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Alicja KASPRZYK

Distribution of strontium in the Badenian (Middle Miocene) gypsum deposits of the Nida area, southern Poland

A succession of different lithofacies including fifteen units, from *a* to *n*, have been distinguished in the gypsum section of the Nida area. Geochemical data show distinct variation of the Sr content in gypsum, between 0.03 and 3.13% (average 0.30% Sr). In gypsum lithofacies, a high Sr concentration averaging 0.5% was found in selenitic gypsum and in gypsorudites. The vertical distribution of strontium throughout the section is not uniform. The average strontium content increases in the middle section and reaches as much as 0.92% Sr in unit *h*. South of the Holy Cross Mts. the horizontal distribution of strontium in gypsum and coeval carbonates is characterized by higher concentration in the northernmost part of the area (Staszów region). Variability of the strontium content throughout the cyclic sequences reflects the evolution of brines during the gypsum formation. The results suggest important diagenesis of the gypsum deposits which allowed the migration of strontium and subsequent crystallization of celestite.

INTRODUCTION

Strontium is a foreign ion commonly incorporated in sulphates during their precipitation or diagenesis (e.g. G. P. Butler, 1973; J. Kushnir, 1980, 1981; F. Orti Cabo *et al.*, 1984; H. Dronkert, 1985; L. Rosell Ortiz *et al.*, *in press*). Detailed geochemical and mineralogical studies of the Badenian gypsum of the Carpathian Foredeep (S Poland) showed a varying content of strontium, suggesting that this element may be useful in the interpretation of the sedimentary and diagenetic evolution of brines and their salts (comp. E. Usdowski, 1973; A. Nadler, M. Magaritz, 1980; J. Kushnir, 1982; E. H. Carlson, 1987).

Data on the strontium geochemistry and mineralogy of the Badenian gypsum deposits of the Carpathian Foredeep are widely scattered in the literature (e.g. A. Morawiecki, T. Domaszewska, 1957; W. Kowalski *et al.*, 1980; J. Parafiniuk, 1987, 1989; A. Kasprzyk,

Table 1

Strontium content in the gypsum deposits of the Nida area

Lithofacies		Content of Sr [%]			
		A. Morawiecki, T. Domaszewska (1957)	B. Siemińska (1982)	J. Parafiniuk (1987)	A. Kasprzyk (1990)
Breccias		–	0.02–0.16	–	0.06–0.68
Massive gypsum	alabastrine gypsum	–	–	0.06*	0.04–0.73
	laminated gypsum	0.08–0.18	0.06*	0.07*	0.06–1.50
	with crystalline aggregates		0.07 – 0.12	–	0.14–0.28
Coarse-crystalline gypsum	skeletal and sabre-like gypsum	0.06–0.12	0.15 –> 1	0.11*	0.08–1.71
	szklica gypsum		0.06*	0.07*	0.08–0.75

* average value

1989*a*, 1993*a*; A. Garlicki *et al.*, 1991). This paper summarizes the earlier geochemical data (Tab. 1) and presents new results on the Sr concentration in the gypsum deposits of the Nida area. This review aims to (1) characterize the regularities of the strontium distribution in a thick, up to 60 m, and laterally extensive gypsum sequence, and to (2) understand the main factors controlling Sr migration and concentration of the evaporites in marginal parts of the Carpathian Foredeep. Thus, it could be important from both a scientific and an economic point of view.

AREA AND METHODS

The area of the study is located in the northern part of the Carpathian Foredeep and comprises two Miocene-filled marginal depressions: the Połaniec and Solec Troughs, where gypsum deposits are well exposed or occur in the shallow subsurface (Fig. 1). Thirty three gypsum sections were selected for a detailed geochemical study based on lithofacies and sedimentary recognition in the field. Elemental determinations of strontium in 300 samples of primary gypsum and carbonate rocks were carried out in the Polish Geological Institute in Warsaw using X-ray fluorescence techniques. The mineralogy of twenty five samples was examined by X-ray diffractometry for the detection of celestite. Geochemical data from other areas south of the Holy Cross Mts. are also included.

GYPSUM SEQUENCE

Sulphates deposited south of the Holy Cross Mts. comprise well-preserved primary lithofacies which originated in a wide range of depositional settings from subaqueous (relatively deep- and shallow-water) to subaerial (S. Kwiatkowski, 1972; A. Kasprzyk, 1991; B. Kubica, 1992). Gypsum lithofacies comprise selenitic, massive and clastic varieties (A. Kasprzyk, 1993*c*). Selenitic lithologies are *szklica* gypsum, sabre-like gypsum, skeletal gypsum and bedded selenites. These lithofacies are from the lower and middle part of the gypsum section whilst in the upper part clastic gypsum varieties occur: gypsarenites and gypsorudites (Fig. 2). The third group is massive gypsum: with selenitic clusters, stromatolitic gypsum, laminated gypsum and microcrystalline (alabastrine) gypsum; all occur in thin intercalations throughout the section.

Eighteen lithostratigraphic units, from *a* to *r*, have been distinguished in the complete gypsum section of the Nida area by A. Wala (1980). In sections studied by the author units *a–n* are distinct (Fig. 2); the occurrence of units *o–r* is questionable (see A. Kasprzyk, 1991). The sequence starts with giant gypsum intergrowths of palmate-like appearance, called *szklica* gypsum — unit *a* (M. Bąbel, 1987, 1991). Overlying bedded selenites (units *b–e*) comprise an alternation of selenite layers (grass-like and cavoli *sensu* G. Richter-Bernburg, 1973) and alabastrine or stromatolitic gypsum (A. Wala, 1979). Units *f–i* are composed of skeletal and sabre-like gypsum (S. Kwiatkowski, 1972) and commonly include intercalations of laminated gypsum, one of which is distinguished as unit *h*. The selenitic lithofacies are followed by an alternation of gypsum laminites or stromatolites with selenitic clusters (units *j*, *l*, *m*) and of clayey-gypsum laminites, clays or clastic gypsum (units *k*, *ł*) — A. Kasprzyk (1991). The upper section — unit *n* is composed of gypsorudites and laminated gypsarenites (T. M. Peryt, A. Kasprzyk, 1992*a*). The succession of facies is cyclic and comprises four regressive cycles 4.3–11.0 m thick (Fig. 2).

Throughout the sequence gypsum is accompanied by carbonates and siliciclastics which form intercalations or irregular bodies within the sulphate deposits. In the upper section, primary, carbonates (microbial carbonates) occur (T. M. Peryt, A. Kasprzyk, 1992*b*). Gypsum is locally replaced by secondary (late-diagenetic) postgypsum limestones.

MINERALOGY

Detailed petrographic and XRD studies show that strontium incorporated in gypsum and associated carbonate deposits either occurs dispersed as isomorphic replacement within the gypsum lattice or forms its own mineral phase — celestite (e.g. J. Parafiniuk, 1989 and references therein). Two generations of celestite are recognized, different in crystal morphology, size and occurrence: the older, syngenetic with gypsum, and the younger — related to diagenetic alterations of the host rocks (B. Siemińska, 1982; J. Parafiniuk, 1987; A.

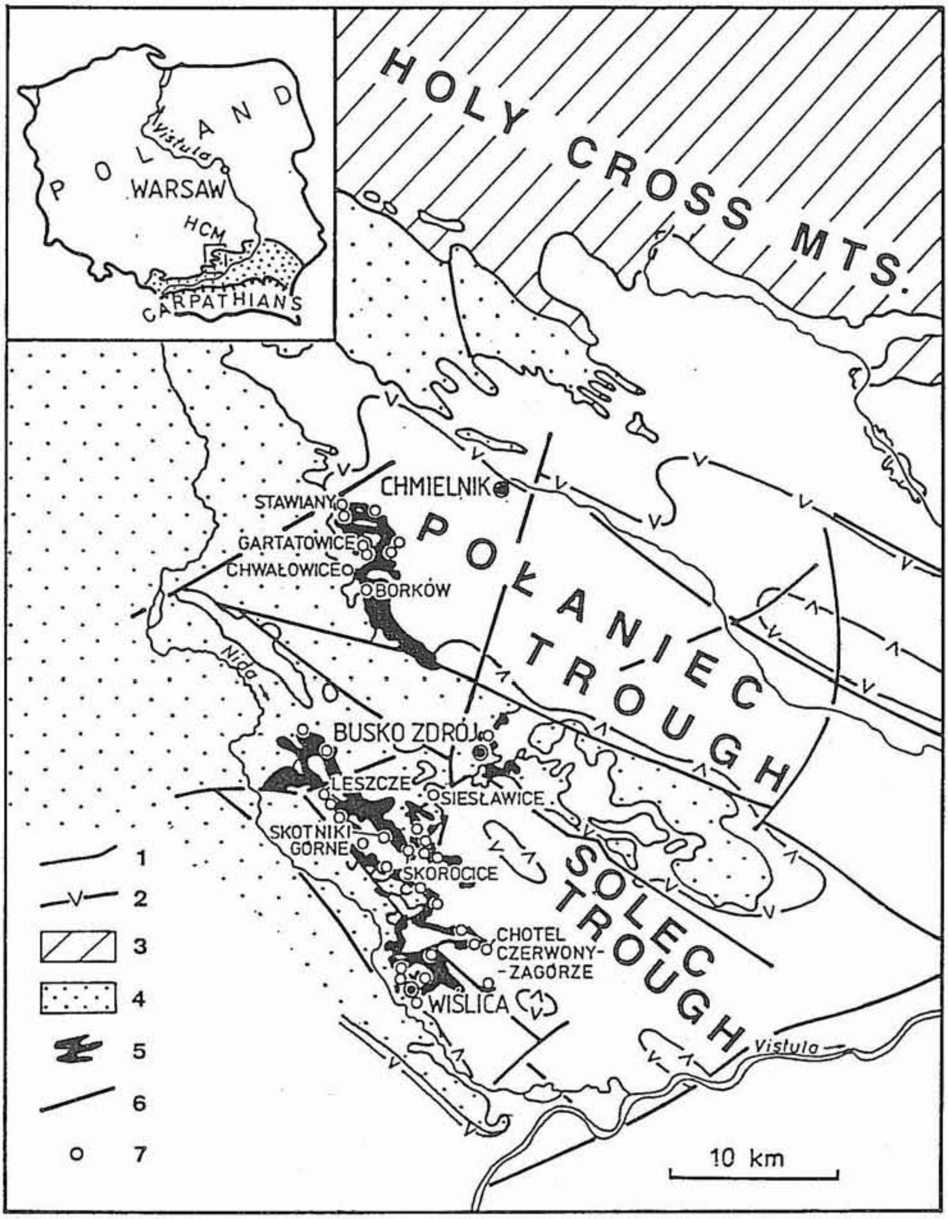

Fig. 1. Location of the studied sections

1 — limit of Badenian; 2 — limit of gypsum; 3 — Palaeozoic; 4 — Mesozoic; 5 — gypsum outcrops; 6 — faults; 7 — exposure studied; HCM — Holy Cross Mts.

Lokalizacja badanych profili

1 — zasięg badenu; 2 — zasięg gipsów; 3— paleozoik; 4 — mezozoik; 5 — wychodnie gipsów; 6 — uskoki; 7 — badane odsłonięcie; HCM — Góry Świętokrzyskie

Table 2

Variability of strontium content in gypsum and carbonate lithofacies

Lithofacies	Number of samples	Sr content [%]		Standard deviation
		extremal	average	
Szklica gypsum	57	0.04–0.75	0.13	0.13
Sabre-like gypsum	41	0.05–3.13	0.48	0.60
Skeletal gypsum	29	0.13–1.71	0.58	0.34
Bedded selenites	40	0.03–1.58	0.18	0.29
Selenitic gypsum	167	0.03–3.13	0.31	0.41
Massive gypsum with crystalline aggregates	15	0.04–0.58	0.14	0.13
Stromatolitic gypsum	25	0.04–1.17	0.22	0.24
Laminated gypsum	27	0.03–2.62	0.35	0.63
Alabastrine gypsum	26	0.04–2.70	0.32	0.54
Massive gypsum	93	0.03–2.70	0.27	0.46
Gypsarenites	22	0.03–1.17	0.19	0.24
Gypsorudites	9	0.07–2.08	0.61	0.75
Clastic gypsum	31	0.03–2.08	0.31	0.48
Gypsum (generally)	291	0.03–3.13	0.30	0.43
Microbial carbonates	6	0.05–0.07	0.06	0.01
Postgypsum limestones	1	10.0	10.0	–
Marls	2	0.13–0.14	0.14	–
Carbonates (generally)	9	0.05–10.0	1.18	3.31
Gypsum and carbonates	300	0.03–10.0	0.33	0.70

Kasprzyk, 1989*a*). The older generation is represented by fine-grained xenomorphic crystals dispersed within the gypsum background. Celestite of the younger generation commonly occurs in radial or druse-like aggregates of prismatic crystals, associated with clay and carbonate. Petrography shows that the bulk of strontium in the carbonate rich fine-grain gypsum zones is bound up in replacement celestite, whereas no discrete Sr phase is identified within the pure selenitic crystals. This suggests that strontium, released during recrystallization and (or) alteration of gypsum (to calcite), has been reprecipitated very locally as celestite.

Lithofacies	Unit	Thickness [m]	Chemistry (average content in %)						Cycle
			n	$CaSO_4 \cdot 2H_2O$	$CaCO_3$	NR	Sr		
laminated clastic gypsum, gypsorudites	n	>9.3	19	82.27	3.12	5.46	0.21	0.21	IV
laminated or stromatolitic gypsum with selenites	m	1.0 – 2.15	8	84.10	3.30	3.28	0.10	0.42	III
clayey-gypsum laminites	ł	0.1 – 1.1	3	57.77	7.52	22.78	0.33		
massive gypsum with selenites / gypsorudites	l	0.4 – 2.0	5	87.83	3.09	1.29	0.23		
laminated gypsum	k	0.7 – 4.5	24	85.38	3.92	2.94	0.67		
stromatolitic gypsum with selenite clusters	j	0.4 – 2.3	17	88.00	1.68	2.75	0.19		
sabre-like gypsum	i	2.65 – 3.45	17	87.08	2.45	1.64	0.54		
laminated gypsum	h	0.05 – 0.5	8	64.61	9.33	6.80	0.92	0.56	II
sabre-like gypsum	g	1.3 – 3.4	25	86.33	4.04	2.51	0.45		
skeletal gypsum	f	1.3 – 3.75	31	87.19	2.53	2.65	0.57		
stromatolitic gypsum	e	0.55 – 1.65	19	87.79	1.74	3.62	0.24	0.19	I
bedded selenites	d	0.7 – 1.95	21	87.94	2.02	3.65	0.20		
alabastrine gypsum	c	0.1 – 0.4	13	86.64	2.84	1.94	0.39		
bedded selenites	b	0.45 – 1.7	22	87.78	2.07	2.77	0.17		
szklica gypsum	a	2.6 – 7.0	57	91.15	0.83	1.81	0.13		

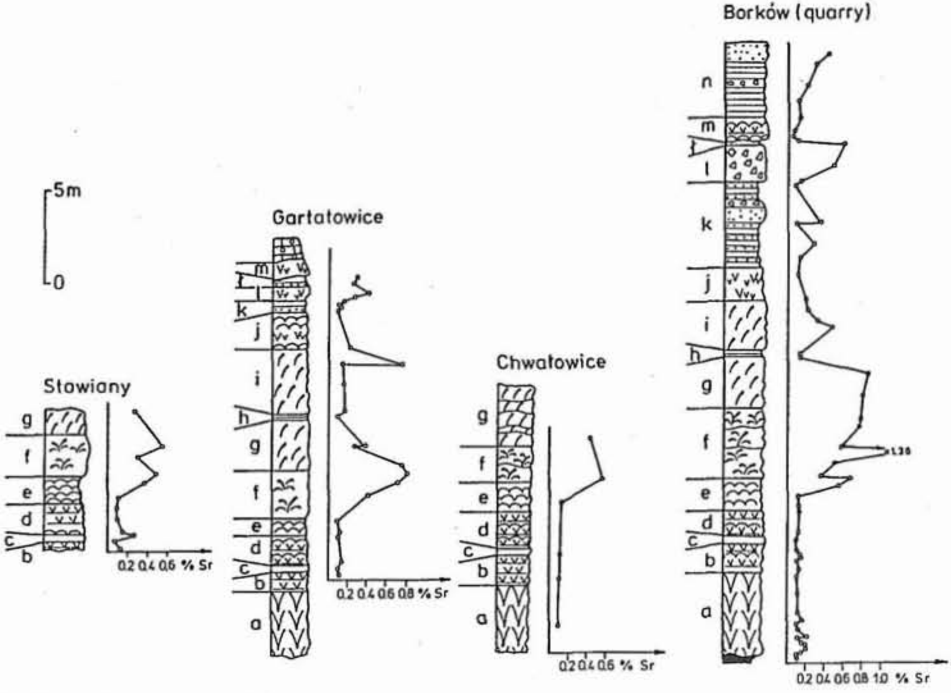

Fig. 3. Strontium content in selected gypsum sections from the northern Nida area
Explanations in Fig. 4
Zawartość strontu w wybranych profilach gipsów północnej części obszaru nidziańskiego
Objaśnienia na fig. 4

VARIABILITY OF STRONTIUM CONTENT

FACIES

Geochemical data show distinct variations in strontium concentration (Figs. 2–4). The values obtained from gypsum and carbonate lithofacies (in total 300 samples) vary between 0.03 and 10% Sr, averaging 0.33% Sr.

Considering the average Sr content in different gypsum lithofacies, the highest values of about 0.5–0.6% were recorded in skeletal and sabre-like varieties and in gypsorudites (Tab. 2). In other lithofacies it does not exceed 0.4% Sr. The lowest Sr concentration was

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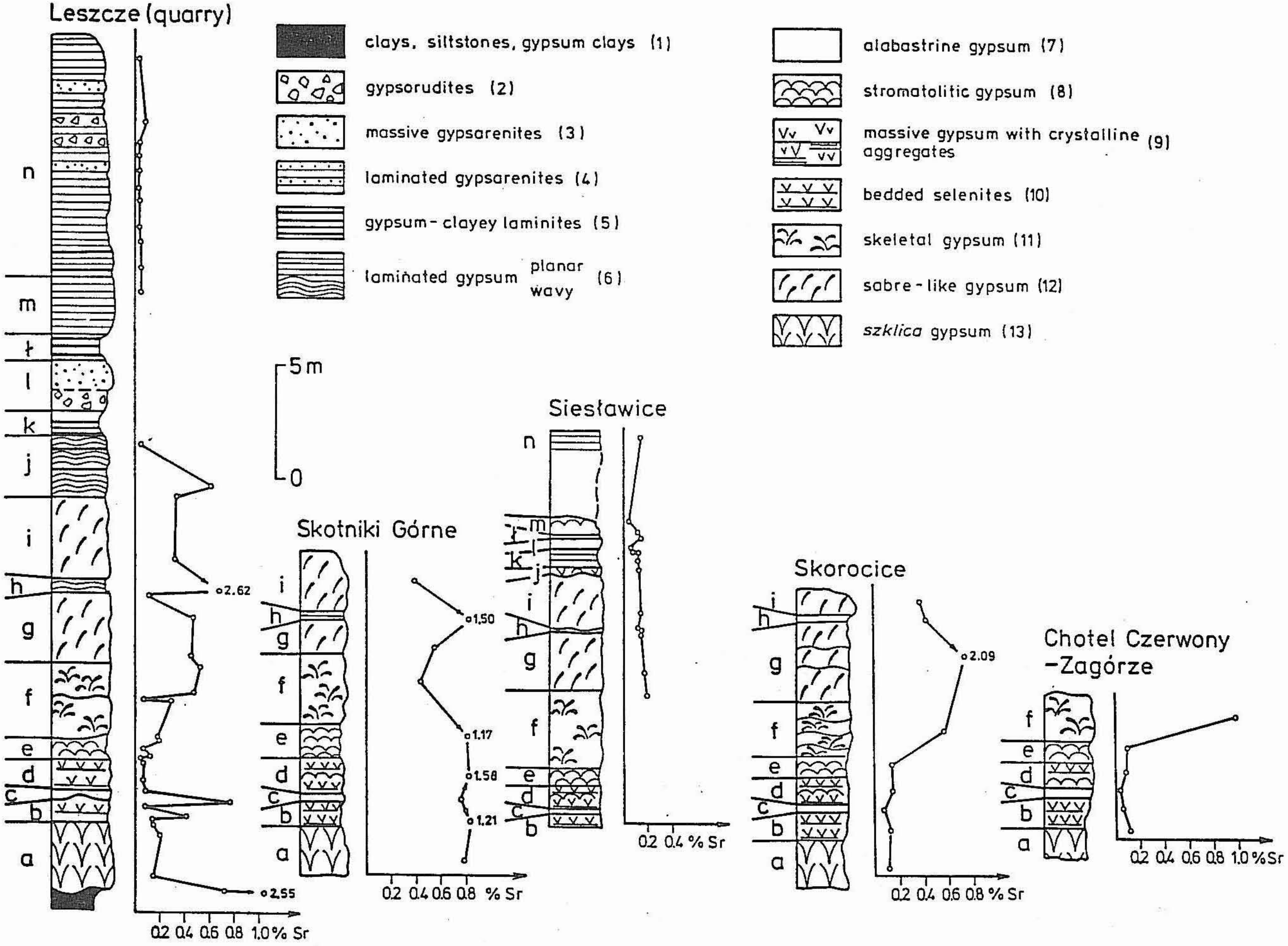
Fig. 2. Chemical composition throughout the lithostratigraphic sequence of units from *a* to *n* in the Nida area
n — number of samples
Skład chemiczny sekwencji litotypów od *a* do *n* w obszarze nidziańskim
n — numery próbek


Leszcze (quarry)
n
m
ł
l
k
j
i
h
g
f
e
d
c
b
a
2.62
2.55
0.2 0.4 0.6 0.8 1.0 % Sr
clays, siltstones, gypsum clays (1)
gypsorudites (2)
massive gypsarenites (3)
laminated gypsarenites (4)
gypsum-clayey laminites (5)
laminated gypsum planar wavy (6)
alabastrine gypsum (7)
stromatolitic gypsum (8)
massive gypsum with crystalline aggregates (9)
bedded selenites (10)
skeletal gypsum (11)
sabre-like gypsum (12)
szklica gypsum (13)
5 m
0
Skotniki Górne
1.50
1.17
1.58
1.21
0.2 0.4 0.6 0.8 % Sr
Siesławice
0.2 0.4 % Sr
Skorocice
2.09
0.2 0.4 0.6 0.8 % Sr
Chotel Czerwony -Zagórze
0.2 0.4 0.6 0.8 1.0 % Sr

measured in *szklica* gypsum and in massive gypsum with crystalline aggregates. The Sr content in some lithofacies, such as gypsorudites, laminated and sabre-like gypsum, is widely dispersed and reflects distinct variations in lithology (Tab. 2). High Sr concentration recorded within the matrix of selenitic gypsum and in separated layers of laminated and clastic gypsum is due to the presence of celestite which significantly increased the content of strontium. This is the case with gypsorudites rich in marly-gypsum matrix, where the wide range of values (from 0.07 to 2.08% Sr) results from the different mineralogical and chemical composition of these deposits (Fig. 2, Tab. 2). Generally, selenitic gypsum as well as clastic gypsum lithofacies are enriched in strontium in relation to massive gypsum varieties.

The highest strontium concentration (up to 10% Sr) is related to postgypsum limestones, locally developed in the sulphate complex (A. Kasprzyk, 1990). Relatively low values averaging 0.08% Sr have been found in microbial carbonates and marls from the upper gypsum section (Tab. 2).

DISTRIBUTION

The vertical distribution of strontium throughout the gypsum section is not uniform and reflects the variety and succession of lithofacies. In the sequence of units from *a* to *n*, Sr concentration increases toward the middle section, in accordance with the increasing content of calcium carbonate and insoluble residue in bulk of samples (Figs. 2–4). The average content of strontium is highest in units *h* and *k* (Fig. 2). High and homogenous relative values are characteristic for units *f*, *g*, and *i*, composed of selenitic gypsum. Concentration of > 1% Sr obtained in some samples distributed randomly throughout the section reflects the presence of celestite, as proved by petrographic and XRD studies. The lowest average Sr content was recorded in the upper section (Fig. 2). The cyclic sequence of lithofacies is expressed in the vertical distribution of strontium (Figs. 3, 4). This is reflected by an evolution of Sr content which could be symmetrically and asymmetrically decreasing-up seen throughout the lower and middle section with a dominant selenitic facies (cyclothems I–III) — Fig. 5.

The horizontal distribution of strontium all over the Nida area shows a distinct relationship between Sr concentration and the location of sections studied (Figs. 1, 3, 4). The highest average content of about 1% Sr was recorded in the southern Nida area (i.e. in the Solec Trough) — Fig. 5. In the north, concentration does not exceed 0.5% Sr. A high Sr content (2.08%) has been reported at Czarkowy where Sr concentrations of economic importance were found (A. Morawiecki, T. Domaszewska, 1957; T. Osmólski *et al.*, 1982). The results

Fig. 4. Strontium content in selected gypsum sections from the southern Nida area

Zawartość strontu w wybranych profilach gipsów południowej części obszaru nidziańskiego

1 — iły, iłowce, iły gipsowe; 2 — gipsorudyty; 3 — gipsarenity masywne; 4 — gipsarenity laminowane; 5 — laminity gipsowo-ilaste; 6 — gipsy laminowane: poziomo, faliście; 7 — gipsy alabastrowe; 8 — gipsy stromatolitowe; 9 — gipsy zbite z agregatami krystalicznymi; 10 — gipsy warstwowane z poziomami selenitów; 11 — gipsy szkieletowe; 12 — gipsy szablaste; 13 — gipsy szklicowe

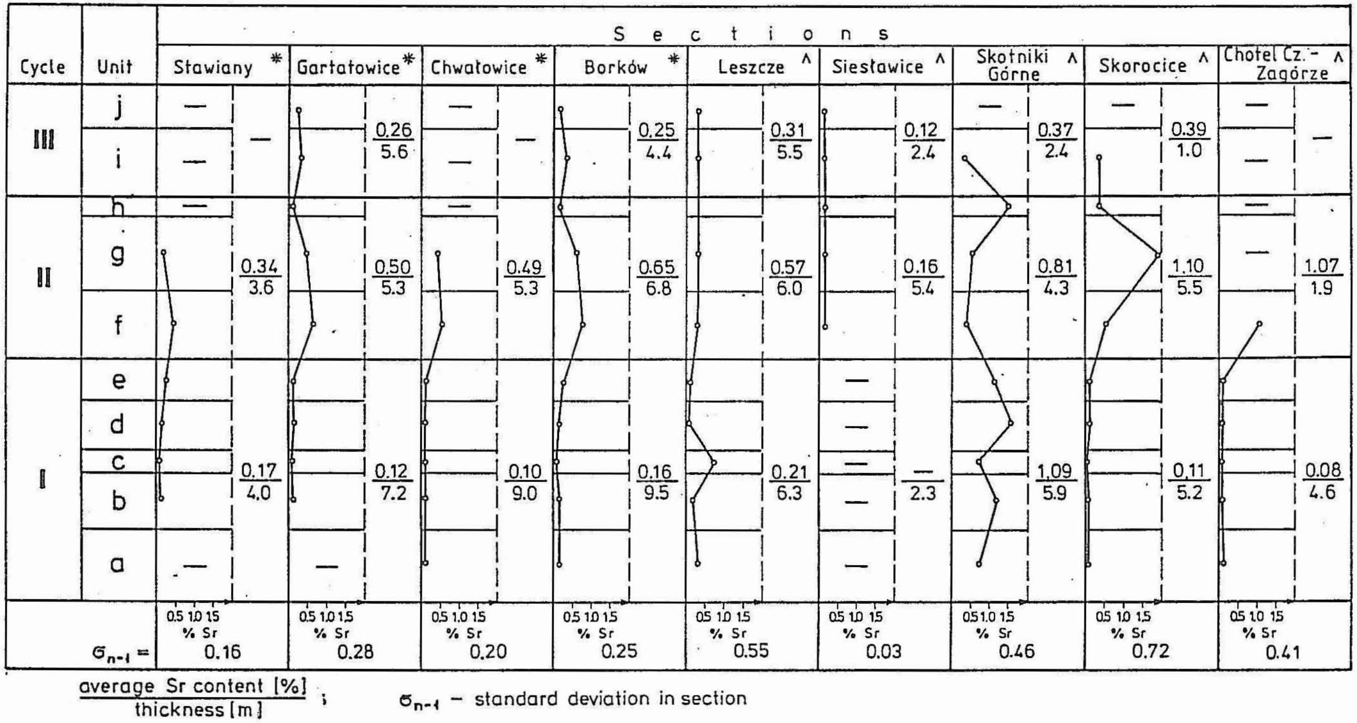


Fig. 5. Comparison of thickness and the average Sr content in cyclothems I–III in selected gypsum sections from the northern (*) and southern (^) Nida area

Porównanie miąższości i średniej zawartości strontu w cyklotemach I–III w wybranych profilach gipsów w północnej (*) i południowej (^) części obszaru nidziańskiego obtained show coincidence between relatively high Sr concentration and local horst-like elements, when the structural pattern of the area is considered (Figs. 1, 5).

Results of geochemical studies reveal some basic differences in the strontium concentration and distribution between the eastern, central and western parts of the area south of the Holy Cross Mts. (Fig. 1). This area includes four sectors with numerous exposures of gypsum and a dense network of boreholes: the Nida region (B. Siemińska, 1982; J. Parafiniuk, 1987; A. Kasprzyk, 1990), Staszów region (A. Kasprzyk, 1989*a*), Osiek region (A. Kasprzyk, 1993*a*) and the Wschodnia river region (A. Kasprzyk, 1989*b*). Gypsum deposits of the western and eastern areas (the Nida and Osiek regions) exhibit a comparable average content of strontium, almost half the value obtained for equivalent facies in the north, i.e. in Staszów region (Tab. 3). In the central area (the Wschodnia river region), sulphate deposits (gypsum and anhydrites) occur at a depth of more than 200 m and show a relatively low Sr concentration (Tab. 3). The average content of strontium in gypsum deposits of the whole area discussed is 0.37% which is very close to the value recorded for sulphates in the margin of the Carpathian Foredeep of the Western Ukraine (B. W. Merlicz, N. M. Dacenko, 1976; J. T. Roskosz *et al.*, 1979).

It is interesting to note that the Badenian gypsum deposits of the Carpathian Foredeep are distinctly enriched in strontium in comparison to the other evaporite formations (Tab. 3). This is best demonstrated by the selenitic lithofacies of the Badenian gypsum, which show an average content of strontium 2–3 times higher than that recorded for equivalent facies from the Messinian of eastern Spain, but comparable with values obtained for selenitic gypsum from recent coastal salinas of SE Spain and southern France (see A. Kasprzyk, 1993*a*).

THE STRONTIUM ENVIRONMENT

The facies variation in the Badenian gypsum section of the Carpathian Foredeep is distinctly reflected by the strontium distribution (Figs. 2–4, Tab. 2), and therefore may be used in the interpretation of brine variations during gypsum formation. However, quantitative measurement of the strontium content in bulk samples may produce seriously misleading results when diagenetic alteration is significant (e.g. L. A. Hardie, 1984). Because of this, the interpretation presented below is based on comparative analysis of the Sr distribution profiles.

Detailed geochemical analysis provides arguments for unstable salinity conditions during gypsum formation in the peripheral part of the Badenian basin (A. Kasprzyk, 1991, 1993*b*). The occurrence of a thick selenitic layer in the lower part of the gypsum sequence supports a rapid rise of salinity, initiating the sulphate precipitation. The high salinity and calm, stratified waters favoured the development of giant gypsum intergrowths (unit *a*), periodically interrupted by an influx of fresh- or brackish-waters and fluctuations in halocline as shown by common dissolution surfaces and the strontium distribution (M. Bąbel, 1987; A. Kasprzyk, 1993*a, b*) — Figs. 3, 4. Deposition of the bedded and stromatolitic gypsum (units *b–e*) took place in an unstable physicochemical regime. This is assumed on the basis of the variable Sr content and the modern facies analogs from coastal salinas of SE Spain and Western Australia where selenitic crusts commonly

Table 3

Average content of strontium in sulphates of different evaporite formations (data from H. Dronkert, 1985; A. Kasprzyk, 1989*b*; A. Garlicki *et al.*, 1991; and this work)

Age/Formation	Locality	Lithofacies	Sr content [%]
Recent/Almeria salines	Spain	gypsum	0.12–0.19
Recent/Abu Dhabi sabkha	Arabia	gypsum	0.04–0.11
		anhydrite	0.23
Miocene — Badenian/ /Carpathian Foredeep	Poland:		
	Nida region	gypsum	0.30
	Osiek region	gypsum	0.38
	Staszów region	gypsum	0.56
	Wschodnia region	gypsum+anhydrite	0.18
	Ukraine	gypsum+anhydrite	0.34
Miocene — Messinian/Sorbas	Spain	gypsum	0..17
Miocene — Messinian/Laga	Italy	gypsum	0.17
Triassic/Windsor	USA	anhydrite+gypsum	0.08
Permian — Zechstein	Germany	anhydrite	0.20–0.25
Permian — Zechstein	Poland	anhydrite	0.01–0.06
Permian/Blaine	USA	gypsum	0.10
		anhydrite	0.15
Permian/Salado	USA	anhydrite	0.07
Permian/Castile	USA	gypsum	0.24
Carboniferous	Spitsbergen	gypsum	0.07
		anhydrite	0.14

alternate with cyanobacterial mats blooming in periods of salinity drops (A. V. Arakel, 1980; F. Orti Cabo *et al.*, 1984; B. W. Logan, 1987). An increase in salinity favoured the deposition of a thick selenitic complex (units *f–i*), relatively rich in strontium (Figs. 3, 4). The facies variation of units *j–m* was created when regression, changes in climate or basin configuration resulted in brackish-water inflow as a result of runoff from the hinterland (A. Kasprzyk, 1993*c*). This affected the distribution of strontium in the basin system as shown by the local high Sr content (e.g. in unit *k* — Figs. 2–4). The deposition of the thick clastic gypsum complex of the upper section (unit *n*) took place in less saline waters where physical accretion dominated chemical precipitation. The high Sr concentration obtained in some samples is related to replacement celestite aggregates within the matrix.

In general, a horizontal distribution of strontium is characterized by a relative decrease in concentration with increasing of burial depth (Tab. 3). It seems that variability of the Sr content throughout the successive cycles reflects changes in brine chemistry and sedimentary regime, both controlled by local or regional factors.

Another question is related to the potential source of strontium in the evaporitic basin of southern Poland. A higher content of Sr (> 1%) is commonly evidence of celestite mineralization, as shown by petrography and geochemistry. Because celestite occurrences are closely associated with the peripheral part of the basin (comp. A. Gàrlicki *et al.*, 1991), it can probably be assumed that strontium was derived from local supplies. Generally, a distinct relationship between strontium and calcium carbonate (Fig. 2) reflects important geochemical fractionation during both early diagenesis (coprecipitation of Sr into calcite or aragonite) or later diagenetic changes of limestones (I. West, 1973) and sulphates by: dissolution-recrystallization (E. H. Carlson, 1987), bacterial sulphate reduction (and thus calcification of gypsum, i.e. gypsum replacement into calcite) — W. Kowalski *et al.* (1980), J. Parafiniuk (1989). Diagenetic processes may have also been favoured by an inflow of meteoric water from the hinterland or direct rainfall (comp. P. A. Scholle *et al.*, 1990). During all those processes, celestite crystallized from pore solutions rich in Sr ions, primarily incorporated in gypsum and associated carbonates, later leached and remobilized to form local concentrations. Thus, the most likely cause of celestite formation in the gypsum deposits would be: (1) supply of continental-derived brines rich in strontium ions, (2) dissolution of subaerially exposed gypsum, (3) diagenetic alteration of gypsum and associated limestones.

CONCLUSIONS

It is highly probable that strontium from the Badenian gypsum of the Carpathian Foredeep could have formed its own mineral phase during evaporite sedimentation. Diagenetic processes such as bacterial sulphate reduction, dissolution and (or) recrystallization, would favour the liberation of large amounts of strontium ions from gypsum. Thus, they could form local higher concentrations within the gypsum rocks. This interpretation is similar to that of I. West (1973) and E. H. Carlson (1987) who reported high Sr concentrations elsewhere at the margins of the Jurassic (Dorset) and Silurian (Ohio Basin) evaporitic basins. They suggested that the strontium forming the celestite was liberated by the diagenetic alteration of sulphates or coeval limestones, as is proposed in this paper.

Results of geochemical and petrographic studies show that higher strontium concentrations are related with the products of the diagenetic alteration of gypsum in structurally elevated areas of the northernmost marginal part of the Carpathian Foredeep. This theory may have implications for Sr prospecting.

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Oddział Świętokrzyski
Państwowego Instytutu Geologicznego
Kielce, ul. Zgoda 21
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Alicja KASPRZYK

ROZKŁAD ZAWARTOŚCI STRONTU W GIPSACH BADENU (ŚRODKOWEGO MIOCENU) OBSZARU NIDZIAŃSKIEGO

Streszczenie

W obszarze nidziańskim gipsy tworzą liczne odsłonięcia, z których 33 wytypowano do szczegółowych badań litofacjalnych i geochemicznych (fig. 1). Podstawowe litofacje stanowią gipsy krystaliczne selenitowe, zbite i klastyczne, obejmujące szereg dalszych odmian litologicznych (tab. 1, 2). Towarzyszą im skały węglanowe: wapienie pogipsowe, margle i utwory mikrobialne. Wyróżnione litofacje tworzą w profilu stałą sekwencję piętnastu litotypów (*a–n*), które reprezentują cztery cykle sedymentacyjne (fig. 2–4).

Wyniki analizy geochemicznej gipsów i wapieni wykazały dużą zmienność zawartości strontu od 0,03 do 10,0% (średnio 0,33% Sr) zależnie od litologii (fig. 2–4, tab. 2). Średnia zawartość strontu (0,3%) w gipsach obszaru nidziańskiego jest prawie 2-krotnie niższa od wartości wyliczonej przez autorkę dla obszaru staszowskiego i jest porównywalna ze średnią (0,34% Sr) otrzymaną przez badaczy ukraińskich dla skał siarczanowych (gipsowo-anhydrytowych) ukraińskiej części zapadliska przedkarpackiego (B. W. Merlicz, N. M. Dacenko, 1976). Najwyższą koncentrację rzędu 0,5% Sr stwierdzono w gipsach szkieletowych i szablastych oraz w gipsorudytach (tab. 2). W pozostałych litofacjach średnia zawartość strontu nie przekracza 0,4% (tab. 2). Duża zmienność zawartości strontu w gipsorudytach i gipsach laminowanych odzwierciedla niejednorodność składu mineralnego i chemicznego tych skał. Najwyższą koncentrację (10% Sr) stwierdzono w wapieniach pogipsowych. Zawartość

Sr > 1% w gipsach i wapieniach wskazuje na obecność celestynu, co potwierdzają wyniki badań petrograficznych i rentgenowskich. Rozpoznano dwie generacje celestynu: starszą — prawdopodobnie syngenetyczną z gipsem, i młodszą — związaną z procesami przemian diagenetycznych gipsów. Cykliczna sekwencja litofacji w profilu znajduje odzwierciedlenie w zmienności zawartości strontu (fig. 2, 5).

Analizując rozkład przestrzenny strontu w skałach gipsowych i węglanowych południowego obrzeżenia Gór Świętokrzyskich, najwyższą średnią zawartość tego pierwiastka — lokalnie osiągającą koncentrację interesującą złożowo — stwierdzono w rejonie staszowskim (fig. 5, tab. 3).

Wyniki badań sugerują, że czynniki regulujące rozkład zawartości strontu są związane zarówno z warunkami sedymentacji w zbiorniku ewaporacyjnym, jak i z późniejszymi procesami dia- i epigenetycznymi, determinującymi stabilność strontu w obrębie macierzystych skał gipsowych. Dalsze poszukiwania złóż strontu winny być prowadzone na obszarach wychodni i płytkiego podpowierzchniowego występowania wapieni pogipsowych i gipsów objętych intensywnymi przeobrażeniami w procesach rozpuszczania-rekrystalizacji i bakteryjnej redukcji lub kalcytyzacji.