of very long duration when compared to the rapid background evaporite deposition. The event should be isochronus in the entire basin.

A marker bed is a selected event bed useful for long-distance correlation. A marker bed, by definition, should be thin, easily recognisable in outcrops, have a high correlation potential, and should represent a well recognised sedimentary event (or sequence of events) on a basinal scale (EINSELE & al. 1996). Event horizons useful for long-distance correlation are described as marker horizons. Helpful features for the recognition of marker beds are their constant position in the section (in relation to lithostratigraphic units) and their occurrence within bundles of strata that reflect a constant continuous sequence of basin-scale depositional processes or, in other words, a constant sequence of events (see SCHWARZACHER 2000). Marker beds or horizons of different origin occurring together in the same thin interval of the section and in a constant sequence are the most valuable for correlation (as in the case of the ‘event-bundle’ concept discussed by WIESE & KROGER 1998, pp. 269-270; cf. ERNST & al. 1983, figs 5-6; and the ‘composite event’ concept discussed by KAUFFMAN 1988, and KAUFFMAN & al. 1991).

The isochronous surfaces reflect ‘time lines’. It is required that these surfaces, as far as possible, should be chronostratigraphic boundaries rather than marker beds, and have the best potential for high-resolution isochronous correlation. The isochronous surfaces are marked by very thin physical units, discontinuities or lithologic boundaries, representing a chosen basin-scale isochronous event most useful for high-resolution long-distance correlation. They are marked by a selected marker horizon, or at the top or base of some selected part of a given marker bed. In practice, isochronous surfaces are commonly placed on ‘master bedding planes’ (SCHWARZACHER 2000).

The following procedure was applied during the stratigraphic analysis. First, after detailed logging of the sections and careful sedimentologic and facies studies, sequences of sedimentary events were recognised and event beds and event horizons were distinguished and correlated. Secondly, the most useful event beds were selected as marker beds for long-distance correlation. Marker beds were designated on stratigraphic sections by small letters, often with additional numbers, corresponding to alphabetically designated lithostratigraphic units distinguished previously (Text-figs 3-4; WALA 1963, 1979, 1980; KUBICA 1992; Appendix, Fig. 3). Finally, based on these marker beds and the sequences of events responsible for their creation, isochronous surfaces were designated and isochronous events defined. The isochronous surfaces were designated by capital letters: A, C/D, Tb, Td, G/H, F1.

Two types of isochronous surfaces were distinguished: high-quality and low-quality isochronous surfaces (Text-figs 4-5). High-quality isochronous surfaces represent short-term events not connected with dissolution and/or erosion. They are represented by dust or ash falls and growth zoning of selenite crystals. Low-quality isochronous surfaces are connected to events such as non-deposition and/or erosion-dissolution. Non-deposition or erosion surfaces could represent relatively long periods of time with many unknown sedimentary events possibly hidden within. Nevertheless only one, the most significant and relatively short-term isochronous event recorded in a given surface was chosen as defining that surface. This event was also specifically selected to secure, as far as possible, the chronostratigraphic potential of the low-quality isochronous surfaces (similarly as unconformities representing sequence boundaries in sequence stratigraphy; e.g. NYSTUEN 1998, pp. 96-98). This chronostratigraphic potential is maintained only when such surfaces are real ‘time barriers’ and all of the strata below them are older than the strata above them within the whole basin (CATUNEANU 2002, p. 28).

The stratigraphic meaning of the non-deposition and/or dissolution-erosion surfaces of the evaporite basin corresponds to erosion surfaces formed during exceptionally rapid sea-level rise, and to condensed beds associated with maximum transgression (KAUFFMAN 1988, pp. 620, 622; KAUFFMAN & al. 1991, p. 805; cf. EINSELE 1998, p. 182). The water level fluctuations in salina-type basins, such as the Badenian basin studied, can be very rapid (even hours or only several years in duration) and large (BAJEL 2004a, b; with references). Such short-term fluctuations can produce erosion or discontinuity surfaces and an associated sedimentary record useful for isochronous or near-isochronous correlation.

Events defining the low-quality isochronous surfaces are sometimes weakly documented and can be controversial. However, such a slightly arbitrary approach in defin-
ing isochronous events and surfaces presumably will help in future discussions of the stratigraphic value of these important surfaces and in correlation with other parts of the basin. Further analysis and comparison with more continuous sections may lead to reassessment and redefinition of the isochronous events defining time-lines around the marker beds.

LITHOSTRATIGRAPHY

Seven lithostratigraphic units lettered from A to G, originally called lithotypes or lithosomes, were distinguished in borehole cores in the Polish Carpathian Foredeep by KUBICA (1985, 1992). These units continue to the east up to the environs of Horodenka in Ukraine (Text-figs 2-4). Further east there are three other units, described in more detail by BABEL (2005 in press) and designated alphabetically as follows:

M – fine-grained gypsum deposits representing mainly gypsum microbialite facies and alabastrine facies

SH – selenite and selenite-gypsum microbialite deposits representing mainly facies with horizontal sabre crystals

SV – selenite deposits representing mainly sabre gypsum facies with crystals curved upward

In Upper Silesia and the Czech Republic (at Koberˇice), in the western area of the basin, and at Broniakówka, at the southern margin of the basin (Text-fig. 2A), the other units are distinguished. They are lettered similarly to the units by KUBICA (1992) because they are exact lithologic equivalents of these units and occur in the same vertical sequence (Text-fig. 4). The lateral continuity of the gypsum layers between the studied western, southern, and northern areas of the basin is interrupted.

Units from A to G are recognised in most borehole cores in the northern area of the Polish Carpathian Foredeep (KUBICA 1992; KASPRZYK, 1989a, 1993). They crop out in the Nida area and, except for unit F, in the Miechów Upland (Text-figs 2-4). The subsurface lateral continuity of units A-G in the northern area of the basin in Poland is well supported by geophysical methods (KUBICA 1994). Such precise geophysical correlation is lacking in Ukraine, where only a few borehole cores were measured in detail (KASPRZYK 1995a). The lateral continuity of unit F, in particular, is poorly documented.

Units A-G change their appearance laterally, passing from west to east. In Ukraine, all the selenite deposits show massive structures unlike the porous ones typical of the Polish-Czech area of the basin. The sabre crystals within the SH and SV units, unlike those from units C-D, and F, which are grey in colour, are honey to brown due to included organic matter. The Ukrainian sections, and especially unit E, contain very little clay. Badenian gypsum deposits in Ukrainian outcrops are commonly entirely or partly altered into secondary alabaster. Most commonly the lowermost part of the section – unit A and the boundary area between units A and M - is composed of such secondary gypsum (Text-fig. 4). Some sections show, however, relict primary features that permit stratigraphic correlation (Appendix, Figs 8, 10, 12-14, 17).

GYPSUM CRYSTAL MORPHOLOGY AND FABRIC AS A STRATIGRAPHIC TOOL

Like those of many other evaporite basins (RICHTER-BERNBURG 1973, ROUCHY 1982, DRONKERT 1985), the

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![Fig. 3. Lithostratigraphy of the Badenian gypsum evaporites in the northern Carpathian Foredeep along the correlation line from Miechów Upland to Bukovyna (Text-fg. 2)](image-url)
Fig. 4. Summary of facies and stratigraphic relations in representative sections of the Badenian gypsum deposits in the northern Carpathian Foredeep along the correlation line shown in Text-fig. 2. (Details are shown in Appendix.)
Badenian selenite beds form laterally continuous units which preserve the fabric and morphology of the gypsum crystals. The giant gypsum intergrowths show a peculiar morphology that has no known equivalent among modern and ancient evaporite gypsum crystals. This indicates the unique composition and properties of the brine in the evaporite basin (see Babel 1991, Rodríguez-Aranda & al. 1995). The presence of such peculiar non-recurring brines and conditions influencing the morphology of the crystallizing gypsum can be treated as an event of stratigraphic value, particularly in the case of the giant intergrowths (unit A, Text-fig. 4), which appear only once in the stratigraphic column.

Apart from the giant intergrowths, some other thin selenite beds also show a peculiar crystal morphology and fabric that is useful for stratigraphic purposes (for example beds h1 and f1, described later in this text; Pl. 5, Fig. 1; Pl. 6, Figs. 1-2; Appendix, Figs 9A-C, 12A-C, 13A-B). Similarly to the giant intergrowths, these thin selenite beds can be treated as event or marker beds reflecting the appearance in the evaporite basin of properties of brine and conditions determining the morphology and fabric of the growing gypsum crystals. Thin selenite beds showing a distinctive crystal habit and reflecting similar ‘events’ are known from other Neogene evaporites (e.g. Schreiber & al. 1977, Rodríguez-Aranda & al. 1995).

The morphology of the gypsum crystals and the associated fabric features, size and arrangement of crystals, are very similar within lithostratigraphic units containing selenites, and usually differ between particular units (Text-fig. 4; Appendix, Figs 6-13, 15-18). This might suggest that these selenites were deposited from different brines. Moreover, there are vertical trends of changes in crystal morphology and fabric within these thick selenite units that are always the same in every outcrop. For example, it is a rule that within unit C-D sabre crystals become commoner and larger up-section (see hachure in selenite units that are always the same in every outcrop. For example, the morphology of selenites can be treated as event or marker beds reflecting the appearance in the evaporite basin of properties of brine and conditions determining the morphology and fabric of the growing gypsum crystals. Thin selenite beds showing a distinctive crystal habit and reflecting similar ‘events’ are known from other Neogene evaporites (e.g. Schreiber & al. 1977, Rodríguez-Aranda & al. 1995).

The changing properties and parameters of the evolving brine, recorded by the sequence of changes in crystal morphology and crystal fabric, can be treated as events that are useful for rough long-distance correlation of the selenite deposits.

It was noticed from early studies that the morphology of gypsum crystals is tied to certain environmental conditions and to some extent can be used as an indicator of these specific conditions (e.g. Lacroix 1897, Cody & Cody 1991, Magee 1991). For example, the morphology of selenites from saltwater pans was found to be related to salinity (Orrt & al. 1984). Discussion of this problem, and recognition of the factors and brine properties which were responsible for the morphology of the Badenian gypsum crystals, requires further study (Babel 1991, 2000) and is beyond the scope of this paper.

MARKER BEDS, EVENTS AND STRATIGRAPHY

Growth zoning in giant gypsum intergrowths

Description: Growth zoning of the giant gypsum intergrowths is very unclear (Babel 1987). Three distinctive coloured zones are easily seen from macroscopic determination and correlation in the field: dark, white, and orange zones (Appendix, Figs 4-5).

Dark zones are discontinuous, ca. 0.5 cm thick, black to dark bands with diffuse boundaries that are best seen on the composition surfaces of the giant intergrowths (Pl. 1, Figs 1-2, Babel 1987, pl. 3, fig. 1). They always occupy a constant position in the upper part of unit A (Appendix, Figs 4-5, 6A, 8A-C). The zones are usually parts of gypsum crystals enriched in flocculent inclusions of organic matter. The inclusions are dark to brown in transparent light under the optical microscope, and some of them are phytoclasts.

White zones, present in gypsum crystals, are seen as 1 mm thick, subhorizontal, continuous wavy to zigzag white laminae with sharp boundaries (Pl. 1, Figs 1-2, Babel 1987, pl. 9, figs 1-2). They cross-cut elongated gypsum subcrystals suggesting that formation of the zone was preceded by dissolution and flattening of the gypsum substrate. The zones represent a dense accumulation of trapped solid inclusions of some very small mineral particles. Radial aggregates of tabular to needle-like gypsum or anhydrite crystals are common among these zones as well.

Rarest of the zoning types are orange-coloured zones formed by tiny orange to brown spots scattered along a single growth zone (Appendix, Fig. 4). The spots appear to be iron oxide or hydroxide compounds.
Interpretation: The dark zones may represent longer periods of microbial and algal blooms in a perennial selenite pan after larger inflows of meteoric waters, such as observed in the Dead Sea (OREN 1999). The presence of phytoplankton suggests such inflows, namely transport by run-off waters from the land. The increased inflow of fresh water could induce some longer period of meromixis reflected by increased ‘accumulation’ of organic matter (see BABEL 2004a). Interpretation of the other zones requires additional studies.

Isochronous surfaces (A) and isochronous events: Up to nine numbered dark growth zones within the giant intergrowths form a bundle of zones designated as isochronous surface A (Text-fig. 4; BABEL 1996; 1999b, fig. 2; Appendix, Figs 6A, 8A-C). The bundle shows a proportional pattern of thickness changes and a constant position in relation to the other white and orange growth zones as well as to the major dissolution surfaces, thus enabling a best fit correlation in the Nida area and Ukraine (PI. 1, Figs 1-2; Appendix, Figs 4-5; cf. MEYERS 1978, p. 382; ANDERSON 1984). The zones represent basin-scale rhythmic growth of giant selenites controlled by climate and hydrologic regimes of deep perennial saline pan.

Although dark growth zones are interpreted as isochronous, it does not mean that the giant intergrowths in Poland and Ukraine grew in the same pan. Growth zoning recorded in adjacent saline pans presumably can be very similar if driven by the same climatic changes, just like the pattern of varves in periglacial or meromictic lakes.

Remarks: Millimetre-scale crystal growth zoning is present in many selenite beds in modern and ancient deposits (e.g. WARREN 1982, 1999). FERSMAN (1919), working on the Saki lake in the Crimea, was probably the first to attempt to count and correlate growth zones in modern selenite crusts. He interpreted them as annual or seasonal and noted that coeval mm-thick zones show different thicknesses in various parts of the lake (similar to the isochronous growth zones recognised in particular parts of the Badenian basin; Appendix, Figs 4-5). Recently the selenites from saltwork pans were investigated by GEISLER-CUSSEY (1986), who found that growth zoning reflects both annual and seasonal (short-term) salinity fluctuations.

The regular mm-scale growth zones observed in some selenite beds presumably have a similar stratigraphic value to that of varves in Pleistocene-Holocene meromictic and periglacial lakes (e.g. ANDERSON & al. 1985, BJORK & al. 1995), tree rings in dendrochronology (GRISSINO-MEYER 2005), or the ‘chemical’ varves in some ancient evaporite meromictic basins (RICHTER-BERNBURG 1985, KIRKLAND 2003). Selenites deposited in seasonally stratified (i.e. monomictic) deeper basins can reflect climatically driven seasonal events similar to those producing varves. Each zone can record a period of increased growth rate of gypsum crystals associated with dry season lowstand, destratification, mixing and homogenisation of the brine column (cf. WARREN 1999, pp. 14, 44; KIRKLAND 2003), and in an ideal case can represent one year (BABEL 2004a). Some mm-scale growth zones in the Badenian selenites were already interpreted as annual varves by KREUTZ (1925) and PETRICHENKO & al. (1997). The most regular, dense, presumably annual growth zones occur in the sabre gypsum crystals within unit C-D and require detailed analysis to reveal their basin-scale isochronous correlation.

Selenite sequences: selenite marker beds b1-b6

Description: The bundle or sequence of marker beds b1-b6 occurs within unit B (Text-figs 3-5). The sequence comprises up to 25 cm thick rows of selenite crystals and their aggregates, commonly of grass-like appearance, intercalated with microbialite, clastic, pedogenic and/or alabastrine gypsum or, rarely, clay. The constant position in the gypsum sequence (below marker bed c), the same proportional changes of thickness of particular selenite beds, and the distribution as well as the appearance of intercalated fine-grained gypsum, readily enables best fit correlation (PI. 2, Figs 1-3; PI. 3, Fig. 1; PI. 4, Figs 1-2; Appendix, Figs 6-9; BABEL & al. 1998, fig. 1; BABEL & BOGUCKIY 1999). Some selenite beds contain characteristic intercalations of orange mud interpreted as dust or ash deposits, and one such intercalation is designated as an isochronous surface Tb (PI. 3, Fig. 1). The other beds show laterally extensive dissolution surfaces. The tops of the selenite beds are commonly flattened or show pockets filled with clastic gypsum (PERRY 1996, figs 9-10). The selenite beds pass laterally into fine-grained gypsum deposits that commonly represent microbialite layers.

Interpretation: Orange mud Tb is interpreted as an isochronous deposit. It occurs, with only a few exceptions, within the same upper part of the selenite bed b1. This suggests that the whole of this bed is also isochronous. The other adjacent selenite beds showing proportionally changing thicknesses are probably also isochronous.

The regular alteration of selenites and fine-grained gypsum suggests cyclic sedimentation and requires an explanation for the driving forces of such a cyclicity. Some selenite beds show features of dissolution on their top surfaces, which are flattened and draped with clastic or pedogenic gypsum and clay, suggesting emersion (see PI. 3, Fig. 2). These features permit the interpretation of such selenites and their covering layers of fine-grained gypsum as shallowing-upward units (cf. STRASSER & al. 1999, p. 205),
Fig. 5. Scheme showing main depositional events in the gypsum section at Oleshiv (Text-figs 2, 4). Selenite marker beds b1-b6 are interpreted as response to fluctuations in the average pycnocline level in a shallow flat-bottomed saline pan. 1-9 – Selenite components (hachure reflects arrangement, sizes and shapes of crystals): 1 – randomly scattered, straight rod-like crystals; short (left) and long (right); 2 – rows of rod-like crystals creating grass-like structures without a sharp base; short crystals (top), long crystals (bottom); 3 – rows of rod-like crystals showing grass-like structures and with a flat base; short crystals (top), long crystals (bottom); 4 – straight grass-like crystals showing palisade-parallel (top) and palisade-radial structure (bottom); 5 – radial or fan-like aggregates of straight crystals grown from common centres (right) and overgrowing fine-grained gypsum dome (left); 6 – rows of small grass-like crystals without a sharp base grown on fine-grained gypsum domes; 7 – rows of small grass-like crystals with a sharp base grown on fine-grained gypsum domes; 8 – aggregates of crystals resembling palm-tree leaves; 9 – flat horizontal synsedimentary dissolution surface within radial aggregates of the grass-like crystals showing syntaxial growth over this surface; 10 – fine-grained homogeneous gypsum (alabaster when massive and white), or other non-differentiated fine-grained or microcrystalline gypsum; 11 – fine-grained (alabaster-like) gypsum with traces of gypsified crenulated microbial mats; 12 – small grass-like crystals covering surfaces of gypsified crenulated microbial mats and intercalating gypsum microbialite deposits; 13 – clay and gypsum-clay deposit; 14 – orange dusty mud; 15 – synsedimentary dissolution surfaces; 16 – small channels filled with sugar-like clastic gypsum; 17 – clay intercalation; 18 – orange dusty mud interpreted as aeolian dust or pyroclastic ash deposit; 50 – horizontal discontinuity surfaces significant for correlation.
and they also suggest that the deposition of the adjacent, over- and underlying selenite beds and intercalated fine-grained gypsum layers could have been similarly controlled by water level fluctuations. Periodic changes in water level and pycnocline level in a salina basin appear to be the simplest and presumably the best explanation for the cyclicity in question. The following detailed interpretation explores this idea, based on the concepts of gypsum deposition developed earlier (Bąbel 2004a).

The Badenian evaporite basin was presumably a salina-type basin with typical frequent, large and rapid fluctuations of water level driven mainly by climate cycles (Bąbel 2004b). The laterally continuous thin selenite beds intercalated with fine-grained gypsum represent deposits of a perennial shallow and flat-bottomed pan in such a basin (Bąbel 2004a, figs 6-7). This saline pan showed monomictic to polymictic hydrologic regimes, with possible short periods of meromixis. The selenite beds were deposited mainly in the hypolimnion or monimolimnion zone below the average pycnocline level. This zone was characterised by a permanent cover of calcium sulphate-saturated brine over the depositional surface. Permanent immersion within such brines, i.e. within the hypolimnion or monimolimnion, is an essential feature enabling the syntaxial growth of thick selenite crusts. The simplest explanation for the ending of selenite crystallisation, and for the transition into the deposition or precipitation of fine-grained gypsum, is that a highly saline brine body was no longer covering the depositional surface. In the shallow perennial saline pan this change might be realised in three ways (Bąbel 2004a): (1) complete brine dilution and transformation of the hydrologic regime of the pan into continuous polymixis which was unfavourable for selenite deposition; (2) deepening (lowering or drop in level) of the pycnocline so that the slope area of the pan came into contact with the upper epi- or mixolimnian water mass, which was permanently in a state favourable for the deposition of gypsum microbialite and fine-grained gypsum; (3) complete drop in the water level (and the pycnocline level) associated with drying out of the pan and the possible deposition of fine-grained pedogenic andelastic gypsum on an emerged selenite crust.

The fine-grained gypsum intercalating selenite crusts is interpreted as deposited on semi-emerged evaporite shoals (developed at the bottom of the pan during the water-level falls), and/or in the shallow epi- or mixolimnian zone above the average pycnocline of the perennial pan (Bąbel 2004a). Clastic fine-grained gypsum could also have accumulated at the bottom of the shallow ephemeral (seasonally drying-out) saline pan.

A tentative reconstruction of changes in water level and average pycnocline level in the perennial saline pan is shown in Text-fig. 5. For simplicity, it was assumed (see Bąbel 2004a for references) that: (1) the changes in water level and average pycnocline level were in phase, (2) the changes in water level were more frequent and rapid than fluctuations of the pycnocline, and (3) the thick selenite beds composed of large crystals devoid of dissolution features and showing continuous growth zoning were deposited in deeper brine than the thin selenite crusts containing smaller crystals (see Bąbel 2004a, figs 6-7). In this interpretation, the changes in average pycnocline level are basically responsible for the cyclic deposition of the selenite sequences. The thicker selenite beds required a longer duration of the average pycnocline ‘highstand’ than the thin beds.

The stratigraphic concept explaining the origin of the precise bed-by-bed correlation of selenite sequences by fluctuations in average pycnocline level presented herein (Text-fig. 5) is similar to the high-resolution sequence- and cyclostratigraphic models for long-distance correlation developed by Strasser (1994) and Strasser & al. (1999). Their models were worked out for shallow carbonate platforms, and are particularly useful in stratigraphic correlation of the flat interiors of such platforms with prevalingly aggradational depositional system (D’Argenio & al. 1999, p. 372, fig. 7). Because of the limited accommodation the stratigraphic record in such environments is commonly incomplete (Strasser & al. 1999). Also in the model applied herein the aggradational system, typical of salina-type or drawdown basins (Warren 1999), is assumed. Conversely, however, I assume more complete stratigraphic record, due to higher accommodation typical of such basins (Bąbel 2004b).

**Selenite marker beds h1-h3**

**Description:** Three stacked selenite beds h1-h3 occur in unit SV (Text-figs 3-4). They contain large domal structures composed of honey-coloured sabre crystals (with upward-curved forms). Selenite bed h1 shows a wavy basal surface coinciding with the tops of the large (up to 1 m in diameter) gypsum-microbialite domes in the layer below (Pl. 5, Fig. 1; Appendix, Figs 9A-C). The overlying selenite domes in bed h1 are an apparent continuation of these structures and show slopes composed of long (15-40 cm) sabre crystals which are horizontal and curved upward. The bundles of such sabre crystals growing against each other on the slopes of adjacent domes created characteristic competitive growth structures (see Appendix, Fig. 7, hachure no. 37 in Key to hachure within lithologic columns; and Pl. 5, Fig. 1) useful for recognition and correlation of this bed. The selenite domes from bed h1 have flattened tops which coincide with a flat or slightly wavy base of the overlying bed (h2). The overlying selenite bed h3 displays a flat or slightly wavy base and top (Appendix, Fig. 11). The tops of
the selenite beds show dissolution features and in places are covered with fine-grained gypsum.

Interpretation: The beds represent the transition from a shallow perennial saline pan, with microbialite-selenite domes growing at the bottom (now present below h1), to a relatively deep, flat-bottomed perennial pan with a hydrologic regime favourable for selenite crystallisation. Beds h1-h3 represent a sequence of depositional events related to synchronous hydrologic changes, fluctuations of the average pycnocline level, and of water level similar to the b1-b6 sequence (see above, and Text-fig. 5), but occurring in the deeper brine. The beds are isochronous or near-isochronous. The flat-topped selenite domes in bed h1 are the products of selenite growth limited by a constant position of the pycnocline (cf. SCHREIBER 1988, p. 203), as observed in the Messinian gypsum at Eraclea Minoa in Sicily (SCHREIBER 1997).

Remarks: The selenite marker beds h1-h3 within unit SV presumably are coeval with some thick, laterally continuous selenite beds appearing around the isochronous surface Td within the adjacent unit B (Text-figs 3-4). These latter beds show a different fabric and do not contain honey-coloured upward-curved sabre crystals like those in unit SV (compare Appendix, Figs 9 and 10). The selenites from unit B and SV were probably deposited in two separate perennial pans. However, the beds under discussion could have been coeval because the hydrologic regimes and sedimentary events of the adjacent saline pans could have been driven by the same extrinsic, presumably climatic, factors.

Selenite marker beds f1-f3

Description: The laterally continuous selenite beds f1-f3 are intercalated within microcrystalline facies in the upper allochthonous unit of the gypsum sequence in Ukraine (Text-figs 3-4; Pl. 6, Figs 1-2; Appendix, Figs 3, 12-14). They correspond to unit F of KUBICA (1985, 1992) and to layer m (sensu BABEL 1996, 1999b), occurring at approximately the same level within allochthonous unit in Poland. As in the case of unit F and layer m in Poland, bed f1 is underlain by clay or directly covers a slightly wavy upper surface of fine-grained gypsum layers, which displays erosion and/or dissolution features. Long, parallel furrows, several cm wide and deep, presumably eroded by strong unidirectional currents, occur directly below bed f1 at Schyrets' quarry and Odaiv (Pl. 6, Fig. 2; Appendix, Figs 13A-B). Bed f1 is about 6 cm-thick and is a very massive selenite crust composed of characteristic conical crystals with morphology and growth structures formed by 'slice-like subcrystals' (see BABEL 1987; 1991, pl. 2, fig. 3b; 1999a, fig. 5A). These growth structures are the same as in the giant intergrowths (unit A); however, the crystals do not create intergrowths, albeit they resemble the component crystals of these giant forms. Bed f1 shows a similar fabric and crystal morphology to the palisade selenite layer occurring at the base of gypsum sequences on the Miechów Upland (e.g. at Rachawice; Appendix, Fig. 16A; BABEL 1991, pl. 2, figs 4-5; pl. 7, fig. 16; ROMAN 1998). The top of bed f1 is a dissolution surface. Bed f2 is a selenite bed similar to f1 but thicker. It contains longer, slightly curved crystals, similar to those from f1, and gypsum microbialite deposits. Bed f3 is covered with a discontinuous layer of clay-gypsum deposits. Bed f3 comprises clusters of typical sabre crystals (see BABEL 1999a, figs 5B-C) forming selenite nucleation cones, 0.5-1 m in size (PERYT 1996, see also DRONKERT 1985).

Interpretation: The selenite sequence f1-f3 marks a period of re-establishment of the selenite pan environment in the depositional area of the microcrystalline gypsum facies, which formerly occupied nearly the whole margin of the basin.

Before deposition of selenite beds f1-f3, the saline pans on the basin margin contained calcium-depleted brines or low-salinity waters which only in some areas were able temporarily to precipitate fine-grained gypsum and halite (ROSELL & al. 1998, BABEL 2005 in press). The peculiar character of these waters or brines, and a low content of calcium ions in particular (BABEL 1999b), were responsible for the predominantly clastic deposition in the microcrystalline facies.

Crystallisation of selenite beds f1-f3 was preceded by basin-wide emersion, pedogenesis, local karst and the deposition of sheet-flood clay and clastic gypsum. Calcium-depleted water disappeared from the basin margin; it evaporated, seeped into the substrate or drained into deeper areas of the basin as in the lowstand scenario in a salina basin discussed by BABEL (2004a, fig. 3). After this emersion, the area was re-connected with the source of new calcium sulphate-enriched brines required for renewed selenite crystallisation. The furrows found below bed f1 at Schyrets' and Odaiv can be interpreted as products of rill erosion during rapid floods of the new brines. After the abrupt rise in water level, brine stratification and a monomictic-polymeric hydrologic regime in the large perennial saline pan became gradually established and selenite deposition started again.

Selenite sequence f1-f3 represents a series of depositional events related to synchronous hydrologic changes, fluctuations in water level and average pycnocline level similar to those in the h1-h3 and b1-b6 sequences (see Text-fig. 5). The f1-f3 beds are also isochronous or near-isochronous.
In the vertical sequence f1-f3, the various crystallographic, growth and morphologic features of the selenite crystals are the same as in the selenite units A to D. It follows that selenites f1-f3 presumably grew in brine having a similar evolution to that obtaining during the deposition of units A-D. This evolution is recorded within a much thinner interval and probably also represents a shorter time interval. Bed f3 passes upward into microcrystalline facies, marking a return to the Ca-depleted brine conditions on the basin margin, as previously after the deposition of unit D (Babel 1999b).

Isochronous surface F1: It is placed at the base of selenite bed f1 and the base of selenite-gypsum microbialite bed m1 in the Nida area (Pl. 6, Figs 1-2; Appendix, Figs 12-13; Babel 1999b).

Isochronous event: It is defined by the establishment of the conditions for permanent gypsum crystallisation on the bottom of the saline pan after the flood of calcium sulphate-enriched brine.

Orange dust marker beds

Description: Orange dusty ‘non-plastic’ mud (marked Tb in Pl. 2, Figs 1-2; Pl. 3, Fig. 1; and T in Appendix, Figs 6, 8-18) commonly fills in the hollows among the apices of selenite crystals and is incorporated into grass-like selenite beds. It forms a kind of the discontinuous wavy laminae 0.1-3 mm thick. In some places, the laminae contain mainly fine-grained gypsum coloured pale orange by some dispersed material. The bottom and top surfaces of the laminae are relatively sharp and the mud does not show lamination or graded bedding. The mud is similar in colour and appearance to the Badenian tuffites recognised in selenite gypsum sections in nearly the whole basin (see KUBICA 1992, p. 34). Grey clay intercalations common in gypsum because it is by KUBICA (1992, fig. 20). The mud differs from the top surfaces. Similar orange mud laminae do not occur in the giant- and coarse-crystalline selenite beds typical of deep pans because the dust was not able to settle through the dense, deep and stratified brine. Such dust was transported in the upper water mass and along the pycnocline and dispersed along the shoreline of the pans (see SONNENFELD 1984, pp. 250-253; SONNENFELD & HUDEC 1985). The deposition of aeolian dust particles directly at the bottom of the pan in brine only a few decimetres deep is difficult because the particles are commonly transported in suspension in wind-driven brine sheets and deposited on the marginal evaporite flats from the sinking brines (LONGMORE & al. 1986).

Pyroclastic laminae or tuffites are common in the Badenian evaporites (see KRACH 1956, BOBROVNIK 1962, KAMIENSKI & GLENSKA 1966, DZHINORIDZE & RAEVSKY 1977). WYSZYŃSKI (1937) recognised seven tuffite laminae within clays intercalated in the middle part of the gypsum and anhydrite deposits N of Stryi. Similar tuffites were found in a borehole core from nearby Oparje (KORENEVSKIY & al. 1977, p. 67), at Korshiv-Ispas 1 (GURZHIY 1969, p. 112), and at Cherche (KUDRIN 1960). KUBICA (1992) found two to three tuffite layers in the lower autochthonous gypsum unit and up to seven in the upper allochthonous unit. At Wieliczka salt mine only three thin tuffite layers were recognised (Wiewiórka 1979, BUKOWSKI 1999). Abundant Badenian tuffite layers occur directly above and below the evaporites and are used for isochronous stratigraphic correlations (BOBROVNIK 1957, GURZHIY 1969, ALEXANDROWICZ 1997, BUKOWSKI 1999).

Isochronous surfaces Tb, Td and isochronous events: Only the orange mud laminae present within bundles of selenite marker beds were chosen as isochronous surfaces (Tb, Td; see Text-figs 4-5, Pl. 2, Figs 1-2; Pl. 3, Fig. 1; Appendix, Figs 3, 8-10) because they are the most easily recognisable and most useful for correlation. The laminae presumably represent aeolian or pyroclastic dust falls which are typical short isochronous events.

Marker bed c

Description: 1-45 cm thick (30 cm on average) layer of fine-grained, snow white to grey, and in places yellow to honey-coloured gypsum appears in a consistent position within the gypsum sections in nearly the whole basin (Text-fig. 4; Pl. 2, Figs 1-2; Pl. 4, Figs 1-2; Appendix, Figs 3, 6A, 8-10, 15A, 18A). The layer commonly shows crenulated microbialite lamination (Babel 1999a, pl. 6, fig. 1), or homogeneous fabric typical of alabastrine facies (Peryt 1996). In some areas a porphyroblastic variety of gypsum is present (Pl. 4, Fig. 2). The base of the layer is
not sharp: fine-grained gypsum covers small ‘grass-like’ selenite lacking dissolution or erosion features. Only locally in the southern Nida area and at Koberčice is the layer underlain by clay. A 0-5 cm (maximum 20 cm) thick cover of non-laminated dark-grey clay or gypsum-clay deposit occurs at the very sharp top of this layer throughout the entire basin. In the eastern area of the basin, bed c thins and locally disappears, and there only this thin clay layer or discontinuity surface enables correlation (Appendix, Figs 9, 18A). The gypsum below this clay layer or discontinuity is commonly porphyrolastic, yellow-coloured, and contains an admixture of calcium carbonate (Pl. 4, Fig. 2). The clay is commonly overlain with fine-grained microbialite gypsum which in many areas forms two to three thin layers designated as the marker beds d1 and d1’ described below (Text-figs 4-5; Pl. 2, Figs 1, 3; Appendix, Figs 6A, 8-10). In the other places, laminated to nodular alabastrine and clastic gypsum occur instead of these beds. In some places, small, flat-bottomed channels are cut into the top surface of bed c, and millimetre to centimetre-size fine-grained gypsum clasts, as well as rounded redeposited crystals, form a kind of lag on this surface (e.g. at Oleshiv S1; Appendix, Fig. 8D). Between the Seret and Zbruch rivers (Text-fig. 2B), the clay overlapping layer c is up to 20 cm-thick, locally shows current ripple cross-lamination, and is enriched in tuffaceous material (‘bentonitic clay’: KLIMCHOUK & al. 1995; TURCHINOV 1999).

The correlative value of this layer was recognised by many authors. The bed was first recognised in the Nida area (‘key layer’: AKERMAN & NIELUBOWICZ 1951; ‘fine-grained gypsum layer’: NIELUBOWICZ 1961; ‘alabaster layer’: KRAJEWSKI 1962, p. 86; ‘white layer’: BOBROWSKI 1963, p. 10). It was designated by WALA as ‘layer Ic’ (WALA 1961), ‘layer c’ (WALA 1962, fig. 1; 1963), and then as the formal lithostratigraphic unit (layer) ‘alabaster from Gartatowice’ (WALA 1980; Appendix, Fig. 6A). Bed c was also noticed in borehole cores in the northern Carpathian Foredeep by KUBICA (1985, p. 41; 1992, p. 24) and was documented along the northern margin of the Foredeep up to the environs of Ivano-Frankivs’k by KASPRZYK (1989a, 1993, figs 3-6 and other papers; 1995a). Bed c was noticed in the Koberčice area (MATI. 1981, p. 247; PERYT & al. 1997a, b; 1998), and in many Ukrainian outcrops by PERYT (1996, and other papers) and BABEL & al. (1998). It was redefined as marker bed ‘1’ by PERYT (2001, fig. 10).

**Interpretation:** Bed c was deposited on a semi-emerged evaporite shoal covered with microbial mats (KASPRZYK 1993; BABEL 1996, 1999a) and subjected in some areas to pedogenesis (Text-fig. 5). The shoal was periodically inundated with brine and the microbial mats were encrusted with gypsum and cemented during salinity rises. Homogeneous alabastrine and porphyroblastic gypsum varieties present in bed c could be a product of direct surface or subsurface precipitation from brine sheets (cf. LOGAN 1987, p. 24; PERYT 1996), or be a result of ‘meteoric’ or vadose diagenesis or pedogenesis (gypsum dissolution and re-precipitation) promoted by rains or run-off water floods (cf. WARREN 1982, MAGEE 1991). In particular, laterally persistent horizons of gypsum porphyroblasts may indicate brine level at the sediment surface (AGNER & BACHMANN 1989, with references; cf. ARAKEL 1980). It is also possible that subsequently dissolved ephemeral halite crusts or efflorescents could have partially dehydrated an underlying gypsum layer. When the next refreshment occurred, the subsequent hydration produced the alabastrine gypsum (B.C. SCHREIBER, personal communication, October, 2003). The clay, clastic gypsum, and dissolution features found at the top of bed c throughout the basin suggest basin-wide brine dilution probably caused by rains. The clay and clastic gypsum were deposited mainly from meteoric water sheet floods. The top of bed c was subjected to pedogenesis, especially in the eastern area of the basin. Termination of evaporite gypsum precipitation could also have been connected with a cut-off from the source and supply of calcium sulphate-saturated brine into the shoal. When the climate became more arid again the progressive evaporite concentration led to a salinity rise and to renewed deposition of gypsum microbialites on evaporite shoals or in ephemeral pans (beds d1, d1’).

**Isochronous surface C/D:** It is placed at the base of the first clay intercalation or first discontinuity surface at the top of the fine-grained gypsum forming bed c (Text-fig. 4-5; Pl. 2, Figs 1-3; Pl. 4, Figs 1-2; BABEL 1996, 1999b).

**Isochronous event:** It is defined by the onset of basin-wide non-deposition and/or erosion following continuous deposition of fine-grained gypsum (gypsum microbialites) on a vast, flat evaporite shoal. This event was connected with a hydrologic change from the brine-covered or brine-soaked shoal (with the brine saturated in calcium sulphate), into a shoal covered with brackish or meteoric water derived mainly from rains. The event was isochronous or near-isochronous because of the extremely gentle relief.

**Remarks:** One undesignated alabaster marker bed, very similar to bed c but thinner and less continuous, appears commonly about 1 m below bed c between the Nida area and Baranów Sandomierski in Poland (KUBICA 1992, p. 24). This 0-20 cm thick bed is also covered with clay.
Marker bed h

Description: A laterally continuous, 10-50 cm thick intercalation of elastic-microbitalite (pedogenic?) gypsum and clay is present in the middle part of unit C-D composed of thick-bedded sabre gypsum facies with vertical crystals (Text-fig. 4; Pl. 5, Fig. 2; Appendix, Figs 3, 6B, 16A, 17). The top of the underlying sabre gypsum bed is commonly eroded and dissolved (corroded). The elastic clay-gypsum sediments display wavy laminations and show features of current deposition (e.g. at Chwalowice and Luchyntsi; Appendix, Figs 6B, 17A) or are homogeneous. Nodular alabastrine gypsum is locally present. Bed h was distinguished in the Nida area by WALA (1962, 1963, 1979; see also KASPRZYK 1994a, figs 3-4; BABEL 1999b, fig. 2). It was correlated in borehole cores along the northern margin of the basin up to the environs of Ivanov-Frankivs’k by KASPRZYK (1989a, 1993, 1995a) and further east in many outcrops up to Odaiv by PERYT (1996) and PERYT & al. (1998). Bed h was redefined as marker bed ‘2’ by PERYT (2001, fig. 10), who correlated this bed with some limestone intercalations occurring in gypsum in the eastern part of the basin (Appendix, Fig. 11A).

Interpretation: Bed h represents interruption of continuous selenite deposition in a deep monomictic and occasionally meromictic pan due to rapid shallowing (cf. KASPRZYK 1993) and destruction of its hydrologic structure, namely a transformation into polymixis characterised by lack of a seasonal or constant pycnocline (see BABEL 2004a). The fall in water level progressed to possible emersion and/or restriction in the supply of calcium sulphate-saturated brine to the depositional area. This restriction contributed to the brine dilution. The fall in water level was caused by evaporitic drawdown of the saline pan and/or drainage of its brine to other deeper areas of the basin. The microbitalite and elastic gypsum comprising bed h was deposited in shallow ephemeral and temporary brackish pans or on semi-emerged evaporite shoals (cf. PERYT 2001). The clay accumulated mainly from sheet-floods of run-off water generated by rains.

Isochronous surface G/H: It is placed at the discontinuity surface at the base of layer h, below the lowermost elastic-microbitalite gypsum or clay, and directly over the tops of selenite crystals in the underlying layer (Pl. 5, Fig. 2; BABEL 1996, 1999b, fig. 2).

Isochronous event: The event is defined by the arrest of continuous selenite deposition in deep perennial saline pans or subbasins. The event was presumably promoted by the rapid fall in water level, and followed the modelled
scenario of a lowstand condition in a salina basin (Bąbel 2004a, figs 2-3).

**High energy events**

Two types of basin-scale high-energy events were recognised in the sections studied.

The first one is the deposition of unique gypsum stromatolitic domes composed of ‘clastic’ gypsum grains (see Appendix, symbols no. 19 and 25 in Key to symbols in Fig. 7, and Figs 6A, 10A-B; Bąbel 1999a, pl. 7, fig. 2). They differ from the commonest gypsum microbialites, which are created by in situ gypsification of microbial mats in a low-energy environment (see Bąbel 1996). The gypsum domes accreted by trapping and binding of gypsum grains by cyanobacterial mats, alternatively with mat gypsification and the growth of thin selenite crusts, in a way described by Bąbel (1999a). These stromatolites were found in the northern Nida area in Poland (Kwiatkowski 1970, 1972; Bąbel 1999a, b) and in the environs of Rohatyn in Ukraine. Both occurrences appear within the same interval of the section: 1.5-3.5 m above marker bed c (Appendix, Figs 6A, 10A-B). The appearance of these unique stromatolites was controlled by specific local conditions (e.g. Hoffman 1967; Shapiro & Awramik 2000) and was probably diachronous (see sections in the Nida area). These stromatolites recorded a series of depositional events related to frequent strong storms and wind waves sweeping gypsum grains over the microbial (cyanobacterial) domes covering the leeside shoals of the shallow saline pans.

The other high-energy events are recorded at Zavallia and Kudrintsy, and are represented by 0.1-0.3 m thick gypsarenite layers sandwiched within gypsified microbial mat deposits (and porphyroblastic gypsum) typical of the flat semi-emerged evaporite shoals (Appendix, Fig 18B). The wave and current ripples on the top surfaces of the gypsarenite suggest a tempestite origin of these layers. The events were probably connected with strong wind waves and currents (cf. Aigner & Bachmann 1989). The cover of clastic gypsum was deposited during the waning phase of the storm and created a local marker bed.

**CYCLIC SEDIMENTATION**

The Badenian gypsum deposits show evidence of cyclic sedimentation at various scales. Growth zoning of gypsum crystals, lamination of gypsum microbialites and the pattern of layering of selenite beds are the most noticeable features. The salina model of sedimentation (Bąbel 2004a, b) suggests the following possible reasons for the cyclicity.

Millimetre-scale crystal growth zoning in selenite beds constitutes the lowest-order cyclicity. It seems that the zones recorded mostly seasonal (year, month, weeks) periods of mixis in stratified monomictic (to polymictic) pans, as discussed before. It is likely that some very regular zoning reflected an annual cycle, with each growth zone representing mixis associated with a dry season lowstand (Bąbel 2004a).

Lamination of gypsified microbial (cyanobacterial) mats is another type of the lowest-order cyclicity. The lamination could reflect periodic floods of brine sheets on evaporite shoals, followed by gypsification of cyanobacterial mats, like in the wet majanna flats in the MacLeod salina in Australia (Logan 1987). Such floods could have been driven by winds or by the temporary fluctuations (rises) in water level that are characteristic of any salina basin. Alternatively, the lamination could reflect a seasonal cycle of gypsification of cyanobacterial mats covering the margins of a monomictic-polymictic pan. Such gypsification could take place during a period of mixis, exactly like in the case of the growth zones of selenite beds. Annual cycles of gypsum precipitation and cyanobacterial mat growth were observed in the monomictic Solar Lake in Sinai (Eckstein 1970, Cohen & al. 1977).

The centimetre- to metre-scale layering of selenite beds can be generally interpreted as a reflection of fluctuations in the water level and average pycnocline level in saline pans occupying a salina basin. This interpretation follows the models for selenite deposition developed earlier (Bąbel 2004a, figs 6-7; cf. Hardie & Euster 1971, fig. 24) and environmental reconstructions of selenite facies by other authors (e.g. Warren 1982, and references in Bąbel 2004a). The suggested interpretation assumes that, in the relatively shallow water and flat-bottomed pans, these fluctuations could produce sequences of isochronous or near-isochronous selenite marker beds reflecting periods of the average pycnocline ‘highstand’ (see Text-fig. 5). In the deeper pans, with the large bottom areas staying permanently below the pycnocline, the accretion of selenites was continuous and they did not record the small-scale fluctuations in water level and pycnocline level that were recorded in the shallow pans.

Thus, the vertical sequence of the units: A-B-C-D (giant-gypsum intergrowths [unbedded or thick-bedded selenites]/grass-like gypsum [thin-bedded selenites]/sabre-gypsum [thick-bedded selenites]; Text-figs 3-4) is interpreted as reflecting large-scale fluctuations in water level in a salina basin: highstand/lowstand/highstand cycle. The distribution of the bedding suggests that the lower-order water-level changes are superimposed on this larger cycle. The smallest-scale changes were recorded only in the lowstand
The salina basin, as discussed in Bąbel (2004b, with refer-
cences), completely obliterated by changes in inflow/outflow ratio in
gested climate control can be complicated or even com-
pared to a working hypothesis. The sug-
ged to be treated as a working hypothesis. The sug-
ected platforms or 'stratification cycles'; see Schwarzacher 2000),
suggesting that they perhaps recorded some subordinate
larger rises in water level and pycnocline level during the
general lowstand (cf. Text-fig. 5). Some subordinate larger-
scale fluctuations are recorded by 0.4-1.5 m layering inter-
vals in the sabre facies. The apparent and laterally extensive
discontinuities between the main sabre gypsum layers with-
in unit C-D (e.g. Appendix, Fig. 17) could represent some
larger drops in pycnocline level and water level during a
more general highstand. The lack or scarcity of such layer-
ing in the giant intergrowths (the lower and middle part of
unit A; Appendix, Figs 6A, 8, 15A) can be explained either
by a lack of similar drops in pycnocline level and water level,
or by deposition in relatively deeper brine than in the case of
the sabre gypsum unit, i.e. permanently below the average
pycnocline level. Rapid drops in water level associated
with relatively long-term.emersions are reflected by breaks
in the normal sedimentary record and are represented by
intervals enriched in clay around isochronous surfaces C/D,
G/H (and similarly: F1).

The nature and duration of all these presumed cyclic
or periodic water level changes require further study; how-
ever, the most simple and most probable factor is climatic
control. The interpretation presented above is simplified
and should be treated as a working hypothesis. The sug-
gested climate control can be complicated or even com-
pletely obliterated by changes in inflow/outflow ratio in
the salina basin, as discussed in Bąbel (2004b, with refer-
cences). Nevertheless, similar cycles in many Messinian
selenite basins (Richter-Bernburg 1973, Schreiber &
al. 1976, fig. 14; Rouchy 1982, Dronkert 1985,
Schreiber 1997, Rosell & al. 1998) and in lake systems
around the world, (e.g. Glenn & Kelts 1991) are inter-
preted as climatically driven. Cycles similar to the high-
stand/lowstand/highstand sequence recorded by units A-
B-C-D are interpreted as related to global climatic
changes promoted by orbital cycles (e.g. Kriegsmann & al.
2001, Roveri & al. 2004). The absence of such cycles in
the eastern area of the basin, where gypsum microbials
predominate, can be explained by sedimentation on a
majanna-type flat in a salina basin (Bąbel 2005 in press).

FINAL REMARKS

In this paper, the event stratigraphic and high-resolu-
tion methodology was applied to the primary shallow-
water gypsum deposits of a large salina-type basin com-
prising mainly evaporite shoal facies (represented typical-
ly by fine-grained gypsum) and saline pan facies (repre-
sented by selenites). This approach has revealed some
new possibilities in isochronous correlation of such evap-
orite deposits.

In the basin studied, some individual beds were corre-
lated precisely over distances of tens to hundreds of kilo-
metres, albeit they were deposited in very shallow to semi-
emerged environments (0.5 m in depth) susceptible to
erosion. Such bed-by-bed correlation was possible because
of the extremely gentle depositional relief in the basin and
the specific type of evaporite deposition, typical of the sali-
na basins, which was aggradation, i.e. vertical accretion of
gypsum sediments, controlled mainly by water level,
water-table level and by fluctuations in the average pycn-
ocline level (Warren 1999). Due to the flat relief, the
changes in water level or pycnocline level were recorded
nearly instantaneously throughout the area. Such fluctua-
tions can be very rapid in a salina basin (especially in com-
parison with typical sea-level changes) and therefore the
depositional or erosional record of such short events can
be used for isochronous or near-isochronous correlation.

The individual selenite beds, in particular, were corre-
lated over great distances and were interpreted as
isochronous or near-isochronous deposits. The best for
correlation were thin (5-30 cm) selenite beds with inter-
calations of fine-grained gypsum (commonly creating
glass-like structures), which represent deposits of the
evolving shallow and flat-bottom saline pans. Each selen-
ite bed is a record of the average pycnocline level high-
stand whereas the intercalated fine-grained gypsum rep-
resents a pycnocline and water level drop or emersion. In
contrast to these well-bedded, grass-like selenites, the
metres-thick, poorly-bedded selenite units with scarce
dissolution surfaces and fine-grained gypsum intercal-
ations do not show precise bed-by-bed correlation in the
basin. These selenites were deposited in deeper saline
pans in which the average pycnocline level drops were
recorded by bedding planes (i.e. by intercalations of fine-
grained gypsum or dissolution surfaces) only in the shal-
low slope areas or swells (Bąbel 1999a, fig. 3). In the
deeper parts of these pans, permanently below the aver-
age pycnocline level, the continuous gypsum crystal
growth did not produce any pronounce bedding.
Nevertheless, the growth zoning in crystals from such
selenite beds can be correlated throughout the basin and
used for precise isochronous correlation in the same
manner as varves or tree-rings.

Precise long-distance correlation is known from sev-
eral different evaporite basins (e.g. Aigner & Bachmann
1989); so far the most precise isochronous high-resolu-
tion correlation was achieved within laminated sulphates
that were presumably deposited in relatively deep meromictic basins below the permanent pycnocline level (RICHTER-BERNBURG 1985, KIRKLAND 2003). The present paper demonstrates that similar correlation is possible in the gypsum evaporites representing the very shallow environments of a salina basin: saline pans no more than a few metres deep and semi-emerged evaporite shoals. The best deposits for isochronal correlation are the primary selenite deposits.

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PLATE 1

Growth zoning defining isochronous surface A in giant gypsum intergrowths; correlated
dark zones and one dark-white zone (marked 3) are numbered as in Appendix, Figs 4-5;
Góry Wschodnie S2, Poland (Fig. 1) and Kasova Hora W, Ukraine (Fig. 2)
PLATE 2

Stratigraphy and selenite sequences near marker bed c; units lettered as in Text-figs 4-5;
Oleshiv: outcrop N of Palahychi N4 (Fig. 1), Pidkamin’ N (Fig. 2) and Podillia (Fig. 3)
PLATE 3

1 – Grass-like selenites intercalating gypsum microbialite and clastic deposits at Mezhyhirtsi; stratigraphic units lettered as in Text-figs 4-5
2 – Grass-like selenite bed covered with fine-grained gypsum showing brecciated and spotted structure which is interpreted as a pedogenic feature (P); a single gypsified cyanobacterial mat is seen as a white band (arrowed) within selenite crust; unit B, Borków
PLATE 4
Stratigraphy and selenite sequences below marker bed c; units lettered as in Text-fig. 4; note large selenite-gypsum microbialite domes; Ozerna cave (Fig. 1) and Tovtry (Fig. 2)
PLATE 5

1 – Sequence of selenite marker beds h1-h3 at Verenchanka; note various-scale domal structures composed of grass-like gypsum and characteristic competitive growth structures (arrowed) between bundles of sabre crystals growing on slopes of the adjacent domes in bed h1.

2 – Marker bed h and isochronous surface G/H within sabre selenite unit C-D at Podillia; the hammer head is 2.3 cm across.
PLATE 6

Sequence of selenite marker beds f1-f3 and isochronous surface F1; Palahychi S1 (Fig. 1) and Odaîv (Fig. 2)
MACIEJ BĄBEL

Event stratigraphy of the Badenian selenite evaporites (Middle Miocene) of the northern Carpathian Foredeep

Acta Geologica Polonica, Vol. 55 (2005), No. 1

On-Line Appendix

World Wide Web Address:
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### Localities in Czech Republic and Moldova

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<td>Kriva, Criva; Moldova</td>
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Fig. 1. Distribution of studied gypsum outcrops in the Badenian (Middle Miocene) evaporite basin in the northern Carpathian Foredeep in Ukraine, Poland, Czech Republic (at Kolberice, area marked by 1) and Moldova (at Kriva, area marked 27); geological map after ATLAS GEOLOGICZNY GALICYI 1885-1914, GARCILLI 1979, PANOW & PILOTNIKOW 1996, and other sources; studied areas are numbered from 1 to 27 and shown on separate detailed maps illustrating distribution of studied sections along the correlation lines.
Fig. 1. Continued. Detailed maps showing distribution of studied gypsum outcrops; Badenian gypsum deposits exposed at the surface are shadowed; map 2 after SARNACKA 1956; map 3 after KUCIŃSKI & NOWAK 1967; map 4 after ROMAN 1998, WALCZOWSKI 1984, WOINSKI 1989.
Fig. 1. Continued. Detailed map showing distribution of studied gypsum outcrops; after many sources cited in BABEL 2002, fig. 7.
Fig. 1. Continued. Detailed maps showing distribution of studied gypsum outcrops; Badenian gypsum deposits exposed at the surface are shadowed; map 6 after TEISSEYRE 1894-1895; map 7 after TEISSEYRE 1895; maps 8-9 after TEISSEYRE 1892-1893
Fig. 1. Continued. Detailed map showing distribution of studied outcrops; Badenian gypsum deposits exposed at the surface are shadowed; after BIENIASZ 1885a, 1896b; TEISSEYRE 1892-1893, 1896
Fig. 1. Continued. Detailed maps showing distribution of studied gypsum outcrops; Badenian gypsum deposits exposed at the surface are shadowed; maps 11-12 after TEISSEYRE 1896; map 13 after BIEVIASZ 1885a, TEISSEYRE 1896; map 14 after BIEVIASZ, 1885a; map 15 after TEISSEYRE 1896, LOMNICKI 1905b
Fig. 1. Continued. Detailed map showing distribution of studied gypsum outcrops; Badenian gypsum deposits exposed at the surface are shadowed; after BIENIAŚ 1985b
Fig. 1. Continued. Detailed maps showing distribution of studied gypsum outcrops. Badenian gypsum deposits exposed at the surface are shadowed; map 17 after BIENIASZ 1885b; map 18 after BIENIASZ 1885b, LOMNICKI 1905a; modified; map 19 after ALTH 1885a; map 20 after ALTH 1885b; map 21 after ALTH 1885a; supplemented; map 22 after BIENIASZ 1898a; map 23 after ALTH 1885b
Fig. 1. Continued. Detailed maps showing distribution of studied gypsum outcrops; Ilidarian gypsum deposits exposed at the surface are shadowed (except for maps 26, 27); map 24 after BIENIASZ 1898a, c; map 25 after BIENIASZ 1898c; maps 26-27 after MACOVEI & ATANASIU 1931.
Fig. 2. Distribution of studied gypsum outcrops and correlation lines in the Badenian (Middle Miocene) evaporite basin in the northern Carpathian Foredeep in Ukraine and north Moldova (locality Kriva; bottom right); after ATLAS GEOLOGICZNY GALICYI 1885-1914, OLSZEWSKI 1911, PANOW & PLOTNIKOW 1996 and other sources (see Fig. 1, maps 6-27 in this Appendix and BABEL 2004).
Fig. 3. Stratigraphy of the Badenian gypsum evaporites in the northern Carpathian Foredeep along the correlation line 4-27 (Miechów Upland-Bukovyna) shown in Fig. 1.
Fig. 4A-C. Correlation of growth zones in the bottom-grown gypsum crystals forming giant intergrowths (unit A) in the Nida area, Poland; correlation line in Fig. 1, map 5; dark growth zone no. 4 as datum; 1 - dark growth zones; 2 - white growth zones; 3 - orange growth zones, 4 - dissolution surfaces; 5 - frequent white growth zones.
FIGURE 4C
Fig. 5.
Correlation of growth zones in the giant gypsum intergrowths (unit A) in Ukraine; correlation line 1 in Fig. 2; dark growth zone no. 4 as datum; see Fig. 4A for explanation of symbols.
Stratigraphic correlation in the Nida area, Poland; correlation line in 5; top of marker bed c as datum; A - lower part of gypsum sequence; i.e. in Fig. 7

FIGURE 6A
Fig. 6. Continued.
B - middle part of gypsum sequence;
key to facies in Fig. 7
### Selenite components:

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**Crystals**

- 1 - Randomly scattered, straight rod-like crystals: short (left) and long (right)
- 2 - Rows of rod-like crystals creating grass-like structures without a sharp base: short crystals (top), long crystals (bottom)
- 3 - Rows of rod-like crystals showing grass-like structures and with a flat base: short crystals (top), long crystals (bottom)
- 4 - Straight grass-like crystals showing palisade-parallel (top) and palisade-radial (bottom)
- 5 - Radar or fan-like aggregates of straight crystals grown from point centers
- 6 - Overgrowing fine-grained gypsum dome (left)
- 7 - Rows of small grass-like crystals without a sharp base grown on fine-grained gypsum dome: short crystals (left), and aggregates of crystals resembling palm-leaf leaves
- 8 - Vertically oriented single sabre crystals: long (left) and short (right)
- 9 - Aggregates of crystals resembling a swallow tail habit
- 10 - Aggregates of crystals resembling palm-leaf leaves
- 11 - Vertically oriented giant gypsum intergrowths showing segmented or chevron structure
- 12 - Obliquely and subhorizontally oriented giant gypsum intergrowths
- 13 - Subvertically-oriented giant intergrowths showing enlarged upper component crystals
- 14 - Palisade of large subvertical crystals similar to component crystals of the giant intergrowths, showing characteristic flat crystal surface and growth structures created by slice-like sub crystals
- 15 - Small crystals similar to component crystals of the giant intergrowths (with characteristic flat crystal surface and growth structures created by slice-like sub crystals: BABEL 1999, fig. 5)
- 16 - Giant intergrowths with enlarged and subparallel component crystals
- 17 - Flat horizontal synsedimentary dissolution surface within giant gypsum intergrowths showing syntaxial growth over this surface
- 18 - Flat horizontal synsedimentary dissolution surface within radial aggregates of the grass-like crystals showing syntaxial growth over this surface
- 19 - Vertical and subvertical crystals (19) and aggregates of split crystals (20)
- 20 - Obliquely oriented and horizontally-curved crystals
- 21 - Horizontally-oriented and downward-curved crystals
- 22 - Obliquely oriented and upward-curved crystals
- 23 - Horizontally-oriented and upward-curved crystals
- 24 - Horizontally-oriented and downward-curved crystals
- 25 - Horizontally-oriented and downward-curved crystals
- 26 - Horizontally-oriented and downward-curved crystals
- 27 - Horizontally-oriented and downward-curved crystals
- 28 - Redeposited horizontally-laying crystals of fine-grained gypsum matrix (selenite debris flow facies)
- 29 - Accumulation of in situ broken, abraded and dissolved crystals (selenite debris facies)
- 30 - Crystals showing concordant orientation of apices
- 31 - Subhorizontally oriented subparallel intergrowths
- 32 - Horizontally-oriented subparallel sabre crystals
- 33 - Obliquely oriented subparallel sabre crystals
- 34 - Obliquely oriented subparallel short rod-like crystals
- 35 - Giant intergrowths with enlarged and subparallel component crystals
- 36 - Gypsum domes with slopes composed of horizontal and upward-curved sabre crystals
- 37 - Short sabre crystals on slopes of small (<0.5 m) gypsum domes
- 38 - Long sabre crystals on slopes of giant (several m) selenite domes
- 39 - Sabre crystals on slopes of vertically-elongated domes resembling columns or trunks
- 40 - Gypsum porphyroblasts and aggregates of porphyroblasts
- 41 - Concentric groups of centrifugally-oriented crystals
- 42 - Small grass-like crystals covering vertically or sub vertically-oriented substrate
- 43 - Druze or geode-like aggregates of centripetally-oriented crystals
- 44 - Large (up to 1 m) transparent and honey crystals filling-in giant dune-like pools or caverns

**Fig. 7** Explanations of nomenclature and symbols for Figs 6, 8-18.
Fig. 7. Continued.

Explanations of hachure and symbols for Figs 6, 8-18.

Key to hachure within lithologic columns:
- **46-65 - Microbialite, fine-grained and microcrystalline gypsum components:**
  - 46 - fine-grained homogeneous gypsum (alabaster when massive and white), or other non-differentiated fine-grained or microcrystalline gypsum; 47 - fine-grained or microcrystalline gypsum showing banded or spotted structure, or with relic laminations (KWIATKOWSKI 1972); 48 - fine-grained (alabaster-like) gypsum with traces of gypsified crenelated microbial mats; 49 - gypsified crenelated microbial mats creating small domal structures; 50 - gypsified microbial mats creating small (< 5 cm) bulb-like “alabaster” domes (BABEL 1996; 1999, pl. 5, fig. 2) intercalated with clay laminae; 51 - wavy laminated gypsum representing gypsed smooth undulating microbial mats; 52 - wavy laminated gypsum representing gypsified smooth microbial mats creating domal structures; 53 - gypsite microlaminite showing crenelated laminae representing gypsified crenelated microbial mats; 54 - flat thin (< 1 mm) laminated gypsum; 55 - flat thick (1-10 mm) laminated gypsum; 56 - fine-grained and microcrystalline gypsum with obscured flat laminae; 57 - fine-grained and microcrystalline gypsum showing obscured wavy laminae; 58 - wavy thin-laminated gypsum showing soft-sediment deformation folds; 59 - fine-grained gypsum showing inclined and cross-sтратification; 60 - breccias of laminated gypsum; 61 - gypsum breccias with alabaster clasts and alabaster matrix; 62 - gypsite breccias with alabaster-like matrix and rounded clasts of laminated (left), microbialite (right, bottom), and homogeneous gypsum (right, top); 63 - secondary alabaster with ghosts and relics of primary sabre crystals; 64 - secondary alabaster with homogeneous and nodular structure; 65 - megaspheres: large (up to 0.5 m) displastic balls or nodules of secondary alabaster with cauliflower-like external surfaces.
- **66-83 - Selenite-microbialite components:**
  - 66 - small isolated subhorizontal intergrowths showing “swallow tail” habit within gypsum microbialite deposits; 67 - large isolated intergrowth with segmented or chevron structure within gypsum microbialite deposits; 68 - single isolated sabre crystals within gypsum microbialite deposits; 69 - aggregate of split sabre crystals within gypsum microbialite deposits; 70 - isolated sabre crystal within homogeneous (alabaster-like) gypsum with relic laminations; 71 - sabre crystals within wavy laminated gypsum microbialite deposits; 72 - short rod-like crystals within wavy laminated gypsum microbialite deposits; 73 - small grass-like crystals covering surfaces of gypsified crenelated microbial mats and intercalating gypsum microbialite deposits; 74 - small isolated grass-like crystals scattered within gypsum microbialite deposits showing crenelated laminae; 75 - small (< 10 cm) microbialite-selenite domes, formed by grass-like crystals covering the bulk-like microbialite “alabaster” domes, sandwiched between clay laminae; 76 - large (up to 30 cm high) laminated microbialite-selenite domes composed of elastic gypsum laminae and grass-like gypsum laminae; 77 - laminated microbialite-selenite domes, composed of elastic gypsum laminae and grass-like gypsum laminae, intercalated with flat laminae of grass-like gypsum; 78 - gyspum dome with cauliflower surface created by gypsified crenelated microbial mats covered with grass-like crystals; 79 - gypsum dome composed of rows of radiating crystals, without sharp base, intercalated with fine-grained gypsum; 80 - gypsum dome composed of rows of grass-like crystals with sharp base intercalated with fine-grained gypsum; 81 - dome composed of gyspum microbialite core and horizontally oriented sabre crystals on slopes; 82 - dome composed of gyspum microbialite and grass-like gypsum and horizontally oriented sabre crystals on slopes; 83 - selenite nucleus (Dronke 1985) created by bottom-grown sabre crystals.
Other lithologic components

Stratigraphy

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Fig. 7. Continued.
Explanations of hachure and symbols for Figs 6, 8-18

Key to hachure within lithologic columns:

84-90 - Other lithologic components: 84 - limestone (non-differentiated); 85 - wavy bedded limestone; 86 - brecciated limestone with calcite druses; 87 - lithothamnian (red-algal) limestone; 88 - marly limestone; 89 - marly clay; 90 - clay and gypsum-clay deposit; 91 - orange dusty clay

Key to stratigraphic symbols:

1-4 - lithostratigraphic units and/or facies; 1 - selenite and selenite-dominated lithostratigraphic units (and/or facies) composed of vertical crystals; 2 - selenite and selenite-dominated lithostratigraphic units (and/or facies) composed of horizontal crystals; 3 - non-selenite lithostratigraphic units (and/or facies) mainly composed of fine-grained gypsum; 4 - designations of lithostratigraphic units; 5-6 - marker beds; 5 - selenite or selenite-dominated marker beds; 6 - marker bed composed of fine-grained gypsum; 7 - designations of marker beds; 8 - high-quality isochronous surfaces; 9 - low-quality isochronous surfaces
Key to symbols showing selected features

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Fig. 7. Continued. Explanations of hatchure and symbols for Figs 6, 8-18.

Key to symbols outside lithologic columns:
1-13 - Features of selenite; 1 - crystals showing characteristic flat surface with growth structures created by slice-like subcrystals (see BABEL 1991, fig. 5A); 2 - sabre crystals broken due to compaction; 3 - synsedimentary dissolution surface; 4 - small selenite-microbialite domes covered with crystals from one side due to action of brine current (BABEL 2002); 5 - large inter- and intracrystalline pores; 6 - small lenticular crystals (<0.5 cm in size); 7 - aggregates of crystals resembling "desert roses" (<0.5 cm in size); 8-13 - growth zones of giant intergrowths; 8-9 - dark growth zones (up to 0.5 cm thick) created by inclusions of organic matter; 8-9 - single dark growth zone; 9 - two adjacent dark growth zones; 10-13 - white growth zones (ca. 1 mm thick) created by tiny mineral inclusions; 10 - single white growth zone; 11 - two adjacent white growth zones; 12-13 - frequent white growth zones.

14-26 - Features of clastics; 14 - erosion surface; 15 - low-angle cross stratification (left) and high-angle cross stratification (centre and right); 16 - current ripples; 17 - wave ripples; 18 - loaded current ripples; 19 - sugar-like clastic gypsum; 20 - small channels filled with sugar-like clastic gypsum; 21 - laterally continuous laminae of sugar-like clastic gypsum; 22 - intraclasts of fine-grained gypsum; 23 - intraclasts of large broken, abraded and dissolved gypsum crystals; 24 - slump and soft-sediment deformation folds; 25 - laterally elongated laminated microbialite-selenite domes composed of sugar-like clastic gypsum laminae (KWAJTOWSKI 1972; BABEL 2002).

26-36 - Mineral components other than gypsum; 26 - clay intercalation and clay showing perfect, flat, mm-scale lamination (left); 27 - clay of clay; 28 - orange dust or dusty clay interpreted as aeolian or pyroclastic deposit; 29 - top of the gypsum bed encrusted with calcite; 30 - base of the gypsum bed encrusted with calcite; 31 - intercalation or admixture of calcium carbonate; 32 - traces of, and gypsum pseudomorphs after dissolved halite crystals; 33 - solution subsidence deformation and breccias related to halite dissolution; 34 - quartz and quartzite pebbles (<2 cm in size); 35 - traces of anhydrite laths (<2 mm in length); 36 - small sulphur nodules.

37-45 - Organic components; 37 - thin (1-3 mm) wavy microbial mat gypsified and encrusted with lenticular gypsum crystals; 38 - gypsified, crenulated microbial mats showing dark colour significant for local correlation; 39 - thin-walled gastropods and/or molluscs; 40 - foraminifers; 41 - nanoplankton; 42 - fish remains; 43 - plant remains; 44 - jet; 45 - fragments of lignite, tree trunks, and tree branches encrusted and covered with gypsum crystals.

46-52 - Features of section; 46 - covered parts of the section; 47 - unknown distance between parts of the section; 48 - poorly exposed parts of the section; 49 - mechanical contacts (faults, shear surfaces related to landslides or slumps); 50 - horizontal discontinuity surfaces significant for local correlation; 51 - well-exposed base surface of the gypsum section; 52 - well-exposed top surface of the gypsum section; 53 - distance between sections.
FIGURE 8A

Fig. 8A-E. Stratigraphic correlation in Ukraine; lowermost part of the gypsum sequence below marker bed c; correlation line 1 in Fig. 2; top of bed c as datum; key to hatchure in Fig. 7.
FIGURE 8B

Fig. 8A-E. Continued
FIGURE 8D
Fig. 9A-D. Stratigraphic correlation in Ukraine; lowermost part of gypsum sequence; correlation lines II and III in Fig. 2; top of marker bed as datum; key to hachure in Fig. 7.
FIGURE 9C

Fig. 9A-D. Continued
FIGURE 9D
Fig. 10A-E. Stratigraphic correlation in Ukraine; gypsum sequence between marker beds e and h; correlation line I in Fig. 2; top of bed c as datum; key to hashure in Fig. 7.
Fig. 11A-C. Stratigraphic correlation in Ukraine: gypsum sequence above marker bed h2; correlation line I in Fig. 2; top of marker bed h3 (Figs 11A-B) and marker bed c (Fig. 11C) as datum; key to hachure in Fig. 7.
FIGURE 12A

Fig. 12A-C. Stratigraphic correlation in Ukraine; middle part of gypsum sequence below the "upper selenites" or marker bed f1; correlation line 1 in Fig. 2; base of bed f1 or base of the "upper selenites" as datum; key to hatchure in Fig. 7
FIGURE 12B

Fig. 11A-C. Continued
FIGURE 12C

Fig. 12A-C. Continued
Fig. 13A-C, Stratigraphic correlation in Ukraine; upper part of gypsum sequence containing “upper selenites”, above marker bed f1; correlation line 1 in Fig. 2; base of bed f1 or base of “upper selenites” as datum; key to hachure in Fig. 7
FIGURE 13B

Fig. 13A-C. Continued
FIGURE 14A

Fig. 14A-B. Stratigraphic correlation in Ukraine: uppermost part of gypsum sequence above "upper selenites" or marker bed (S); correlation line I in Fig. 2; datum as in Fig. 13; key to hachure in Fig. 7
FIGURE 14B
Fig. 15A-B. Stratigraphic correlation between southern Poland and the Czech Republic, section at Kobelfice after PERYT & al. 1997a, b, and own data; Czernica after KRACH 1954, RANIECKA-BOBROWSKA 1957, SARNACKA 1968, and own data; correlation line in Fig. 1; top of sabre gypsum unit C-D as datum; key to hachure in Fig. 7; A- lower part of gypsum sequence
Fig. 15A-B. Continued. B - upper part of gypsum sequence
FIGURE 16A

Fig. 16A-B. Stratigraphic correlation between Miechów Upland and Nida area in Poland; correlation line in Fig. 1; top of sabre gypsum unit C-D as datum; key to hachure in Fig. 7; A - lower part of gypsum sequence.
Fig. 16A-B. Continued.

B - upper part of gypsum sequence
FIGURE 17A

Fig. 17A–D. Stratigraphic correlation in Ukraine; gypsum sequence around marker bed h; correlation line F in Fig. 2; base of bed h as datum; key to hashure in Fig. 7
FIGURE 18A

Fig. 18A-B. Stratigraphic correlation in Ukraine and Moldova, section at Kriva in Moldova after PERYT & al. 1995; correlation line III in Fig. 2; without datum; key to hachure in Fig. 7; A - lower part of gypsum sequence
Fig. 18A-B. Continued.
B - upper part of gypsum sequence
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## Localities in Poland

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## Localities in Czech Republic and Moldova

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