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THE "WEALDEN" OF CENTRAL BASQUE-CANTABRIAN REGION (VILLARO FORMATION): PETROLOGY AND STRATIGRAPHIC CORRELATION WITH THE WESTERN FORMATIONS

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RESUMEN

En este trabajo se aportan nuevos datos sobre la correlación estratigráfica y paleogeografía de los sedimentos wealdenses (Cretácico basal) en un amplio sector que comprende la parte oriental de Cantabria y el sur de Bilbao. Se documenta un importante período regresivo durante el Berriasiense-Barremiense. El análisis de facies permite reconstruir un amplio sistema deposicional fluvio-lacustre para las Formaciones de Bárcena Mayor, Vega de Pas y Villaro. La primera de ellas descansa discordantemente sobre las formaciones lacustres y marino-someras del Grupo Cabuérniga en el E. de Cantabria. Periódicamente se desarrollaron extensos lóbulos deltaicos arenosos que han determinado la existencia de cinco crestones areniscosos de gran continuidad lateral en las áreas de afloramiento de la Fm. de Villaro (zona sur de Bilbao). Los cambios verticales significativos en el contenido en feldespato potásico y plagioclasas de las muestras de arenisca recogidas en las unidades arriba mencionadas permiten establecer una correlación estratigráfica entre la Fm. de Bárcena Mayor y los dos crestones inferiores del M. Villaro. Por su parte, la Fm. de Vega de Pas equivale a los tres crestones superiores del M. Villaro. Finalmente los fósiles identificados sugieren un ambiente fundamentalmente lacustre para los sedimentos de la Fm. de Villaro. No obstante, se detectan periódicas influencias de aguas salobres que hacen pensar en conexiones intermitentes con ambientes marinos someros, entonces situados verosímilmente al norte de Bilbao.

ABSTRACT

This paper deals on stratigraphic correlation and paleogeographic reconstruction for the Wealden sediments (Lowermost Cretaceous) in the Eastern Cantabria-Bilbao range. It documents an important regressive period in the Berriasian-Barremian age. The facies analysis leads us to think in a fluvio-lacustrine depositional system for the Bárcena Mayor, Vega de Pas and Villaro Formations. The first of them unconformably overlies the lacustrine and shallow-marine formations of the Cabuérniga Group in the Eastern Cantabria area. There are periodic developments of deltaic lobes determining five sandy cycles with a marked lateral continuity in the outcrop area of the Villaro Formation. The significant vertical changes in the orthoclase and plagioclases averages in the sandy samples allows us to establish an equivalence between the Bárcena Mayor Formation and the two lower sandy cycles of the Villaro Member. The Vega de Pas Fm. is to be corresponded with the three upper ones. On the

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other hand the observed paleofauna suggest a brackish-water salinity for the Villaro lake probably owing to sporadic connections with shallow-marine environments located at the north of Bilbao.

LABURPENA

Cantabriako ekialdea eta Bilboko hegoaldea hartzen dituen sektore zabaleko sedimentu wealdiarren koerlazio estratigrafiko eta paleogeografikoari buruzko argibide berriak ematen dira ikerlan honetan. Berriasiar-Barremiar denboratarteko itsas--atzeratzaldi garrantzitsua ondorioztatzen da. Fazien analisiak ibai-lakutar depositatze-sistema zabal bat berreraikitzen laguntzen du Barcena Mayor, Vega de Pas eta Villaro izeneko formazioetarako. Aipatu lehenengoa Cantabriako ekialdeko Cabuerniga Taldeko laku eta sakonera gutxiko itsas formazioen gainean ezartzen da modu desbaterakorrez. Aldizka delta-lobulo hareatsu zabalak ageri ziren Villaro formazioko agerguneetan diren alboko jarraitasun haundiko bost barra harearritsu sortarazi zituztelarik. Goian aipatu unitateetan hartutako harearri-laginetako plagioklasa eta feldespato potasikoaren edukinean nabari diren bertikaleko aldaketek koerlazio estratigrafikoa egitea ahalbidetu dute, Barcena Mayorreko formazioaren eta Villarokoaren behekaldeko barra bien arteko koerlazioa hain zuzen. Bestalde, Vega de Pas formazioa Villarokoaren goikaldeko hiru barrei dagokie zuzenean. Azkenik, aztertutako fosilek nabariro giro lakutarra adierazten dute Villaro formazioaren sedimentuetarako. Halaz ere, ur gazien aldizkako eragina ere ageri da nabarmen, beronek Bilboko iparraldean bide zen sakonera gutxiko itsas-giroarekin aldizkako loturak egiaztatzen dituela.

1. INTRODUCTION

The terrigenous sediments of Malm-Barremian age in the northern area of Spain have often been referred to in the literature as "Wealden" (GONZALEZ LINARES, 1876; PALACIOS, 1915; CIRY, 1940: RAT, 1959, 1962, 1963; RAMIREZ DEL POZO, 1971; PUJALTE, 1977, 1979, 1981, 1982, 1985; BADILLO, 1982; GARCIA GARMILLA, 1987, 1988; GARCIA GARMILLA & PUJALTE, 1988) owing to their similarities with those of the Weald, which is the type-area in the south of England (DREW, 1861; KIRKALDY 1939; ALLEN, 1941, 1948, 1949, 1959, 1975; ARKELL et al, 1947; WEST, 1975; BATTEN, 1975). Although the terrigenous character of these deposits is conspicuous, some marine-calcareous episodes and basaltic rocks exist at the base of the Wealden series breaking the monotony of the sedimentary record.

The Wealden sedimentary pile (about 1500 m. thick) shows very different facies features in the eastern part of Cantabria and the Bilbao area in Biscay (Fig. 1). In fact whereas the Cantabrian deposits accumulated mainly in fluvial environments, those of Bilbao area are indicative of a lacustrine complex with five significant sandy deltaic episodes determining five coarsening upwards sequences. The vertical changes in the sandstone composition and grain-size are of interest with regard to the stratigraphic correlation between the formations in Cantabria and Bilbao (Fig. 2). The paleocurrent analysis data are in agreement with the petrologic parameters obtained.

The accurate observations in several sectors of this region reveal an evident influence of the tectonism as a factor closely controlling the Mesozoic deposition (FEUILLEE & RAT, 1971; SOLER Y JOSE, 1972; MELENDEZ HEVIA, 1976; GARCIA MONDEJAR, 1979; BOILLOT, 1984 a,b,; FERNANDEZ MENDIOLA, 1986). However these results are difficult to verify just in the central sector of the Basque-Cantabrian Basin. We can rarely see the outcrops of the Lower Wealden terms except in the Ramales area (Fig. 1). On the other hand this region experienced a very strong post-sedimentary tectonic activity, which created the actual structural configuration. Finally data from several wells show the subsurface thickness of the Wealden, although in some places thickness reflects structural folding and faulting at depths about 1500-2000 m.

2. "WEALDEN" SEDIMENTATION IN THE BILBAO AREA (THE VILLARO FORMATION)

The most representative and thick succesion of the Villaro Formation (Upper Berriasian-Barremian, up to 1300 m.) is located in the Bikotz section (Fig. 1) in which the three members of the unit (Zollo-Elejabeitia Member, Ibarretxe Member and Villaro Member) are well exposed. The transition between the members is gradual and concordant (intertonguing).

The Zollo-Elejabeitia Member (120 m.) is the lowest exposed member of the Wealden succesion (Fig. 3) and crops out near the Villaro Fault (Fig. 1). Adjacent to the fault the strata are intensely deformed (joints, little faults and schistosity subparallel to stratification planes). This unit is composed of grey and black shales bearing bivalves and gastropods of brackish-water environments (*Corbula, Cercomya, Cassiope*) and ill-preserved flora remains. Other lithologies are fine-grained sandstones and occasional argillaceous limestones. The rare sedimentary structures consist of symmetrical ripples and varve-like laminations lacking major current structures. Several thickening-coarsening sequences about 2-3 m. thick can be observed.

The fossils and undisturbed laminae suggest a quiet-water depositional environment closely similar to lacustrine settings. However the fossils indicating brackish-water conditions lead us to think in eventual relations with more saline waters. The facies associations suggest the rythmite-mud and muddy delta models described by HASZELDINE (1984) for the lake sediments of the Upper Carboniferous of NE England. The salinity changes can modify this interpretation towards a lagoonal complex environment.

The Ibarretxe Member (150 m.) is the second member of the Villaro Formation and includes dolomitic black shales and parallel-laminated carbonates showing chicken-wire structures (Figs. 4f,5 &6). Whereas the dolomitic black-shales constitute the background sedimentation of the unit, the dolomite appearing in scarce horizons is perhaps the most characteristic lithology of the Ibarretxe Member. The fossil representation is relatively poor (*Corbula*, ill-preserved ostracods, equisetales, ginkgoales and other stem fragments). The lithology, bedding and dolomite content suggest a saline lacustrine or lagoon environment with sporadic periods of shallowing and dessication.

One of the most peculiar features of this unit is the presence of spilithic layers just at the base of the stratigraphic section (Fig. 5). They are mainly inequigranular seriate-textured basaltic rocks in which the diagenetic processes are complex and include the precipitation of pyrite, chlorite, gypsum, dolomite and calcite.

The Villaro Member represents the background sedimentation of the Villaro Formation (Figs. 2 and 7). It is composed mainly of black shales with five very thick fine-grained sandy and silty intervals which stand out topographically (I, II, III, IV, V). The thickest of them are the II (80 m.), IV (220 m.) and V (120 m.) intervals. There are also sporadic intercalations of grey limestones and black dolomites with pyrite. The sandstones show symmetrical ripples, ripple cross-lamination, flaser bedding, and planar, sigmoid and trough cross-bedding. The fine-grained sediments contain linsen stratification, rippled silts and intercalations of sandy grey marls. There are several layers of shell accumulation, not all of them showing the same characteristics. Some of them have been produced by reworking of bivalve and gastropod remains (Fig. 4b). They are lumachels in which the shells appear eroded and disordered. The accumulations can be mono-or polyspecific (*Paraglauconia, Corbula*, oysters). It seems probable their deposit in an aqueous environment affected by turbulence phenomena.

Unlike these ones, other accumulations consist of shells in living position, coexisting young and old forms in the same stratigraphic horizon. Probably these associations denote a lack of transport. In fact, they are mass-mortality horizons, which indicate sharp changes in the temperature and/or salinity of the depositional environment. This assertion does not disagree with the general replacement of brackish-water fauna by marine species towards the lower Aptian time.

Pyrite is particulary abundant in the lower part of the unit, replacing bivalve shells, as individual crystals (Fig. 4d), in argillaceous nodules, or in bundles subparallel to stratification. The fossil contribution consists on *Ilyocypris, Cercomya garmillai* (GARCIA GARMILLA y CALZADA, 1987), *Corbula, Cassiope* and teleostean remains (Fig. 8d). They suggest a fresh/brackish-water environment of low energy with sporadic marine ingressions. Finally there are a few intercalations of grey limestones and black dolomites in which fossil material cannot be observed.

Towards the SE (Aramaio section, Fig. 1) the black-shale/sandstone ratio increases probably indicating the most distal

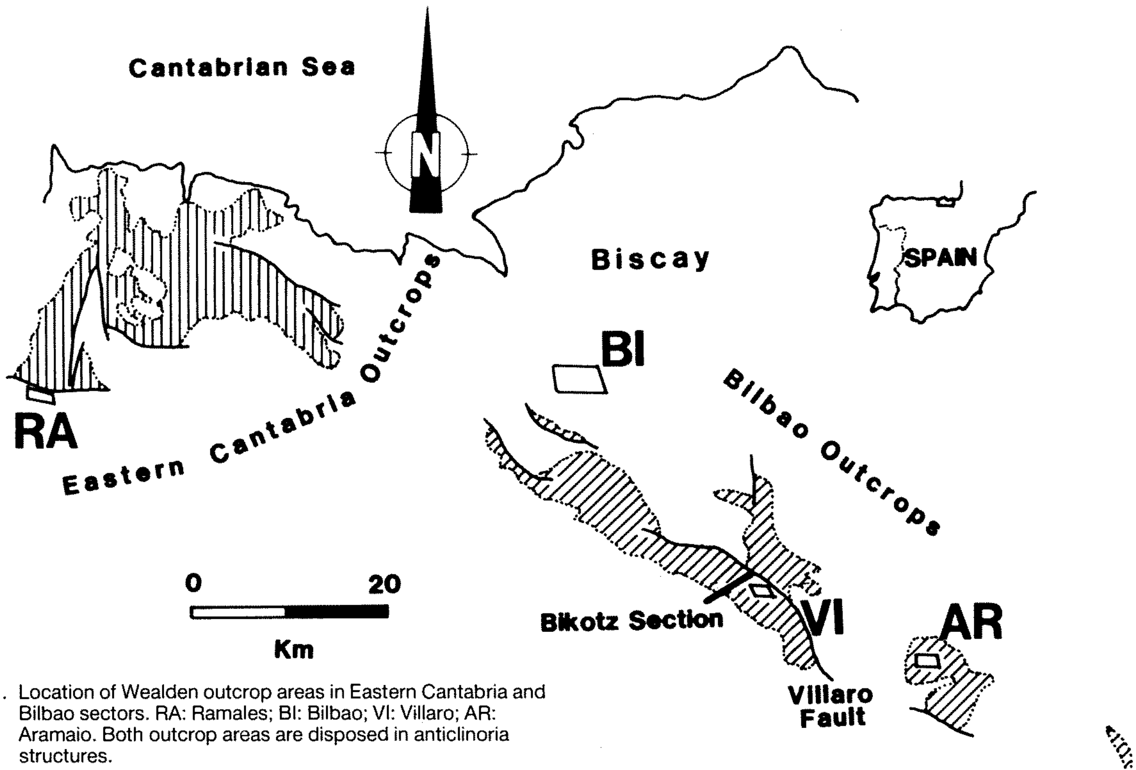

Fig. 1. Location of Wealden outcrop areas in Eastern Cantabria and Bilbao sectors. RA: Ramales; BI: Bilbao; VI: Villaro; AR: Aramaio. Both outcrop areas are disposed in anticlinoria structures.

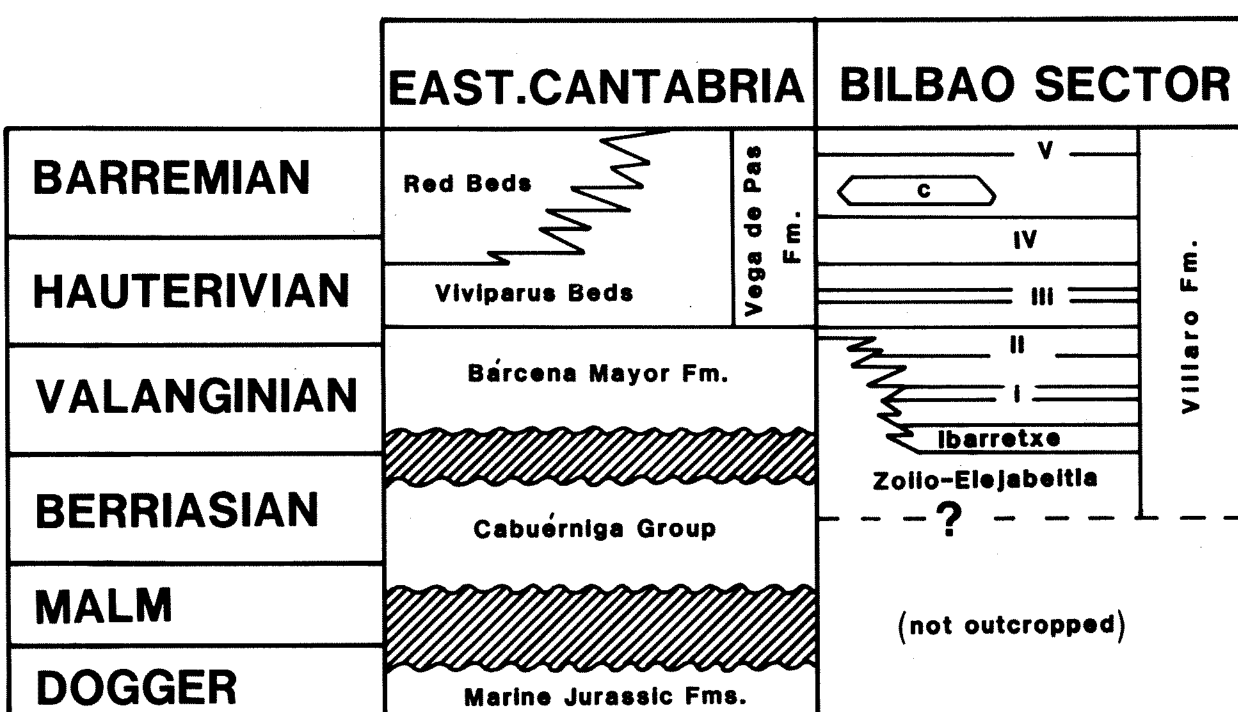

Fig. 2.- Correlation table showing the stratigraphic units of Eastern Cantabria and Bilbao and their lateral and vertical relationships. Sandy cycles (I-V) are shown in detail in Figure 7.

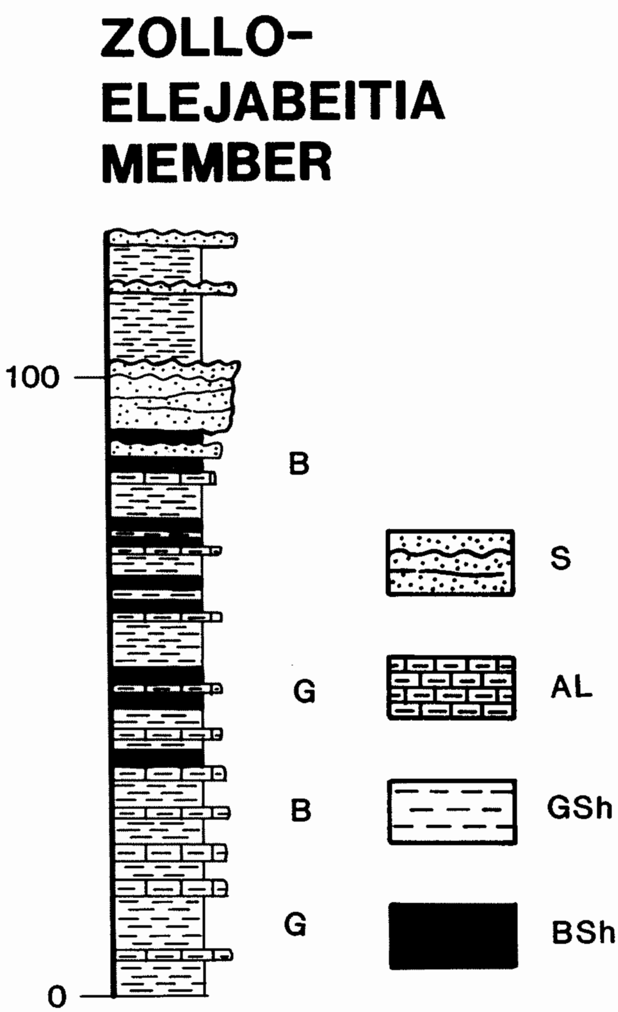

Fig. 3. Stratigraphic section of the Zollo-Elejabeitia Member. Vertical scale in meters. B: bivalve accumulations; G: gastropod accumulations; S: sandstones; AL: argillaceous limestones; GSh: grey shales; BSh: black shales.

but not the deepest area with respect to the fluvial sources of Eastern Cantabria (Fig. 8b). Perhaps the most characteristic facies in the Aramaio sector are the algal-laminated micritic limestones (Fig. 4c) sometimes in strata as much as 2 m. thick.

The presence of widely disseminated organic matter and pyrite in the sediments suggests a very restricted, strongly euxinic environment, perhaps no deeper than 30 m. with water salinities between fresh and brackish, rarely saline. A lacustrine environment has been suggested, but two considerations are of interest: the first is the presence of five well-developed sandy cycles culminating in the same prograding-bar sequences (Figs. 7, 8a). Their respective vertical successions reinforce the idea of tectonic controls upon the sedimentation. Succesive pulsations were responsible for periodic subsidence stages in the Bilbao sector, causing depth changes from delta plaines to prodeltas. These events caused the peculiar sedimentary style of the Villaro Member and probably ocurred more often than has been verified only with data from outcrops. It is suggested so from data from the largest wells drilled in the region (ARAMAIO-I, 1961; UBIDEA-I and AITZGORRI-I, 1964; URBASA-2, 1967; ARRATIA-I, 1980). The second point to consider is the occasional relation between this setting and shallow-marine environments (ROBADOR,, 1984) located with all probability to the north of Bilbao (Fig. 9).

The paleocurrent measures from directional structures show a transport from NW(W) to SE(E) throughout both areas (Eastern Cantabria and the Bilbao sector, Fig. 10). These data suggest the presence of a very active fluvio-lacustrine depositional system during the Berriasian-Barremian in the Cantabria-Bilbao range. Paleocurrents reveal the development of sandy-silty deltaic systems located to the east of Cantabria, but during the Ibarretxe Member time the paleoenvironment could be related to marine waters with wide areas with a shallowing trend.

3. "WEALDEN" SEDIMENTATION IN EASTERN CANTABRIA (BARCENA MAYOR AND VEGA DE PAS FORMATIONS)

3.1. The Bárcena Mayor Formation

The easternmost outcrops of The Bárcena Mayor Formation (350 m.) are placed near Ramales village (Cantabria). This unit unconformably overlies the Cabuérniga Group composed of fluvial, lacustrine and shallow-marine strata deposited in Late Jurassic-Early Cretaceous time (PUJALTE, 1982). The Bárcena Mayor Fm. (Fig. 11) contains as much as 70% sandstone, sometimes with intercalated granule-sized conglomerates. Medium to coarse sandstones are yellowish brown in colour with red tones owing to iron oxides. The sedimentary organization consists of thinning-fining upwards about 2-10 m. thick, with good lateral continuity and cut and fill channelized stratification planes. Sedimentary structures are developed at metrical scale: planar and trough cross-bedding with an erosive and microconglomeratic base on top of fine-grained lithologies and frequent reactivation surfaces. Syndepositional deformation structures (hydroplastic folding, ball and pillow) can also be observed. Mudstone sediments are mainly fissile black shales bearing organic matter and vegetal remains (trunk fragments and leaf impressions). Sometimes mudstones are massive or ill-structured perhaps due to more or less intense bioturbation.

These features suggest a fluvial depositional environment for this formation. The sequential arrangement is to be conciliated with channel-infilling processes related to meandering and braided river systems. On the other hand the fine-grained sediments are interpreted as deposited in floodplains or abandoned channels.

The Bárcena Mayor Formation grades upward into the lower part of Vega de Pas Formation. The transition is marked by an increase in fine-grained sediments, a diminution in grain size and a change in sandstone composition from quartz – and lithic– arenite to arkose.

3.2. The Vega de Pas Formation

In its type-area the Vega de Pas Formation (950 m.) is composed of two members (PUJALTE, 1977); Viviparus Beds (the lower) and Red Beds (the upper). Both units intertongue laterally and vertically. The Red Beds Member is better represented in Western Cantabria outcrops, passing laterally and

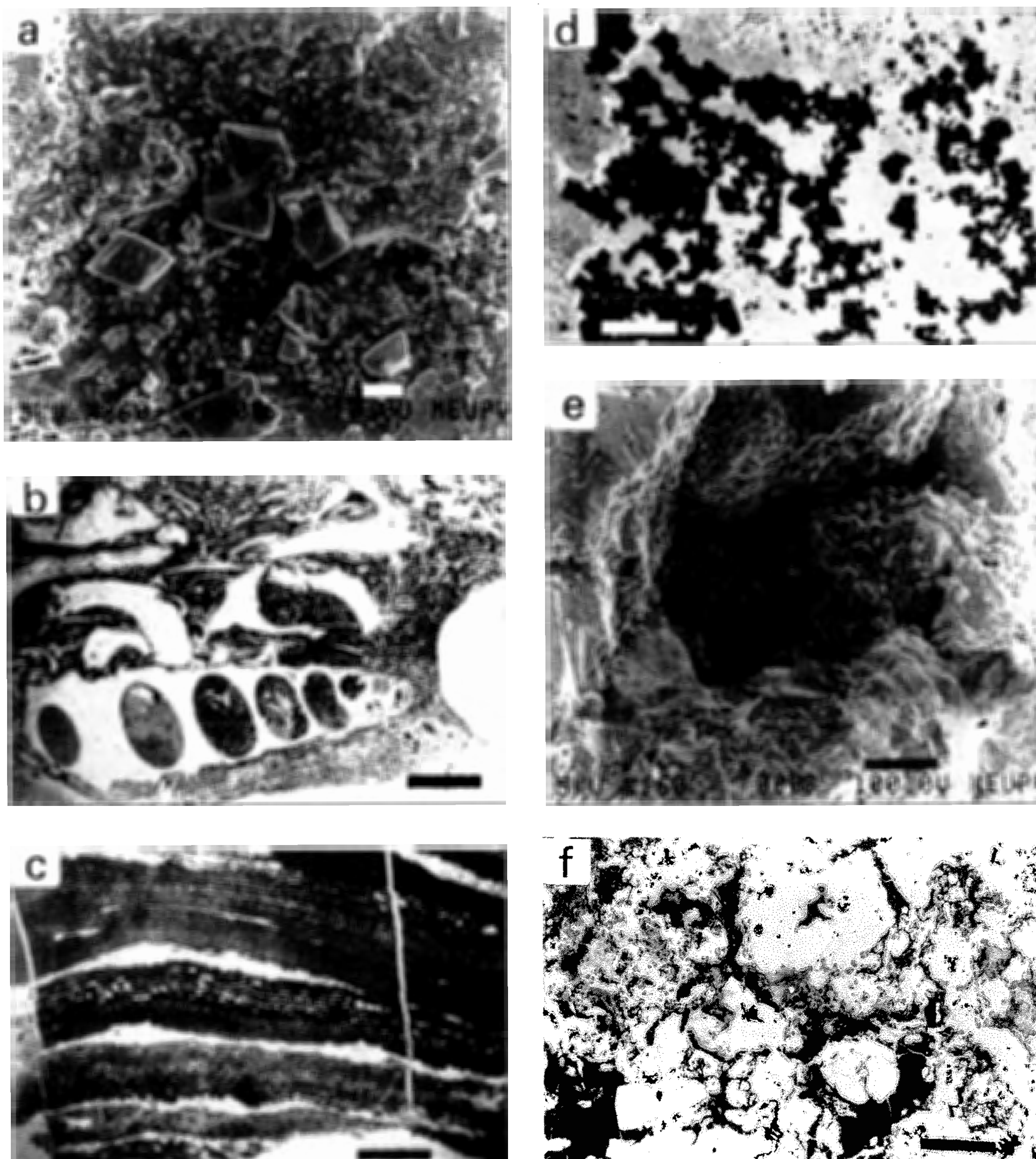

Fig. 4. (Set of six photos).- a) S.E.M. photo showing well-formed dolomite crystals. Ibarretxe Member. Bar scale is 10 microns. b) Lumachel consisting largely of gastropod debris *(Paraglauconia)* at the top of sequence V of the Villaro Member. Bar scale is 2.5 mm. c) Laminated mudstone probably of algal origin. Sequence V of the Villaro Member (Aramaio). Bar scale is about 3 mm. d) Micrite with euhedral pyrite crystals in the prodelta facies of the Villaro Member (sequence II). Bar scale is 1 mm. e) Epitaxial overgrowths of kaolinite-habit crystals on the surfaces of quartz grains with partial infilling of the pore spaces. Quartzarenites of the Red Beds Member. Bar scale is 100 microns. f) Wholly calcitized nodules in a complex disposition reaching to the coalescence. Ibarretxe Member. Bar scale is about 0.5 mm.

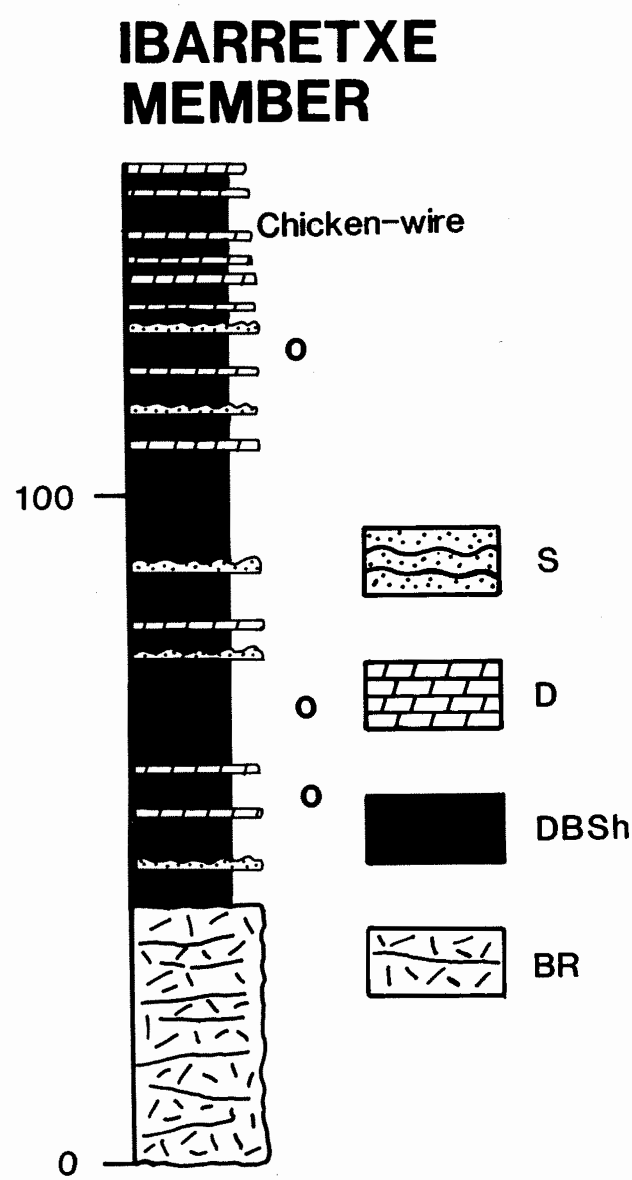

Fig. 5. Stratigraphic section of the Ibarretxe Member. Vertical scale in meters. Dolomites with chicken-wire structures are located at the upper part of the section. O: ostracod accumulations; S: sandstones; D: dolomite; DBSh: dolomitic black shales; BR: basaltic rocks.

vertically to the Viviparus Beds Member in Eastern Cantabria. In this area there is also an important facies transition from Red Beds in the south to Viviparus Beds in the north. Finally marine sediments of Early Aptian age (Urgonian) are transgressive upon Wealden deposits from east to west.

The Viviparus Beds Member

It is composed of yellow fine-grained sanstones and black shales bearing fresh-water fossils *(Viviparus, Unio)*. The stratification shows a very wide planar geometry with clear lateral continuity (Fig. 8c). The current structures are very rare. Only symmetrical ripples together with ill-developed trough cross-bedding can be observed.

The lithological and palaeontological features of this unit suggest a very shallow, low-energy, fresh-water depositional environment. A lacustrine setting seems to be the most probable. Nevertheless the lateral and vertical intertonguing of the Viviparus Beds Member with fluvial units such as Red Beds Member and Bárcena Mayor Formation allow to consider that it was deposited in a relatively extensive floodplain. More or less ephemeral pools would have been present in the floodplain and very scarce shallow channels occasionally furrowed that setting.

The Red Beds Member

It consists of red shales, siltstones and medium to fine sandstones in thinning-fining upward sequences with erosive bases. Sandstones show channel morphologies, cross-bedding, flute-marks and groove-marks. Laminated or massive-bioturbated mudstones are very rich in plant remains. Some ill-structured muddy horizons have been interpreted as paleosoils. The sedimentological features of the Vega de Pas Formation are in agreement with fluvial complexes predominantly with meandering rivers (Red Beds) characterized by extensive floodplains (Viviparus Beds).

The red colour of sandstones and mudstones of the Red Beds Member is owed to the presence of iron oxide as thin-section analyse under the microscope demonstrates. This probably indicates an open circulation and more oxygenated conditions than the reducing ones attributed to the Viviparus Beds Member.

4. PETROLOGIC DESCRIPTION

The majority of the observed lithologies are shales, siltstones and fine-grained sanstones, rarely carbonate sediments. The quartz average in sandstones is very high (85-96%). Some of the units (i.e. Ibarretxe Member, Bárcena Mayor Formation) are typically quartzarenites. Sublitharenites are present in Zollo-Elejabeitia Member, Villaro Member and Viviparus Beds Member. Finally the Red Beds Member is composed of sublitharenites and subarkoses. These significant compositional changes throw a new light upon the stratigraphic correlation between the Wealden formations in Cantabria and Bilbao.

More than 200 thin sections were examined under the microscope and a few of them were observed under the S.E.M. (Scanning Electron Microscopy). The percentages were obtained from point counting to 2000 per each section. The preparations were stained with a sodium cobaltinitrite solution for the determination of K-feldspar.

The monocrystalline quartz frequently contains tourmaline and apatite inclussions together with fluid vugs normally in alignment. Polycrystalline quartz shows sutured boundaries between the crystals, sometimes directionally enlarged (shearing) suggesting a metamorphic source rock. The albitic plagioclases are not frequent (0.3-1.6%) and they are less-altered than orthoclase. The compositional change in the Fd+Plg average of the Villaro Member sandstones is very characteristic. In fact whereas the first and second sandy cycles (I, II) have relatively little Fd+Plag (0.5-1%), these values increase in the three upper cycles (III, IV, V) reaching up to 4.5% (Fig. 12, Table 1). This is an important compositional

TABLE 1

	Q	Fd	Plg	Chert grains	Metamorphic grains	Mudstone grains	Carbonate grains	Micas	Matrix	Major Components Q	F	L
Zollo-Elejabeitia M.	29.94	0.40	1.25	0.77	0.90	5.15	0.00	6.04	50.07	77.94	4.29	17.75
Ibarretxe M.	48.27	0.05	1.20	0.28	1.95	0.00	0.00	1.66	36.75	95.19	1.70	3.10
Villaro M.	57.14	2.12	3.09	1.25	1.02	1.09	0.69	3.08	20.61	91.64	3.40	4.95
Bárcena Mayor Fm.	88.24	0.68	0.31	1.25	0.83	0.03	0.00	0.95	4.80	96.59	1.04	2.34
Viviparus Beds M.	76.65	0.65	0.73	1.55	1.61	0.66	0.00	1.90	12.75	93.91	1.73	4.55
Red Beds M.	71.31	1.71	1.67	1.57	1.21	0.58	0.64	1.24	16.57	89.79	4.06	6.12

feature because the high subsidence conditions during the Wealden deposition and the lack of sharp vertical changes of facies suggest source-related causes for the variation. In addition regional paleogeographic considerations reinforce the idea of higher rates of subsidence during the Villaro Member time of deposition than during that of the Bárcena Mayor Formation.

Chert fragments are not uncommon in Wealden sandstones owing to their resistance to weathering. They appear as rounded to well-rounded grains sometimes showing schistosity (lidite type). Metamorphic grains have been derived from micaschists and quartz-micaschists. Micas have a very irregular distribution except for the quartzarenite samples. They consist mainly of white micas (moscovite). The more common accesory minerals are tourmaline, zircon, pyrite, chlorite, epidote and sphene.

Mudstone fragments are composed of shaly, micritic or oxide grains, sometimes as a result of early cement destruction during the first stages of diagenesis. Their shape is contorted and adapted to other more resistant grains as a result of compaction. Carbonate fragments are very rare and can only be found in the upper part of the Red Beds Member and some horizons of the Viviparus Beds Member. They consist mainly of bivalves, gastropods, bryozoans, brachiopods and serpulids.

The matrix content is particularly high in the sandstones of the Villaro and Vega de Pas Formations. Its components are silt-sized micas and quartz and argillaceous minerals. Detrital illite is well represented in the Villaro Formation and kaolinite booklets frequently appear in the Vega de Pas sandstone (Fig. 4e). Carbonate mud (micrite) rarely appears. Chlorites show minute-fibrous crystal-aggregate habits sometimes in epitaxial overgrowths on framework grains (i.e. Bárcena Mayor quartzarenite) or in more complex structures (i.e. Viviparus Beds graywacke). Syntaxial quatz overgrowths are the most common type of cement in sandstones. Nevertheless sometimes the cement has a carbonate composition (calcite and dolomite). Iron oxides are not particularly abundant with the exception of the samples of the Bárcena Mayor Formation and Red Beds Member.

The compositional features described above denote a general change from litharenite/quartzarenite to graywacke/subarkose from the base to the top of the Wealden stratigraphic section. This petrologic evolution can be explained as a result of the important subsidence regime which characterized the studied area during the time of deposition of the Vega de Pas Formation and the III, IV and V sandy cycles of the Villaro Formation. Rapid burial of sediments could be a reason for the K-feldspar and plagioclase preservation. Other factor controlling the percentage of K-feldspar is the predominance of low-energy subenvironments corresponding to the Vega de Pas and Upper Villaro Formations. The genetic significance of the appearance of the upper graywackes seems to be closely related to degradation of the source-area (Paleozoic sandstones), together with the redeposition of old sandstones (i.e. the Buntsandstein). On the other hand, it is well-known from sedimentological data that the Wealden Basin in Bilbao area experienced a high subsidence regime, and that it was accompanied by a conspicuous stability of the lacustrine depositional setting. The Basin was very restricted and controlled by significant faults, many of them with a long history (BOILLOT et al., 1973; PUJALTE, 1979, 1982).

5. PALEOGEOGRAPHIC SETTING

Facies analysis and petrologic data suggest a fluvio-lacustrine depositional system for the Wealden sequence of Berriasian-Barremian age in the Eastern Cantabria-Bilbao area (Fig. 9). Shale is the dominant lithology in the stratigraphic sequence. The lack of large-scale current structures suggests a general low-energy setting, but sandy episodes testify to fluvial arrivals periodically well developed. This cyclic pattern is perhaps the main argument for tectonic controls upon the Wealden sedimentation and/or periodic floods in the Cantabrian fluvial system. With all probability this region was influenced by the Finisterre uplift at NW of the Iberian Peninsula and by the southward tilting linked to the Biscay Bay opening during the Late Jurassic-Early Cretaceous (BOILLOT et al, 1973, 1979, 1985; MALOD et al, 1982). PUJALTE (1982) reached a similar conclusion for the western and central areas of Cantabria.

Finally the Aramaio black shales, the finest-grained Wealden sediments, suggest very distal zones with respect to the cantabrian fluvial sources and probably represent the central part of the lacustrine environment. This grain-size distribution points to generalized paleocurrent patterns from W to E. Nevertheless the very coarse sandstones and conglomerates of the Wealden in the south sector of the Basque-Cantabrian Region does not disagree with the existence of alluvial fan/fluvial systems draining from south to north (GARCIA-GARMILLA & BADILLO, 1986, 1987, 1988 y 1989). However further studies are needed to corroborate this hypothesis.

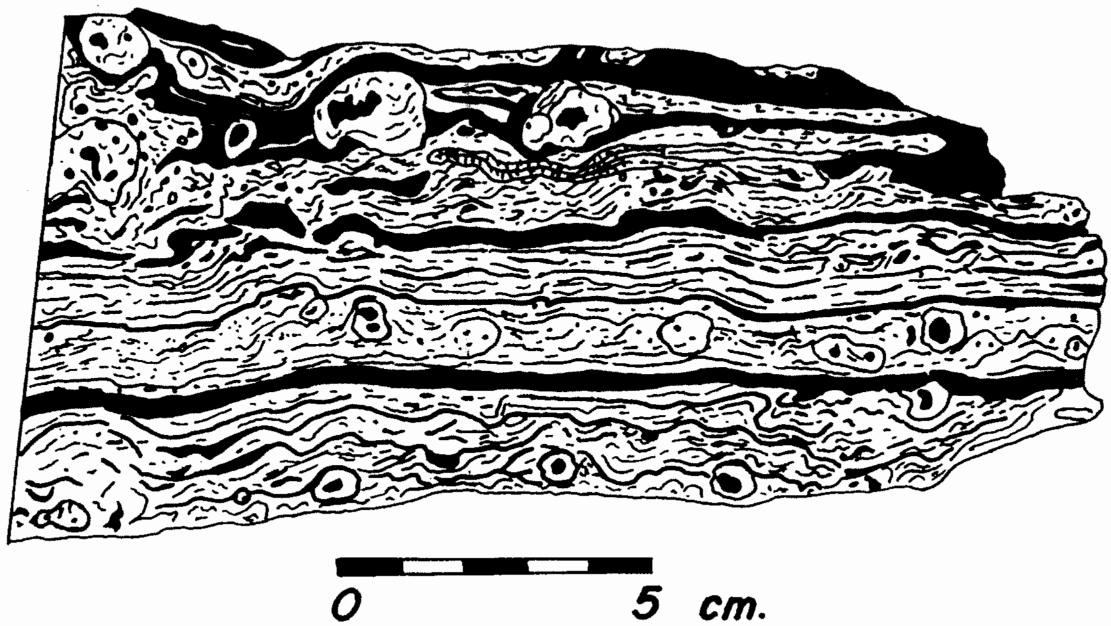

Fig. 6. Calcitized chicken-wire structures in a calcareous horizon at the top of the Ibarretxe Member.

6. CONCLUSIONS

We have utilized petrologic and sedimentologic criteria for the enlightening of paleogeography and stratigraphic correlation of the Wealden formations in the central domain of the Basque-Cantabrian Region. The lithology and paleontology of the Villaro Formation suggest a restricted lacustrine environment with episodic influx of sandy deltaic lobes and periodic mixing with marine waters. Meandering streams flowed across broad floodplains in the Cantabrian area. Correlation between the two areas is based on systematic changes in the orthoclase and plagioclase content of sandstone. The data suggest that the two lower sand-cycles of the Villaro Member (I, II) are equivalent to the Bárcena Mayor Formation, and the cycles III, IV and V correlate with the Vega de Pas Formation. The upward-fining nature of the stratigraphic sequence reflects a progressive degradation of the source-areas located to the west and south of Bilbao, together with a gradual acceleration of the subsidence around the Hauterivian-uppermost Barremian age. Subsequent events during Aptian-Albian (Urgonian and Supraurgonian Complexes) in this region reinforce these suggestions (GARCIA-GARMILLA et al, 1984; 1985; BADILLO & GARCIA-GARMILLA, 1985; FERNANDEZ MENDIOLA, 1986; BADILLO et al, 1988).

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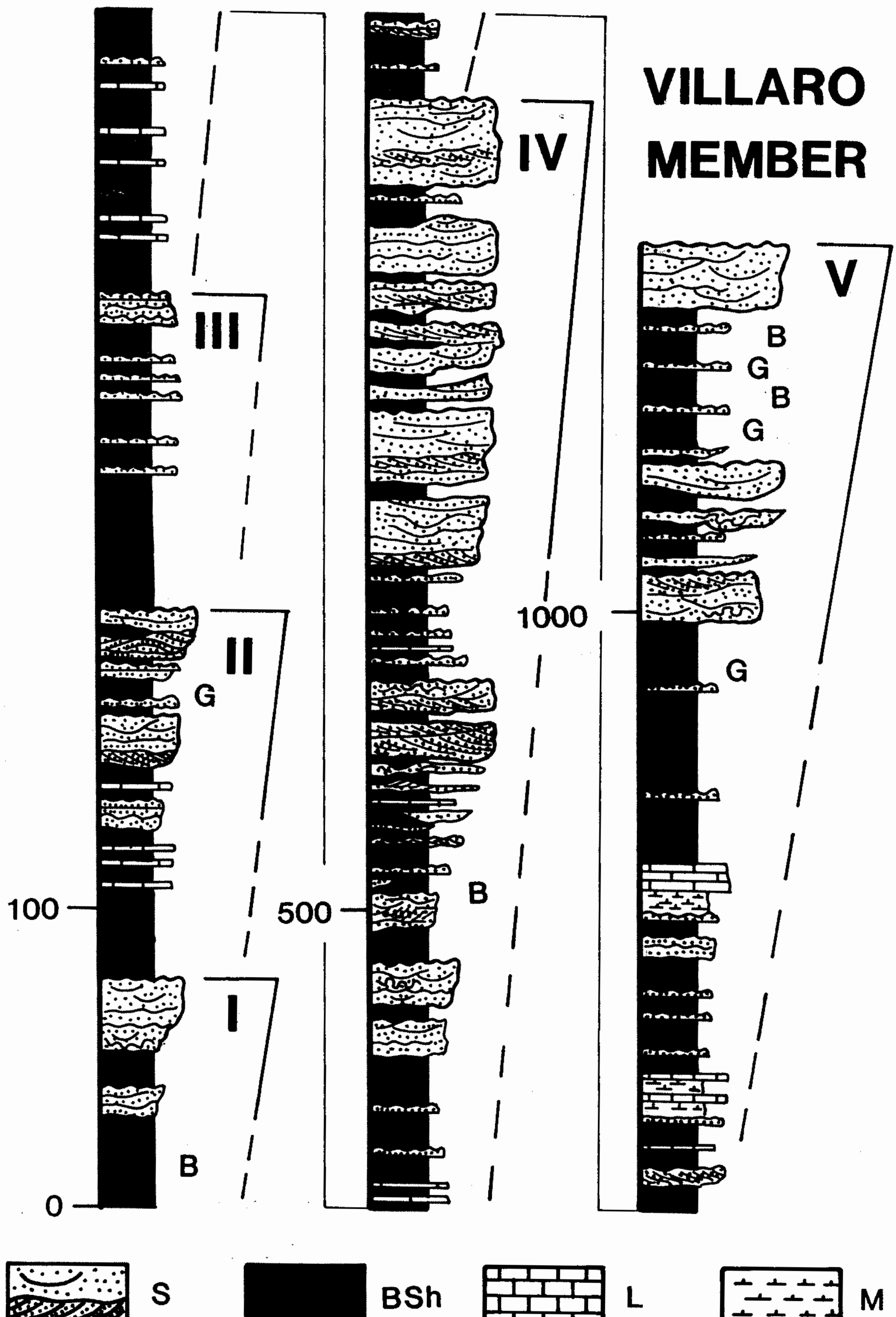

Fig. 7. Stratigraphic section of the Villaro Member indicating the vertical development of the five sequences mentioned in the text. Vertical scale in meters. B: bivalve accumulations; G: gastropod accumulations; S: sandstones; BSh: black shales; L: limestones; M: marls.

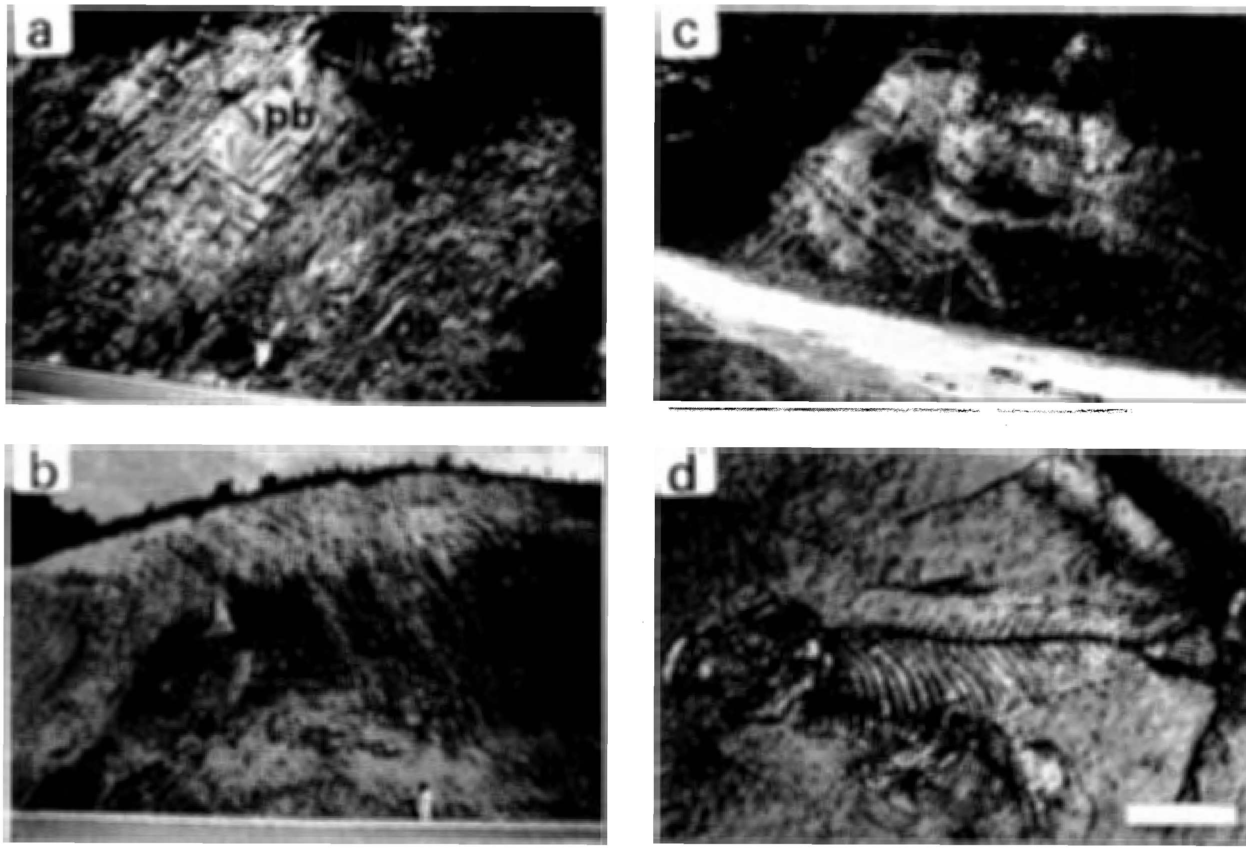

Fig. 8. (set of four photos). a) Sand-bar progradational sequence in the fourth crest of the Villaro Member. Prodelta black-shales evolve to distal bar (db) and proximal bar (pb) facies associations. The last of these is represented by thick-bedded sandstones with cross-bedding stratification of metrical scale. Distal bar sandstones show eroded surfaces, shaly channel-infilling and deformational structures. b) Well-developed angular fold with subhorizontal axis affecting shale-sandstone sequences at the upper part of the Villaro Member near Aramaio village (see also Figure 1). Shale as background sedimentation is attributed to distal areas within a deltaic-lacustrine setting. c) Alternance of dark shales and fine-grained sandstones without apparent sequential arrangement in the Viviparus Beds Member (Eastern Cantabria). The tabular morphology of strata is the most peculiar feature of this unit. Sandstones are interpreted as overbank deposits within widespread fluvial flood-plains. d) Teleostean remains in black-shale facies of the upper part of the Villaro Member. Bar scale is 1 cm.

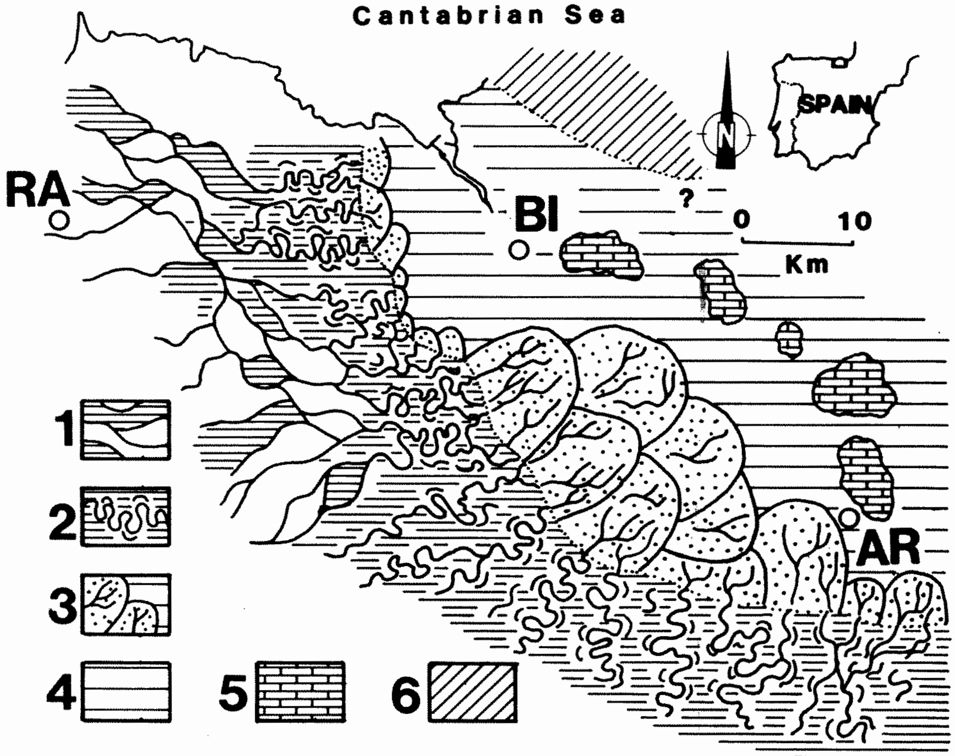

Fig. 9. Paleogeographic setting for the Wealden depositional phase in the central sector of the Basque-Cantabrian Region, showing fluvio-lacustrine systems with sandy deltaic lobes developed in the Bilbao area. Calcareous lacustrine facies bearing organic matter and algal laminations occurred along the Bilbao-Aramaio transversal. Shallow marine environments were placed to the north of Bilbao passing transitionally to brackish-water lacustrine environments of the Villaro Fm. Extensive floodplains were associated with meandering rivers of the Vega de Pas Fm. RA: Ramales; BI: Bilbao; AR: Aramaio; 1: braided rivers; 2: meandering rivers; 3: sandy deltaic lobes; 4: lacustrine shales; 5: fetid lacustrine limestones; 6: shallow marine calcareous sediments.

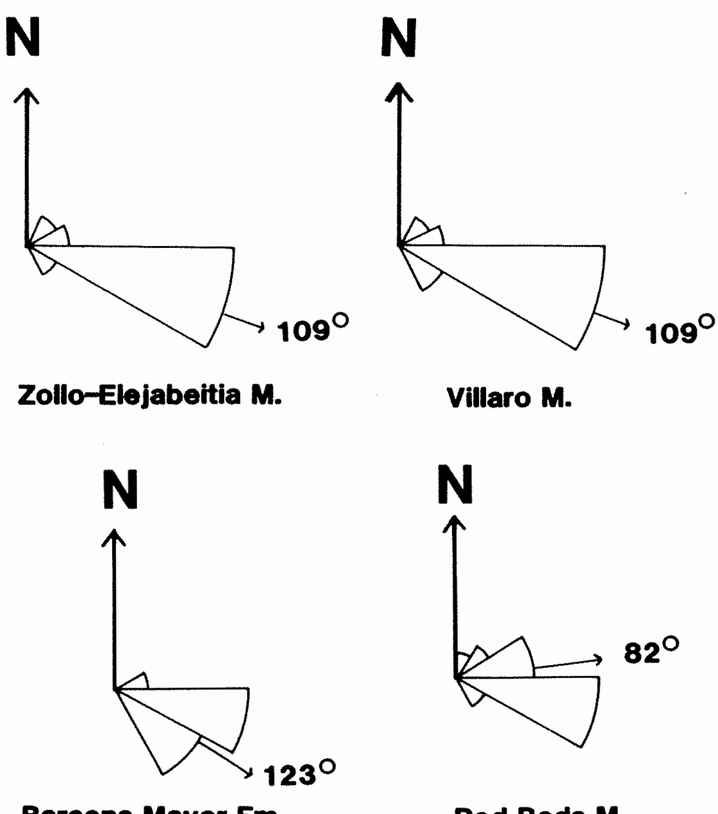

Fig. 10. Paleocurrent diagrams from cross-bedding, flute-marks and groove-marks, for the Bilbao Wealden units (Zollo-Elejabeitia and Villaro members) and those of Eastern Cantabria (Bárcena Mayor Formation and Red Beds Member). The general trend is from NW(W) to SE(E). (The magnitude of the sectors indicates relative percentages).

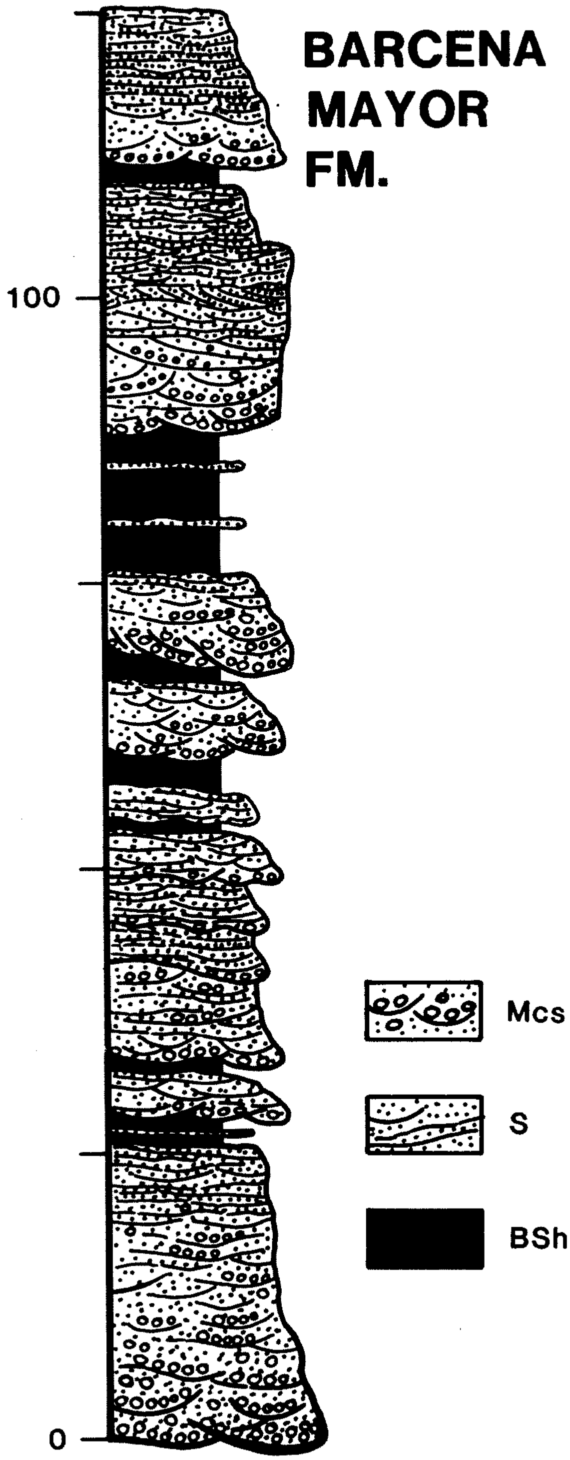

Fig. 11. Stratigraphic section of the Bárcena Mayor Fm. Vertical scale in meters. Microconglomeratic sandstones are by far the best represented lithology of this unit. Mcs: microconglomeratic sandstones; S: sandstones; BSh: black shales.

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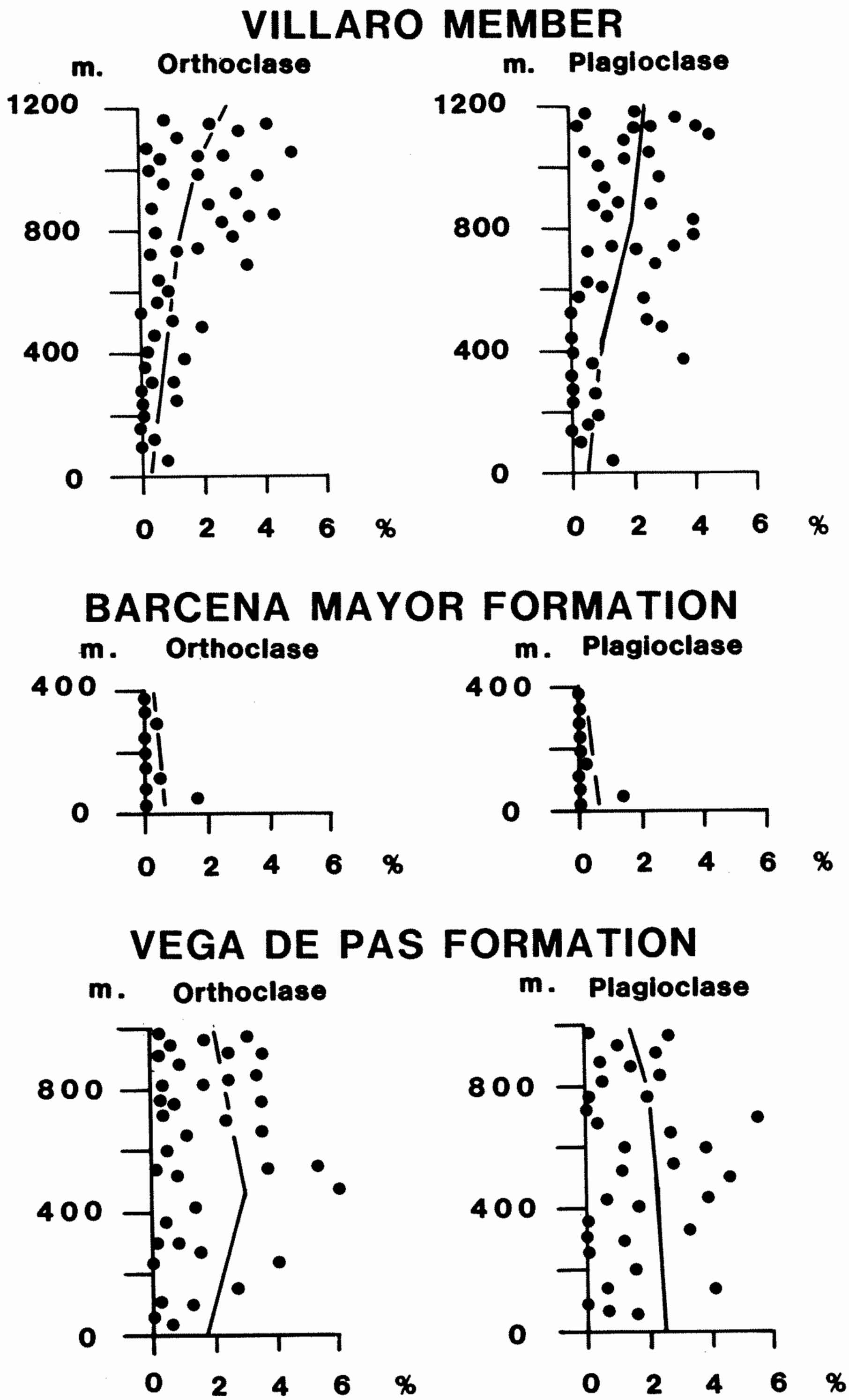

Fig. 12. Vertical evolution of orthoclase and plagioclase percentages in the Villaro Member and Bárcena Mayor and Vega de Pas Formations. Vertical scale in meters. The samples corresponding to the two lower sequences of the Villaro Member (below 200 m. in the section) are relatively poor in K-feldspar and plagioclase (less than 2%) whereas the samples from the three upper sequences may reach 5.3% of orthoclase. This significant change may be correlated with the average composition of the sandstones of the Cantabrian Formations.

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