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DIAGENETIC PROCESSES IN THE IBARRETXE MEMBER (LOWER CRETACEOUS, BILBAO, NORTHERN SPAIN)

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RESUMEN

En este trabajo se describen en detalle los principales procesos diagenéticos constatables en los sedimentos del Miembro Ibarretxe. Esta unidad estratigráfica está constituida por los depósitos más antiguos aflorados del Cretácico inferior al sur de Bilbao (parte inferior del "Wealdense" o Fm. de Villaro). Las diferentes fases diagenéticas identificadas consisten en la precipitación de yeso, pirita, clorita, dolomita y calcita. El Miembro Ibarretxe está compuesto por rocas volcánicas en su parte inferior y evaporitas fuertemente calcitizadas a techo. La evolución diagenética en ambos tramos refleja procesos diagenéticos bien diferenciados. Mientras en las rocas volcánicas amigdaloides la diagénesis es muy sofisticada y está condicionada por su peculiar mineralogía, en la parte superior de la unidad pueden observarse texturas indicativas de procesos evaporativos. En este trabajo se presentan varias razones para pensar en historias diagenéticas independientes en la parte superior e inferior del Miembro Ibarretxe. Verosímilmente la presencia de depósitos arcillosos en los tramos intermedios de la unidad pudo actuar como una barrera impermeable que individualizó los fenómenos diagenéticos referidos.

ABSTRACT

The present work describes the precipitation of gypsum, pyrite, chlorite, dolomite and calcite as the main diagenetic processes in the Ibarretxe Member, which includes the lowermost Cretaceous sediments to the south of Bilbao city ("Wealden", Villaro Fm.). The Ibarretxe Member is composed of volcanic rocks in the lower part and wholly-calcitized evaporitic rocks in the upper part. The diagenetic evolution in both parts reveals very distinct processes. Whereas in the amygdaloidal volcanic rocks the sophisticated diagenesis is closely controlled by their peculiar mineralogy, diagenesis in the upper part of the unit is dominated by the presence of evaporative textures. There are several reasons that support the presence of two diagenetic sequences with completely separate diagenetic evolutions. Perhaps the largely shaly composition of the sediments of the middle part of the Member determined the creation of an impermeable barrier isolating the diagenetic phenomena from the base to the top of the unit.

LABURPENA

Idazlan honetan Ibarretxe Adarreko sedimentuetan izan diren prozesu diagenetikoak aipatzen dira modu zehatzean. Aipaturiko unitate estratigrafikoa Bilboko hegoaldean azaleratzen diren Behe-Kretazikoko materialerik zaharrenetaz dago osoturik

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("Wealdiarra" edo Villaro Formazioaren behekaldea). Ondorioztaturiko fase diagenetiko desberdinak igeltso, pirita, klorita, dolomita eta kaltzitaren prezipitazioan dautza. Ibarretxe Adarra bere behekaldean harri bolkanikoz eta goikaldean gogorki karezturiko harri ebaporitikoz dago osotua. Alde biotako bilakabide diagenetikoak argi erakusten du izandako prozesu diagenetikoen desberdintasun garbia. Harri bolkanikoen amigdaloideetako diagenesia oso berezitua eta harrion berezko mineralogiak baldintzatua ere izan den bitartean unitatearen goikaldean prozesu ebaporitikoen ondorio diren ehundurak ageri dira. Ikerlan honetan zenbait arrazoi aurkezten dira Ibarretxe Adarreko goikalde eta behekaldeko bilakabide diagenetikoek elkarreko loturarik izan ez dutela sinistu erazteko. Seguruen unitatearen erdikaldeko deposito bustintsuek muga iragazezinarena egin zezaketen aipaturiko prozesu diagenetikoen banaketa hori erraztuz.

1. INTRODUCTION

A very thick stratigraphic series (up to 1300 m.) corresponding to the lowermost Cretaceous outcrops to the south of Bilbao. It has been referred as "Wealden" in the literature, and comprises a great pile of clayey sediments consisting largely of black shales alternating with five well-developed sandy episodes **(Fig. 1).** These sediments are exposed along the exhumed axial zone of an important NW-SE structure: the Bilbao Anticlinorium. The age of the Wealden sediments is approximately Upper Berriasian-Barremian according to several methods of stratigraphic correlation **(GARCIA-GARMILLA 1987, 1988, 1989b).**

One of the peculiar lithological features of the Wealden deposits is the presence of volcanic rocks and evaporitic layers in the lowermost part of the sequence. Owing to the sophisticated mineralogy of these rocks, the diagenetic history of the whole shows very unusual characteristics **(GARCIA-GARMILLA, 1989a).** Nevertheless there is a remarkable palaeogeographic evolution from the subarid, shallow-marine environment of the Ibarretxe Member to the lacustrine environment influenced by river-dominated deltas of the rest of the Wealden **(GARCIA-GARMILLA & PUJALTE, 1988).**

The presence of volcanic rocks in the Lower Cretaceous sediments to the south of Bilbao has been first mentioned by **OLIVE y RAMIREZ DEL POZO (1978),** and the sedimentary sequence was studied by **RAT (1959), RAMIREZ DEL POZO (1971)** and more recently by **GARCIA-GARMILLA (1987, 1989b)** and **GARCIA-GARMILLA y CARRACEDO (1989).** However an accurate description of the volcanic, evaporitic

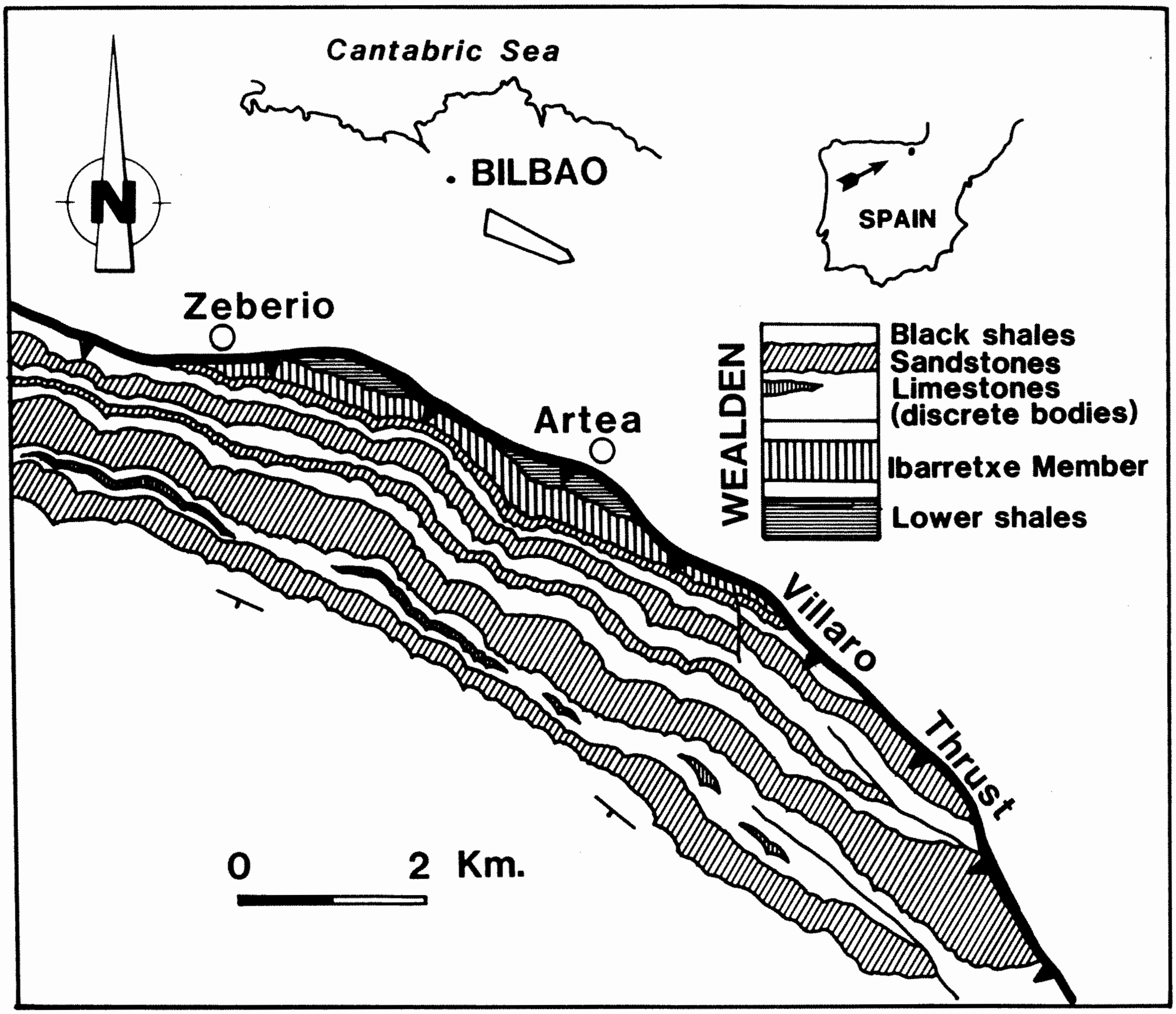

Fig. 1- Map showing the outcrop area of the Ibarretxe Member. The Wealden sequence is composed of black shales with five sandy intervals intercalated. The northern boundary of the Wealden outcrops is the important Villaro Thrust.

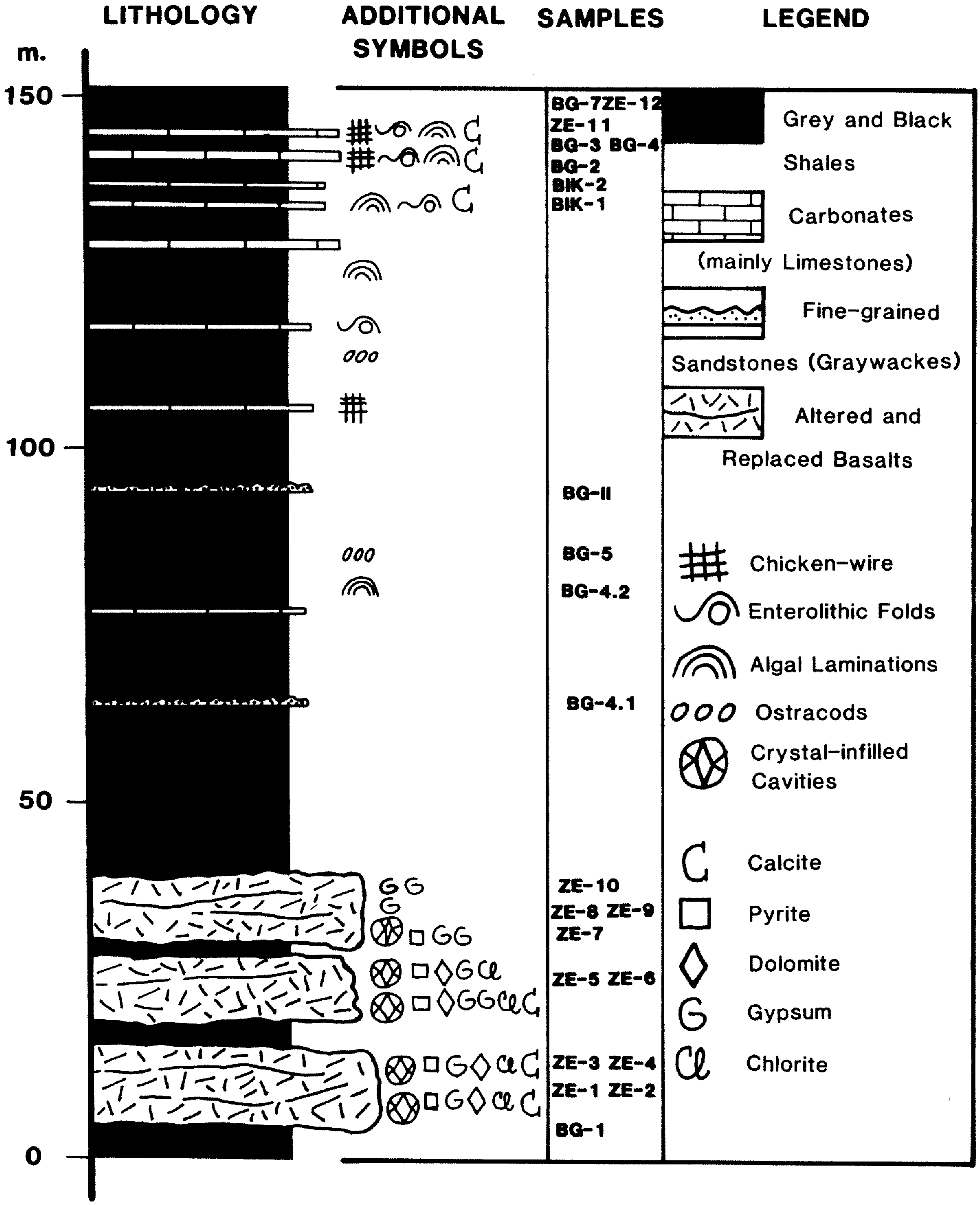

Fig. 2- The Ibarretxe Member stratigraphic section, showing lithologies, primary and diagenetic structures, some mineralogical features and the position of the several samples collected for analysis under the microscope.

and carbonate layers of the Ibarretxe Member together with a discussion about the diagenetic processes which affected them has not been done up to now.

2. THE IBARRETXE MEMBER

The "Ibarretxe" name comes from the family-houses ("baserriak") near Castillo y Elejabeitia village (Artea in basque language). The Ibarretxe Member is partly affected by the Villaro thrust and its composition is conspicuously shaly with basaltic layers intercalated in the lower part and carbonate ones in the middle and upper parts of the section **(Fig. 2).**

Thickness of the Ibarretxe Member is about 150 m. Its main lithology consists of black and grey laminated shales bearing some fossil remains, such as ill-preserved bivalves (***Corbula, Pseudoptera***) and smooth-tested ostracods. In addition some vegetal fragments have been found (gingkoales stems). Pyrite is present possibly as a result of strongly reducing conditions in the depositional environment, but in some cases it seems to proceed from a more sophisticated diagenetic origin. The volcanic layers in the lower part of the Ibarretxe Member appear in the field as grey-coloured, fine-grained, ill-structured rocks containing pyrite and isolated relict phenocrystals. They are in concordance with the underlying and overlying sediments, as cartographical results demonstrate.

On the other hand the carbonate horizons have individual thicknesses of 10-30 cm. They are composed of micritic limestones, which sometimes show fine laminations whose convexe-up morphologies suggest a possible algal origin. Nevertheless there are relatively frequent nodular forms with enterolithic folding associated, together with fine layers showing chicken-wire structures **(Fig. 3)**. These features, at present calcitized, suggest a primary origin from an evaporitic environment, in which the anhydrite (not present now) could have precipitated.

Finally, very-fine-grained graywacke sandstones are very rare in the studied section. They appear as scarce layers of about 5 cm. in individual thickness. The sandstones show symmetrical ripples at the top, probably originated by very gentle wind currents affecting waters of shallow ponds and pools.

3. DEPOSITIONAL SETTING

The predominance of shaly lithologies in the Ibarretxe Member suggests a low-energy depositional environment, mainly of lacustrine type with periodic reducing conditions. The presence of ostracods concentrated in very fine layers **(Fig. 4a)** indicates opportunistic species blooming during particular periods of salinity changes, perhaps in relation to seasonal controls **(GIMENEZ & CALVET, 1989).** The above-mentioned bivalves are typical of fresh and brackish-water conditions, and the vegetal remains suggest a humid ambient.

On the contrary, the existence of carbonate layers with chicken-wire structures and nodules are indicative of episodes of very different character. In fact, these features are not uncommon in sabkhas and shorelines of saline lakes **(EUGSTER & KELTS, 1983)** as soon as in arid coastal areas **(SHINN, 1983)**. It has been reported the formation of anhydrite nodules within old algal mats in present sabkhas **(SHEARMAN, 1966, 1978; HARDIE, 1984; KENDALL, 1984)**. These nodules growth provoking the folding of the algal lamellae (enterolithic folding).

The above mentioned considerations suggest that the lacustrine setting was perhaps sporadically connected with marine waters. Therefore, the salinity could probably have oscillated significatively from fresh to hypersaline waters. The shallowing of more or less widespread areas was responsible for the development of typical evaporitic structures. Nevertheless, gypsum could have precipitated directly in non-extreme arid conditions. The association gypsum-carbonate is typical of non-alkaline lakes under moderately arid environmental conditions **(SHEARMAN, 1978).**

4. PETROGRAPHIC DESCRIPTION

Depending on outcrop availability, 23 samples were collected in the Ibarretxe Member for thin-section analysis **(Fig. 2).** Eleven of them were taken from the lower part of the unit, the volcanic layers, and eight of them from the overlying carbonate rocks bearing relicts of evaporitic textures.

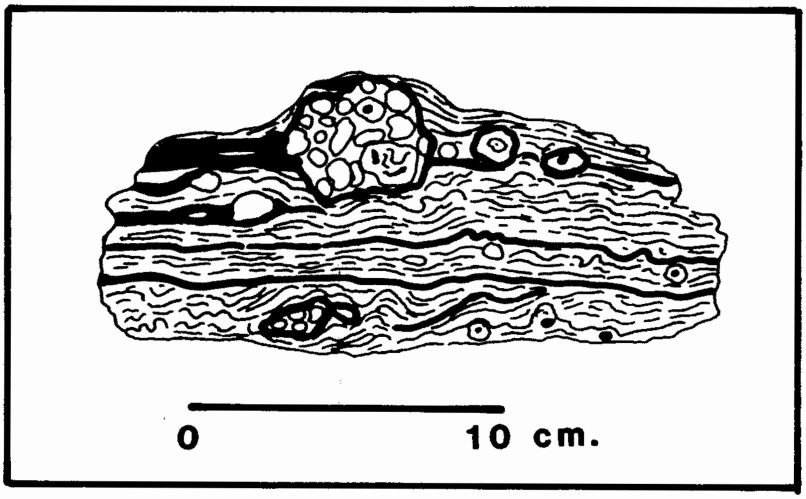

Fig. 3- Calcitized nodules in the ZE-11 sample. The growth of the nodules causes enterolithic folds. The finest micritic layers (dark-coloured) are possibly of algal origin.

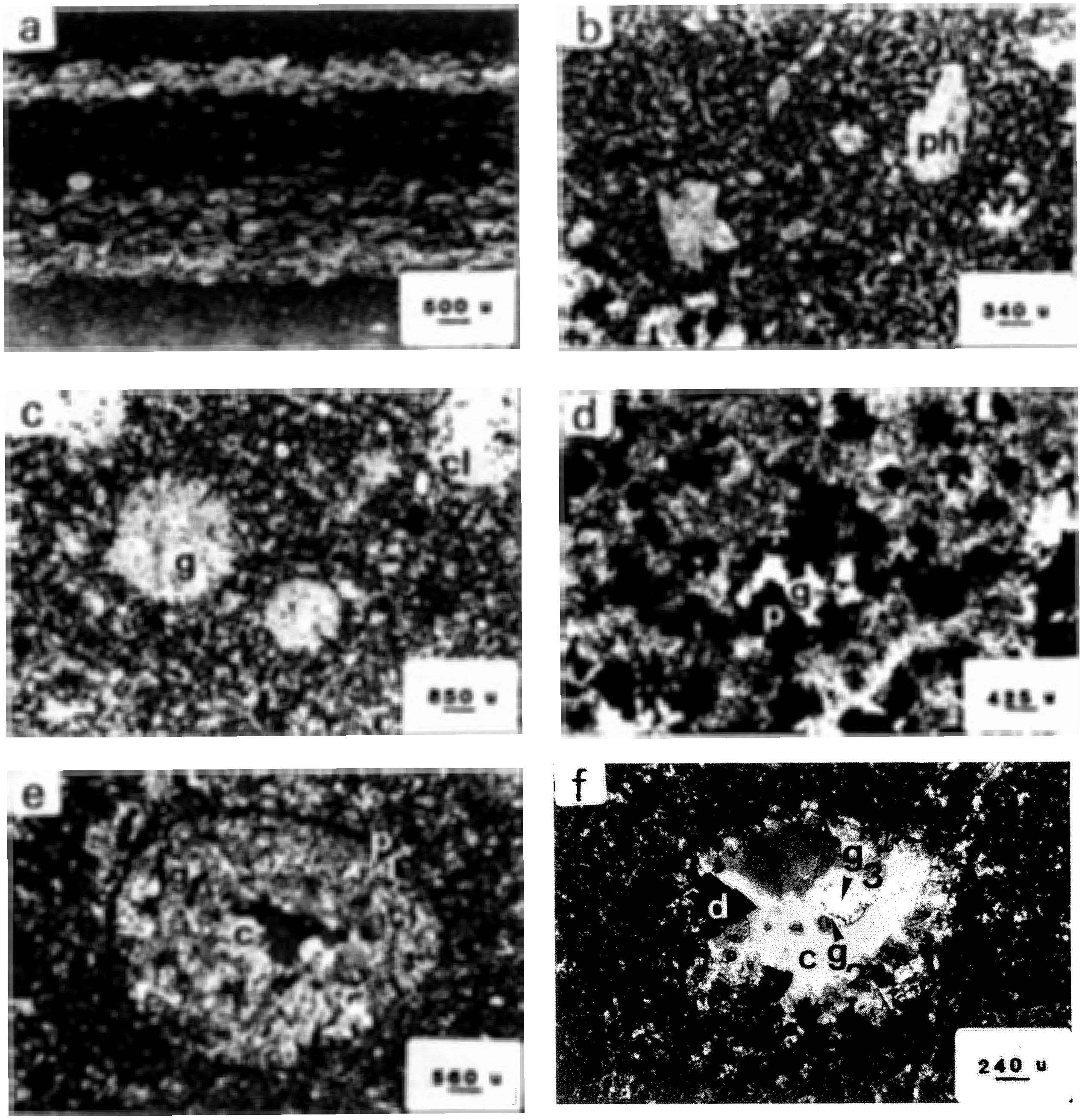

Fig. 4- a) BG-5 sample. PPL. Ostracod accumulations in a micritic limestone. The concentration style of the tests suggests they are opportunistic species; **b)** ZE-8 sample. PPL. Inequigranular seriate-textured basalt-type showing the plagioclase phenocrystals (ph) totally calcitized; **c)** ZE-3 sample. PPL. Several cavities within a groundmass of altered volcanic rock, filled with gypsum (g) and chlorite (cl). The shape and arrangement of the cavities suggest the possibility of a basaltic host-rock of amygdaloidal type; **d)** ZE-4 sample. XPL. Distorted cavities with the walls densely covered with crystalline aggregates of pyrite (p). Gypsum (g) completes the infilling; **e)** ZE-3 sample. XPL. Well-rounded cavity in which the wall accurately controlled pyrite precipitation (p^1). A close packing of gypsum crystals (g) and fibrous chlorite (cl) grew afterwards. Finally, calcite (c) completes the amygdala; **f)** ZE-8 sample. XPL. In this cavity well-formed dolomite rhombohedra appear (d). In the central part fibrous gypsum (g^2) is seen growing radially from calcite crystals (c). Crystalline gypsum (g^3) completes the infilling of the amygdala.

An accurate analysis of the samples under the microscope reveals very different diagenetic processes in the upper and the lower parts of the unit. In fact, whereas in the upper part the diagenetic evolution is in close relationship with evaporative processes, in the lower part the particular mineralogy of the host-rock is an important factor controlling the precipitation of Fe and Mg-rich minerals.

The lower volcanic layers show under the microscope very characteristic altered textures. The rock groundmass is largely composed of an inequigranular seriate-textured basalt showing the largest crystals with a high grade of calcitization **(Fig. 4b).** The groundmass small crystals are probably altered plagioclases and augite; sometimes dolomite or gypsum include them in a poikilotopic texture. One of the most outstanding features of the basaltic rocks is the existence of small cavities (maximum 5 mm. in diameter) which were the setting for diagenetic and/or hydrothermal processes of mineral precipitation. With all probability the host-rock is a volcanic, perhaps basaltic rock of amygdaloidal type **(Fig. 4c).** It is possible to see under the microscope a groundmass composed of tabular-shaped microcrystals of plagioclases, calcitized phenocrystals and several metallic ores as accesory minerals. But there is not any evidence of metamorphic processes affecting the rock.

Pyrite (p) seems to be a characteristic hydrothermal mineral. It is possible to see it frequently as isolated crystals within the basaltic groundmass, infilling fractures, in the outer margin of the cavities or covering the inner walls of the amygdalae forming crystalline aggregates **(Fig. 4d).** The possibility of a pyrite originated from late-magmatic hydrothermal conditions cannot be discarded. On the other hand, the recent limonitization of the pyrite is not an uncommon feature in these rocks. Sometimes the only relict of pyrite is a cubic mold, left by superficial alteration phenomena caused by the humid and temperate climate of the Basque Country.

It is very difficult to find any link between the basaltic host-rock and the presence of gypsum (g) as enlarged fibrous crystals normally covering the amygdalae walls **(Fig. 4e).** It has been possible to establish three generations of gypsum (g^1, g^2, g^3), the last two growing upon blocky calcite **(Fig. 4f).** The g^1 phase is the better-developed into the host-rock. It appears as crystals radially attached to amygdalae walls or, more rarely, in poikilotopic textures enclosing the microcrystals of the groundmass. The origin of the gypsum is an enigma. As we will see, one hypothesis would be a provenance from old sulphates present in the basaltic layers. Normally the gypsum is to be formed under exogenetic conditions. It can be found as a primary constituent in close association with sulphides (pyrite). Perhaps this denotes an origin related to hydrothermal veins. The presence of compacted shales above and below the volcanic rocks makes difficult to admit the infiltration of solutions bearing sulphates into the rock. Therefore we think sulphates could better come from a reaction between volatile S and Ca from the plagioclase, or, perhaps, from old sulphates incorporated into the magma during its ascensional course. The presumably underlying Keuper evaporites could be a good candidate for these sulphates.

The recognition of the microscopic textures reveals a very close relationship between the chlorite (cl) **(Fig. 5a)** and the first dolomite (d^1) **(Fig. 5b)** precipitations. It is possible to identify fibrous chlorite growths on the sides of dolomite rhombohedra. The second dolomite (d^2) includes very small pyrite cubes (p^2) **(Fig. 5c).** The more central position of the d^2 rhombohedra in the amygdalae the more clear and limpid dolomite. Sometimes an intense brown-coloured, coarse-crystalline dolomite (ferrodolomite) infilles the cavities. On the other hand, green chlorite and blue chlorite can be found as isolated crystals (sometimes zoned). The chlorite is placed normally on the amygdalae walls. The dolomite (d^1, d^2) could be formed as a result of the CO$_2$ gas together with the remobilization of Mg and Fe ions (ferrodolomite). There are well-known examples of dolomitization in relation to the dissolution and transport of Mg ions **(FREEMAN, 1972; WANLESS, 1979; LAND, 1980).**

The blocky calcite (c) is commonly filling up the cavities **(Fig. 5d)** and frequently appears as calcitized phenocrystals. The subhedral phenocrystals can include wavy textures, possibly as a result of chlorite replacements. The pyrite crystals are in some way controlled by the surface of the large phenocrystals. On the other hand, there are typical dedolomitization textures, i.e. well-formed rhombohedra of calcitic composition (pink-stained under Alizarin Red-S). Further palaeogeographical considerations **(GARCIA-GARMILLA, 1987, 1989b)** would suggest an origin for the calcite through meteoric water input from groundwater, rivers, streams and springs into a restricted basin **(DECIMA et al, 1988).** In fact, this is in agreement with the general regressive trending of the depositional sequence (from shallow-marine to fresh-water lacustrine environment). Nevertheless one factor must be taken into consideration: the largely abundant shaly lithologies of the middle part of the Member could act as an effective barrier causing a completely separate evolution of the diagenetic processes in the upper and lower parts of the unit. According to the ideas of **VALLANCE (1974)** the carbonate could be the result of the exhalation of CO$_2$ gas from the basaltic rock and the presence of free Ca cations.

Table 1 shows the composition of the volcanic rocks of the Ibarretxe Member (samples 1-7) in comparison with four standard-types. Most of the samples, if not all, are intensely altered, having a wide range of composition. The high content of Fe$_2$O$_3$ and S is owed to the conspicuous presence of pyrite. The H$_2$O$^+$ (loss by heating at 1000°C) indicates the presence of secondary minerals (carbonates, pyrite and chlorites), which are not characteristic of the original paragenesis of the rock. Finally, the low averages of Al$_2$O$_3$ and SiO$_2$ are representative of the abundance of non-silicate mineral phases.

The middle part of the Ibarretxe Member has a clearly lutitic composition: grey and black shales together with fine-grained carbonates (micrite). In the latter several ostracod accumulations can be recognized **(Fig. 4a).** In fact the concentration style of their tests seems to indicate the existence of opportunistic species which could bloom at some particular salinity conditions. Obviously the microfacies changes vertically from mudstone to wackestone to packstone. On the other hand the scarce sandstones of the unit are mainly very fine- grained, ill-textured graywackes bearing carbonate cement (blocky calcite).

The diagenetic features of the upper carbonates of the Ibarretxe Member suggest a possible composition of the initial sediment close to anhydrite, owing to the presence of nodules **(Fig. 5e)**, chicken-wire structured layers and the subsequent enterolithic folding **(Fig. 5f)**. The texture is well-preserved but the anhydrite do not appear. The nodules are completely calcitized and show very diverse sizes and shapes. Their size varies from less than 1 mm. to compound nodules of as much as 5 cm. Their shape is subrounded or ovoidal, frequently deformed by coalescence, or mound-like (pseudodiapiric) **(Fig. 6a, b)**. There are two basic causes for the precipitation of evaporative carbonate. The first is an evaporative basin receiving continuous marine inflow and having reflux circulation during the several phases of evaporative concentration **(SLOSS, 1969; SCHMALZ, 1969).** The second cause

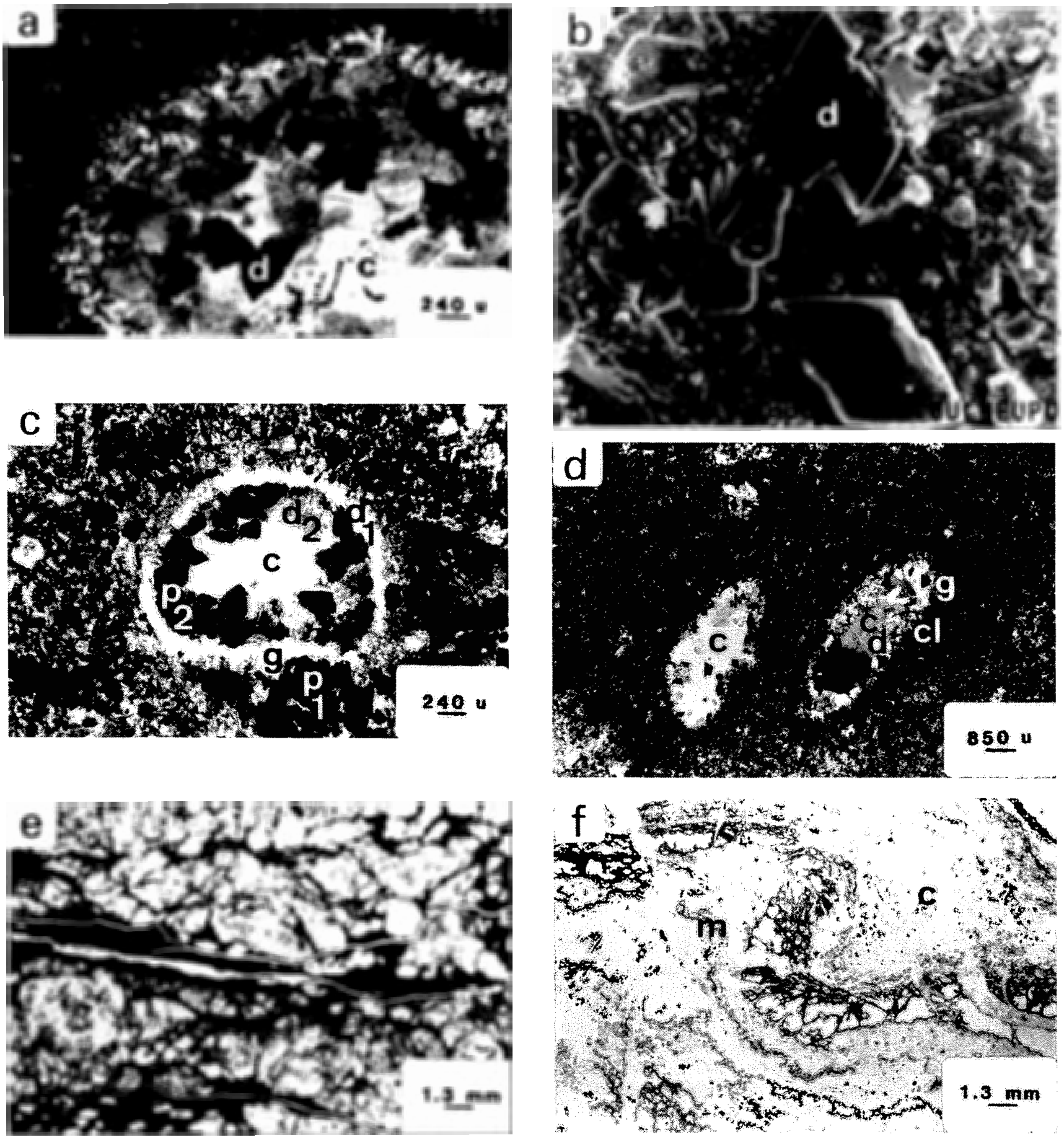

Fig. 5- a) ZE-9 sample. XPL. A magnification of an amygdala showing chlorite (cl) attached to the wall, euhedral dolomite (d) and blocky calcite (c); **b)** ZE-5 sample. S.E.M. image. Well-formed single and radial-aggregate dolomite crystals (d) with the characteristic rhombohedral habit; **c)** ZE-8 sample. PPL. A vacuole within basaltic groundmass. Dolomite (d^1) and gypsum (g) are covering the wall. Well-developed dolomite (d^2) including tiny pyrite crystals (p^2) and late calcite (c) are the following phases; **d)** ZE-9 sample. XPL. Two amygdalae elongated according to a preferred direction. The genetic order is: chlorite (cl), gypsum (g), dolomite (d) and blocky calcite (c); **e)** BIK-1 sample. PPL. Nodules in a complex disposition. The growth of nodules created a demand for space provoking the contortion of the layers. Coalescence phenomena are conspicuous. The nodules (probably early anhydrite) are totally calcitized; **f)** ZE-11 sample. PPL. A typical chicken-wire structure affected by enterolithic folding. It is possible to see thin, very contorted micritic laminae (m). Probably they were formed as a result of algal-mats growth. A generally accepted origin for these intestine-like contortions is that development of the anhydrite nodules commonly displaces the previous chicken-wire layer. Unfortunately the very-coarse blocky calcite (c) has totally replaced the previous evaporitic materials.

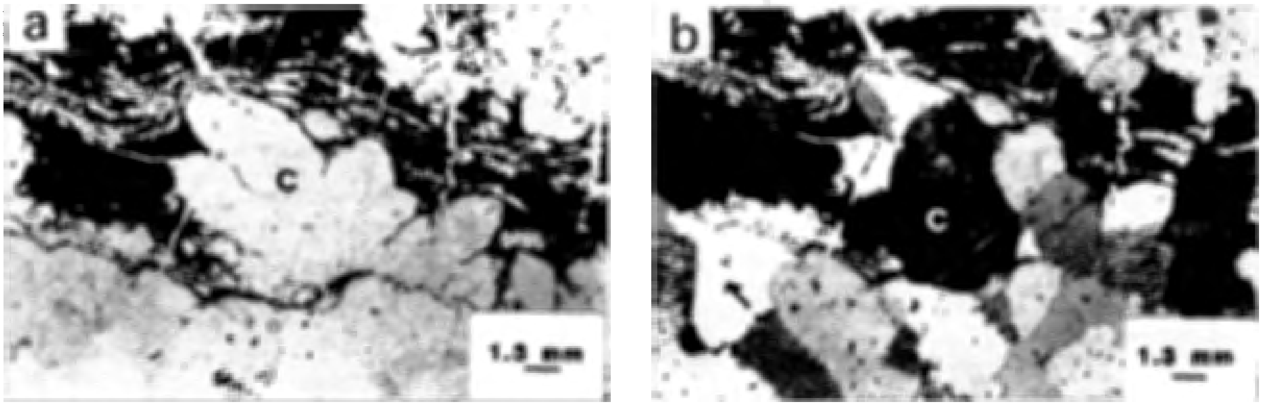

Fig. 6- ZE-11 sample. Completely calcitized (c) pseudodiapiric nodules. These structures are typical of sabkha anhydrite precursors. They are evidently growth structures. The micritic algal lamellae are conspicuously folded. **a)** PPL; **b)** XPL.

is from meteoric groundwaters, conciliable with the sedimentary settings which followed the Ibarretxe Member time of deposition.

5. DIAGENETIC EVOLUTION

As it has been exposed above, diagenetic processes in the Ibarretxe Member have been very different in the lower and the upper parts of the unit. As far as the lower part is concerned, the high grade of alteration of the original rock is conspicuous. For this reason, it is hard to distinguish the original type of source rock. In addition, assimilation of sedimentary materials into the ascending magma could explain the origin of several mineral phases, particularly carbonates and sulphates. From our data at present, we propose the following sequence of hydrothermall/diagenetic/meteoric events **(Fig. 7)**:

0) Source rock: Amygdaloidal basaltic rock?

1) Pyrite (p^1) covering fractures and the outer margins and walls of the amygdalae. ORIGIN: probably late-magmatic, from hydrothermal conditions.

2) Gypsum (g^1) covering the walls; replacing the basaltic groundmass. ORIGIN: from reaction volatile (S) + free Ca.

3) Chlorite (cl) in fibrous aggregates. ORIGIN: from alteration and remobilization of ferro-magnesian minerals.

4) Dolomite (d^1 and d^2) and ferrodolomite, in euhedral crystals growing towards the center of the amygdalae. d^1 is placed at the border in close relationship with cl. Sometimes d^2 begins including pyrite (p^2). ORIGIN: from CO_2 gas together with the remobilization of Mg.

5) Blocky calcite (c) completing the amygdalae. There are also calcitized phenocrystals and dedolomitization textures. ORIGIN: late-magmatic (posthumous gas), late-incorporated (hydrothermal), or assimilated CO_2 gas into the volcanic rock together with an excess of Ca.

6) Gypsum (g^2 and g^3). g^2 is fibrous and growths directly upon c. g^3 is medium crystalline. ORIGEN: possibly the same as g^1 or perhaps assimilated into the magma.

7) Recent limonitization and dissolution of the pyrite. The so-formed sulphates could react with Ca. As a result of this, gypsum could precipitate.

8) Recent irregular decalcification processes.

TABLE 1
CHEMICAL COMPOSITION OF SAMPLES OF THE IBARRETXE MEMBER

% Weight	1	2	3	4	5	6	7
SiO_2	27.76	15.20	45.08	13.28	49.65	49.47	47.93
TiO_2	0.33	1.34	3.39	3.00	3.00	3.15	2.76
Al_2O_3	6.15	8.14	15.32	7.59	14.88	14.58	9.87
Fe_2O_3	3.23	26.98	5.23	30.31	3.84	4.22	2.17
FeO	2.36	0.99	2.66	0.83	1.99	1.97	8.11
MnO	0.28	0.02	0.012	0,012	0.015	0.025	0.020
MgO	9.26	0.53	0.22	0.09	6.68	6.6	9.28
CaO	19.00	2.38	2.21	0.25	0.94	1.06	6.40
Na_2O	3.63	4.07	6.4	3.09	5.32	5.58	2.42
K_20	0.27	0.53	1.33	0.16	0.11	0.10	0.15
H_2O^+	16.51	16.26	7.19	17.55	6.76	6.48	6.15
P_2O_5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
H_2O^-	0.23	0.48	0.93	0.23	1.51	1.66	0.61
S_2	4.48	18.23	7.02	19.15	3.30	3.10	2.13

STANDARD TYPES

% Weight	Tholeiitic Basalt (27 analysis)	Alkali Basalt (45 analysis)	Calc-alkali Basalt (48 analysis)	Pillow-lava Basque-Cantabric Basin (1 analysis)
$Si0_2$	49.99	46.19	51.31	40.28
TiO_2	1.40	2.54	0.88	3.50
Al_2O_3	15.65	15.02	18.60	15.26
Fe_2O_3	1.74	2.70	2.71	1.13
FeO	8.06	9.01	8.17	7.07
MnO	0.19	0.17	0.15	0.14
MgO	7.98	4.89	5.95	8.12
CaO	11.36	10.82	10.30	8.58
Na_2O	2.70	2.78	2.93	4.32
K_2O	0.19	0.89	0.74	3.32
H_2O^+	0.60	0.45	0.30	7.40
P_2O_5	0.13	0.38	0.12	n.d.
H_2O^-	n.d.	n.d.	n.d.	
S	n.d.	n.d.	n.d.	n.d.

In the upper part of the unit, diagenetic evolution is mainly controlled by the initial evaporative textures and the complete replacement by blocky calcite. The proposed diagenetic sequence is the following one **(Fig. 7)**:

- **0)** Possible source rock: Anhydrite rock? (not present). Preserved textures: nodules (scarce and coalescent, sometimes pseudodiapiric), chicken-wire layers, enterolithic folding.
- **I)** Gypsum? (not present). ORIGIN: from hydration of the anhydrite?
- **II)** Blocky calcite (c) frequently very-coarse crystalline. It replaces completely the previous evaporitic materials. ORIGIN: from phreatic fresh-waters perhaps in relationship with the regressive trending of the depositional system (from non-open shallow-marine to lacustrine environment).
- **III)** Recent irregular decalcification processes.

6. CONCLUSIONS

The hydrothermal/diagenetic features of the Ibarretxe Member suggest a separate post-depositional evolution for the lower volcanic rocks and the upper evaporites. The minerals infilling spilite amygdalae (pyrite, chlorite, dolomite, calcite) are typical of conventional hydrothermal/diagenetic processes. Nevertheless, a second possibility is the pass of the basaltic effusion through evaporitic layers (such as the Keuper gypsums), with enrichment of the magma in sulphates and carbonates. Another argumentation is that the late-magmatic, volatile-rich, bearing-sulphur liquids could react with the Ca-excess of the basaltic rock.

On the other hand the completely calcitized evaporative textures of the upper part of the Ibarretxe Member constitute another outstanding diagenetic feature of the unit. The origin of the calcite replacing the nodules and chicken-wire structures could be attributed to input of meteoric fresh waters. In fact, the palaeoenvironmental evolution reflects a progressive change from the Ibarretxe Member evaporites to more humid, fresh-water environments: a complex lacustrine setting bearing fluvially-controlled deltaic sand lobes **(GARCIA-GARMILLA, 1987, 1989b).** As a result of this, a more conspicuous influence of the underground fresh waters in the diagenesis of the upper part of the unit is inferred. Probably these palaeogeographic events were the responsible for the whole and widespread calcitization of the evaporitic rocks of that part of the Ibarretxe Member.

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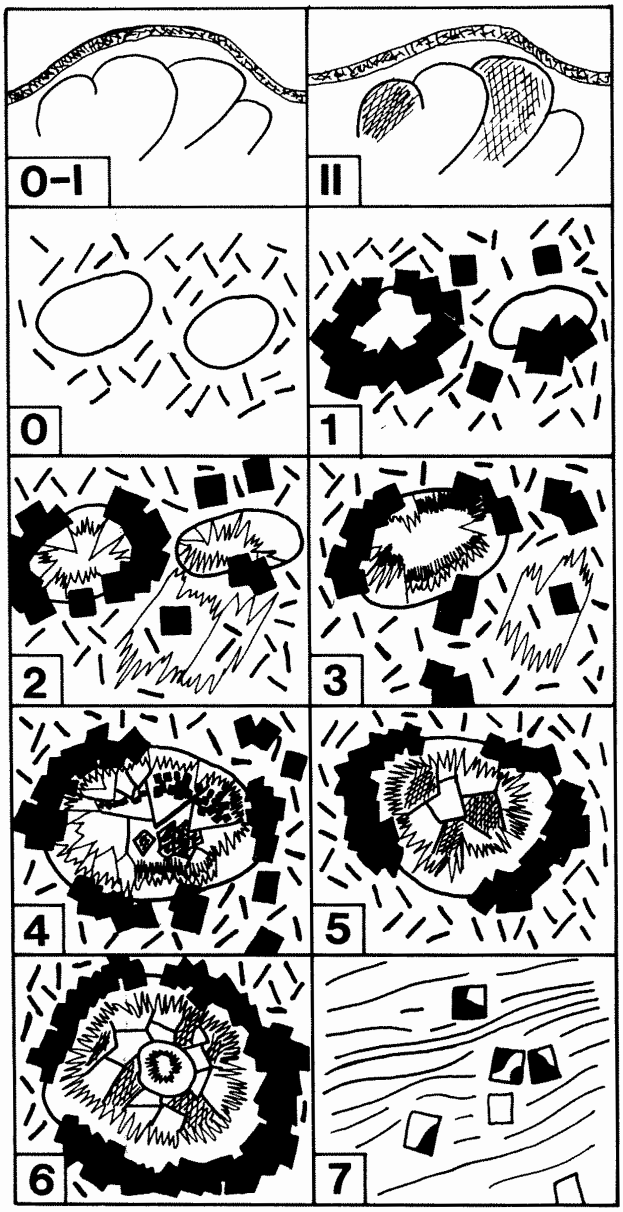

Fig. 7- Hydrothermal/diagenetic/meteoric evolution in the lower **(0-7 stages)** and upper **(0-II)** parts of the Ibarretxe Member. The several hydrothermal/diagenetic/meteoric stages are explained in the text (see 5. Diagenetic evolution).

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