THE BASQUE—CANTABRIAN BASIN BETWEEN THE IBERIAN AND EUROPEAN PLATES SOME FACTS BUT STILL MANY PROBLEMS

P. Rat (*)

(*) Université de Bourgogne, Centre des Sciences de la Terre, Unité CNRS 157. 6 Bd Gabriel, 21000 DIJON, FRANCE.

RESUMEN

La Cuenca vasco-cantábrica pertenece al conjunto pirenáico. Su historia, desde el Triásico hasta el final del Eoceno (200 millones de años aproximadamente) estuvo también estrechamente ligada a la del Mar Cantábrico. En realidad hubo dos cuencas sucesivas de paleogeografía y control tectónico diferentes.

Empezó en el Triásico con la ruptura post-hercínica de la corteza continental de Europa occidental. Se desarrolló una cuenca intracratónica de manera muy semejante a las demás cuencas europeas como las cuencas de París y de Aquitania. Su relleno se realizó en dos etapas: la crisis callovo-oxfordiense, en relación con el fin de la apertura del océano ligur y el *rifting* del Mar Cantábrico, al final del Jurásico, en relación con el principio de la apertura del Atlántico al norte de la línea de Gibraltar.

Posteriormente, cambió la organización estructural y se constituyó entonces la verdadera Cuenca Vasco-cantábrica caracterizada por dos aspectos diferentes. En primer lugar fue un margen pasivo, de tipo divergente, muy claro al este de Bilbao, con fracturación (fosas wealdenses); distensión continental (Complejo urgoniano) y subsidencia del margen (surcos de flysch). A esto se añade el carácter de cuenca de zona transformante, cuya geometría no está todavía aclarada. La traslación relativa senestra, y finalmente el acercamiento de las placas de Iberia y Europa rigieron su evolución y su cierre al final del Eoceno.

Las formaciones distales del sistema sedimentario (flysch, margas y calizas hemipelágicas) fueron enérgicamente plegadas, con formación de cabalgamientos, según el Arco vasco, por lo que no es fácil identificar y localizar el verdadero límite entre ambas placas. La organización sedimentaria implica la existencia de bloques intermedios y de cuencas elementales o surcos. Parece verosímil pensar que se trataba de una amplia zona de fallas de desgarre.

Sería conveniente efectuar nuevas investigaciones con el fin de identificar y dilucidar el funcionamiento de algunas estructuras cretácicas claves.

Palabras clave: Cuenca Vasco-cantábrica, Pirineos, Mar Cantábrico, cuenca intracratónica, margen pasivo, zona transformante, Triásico, Jurásico, Cretácico, Eoceno, fosas wealdenses, plataformas urgonianas, surcos de flysch, Placa Ibérica.

ABSTRACT

The Basco-Cantabrian basin is part of the Pyrenean system; its evolution, about 200 m. y. in duration, from lower Triassic to the end of Eocene, is bound to the history of the Bay of Biscay. In fact two basins, under different tectonic control, followed each other.

From Triassic to late Jurassic, a cratonic one was developed, initiated during the break up of the continental crust of Western Europe, before the opening of the Central Atlantic, in a way similar to other West European basins like the Anglo-parisian and Aquitanian basins. The were infilled in two phases: the Callovo-Oxfordian crisis while the spreading of the Ligurian Alpine ocean was achieved and the rifting of the Bay of Biscay in connection with the opening of the Atlantic north of the Gibraltar line.

From early Cretaceous to late Eocene, an interplate mobile basin between Iberia and Europe. It belonged to the same generation as the Parentis and Adour basins in France, the Asturian basin in Spain.

First, it was a divergent passive continental margin, clearly visible East of Bilbao; rifting (Wealden grabens), stretching with listric faults and rotational blocks (Urgonian platforms and basins), rapid and variable subsidence (turbidite troughs).

It was also a more complex basin in a transform system, the structural pattern of which is not yet satisfactorily known, controlled by the sinistral displacement of the Iberian plate from Europe, and finally closed by the convergence of these plates.

The deep part of the sedimentary accumulation (flysch, hemipelagic marls and limestones) is strongly folded and overthrust, forming the Basque Arc. Therefore it is not easy to determine the real position of the plate boundary within the basin. The sedimentary organization reveals intermediate blocks (Biscay High, Basque massifs) and troughs. Today the structures are not always in harmony with the Cretaceous structural pattern of the basement. A braided transform system is likely.

Further field investigations are needed to find missing clues and ascertain the setting of the Cretaceous basin.

Key words: Basque-Cantabrian basin, Pyrenees, Bay of Biscay, intracratonic basin, passive continental margin, transform system, Triassic, Jurassic, Cretaceous, Eocene, Wealden grabens, Urgonian platform, Turbidite troughs, Iberian plate.

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In spite of some former opinions (Olagüe, 1951) there is no doubt that the Basco-Cantabrian basin is really part of the Pyrenean system. Its tectonic features, its evolution are bound to the history of the Pyrenees, to the opening of the Bay of Biscay and to the relative displacement of the Iberian and European plates. In comparison with the basins of the same generation in the Iberian peninsula and Southern France, it enables to locate and witness the initiation and development of part of the North-Iberian continental margin, especially during the Cretaceous. So it is a key area to understand the irritating problem of the Pyrenees.

1. PRESENTING THE PROBLEMS

1.1. Meaning of the term "Basque-Cantabrian basin"

Today what is commonly called the Basque-Cantabrian basin seems fairly well defined: a Mesozoic folded complex which rests on the Paleozoic Asturian massif to the west and envelops the Paleozoic Basque massifs to the east. Nervertheless on closer examination the pictures is more complicated.

In space:

— To the north, the outcrops are cut by the coast (Mar Cantábrico, Golfo de Vizcaya, Biscay Bay, Golfe de Gascogne). However, at least the continental shelf and slope as far as the Capbreton canyon, are to be included in the basin.

— To the east, it comprises at least the western Basque massifs and their post-Variscan cover. Thus the Basco-Cantabrian basin is connected with the North-Pyrenean zone in France.

— To the west, the Mesozoic formations disappear around the Asturian mountains. On that side, their present limits almost coincide with the Mesozoic shoreline. Yet the post-Cretaceous erosion has destroyed all traces of the coast-line. Some Cretaceous outcrops, occurring along the Asturian coast suggest that the Basque-Cantabrian and the Asturian basins were connected. The second one includes the Le Danois Bank offshore and the Oviedo area onshore. However today they are separated by a high area, part of which being the Santander spur.

— To the south, the Cantabrian thrust (continuation of the Southern Pyrenees thrust) over the Cenozoic of the Ebro and Duero Basins seems to be a natural boundary. Yet in Mesozoic times, especially during the Cretaceous, the Basque-Cantabrian basin was no more than the distal part of a wider system including the main part of the present Iberian chains.

In time:

The history began as early as the post-Variscan extensions, i.e. during the Permian. However the distinctive character of the basin appeared only at the end of the Callovian. During Triassic and Jurassic times, it was part of a broader palaeogeographic system. Its closing was initated in the Late Eocene by the Pyrenean folding which entirely altered the structural and palaeogeographic pattern of the area. It lasted about 200 m. y.

1.2. Before the Pyrenean orogeny.

In order to understand the Basque-Cantabrian basin while it was in operation (Triassic-Eocene), the first difficulty is to go back into the past prior to the Pyrenean structures (fig. 2). As yet there is no complete agreement concerning the present structures, especially in the Basque country between the French-Spanish frontier and Bilbao. Ideas fluctuated as for the Pyrenees: from wide nappes according to the views of L. Bertrand (Mengaud, 1920) to autochtonous rooted Hercynian massifs in conformity with the thought of Ch. Jacob and the field demonstrations of M. Casteras in France (Karrenberg, 1934; Lamare, 1936; Ciry, 1940; Rat, 1959). Today's authors come back to the idea of important horizontal displacements (Soler *et al.,* 1981; Rat, 1983) involving not only the post-Variscan sedimentary cover but even the Paleozoic blocks: translation, rotation of the Basque massifs which may have been like extruded nuclei, from their initial location.

There is the misleading risk of projecting on the Mesozoic paleogeography the Tertiary Pyrenean trends of a sedimentary cover disconnected from its Variscan basement, especially regarding the location and the orientation of the structures (fig. 3). Thus in the Basque area it is too easily assumed that faults trend in NW-SE directions on the analogy of present day folding. This matter will be discussed further.

1.3. Contributions and enigmas of plate tectonics.

Plate tectonics introduced the concept of an Iberian plate moving with respect to the European plate,

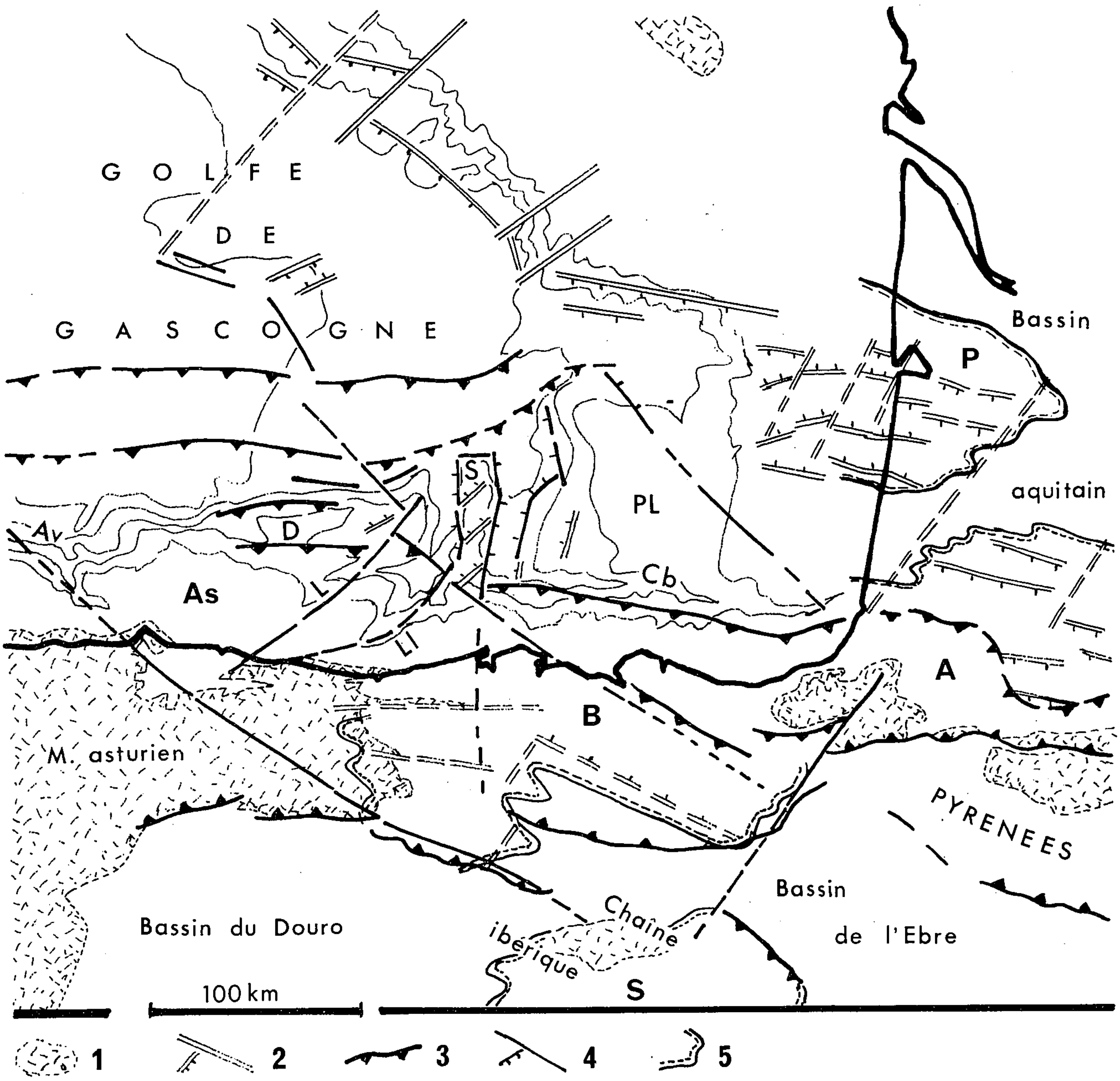

Fig. 1.—The Basque-Cantrabrian basin in its structural setting (After Deregnaucourt and Boillot, 1982, for the Bay of Biscay). 1.—Outcrops of Palaezoic basement; 2.—Mesozoic normal and wrench faults; 3.—Palaeogene overthrusts; 4.—Palaeogene and Neogene normal and wrench faults; 5.—Approximate limits of the Wealden grabens (A. Adour As. Asturian; B. Basque-Cantabrian; P. Parentis; S. Soria). Canyons: Av. Avilés; Cb. Capbreton; L. Lastres; Ll. Llanes. Uplifted blocks of the continental shelf: D. Le Danois bank; Pl. Landes plateau: S. Santander spur. Isobaths in fathoms, contour interval 500.

Fig. 1.—La cuenca Vasco-Cantábrica en su contexto tectónico (según Deregnaucourt y Boillot, 1982, para el Golfo de Vizcaya). 1. Afloramientos del zócalo paleozóico; 2. Fallas normales o de desgarre mesozóicas; 3. Cabalgamientos paleógenos; 4. Fallas normales o de desgarre paleógenas y/o neógenas; 5. Límites aproximados de las fosas weáldicas (A. Adour; As. Asturias; B. Vaco-cantábrica; P. Parentis; S. Soria). Cañones submarinos: Av. Avilés; Cb. Capbreton; L. Lastres; Ll Lanes. Bloques elevados de la plataforma continental: D. Banco Le Danois; Pl. Plataforma de Las Landas; S. Espolón de Santander. Isobatas en brazas. Equidistancia 500

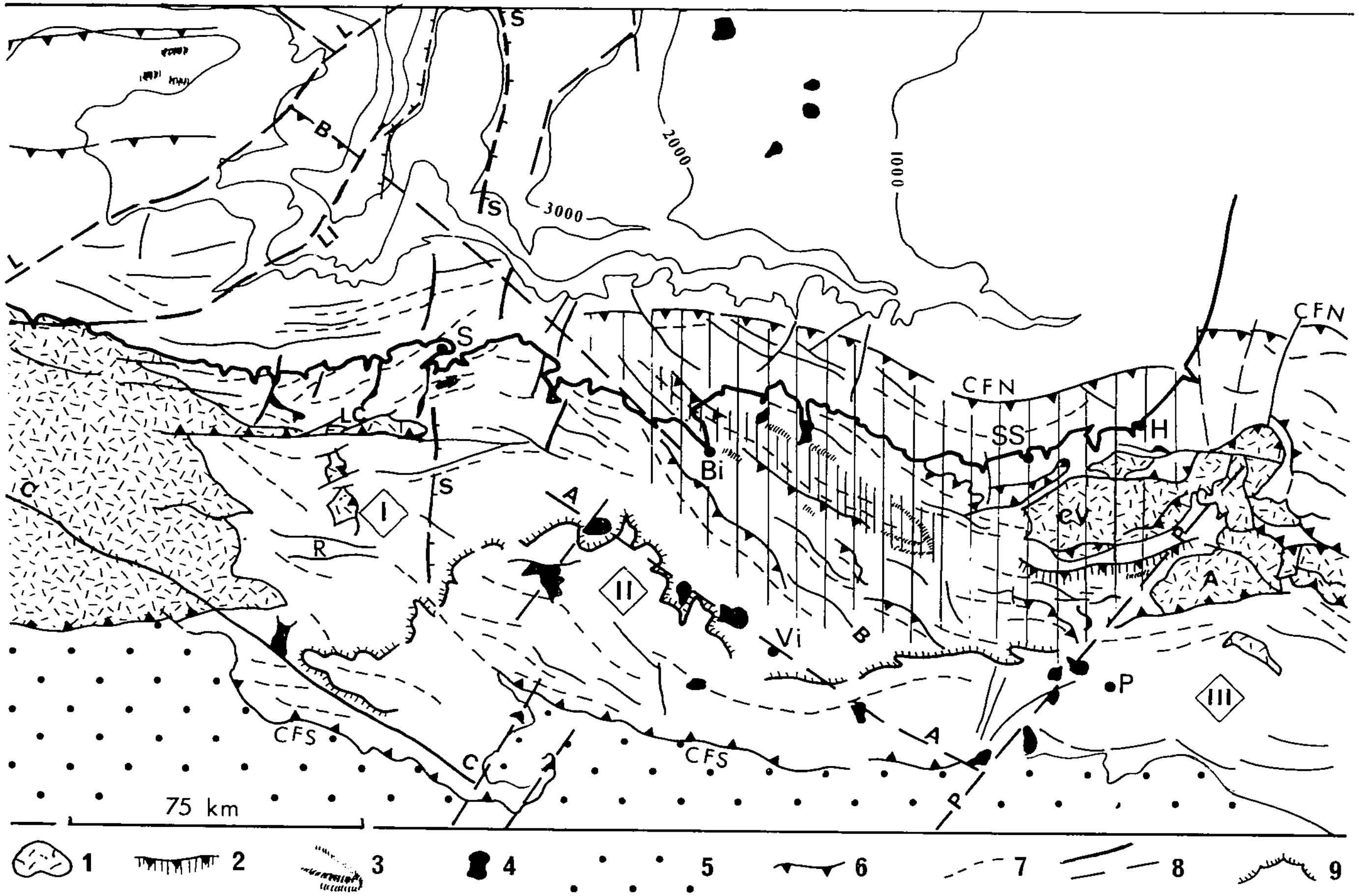

Fig. 2.—Structural sketch of the Basco-Cantabrian area. 1.—Palaeozoic massifs: Asturian massif to the west, Basque massifs to the east (A. Aldudes; CV. Cinco Villas); 2. Marble nappe and Biscay synclinorium; 3. Upper Cretaceous volcanic outflows; 4. Diapirs of Keuper clay and salt; 5. Oligocene-Miocene infillings of the Duero and Ebro basins; 6. Main overthrusts (CFN. North Pyrenean thrust; CFS. South Pyrenean and South Asturian thrust); 7. Axes of major folds; 8. Main structural features (normal and transcurrent faults, flexures); 9. Upper Cretaceous limestone scarp. Longitudinal structures: A. Alava diapir line; B. Bilbao fault C. Cantabrian fault. Transverse structures: L. Lastres Canyon; Ll. Llanes canyon; P. Pamplona fault (Navarrese diapir line). E-W structures: LC. Las Caldas thrust (= Escudo de Cabuerniga thrust); R. Diapiric área of the Ebro dam (= Reinosa diapiric area). N-S structures: SS. Santander fault (offshore) continued by the Rio Miera flexure. Main structural units; Vertical hatching: Basque Arc; Blank: The southern blocks: Santander or peri-Asturian block (I), Alava block (II), Navarrese or Ebro block (III); Continental shelf after Deregnaucourt (1981) and Malod (1982): isobaths in metres.

Fig. 2.—Esquema estructural de la región vasco-cantábrica. 1. Macizos paleozóicos: M. asturiano al oeste, macizos vascos al este (A. Aldudes; CV. Cinco Villas); 2. Manto de los mármoles y sinclinorio de Vizcaya; 3. Formaciones volcánicas del Cretácico superior; 4. Diapiros de Keuper; 5. Relleno continental oligo-miocénico de las cuencas del Duero y el Ebro; 6. Cabalgamientos mayores (CFN. Cabalgamiento frontal norpirenáico; CF. Cabalgamiento frontal surpirenáico y surasturiano); 7. Ejes de pliegues principales; 8. Grandes fallas, desgarres o flexuras; 9. Cuesta de las calizas del Cretácico superior. Accidentes tectónicos longitudinales: A. Alineación de los diapiros alaveses; B. Sistema de fallas de Bilbao; C. Falla Cantábrica. Accidentes transversales: L. Cañón de Lastres; Ll. Cañón de Llanes; P. Falla de Pamplona (Alineación de los diapiros navarreses). Accidentes E-W: LC. Cabalgamiento de Las Caldas (o del Escudo de Cabuérniga); R. Franja diapírica del Pantano del Ebro (o de Reinosa). Accidentes N-S: SS. Falla de Santander y su prolongamiento sur, la flexión del Río Miera. Grandes unidades estructurales. Rayado vertical: Arco vasco: En blanco, bloques meridionales: Bloque Santanderino o Peri-asturiano (I), Bloque Alavés (II), Bloque Navarrés o del Ebro (III); Plataforma continental según Deregnaucourt (1981) y Malod (1982); isobatas en metros.

first during the period of activity of the Basque-Cantabrian basin (and controlling structural arrangement), later during its closing. However the suggested models are contradictory.

Where to locate and how to conceive the contact between the Iberian and European plates which, logically, must be somewhere within the Basque-Cantabrian basin? Structural, palaeomagnetical, stratigraphical, mineralogical... investigations prompted by this interrogation, as well as offshore data, have not solved the problem, yet, neither did the theoretical hypotheses which flourish. Would a concrete analysis of the sedimentary infilling clarify the situation?

The Leiza fault with its metamorphism (Nappe des Marbres) seems to be the continuation of the North Pyrenean fault which is considered as the present trace of the North Iberian margin. However there is no continuity within the Basque massifs (fig. 2). Mapping gives the impression of a sinistral horizontal movement along the Pamplona transcurrent fault (Navarrese diapir line). This transverse feature is perplexing. It seems to be a segment of the long SW-NE late Hercynian fault which runs across a large part of the Spanish peninsula, perhaps the whole peninsula (Logroño - Sta María de Nieva fault) and which is a major feature of the Hercynian basement of the Iberian plate (Capote, 1983). The SW-NE left-lateral displacement along the Pamplona fault is consistent with the probable direction of the Pyrenean compression However its continuation within the Western Basque massifs, i.e. within the European plate, is not compatible with the expected lateral movement between the Iberian and European plates along the Leiza fault (Nappe des Marbres) - North Pyrenean line (Ducasse *et al.*, 1986). Unless the horizontal movement of the Pamplona fault took place only after the left-lateral displacement of Iberia and Europe. Thus the Pamplona fault could be compared to the Aviles transcurrent fault (offshore extension of the Cantabrian fault): a previous Late Hercynian structure submitted to a vertical movement during the active period of the Basque-Cantabrian basin and later a horizontal displacement caused by the Pyrenean compression in the Tertiary.

What happens to the west? The simplest hypothesis is to continue the front of the Nappe des Marbres within the synclinorium of Biscay. German authors (Engesser *et al.*, 1984), think that the Nappe des Marbres is continued by the Atchuri thrust (Atchuri Störung) which disappears into the sea between Deva and Zumaya. However, in that zone, only the Mesozoic cover seems to be involved in a horizontal overthrust of several kilometers (écaille du Pagoeta, Rat, 1959) and there is no occurrence of metamorphism as in the Nappe des Marbres.

On the contrary, in the synclinorium of Biscay, large volcanic outpourings, Upper Cretaceous in age, mark out the geometrical extension of the Marble Nappe. It is likely that the Nappe zone, active during the eastward displacement of the Iberian plate (from late Aptian to early Campanian times) exists under the syncli-

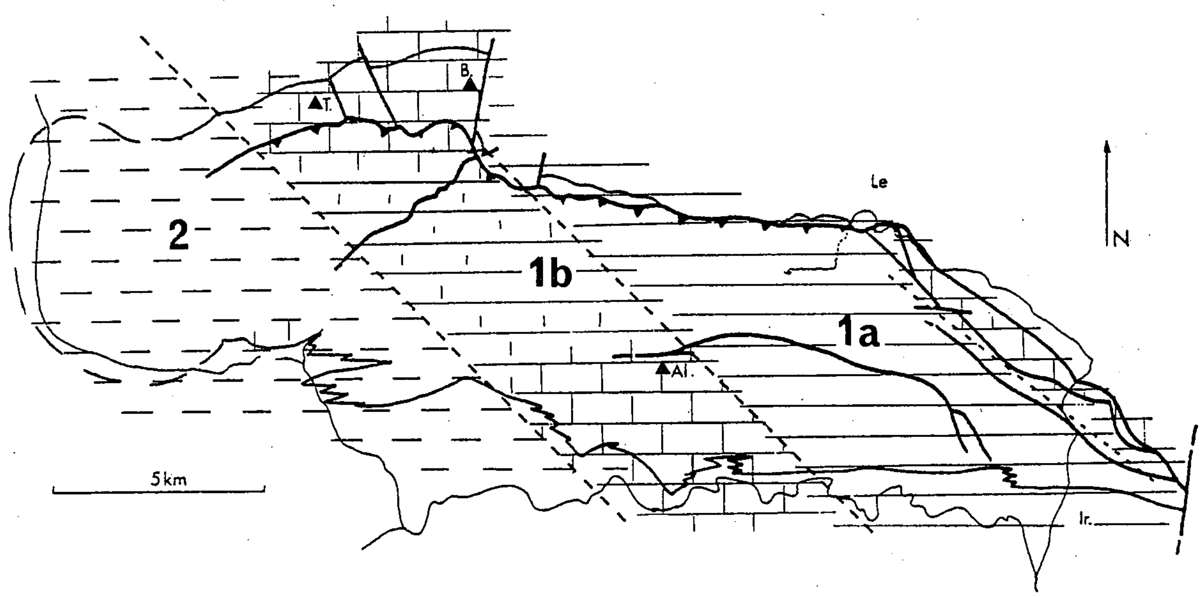

Fig. 3.— Cretaceous and Tertiary tectonics at variance: The Aralar range (after Floquet and Rat, 1975). 1. Urgonian carbonate platform: inner platform (aa), rim with mud-mounds (b); 2. Outer basin with black clays and sandstones; The Mesozoic cover is detaches from the Hercynian basement (basal decollement due to Keuper marls). The trend of the present anticlinal and thrust structure is oblique relativa to the fault which affected the basement and induce the Urgonian morphology; Al. Altxueta; B. Balerdi; T. Txindoki; Le. Lecumberri; Ir. Irurzun.

Fig. 3.—Discordancia entre las estructuras cretácicas y las estructuras terciarias: la Sierra de Aralar (según Floquet y Rat, 1975. 1. Plataforma carbonática urgoniana: plataforma interna (a), borde externo con lentejones calizo (b); 2. Cuenca de margas negras, en la parte inferior del sistema deposicional; La cobertera mesozóica está despegada de su substrato a favor de las margas plásticas del Keuper; su orientación es oblicua con telación a la falla de zócalo que ha controlado la morfología urgnoniana; Al. Altxueta; B. Balerdi; T. Txindoki; Le. Lecumberri; Ir. Irurzun.

norium and is sealed and hidden by Campanian and Eocene flysch deposits. Yet is it justified to assing the NW-SE end of the Biscay folds (accident du Calamo, Amiot *et al.,* 1982) to the fault complex which gave rise to the upper Cretaceous basalt flows? Boess and Hoppe (1986) have a very different interpretation: for them it would be a transform fault system, approximately north-south.

How to place the north of Biscay with respect to the parts of the Iberian margin which are known (Santander and Alava platforms, Bilbao slope) before the lateral displacement required by plate kynematics in the Atlantic ocean? At present these two parts are exactly facing each other and connected without apparent discontinuity. How to place on a palinspastic map the western Basque massifs? Paleogeographic reconstructions elude the difficulty, as they are unable to a countfor the extensión and lateral displacements. These movements should be recorded in the Cretaceous sedimentary serie. Is it possible to find the clue to their existence, their location... or to demonstrate they are not to be found where we imagine?

2. THE INTRA-PLATE BASIN (UPPER PERMIAN - LOWER CRETACEOUS)

2.1. First outline of an Aquitanian-Cantabrian basin (Permian - Triassic).

As for the other basins of Iberia and France, the subsidence of the Basque-Cantabrian basin started with the post-Hercynian continental extension: initiation of Permian basins and beginning of the post-Hercynian planation which yielded a great amount of siliciclastics.

These Late Hercynian structures (Capote, 1983) comprise several groups:

— A W-E family, marked by Stephanian basins, which is visible today in the Escudo de Cabuérniga range and also in the diapir system of Reinosa, and which could be involved in the Cretaceous palaeogeography.

— A NW-SE family: The Asturian fault (Cantabrian fault, Aviles fault. Ventaniella fault) also played a part in the Cretaceous palaeogeographic pattern and, in the Tertiary period, acted as a transcurrent fault. The Iberian ranges and the tectonic features of Biscay (which are in this point parallel to the Cretaceous continental margin) follow this NW-SE trend.

— A SW-NE family, with the long Logroño, Sta María de Nieva fault, the Tertiary expression of which would be the Pamplona fault and the lateral displacement of the Basque massifs.

Extension and subsidence are clearly at work during the Triassic period. Rapid and important variations in thickness, basic lava flows (ophites) evidente a general block-faulting of the basement although it is not possible to reconstruct the structural pattern because of posterior deformations. By their chemical composition, these ophites are related to tholeiites, to basalts of the oceanic crust. Tey would imply an oceanic aperture which did not develop (Boess and Hoppe, 1984).

As in the contemporaneous French basin (Curnelle and Dubois, 1986) the Triassic sedimentation is not the infilling of a topographic depression, nor the effect of a simple isostatic subsidence of the basement; it is the consequence of a crustal extension concerning West Europe, of a complex continental rifting, the major effects of which being felt within the Aquitanian and Basque-Cantabrian basins. Those Permo-Triassic tectonics (probable W-E to NW-SE extension) could be related to a major fault-system Biscay-Baffin. The Cantabrian Triassic as well as the Aquitanian and Pyrenean Triassic formations represent deposits preceding an oceanic aperture and not a post-orogenic molasse (Curnelle, 1983).

2.2. The Triassic-Jurassic cycle.

As in the French basins also, the sedimentary series enables to identify a wide transgression-regression cycle from middle Triassic to late Jurassic times, on the Hercynian basement, the structure and behavior of which remained unchanged along this length of time. Within this large cycle, several regressive sequences (shallowing upward) can be distinguished from the Liassic stage onwards.

2.2.1. The Triassic stage: initiation of the Mesozoic basins (—245? to —205 m.y. approximately).

— The lower sandstone-conglomerate formation (Buntsandstein facies) unconformably overlaps the Hercynian basement. The unconformity is well exposed on the periphery of the Asturian massif. Thicknesses vary considerably (Saiz de Omeñaca, 1974): from about 50 m at the Peña Labra (near the Ebro springs) to 300 m at Puentenansa and 800 m on the isopach maps given by Garrido and Villena (1977). The clastic material gets finer upwards, near the present Paleozoic outcrops (Asturias, Basque massifs) as well as in the center of the basin (Campos, 1979).

— A carbonate formation (Muschelkalk facies) is known around the Basque masifs: Lamare (1936) mentioned limestone lenses, containing *Pseudomonotis* known in Alpine seas, and Campos (1979) dolomites, magnesium limestones, beds containing bivalves and echinodermata (about 50 m) and also limestone and dolomite inclusions scattered within the lower Keuper clays. Thus we can discern a first marine ingression on the eastern part of the future Basque-Cantabrian basin.

— The clay and evaporite formation (Keuper facies) is important in its tectonic implications (diapirism, decollements) They are variegated clays, red, green, gray, often containing gypsum, sometimes salt, with little bipyramidal cristals of quartz. They are associated with decayed dolomite blocks and ophite blocks interspersed at random in the clays and frequent in outcrops.

To conclude, in this first phase, the Basque-Cantabrian region belonged to a wider tectono-sedimentary system bounded to the south-west by the Iberian meseta, to the north-east by the Armorican—French Central massif positive area and which also included the Aquitanian basin in France, the Asturian basin and the Iberian ranges in Spain. Its axis was a rifting zone which preluded the separation between the Iberian and European plates. It was open to the east if we refer to thè location of the Muschelkalk limestone facies and their Alpine affinities.

2.2.2. Lower Liassic stage: development of marine platforms (-205 to -195 m.y. approx.) Much shorter than the first, this second phase is correlative to the general spreading of the marine environment as in the French basins. There is a progressive transition from Keuper lagoons to Liassic open seas, by means of Rhaetic and Hettangian limestone and dolomite beds.

It is not possible to draw the lower boundary of the Liassic deposits. The first known ammonites, in Asturias, are Sinemurian in age (Mouterde, 1971). Then come the rythmic marl-limestone alternations of the Lotharingian (upper Sinemurian) time, observed in Ramales (Rat, 1959).

2.2.3. Middle Lias - Dogger phase (—195 to — 150 m. y. approx.). As for the French basins (Curnelle and Dubois, 1986), it can be referred to as a regressive megasequence included in a transgression-regression eustatic cycle.

— Thick argillaceous or marly-calcareous formations (marly Lias). Marls predominate from Pliensbachian to lower Toarcian.

— Progressive transition (Aalenian) to Dogger limestones. At that time, shallow carbonate platforms coexisted with deeper marly facies with ammonites, suggesting an organization similar to that of the Paris and Aquitanian basins. Nevertheless the sparse and poor outcrops, between the Santander area and the surroundings of the Cinco Villas massif, do not allow a palaeogeographic reconstruction. However in the eastern part of the basin, great differences in thickness and even facies led Soler y José (1972) to identify positive and negative blocks.

Certainly, like the Aquitanian basin (Curnelle and Dubois, 1986) and the Asturian basin the Basque-Cantabrian basin was hereafter a dependence of the proto-Atlantic front, bur we have no local paleogeographic argument on which to rely. However a new feature seems to appear on the proximal side; an Ebro block without or with only thin deposits separates two subsiding marine areas: the Pyrenees to the north, and the straits of the Iberian ranges, directed NW-SE, to the south (Bulard, 1972). As if two subsiding intracontinental zones, one Pyrenean, the other Iberian, diverged from the west part of the Basque-Cantabrian basin.

2.3. Emergence and fracturation: Upper Jurassic events (—150 to —135 ? m.y. approx.).

Two important events entirely changed the landscape. The first one (lower Oxfordian or upper Callovian - lower Oxfordian) seems to be responsible to the west (peri-Asturian area) for a stratigraphic gap followed by continental sediments lying somewhat unconformably on marine Callovian formations; to the east, also for a missing interval and a less marked change in deposition, still in shallow marine water. The second event (late Jurassic: Kimmeridgian - Portlandian times) endend the marine sedimentation in the whole basin.

Western Europe begins to fracture: the sedimentary pattern changes altogether. In France the wide Aquitanian is divided in two active subbas ins: Parentis and Adour. In Northern Spain the Basque-Cantabrian and the Soria basins belong to the same generation (fig. 1). It is an essentially tectonic phenomenon. i.e. the intracontinental rifting preceding the aperture of the Northern Atlantic.

3. INITIATION OF THE CANTABRIAN MARGIN (LATE JURASSIC TO ALBIAN).

With the late Jurassic tectonic events begins a new history in which three major phases can be recognized (fig. 4): 1) The Iberian plate begins to part from the European plate (rifting phase, Wealden grabens). 2) The North Iberian (or Cantabrian) margin develops (phase of continental crust extension, inducing subsiding tilting blocks: Urgonian stage). 3) A marked continental slope separates the Iberian platform to the south from bathyal floors were turbidites accumulate, to the north (subsiding phase in the evolution of the passive margin, flysch deposits).

This view, which is very clear for the central part of the Basque-Cantabrian basin, between Santander and the Basque massifs, must be completed and take into consideration the other "side" of the basin: the European margin.

According to the majority of authors, the northern Basque massifs (Cinco Villas, Rhune, Labourd) belong to the European plate while the southern Aldudes would be a block of the Iberian plate. However Schott (1985), on the basis of paleomagnetic data, also relates the Aldudes massif to Europe. Unfortunately it is not easy to decipher this area which has bee strongly disturbed by tectonics and is screened by an important weathered cover and flourishing vegetation.

In addition to this structural rearrangement, there was a tectono-eustatic regression related to the opening of the North Atlantic ocean and perhaps a slight uplift of Western Europe. From then on, the history of the North Iberian margin took place in the eustatic transgressive movements of the Cretaceous period.

3.1. The Purbeck-Wealden grabens: initiation of the continental rifting (Kimmeridgian - Barremian: — 140 to -112 m.y. approx.)

The use of the terms "Purbeck-Wealden complex" and "Wealden grabens" are apt to express the importance of the accumulation of mostly non marene sediments which is the main feature and pattern of this phase. A thick sedimentary complex is clearly distinct from the underlying and overlying deposits. It is bounded at the bottom by an unconformity (Callovo-Oxfordian in the peri-Asturian area where it is most visible) and on

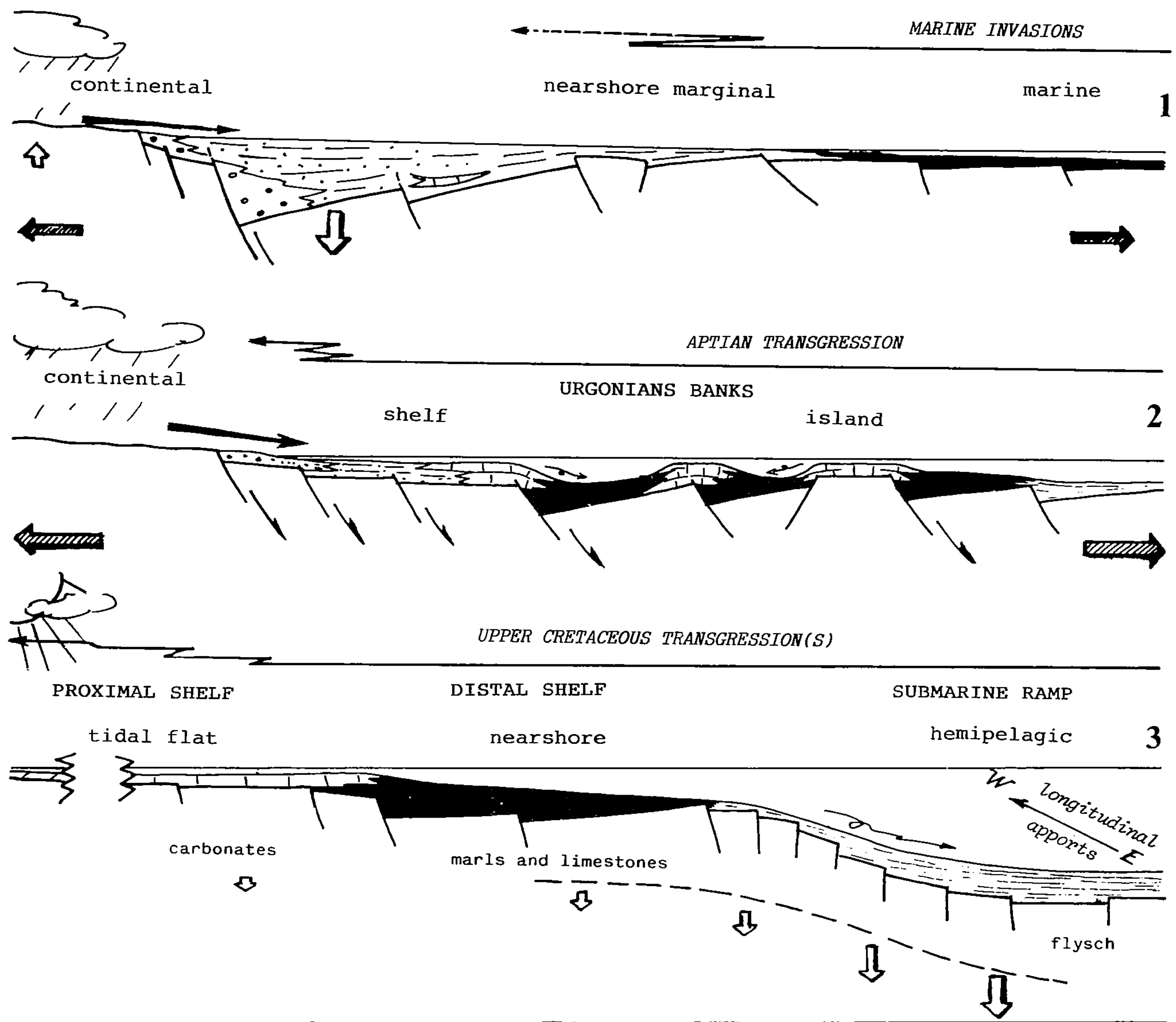

Fig. 4.—Initiation and development of the Basque segment of the passive. North Iberian margin (after Rat *et al.*, 1982, modified). 1. Beginning of the rifting (Wealden grabens), uppermost Jurassic-Barremian; 2. Phase of crustal stretching (rotating blocks, Urgonian sedimentary systems), Aptian to middle Albian; 3. Distal subsidence (flysch troughs), Upper Albian to Eocene.

Fig. 4.—Génesis y evolución del margen pasivo norteibérico en el sector vasco (según Rat *et al.*, 1982, modificado). 1. Etapa de rifting (fosas weáldicas), Jurásico terminal; Barremiense; 2. Etapa de estiramiento cortical (bloques basculados, sistemas deposicionales urgonianos), Aptiense; Albiense medio; 3. Etapa de subsidencia distal (surcos de flysch), Albiense superior; Eoceno.

top by the Aptian (Urgonian) transgression. Compared to the Jurassic below and the Urgonian above, it is a continental episode.

Differences in facies and thickness prove that the region was divided into sub-basins which behaved independently (fig. 5).

3.1.1. The peri-Asturian area (=Cantabrian grabens)

This is the best known and the best understood part of the basin. Even though its thick and poorly fossiliferous series, very much covered with vegetation, are difficult to elucidate (which explains some disagreement among authors: Pujalte, 1981; Salomon, 1982; Wiedmann *et al.* 1983...), their position remained almost unchanged with respect to the basement and they underwent little deformation in spite of local disturbances due to the extruded Keuper.

At present the chief part of the sedimentary mass is limited to the north by the Escudo de Cabuerniga range (Las Caldas anticline) and separated from the Santander littoral zone. The Escudo de Cabuerniga fault system may have already acted as a limit of the basin during the Cretaceous period. To the south, the limit of the graben coincides with the Urbieza fault (a segment of the Cantabrian fault) although the area of deposition may have been more extensive (García Mondéjar and Pujalte, 1981). This is a graben structure. It is affected in its middle by a less subsiding zone, "a complex stripe, poorly delimited and not well known, which shall be named stripe of the Ebro reservoir (franja del Pantano del Ebro)" (García Mondéjar and Pujalte, 1981) in which the synsedimentary halokynesis of the Keuper gypesous marls was probably important. Pujalte (1982), Salomon (1982) agree upon the asymetry of the graben, more depressed toward the south (although the isopachs from Ramírez del Pozo (1971) give a different picture).

Pujalte (1981, 1982) proposed a coherent paleogeographic reconstruction. A SW-NE and N-E gentle slope system was built: from weathered lands, submitted to ablation, toward low areas occupied by marshes, lakes, swamps, temporarily invaded by marine ingressions; in between, piedmont fans, alluvial plains. The topographical surface, maintained regular and fairly horizontal by the fluviatile sand and clay deposition, was not in accordance with the rapid and unequal sinking of the basement: sedimentation kept pace with subsidence.

Most of the sedimentary accumulation consists of sandstone, clay, alternations of sandstone and clay; red colours are frequent. It can reach 1000 m in thickness. Several sequences and several unconformities can be recognized.

Thus the Cantabrian graben acted as a sedimentary trap either for an autochtonous sedimentation (lacustrine or marine according to time and place) or allochtonous detrital deposits supplied from the southwest or the west.

3.1.2. Relationships with the Soria graben.

Although lying more to the south, in the Iberian ranges, the Soria graben belongs to the same family, but it is more remote from the sea (Salomon, 1982).

Its history begins in the Kimmeridgian stage: first the eastern and northeastern zone sags down; the basement is unequally deformed and the centres of maximum subsidence shift toward the eastern edge. Cumulative thicknesses may be over 5000 m. The basin is at first a large lacustrine cuvette girdled by piedmont alluvial fans at the foot of new and active tectonic scarps; then siliciclastic formations spread. Frequently black argillaceous shales, containing brackish faunas occur. They evidence a somewhat restricted environment, together with thick evaporite strata (dolomites, gypsum). Cubicpyrite and associated chloritoid suggest anchimetamorphism.

In a second phase (beginning in the Barremian), relatively homogeneous deposits (quartz conglomerates, feldspar sandstones), less thick (500 m), resulting mostly from fluviatile spreading, lay unconformably, migrating to the south-east.

Like the Cantabrian graben, the graben of Soria is asymmetrical but the more active faults are in the north-east. Salomon (in Amiot *et al.,* 1982), surmises that a transverse wrench fault, hidden under the Bureba Tertiary blanket, exists between the two grabens. He assumes it has a N60 to N75 trend.

3.1.3. The Bilbao graben.

In the anticlines of the Bilbao zone, conditions were quite different: it is the Black Wealden area. Thicknesses are considerable but only minimun estimates can be obtained because the bottom beds are not exposed: more than 2000 m. They are detrital sandstones and dark shales: lacustrine, brackish, estuarine, brackish grading into marine. The age is uncertain: Berriasian? Hauterivian? Barremian (Ramírez del pozo, 1971; García Mondéjar and García Pascual, 1982; García Garmilla, 1987).

In the south, the boundary of these thick accumulations corresponds to the Alava diapir line. In the north, they disappear under the synclinorium of Biscay (fig. 4).

To the northwest, the transition to the Red Wealden of Santander is rapid. To the southeast it seems that they come to an end somewhere in the Aralar Sierra. Thicknesses (600 m according to Soler y José, 1972a) and lithology in the west of the sierra belong to the Bilbao type. In the east of the sierra, clastic accumulations considerably thin out and pass laterally into contemporaneous calcareous shales and lacustrine limestones with charophytes: a platform Wealden is opposed to a subsiding basinal Wealden in the western area, according to a structural pattern already displayed in Jurassic times (Floquet and Rat, 1975) and which will again be found in the Urgonian (fig. 3). Beyond, on the Oroz Betelu massif, there are no Wealden deposits. Aralar then must be on the edge of the Bilbao Wealden gra-

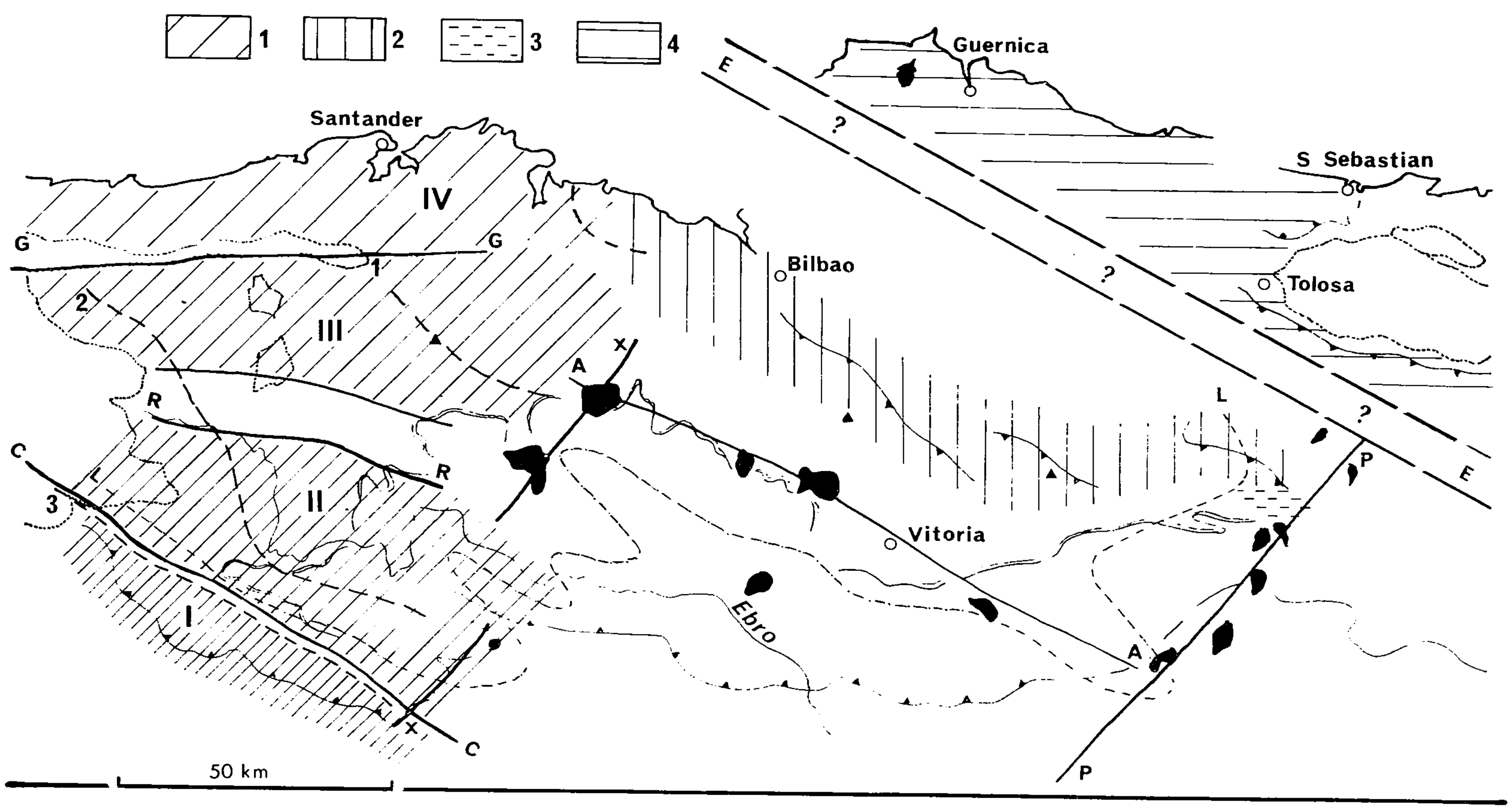

Fig. 5.—The Wealden grabens and platforms. 1. Peri-Asturian area (Cantabrian grabens); 2. Bilbao graben; 3. Brackish platform facies in the eastern part of the Aralar range; 4. Guipuzcoa platform (It is represented unattached to the south-western Iberian aea. In addition it must have been lying farther east; it has been drawn as a straight alignment as it was probably before bending of the Basque Arc by Tertiary Pyrenean orogenesis; LL. 500 m. Isopach (Ramírez del Pozo, 1971) gives the approximate southward limit of the Wealden grabens. Major fault structures of the basement: 1. NW-SE structures: E. Presumed limit between European and Iberian plates; A. Alava diapir line; C. Cantabrian fault; 2. Transverse structures: P. Pamplona fault; X. Western diapir line (Mena, Poza de la Sal). 3. W-E structures: G. Escudo de Cabuérniga thrust; R. Diapir area of the Ebro dam (or of Reinosa). In the peri-Asturian area (after García Mondéjar and Pujalte) tectonic units (I to IV) are not in agreement with the sedimentary scenery. Example of the Berriasian: 1. Limit of the subtidal area with oolitic shoals; 2. Limit of the coastal plain (marine and brackish water); 3. Limit of the alluvial plain (fluviatile or lacustrine fresh water).

Fig. 5.—Fosas y plataformas weáldicas. 1. Dominio peri-asturiano (fosas cantábricas); 2. Fosa de Bilbao; 3 Facies de plataforma en la parte este de la Sierra de Aralar; 4. Plataforma guipuzcoana (Se ha dibujado desligada de la parte situada al suroeste; debió de estar situada más al este. También se ha alineado con el macizo de las Cinco Villas como debía de encontrarse antes de la curvatura del Arco vasco por la compresión pirenáica); LL. Isopaca de 500 m. (Ramírez del Pozo, 1971) que constituye el límite de las cuencas weáldicas hacia el sur. Accidentes fundamentales del zócalo: 1. NW-SE: E. Límite presumido de las placas Europa e Ibérica; A. Alineación de los diapiros alaveses C. Falla Cantábrica; 2. Transversales, SW-NE; P. Falla de Pamplona; X. Alineación de los diapiros occidentales (Mena, Poza de la Sal); 3. W-E: G. Cabalgamiento del Escudo de Cabuerniga; R. Franja diapírica del Pantano del Ebro (o de Reinosa). En el dominio peri-asturiano (según García Mondéjar y Pujalte), la disposición de las cuencas no está de acuerdo con las unidades tectono-sedimentarias (I a IV). Ejemplo de la paleogeografía berriasiense: 1. Límite de la zona submareal con barras oolíticas; 2. Límite de la llanura mareal y deltaica (agua salada o salobre); 3. Llanura aluvial (agua dulce, fluvial o lacustre).

ben against the Pamplona fault (Umbral de Gulina: Soler y José, 1972).

3.1.4. The Guipuzcoa platform: its implications.

The outcrops exposed near Tolosa, those of the slabs which are surrounding the Cinco Villas massif, and those of the Guernica ria are quite different. Thicknesses are small (less than 150 m); deposits generally consist of limestones and dark clays containing serpulids, gastropods, oysters, and eventually echinoderm debris. They indicate shallow muddy bottoms, somehow connected with the sea or isolated with reducing, sometime dolomitic muds (Soler y José, 1972b).

This platform sedimentation (the lithology of which is well characterized in the Guipuzcoa province near Tolosa) poses a fundamental problem (fig. 5). Did it belong to the same geographic province as the formations located today southwest of the synclinorium of Biscay? Or was the Guipuzcoa Wealden platform, initially more in the east, transported in front of the Bilbao graben after the relative movement of the European and Iberian plates? The only thing we can say is that an important fault structure must have separated the platform and the trough.

Investigations concerning both the Tolosa area and the Aralar sierra (Soler y José, 1972a) tend to consider the Guipuzcoa facies as similar to some of the Aralar beds; however there must be a paleo-high, from Alzo to Leiza, separating the Aralar depression from the Tolosa area; in fact it could even be a more important structural feature. it must be remembered that the Guipuzcoa facies are greatly similar to the northern facies of France exposed in the Adour basin.

Therefore it seems that, in Wealden palaeogeography, what is north of the synclinorium of Biscay can be clearly separated from what lies to the south. This argument supports the view that the limit between Iberian and European plates ran along the northern edge of the Bilbao graben, where the synclinorium of Biscay is found today. In this respect, it could be worth while re-examining and comparing the platform formations of Guipuzcoa, Aralar, and of the Bilbao graben without forgetting the analogies with the south of the Aquitanian basin.

3.2. The Urgonian complex: extensional phase (Aptian - Middle Albian: — 112 to — 100 m.y. approx.)

In the beginning of Aptian times, there is again a radical, and probably rapid, change with respect to the Wealden period. The first outstanding feature is the advance of marine facies toward the south. They form a fairly well outlined embayment. The second is the appearance and successful development of a new depositional model: the Urgonian carbonate platform which competes with the terrigenous sedimentation or takes its place. The result is, at first sight, a rather chaotic sedimentary arrangement: the Urgonian Complex, in which recent works have thrown some light (Rat, 1959; Ramírez del Pozo, 1971; García Mondéjar, 1979; Pascal, 1985; etc...).

3.2.1. The deformation and its history, through its sedimentary consequences.

What caused this spectacular change? The Urgonian model was already existing, during the Barremian, for example in the southeast of France and in other places on the margins of the Tethyan sea. Why did it settle so easily at that time in the Cantabrian basin and the Pyrenean area?

The usual answer "the Aptian transgression" comprises at least three elements: a) a eustatic rise in sea level favoured the opening of marine straits and easy comunications with the Tethyan ocean, with warm currents circulating between the Europe and Africa plates, as well as a marine incursion on the edges of these plates. b) The northern margin of the Iberian plate began to sag down.. c) This edge (distal part of the Basque-Cantabrian basin) was segmented into differentially sinking blocks.

Thus can be explained on the one hand the relative stability of the south coastline of the Urgonian bay (it can be referred to as a "structural embayment"), on the other hand the emplacement of the Urgonian buildups. When studying how these constructions grew, evolved and how they were distributed, valuable information is also obtained on the evolution of the basin itself through Aptian to Albian times (fig. 6).

— In the beginning the distal part of the basin subsides and Urgonian carbonate ramps develop (lower Aptian — Bedoulian: 1st Urgonian system according to Pascal). Marine environments seem to onlap progressively onto almost undeformed Wealden alluvial flats. Scanty terrigenous arrivals (possibly because of the recession of the shoreline which shifts more to the south) enable the carbonate ramps with *Toucasia, Iraqia,* miliolids, to develop laterally, without appreciable differences from one place to another; they grade seaward into marly formations. The resulting Urgonian mass is well-stratified and in accordance with the proximal-distal pattern. Keeping pace with subsidence, it tends to prograde northward.

— In the beginning of the Gargasian, a sedimentary disconformity is evidenced by emersions and above all by the disappearance of *Iraqia* limestones which are replaced, in many places, by marls rich in *Exogyra, Plicatula,* ammonites, *Hedbergella.* The *Mesorbitolina* Urgonian limestones occupied a more restricted area and were discontinous. The littoral platforms, in which terrigenous material penetrates, are opposed to the isolated insular platforms, which evidences block faulting of the basement (García Mondéjar, 1983; Pascal 1985). It proves a local fault-controlled subsidence. However this change is part of a more general event. As a matter of fact this is the time when Urgonian platforms disappear in south east France: there is a general agreement that sea leve rose around the Mediterranean belt and on a world-wide scale.

During the Gargasian (2nd Urgonian system of Pascal) slopes are gentle between Urgonian platforms located on highs and basins in which the Urgonian production could not compensate the rapid subsidence. At

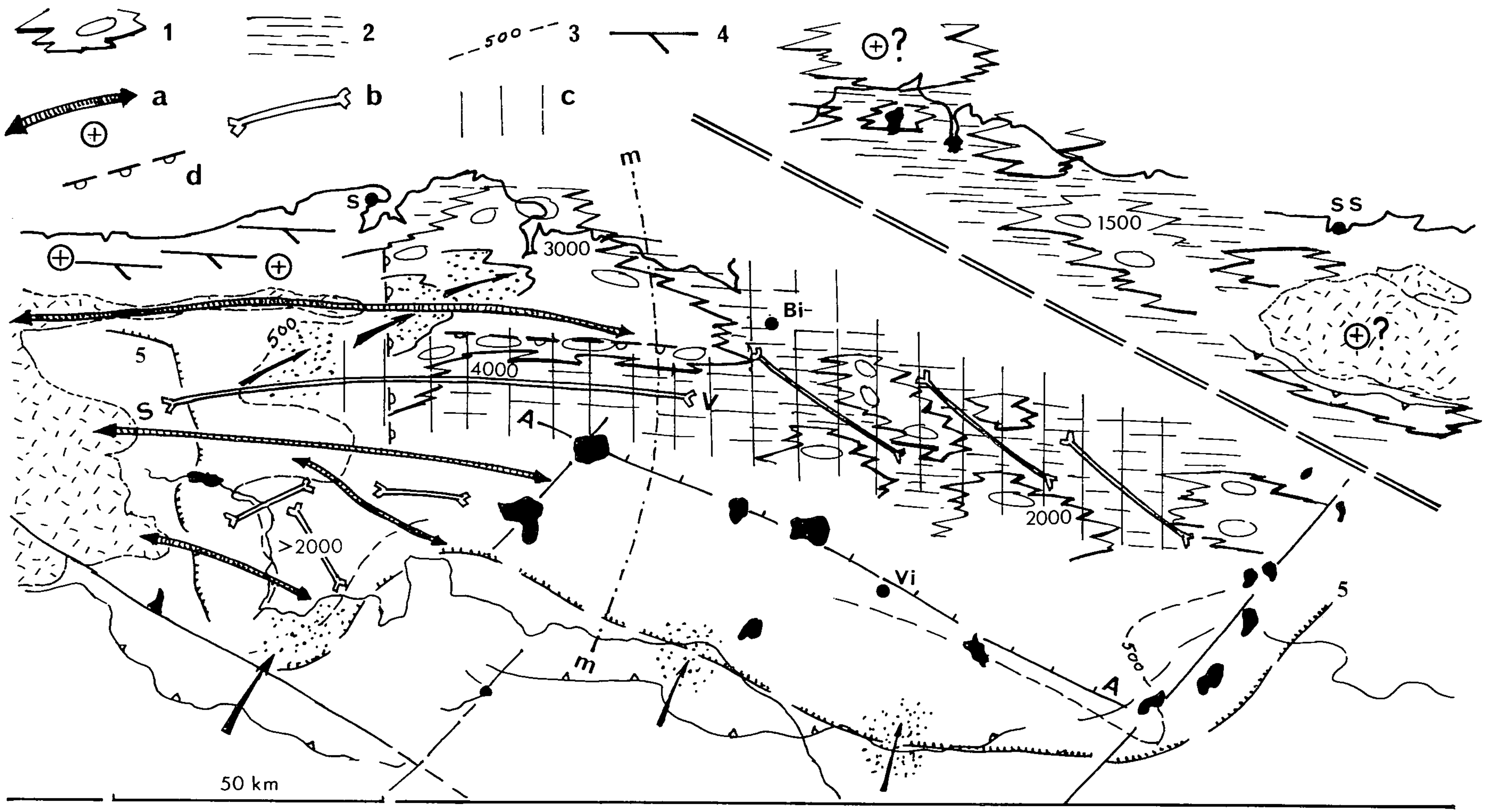

Fig. 6.—Geographic pattern of the Urgonian complex (after García Mondéjar, 1983 and Pascal, 1985, modified). Palaeogeography: 1. Urgonian banks with rim of mud-mounds (latest Aptian to middle Albian); 2. Black marl basins; 3. Isopach 500 m (after García Mondéjar to the west and Ramírez del Pozo, 1971 to the east); 4. Unconformities, emergences west of Santander (Latest Aptian-Albian); 5. Presumed maximum extension of the marine embayment; mm. Aproximate limit of the Asturian mineralogical province towards the east (Pascal). Structure: a. Positive areas or axes; b. Areas of maximun subsidence (Numbers give an indication of the presume thickness, in meters, of the whole Urgonian complex); SV. Silio-Soba; Valmaseda axis of migration of centers of maximun subsidence; c. Subsiding zone at the foot of the Alava diapir line (AA); d. W-E fracture zone which induced the Urgonian barrier near Ramales, at the southern rim of the Santander platform; Rio Miera N-S flexure.

Fig. 6.—Organización geográfica del Complejo urgoniano (adaptado de García Mondéjar, 1983 y Pascal, 1985, modificado). Paleogeografía: 1. Bancos urgonianos rodeados de lentejones de barro (Aptiense terminal-Albiense medio); 2. Cuencas de margas negras; 3. Isopaca de 500 m (al oeste tomada de García Mondéjar; al este de Ramírez del Pozo; 1971); 4. Discontinuidades, emersiones al oeste de Santander (Aptiense terminal-Albiense); 5. Extensión máxima supuesta del estuario; mm. Extensión aproximada de la provincia mineralógica asturiana hacia el este (Pascal). Estructuras: a. Áreas y ejes positivos; b. Área de subsidencia máxima (los números dan una indicación, en metros, de la potencia probable del Complejo urgoniano); SV. Alineación Silio-Soba-Valmaseda de migración de los centros de subsidencia; c Área subsidente al noreste de la línea de los diapiros alaveses (AA); d. Flexura E-W que controla la "barrera de Ramales", en el frente sur de la plataforma santanderina; Flexión N-S del Río Miera.

the end of Aptian times (Clansayesian, 3rd Urgonian system of Pascal), differences are more prominent: the Urgonian slopes, with mud-mounds on tops and slumps-on the lower parts were a permanent feature and testified to increased vertical movements of active faults which remained at the same place and marked the boundaries of the basins during Albian times.

The evolution of the strain-pattern may be interpreted as follows: a) distal downwarping indicates the beginning of distension (lower Aptian); b) as extensión increases, the basin breaks up in diversely down-dropping blocks (upper Aptian-Albian). For some of them, the tilting and rotation along listric faults can be deduced from variations in thickness and indications of paleodepths. Moreover diapiric rises of Keuper have been discerned by their sedimentary effects. It is undoubtedly an episode of continental rifting, with extensión and thinning of the crust in harmony with the surmise of plate kinematics, a total drifting of about 130 km between Europe and Iberica, which came to an end about -111 m.y. ago at the end of Aptian (Olivet, 1978).

3.2.2. Relationships between Iberia and Europe.

As for the Wealden, problems arise in the north and in the east. Was the Urgonian Complex of North Biscay, which has been subsequently torn by the Pyrenean orogeny, part of the same system or was its position definitely more in the east? And what about the Basque massifs in this arrangement? Plate kinematics (Oliver, 1978) introduces, between Europe and Iberia, a left lateral horizontal displacement, initiated at the close of Aptian. Does the present knowledge on Basque-Cantabrian stratigraphy help to clear up the subject?

In the northern part of the synclinorium of Biscay, from the surroundings of the Cincò Villas massif to Guernica, Pascal traced his successive Urgonian systems but Pyrenean tectonism makes it difficult to reconstruct their pattern. The continuity with units located southward (Bilbao, Durango ranges and Aitzgorri mountain) is obscured by the upper Cretaceous and Eocene sedimentary cover. Should this northern part be considered as the distal zone of the Cantabrian system or was it completely separate and independent? So far there is no decisive elemento answer this question.

Some Pyrenean features can be seen in this area. For instance, at the base of the Urgonian Complex, occur *Deshayesites* marls which are known in the Pyrenees and the Adour basin; but the same facies also exists in the Aralar sierra and the Durango ranges (Fernández Mendiola, 1986) which belong to the southern, Iberian, part of the urgonian Complex and it is similar to the facies described by Mengaud (1920) at Las Estacas de Trueba (Santander).

On the other hand, what is known of the distribution of heavy minerals lead to the conclusion that there was an Asturian source area from which minerals of metamorphism were derived whereas another source area dominated by ubiquitous minerals (tourmaline, zircon, rutile and also anatase and chlorite) could be located in the Pyrenees (Pascal, 1985). But the limit between them is a matter of uncertainty (fig. 6). This question should be followed up.

Already in 1920, Mengaud noticed similarity in facies (White Urgonian) and in succession (two limestone units separated by *Exogyra* marls) between the Urgonian west of Santander (Iberian plate) and the Urgonian of La Clape massif (Pyrénees Orientales, France, European plate). Today these two series, although they correspond in lithology and age, are about 600 km apart. During the Aptian, they were possibly still more distant. Therefore the Urgonian formations de not enable us, at least for the moment, to decide whether or not the northern part of the Basque Arc was facing the southern part.

A SUBSIDING SEDIMENT LOADED MARGIN: A BASIN BETWEEN TWO PLATES (UPPER ALBIAN - EOCENE).

4.1. General view.

4.1.1. The structural and sedimentary framework.

From upper Albian, morphology, structure, sedimentation on the southern part of the Basque-Cantabrian basin outline a continental margin on which a thick sedimentary burden is piling up (fig. 4):

— To the south, on the continental shelf, terrigenous material is carried and accumulates (Albian: Utrillas Sands). It is a wide proximal platform which "Atlantic" transgressions invade largely as far as the present day Iberian ranges (Amiot *et al.,* 1987; Floquet, 1987, 1988).

On top and on the front of the slope (south of Biscay), during Albian times, deltaic deposits are prograding (Valmaseda delta), in which the last Urgonian constructions are intercalated. Later they are overlain by marls, marly limestones and limestones (Navarro-Cantabrian basin, Estella basin) of upper Cretaceous age. It may be classified as a distal platform.

— At the fore part of the slope (around the Aralar range and in the synclinorium of Biscay) extend deep flysch troughs (Mathey, 1986) in which thick turbidites, volcanic and volcanoclastic sequences accumulate. The composition of the lava suggests that they originated from a thinned continental crust (Rossy, 1974; Azambre and Rossy, 1976; Boess and Hoppe, 1986). They are Albian to Lower Cenomanian in age (Lamolda *et al.,* 1983). The limit between the two plates may tentatively be placed under this thick volcanic complex (over 1000 m), approximately in the NW prolongation of the Nappe des Marbres.

If the pattern is clearly visible in the south, it is all the more puzzling in the north.

The initiation of a North Iberian slope with, at the botom, a trough deep enough for turbidites to flow in (but still above the CCD) and sinking more rapidly than sedimentation could compensate, however abundant it may have been, agrees with the picture of an expansio-

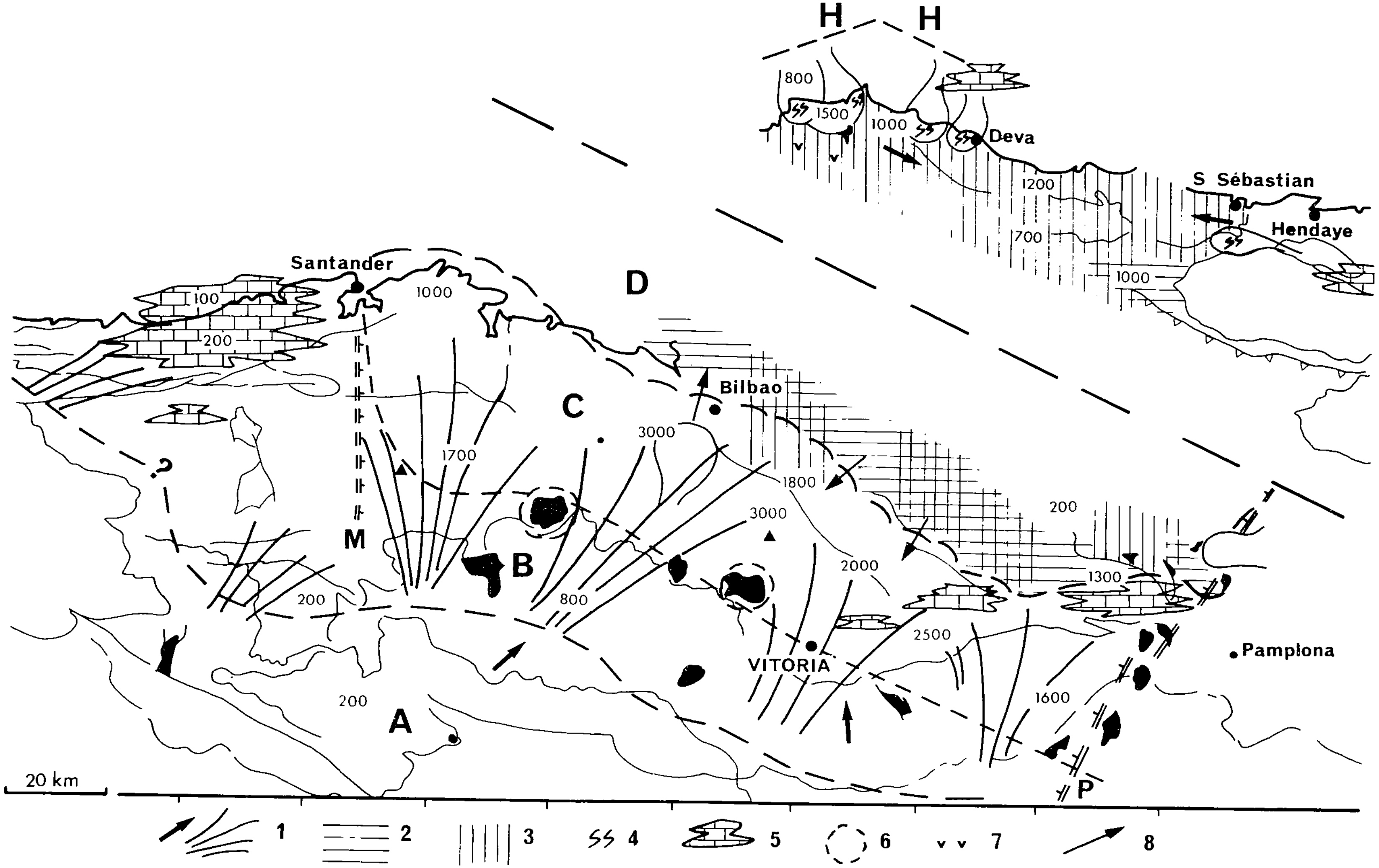

Fig. 7.—Organization of the detrital sedimentation on the Iberian passive margin: the supra-Urgonian sandstone complex (after Pascal, 1985). A. Continental deposits (Utrillas Sands); B. Area of moderate thickness; C. Delta front: over 1000 m thick; D. Deep basin; H. Biskaya Hoch; M. Río Miera flexure; F. Pamplona fault. 1. Zones of terrigenous arrivals: deltaic lobes (Arrows indicate the directions, after Olive Davo et al., 1984); 2. Black marls, clays and silts; 3. Turbidite accumulations (Black flysch); 4. Slumpings; 5. Urgonian limestone banks; 6 Diapiric "atolls"; 7. Volcanics; 8. Progradation.

Fig. 7.—El sistema deposicional detrítico sobre el margen pasivo en el transcurso del Albiense superior. Complejo Areniscoso Supra-urgoniano (según Pascal, 1985). A. Facies continentales "Utrillas"; B. Área de espesores moderadas; C. Frente deltáico: potencia superior a 1000 m; D. Cuenca profunda; H. Umbral de Vizcaya (Biskaya Hoch); M. Flexión del Río Miera; P. Falla de Pamplona. 1. Zonas de aportes detríticos: lóbulos deltaicos (las flechas indican las direcciones de los aportes según Olive Davo *et al.,* 1984); 2. Margas negras; 3. Turbiditas (Flysch negro); 4. Deslizamientos submarinos; 5. Bancos urgonianos; 6. "Atolones" diapíricos; 7. Volcanismo; 8. Progradación.

nal passive continental margin along a spreading ocean (Bay of Biscay). But more precisely what lay in front of the Basque segment of the Iberian margin during upper Cretaceous? Vulcanism does not imply the proximity of an oceanic crust. Moreover it must be kept in mind that a sinistral lateral movement of Iberia with respect to Europe (that is to say of the southern edge of our basin relative to its northern edge) may have occurred. According to plate kinematics (Olivet, 1978) the process lasted from — 110 to — 80 m.y. (from uppermost Aptian to upper Santonian or lower Campanian).

4.1.2. The stratigraphic succession and its division.

The infilling of this mobile basin was mostly governed by tectonics. However other factors were involved: the middle Cretaceous transgression with its hazards, the uppermost Cretaceous regression. How to analyse the sedimentary content? There is no general agreement among authors as to the identification of major unconformities and large scale sequences (Amiot *et al.* 1982; Wiedmann *et al.,* 1983).

In the mobile and complex Basque deep zone, between the Aquitanian and Iberian shelves, Mathey (1986) recognizes three successive formations, overlying the black siliciclastic flysch and the sandstones of upper Albian to lower Cenomanian age: a) A calcareous flysch unit (Cenomanian to Santonian). Bioclastic turbidites accumulate in two distinct troughs: near St-Jean-de-Luz in France, north or the Basque massifs; near Plencia west of the synclinorium of Biscay. Elsewhere deposits are extremely thin marls or Globotruncanid hemipelagic limestones. b) A siliciclastic flysch (Campanian-Maastrichtian p.p.): one single large trough (Orio trough) extending from Hendaye to the synclinorium of Biscay. c) Alternating marls and pelagic limestones in which Mathey studied only the Maastrichtian part but which continue into Paleocene times. d) In addition siliciclastic flysch again in Eocene times.

In the south, Floquet (1988) has worked out a very well documented description of the upper Cretaceous series in the wide Castilian epicontinental platform which was submerged by the upper Cretaeous transgressions. Eustatic or tectonic variations were much more perceptible there than in the hemipelagic environments of the Basque deep zone. He was able to recognize unconformities of different hierarchical ranks. Thus correlations could be attempted between the events in the deep zone and those of the Castilian platform (Amiot *et al.,* 1982; Amiot, Floquet and Mathey, 1983):

— Transgressive sequence of middle Cretaceous (upper Albian— Turonian, —100 to —88 m.y. approx.). On the platform, it begins with the spreading of continental detritus (Utrillas) and is ended by subtidal or intertidal limestones. In the Basque trough, siliciclastic flysch and sandstones of Upper Albian are replaced by limestones and alternations of marl and limestone with globotruncanids or by the first calcareous flysch formation. This sequence corresponds to Wiedmann's *et al.* (1983) Megasequence 2: 1) Deltaphase 2) Maximal transgression.

The progressive occurrence of a littoral carbonate system may have originated from the sagging of the Iberian plate margin (Floquet, 1987). The progress was checked during the lower Cenomanian by what has been defined as the Ebro swell (Feuillée, 1967). The prograding carbonate filling of the Castilian platform is contemporaneous with the calcareous turbidites of the Basque trough. Conversely the sequence possibly came to an end because subsidence slowed down or ceased, thus putting an end to the neritic carbonate production.

— Marl/limestone shallowing upward sequence ranging from outer littoral environments (marls) to intertidal and supratidal environments (Coniacian-Santonian, -88 to -83 m.y. approx.) on the Castilian platform. The calcareous flysch trough extended rapidly southeastwards in the synclinorium of Biscay. As before the sinking of the Iberian plate margin seems to initiate and bring about the readjustment of a littoral system (Floquet, 1987). The end would again result from the decrease or stoping of the movement.

d— Regressive sequence finally arriving at emergence on the Castilian platform (Campanian-Maastrichtian-Danian, -83 to -65 m.y. approx.). It corresponds, (fig. 8) in the Basque deep zone, to sandstone flysch then to marl/limestone alternations and rosy *Globorotalia* limestones. In both areas, it begins with a terrigenous input which infers deformation of the provenance land area. The European and Iberian plates may commence to converge.

The main presiding factors proved to be: first the subsidence of the two margins, North Iberian and South Aquitanian, as well as deformations relative to the horizontal displacement of the Europe and Iberian plates; then the eustatic fluctuations. The first sequence evolved in the incipient subsidence of the North Iberian margin and the middle Cretaceous transgression; the second may be the result of another sea-level rise; the third is completed at the close of the late Cretaceous regression.

4.2. Relationships between Iberia and Europe.

4.2.1. Upper Albian: the black flysch basins.

During the Upper Albian, the morpho-sedimentary pattern seems clear as regards the Iberian part of the basin (fig. 7): 1) Spreading of the Utrillas Sands on land surfaces. 2) Thick deltaic accumulation on the distal part of the platform. The sandstone and clay Valmaseda formation is about 3000 m thick; the volume of the deltaic system can be compared to the present Rhone delta. In the deltaic area, on higher places, a few isolated Urgonian lenses are still building up, on places sheltered for a while from the material of distributary channels (Pascal, 1985), on diapiric highs or still rotating blocks. 3) Turbidites or turbiditic interdigitations discerned in various points of the Bilbao anticlinorium (Olive Davo *et al.,* 1984).

In fact, the area in which turbidite accumulations are best characterized (Black Flysch) is the present coastal area north of the synclinorium of Biscay, that is to say the presumed "European" part of our basin. The direction from which the clastics were derived implies a source area located farther in the north (Feuillée, 1967; Biskaya-Hoch of German authors: Voort, 1964; Engeser *et al.*, 1984): an area of relatively elevated basement, similar to the Basque massifs and belonging to the European plate? For Olive Davo (1984) SE-NW directions of provenance of the material would indicate that the Cinco Villas massif was also a supply area. The Basque-Cantabrian basin would then be somehow symmetrical northwards and southwards; but it was presumably the time when the Iberian and Europe plates moved relative to each other; according to this hypothesis, the Biskaya-Hoch, as well as the Basque massifs and all the Deva Black Flysch system must have been standing definitely more in the east.

Therefore, although the Udala flysch and the Deva flysch seem very similar and lie close to each other nowadays, they may have originated from distinct physiographic units. This hypothesis is likely since various black flysch basins are known to have existed approximately at that time in the Pyrenean area (It is commonly admitted that the lateral displacement of plates may have induced the development of several pull-apart basins). With our present knowledge, no more can be said. Further investigations may enable to individualize the two basins.

4.2.2. The palaeogeography of the upper Cretaceous flysch units.

During the Campanian, while the horizontal displacement was supposed to be ended, Mathey (1986) describes a single trough (Orio trough) in which sandstone flysch accumulated between the Aquitanian platform (Europe plate) and the Castilian platform (Iberian plate); longitudinal currents circulated from east to west. This picture seems logical. Taking into account the interval between the two plates suggested by geophysics, the floor of the trough between the two slopes would have been approximately 150 km wide (fig. 8).

Going back into the past, at the time of calcareous flysch sedimentation, Mathey then recognizes two separate troughs: in the south the Plencia trough, in the synclinorium of Biscay, the supply of which was derived from the south during Upper Santonian; in the north, the trough of St-Jean-de-Luz. In between a marl limestone deposition area situated on the north of Biscay and possibly including the Basque massifs.

The Cinco Villas massif, the most westerly Basque massif, was probably at times a positive fault-block: as shown by several upper Cretaceous strata resting directly on the Palaeozoic basement (Feuillée, 1978); it does not imply that no pre-Cenomanian deposits existed and may be explained by the denudation of the sedimentary blanket (ophite and Urgonian limestone fragments are found in breccias intercalated in upper Cretaceous layers). The massif was already a marginal or outer block detached from the streched edge of the Europe plate, somewhat disconnected from the plate. It was uplifted during middle Cretaceous (which would coincide with the start of the left lateral motion) then sank down according to the general tendency and was covered with sandstone flysch during the Campanian (when the horizontal displacement came to a standstill) and finally pushed up by the Pyrenean compression.

It is conceivable, and this agrees with the picture suggested by Mathey, that the contact and mobile zone between the two plates was in the north, beyond the submarine flat where the Plencia flysch was spreading. On the European side, it would have been bordered by a chaotic external ridge of fault blocks corresponding to the western Basque massifs and the Biskaya-Hoch, for which the term microplate has been proposed (Boess and Hoppe, 1986). This complex broken up high structure could have, according to time and place, either been covered with calcareous and clayey hemipelagic muds, or providing autochtonous bioclastic material, or without deposition or else subjet to denudation. The St-Jean-de-Luz flysch trough would have been lying between the European (Aquitanian) slope and the ridge which could also have contributed to its supply with its bioclastic products.

4.3.2. The Eocene flysch.

The end of Maastrichtian, the Danian are a period of sedimentary quiet: the "calcaires rosés du Danien" well known from Hendaye to the Bilbao ria, result from hemipelagic sedimentation (with small globorotalids) in which only a limited clayey phase enters.

The morphological pattern is still that of an epicontinental shelf rising above a deep basin. This is clearly evidenced by the large quantities of heterogeneous calcareous material, formed in shallow water and containing coralline red algae and benthonic foraminifera, which are now found in deep deposits, in the Danian escarpment on the north side of the synclinorium of Biscay (Rat, 1959; Plaziat, 1975), near orio (Mathey, 1986). Towards the south-west, the continuity of outcrops is cut off by the wide anticlinal zone of Bilbao and the provenance of the material cannot be ascertained. Farther in the south, in the Alava province, a transgressive sea, marked by inner littoral deposits, came back and invaded part of the land from which it had previously retreated.

Later, in the synclinorium of Biscay as well as in the coastal monocline where beautiful deep-sea fan structures have been described, the Eocene siliciclastic flysch is a replica of the Campanian flysch. The palaeogeographical pattern seems very similar: a single wide trough incorporating the western Basque massifs.

However, towards the east, the flysch trough extended farther, going beyond the Pamplona fault as far as the Pic d'Orhy. It has been referred to as a southeastward flysch "transgression", from middle Cretaceous to Eocene (Feuillée and Rat, 1971), or as a flysch trough developing by longitudinal extension (Feuillée *et al.*, 1973). Closer study of these data in the light of our present concepts would probable be profitable. It may be the eastward progression of downwarping of the North Iberian margin.

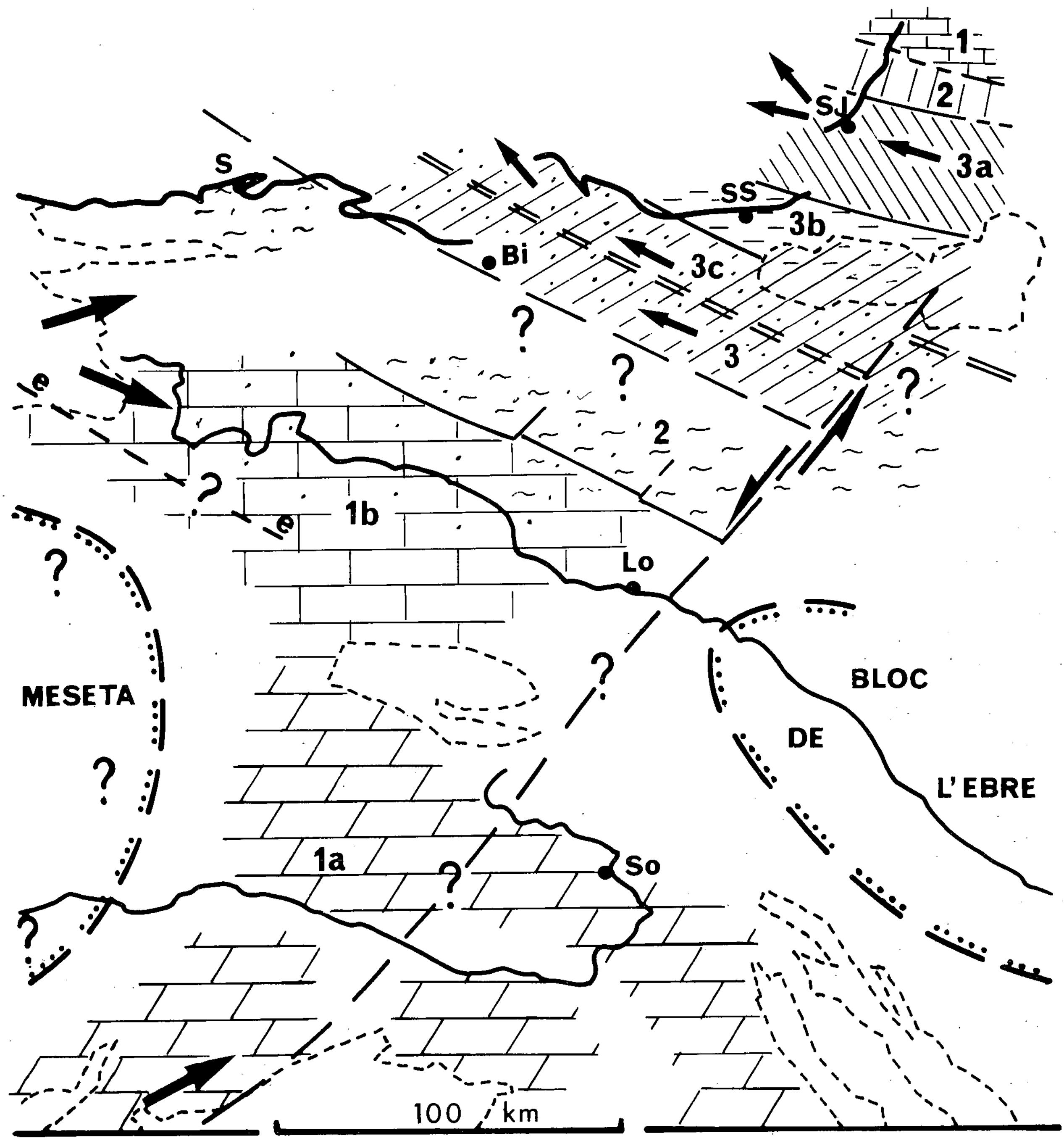

Fig. 8.—The interplate basin and its Iberian hinterland in Lower Campanian time (adapted, after Floquet and Mathey, 1984). European margin: 1. Marls and micritic limestones on distal platform; 2. Marls with planctonic microfauna on the continental slope; 3. Deep zone (a. Haicabia calcareous flysch; b. Marls and micritic limestones with planctonic foraminifera, corresponding to an uplifted ridge between the flysch troughs; c. Siliciclastic flysch formations). Iberian margin: 1. Castilian proximal platform (a. Dolomitic limestones, clayey dolomites, evaporites: sheltered and restricted environments, sebkhas; b. Rudistid limestones: open marine environments); 2. Distal platform (inner to outer littoral environments): thick calcareous marl units with planctonic foraminifera, marls with echinids; Dotted surface: sand components; Arrows: direction of terrigenous arrivals; e. Ebro swell. B. Bilbao; Lo. Logroño; S. Santander; Sj. St-Jean-de-Luz; So. Soria; SS. San Sebastian.

Fig. 8.—La cuenca interplaca y el dominio continental ibérico colindante en el Campaniense inferior (adaptado de Floquet y Mathey, 1984). Margen europeo: 1. Calizas finas de plataforma distal; Margas de microfauna planctónica sobre el talud continental; 3. Zona profunda (a. Flysch calizo de Haicabia; b. Margas y calizas finas de microfauna planctónica: umbral entre los surcos de flysch; c. Flysch arcilloso-arenoscoso). Margen ibérico: 1. Plataforma castellana proximal (a. Calizas dolomíticas, dolomías arcillosas, evaporitas de plataforma interna, laguna, sebkhas; b. Calizas de rudistas de plataforma abierta); 2. Plataforma distal: series potentes de margas calizas con foraminíferos planctónicos, margas con equínidos; Punteado: Componentes arenosos; Flechas: direcciones de los aportes terrígenos; e. Umbral del Ebro. B. Bilbao; Lo. Logroño; S. Santander; SJ. St-Jean-de-Luz; So. Soria; SS. San Sebastián.

The increase of siliciclastic arrivals and the extension of the flysch depositional areas imply tectonic factors: were they brought about as a result of the collision between the Iberian and European plates as was already the case for the Campanian sandstone flysch?

5. CLOSING OF THE BASIN AND PYRENEAN TECTONICS.

5.1. The events

To put it simply, they can be classified in two categories:

— Pyrenean orogenic climax (end of Eocene-Oligocene): compression, folding, thrusting.

— Late Pyrenean dislocations and movements (Oligocene-Neogene) which produced among other things the present day Cantabrian margin and the relief of the range.

The main compressional phase, responsible for the end of deposition and the majority of the present structures, is not clearly seen, particulary in the Basque Arc because unconformable beds are lacking. If the sea retreated from the region centered on the Alava province during the Eocene, in the Basque Arc (synclinorium of Biscay) the ultimate existing formation dates back from Uppermost Lutetian. It can then logically be inferred that, as in the Pyrenees, the major folding took place in Upper Eocene times.

During the compression, folding and uplift of the Hercynian basement and its sedimentary cover, marine sediments continued to be deposited in external basins which were folded only later, during Oligocene.

In the north, near Biarritz, as near Santander (San Vicente de la Barquera) similar facies evidence largely open marine areas. In the south, in the Navarrese basin, the deposits, in perfect continuity, prove that marine influences were less and less felt and were replaced by restricted environments preceding continental filling. This process lasted during upper Eocene and a great part of Oligocene; to flysch deposits which end only at the beginning of Bartonian suceded the Pamplona marine marls which range from Bartonian to Oligocene as in the Biarritz series. Then they pass into a marine molasse and a molasse rich in gypsum layers and finally a coarse detrital, more and more conglomeratic formation. An inversion of subsidence seems to have occurred of each side of the Pamplona fault during the Eocene: in the west, the thick Cretaceous series (Estella basin, Barranca) is overlain only by a thin neritic film; in the east, on the thin upper Cretaceous limestone accumulates a thick marl series, among which the Pamplona marls.

5.2. The structures.

Without going into detail concerning structures and their possible meaning, it may be interesting to dwell on some features related to the Mesozoic basin.

5.2.1. Two parts are opposed by their style and tectonic trends (fig. 2):

— A large relatively quiet area in which the influence of the basement is felt everywhere; upper Cretaceous and Tertiary series are moderately thick. It is the distal part of the Iberian plate. It is divided into three regions, separated by transverse fractures: Santander block (Engeser *et al.,* 1984), Alava block, Navarre (or Ebro) block.

— The Basque folded Arc, including the western Basque massifs. There upper Cretaceous and Tertiary series are thick; their deformations, folds and thrusts do not affect the Hercynian basement. It corresponds to the deep interplate zone.

So, in upper Createous and Tertiary times, the two parts of the Iberian margin are found again in the Pyrenean tectonic pattern: the shelf on thick and rather stable continental crust, the stretched and depressed zone between the Iberian and European plates.

5.2.2. The Basque saddle.

The folded mountain range is limited in the north by the prolongation of the North Pyrenean thrust in the present continental slope (Boillot *et al.,* 1973), in the south by the succession of South Pyrenean and South Asturian thrusts on the sunken Ebro and Duero Tertiary basins. Its width is of the order of 120 km. As in the Pyrenees the suture between the two plates cannot be reduced to a single line running within the Basque Arc.

However in the Pyreneo-Cantabrian range which extends from the Mediterranean to the north-west corner of Spain, the Basque-Cantabrian segment forms a topographic saddle, with a maximun height of 1707 m (at the Castro de Valnera, south of Santander). It is a narrow zone in the range. These characteristics are certainly related to a) the downwarping of the basement due to the Mesozoic deep subsidence (controlled by faults then thermally and in response to the sedimentary loading) b) the junction with the NW-SE set of faults and subsiding blocks of the present day Iberian ranges.

5.2.3. The behaviour of the Basque massifs and the Pamplona fault.

Interpretation largely depends on how the Aldudes massif is considered. Does it belong to the Iberian plate as is generally thought or is it a part of the European plate according to Schott's suggestion (1985) based on palaeomagnetic data. The latter hypothesis is more simple: As the other western Basque massifs (Cinco Villas, Rhune, Labourd), it would be a fragment of the Europe plate, an element (microplate) of its block-faulted external ridge, which has previously been described.

The first hypothesis leads to an embarrassing situation: after the sinistral horizontal displacement of the two plates, an isolated Iberian block would have come to stand right on the side of the European blocks.

There is another baffling fact. The metamorphic zone (Marble nappe) which would be the trace of the contact between plates, is interrupted towards the east, north of the Aldudes massif, against the prolongation of the Pamplona fault. Had the structural pattern been the same during the Cretaceous, no lateral movement between the two plates would have been possible (see 1.3.).

The following hypothesis may be suggested: a) The Pamplona fault is really a deep and old fracture of the Iberian basement. b) During Cretaceous times, it would have moved only vertically. It separated subsiding basins in the west from a more stable area in the east. Such a motion is not opposed to a horizontal displacement along the limit of the Iberian plate which was just in the north. c) During the Tertiary, at the time of compression due to continental collision, the two blocks separated by the Pamplona fault would have unequally encroached on the Europe plate; so transverse faulting could cross the deformed zone and displace the advanced tectonic units of the Europe plate with respect to each other (i.e. the eastern Basque massifs with respect to the western ones); thus wrench faulting would have cut through zone of contact between the two plates, i.e. the North Pyrenean fault and the metamorphic zone.

A lateral movement during the Tertiary could explain: a) that west of the Pamplona fault, folds and thrusts are verging to the north while east of the fault they are facing to the south; b) that the Aldudes massif, an element of the European plate, upheaved and ejected by compression, overthrusts the edge of the Iberian plate (Renewed study of contacts is necessary to prove that this hypothesis is correct) c) the curve of the Basque Arc east of the synclinorium of Biscay. The suggested rotating movement is contrary to the rotation used by Engeser (1986), according to some palaeomagnetic data.

Going further into hypotheses, the Pamplona fault could separate two zones corresponding to a different style of contact between the European and Iberian plates: in the west a beginning of subduction of the European margin under the Iberian plate (Boillot *et al.,* 1979); in the east the opposite tendency (Velasque and Ducasse, 1987). Other pending problems.

6. CONCLUSIONS

6.1. The span of time during which the Basque-Cantabrian basin was in existence is about 200 m.y. from the end of Permian to the end of Eocene. In fact two basins, subject to different tectonic controls, followed each other.

6.1.1. *From Triassic to upper Jurassic* (about 120 m.y.) *it was an intraplate basin* (an intracratonic, epicontinental basin) on a stable Hercynian basement. Formed during the extensional phase, at the time of the intracontinental rifting which affected western Europe and preceded the aperture of Central Atlantic in Liassic times, it evolved in the same way as the other West European basins: Anglo-Parisian basin and Aquitanian basin (to which it was united), Lusitanian basin. Its history is comprised in the transgression-regression cycle of the Triassic-Jurassic periods. The repeated regressive sequence could in the end keep pace with subsidence so that the sea could never deepen. High positive swells separated these basins: a "môle armoricain-occitan" (Armorican-Central massif swell) according to Curnelle and Dubois (1986), the Castilian meseta and most probably the Ebro block in Spain.

This basin emerged in two phases: first in the west during what may be called the Callovo-Oxfordian crisis (Marchand, 1986) related to the end of the Ligurian-Piedmontese ocean aperture (end of Dogger, about -150 m.y.) then the entire basin emerged with the uppermost Jurassic "event". As in the French basins (Aquitanian basin: Curnelle and Dubois, 1986: Paris basin: Rat *et al.,* 1987) a transgressive cycle was over and a new palaeogeographic pattern set in with new sedimentary axes. This was a tectonic event due to the rifting announcing the aperture of the Atlantic ocean north of the Gibraltar transform line.

6.1.2. *From uppermost Jurassic to the end of Eocene* (about 90 m.y.) *the basin developed on a passive continental margin* (an interplate basin if it is not restricted to its southern edge). Controlled by the relative displacements of the Europe and Iberia plates and the resulting aperture of the Bay of Biscay and of the Pyrenean furrow, it had two aspects:

It was developing on *a spreading margin,* as is clearly seen east of Bilbao. A continental margin was being formed and evolved: by rifting, crustal stretching with rotating sinking blocks then downwarping due to thermal subsidence (fig. 4). It was algo *a complex transform zone basin* (a transverse margin basin) although its organization is much les clearly deciphered. The pattern and rank of the wrench-fault sets, the time during which they were operative are a matter of controversy. For instance, what part was played by the Pamplona fault, or the complex fault set referred to under the simplifying name of Bilbao fault, when the basin was active then during the Pyrenean compression (Deregnaucourt, 1981; Malod, 1982).

6.2. Lateral movements, shear fractures seem necessary to explain the block faulting on continental margins, the general subsidence with local uplifted blocks ("Biskaya-Hoch", Basque massifs), the structural features which are oblique with respect to the general trend within the Bilbao anticlinorium (figs. 2 and 5), the sudden spreading of flysch troughs...

The general interpretations which have been offered range from a simple crustal extension between Iberia and Europe (Martínez Torres *et al.,* 1984; Ducasse *et al.,* 1986...) to a lateral displacement of several hundred kilometres (Olivet, 1978). The available data seem to support intepretations which imply a lateral component and wrench faulting in addition to the distension at work between the two plates; provided that this lateral movement is seen as involving a complex set of fractures in a wide area, as in the North Pyrenean transform zone.

There is still an important question to be solved in this extensional and then compressional zone: *where is the prolongation of the North Pyrenean thrust to be placed today?* Along the continental slope as suggested by Boillot (fig. 1) or inland along the front of the Cinco Villas massif and in the north of the anticlinorium of Biscay (écaille du Pagoeta, Atchuri Stoerung)?

6.3. An outstanding event occurred in the beginning of Aptian times. So far sedimentary formations were quite similar to those of the West European basins: German Triassic, Liassic marls, Dogger limestones, faunas with boreal affinities, Purbeck and Wealden beds of British and German type. From Aptian onwards, facies are described as Tethyan: Urgonian limestones, large warm-water foraminifera (Orbitolina, Alveolina, later nummulites, Discocyclina...), rudistids. No chalk was deposited. This biosedimentary event was very likely due to the opening of the Pyrenean arm of the Tethys sea by the widening away of the European and Iberian plate edges so that Tethyan waters could find their way westwards. On the contrary the Iberian seaway permitted only limited communications during the Jurassic, in an epicontinental environment (Bulard, 1972); in upper Cretaceous times, it acted more as a barrier (a hinterland for the Cantabrian basin) than a passageway (Floquet, in Rat *et al.,* 1985).

6.4. Therefore the Basque-Cantabrian basin is tectonic in origin at the junction of two sets of extensional faults initiated in Later Permian and Triassic times. The "Bay of Biscay-Pyrenees-Provence" set separated the Iberian plate from the European plate during upper Jurassic after the aborted Triassic attempt. The second set, corresponding to the "Iberian Ranges", remained within the Iberian plate allowing only an epicontinental seaway to be opened during the Jurassic and the upper Cretaceous. Eustatic sea-level changes were a subsidiary control in the evolution of the sedimentary basin. Other factors also played a part: the geographic (and consequently climatic) situation near the tropic of Cancer during the Cretaceous; the opening of the Pyrenean furrow which could be felt from Aptian onwards; the existence of a hinterland (Iberian meseta, Ebro block?) which supplied enough terrigenous material to keep pace with the subsidence of the Wealden basins and feed the downwarping margin during upper Cretaceous.

6.5. Further field investigations on the various sedimentary systems would help to understand the Cretaceous mechanisms of the North Iberian margin. The models of many Basque-Cantabrian sedimentary systems are known; it would be interesting to find out the sysnsedimentary and postsedimentary deformations to which they were subjected during the period of activity of the Basque-Cantabrian basin, before they were disturbed or dislocated by the Pyrenean orogenesis.

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