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LITHOGEOCHEMISTRY OF SOME CARBONATE SECTIONS OF THE DINANTIAN IN THE VESDER REGION, (BELGIUM).

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ABSTRACT.- Three sections of Tournaisian and Visean carbonate rocks have been analyzed for Mg, Na, Sr, Zn, Pb, Fe, Mn, Ni, Co, Ba, Cu, organic matter and HCl insoluble residue. The data have been treated by univariate and multivariate statistical analysis. The Na content generally points to a normal to intermediate high saline environment. It is shown that the use of Sr as a facies indicator is questionable in the studied sections. Irregular halos of Mn, Fe, Pb, Zn and Ni may be developed around faultzones. They are interpreted as epigenetic patterns related to mineralization. The factor analysis allows us to group the elements. The most important factors are related to the halos developed around the faultzones, to the sedimentation environment and to the dolomitization process. The insoluble residue has only a limited influence on the geochemical distribution. This feature and the occurrence of high trace element content especially in the dolostones is in contrast with the findings in the Dinant synclinorium.

INTRODUCTION.

Several authors consider the lithogeochemistry of carbonate rocks as a tool to obtain information about the sedimentary environment and the diagenesis (e.g. VEIZER *et al.* 1978) and to indicate potential areas of Pb-Zn mineralization (e.g. RUSSEL, 1975; KRANZ, 1976). Whether the proposed geochemical indicators are applicable for different geological times and in different basins, however, is still a matter of discussion. The stratigraphy, the paleogeography and partly the sedimentology of the Dinantian carbonate rocks in Belgium have been studied extensively. Mineral occurrences of Pb and Zn are known. Therefore the study of the Dinantian carbonate rocks may contribute to a better understanding of the lithogeochemical distribution in carbonate environments.

The present study forms part of a general investigation of the lithogeochemistry of the Dinantian carbonate rocks in the

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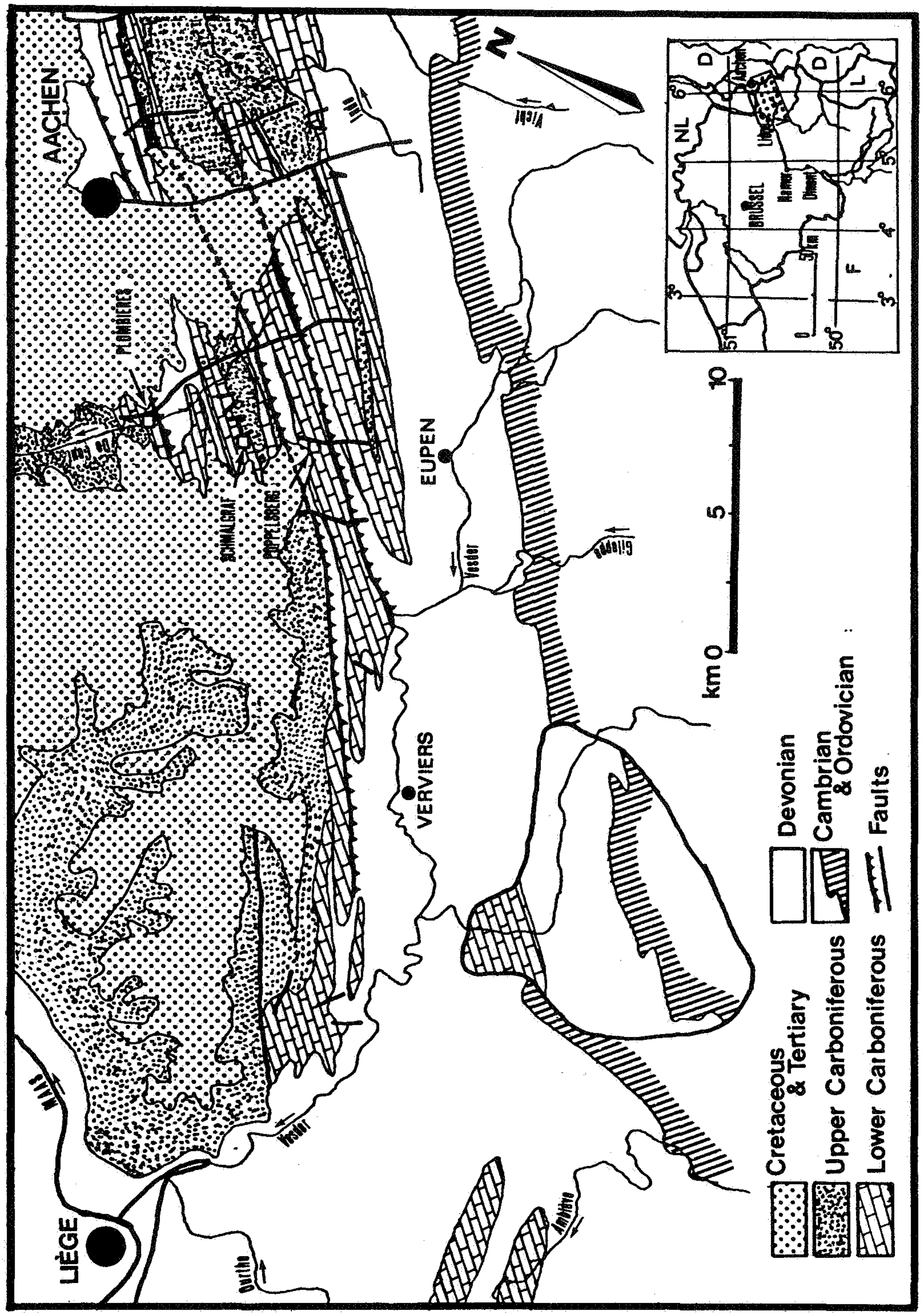

Fig. 1 -

Outline of the geology of the Vesder syncline and situation of the studied sections.

Dinant synclinorium, in the Vesder syncline as well as in the Namur syncline. Part of the results for the Dinant synclinorium has already been published by VAN ORSMAEL *et al.* (1980).

The Vesder syncline is situated between Aachen (Germany) and Liège (Belgium) and to the N of the Stavelot-Venn anticline. Based on several authors (e.g. BOONEN and KASIG, 1979; KNAPP, 1978) figure 1 gives an outline of the geology of the Vesder syncline. It is characterized by a sequence of Devonian and Carboniferous formations, folded during the Hercynian orogeny. Longitudinal faults, with a general strike of NE-SW have often broken up the anticlinal structures. Normal faults are younger and have a strike of NW-SE. The series of longitudinal faults, some of which are satellite faults of the so-called Midi-Eifel overthrust fault, displaced the S-part over the N-part of the Vesder syncline.

In the Vesder syncline, many Pb-Zn mineralizations occurred, which gave rise to important mining activities in the past (e.g. MORESNET, BLEYBERG). These ore deposits are generally related to the normal faultzones and are considered to be epigenetic (de MAGNEE, 1967).

Paleogeographically, the Dinantian carbonate rocks have been deposited in a shallow shelf environment (BOONEN and KASIG, 1979; KASIG, 1980).

Three sections, containing strata from the Tournaisian 2b to the Visean 2b, have been investigated. They are all situated in the De Geul-valley. As they are displaced to a certain extent by longitudinal faults, their position is considered to be allochtonous.

STRATIGRAPHY AND SEDIMENTPETROGRAPHY OF THE SECTIONS.

The general stratigraphy of the Dinantian in the Vesder-De Geul region is given in figure 2.

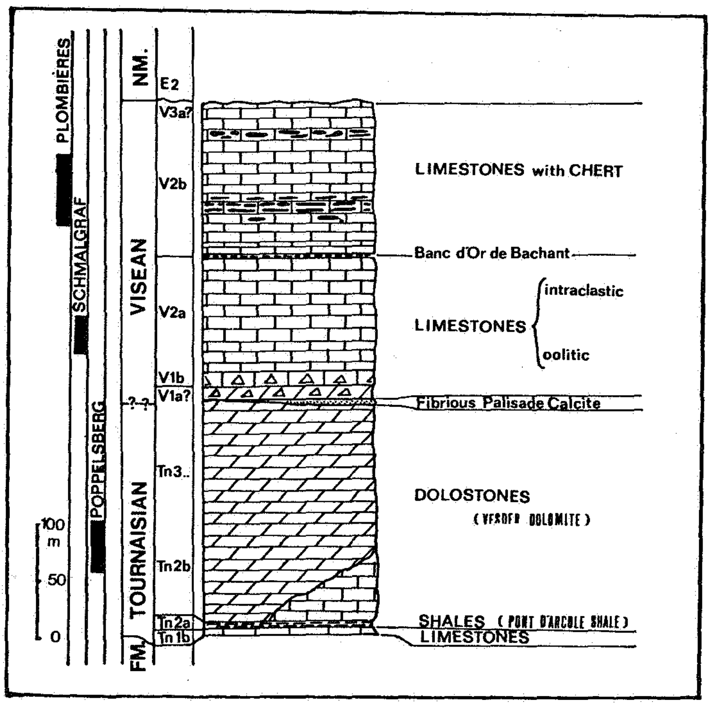

Fig. 2 - General stratigraphy of the Dinantian in the Vesder-De Geul region.

The carbonate sequence of the Tournaisian starts with partly dolomitized limestones (Tn1b) followed by the Pont d'Arcole shales (Tn2a). The main units consists of the Vesder Dolomite, which is sometimes not completely dolomitized in its lower part (Tn2b). In this unit, the Poppelsberg section has been investigated. Whether the upper part of the dolostones belongs to the Tn3 and/or to the V1a is not yet clear. Sometimes on top of this unit, a zone of fibrous palisade calcite, up to 4 m thick, is present. This is followed by a series of dolostone- and limestonebreccias. These breccias are considered as equivalent to the "Ourthe Breccia" of the Dinant basin.

Above these breccias, an important succession of limestones (V2a) is present, characterized by oölites, pellets and intraclasts. The Banc d'or de Bachant forms the basis of the V2b sequences, which consist of limestones mostly with chert-nodules. Details and paleogeographical considerations will be published elsewhere.

The stratigraphic subdivision of the Dinantian in the Aachen region (KASIG, 1980) differs from that in the Vesder-De Geul region by the absence of the important breccia sequences.

The situation of the studied sections is given in figure 1 and the stratigraphical position is indicated in figure 2.

The section at Poppelsberg belongs to the Vesder Dolomite of the Tn2b. Two less important longitudinal faults are present, one in the lower part and the other in the upper part (figure 3). The dark-grey dolostones have a homogeneous coarse-grained and porous aspect. Weathering turns them to a brown, granular and friable rock. Relicts of crinoids are often present. Many whitish dolomite spots (1-30 cm) with euhedral dolomite crystals, and dissolution cavities of the same dimensions are present. Also small pyrite crystals and their oxydation products occur sometimes in these spots and cavities. Small dolomite veins of ~1 mm thickness occur regularly.

In thin sections, the dolostones consist of impure dolomicrosparite and dolosparite; the grain size normally varies between 40 and 120 μ. The cavities and dolomite spots are often bordered by large dolomite rhombohedrons up to 1-2 mm.

A systematic variation in grain size and in the occurrence of cavities and spots has not been observed. KASIG (1980) suggests an early-diagenetic origin for the equivalent Upper (dark) Dolomites in the Aachen region.

The second section is situated S of the ancient Schmalgraf mine. It is composed of Visean 2a limestones. A near vertical normal fault is present. It is filled up with calcite, limonite and dendroide galena crystals varying in size from 1 to 3 mm. An AC-diaclase system is well developed. The diaclases are often filled up by calcite. In the studied section two important calcite veins are present in the diaclases. Superficially the limestones show a bright-white colour indicating their purity. Fresh surfaces are normally grey.

Pellets and intraclasts are abundant. The matrix is mostly microsparitic and sometimes micritic. Using the classification index of Elf-Aquitaine (1975), the features of these limestones indicate a subtidal sedimentation environment.

The section at Plombières belongs to the Visean 2b. The limestones have a grey to bluish-black color. Cherts are common. Crinoids and brachiopods are found in minor quantities and corals and gastropods are rare. In the upper part clay-rich beds occur; they are considered as bentonite beds by THOREZ and PIRLET (1979). These have not been analysed. The section shows strongly folded structures. In the upper part a zone with several small longitudinal faults is present.

In thin sections the limestones are microsparitic to micritic. Pellets are only found in some beds. Several sedimentary cycles, as described by GREBE (1957) and, BOONEN and KASIG (1979) in the Visean 2b of the Aachen region, were also found in Plombières. No attempt has been undertaken to sample the different phases of these cycles, because of their varying thickness and their incomplete succession. The features present indicate a sub- or intertidal deposition environment for these limestones.

ANALYTICAL PROCEDURES.

The different beds in the three sections were sampled by chip sampling. Chips of weathered rocks were avoided. Also chert fragments were not included in sampling.

The analytical procedures are the same as described by VAN ORSMAEL *et al.* (1980). The following elements have been analyzed : Mg, Na, Sr, Zn, Pb, Fe, Mn, Ni, Co, Ba and Cu. The organic carbon content (Org C) was determined with the Wackley and Black method (ALLISON, 1965). No correction for the pyrite content has been made, because the amount of pyrite was always less than 1 %. The insoluble residue (IR) was determined gravimetrically after the HCl (12,5 N) attack.

The analytical precision, measured on duplicate samples is better than 20 % at the 95 % confidence level for Mg, Na, Sr, Zn, Fe, Mn, and Org C. For Pb, Cu, Ni and IR it is better than 40 % and for Co and Ba it is over 50 %. The last elements often show contents close or below the detection limit.

RESULTS.

UNIVARIATE.

The univariate statistics are listed in table 1 for the three sections. For calculating the mean ($\overline{X}$) and the standard deviation (s), exceptional samples were left out : for the Poppelsberg section one sample with the highest Fe content, for the Schmalgraf section the two calcite veins, and for the Plombières section six samples with high IR and/or high organic carbon content. These samples are marked with a dot in the geochemical profiles (figures 3, 4 and 5). For the statistical treatment the values below the detection limit, have been set equal to half the detection limit; these values are for Ba 6 ppm, for Pb 1 ppm and for Ni, Co and Cu 0.5 ppm.

From table 1 it can be deduced that the trace element content of Na, Zn, Pb, Fe, Ni and Co is higher in the dolostones than in the limestones. Only Sr, Mn and Ba are higher in the limestones. This feature is in contrast with the findings in the Dinant synclinorium, where dolostones have generally lower trace element contents. In comparison with literature data about averages in carbonate rocks (e.g. GRAF, 1960; WOLF *et al*, 1967) the high content of Pb and Zn is striking.

As more than 60 % of the data for Ba, Co and Cu are below the detection limit, these three elements will not be treated in the further discussion.

In figure 3, 4 and 5 the geochemical profiles are given.

From the Poppelsberg section (figure 3) the positive correlation of Fe, Mn, Zn, Ni and to a lesser extent Pb, is clear. Na and Sr are negatively correlated. Also the high and variable content of several elements around the faults in the thin-bedded dolostones is obvious. In the upper part of the section, higher contents of Zn, Pb, Fe and Mn occur; in the lower part, however, higher values occur only for Fe, Mn, Ni and possibly for org C. These higher values are not significantly correlated to higher IR values.

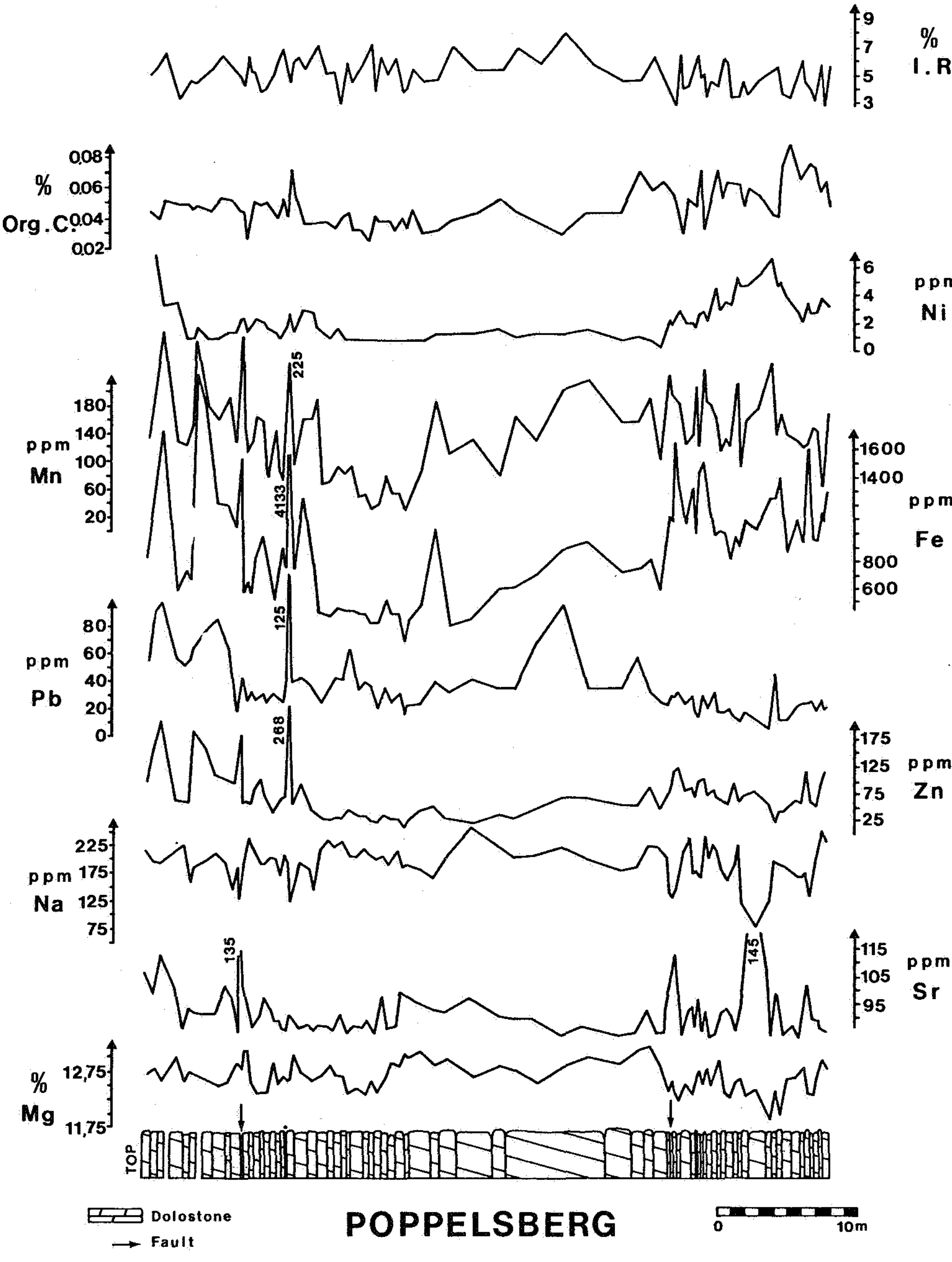

Fig. 3 – Geochemical profile of the Poppelsberg section.

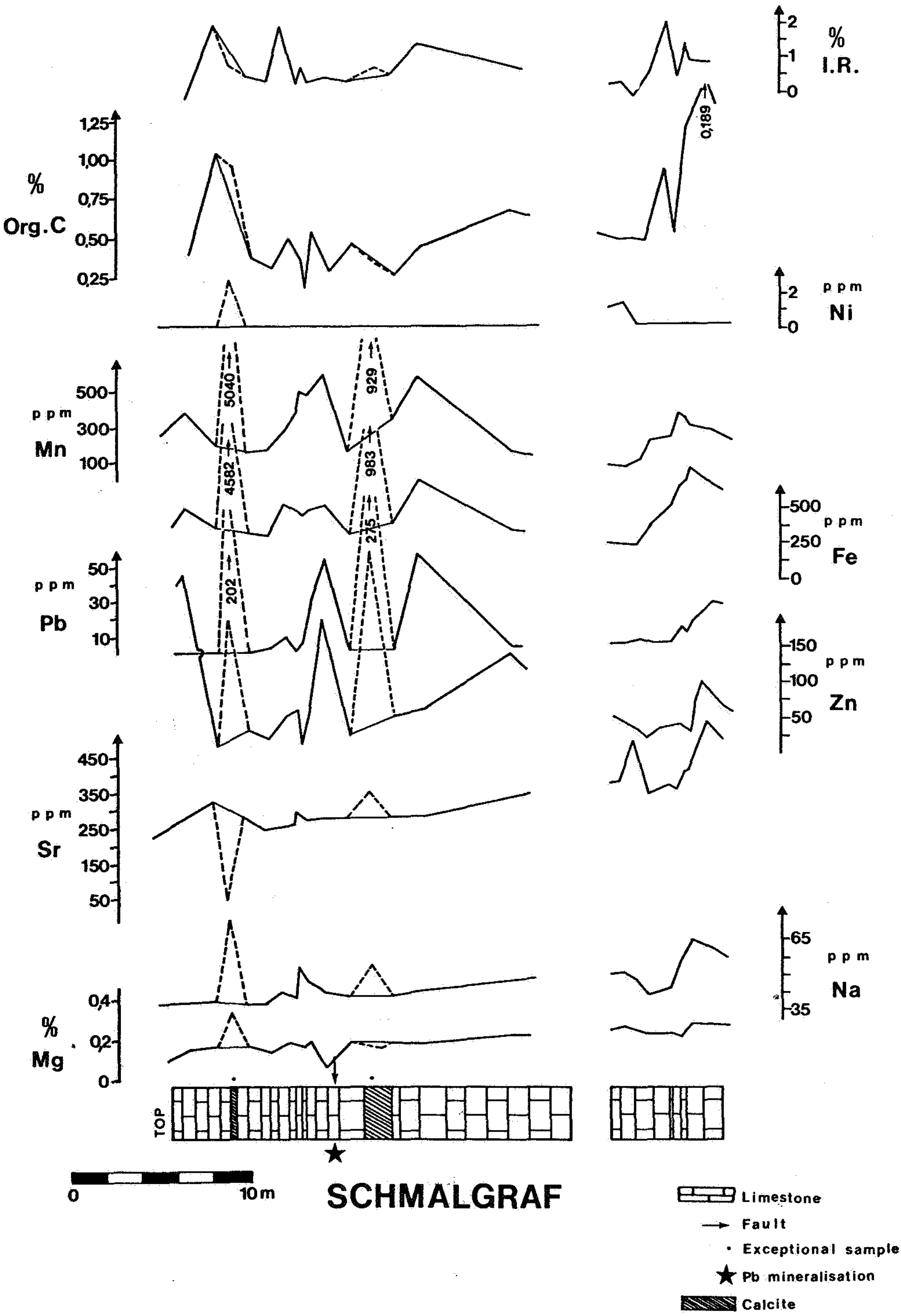

Fig. 4 – Geochemical profile of the Schmalgraf section.

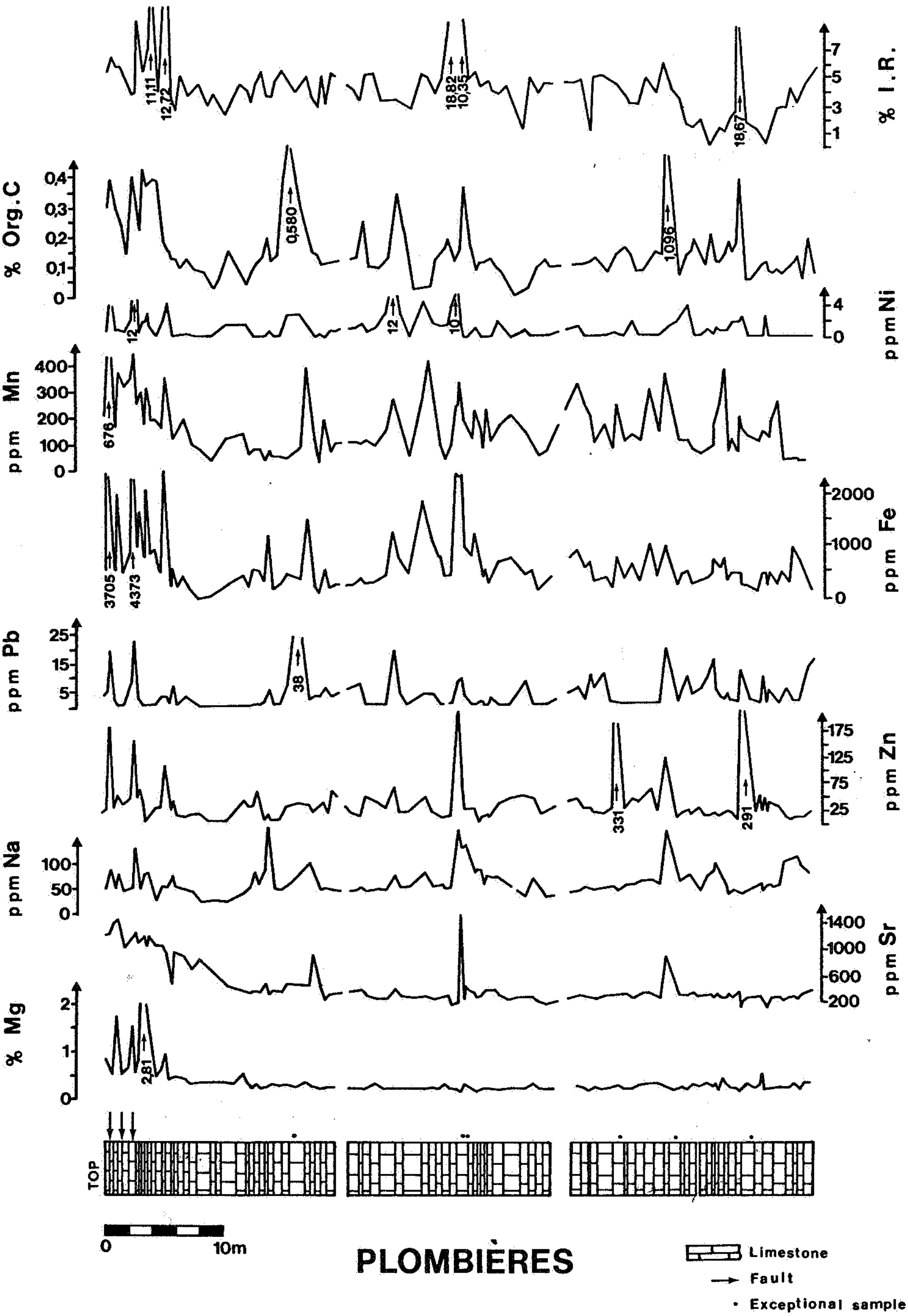

Fig. 5 – Geochemical profile of the Plombières section.

	Poppelsberg (dolostones) N = 83		Schmalgraf (limestones) N = 21		Plombières (limestones) N = 101	
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
Mg: %	12.5	0.3	0.2	0.04	0.4	0.3
Na: ppm	181	38	41	11	61	22
Sr: ppm	96	10	326	76	593	317
Zn: ppm	81	38	77	62	44	53
Pb: ppm	30	19	10	16	3.5	4.7
Fe: ppm	939	408	491	145	845	2132
Mn: ppm	128	59	285	164	150	112
Ni ppm	2.4	2.0	0.6	0.3	1.5	2.0
Co: ppm	1.5	1.3	0.5	-	0.7	0.7
Ba: ppm	11.3	7.1	27	63	17.8	46
Cu: ppm	1.0	1.0	1.4	1.7	0.8	0.7
Org C: %	0.05	0.02	0.06	0.04	0.15	0.10
IR: %	5.8	1.2	1.0	0.7	4.9	3.4

Table 1: Univariate statistics (N = number of samples; $\bar{X}$ = mean, s = standard deviation)

In the Schmalgraf section (figure 4) the calcite veins are characterized by high Fe, Mn, Zn and Pb contents. The covariance of these elements is also obvious.

The upper part of the Plombières section (figure 5), where a faultzone is present, is characterized by higher contents of Mg. Also most other elements, especially Zn, Sr, Fe, Mn, Org C, Ni and IR, show a different pattern in comparison with the remaining part. Covariances between elements are less clear than in the other sections. Only a Mn-Fe correlation is suggested.

MULTIVARIATE.

The correlation matrix is given in table 2. A significant correlation between Na-Mg and Fe-Mn, both positive, occurs in the three sections. The strongest correlations are Zn-Fe, Zn-Mn and Fe-Mn for the dolostones, and Mg-Sr and Sr-Org C for the limestones. The elements Mn, Fe and Sr show the largest number of correlations with other elements. The IR shows no significant correlations, this in remarkable contrast to the findings in the Dinant synclinorium (VAN ORSMAEL *et al.*, 1980).

In order to group the elements with mutual correlations, a R-mode factor analysis was carried out on the data. The programme FACTOR from the SPSS-package (NIE *et al.* 1975) was used for this purpose. After calculating the principal components, those with an eigenvalue larger than 0.9 were transformed by a varimax rotation into factors. Data with a factor score above 3.5 were omitted, in order to avoid distortion by mere exceptional values and the principal components and factors were recalculated. The exceptional samples were also omitted from the correlation matrix (table 2) and are noted by a dot in figure 3, 4 and 5.

The results of the factor analysis are given in table 3. The factors considered explain more than 70 % of the total variance. In the first two sections, a factor is present relating the elements Zn, Mn, Fe and partly Ni and Pb. The insoluble residue occurs only in the weak factors as already suggested by the correlation matrix. The factor analysis results will be discussed in the following paragraph.

DISCUSSION.

VEIZER *et al.* (1978) proposed the Na content as a measure of paleosalinity for Paleozoic carbonate rock. These authors placed the division between normal saline and hypersaline environments near 230 ppm Na. As it can been seen in fig. 3, 4 and 5, this 230 ppm Na level is only exceptionally reached in the sections under consideration. This indicates a normal to intermediate high saline deposition environment for the studied limestones and dolostones. Nevertheless the high Na content in the Poppelsberg dolostones is remarkable. It is higher than in the limestones of the Vesder syncline and it is also higher than in the equivalent formations of the Dinant synclinorium (VAN ORSMAEL *et al*, 1980). It is generally accepted that at the time of the Upper Tournaisian the carbonate rocks of the Vesder syncline were deposited closer to the coast than the sediments of the Dinant synclinorium. Moreover, KASIG (1980) suggests an early-diagenetic origin and a restricted deposition environment for the Upper Tournaisian dolostones.

The Sr content or the calculated 1000 Sr/Ca ratio was proposed by VEIZER and DEMOVIC (1974) and by KRANZ (1973) as a diagenetic indicator for dolostones and as a facies indicator in limestones. The Lower part of the Plombières section has a general low content of Sr with a mean of 470 ppm. In the upper part, however, a high

	Mg	Na	Sr	Zn	Pb	Fe	Mn	Ni	Org C	IR
Mg	P.1.00	0.26	-0.22	-0.10	0.12	-0.30	-0.19	-0.27	-0.11	0.14
	S.1.00	0.58	0.61	-0.39	-0.51	-0.02	-0.53	0.31	0.56	0.09
	L.1.00	0.28	0.71	0.16	0.11	0.17	0.44	0.32	0.53	0.06
Na		P.1.00	-0.43	-0.09	0.15	-0.16	-0.26	-0.07	0.12	0.12
		S.1.00	0.67	-0.15	0.10	0.52	0.08	0.15	0.61	0.06
		L.1.00	0.09	0.06	0.27	0.33	0.16	0.24	0.29	0.12
Sr			P.1.00	0.39	-0.05	0.29	0.38	0.29	-0.13	-0.10
			S.1.00	-0.26	-0.09	0.07	-0.30	0.14	0.73	-0.06
			L.1.00	0.09	0.13	0.07	0.45	0.23	0.61	0.13
Zn				P.1.00	0.18	0.84	0.68	0.32	0.08	-0.10
				S.1.00	0.29	0.25	0.37	-0.15	-0.11	-0.24
				L.1.00	0.24	0.18	0.38	0.28	0.11	0.21
Pb					P.1.00	0.03	0.15	-0.27	-0.19	0.09
					S.1.00	0.52	0.73	-0.13	0.01	0.12
					L.1.00	0.13	0.31	0.61	0.26	0.12
Fe						P.1.00	0.69	0.45	0.33	-0.08
						S.1.00	0.55	-0.39	0.39	0.25
						L.1.00	0.35	0.23	0.33	0.19
Mn							P.1.00	0.38	0.02	-0.05
							S.1.00	-0.33	-0.17	0.17
							L.1.00	0.45	0.38	0.19
Ni								P.1.00	0.43	-0.15
								S.1.00	-0.08	-0.18
								L.1.00	0.36	0.17
Org C									P.1.00	-0.14
									S.1.00	0.35
									L.1.00	0.16
IR										P.1.00
										S.1.00
										L.1.00

Table 2

Correlation matrix of the different sections

P: Poppelsberg: N = 83, correlations significant above 0.26

S: Schmalgraf: N = 21, correlations significant above 0.50

L: Plombières: N = 101, correlations significant above 0.23

(99% confidence)

Sr content prevails in the range of 800 to 1400 ppm. If Sr can be used as a facies indicator, this high Sr content would indicate a sedimentation environment with hypersaline tendencies or with a high proportion of the stable low-Mg calcite precipitation. Neither of these explanations is probable. Sedimentpetrographic features or the Na content do not point to a hypersaline environment. The precipitation of low-Mg calcite is more characteristic for sedimentation towards the deep sea. The latter assumption can not be accepted as the studied limestones are deposited on a shallow shelf area. The high Sr content may be explained by the presence of clay material and organic matter, rather high in this portion of the section and occurring as a film around limestone fragments and intraclasts. This feature, characteristically present in the upper part of the Plombières section, could produce a shielding effect, inhibiting the loss of Sr during diagenesis.

The dolostones of the Poppelsberg section show a 1000 Sr/Ca ratio of 0.37 to 0.75. This range points to a late diagenetic origin. KASIG (1980) however suggests early-diagenetic dolostones.

Summarizing, the use of Sr for facies analysis as described in the literature, is questionable in the studied area. Further investigations are needed in order to test the applicability of the Sr content as a facies and diagenesis indicator.

High and variable contents of several trace elements are found around faultzones. This is the case for Mn, Fe and Ni and for Zn, Pb, Mn and Fe respectively in lower and upper part of the Poppelsberg dolostones. This feature - in any case less pronounced - may also be present in the limestones of Schmalgraf. The first section is situated about 200 m west of the transversal fault at Rabotrath, known as mineralized. The Schmalgraf section contains a weak mineralization of Pb in the faultzone and the vein calcite, associated with the mineralization displays high contents of Pb, Zn, Mn and Fe. Because of this situation and because of the element association, it is thought that this geochemical pattern is related to the faultzones and to mineralizing solutions circulating through the fault and printing the rocks. It must be mentioned that the higher contents of the Pb, Zn, Mn, Fe and Ni occur in the Poppelsberg dolostones within thin beds. Normally one would also expect higher contents of IR, related to clayey material; this is not the case. Therefore the printing of the dolostones would have taken place not only because of the higher porosity but probably also because of the bedding planes.

Also the Plombières section shows higher contents of trace elements around the faultzone in the upper part (fig. 5). However, more elements i.e. Sr, Zn, Pb, Fe, Mn, Org C and IR are involved here. As discussed in connection with the Sr distribution, the sedimentpetrographic features are peculiar in this part of the section. Although there is a beginning dolomitization around the faultzone, as demonstrated by the presence of dispersed dolomite rhombohedrons, it is thought that the geochemical pattern is more related to the sedimentary characteristics of these beds.

The elements Mn, Fe, Zn and Pb are grouped together in factor 1 (Poppelsberg) and in factor 2 (Schamlgraf) by the multivariate analysis (table 3). The factors show high scores around the faultzones. In Poppelsberg the two faults show different patterns. The fault in the upper part displays a halo of Mn, Fe, Zn and Pb and the fault in the lower part a halo of Mn, Fe and Ni. This could possibly be related to zoning of the mineralizing solution or to distances from a main mineralization. The characteristics of the halos will have to be further investigated, as they may have important applications for assessing the mineral potential of faultzones (whether or not mineralized or connected with mineralized fault) and for a better evaluation of drill cores.

	POPPELSBERG N = 83					SCHMALGRAF N = 21				PLOMBIERES N = 101				
FA	F1	F2	F3	F4	comm	F1	F2	F3	comm	F1	F2	F3	F4	comm
eigenv.	2.74	1.74	1.73	1.01		3.07	2.78	1.47		2.45	1.78	1.55	1.28	
%	27.4	17.4	17.3	10.1		30.7	27.8	14.7		24.5	17.8	15.5	12.8	
Σ	27.4	44.8	62.1	72.2		30.7	58.5	73.2		24.5	42.3	57.8	70.6	
Zn	0.91	0.00	-0.09	-0.05	0.85	-0.20	0.62	-0.35	0.55	0.05	0.33	0.72	-0.13	0.64
Fe	0.87	0.30	-0.10	-0.04	0.86	0.42	0.72	0.33	0.80	0.10	0.01	0.39	0.72	0.68
Mn	0.83	0.02	-0.26	0.03	0.76	-0.15	0.86	0.20	0.80	0.51	0.35	0.49	0.07	0.63
Ni	0.39	0.71	-0.15	-0.03	0.68	0.16	-0.34	-0.56	0.46	0.24	0.80	0.17	0.13	0.75
Pb	0.36	-0.67	0.31	-0.07	0.68	-0.00	0.83	0.09	0.70	0.04	0.89	0.05	0.13	0.81
Sr	0.36	-0.03	-0.71	-0.01	0.63	0.86	-0.17	-0.13	0.78	0.92	0.04	0.07	-0.07	0.86
Na	-0.04	0.02	0.82	0.05	0.68	0.90	0.18	-0.05	0.85	0.13	0.25	-0.11	0.80	0.72
Mg	-0.12	-0.35	0.46	0.16	0.37	0.73	-0.53	-0.03	0.82	0.86	0.10	0.03	0.12	0.76
IR	-0.02	0.09	0.11	0.97	0.97	0.11	-0.03	0.88	0.78	0.04	-0.07	0.69	0.23	0.53
C	0.16	0.76	0.34	-0.16	0.74	0.84	-0.01	0.29	0.80	0.72	0.17	0.06	0.34	0.67

Table 3: Factor analysis results of the three sections.

The factor analysis results, given in table 3, are complex. This is not surprising as many processes such as sedimentation, diagenesis, dolomitization and printing by circulating solutions, have influenced the geochemical distribution. In the Poppelsberg dolostones, the irregular halos around the faults produce the first factor, explaining 27 % of the total variance. The second factor groups the elements Ni, Pb (negative) and Org C. It is not clear whether this association is related to the sediments themselves or the development of the halos. The contrast between Ni and Pb has been accentuated by the rotation of the factors. The third factor expresses the dolomitization process and is characterized by the negative correlation between Mg and Sr. Also the Na content seems to be related to this process. The fourth factor reflects the independent behaviour of the insoluble residu.

The small number of the Schmalgraf samples results in a less reliable multivariate analysis. Factor 1 (Na, Sr, Mg and Org C) is probably related to the sedimentary environment. There is a parallellism between factor 2 and factor 1 of the Poppelsberg section - the influence of the mineralization -, and between factor 3 and factor 4 of Poppelsberg - the influence of IR-.

The factor analysis results of the Plombières section are complicated by the presence of two sets of data as demonstrated by the geochemical profile (fig. 5). The upper part is characterized by a beginning dolomitization and by peculiar sedimentary features; the remaining part shows a nearly normal distribution pattern. The first factor (Sr, Mg, Org C and Mn) shows only high scores on samples of the upper part. The second factor, expressing the strong correlation between Ni and Pb, shows high scores spread over the whole section. The third and fourth factors are linked to beds, rich in clayey material and/or Org C. They are related to the lithology.

The geochemistry of the Vesder syncline carbonates is markedly different from the geochemistry of the Dinant synclinorium. In the Vesder syncline the dolostones have higher trace element contents than the limestones, the IR has only a small influence on the geochemical distribution and irregular halos may be developed around faults. In the Dinant synclinorium these features are opposite or absent. Here the limestones have higher contents than the dolostones, the IR has an important influence and the faultzones show a nearly normal pattern. These features may be significant for the occurrence of mineralizations in the Vesder region and for their absence in the Dinant synclinorium. It is hoped that by further investigations, the links between the geochemical features and the metallogeny will be clarified.

CONCLUSIONS.

The limestones and dolostones of the three studied sections, have been deposited in a normal to intermediate high saline environment. This feature is also reflected by the Na distribution. The use of Sr as a facies and diagenesis indicator is doubtful.

The dolostones of the Poppelsberg section show stri kingly high contents of Zn, Fe and Mn, and to a lesser extent of Pb. This high content seems to be regionally present in the Vesder synclinorium (research in progress). The question arises whether these high contents reflect the metallogenetic province and thus related to mineralization or whether they are to be considered as a regional high background.

Irregular halos of Mn, Fe, Zn, Pb and Ni may have developed around faultzones. These halos seems to be better expressed in dolostones than in limestones. Also the calcite veins, associated with the mineralization of Schmalgraf, show high contents of Pb, Zn, Fe and Mn. These two features may have important applications for the evaluation of the mineralization potential of faultzones.

The multivariate analysis shows that the geochemical distribution of the studied sections is most influenced by the sedimentary environment, by diagenesis and dolomitization and by the formation of halos around faultzones.

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