KONINKRIJK BELGIE

MINISTERIE VAN ECONOMISCHE ZAKEN
Administratie der Mijnen - Geologische Dienst van België
Jennerstraat, 13 - 1040 Brussel

SEDIMENTOLOGY AND LITHOGEOCHEMISTRY OF THE UPPER FAMENNIAN-TOURNAISIAN STRATA IN THE OMOLON REGION (NE - USSR)

by

R. SWENNEN (1-2), J. BOUCKAERT (3), K.V. SIMAKOV (4), W. VIAENE (2).

PROFESSIONAL PAPER 1985/8
Nr 221

BELGISCHE GEOLOGISCHE DIENST - PROFESSIONALE PAPER 1985/8 - N° 221

SEDIMENTOLOGY AND LITHOGEOCHEMISTRY OF THE UPPER FAMENNIAN-TOURNAISIAN STRATA IN THE OMOLON REGION (NE-USSR)

by

R. Swennen[1,2], J. Bouckaert[3], K.V. Simakov[4] and W. Viaene[2].

1. Aspirant-NFWO
2. Fysico-chemische Geologie
   Katholieke Universiteit Leuven
   Celestijnenlaan 200 C
   B-3030 Heverlee (Leuven)
   Belgium
3. Geologische Dienst van België
   Jennerstraat 13
   1040 Brussel
4. SVKNII, UI. Portovaya 16
   685005 Magadan
   USSR

ABSTRACT

In this paper, a lithological and sediment petrographic description and interpretation, for each of the sections, enumerated in Simakov et al., (1983) is given. Facies changes grading from deep subtidal to restricted supratidal are described from four reference areas. They indicate that sedimentation was influenced by active tectonism.

Furthermore, the lithogeochemical distribution patterns of Mg, Sr, Na, Zn, Pb, Fe, Mn, K and IR (Insoluble Residue) are enclosed. Different anomalies were found. These anomalies are related to exhalation of ore solutions during active tectonic phases, to restricted facies intervals,to dolomitization related phenomena and to the (possible) occurrence of epigenetic fault-related ore bodies.

SAMENVATTING

Van elk van de in Simakov et al., (1983) opgesomde profielen wordt in deze publicatie een lithologische en sedimentpetrografische beschrijving en interpretatie gegeven. De facies veranderingen variëren van diep subtidaal tot supratidaal. De kenmerken vanuit de verschillende deelgebieden tonen aan dat sedimentatie beïnvloed werd door aktief tektonisme.

Tevens werden de lithogeochemische distributiepatronen van Mg, Sr, Na, Zn, Pb, Fe, Mn, K en IR (onoplosbaar residu) achterhaald. Verscheidene anomalieën werden aangetroffen. Deze kunnen verklaard worden ofwel door ertsvorming die geassocieerd is met een tektonisch aktieve periode, door hypersaliene facies intervals, door fenomenen in associatie met dolomitisatieprocessen en door de (mogelijke) aanwezigheid van epigenetische breukgebonden mineralizaties.

INTRODUCTION

Since 1965, a research program on the Upper Famennian and Tournaisian strata in the Omolon region (NE-USSR) is carried out (for references see Simakov et al., 1983; p. 337). It includes also a comparative study of the Upper Famennian-Tournaisian sequences in the Franco-Belgian area and in the North-East USSR and is elaborated by a Soviet-Belgian-Dutch group of geoscientists. This research was sponsored by the NEISRI (North Eastern Interdisciplinary Science Research Institute), the Belgian Geological Survey and by the Geofiles Foundation.

In 1981 Belgian geoscientists started to work on the biostratigraphy of the Upper Famennian and Tournaisian strata in the Omolon region (Conil et al., 1982). The sections exposed in this area, especially the Ustyevoy section (Perevalny area), might be of particular interest for a new definition of the Devonian-Carboniferous boundary (I.U.G.S.-working group of the Devonian/Carboniferous boundary). On the basis of the results of the first field campaign, a second fieldtrip in August 1983 studied the biostratigraphy, the sedimentology and the lithogeochemistry of these strata. Results of this collaboration program were presented at the 27th International Geological Congress in Moskou 1984 (Simakov et al., 1983; Shilo et al., 1984). These data were used as a basis of the excursion number 067 of that International Congress.

This paper presents additional data on the lithology, sedimentpetrography and lithogeochemistry of the Devono-Carboniferous strata in the Omolon region. More advanced conclusions and deductions are published in a separate paper (Swennen et al., 1986).

METHODS

More than 500 thin sections were studied. Where necessary, staining by Alizarine Red S and potassum ferricyanide was used (cfr. Dickson, 1966). Lithogeochemical analyses were performed on representative samples, which were collected by chip-sampling. Chips of weathered rocks as well as cherts were avoided. Analyses were carried out for Mg, Na, Sr, Zn, Pb, Fe, Mn and K by the use of Atomic Adsorption Spectrometry. The analytical procedures are the same as described by Van Orsmael (1982). The insoluble residue (IR) was determined gravimetrically.

On a selected number of samples the clay mineralogy was determined. The method slightly differs from the one described by Decleer (1985). In this study 3 N HCl was used to remove the carbonates; furthermore decalcification was stopped as soon as enough material (< 38 μm) was obtained. For each sample, three diffractometer patterns were measured, namely under normal conditions (52 % relative humidity), after glycerine saturation and after heating until 500° C.

DESCRIPTION OF THE SECTIONS

The Upper Famennian-Tournaisian strata in the Omolon region have been studied in four representative composite sections namely Pushok, Perevalny/Sikambr, Elergetkhyn and Uljagan; the first three sections are situated in the southern part of the basin, the last one in the north (figure 1). Within each section, several suites have been distinguished by Simakov et al., 1979. The section numbers, as well as the unit numbers, used by the former mentioned authors, are also used within this paper. A detailed log of the sections described here can be found in Shilo et al., 1984. All the plates enumerated in this paper, refer also to this last cited publication.

Since a suite corresponds to a unit of strata with characteristic lithological features, which can be mapped out, this term is equivalent to the term "formation". Therefore, the last term is used in this paper.

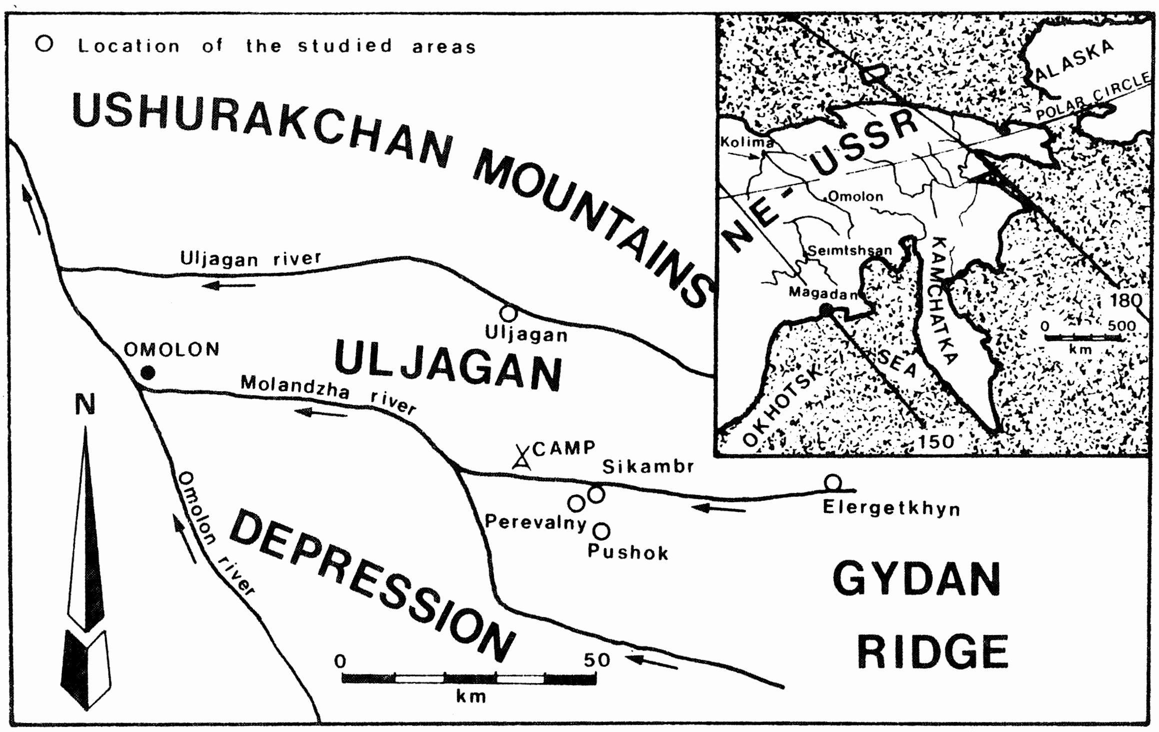

Figure 1 : General situation of the area studied.

1. PUSHOK AREA

The Pushok section (XV) which is the only section exposed in this area shows the Pushok Formation and the lower part of the Sikambr Formation.

Lithology and sediment petrography

Description

The most important feature at the lower part of the Pushok Formation is the occurrence of two intensively silicified biostromal limestones. The biostromes, consisting mainly of stromatoporoids and corals, are enclosed in a biomicrite (bioclastic wackestone) in which calcispheres, ostracodes and birdseyes (with geopetal infilling) occur. Locally intramicrites (intraclastic wackestone) are intercalated. These limestones are intensively recrystallized and silicified. Some dolomite spots occur in association with the chert layers. Pyrite crystals are present all over the rock.

The top of the biostromes is characterized by the occurrence of dessication cracks and the appearance of important quantities of silicified anhydrite nodules. Within these nodules mega-quartz crystals with a felted texture (plate 11.3) and lath-shaped anhydrite relics occur.

The middle part of the Pushok Formation consists of an alternation of partly dolomitized biomicrites (bioclastic wackestone), dolomitized algal mats and hypidiotopic to xenotopic dolostone levels (plate 11.1) full of silicified anhydrite nodules. Within the dolomitized biomicrites crinoids, brachiopods, foraminifera and gastropods are the most common bioclasts. Here also, pyrite crystals are present; pyritization predates the silicification. The last occurs very selectively and alters especially the sparite bioclasts.

The top of the Pushok Formation is composed of a coated grain succession (biosparite : bioclastic packstone) consisting of coated crinoids, brachiopod fragments and algae (plate 11.5 and 6). The coated grains often display a pseudo-pelletoid texture. These strata are partly or completely dolomitized; dolomitization starts within the sparitic phases.

The lower part of the Sikambr Formation is composed of biooosparites; higher upwards they alternate with pelintrasparites (intraclastic packstone), coated grain strata and intraoosparites (oolitic grainstone). Within these strata algal lumps and clasts are sometimes present. The oolites often develop around fragments of bioclasts, mainly around crinoid ossicles (plate 11.7). The sparite matrix and all the sparite phases are partly or completely dolomitized (plate 11.8). Dedolomitization is also a prominent feature. Besides minor amounts of detritical quartz, pyrite crystals were also observed.

Interpretation

The biostromal sequences in the lower part of the Pushok Formation indicate rapid changing sedimentation conditions in a shallow subtidal to supratidal environment. It is likely that the extinction of the biostromes occurred under supratidal hypersaline conditions. The overlying sequences reflect regressive sabkha-type fluctuations. Sedimentation environments changed from shallow subtidal over intertidal to restricted supratidal. A general transgression, however, followed; it is indicated by the presence of coated grains and oolitic strata which occur at the top of this section. They were probably deposited in a shallow subtidal sedimentation environment.

Lithogeochemistry

The lithogeochemical profile is given in figure 2A and the geochemical data are enumerated in table 1. Only six representative samples were analyzed.

The lower part of the section is partly dolomitized as it can be deduced from the Mg-pattern. High Zn, Fe and Mn values and high to very high Pb values (up to 273 ppm) were recorded in this interval. These values reflect an anomaly. Low Na characterizes these limestones.

The limestones in the upper part of the section display normal litho-geochemical trace element contents.

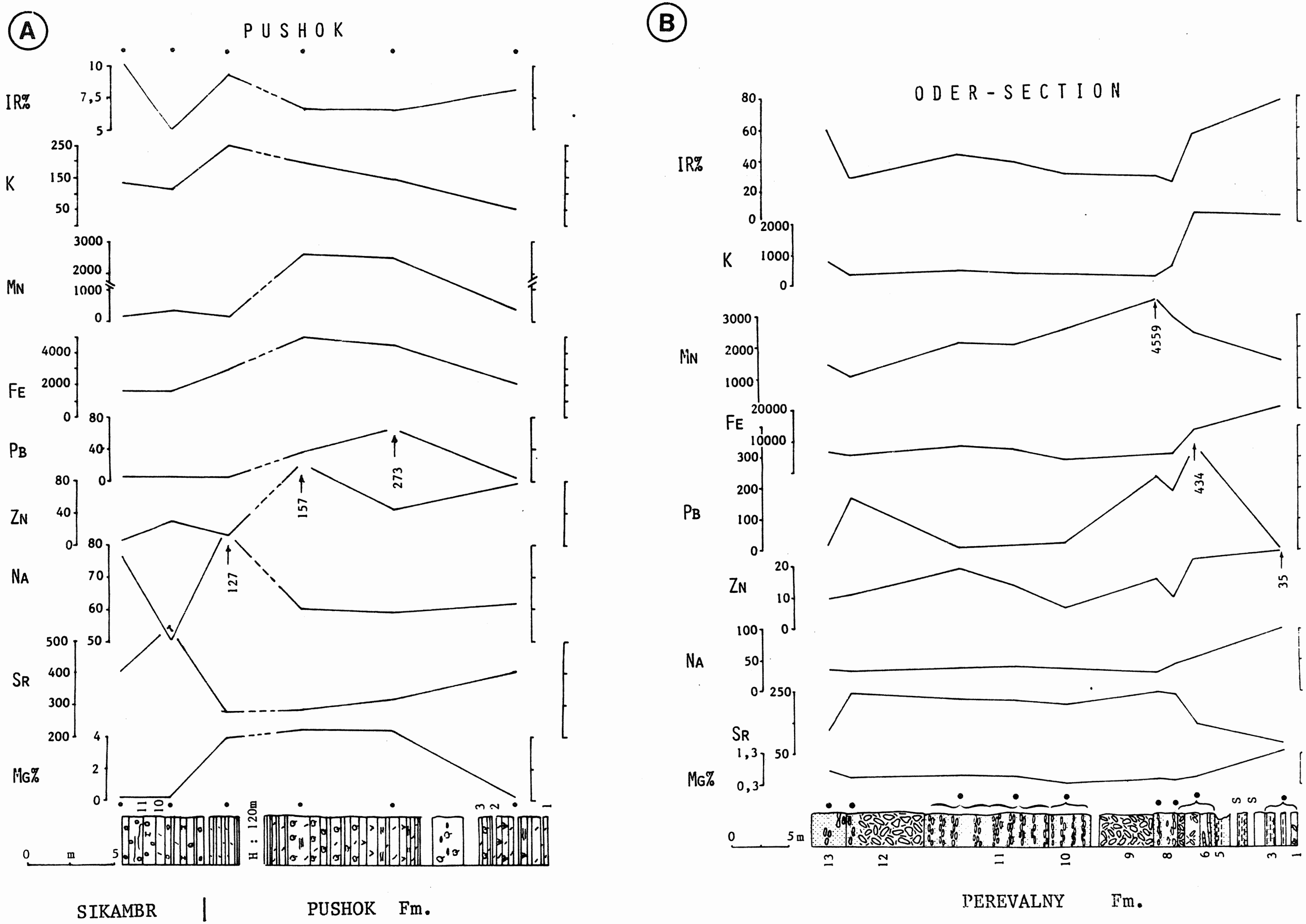

Figure 2 : Geochemical profile of the Pushok and Oder sections

sample number	unit number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
SH1	XV1,2,3	0,32	401	64	77	3	2028	369	52	8
SH2	-	4,43	312	59	43	273	4578	2503	141	7
SH3	-	4,47	279	60	157	37	4931	2581	196	7
SH4	-	3,93	286	127	10	1,5	2991	160	247	9
SH5	XV9-10	0,19	549	51	31	3	1648	326	115	5
SH6	XV11	0,21	403	77	5	4	1635	139	132	10
n = 6	$\bar{X}$	2,26	372	73	54	54	2969	1013	147	8

TABLE 1 : Lithogeochemical data of the Pushok section ($\bar{X}$ = mean value; n = number of samples; unit number refers to Simakov et al., 1979).

2. PEREVALNY/SIKAMBR AREA

In the Perevalny/Sikambr area the different sections (Oder, Nizhnenaled, Ustyevoy, Verkhnenaled, Beregovoy, Sikambr A, Sikambr B and Povorotny) give a complete overview of the Upper Famennian-Tournaisian succession. The exact location of these sections is given by Simakov et al., 1983 (p. 354).

A. ODER SECTION (XII : Perevalny Formation)

Lithology and sediment petrography

Description

Coarse grained Famennian sandstones overly volcanites of the presumably Frasnian Pylkatveem Formation. The sequence is composed of the following lithologies :

- oligomic conglomerates, composed of red and green colored volcanogenic clasts. The size of the fragments grade up to 4-5 cm (very coarse pebbles) : the size distribution is very homogeneous. The pebbles are often well rounded. Ellipsoidal pebbles are often oriented with their axes of elongation parallel to the bedding. These strata occur especially in the lower part of the Perevalny Formation.
- coarse-grained red colored sandstones. Rare fossils (brachiopods and crinoids) are dispersed over these strata; they are often completely leached out. The sandstones alternate with shales and/or gravelly beds.
- sandy, green colored shales with nodular sandy limestone intercalations. The nodules, which have a diameter up to 5 cm, occur in semi-continuous layers, parallel to the stratification. Fossils, such as brachiopods and crinoids, are rare. This lithology becomes more and more important towards the top of the section. In the upper part the carbonate intercalations form continuous layers.

Interpretation

This sequence developed at the initial stages of a transgression in a shallow marine nearshore environment. The lithology distribution in the sequence suggests minor fluctuations within the sedimentary environment. The preponderance of sandy shales with nodular limestone intercalations towards the top of the sequence indicates a deposition in a more uniform subtidal environment.

Lithogeochemistry

Analyses were only performed on the nodular sandy carbonate intercalations. The lithogeochemical profile and the geochemical data are given in figure 2B and table 2 respectively.

As can be deduced from the geochemical profile, the carbonate intercalations are very impure, especially in the lower part of the section. Their high quartz and clay content is reflected by the high IR, K and Na : these variables together with Fe display a covariant distribution pattern. The K and Na (partly) content is directly related to the amount of clay minerals; Fe seems to be mainly adsorbed on these phases. Sr has a distribution pattern which is opposite to these variables. It shows that Sr is nearly completely related to the $CaCO_3$ phase, a feature that can also be observed in other limestone strata. The carbonates are also characterized by high Pb concentrations, with a rather important anomaly of at least 4 m thickness in the lower part of the section. Here a Pb content up to 434 ppm was measured. Ore microscopy revealed the presence of dessiminated galena spots. Anomalous Mn values were also recorded within these strata. It seems probable that similar or higher Pb and Mn values occur within the sandstones since galena and pyrolusite spots were observed macroscopically. However, the sandstones were not analyzed.

sample number	unit number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
SO1	XII1,2,3	1,36	82	106	35	1,5	20793	1585	2205	80
SO2	XII6,7	0,52	141	52	22	434	13447	2450	2319	59
SO3	XII8A	0,43	240	41	10	193	6011	3039	611	29
SO4	XII8B	0,48	246	33	16	236	5618	4559	291	32
SO5	XII10	0,33	203	36	7	24	3913	2595	367	34
SO6	XII11A	0,54	220	41	14	13	7648	2069	390	41
SO7	XII11B	0,58	225	38	19	10	8509	2156	459	46
SO8	XII12	0,56	244	33	11	169	5456	1068	367	32
SO9	XII13	0,75	124	35	10	17	6714	1492	770	63
n = 9	$\overline{X}$	0,62	192	46	16	122	8679	2335	864	46

TABLE 2 : Lithogeochemical data of the Oder section ($\overline{X}$ = mean value; n = number of samples)

B. NIZHNENALED SECTION (VI : Perevalny (upper part) and Elergetkhyn (lower part) Formation)

Lithology and sediment petrography

From a lithologic and sediment petrographic point of view, the section can be divided into two parts, namely a lower part consisting of sandy/silty carbonates with shale partings (VI 1/9 : upper part of the Perevalny Formation) and an upper part where nodular limestones alternate with shales (VI 10/14 : lower part of the Elergetkhyn Formation).

Description

a) Lower part of the section (VI 1/9)

The limestones are composed of sandy/silty biosparites (bioclastic grainstone to packstone) alternating with sandy/silty biomicrites (bioclastic wackestone). The intensively hashed bioclasts, consisting of moravamminids, crinoids, brachiopods, corals, echinoid spines, ostracodes, etc ... are often micritized. The micritization seems to be spatially associated with the silicification.

The analysis of the clays of sample SN1 revealed chlorite as the most important phase. Furthermore an ordered chlorite-montmorillonite (cfr. Sarkisyan and Kotelnikov, 1972) was observed, as well as kaolinite. Illite, with a very low crystallinity, occurs in a very small amount.

b) Upper part of the section (VI 10/14)

These strata are mainly composed of an alternation of shales with nodular biomicrites (bioclastic wackestone to packstone) and pelbiomicrites (bioclastic wackestone); the latter becoming more important towards the upper part of the section. Moravamminids and crinoids are the most important components (plate 14.7). However, from VI 12 on a drastic decrease in their content was observed. Hashed brachiopods, gastropods, ostracodes, foraminifera, bryozoans, etc ... are of minor importance. Sponge spicules were rarely observed. These strata are often intensively recrystallized. Minor pyrite spots occur, especially at the base of the Elergetkhyn Formation.

A study of the clay fraction of sample SN8-9 revealed a similar composition as in the previously described sample SN1; however, a clear decrease of the chlorite and an increase in illite and ordered chlorite-montmorillonite content is observed.

Interpretation

The sediment petrographic features suggest an open marine rather deep subtidal sedimentation environment. The transgression, already observed in the Oder section (Perevalny Formation) seems to persist. Biomicrites (bioclastic wackestone) become more and more important. A remarkable feature is the preponderance of the moravamminids and crinoids. From VI 12 on, a minor regressive trend is reflected by the deposition of pelbiomicrites (bioclastic wackestone) and the change in bioclast content; however, sedimentation remained in a subtidal environment.

Lithogeochemistry

As far as possible analyses were performed on carbonate material. The lithogeochemical profile is given in figure 3A; the geochemical data are enumerated in table 3. From the geochemical profile it is clear that, on the basis of the IR, K, Fe, Pb and Sr distributions this section can be subdivided in two parts, identical to the above-described lithologic units.

a) Lower part of the section (VI 1/9)

The high IR content in this interval is mainly caused by the silicification of the strata; however, the higher K contents reflect also higher amounts of detritus (clays, ...). The high

Fe values are caused on the one hand by Fe adsorbed on clays and on the other hand by Fe provided by the oxidized pyrite spots. The Mg distribution reflects the degree of dolomitization (idiotopic type). The negative correlation between Mg and Sr is related to this dolomitization since it is well known that dolomitization will lower the initial Sr content of the limestone. The Mg-Fe correlation seems to be coincidant since it is not likely that such low dolomite proportions would influence significantly the Fe content. The Na, Zn, Pb and Mn distributions display a rather uniform pattern.

b) Upper part of the section (VI 10/14)

Most of the variables in this part display normal contents and a uniform distribution pattern. Only Sr and Fe are somewhat high in these limestones. An important Pb anomaly, with two peak values of 770 ppm and 293 ppm, is present. These anomalies are caused by dessiminated galena which is associated by pyrite. The latter sulphide displays framboidal or euhedral textures. Goethite pseudomorphs after pyrite are common.

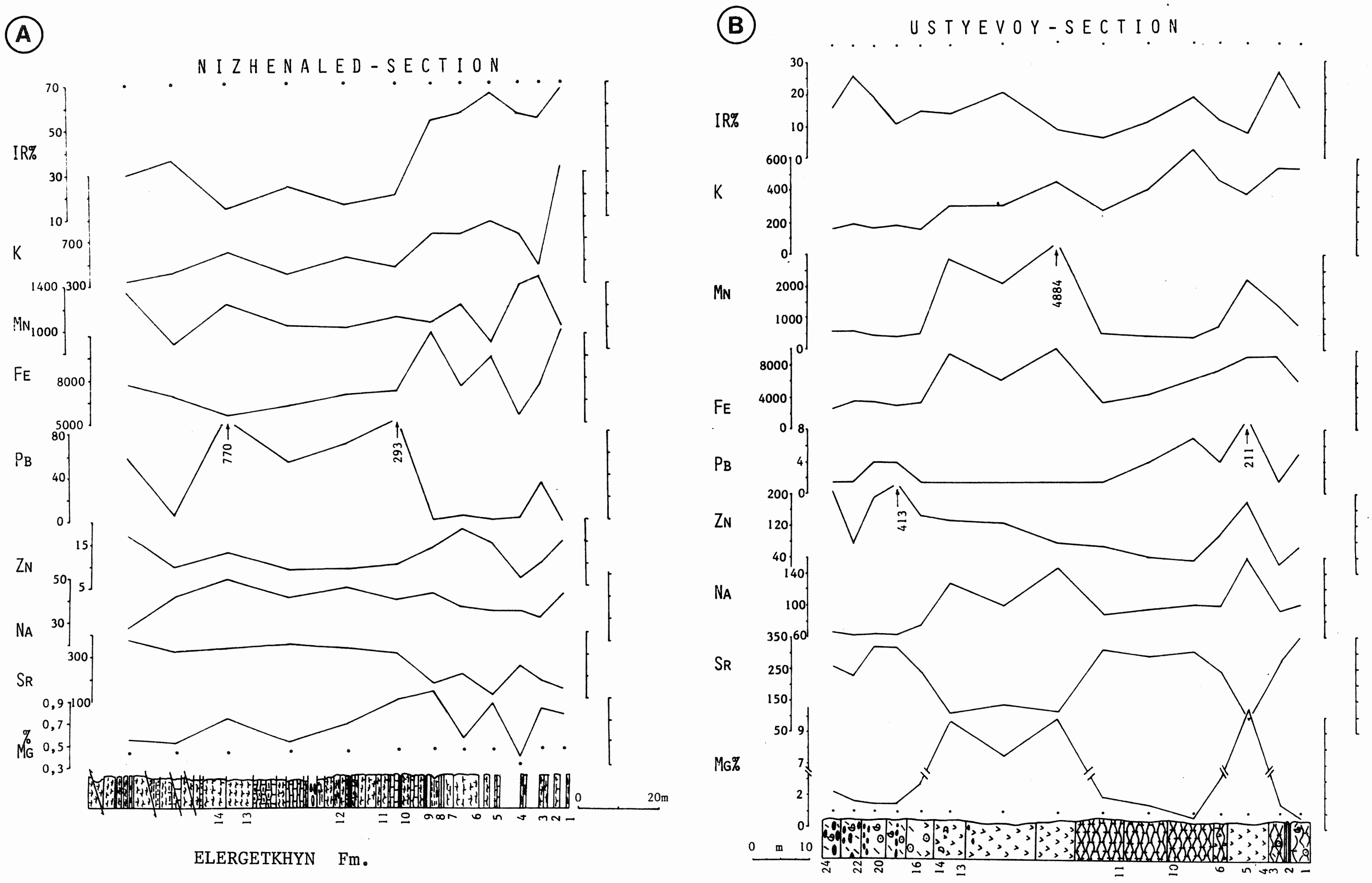

Figure 3 : Geochemical profile of the Nizhnznaled and Ustyevoy sections

sample number		unit number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
SN1		VI1,2	0,77	146	41	15	1,5	11300	1009	1353	71
SN2		VI3	0,81	188	31	10	35	7515	1450	476	57
SN3	A	VI4	0,38	249	34	7	4	5662	1391	733	59
SN4		VI5	0,86	126	34	15	1,5	9459	862	851	68
SN5		VI6/7	0,54	213	36	18	9	7554	1207	734	58
SN6		VI8/9	0,98	174	42	14	1,5	11053	1052	733	55
SN7		VI10/11A	0,90	313	40	10	293	7295	1108	451	22
SN8		VI11B	0,68	335	45	9	70	7191	1017	554	18
SN9	B	VI12	0,53	353	41	9	54	6362	1036	402	27
SN10		VI13/14A	0,73	335	49	13	770	5623	1228	611	17
SN11		VI14B	0,51	323	41	10	7	6840	886	416	39
SN12		VI14C	0,55	369	27	17	58	7710	1367	346	32
lower part n=6		$\overline{X}$	0,72	183	36	13	9	8757	1162	813	61
upper part n=6		$\overline{X}$	0,65	338	40	11	209	6837	1107	465	26
n = 12		$\overline{X}$	0,69	260	38	12	109	7797	1134	639	44

TABLE 3 : Lithogeochemical data of the Nizhnenaled section ($\overline{X}$ = mean value; n = number of samples)

C. USTYEVOY SECTION (II : Elergetkhyn Formation)

Lithology and sediment petrography

This section can be divided in the following lithological units :

a) nodular bioclastic limestones (II 1-3)
b) xeno- to hypidiotopic dolostones (II 4-6)
c) nodular limestones with shale intercalations (II 7-11)
d) xeno- to hypidiotopic dolostones (II 12-14)
e) bioclastic limestones (II 15-24)

Description

a) Nodular bioclastic limestones (II 1-3)

The lower part of this unit consists of nodular biopelsparites (pelletic packstone), whereas nodular biomicrites (bioclastic wackestone) are more common in the upper part. Crinoids, brachiopod and ostracode shell fragments, moravamminids, gastropods, corals and bryozoans were recognized as bioclasts. Locally dolomitization is present, altering especially the crinoids.

b) Xeno- to hypidiotopic dolostones (II 4-6)

This unit is intensively dolomitized. The few limestone intercalations which were sampled show that the original strata consisted of pelbiomicrite (bioclastic wackestone) which were mainly composed of a hash of crinoids, moravamminids, foraminifera, ostracodes, echinoid spines, etc .... Dolomitization seems to start within the crinoid ossicles. To a certain extent these pelbiomicrites are comparable to those in the under- and overlying strata. An important difference however, is the presence of small silicified horizons which can be up to 50 cm long. They occur in semi-continuous layers, parallel to the stratification. It is not yet clear if these layers are related to a synsedimentrary feature e.g. algal mats or to a diagenetic process.

c) Nodular limestones with shale intercalations (II 7-11)

The lower part of this unit is characterized by the presence of biopelsparites (pelletic packstones). Bioclasts such as brachiopods, crinoids, gastropods, foraminifera and echinoids occur frequently. Sometimes these strata are intensively dolomitized forming a xenotopic dolosparite. Crinoid ossicles are often coated or silicified.

The upper part of this unit is composed of a so-called moravamminid micrite (bioclastic wackestone to packstone) since these fossils can make up 80 % of the total bioclastic content (plate 14.3). These are associated with minor amounts of crinoids, brachiopods, echinoids, etc ... Dolomitization and silicification spots were frequently observed. Two dolomite generations were recognized, namely an anhedral type (xenotopic dolosparite) and a saddle dolomite with undulous extinction. Furthermore microgranular quartz, mega-quartz and length slow chalcedony were recognized. At the top of II 8 (sample RC 33) inclusion-rich volcanogenic quartz grains, with a cracklé-texture, are present.

d) Xeno- to hypidiotopic dolostones (II 12-14)

This unit, which was exposed in a trench (see Simakov et al., 1983, p. 378-379), is composed of xeno- to hypidiotopic dolostones with bentonite intercalations. Dedolomitization is a common feature within these strata. The original lithology consisted probably of pelbiomicrites (bioclastic wackestone) alternating with moravammid micrites (bioclastic wackestone to packstone) comparable to the above described strata. At the top of this unit some chert and dolomite nodules occur. The last are pseudomorphous after anhydrite nodules.

e) Bioclastic limestones (II 15-24)

These strata consist mainly of biomicrites to biosparites (bioclastic wackestone to packstone). A subdivision in a lower part rich in moravamminids (II 15-17) and an upper part (II 18-24) scarce in moravamminids can be elaborated. Two dolomite generations were recognized, namely a xenotopic dolosparite and a hypidiotopic saddle dolomite. The last type preferentially occurs near stylolites. Dedolomitization was often observed.

In the lower part the moravamminid content grades up to 50 %. In this unit it can be observed that a decrease in the moravamminid content always corresponds with an increase in coral and gastropod contents. Along with these bioclasts crinoids and brachiopods occur frequently.

The upper part, which is chert-rich, is mainly composed of a hash of bioclasts such as crinoids, brachiopods, echinoids, foraminifera, ostracodes, calcispheres and bryozoans. Locally algal lumps and dascycladacean algae are present. Few (thick-walled) moravamminids occur. Low numbers of pellets are scattered throughout this unit (plate 14.4).

Interpretation

From the description it is clear that biomicrites (dolomitized or not) are the most important lithology. Its diversified bioclast content points to an open marine, relatively deep subtidal sedimentation environment. Minor fluctuations within this environment (possibly variations in depth) caused the development of moravamminid micrites. A rapid shallowing of the environment has to be accepted for the strata of unit II 14; here an interval with pseudomorphs after anhydrite nodules occurs. However, a real evaporitic regime did not develop since the sedimentation of moravamminid-micrites continued in the overlying strata. A clear change in sediment type occurs in II 18. From then on moravamminids become a minor component, and algal lumps and dascycladacean algae are present. These strata developed in an open marine shallow subtidal environment, indicating a regression.

Dolomitization is abundant. Two generations can be distinguished namely a xenotopic dolosparite and a hypidiotopic saddle dolostone type. No arguments were found for an early-diagenetic origin of one of these generations. Therefore these dolostone strata cannot be related to a sedimentation environment. Moreover the dolomitized lithologies are nearly identical to the surrounding strata, except for the strata II 14. In several samples a relation between dolomitization (xenotopic dolosparite) and silicification seems probable. Silicification occurred within crinoid and brachiopod debris. Dedolomitization was often observed.

Lithogeochemistry

The lithogeochemical profile is given in figure 3B and the geochemical data in table 4. A covariance between Mg, Sr (negative), IR, Na, Fe and Mn is reflected in the geochemical profile and shows the contrast between dolostones and limestones. From a geochemical point of view there is no clear difference between the dolostones of the interval II 4-6 and II 12-14. Only for Pb, a content of 211 ppm was recorded in the II 4-5 sample. This high Pb content explains also the high mean value for Pb within the dolostones (table 4).

The lowering in Sr content during dolomitization is a well known phenomenon. The low Sr content within the dolomitized intervals could indicate that dolomitization affected the purest limestones. The high Fe and Mn content is not in agreement with petrographic observations since these dolostones did not stain with potassium ferrycyanide. Therefore the high Fe and Mn content is related to dedolomitized intervals. As shown by Swennen et al., (1984) dedolomitization is often characterized by an Fe and Mn increase, and by a Sr decrease. The presence of dedolomitized intervals, which already were indicated by the thin sections, could also explain the relative low Mg content of these dolostones ($\sim$ 10 % Mg). However, incomplete dolomitization could also be invoked.

From the geochemical profile (fig. 3B) it is also clear that a Na and K decrease and a Zn increase towards the top is present. Since the K and Na distribution are related to the clay content this trend reflects a decrease in the clay content. This decrease is not reflected in the IR distribution probably because silicification, which is pronounced in the upper part of the section, controls the IR distribution pattern. The increase in Zn content is important causing an anomaly near the top of the sequence. Detailed ore microscopy of these anomalous strata revealed the presence of minor traces of framboidal and euhedral pyrite, marcasite and dessiminated sphalerite. A spatial relation with the saddle dolomite is probable.

sample number	unit number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
SU1	II1	0,70	349	98	66	5	6051	768	534	18
SU2	II2/3	2,46	272	93	22	1,5	9174	1442	540	29
SU3	II4/5	10,55	88	158	180	211	9058	2232	381	10
SU4	II6	3,22	243	98	95	4	7515	803	467	14
SU5	II7/8/9	0,67	305	101	33	7	6375	394	663	16
SU6	II10	1,52	290	96	41	4	4327	426	409	14
SU7	II11	2,00	309	90	65	1,5	3441	511	279	9
SU8	II12A	9,87	117	147	75	1,5	10289	4884	359	11
SU9	II12B	7,52	138	100	124	1,5	6090	2111	310	23
SU10	II13/14	9,69	111	128	134	1,5	9395	2864	309	16
SU11	II15/16/17	2,82	244	76	145	1,5	3410	508	161	17
SU12	II18	1,47	322	64	413	4	3009	397	190	13
SU13	II19/20/21	1,51	320	65	189	4	3573	469	166	21
SU14	II22/23	1,70	229	63	78	1,5	3510	581	188	29
SU15	II24	2,25	259	67	210	1,5	2633	573	166	18
limestones Mg ≤ 2,00 % n = 7	$\overline{X}$	1,37	303	82	126	4	4327	507	347	17
dolostones Mg > 9,00 % n = 3	$\overline{X}$	10,04	105	139	130	71	9581	3327	350	12
total n=15	$\overline{X}$	3,86	240	96	125	17	5857	1264	341	17

TABLE 4 : Lithogeochemical data of the Ustyevoy section ($\overline{X}$ = mean value; n = number of samples)

D. VERKHNENALED SECTION (VII : upper part of the Elergetkhyn Formation)

Lithology and sediment petrography

Description

The strata exposed in this section consist mainly of biomicrites (bioclastic wackestone). Only at the top (VII 15) biopelsparite (pelletic packstone) intercalations were recognized (plate 14.8). The majority of the bioclasts are intensively broken; therefore it was often difficult to characterise the different components. Predominant bioclasts are crinoids, brachiopods, foraminifera and echinoid spines. Stromatoporoids, gastropods and bryozoans are rare; the first occur mainly in the lower part of the section whereas the other two mainly in the middle part. Algae fragments and oncolites occur abundantly in the lower part of the section (VII 1-8). Locally algal mats start to develop. This is also the case within the uppermost strata where the algal mats are associated by oncolites. Foraminifera and crinoids are sometimes micritized (coated grains).

Cherts occur all over the section. Silicification (length-slow chalcedony) of crinoids is a common feature. Individual pyrite crystals often occur; however, their content is low.

Interpretation

For the base of this section an intertidal to shallow subtidal sedimentation environment is suggested by the presence of oncolites and algal mats. With the exception of the uppermost beds, a subtidal sedimentation environment with an open marine circulation is accepted for the other strata. The presence of hashed bioclasts, especially in the central part of the section points to a turbulent and consequently a relatively shallow marine environment. The presence of algal mats in association with biopelsparites at the top of this section can be interpreted in a similar way as the lower strata, namely as a sedimentation in a shallow subtidal to intertidal environment.

Lithogeochemistry

The lithogeochemical profile is given in figure 4A and the geochemical data in table 5. These limestone strata ($\overline{X}$ Mg = 0,64 %) are rather impure ($\overline{X}$ IR = 30 %). From the geochemical profile it is clear that normal values occur for most variables with no clear covariance between them. Zn values are somewhat higher in the lower part of the section with values up to 234 ppm. On the contrary, an increase of Fe can be observed towards the top. Slightly higher concentrations of Pb occur in the upper part of the section. These higher values are possibly linked with the high content in clay.

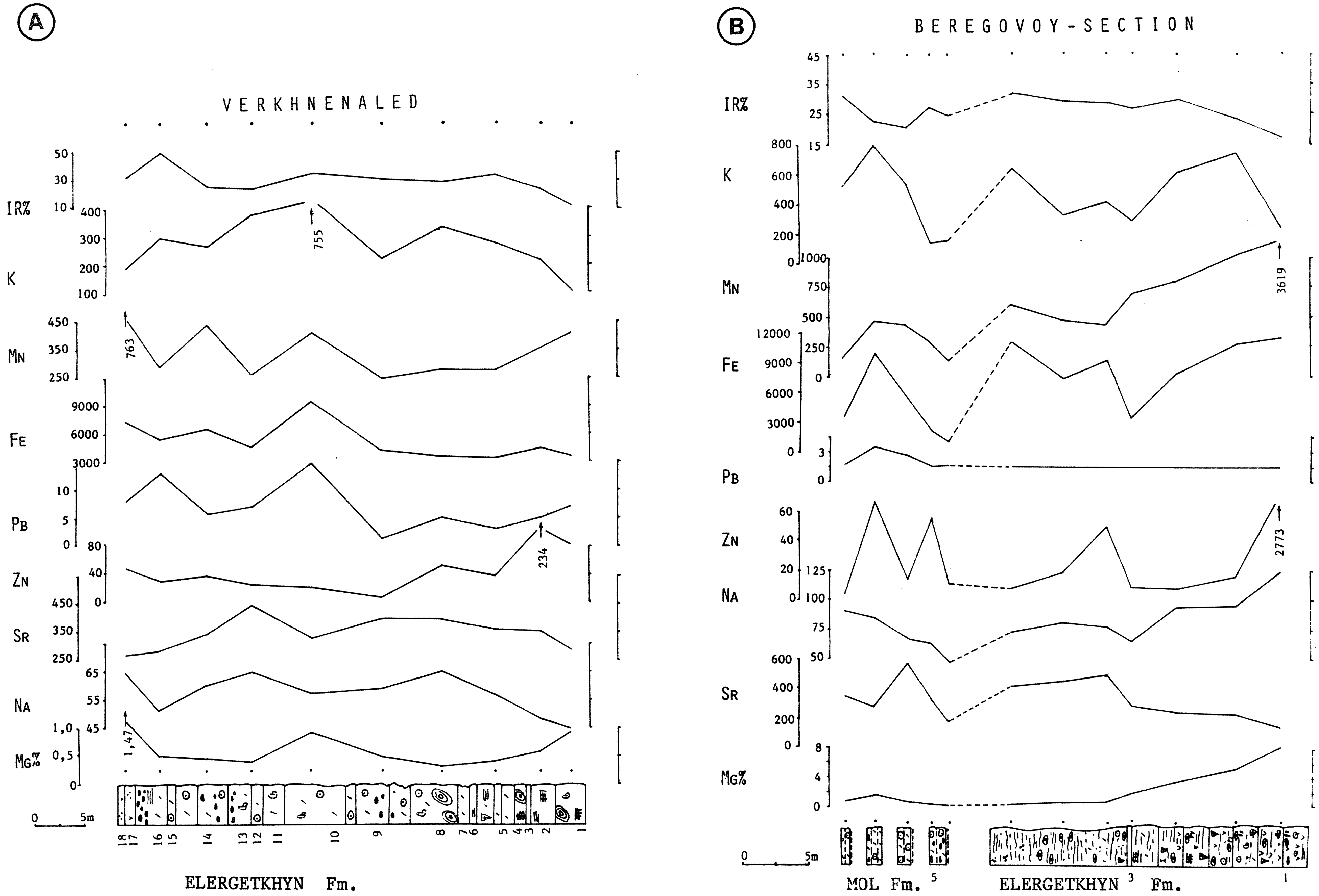

Figure 4 : Geochemical profile of the Verkhnenaled and Beregovoy sections

sample number	unit number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
SV1	VII1	0,92	291	44	84	7	3819	403	111	12
SV2	VII2,3	0,56	353	48	234	5	4511	353	223	24
SV3	VII4,5,6	0,40	360	57	38	3	3439	273	277	34
SV4	VII7,8	0,32	398	65	55	5	3588	273	337	29
SV5	VII9	0,49	399	59	8	1,5	4280	250	230	30
SV6	VII10,11	0,93	328	57	21	15	9479	416	755	35
SV7	VII12,13	0,40	447	65	24	7	4633	258	380	24
SV8	VII14	0,46	348	60	38	6	6437	432	270	25
SV9	VII15,16	0,50	277	51	28	13	5094	289	297	50
SV10	VII17,18	1,47	270	65	50	8	7305	763	190	33
n = 10	$\overline{X}$	0,64	347	57	58	7	5258	371	307	30

TABLE 5 : Lithogeochemical data of the Verkhnenaled section ($\overline{X}$ = mean value; n = number of samples)

E. BEREGOVOY SECTION (III : upper part of the Elergetkhyn and lower part of the Mol Formation)

Lithology and sediment petrography

Description

The lower part of this composite section consists of chert-rich idiotopic dolostones and biomicrites (bioclastic wackestone); the upper part consists of biosparites (bioclastic packstone).

Within the idiotopic dolostones, cherts and silicified anhydrite nodules are abundant. Furthermore, silicification of bioclasts such as corals, brachiopods and stromatoporoids is present. Chertification predates dolomitization since sedimentary structures are well preserved in these nodules. However, small dolomite euhedra often occur within these nodules so that a genetic link between the dolomitization and chertification seems possible. It should also be noticed that most of the cherts incompletely developed : only an outer chert-fringe occurs in the middle part of the bed. The cherts in this lower part are often surrounded by euhedral and framboidal pyrite and locally sphalerite was recognized. Furthermore these levels are characterized by the presence of authigenic quartz crystals and by calcite veins.

Higher in the sequence a decrease in dolomite content can be observed and biomicrites (bioclastic wackestone) become the most common lithology. Within these limestones, crinoids, brachiopod fragments, echinoid spines, foraminifera, ostracodes and few moravamminid pieces occur. Locally corals, algae, gastropods and stromaporoids were recognized. In one sample charophyte relics were determined. In the uppermost sample (III 4) of the first section, few protooolites were present.

These strata are often recrystallized. Dolomitization is manifested by single brown-coloured and zoned euhedra as well as by saddle dolomite. These dolomite types are different from those observed in the lower part. Dedolomitization often occurs. Sometimes silicification of bioclasts is developed. Goethite spots (pseudomorphous after pyrite) frequently occur.

Within the uppermost thin-bedded biosparites (bioclastic packstone) different chert horizons were observed. Crinoids, some ostracodes, brachiopod pieces, few moravamminids, gastropods and bryozoans are present. These are often silicified. Locally these strata are dolomitized. In such cases an idio- to hypidiotopic texture can be observed.

Interpretation

Considering the variety of bioclasts within these strata, a shallow open marine sedimentation environment (supra- to subtidal shelf) is indicated. Slight variations within the sedimentation environment may be accepted since in the lower part relics of anhydrite nodules and algal fragments were observed.
There seems to exist a relation between dolomitization, (incomplete) chertification and mineralization because of their spatial relationship.

Lithogeochemistry

The lithogeochemical profile is given in figure 4B and the geochemical data in table 6. The geochemical profile shows a clear decrease in Mg content towards the top. A similar trend, at least in the first section (III 1-4) can be observed for Na and Mn; an opposite trend is recognized for Sr and IR. These phenomena can be explained by the degree of dolomitization, where Na and Mn were introduced into the system, whereas Sr is depleted. The negative IR-Mg relation could indicate that dolomitization preferentially occurred in the purest limestones. The Mn pattern however can also be interpreted as a halo which occurs around the important Zn anomaly of 2723 ppm in the lower part of the section. Furthermore, some covariance between K and Fe is present and indicates that Fe is mainly adsorbed on clay phases.

sample number	unit number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
SB1	III1A	8,66	148	125	2723	1,5	11838	3619	248	15
SB2	III1B	5,13	237	93	16	1,5	11014	1030	744	20
SB3	III2	3,56	252	89	8	1,5	8025	773	605	27
SB4	III3A	1,82	295	66	9	1,5	3560	674	284	25
SB5	III3B	0,83	494	78	49	1,5	9432	426	413	26
SB6	III3C	0,70	452	82	19	1,5	7706	461	324	27
SB7	III4	0,66	414	73	8	1,5	11068	605	655	30
SB8	III5A	0,10	179	47	11	1,5	1030	135	153	77
SB9	III5B	0,41	342	62	55	1,5	2140	295	141	37
SB10	III5C	0,86	572	67	13	4	5564	395	521	30
SB11	III5D	1,79	274	85	66	5	9952	459	798	43
SB12	III5E	0,72	353	91	3	1,5	3547	145	516	15
n = 12	$\overline{X}$	2,10	334	80	23 *	2	7073	491 *	450	31

TABLE 6 : Lithogeochemical data of the Beregovoy section ($\overline{X}$ = mean value; n = number of samples; * = calculated without sample III1A)

F. SIKAMBR SECTION A (XXIII : middle and upper part of the Mol and lower part of the Sikambr Formation)

Lithology and sediment petrography

Description

This section can be divided in 3 parts namely :

a) a lower part composed of nodular limestones alternating with shales (below the diorite dyke; middle part of the Mol Formation);

b) a middle part where bioclastic limestones occur. At certain levels silicified anhydrite nodules and few cherts were observed (above the diorite dyke; upper part of the Mol Formation);

c) the uppermost part where oolitic strata become the most prominent lithology (lower part of the Sikambr Formation).

a) Lower part : the nodular limestones (alternating with shales) consist of biomicrite (bioclastic wackestone) which in the lower part of the sequence is mainly composed of a hash af ostracodes, calcispheres and moravamminids. The last component may occur in such high concentrations that a moravamminid packstone fabric is created. Upwards broken gastropods, brachiopod and foraminifer fragments as well as crinoids become the most prominent bioclasts. Sponge spicules also were observed. These strata often display bioturbation features. Sometimes they are intensively recrystallized so that the micrite matrix is transformed into sparite. Pyrite spots (up to 15 %) and their oxydation products occur throughout the unit; their content increases towards the dyke. Therefore a genetic link between the diorite dyke and widespread pyritization is probable. The strata near the dyke ($\sim$ 5m) are completely recrystallized; only a few relics of brachiopods, crinoids, moravamminids and ostracodes remain.

b) Middle part : three units can be distinguished from bottom to top namely :

- a biomicritic (bioclatic wackestone), ± 14 m thick, with several horizons with silicified anhydrite nodules. Relics of crinoids, calcispheres, ostracodes, moravamminids, brachiopods and sponge spicules occur; they are often micritized yielding a pseudo-pelletoidic fabric. Beside some silicified bioclasts, minor pyritic and dolomite spots are present.

- an alternation of biomicrites (bioclastic wackestone), biopelmicrites and biopelsparites (both consist of pelletic to bioclastic packstone; plate 12.1). The bioclast content, within this ± 23,5 m thick unit, is comparable to that of the underlying biomicrites, however, a drastic decrease in the number of moravamminids and sponge spicules is apparent. Furthermore, few algal clasts were observed. In the lower part of the unit silicified anhydrite nodules occur. Towards the top minor amounts of coated grains are present. Silicification of bioclasts was observed throughout the unit. Locally minor pyrite and dolomite spots occur.

- coated grain succession (bioclastic packstone) in alternation with biopelsparites (pelletic packstone), about 11,5 m thick. The coated grains consist of a hash of micritized bioclasts. Algal fragments and lumps are common. Silicification of crinoid remnants was observed.

c) Uppermost part : within the biooosparites and oosparites (oolitic packstone; plate 12.4), which sometimes alternate with peloosparites (oolitic packstone) two types of oolites can be distinguished, namely large oolites with many fine-radial cortical layers and superficial oolites developing around a bioclast fragment. Locally algal clasts and lumps were observed. Silicification of crinoids is present.

An analysis of the < 2 μm fraction was carried out on sample SS6, which occurs just below the dyke and on sample SS27, where an influence by the dyke may be considered as negligible. Along with quartz, undissolved calcite and dolomite traces, ordered chlorite-montmorillonite (cfr. Sarkisyan and Kotelnikov, 1972) and illite were observed in both samples. The X-ray pattern of sample SS27 is shown in figure 5. From this figure it is also clear that the illite is characterized by a low degree of crystallinity. Furthermore chlorite and kaolinite were detected in sample SS6. This might suggest a relation between these clay-minerals and the presence of the dyke. However, more analyses are needed for confirmation.

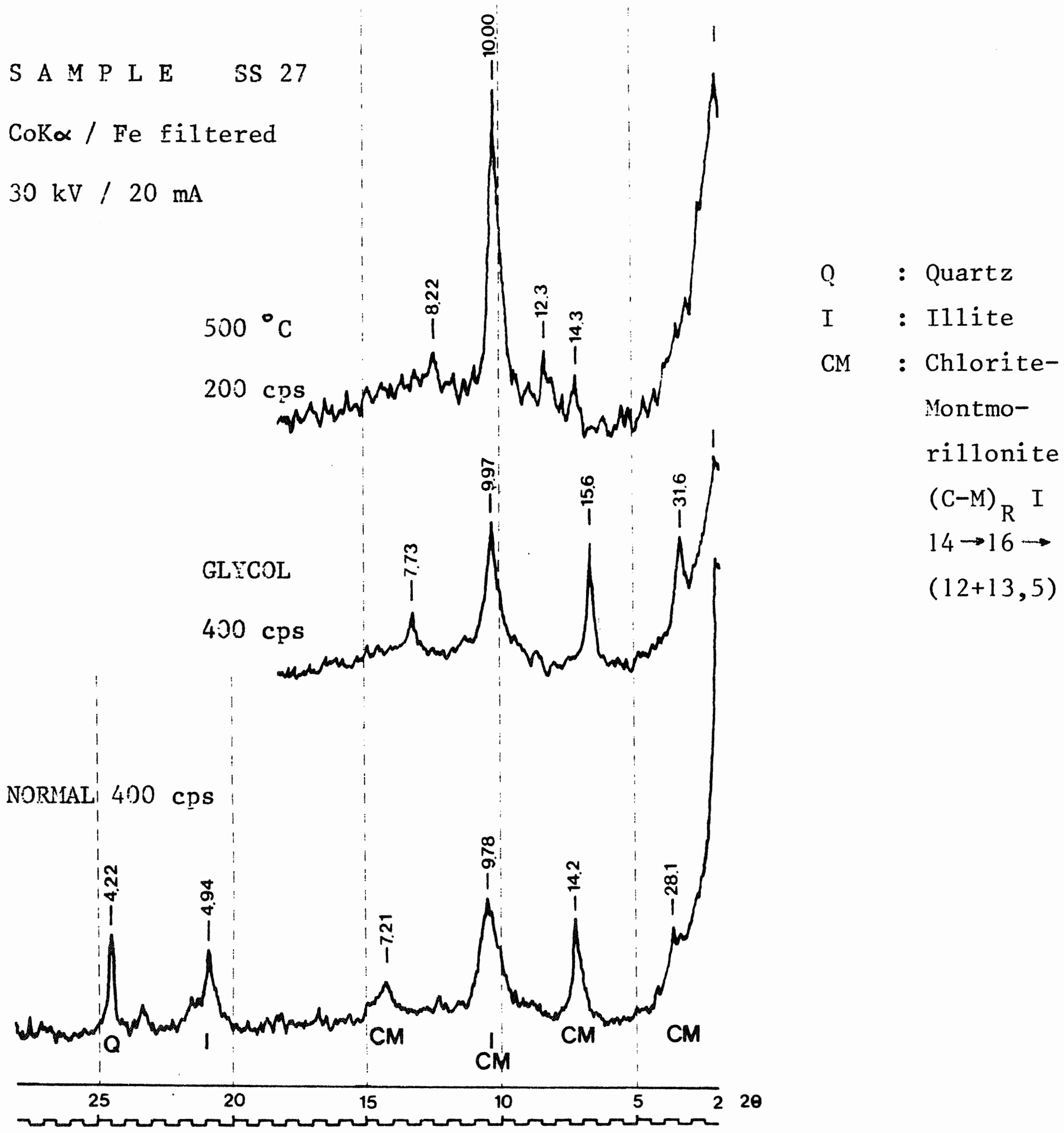

Figure 5 : X-ray pattern of sample SS27

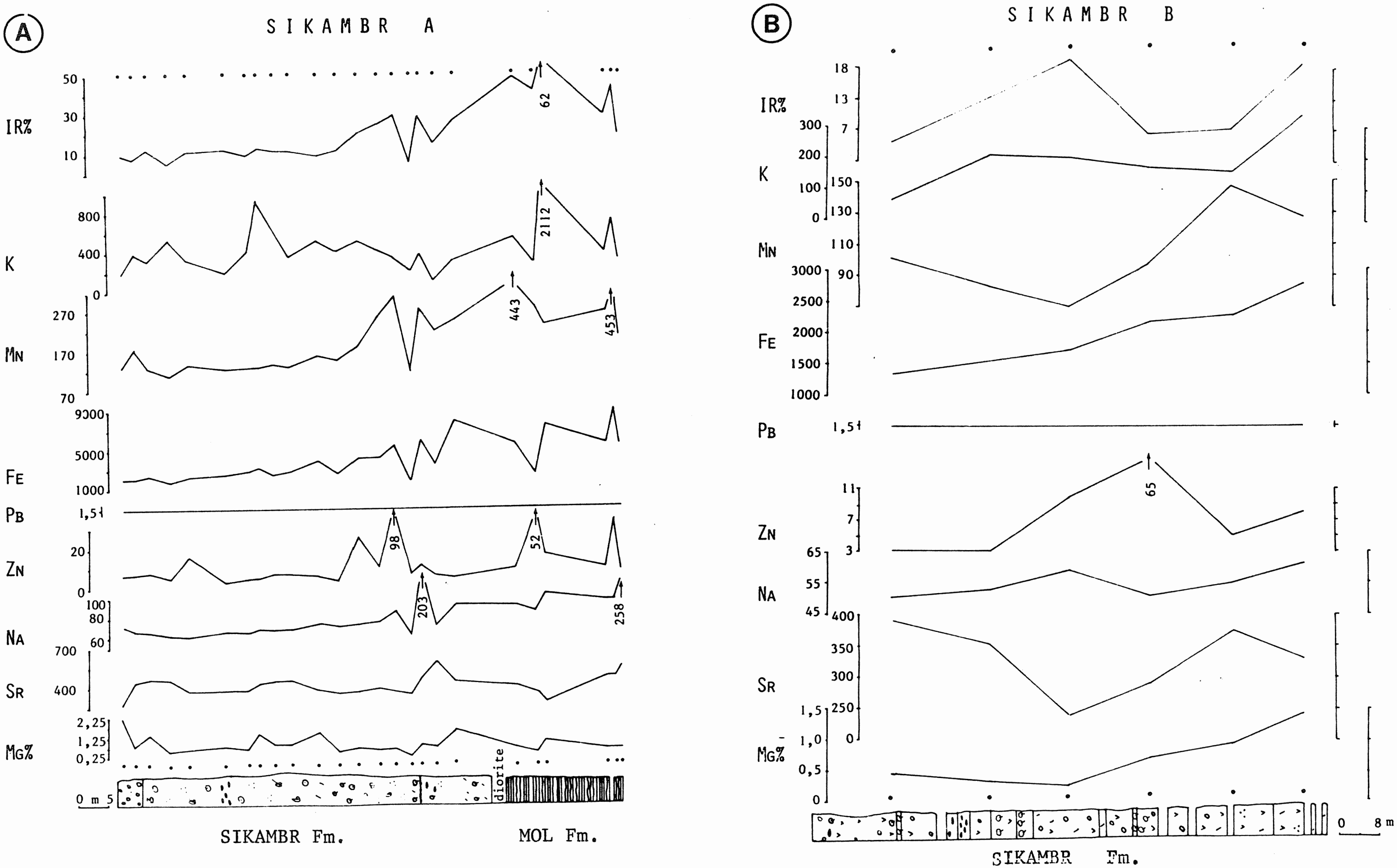

Figure 6 : Geochemical profile of the Sikambr A and Sikambr B sections

Interpretation

A general shallowing of the sedimentation environment is present here. The nodular limestones with shale intercalations were deposited in a relatively deep subtidal environment. The overlying bioclastic limestones developed in an open marine subtidal environment where minor regressive fluctuations occurred. During such regressive periods the development of algae and the formation of anhydrite nodules started. It is only from the Sikambr Suite onwards that shallow subtidal sedimentation conditions persisted.

Lithogeochemistry

The lithogeochemical profile and the geochemical data are given respectively in figure 6A and table 7. These strata display moderate Mg, Sr, Zn, Mn, K and IR values. The Na and Pb contents, however, are very low. A clear upward decrease in the content of Na, Fe, Mn and IR is present. A covariance between these elements occurs, suggesting that Fe and Mn are adsorbed on IR phases; the Na is provided by clays. It is to be remarked that a similar K distribution is absent; this could indicate that the geochemical pattern in the lower part of the section is influenced by the dyke.

sample number	unit number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
SS1	(308)	0,49	537	258	7	1,5	5347	202	330	20
SS2	(302-7)	0,55	458	91	33	1,5	8914	453	700	44
SS3	(301)	0,49	442	90	9	1,5	5493	269	398	31
SS4	(RC294)	0,89	270	103	16	1,5	7346	235	2112	62
SS5	(312)	0,28	336	71	52	1,5	2356	282	277	41
SS6	(RC290)	0,69	389	82	5	1,5	5523	443	545	48
SS7	(601)	1,45	433	82	5	1,5	7760	246	325	28
SS8	(602)	0,68	590	42	6	1,5	3523	220	122	17
SS10	(603)	0,80	477	203	11	1,5	5787	271	368	30
SS11	(315)	0,27	355	21	7	1,5	1769	118	204	8
SS13	(604)	0,59	385	69	98	1,5	5453	313	351	31
SS14	(605)	0,54	391	49	10	1,5	4147	259	421	28
SS15	(606)	0,66	363	45	25	1,5	4067	183	507	22
SS16	(607)	0,50	357	41	4	1,5	2608	154	408	14
SS17	(609)	1,42	387	44	6	1,5	3886	164	509	12
SS18	(610)	0,83	444	35	7	1,5	2896	130	279	14
SS19	(611)	0,82	441	34	7	1,5	2458	128	606	13
SS20	(612)	1,34	415	38	5	1,5	3184	116	910	15
SS21	(613)	0,64	388	30	5	1,5	2809	126	403	12
SS22	(614)	0,75	373	32	3	1,5	2495	123	200	14
SS23	(616)	0,59	376	25	16	1,5	2282	135	330	13
SS24	(617)	0,53	441	27	5	1,5	1894	109	530	8
SS25	(618)	1,32	455	33	8	1,5	2458	129	312	14
SS26	(619)	0,82	432	34	7	1,5	2057	176	399	10
SS27	(620)	2,28	263	44	7	1,5	2044	131	189	12
n = 25	$\overline{X}$	0,81	408	65	15	1,5	3942	205	469	22

TABLE 7 : Lithogeochemical data of the Sikambr A section ($\overline{X}$ = mean value; n = number of samples)

G. SIKAMBR SECTION B (XXIII : middle part of the Sikambr Formation)

Lithology and sediment petrography

Description

The lowest 20 m of this section are composed of an alternation of biopelsparites (pelletic packstone) and biointrasparites (intraclastic to bioclastic packstone). Crinoids, brachiopod fragments, micritized foraminifera, corals and algal clasts occur in variable amounts. Locally oolitic or coated grain intercalations occur. The matrix in most of the samples is completely dolomitized (idiotopic-type). The dolomite rhombs have a rather uniform size (about 30 μm). Locally minor silicification spots were observed.

The overlying 45 m are composed of alternating sequences of dolomitized biooosparites and oosparites (oolitic packstone to grainstone; plate 12.5 and 6). Coated grains and superficial oolites often occur. Sometimes a syntaxial rimcement was observed around crinoids. Broken brachiopods occur locally. Upwards algal filaments and lumps occur frequently. Silicification, starting in the sparite matrix occurs. Dolomitization is a widespread phenomenon. Locally the biooosparite and oosparite strata are overlain by a thin dolostone bed (idiotopic type). Within these levels silicified anhydrite pseudomorphs occur abundantly.

Interpretation

These strata were deposited in a shallow marine relatively restricted environment. Initially sedimentation in a subtidal environment may be accepted; towards the top a shallowing occurred. Supratidal intervals possibly are indicated by the levels with anhydrite nodules. The dolostones which occur herein could be early-diagenetic in origin.

Lithogeochemistry

The lithogeochemical profile is given in figure 6B and the geochemical data in table 8. Only 6 representative samples were analyzed. The geochemical data clearly show that dolomitization seems not to be so widespread as was predicted from field- and sediment petrographical observations. The content of most of the variables is moderate to low. A covariance between Mg and Fe, and Sr and Mn is present. Because of the low number of samples an interpretation for these variations is not given.

sample number	unit number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
SS28	-	1,43	330	63	8	1,5	2771	128	339	19
SS29	-	0,91	373	55	5	1,5	2245	146	155	8
SS30	-	0,71	293	48	65	1,5	2132	97	168	7
SS31	-	0,26	234	57	10	1,5	1719	70	199	19
SS32	-	0,30	353	53	3	1,5	1506	83	204	13
SS33	-	0,46	387	50	3	1,5	1330	102	68	5
n = 6	$\overline{X}$	0,68	328	54	16	1,5	1951	104	189	12

TABLE 8 : Lithogeochemical data of the Sikambr section B ($\overline{X}$ = mean value; n = number of samples).

H. POVOROTNY SECTION (IV : uppermost part of the Mol and Sikambr Formation)

Lithology and sediment petrography

Description

This section can be divided in four units, namely :

a) a lower part, composed of pelletic to bioclastic limestones (VI 17-22);

b) a middle part, characterized by the alternation of intraclastic and bioclastic limestones evolving upwards into oolitic strata. This sequence terminates by a thin horizon of dolostones with silicified anhydrite nodules. (IV 23-36);

c) a succession of limestone breccias, algal micrites and zebra limestones (IV 37-43);

d) an uppermost part, composed of bioclastic limestones (IV 44-54);

a) The lower part (uppermost part of Mol Formation) consists of bioturbated pelbiomicrites (bioclastic wackestone) and pelbiosparites (bioclastic to pelletic packstone). Crinoid ossicles, sometimes still as crinoid stems of 3 cm long and 1 cm in diameter, are the most prominent bioclasts. Furthermore, corals, gastropods, brachiopod and bryozoan fragments occur along with echinoid spines, ostracodes, foraminifera, calcispheres and algal fragments.

The crinoids are often partly micritized forming the initial stages of a coated grain. Syntaxial rim cements often develop around the ossicles. Locally these strata are recrystallized and/or dolomitized.

b) The middle part of the section (lower part of the Sikambr Formation) is characterized by alternating sequences of the following lithologies (from bottom to top) :

- intrabiosparites (bioclastic packstone) grading into intra-oosparites (oolitic packstone). Crinoids, broken brachiopods, foraminifera, calcispheres and algal filaments are the most frequent bioclasts. Some of them are micritized. Locally the sparitic matrix of the strata is intensively dolomitized.
- oopelsparites (pelletic to oolitic packstone) and biooosparites or oosparites (oolitic packstone; plate 10.7). The oolites are nearly always completely micritized. A bimodal distribution in diameter (200 μm and 450 μm) is often present. Furthermore superficial oolites and coated grains are very common. Locally some bioclastic levels, mainly composed of debris of crinoids and brachiopods occur. Sometimes algal clasts are present. Around the crinoids a syntaxial overgrowth develops. The matrix is often completely dolomitized whereas silicification occurs in the uppermost sequences. In the lower sequences the oolites are poorly developed, but upwards oosparites become the most prominent lithology. A decrease in crinoid and brachiopod content and an increase in algal clasts and algal micritic horizons towards the top occurs.
- idiotopic dolostones with quartz nodules. The size of the dolomite crystals varies around 30 micron. The quartz nodules are pseudomorphs after anhydrite; the following arguments are present :
  - ° the cauliflower and chickenwire structure
  - ° the occurrence of length-slow chalcedony and length-slow chalcedony spherulites which grade into mega-quartz
  - ° the presence of a felted texture which can be recognized within the mega-quartz crystals
  - ° the occurrence of lath-shaped anhydrite remnants within the mega-quartz crystals.

c) A succession of limestone breccias, algal micrites and zebra limestones. Different units were distinguished (fig. 7), namely :

1. a limestone breccia with at its base a nearly continuous layer of silicified anhydrite nodules and a brown chert layer. The breccia fragments consist of algal micrites and oolitic limestones. At the top a palisade calcite layer occurs (thickness : 200 cm);
2. oolitic limestone (oomicrite : oolitic wackestone) overlain by chert layers and a clay seam (bentonite ?) (thickness : 225 cm);
3. algal micrites with palisade calcite intercalations. These strata are often updomed, causing a brecciation of these strata (plate 8.4 and 9.6). Therefore the palisade calcite crystals (plate 9.5) could be pseudomorphous after selenite (thickness : 283 cm);
4. algal micrites, sometimes with oncolites (plate 9.4). This unit contains silicified anhydrite nodules in semi-continuous layers (plate 8.2). Lath-shaped calcite pseudomorphous probably after anhydrite also occur (plate 9.3; thickness : 495 cm);
5. alternation of algal micrites and zebra limestones (plate 8.1). Slump structures were recognized. The thickness of this unit is difficult to estimate since several gaps occur. Possibly these suggest the presence of an other lithology. The zebra limestones are characterized by a cyclic alternation of dark and white coloured layers. Small fault-like displacements, crosscutting several layers, are one of the characteristic features (plate 8.3 and 10.1, 2, 3 and 4). Within the black layers cryptoalgal textures are present. The coarse-grained layers are composed of two symmetrically arranged calcite generations indicating that the zebra structure is diagenetic in origin (plate 10.2 and 3; see Fonboté and Amstutz, 1983).

d) The uppermost part of this section (middle to upper part of the Sikambr Formation) is composed of pelbiosparites to biosparites (pelletic to bioclastic limestones). Near the base they are thin-bedded. Upwards they become more and more massif. In the thin-bedded strata algal clasts, moravamminids and coated crinoid ossicles are the most prominent bioclasts. Also micritized foraminifera, gastropods, corals and brachiopod fragments were recognized.

Towards the top a clear decrease in the algal clast content was observed. Within these bioclastic limestones silicified and dolomitized anhydrite nodules occur, mainly in the lower part; cherts are better represented in the upper part.

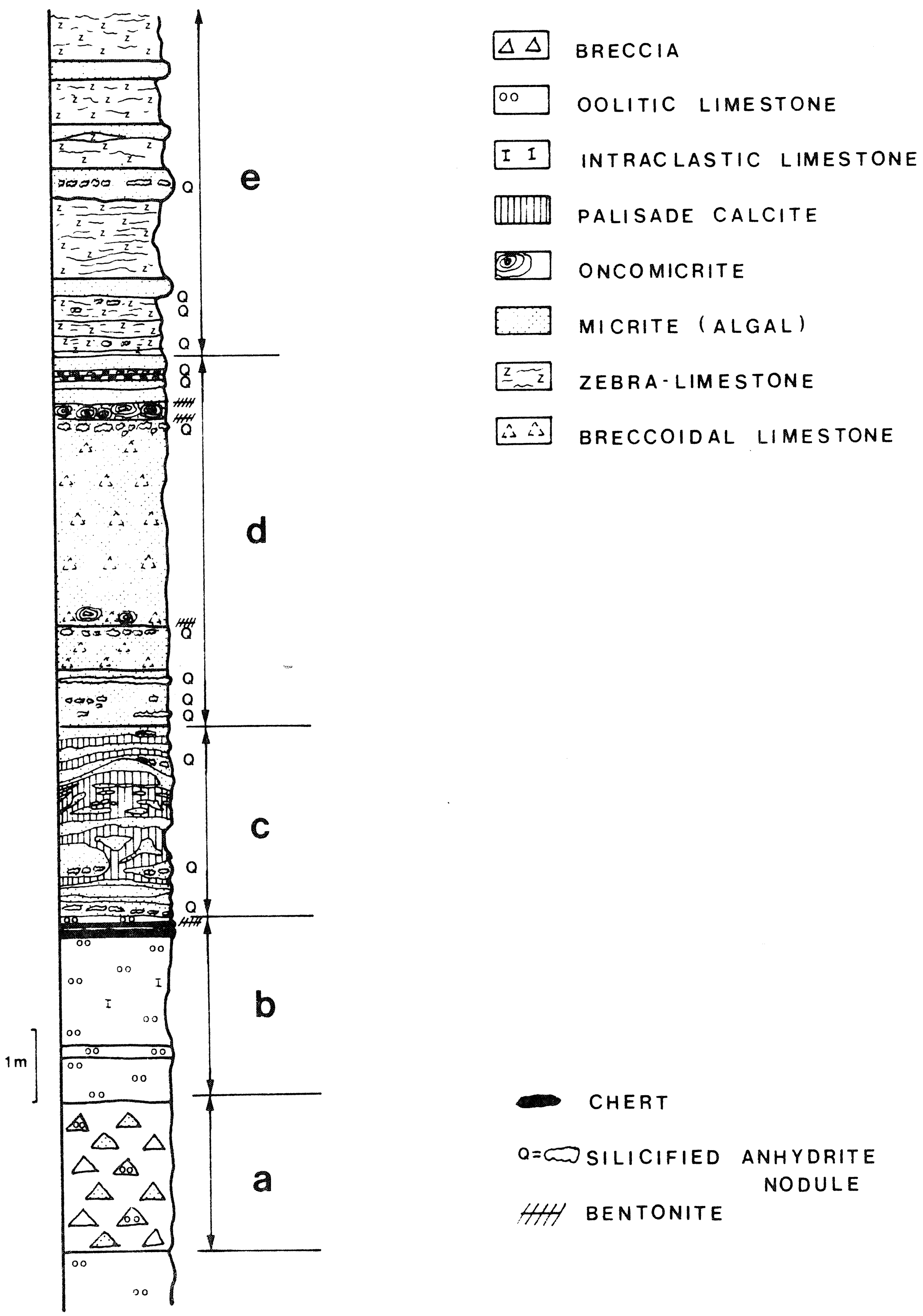

Figure 7 : Lithological succession of the Middle Sikambr Formation (Povorotny section)

Interpretation

The pelbiomicrites and sparites suggest an open marine subtidal environment. Small regressive fluctuations within this environment occurred and are reflected by variations in the bioclast content (e.g. vermiform gastropods, ...). The overlying sedimentary sequences, ranging from intrabiosparites to oosparites and overlain by a thin unit of dolostones with silicified anhydrite nodules, reflect a sedimentation environment changing from subtidal to intertidal and supratidal. The dolostone units are probably early-diagenetic in origin. In comparison with recent early-diagenetic dolostone occurrences however, their grain size is high. These minor regressive sequences are often incomplete. The uppermost dolostone unit is less developed above IV 30. However, from this level on, algae become a major component.

A general regression is indicated by the decrease in bioclast content and by the algal micrites with their enormous quantity of silicified anhydrite nodules. It is possible that the palisade calcite crystals, which occur above this interval, are pseudomorphous after selenite. All these features indicate a restricted hypersaline depositional environment.
From IV 46 on, a gradual opening of the sedimentary basin is reflected by the presence of biosparites. This opening occurred with several pulsations since algal micrite intercalations with silicified anhydrite nodules are still present. However, at the top of this section sediments reflect an open marine regime.

Lithogeochemistry

The lithogeochemical profile and the geochemical data are given respectively in figure 8 and table 9. Three parts can be recognized in the geochemical profile namely :

a) Lower part (IV 21-36). The strata are characterized by a uniform distribution for most of the elements. The variable Mg content

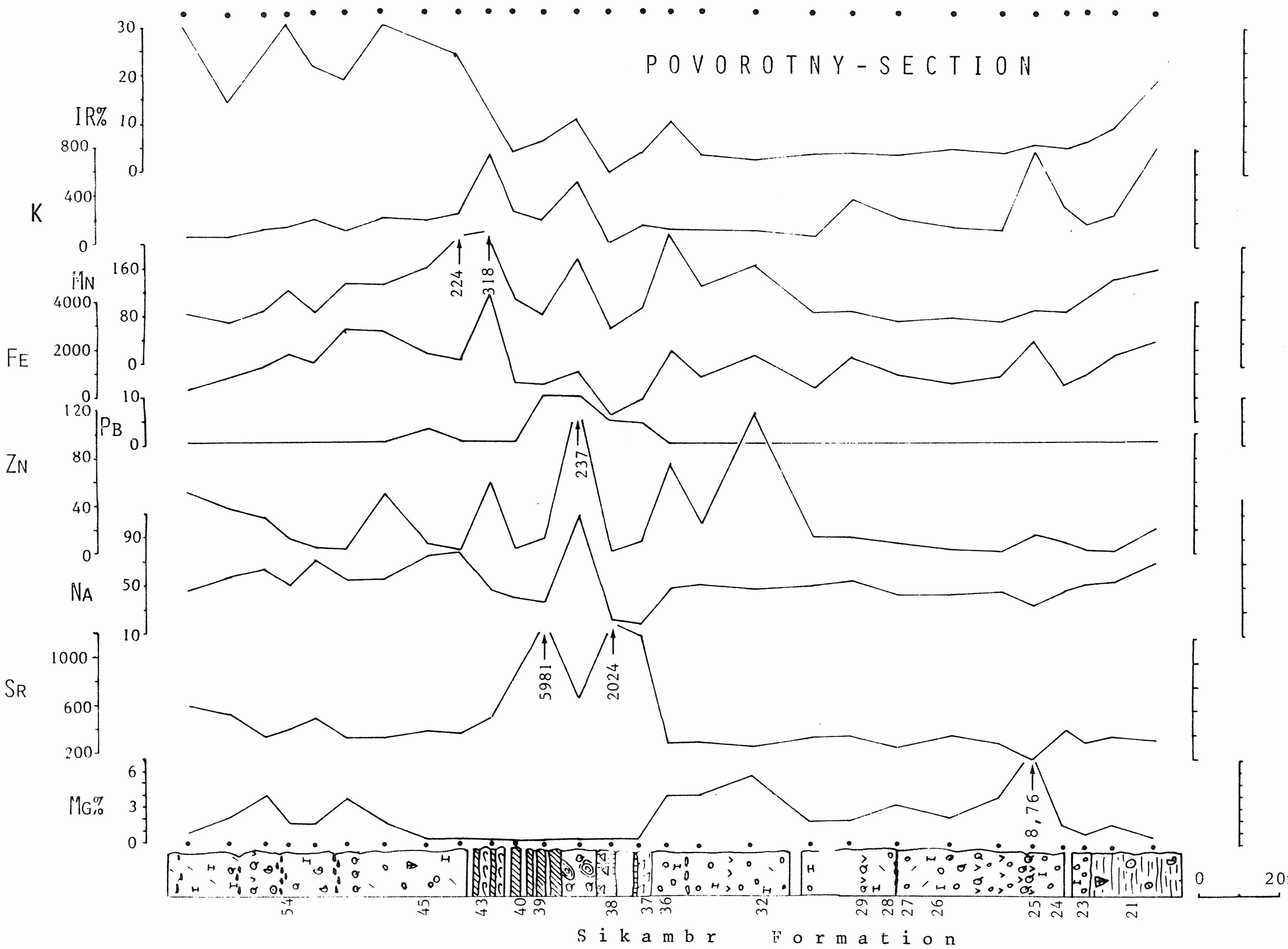

Figure 3 : Geochemical profile of the Povorotny section

shows that these limestones are partly dolomitized. A covariant variation between Zn, Fe and Mn seems to be linked to some extent to the Mg distribution. Sample IV 25A was taken within the idiotopic dolostone strata. The relative high Sr (199 ppm), Fe (3626 ppm) and K (783 ppm) contents are compatible with an early-diagenetic origin of these strata (cf. Weber, 1964).

b) Middle part (IV 37-43). Within these relatively pure limestones an important Sr anomaly is present. Values up to 5900 ppm Sr occur within the zebra limestones. Within the palisade calcite and algal micrites Sr concentrations of respectively 2024 ppm and 664 ppm were measured. Such extreme high values are characterized for a restricted hypersaline sedimentation environment (Veizer and Demovic, 1981; Kranz, 1976; Swennen et al., 1983). Thus these data confirm the sediment petrographical interpretation. Na values within these strata are low, except within the algal micrites. The low Na values within the zebra limestones can be explained by their complex diagenetic recrystallization history, whereas the low Na contents in the palisade crystals are compatible with their pseudomorphous nature. Within the algal micrites high Zn concentrations occur (237 ppm). Pb concentrations are also somewhat higher than elsewhere. This indicates that restricted environments are traps for base-metal enrichments (Samama et al., 1978).
In the top of this part high Fe and Mn values were recorded. Their content decreases upwards.

c) Upper part (IV 44-54). The strata within this part of the section are locally dolomitized. Their IR content is rather high; this could be related to silicification and chertification of these strata. However, also a higher clay content has to be accepted since higher Na and K values were recorded. Their contents, as well as the Fe and Mn contents, decrease towards the top.

TABLE 9 : Lithogeochemical data of the Povorotry section ($\overline{X}$ = mean value; n = number of samples) (see next page)

sample number		unit number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
SP1		IV21	0,57	355	70	20	1,5	3330	163	810	19
SP2		IV22	1,74	387	55	2	1,5	2787	151	255	10
SP3		IV23	0,98	340	53	3	1,5	1972	115	190	7
SP4		IV24A/B	1,69	431	48	9	1,5	1540	93	332	5
SP5		IV26A	8,76	199	35	17	1,5	3626	96	783	6
SP6		IV25*	4,05	334	47	2	1,5	1861	73	132	4
SP7	A	IV26*	2,33	394	44	4	1,5	1651	81	160	5
SP8		IV27/28	3,16	296	44	9	1,5	1898	77	231	4
SP9		IV29/30	1,91	377	55	14	1,5	2676	91	386	4
SP10		IV31	1,77	359	50	13	1,5	1441	87	74	4
SP11		IV32/33	5,61	279	47	115	1,5	2774	168	125	3
SP12		IV34/35A	3,90	320	51	25	1,5	1886	132	124	4
SP13		IV35B/36	3,94	318	48	74	1,5	3046	221	101	11
SP14		IV37/38	0,12	1247	18	10	4	973	95	163	4
SP15		IV39P	0,21	2024	21	1	5	244	60	34	0
SP16	B	IV39A1	0,22	665	108	237	11	2059	179	512	11
SP17		IV39Z	0,12	5981	36	11	11	1503	84	224	6
SP18		IV40	0,10	858	40	4	1,5	1664	112	279	4
SP19		IV42	0,22	502	46	60	1,5	5312	318	775	13
SP20		IV44	0,30	368	77	3	4	2573	224	263	25
SP21		IV45A	0,32	392	76	8	1,5	2884	161	208	28
SP22		IV45B	1,63	344	55	50	1,5	3823	132	217	32
SP23		IV46	3,62	333	57	4	1,5	3832	135	110	20
SP24	C	IV47	1,47	494	72	5	1,5	2411	87	202	22
SP25		IV48	1,64	399	51	11	1,5	2817	127	139	31
SP26		IV49	3,84	363	64	29	1,5	2256	90	125	25
SP27		IV50	2,08	533	58	37	1,5	1775	71	61	14
SP28		IV54B	0,76	594	46	51	1,5	1318	83	62	29
A n=13		$\overline{X}$	3,11	338	50	24	1,5	2345	119	285	7
B n=6		$\overline{X}$	0,17	1880	45	54	6	1959	141	331	6
C n=9		$\overline{X}$	1,74	424	62	22	2	2632	123	154	25
Σ n=28		$\overline{X}$	2,04	696	53	30	3	2300	125	253	13

3. ELERGETKHYN AREA

The Elergetkhyn area is one of the key areas for the Upper Famennian and Tournaisian strata of the Omolon area. A nearly continuous section can be composed from the sections of the Livan Mountain, Gytgynpylgin Creek and Karst Mountain.

A. LIVAN MOUNTAIN (XVI : Andylivan Formation) and GYTGYNPYLGIN CREEK (XVII and XVII A : Gytgylpylgin, Kuluk and base of the Karst Formation)

Lithology and sediment petrography

Description

Andylivan Formation : the lower 30 meter of this formation consists of an alternation of thin- and thick-bedded nodular biomicrites (bioclastic wackestone) and pelbiomicrites (bioclastic wackestone). These strata are mainly composed of moravamminids, crinoids, broken brachiopods or brachiopods which are still in live position, ostracodes, stromatoporoids and echinoid spines (plate 12.7). Bioturbation and trace fossils are common. Up to 30 % of detrital quartz is present. Fe-rich calcite veins, composed of several generations, frequently occur. Silicification by length-fast chalcedony was observed.

Towards the top a gradual transition to the uniformily bedded Gytgynpylgin strata occurs. These clay-rich biomicrites (bioclastic mudstone; plate 12.8) have a typical "flaser texture". Furthermore many pyrite spots characterize these intensively chertified strata. Moravamminids are a major component and crinoid ossicles are minor. Furthermore sponge spicules becomes an important biochem. Locally some trilobite fragments were observed.

Gytgynpylgin Formation : the base of this formation is composed of clay-rich biomicrites (bioclastic mudstone), which possess a bed thickness varying between 10 and 30 cm. Chertification is a predominant feature; since sediment sinks down below the cherts, chertification occurred prior to lithification. Flaser-textures and pyrite spots are common. Moravamminids are the most important biochem.

In the middle part of this formation shale intercalations occur in the biomicrites (bioclastic mudstone). These strata are often completely silicified; only the few ostracodes, the crinoids and the many sponge spicules are not transformed. Some trilobite pieces and bryozoans were observed.

Upwards an increase in the bioclast content is apparent. Most of the bioclasts are, at present, replaced by Fe-calcite. Some rusty-coloured discrete horizons were observed, which might be interpreted as hardgrounds.

At the top of this formation the bioclast variability increases; besides the mentioned bioclasts, gastropods and brachiopod fragments occur.

Kuluk Formation : biosparites (bioclastic grainstone) composed of a hash of crinoids, brachiopods and ostracodes occur at the base of this formation. Upwards calcispheres and foraminifera also occur; they are often micritized. The majority of the strata are intensively recrystallized. Dolomitization is scarce and consists of Fe-poor hypidiotopic dolostone. Silicification of crinoid ossicles by length-fast chalcedony was observed. Silicified anhydrite nodules are rare. They are characterized by an outer fringe of lutecite (length slow chalcedony). This fringe is followed by spherulites with in the center lutecite which grades into mega-quartz. Within these mega-quartz crystals, lath shaped anhydrite relics occur. Sometimes a felted texture is preserved.

Dolomitization clearly increases upwards giving an Fe-rich xeno- to hypidiotopic dolosparite (grainsize : 120 μm to 150 μm). The dolomite crystals are impure and inclusion-rich (plate 13.1); sometimes they are zoned. Locally minor dedolomitization spots occur. Silicified algal mats occur next to silicified anhydrite nodules. A moldic porosity often develops due to the selective leaching of bioclasts. At certain levels these cavities are filled by secondary calcite and/or chalcedony. Many small and irregular shaped pyrite crystals as well as few sphalerite traces occur between the dolomite crystals. These pyrite crystals are often altered to goethite.

At the top of this formation a breccia, composed of dolomite, silicified anhydrite and chert fragments occurs. The matrix is composed of heterogeneous dolosparite. Two crystal sizes occur namely one of about 270 μm and the other of about 120 μm. The cavities between the fragments and the dolomite crystals are filled by secondary calcite. Dessiminated sphalerite and goethite (pseudomorphous after pyrite) crystals were observed as interporosity infillings.

Karst Formation : the base of the Karst Suite is composed of a biosparite (bioclastic grainstone). Besides the crinoids, which often possess a syntaxial rimcement, calcispheres, foraminifera and brachiopod fragments are present. Most of these bioclasts are partly or completely dolomitized.

Interpretation

The Upper Devonian transgression in the Elergetkhyn area started with the deposition of biomicrites and pelbiomicrites (Andylivan Formation). According to the petrographic features a subtidal open marine depositional environment is indicated. Towards the top of this formation, however, rather deep subtidal sedimentation conditions occurred, since sponge spicules and trilobite relics were recognized. Typical is also the "flaser-texture" which could have a bioturbation origin. For these reasons this sequence reflects an important transgression. Furthermore pyrite concretions, showing a spatial relationship with early-diagenetic chertification, were recognized.

Sedimentation in this rather deep subtidal environment persisted during the lower part of the Gytgynpylgin Formation. From the middle part of the Gytgynpylgin Formation on this major transgression changed into a regression. In the beginning this change is only observable by an increase in the bioclast content (change from bioclastic mudstone to bioclastic wackestone) and later by the bioclast variability. Firstly crinoids appear and upwards also brachiopod fragments occur.

In the overlying Kuluk Formation foraminifera and calcispheres are present; sedimentation occurred in a low subtidal environment with the deposition of bioclastic grainstones. Minor regressive fluctuations towards intertidal or even supratidal environments are documented by the occurrence of silicified anhydrite nodules. Towards the top of the Kuluk Formation low tidal shelf sedimentation became more and more prominent. The association between silicified anhydrite nodules and the xeno- to hypidiotopic dolosparites suggests that there exists a genetic link between both. The culminating point of this regression was reached at the end of the Kuluk Formation with the formation of a breccia which is mainly composed by fragments of silicified anhydrite nodules. An evaporitic collapse origin cannot be ruled out.

Upon these breccias a transgression started with the deposition of biosparites. Because of the variability of the bioclasts and the fact that most of these bioclasts are partly or completely micritized a rather low subtidal shelf sedimentation environment for these strata seems most probable.

Lithogeochemistry

The lithogeochemical profile and the geochemical data are given in figure 9 and table 10. The lithogeochemical profile can be subdivided into five parts which more or less correspond to the different formations.

- At the base of the Andylivan Formation relatively pure limestones occur. These strata are characterized by moderate concentrations for all elements.
- The top of the Andylivan Formation and the major part of the Gytgynpylgin Formation are characterized by impure limestones. These strata possess high IR, K and Fe values. A slight increase in Zn and Na content is also present. The high IR, K and Na values are related to the lithology i.c. to the clay-rich silicified (chertified) biomicrites. Zn and Fe are partly adsorbed on the clays; however, Fe originates also from oxidized pyrites.
- The top of the Gytgynpylgin Formation is characterized by relatively pure limestones, possessing a high Sr content. It is possible that these high values are due to a "shielding-effect" by clays, since these limestones alternate with shales. However, since this Sr anomaly occurs at the dolomitization front a relation to the dolomitization process seems more probable. The other element contents are moderate.
- The Kuluk strata are characterized by variable Mg contents. A clear covariance between Mg, Fe and Mn is present and confirms the petrographical observations that these dolostones are rich in Fe and Mn. Important here is the Zn-Pb anomaly occurring near the Devono-Carboniferous boundary (the top of the Kuluk Formation). The Zn distribution is covariant with Mg, and consequently also with Fe and Mn. These high values can be explained by the traces of sphalerite occurring as small crystals between the dolomite crystals.
- The limestones at the base of the Karst Suite display normal geochemical values.

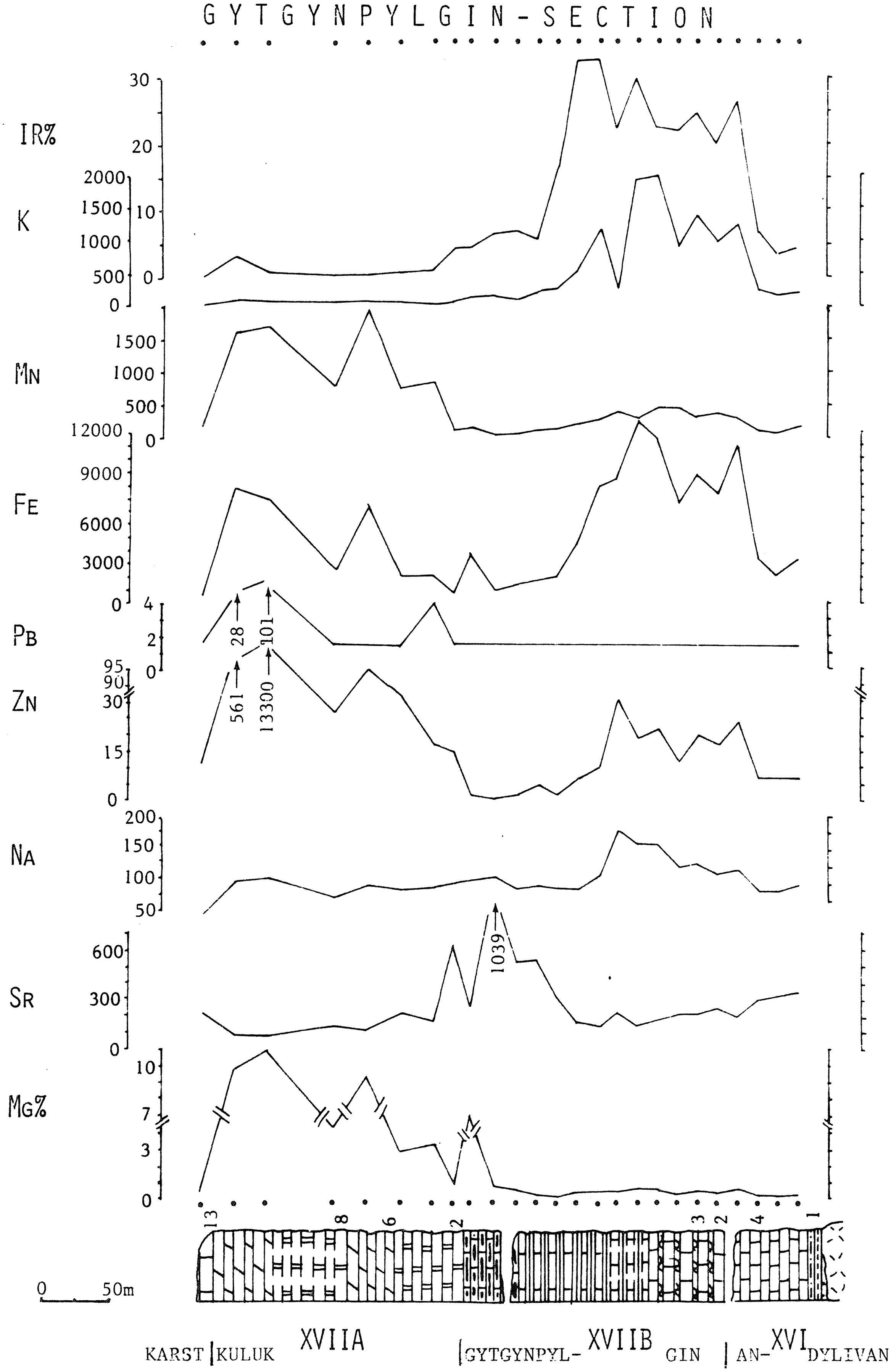

Figure 9 : Geochemical profile of the Livan Mountain and Gytgynpylgin creek sections

unit R.S.	sample number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
Gyd 1	SL1	0,39	333	91	7	1,5	3372	157	201	8,6
Gyd 2	SL2	0,32	316	79	7	1,5	2145	79	176	7,3
Gyd 3	SL3	0,37	297	81	7	1,5	3360	96	250	13,7
And 4	SL4	0,79	206	111	24	1,5	11932	286	1243	53,2
And 5	SL5	0,54	245	105	17	1,5	8593	376	994	40,7
And 6	SL6	0,61	209	120	20	1,5	9691	338	1353	49,7
And 7	SL7	0,42	212	114	12	1,5	7520	428	895	44,2
Gyd 8	SL8	0,66	178	151	22	1,5	12362	465	1991	45,3
Gyd 9	SL9	0,82	148	151	19	1,5	13942	300	1947	60,0
Gyd 10	SL10	0,48	230	172	31	1,5	9444	406	257	44,7
Gyd 11	SL11	0,53	143	104	10	1,5	8963	265	1199	65,9
Ele 12	SL12	0,47	165	83	7	1,5	4560	229	559	65,3
Ele 13	SL13	0,24	302	83	2	1,5	2032	129	292	31,8
Ele 14	SL14	0,35	540	87	5	1,5	1794	109	230	11,5
Ele 15	SL15	0,62	513	82	2	1,5	1481	79	102	13,8
Ele 16	SL16	0,85	1039	100	1	1,5	1105	63	151	13,2
Ele 17	SL17	7,03	265	96	2	1,5	3735	184	137	9,0
Ele 18	SL18	0,88	622	91	15	1,5	892	139	80	9,4
Kul 19	SL19	3,45	172	84	17	4	2157	862	47	2,4
Kul 20	SL20	2,93	217	81	32	1,5	2145	773	61	2,1
Kul 21	SL21	9,48	120	88	95	1,5	7280	1955	88	0,9
Kul 22	SL22	4,47	150	70	27	1,5	2520	787	57	0,8
Kul 24	SL23	10,98	76	99	13300	101	8074	1732	68	1,9
Kul 25	SL24	9,76	81	94	561	28	8840	1616	111	6,5
Kul 26	SL25	0,15	226	43	11	1,5	516	213	26	0,3
n = 25	$\overline{X}$	2,30	280	98	17*	2*	5538	483	501	22,5

TABLE 10 : Lithogeochemical data of the Gytgynpylgin section ($\overline{X}$ = mean value; n = number of samples; * = calculated without sample SL23 and SL24).

B. KARST MOUNTAIN (XVIII : Karst and Sikambr Formation)

Lithology and sediment petrography

Description

Karst Formation : the major part of this formation (XVIII 1-5) is composed of biosparites (bioclastic packstone and grainstone; plate 13.4). These strata are intensively recrystallized. Mainly crinoids (up to 40 %), brachiopods, brachiopod spines and stromatoporoids occur as bioclasts. The last are nearly always silicified. Furthermore micritized foraminifera and few algal filaments are present. Coated grains resembling intraclasts frequently occur (plate 12.3). Locally levels with oncolites as for example in unit XVIII 3, give rise to biooncosparites (oncolitic packstone). Around the crinoids a syntaxial rimcement is often developed. Beside detritical quartz grains, authigenic quartz is present, the last being restricted to micrite phases. Some cherts occur. Towards the top of the sequence major parts of the strata are silicified.

At the top of the Karst Formation (XVIII 6 top) a gap of several meters in the outcrop is present. Debris material revealed the presence of dolostones and limestones with relics of anhydrite nodules.

The uppermost strata (XVIII 7) are composed of intensively silicified biosparites (bioclastic packstone). Mainly stromatoporoids and brachiopods occur. These strata already resemble a boundstone. Crinoids occur; however, their content is low.

Sikambr Formation : the base of this formation (XVIII 8-10) is composed of an oosparite (oolitic packstone to grainstone; plate 13.6). The oolites, some of which of several millimeter in diameter, are micritized. Locally some micritized foraminifera and crinoids occur. Pressure solution phenomena are widespread in this interval.

Furthermore the matrix is intensively silicified. After preferential weathering and erosion of the oolites a honey-comb structure is left.

Within this sequence some biomicrite (bioclastic wackestone), intrasparite (intraclastic packstone), biointrasparite (intraclastic packstone) and biooosparite (oolitic packstone) levels occur. They become more prominent towards the top of the considered interval. Within these strata algal filaments, brachiopods, ostracodes, calcispheres and foraminifera are the most prominent biochems. They are often micritized; locally coated grains are formed. Dolomitization was observed throughout this unit; the crystals are well-developed euhedra of about 30 μm and occur only in the matrix. Dolomitization predates silicification.

This sequence is followed by an outcrop hiatus. Debris material showed the presence of silicified anhydrite nodules within dolostones and limestones.

The middle part of this sequence (XVIII 12-13) is composed of biosparites (bioclastic packstone to grainstone; plate 13.7). This lithology is comparable to the sequence of the Karst Suite. However, an increase in the coated grain content can be observed. Locally thin-bedded biomicritic (bioclastic wackestone) strata are present. They are clay-rich and intensively silicified.

After an oosparitic (oolitic packstone) - oncosparitic (oncolitic packstone) intercalation (XVIII 14 base) a biointrasparite (intraclastic packstone) follows (XVIII 14 top). Coated bioclasts such as crinoids, brachiopods and foraminifera are associated with these strata. Also algal lumps were recognized. Sometimes the oosparites are dolomitized; dolomitization nearly always starts in the sparite matrix. The intraclasts of the upper part are often very large in size; these are associated with micritized bioclasts. The bioclasts in this succession are identical to the ones described above. Near the top of this sequence some chert nodules occur; at the top of this unit a continuous chert layer is present.

The overlying strata are a coated grain succession (intrabiosparite: bioclastic packstone). Locally pelsparite (pelletic packstone; plate 13.8) intercalations occur. Bioclasts such as crinoids, brachiopod fragments, algal clasts, foraminifera and calcispheres frequently occur. The last two become more prominent towards the top of the section. Micritization alters the bioclast. Silicification of crinoids was observed. Cherts become an important component towards the top of the succession. Here several dyke intercalations occur. Locally idiotopic dolomite spots were observed; they preferentially occur within micrite phases.

An analysis of the < 2 µm fraction was carried out on samples SK3-4, SK19 and SK21. The purpose was to investigate differences in clay-mineralogical composition in limestone strata which occur near a dyke (at the top of the section) in comparison to those occurring elsewhere in the sequence. Beside quartz and not completely dissolved calcite and dolomite in the studied < 2 µm fraction, illite, with a very low degree of crystallinity, was observed. Furthermore in samples SK19 and 21 more traces of kaolinite occur; its content however is very low. Therefore it seems not likely that a relation with the presence of the dyke should be considered.

Interpretation

The biosparites in the lower part of this section (Karst Formation) suggest an open marine environment. The fact that coated grains and algal relics commonly occur indicates a rather shallow subtidal environment. Small fluctuations in this environment are reflected by the presence of the oncolite horizons, indicating very shallow subtidal to intertidal depositional environments. These biosparites are overlain by strata with anhydrite relics. For this interval, where only debris material was available, an intertidal to supratidal depositional environment is proposed. The overlying boundstone-type strata indicate a renewed sedimentation in a subtidal sedimentation environment. However, its exact stratigraphical position is difficult to deduce since these strata are displaced by several faults.

The oolitic base of the Sikambr Formation, which is followed by bioclastic to intraclastic strata, reflects a gradual deepening of the sedimentation environment evolving from rather turbulent, shallow subtidal to rather deep subtidal. The overlying strata with anhydrite relics indicate again a restricted hypersaline intertidal to supratidal environment. It is followed by deposition in a rather stable open marine subtidal sedimentation environment where the biosparites and the coated grain succession developed. Small fluctuations certainly occurred within this sequence as for example at the base of XVIII 14 where oncosparitic strata were formed.

Cherts occur frequently from XVIII 14 top on. They become a prominent feature in the overlying strata. A possible relationship between the dykes and the widespread silicification and dolomitization seems probable since their intensity increases towards the dykes.

Lithogeochemistry

The lithogeochemical profile is given in figure 10 and the geochemical data in table 11. With the exception of sample SK11 (XVIII 13 : silicified biomicrites), the Karst and Sikambr limestones are relatively pure (low Mg, IR and K content). For Sr a rather constant increase occurs towards the top of the section. A local high in the oolitic interval between the levels with relics of anhydrite nodules (XVIII 6 and 11) is present. For the Na distribution two peaks can be observed. The first occurs in the interval between levels with anhydrite relics, the second is present at the top. Such a pattern can also be observed for Fe, K and IR; they display a covariant behaviour. On the contrary Mn has an opposite pattern.

The fact that Sr and Na display higher values between the intervals with anhydrite relics indicates that their distribution may be related to the paleo environment; higher values are present when sedimentation occurred in a restricted environment. During such periods, the relative content of clays and the elements adsorbed on them (here Fe) will also increase. This interpretation, which indicates that Sr and Na are facies (i.c. paleosalinity) indicators is in agreement with published data (Veizer and Demovič, 1974; Veizer et al., 1978; Swennen et al., 1983). However, the constant increase in Sr content might also indicate more restricted sedimentation conditions for the youngest strata. These limestones possess also higher Na, Fe, IR and K values. Since near the top of this section many dykes occur, an influence of the lithogeochemical pattern by these dykes can not be ruled out. From figure 10 it is also clear that the Zn and Pb contents are very low. The Zn content of the Karst strata is lower than these of the Sikambr Formation.

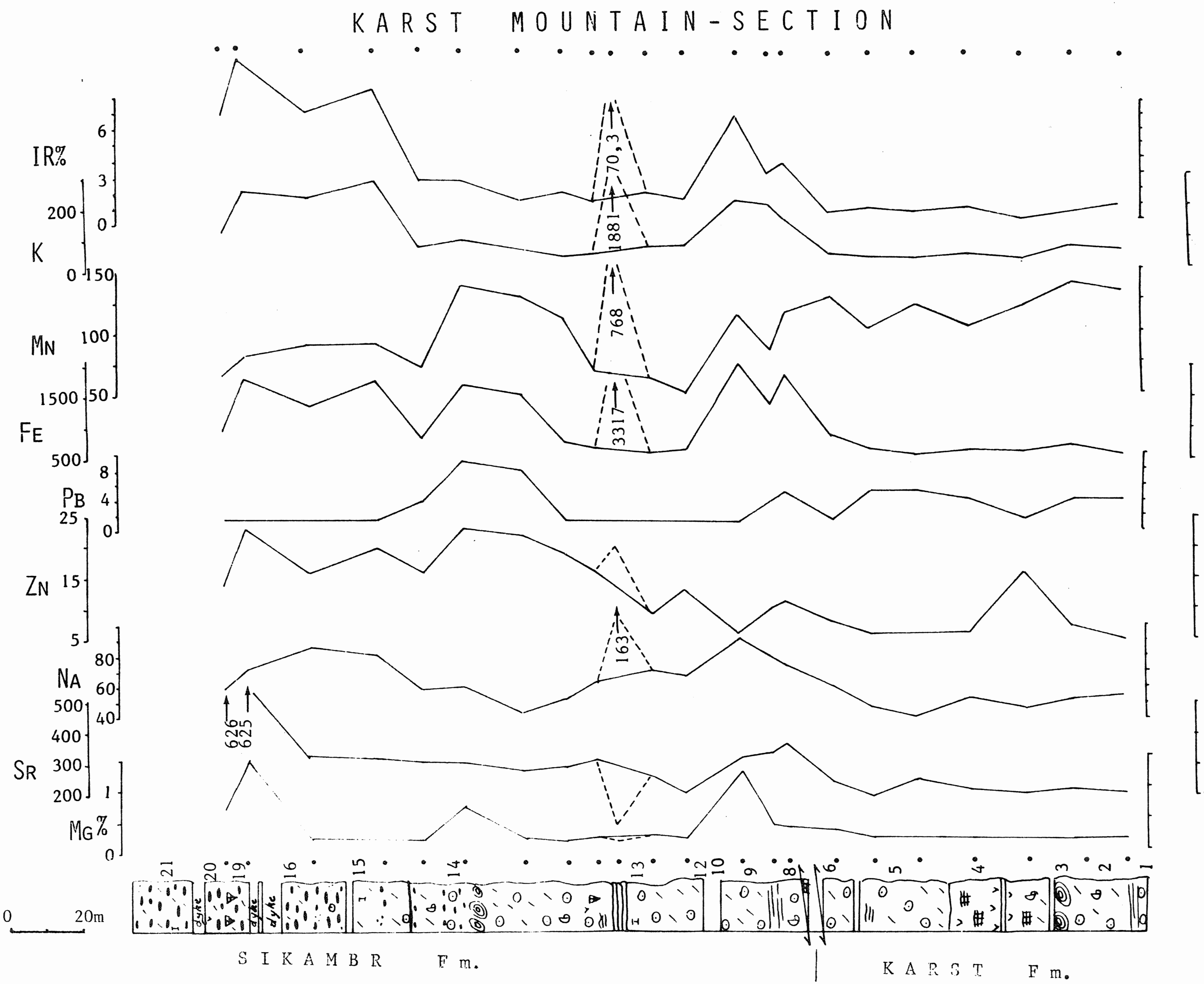

Figure 10 : Lithogeochemistry of the Karst section

unit number Conil	sample number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
RC732-735	SK1	0,17	212	54	5	4	590	131	60	0,9
RC735-738	SK2	0,17	220	51	7	4	726	138	68	0,5
RC692-697	SK3	0,17	208	45	16	1,5	615	120	29	1,1
RC698-701	SK4	0,18	217	52	6	4	652	106	48	0,9
H26 13m	SK5	0,18	249	40	6	5	565	121	35	0,6
H26 13m	SK6	0,18	197	47	6	5	627	103	40	0,9
RC703-704	SK7	0,32	240	60	8	1,5	874	128	47	0,6
RC705	SK8	0,35	366	73	11	5	1861	113	162	3,7
RC706-707	SK9	0,37	332	80	10	5	1355	85	207	3,1
RC708-711	SK10	1,28	315	91	6	1,5	2219	114	219	6,9
RC712-715	SK11	0,19	211	67	13	1,5	615	50	79	1,5
RC743-746	SK12	0,22	275	72	9	1,5	578	63	78	1,9
RC746-3,4m	SK13	0,14	102	163	20	1,5	3317	768	1881	70,3
RC747-750	SK14	0,20	308	63	16	1,5	676	68	55	1,4
RC751-754	SK15	0,17	289	52	19	1,5	800	110	45	2,0
RC754-757	SK16	0,18	285	44	22	8	1565	130	68	1,5
RC757-760	SK17	0,71	305	61	23	9	1713	139	101	2,9
RC761-764	SK18	0,18	315	59	16	4	874	73	80	2,8
RC765-769	SK19	0,21	325	81	20	1,5	1787	94	287	8,6
RC770-774	SK20	0,22	321	86	16	1,5	1380	92	241	7,1
RC775-780	SK21	1,45	625	71	23	1,5	1812	82	260	10,9
RC781-784	SK22	0,69	626	59	14	1,5	948	67	129	6,9
n = 21	$\overline{X}$	0,37	307	62	13	3	1087	101	111	3,2

TABLE 11 : Lithogeochemical data of the Karst area ($\overline{X}$ = mean value (calculated without sample SK13) n = number of samples)

4. ULJAGAN AREA

In the Uljagan area two sections were sampled namely the Triniti (XXV) and Bazov (XXIV) section. They cover respectively the Triniti Formation and the Upper Uttykelly and Lower Khurendza Formation.

A. TRINITI SECTION (XXV : Triniti Formation)

Lithology

Nodular limestones alternating with black silicified shales. Lithologically these strata resemble the "Souverain-Pré" deposits of Belgium (Ourthe valley). Presumably, these sediments have been deposited in a relatively "deep" marine offshore shelf environment.

Lithogeochemistry

Four representative samples have been taken over an interval of 40 m. The results are shown in figure 11 and table 12. Moderate Mg, Sr, Na, Pb, K and IR concentrations occur, whereas Fe and Mn are high. A decrease of the last elements is present towards the top of the section.

B. BAZOV SECTION (XXIV : Upper Uttykelly and Lower Khurendza Formation)

Lithology and sediment petrography

Description

The lower part of this section (XXIV 1-7; Upper Uttykelly Formation) is mainly composed of intensively recrystallized and silicified biomicrites (plate 14.1) and biosparite (bioclastic wackestone to packstone). In the lowermost part pelbiosparites (bioclastic packstone) occur. Crinoids make up the bulk of the bioclasts; furthermore, echinoid spines, bryozoans, ostracodes and shell relics (brachiopods ?) are present. Needle-like calcite resembling sponge spicules occur. However, recrystallization obliterated most of the features. This is also the case for the silica spheres, which are possibly radiolarians. Bioturbation phenomena and "annelid-burrows" (at present filled with micrite) give the rocks a typical "flaser-structure" (plate 14.2).

Silicification, pyritization (scattered spots) and recrystallization probably are related to the Lower Cretaceous diorite and granodiorite dyke intrusions. Silicification locally alters the rock completely. Pyrite spots are scattered throughout this section, especially near shale-rich intervals. Calcite, when recrystallized, displays a rhombohedron habitus.

At the top (Khurendza Formation) similar strata occur; however, a clear increase in crinoid content can be observed. Bioturbation also occur frequently.

Interpretation

The few observable features within these biosparites, e.g. the bioturbation (annelid burrows, etc ...) point to an open marine subtidal sedimentation environment. Rather deep marine conditions may be inferred from the few radiolaria-like and sponge spicula-like debris horizons; however, since diagnostic features are completely obliterated, this interpretation has to be treated with caution.

Lithogeochemistry

The lithogeochemical profile and the geochemical data are given in figure 11 and table 12. The data show the high degree of silicification (IR : $\overline{X}$ = 74 %). The high Fe, Na and K concentrations can also be explained by the alteration of the dykes. This is especially pronounced in the lower part of the section where a dyke is present. Around this dyke low Sr and Zn and high Na, Fe, K and IR contents were recorded. Due to these secondary phenomena it will be difficult to compare these data with those from equivalent strata elsewhere in the Omolon region.

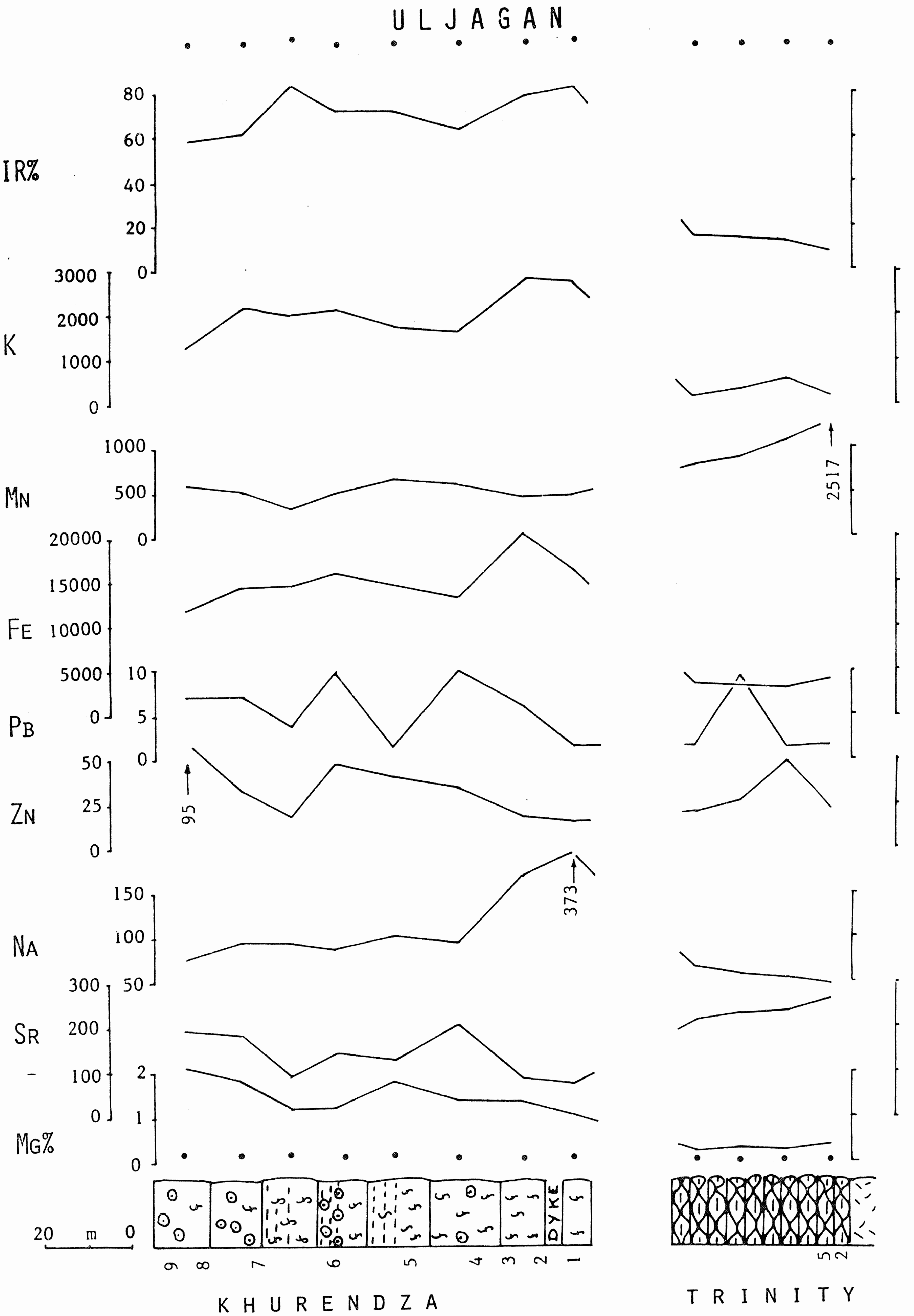

Figure 11 : Geochemical profile of the Trinity and Khurendza sections

sample number	unit number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
ST1	-	0,36	263	45	23	1,5	3832	2517	139	11
ST2	-	0,24	234	53	49	1,5	2856	1108	527	16
ST3	-	0,31	234	57	26	9	3263	877	306	17
ST4	-	0,25	217	65	21	1,5	3453	816	171	18
n = 4	$\overline{X}$	0,29	237	55	30	3	3351	1329	286	16
	σ	0,06	19	8	13	4	406	801	176	3

sample number	unit number	Mg %	Sr ppm	Na ppm	Zn ppm	Pb ppm	Fe ppm	Mn ppm	K ppm	IR %
SB1	XXIV1	1,01	73	373	14	1,5	16576	490	2703	86
SB2	XXIV2,3	1,32	89	171	17	6	20249	453	2825	80
SB3	XXIV4	1,35	203	95	33	10	13719	628	1629	66
SB4	XXIV5	1,80	130	101	41	1,5	14535	657	1668	74
SB5	XXIV6,7A	1,22	148	88	48	10	16304	498	2083	74
SB6	XXIV7B	1,18	92	94	18	4	14671	313	1995	85
SSB7	XXIV7C	1,80	180	97	33	7	14399	506	2151	65
SB8	XXIV8,9	1,07	192	76	95	7	12339	540	1255	61
n = 8	$\overline{X}$	1,47	138	137	37	6	15349	511	2039	74
	σ	0,37	50	100	26	3	2396	106	534	9

TABLE 12 : Lithogeochemical data of the Trinity and Bazov section ($\overline{X}$ = mean value; σ = standard deviation; n = number of samples).

CONCLUSIONS

From the lithological and sediment petrographic description of the different sections it is obvious that sedimentation occurred in a block-faulted basin. The major active tectonic period occurred around the Devono-Carboniferous boundary. This period was preceded by sedimentation of strata which mainly were formed in a relatively deep subtidal basin. Above the Devono-Carboniferous boundary sedimentation mainly occurred on a shallow shelf. In the last environment sedimentation graded from subtidal, to intertidal and supratidal; the last facies are often characterized by the development of anhydrite nodules, which at present are silicified or dolomitized.

Some of the lithogeochemical anomalies show a relation to the sedimentological evolution within the Omolon basin. A major regional strata-bound anomaly (Zn, Mn, (Pb)) was found near the Devono-Carboniferous boundary in the Pushok, Perevalny/Sikambr and Elergetkhyn areas. Several features (e.g. dolomitization, silicification, ...) point to a submarine sediment-hosted exhalative origin. A second anomaly (Sr, Zn) occurred within the hypersaline facies intervals of the Sikambr Formation (Perevalny/Sikambr area). This anomaly clearly is facies related. Remarkable fact here is the lixivation of base metals during the diagenetic crystallization of algal micrites to zebra limestones.

The lithogeochemical distribution patterns are mainly controlled by the amount of insoluble residue. Another factor which has a major impact on the lithogeochemistry is diagenesis. For example shielding effects in clay-rich strata often influences the lithogeochemical distribution pattern. Dolomitization locally may yield a Sr anomaly within the limestones near the dolomitization front.

Fault related epigenetic (Pb, Mn) anomalies also were recognized (Perevalny/Sikambr area). They have a local significance; however, they may indicate the presence of concealed Pb mineralizations in the Omolon basin.

ACKNOWLEDGEMENTS

The authors are especially indebted to M.J.M. Bless and R. Conil for helpful suggestions and critical comments on a former draft of this paper. E. Poty and M. Streel are thanked for their stimulating discussions. This paper would not have been possible without the excellent field collaboration with Ye. V. Kolesov, L. Kulagina, Yu. I. Onoprienko, T.P. Razina and L.V. Smirnova. Technical assistance has been given by A.Y. Balabas, A. Caproens, D. Coetermans, V.P. Dotsenko, A. Fedorov, C. Moldenaers, G. Van den Eynde and T.N. Velikoda.

This study has been supported by the U.S.S.R. Academy of Sciences, the Nort-Eastern Interdisciplinary Science Research Institute of the U.S.S.R. Academy of Sciences, the Geological Survey of Belgium, the National Fund for Scientific Research of Belgium, the Belgian Ministry for National Education and the Geofiles Foundation.
R. Swennen benefited of a research grant from the National Fund for Scientific Research of Belgium.

REFERENCES

CONIL, R., POTY, E., SIMAKOV, K.V. and STREEL, M., (1982) - Foraminifères, spores et coraux du Famennien supérieur et du Dinantien du massif de l'Omolon (Extrême - Orient Soviétique). Ann. Soc. Géol. Belg., 105, p. 145-160.

DECLEER, J., (1985) - Comparison between mounting techniques for clay minerals as a function of quantitative estimation by X-ray diffraction. Bull. Soc. Belg. Géol., 94, Vol. 2, (in press).

DICKSON, J.A.D., (1966) - Carbonate identification and genesis as revealed by staining. Jour. Sed. Petrol., 36, p. 491.

FONBOTE, L. and AMSTUTZ, G.C., (1983) - Facies and Sequence Analysis of Diagenetic Crystallization Rhythmites in Strata-Bound Pb-Zn-(Ba-F) Deposits in the Triassic of Central and Southern Europe. In : Mineral Deposits of the Alps and of the Alpine Epoch in Europe (ed. by H-J Schneider) Springer Verlag Berlin, Heidelberg, p. 348-358.

KRANZ, J.R., (1976) - Strontium - ein Facies - Diagenese Indicator im Oberen Wettersteinkalk (Mittel Trias) der Ostalpen. Geol. Rundsch., 65, p. 593-615.

SAMAMA, J.C., MIGUEL DE SA, L.C. and REY, M., (1978) - Les minéralisations plombozincifères du Trias ardéchois en tant que pré-évaporites. Les problèmes des relations à diverses échelles. Sc. de la Terre, 22, p. 138-158.

SARKISYAN, S.G. and KOTELNIKOV, D.D., (1972) - Genesis and thermodynamic stability of dioctahedral and trioctahedral mixed-layer minerals in sedimentary rocks. Proc. Int. Clay Conference, Madrid, p. 281-289.

SHILO, N.A., BOUCKAERT, J., AFANASJEVA, G.A., BLESS, M.J.M., CONIL, R., ERLANGER, O.A., GAGIEV, M.H., LAZAREV, S.S., ONOPRIENKO, Yu. I., POTY, E., RAZINA, T.P., SIMAKOV, K.V., SMIRNOVA, L.V., STREEL, M. and SWENNEN, R., (1984) - Sedimentological and Paleontological Atlas of the Late Famennian and Tournaisian Deposits in the Omolon Region (NE-USSR). Ann. Soc. Géol. Belg., 107, p. 137-247.

SIMAKOV, K.V., BLESS, M.J.M., BOUCKAERT, J., CONIL, R., GAGIEV, M.H., KOLESOV, Ye. V., ONOPRIENKO, Yu. I., POTY, E., RAZINA, T.P., SHILO, N.A., SMIRNOVA, L.V., STREEL, M. and SWENNEN, R., (1983) - Upper Famennian and Tournaisian Deposits of the Omolon Region (NE-USSR). Ann. Soc. Géol. Belg., 106, p. 335-399.

SWENNEN, R., (1985) - Lithogeochemistry of Dinantian carbonates in the Vesdre basin (Verviers synclinorium : E-Belgium) and its relations to paleogeography, lithology, diagenesis and Pb-Zn mineralizations (in press). Academica Analecta, Klasse der Wetenschappen, Jg. 47.

SWENNEN, R., BOONEN, P. and VIAENE, W., (1983) - Stratigraphy and Lithogeochemistry of the Walhorn Section (Lower Visean; Vesder Basin; E-Belgium) and its Implications. Bull. Soc. Belg. Géol., 91, p. 239-258.

VAN ORSMAEL, J., (1982) - Lithogeochemie van de Dinantiaan karbonaat-gesteenten in het Synclinorium van Dinant. Unpubl. Ph. D. thesis Cath. Univerisity of Leuven (Belgium).

VEIZER, J. and DEMOVIC, R., (1974) - Strontium as a Tool in Facies Analysis. J. Sed. Petrol., 44, p. 93-115.

VEIZER, J., LEMIEUX, J., BRIAN, J., GIBBLING, M. and SAVELLE, J., (1978) - Paleosalinity and Dolomitization of a Lower Paleozoic Carbonate Sequence; Somerset and Prince of Wales Islands, Arctic, Canada. Can. J. Earth Sc., 15, p. 1448-1461.

WEBER, J., (1964) - Trace Element Composition of Dolostones and Dolomites and its Bearing on the Dolomite Problem. Geochim. Cosmochim. Acta, 28, p. 1817-1968.