LEIDSE GEOLOGISCHE MEDEDELINGEN, Vol. 37, 1966 pp. 7-32, separately published 15-9-1966

THE GEOMORPHOLOGY OF THE SURROUNDINGS OF THE RIA DE AROSA (GALICIA, NW SPAIN)

BY

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SUMMARY

This paper is intended to provide a geomorphological introduction to a series of papers on the sedimentology and weathering phenomena of the Ría de Arosa area.
The area contains a large mass of coarse-grained porphyritic granite surrounded by other crystalline rocks. The granite is deeply weathered and displays typical features such as spheroidal weathering and tors.
The main relief elements are the following. (a) Low-angle slopes, many of which are foot-slopes (glacis) developed mainly on deeply weathered rock, and covered in many parts by colluvium and bedded slope-deposits (Nonn 1964). The latter locally continue below the present sea-level as kaolinite deposits. The low-angle slopes occupy a large area on the intrusive granite around the Ría de Arosa. (b) Rounded residual hills. (c) Mountain massifs in metamorphic rocks and migmatites, with steep slopes and flatter top-surfaces which are perhaps remains of a peneplain. The distribution of these features is given on the geomorphological map.
The drainage pattern has been strongly influenced by some of the fracture directions of the basement rocks and by late-Tertiary faults. The latter broke up a Tertiary peneplain and created a long N-S rift. It may also have affected the coast and influenced the bottom topography around the Galicia Bank (Black et al. 1964).
The main rivers maintain their original SW directions at the points where they cross the rift. Because these points had been lowered by subsidence of the rift zone, the downstream parts of the valleys, now occupied by the rias, became antecedent valleys in the rising block W of the rift. It is not necessary to assume individual subsidence of each of the rias. The valleys may be merely the result of denudation and erosion which processes must have continued on the present ria bottoms during the glacials when the sea-level was lowered. The rias must have existed in at least the last two interglacials, and probably much earlier (Mensching 1961); there are no indications of differential tectonic movements since then.

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RÉSUMÉ

Géomorphologie des alentours de la Ría de Arosa (Galice, Espagne nord-occidentale).

La présente communication doit servir d'introduction géomorphologique à une série d'études sur la sédimentologie et l'altération superficielle dans la région de la Ría de Arosa.
Le sous-sol de la région consiste en un massif intrusif de granite grenu porphyroide entouré d'autres roches crystallines (gneiss, granite migmatique, micaschiste). Le granite grenu, en particulier, est soumis à une altération profonde et présente partout des exemples d'altération sphéroidale (Fig. 4—8).
Les principaux éléments du relief sont les suivants (Fig. 14).
(a) Pentes faibles (Fig. 9—11), en partie glacis, développées surtout sur roche pourrie (Fig. 12), et couverte en partie de colluvions (Fig. 12, 13) et localement de dépôts de pente stratifiés (dépôts torrentiels de Nonn, 1964) (Fig. 15, 17). Ces derniers se poursuivent comme dépôts caolinitiques un peu sous le niveau actuel de la mer (Fig. 16). Les terrains à pentes faibles occupent une grande surface autour de la Ría de Arosa (Fig. 9).
(b) Collines résiduelles arrondies (Fig. 18).
(c) Massifs montagneux à fortes pentes (Fig. 20, 21) et à surfaces aplanies, qui peuvent être des restes d'une ancienne pénéplaine (Fig. 22—24). La distribution de ces éléments est représentée sur une carte géomorphologique.

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Le réseau fluvial a été fortement influencé par les directions des fractures du soubassement (Fig. 27—29) et par des failles d'âge tertiaire récent. Ces dernières ont rompu la pénéplaine et créé la fosse (Fig. 1, 3) qui parcourt toute la Galice du S. au N. Elles ont également affecté la côte et influencé le relief sous-marin autour du banc de Galice (Black et al. 1964, Fig. 31).
Les rivières principales retiennent leurs cours en direction SW où elles croisent la fosse, sans être déviées (Fig. 1). À ces endroits les profils en long ont été affaissés. Par conséquent leurs vallées inférieures, à présent en partie occupées par les rias, devenaient des vallées antécédentes dans le bloc à l'W de la fosse (Fig. 26). Il n'est pas nécessaire d'admettre un affaissement individuel de chacune des rias. Il est plus probable que ces vallées ont été approfondies et élargies par le seul effet de dénudation et d'érosion. Ces deux processus ont été actifs pendant les périodes glaciaires également sur les fonds des rias, à sec à ces époques. Les rias ont existé en tous cas pendant les deux derniers interglaciaires, et probablement beaucoup avant (Mensching 1961). Il n'y a pas d'indices de mouvements tectoniques différentiels depuis ces temps.

ZUSAMMENFASSUNG

Geomorphologie der Umgebung der Ría de Arosa (Galizien, NW-Spanien)

Dieser Beitrag soll eine geomorphologische Einführung in eine Reihe von Arbeiten über die Sedimentologie und Verwitterungserscheinungen im Gebiete der Ría de Arosa sein. Das Gebiet besteht in geologischer Hinsicht aus einer grossen Intrusionsmasse grobkörnigen porphyrischen Granits, umgeben von anderen kristallinen Gesteinen. Besonders der Granit ist tief verwittert und erzeugt Spheroiden (Wollsäcke) und Granitklippen (Fig. 4—8).
Die wichtigsten Reliefeinheiten sind folgende (Fig. 14).
(a) Flachhänge (Fig. 9—11), zum Teil Fussflächen („Glacis"), hauptsächlich auf tief verwittertem Gestein entwickelt (Fig. 12), und teilweise mit Kolluvium (Fig. 12, 13) und geschichtete Hangablagerungen (Fig. 15, 17) bedeckt (Nonn 1964). Letztere sind stellenweise als Kaolinitschichten unter dem heutigen Meeresspiegel zu verfolgen (Fig. 16). Das Gebiet mit Flachhängen ist besonders ausgedehnt in der Umgebung der Ría de Arosa (Fig. 9).
(b) Rundliche residuelle Hügel (Fig. 18).
(c) Isolierte Bergmassive mit steilen Hängen (Fig. 20, 21) und einer flächeren Oberseite (Fig. 22—24), die ein Rest einer früheren Rumpffläche sein könnte.
Die Verbreitung dieser Formelemente ist auf einer geomorphologischen Karte dargestellt worden.
Das Flussystem ist stark von den Kluftrichtungen im Grundgebirge (Fig. 27—29) und von tertiären Verwerfungen beeinflusst. Letztere haben die tertiäre Rumpffläche zerstückelt und den langen N-S verlaufenden Grabenbruch (Fig. 1, 3) geschaffen der ganz Westgalizien durchschneidet. Auch die Küste und das untermeerische Relief in der Nähe der Galicia Bank (Black et al. 1964, Fig. 31) können davon betroffen sein.
Auffallenderweise behalten die Hauptflüsse ihre SW-Richtungen an den Stellen wo sie den Grabenbruch kreuzen, und sind nicht abgeleitet worden (Fig. 1). Da diese Stellen sich senkten wurden die Unterläufe der Täler, in denen die jetzigen Rias liegen, dabei zu antezedenten Durchbruchstälern in den sich hebenden Gebirgsstreifen westlich des Grabens (Fig. 26). Es braucht dabei keine Bodensenkung der individuellen Rias mitgewirkt zu haben. Wahrscheinlich haben nur starke Denudation und Erosion die Täler verbreitert und vertieft. Letztere Prozesse haben jedenfalls in den Glazialzeiten weiter gewirkt, auch auf den Riaböden die damals trocken lagen.
Die Rias bestanden jedenfalls schon während der letzten zwei Interglazialen, wahrscheinlich schon viel früher (Mensching 1961). Es sind keine Anzeichen für differentielle Bodenbewegungen seit jener Zeit vorhanden.

RESUMEN

Geomorfología de los alrededores de la Ría de Arosa (Galicia).

Esta contribución sirve como introducción geomorfológica para una serie de estudios sobre la sedimentología y la meteorización en la región de la Ría de Arosa. La región comprende un macizo de granito intrusivo de grano grueso y porfídico, rodado por rocas metamórficas y granitos migmáticos. Especialmente el granito porfídico ha sido sometido a una desagregación profunda y muestra una disyunción esferoidale típica (Fig. 4—8).
Los elementos principales del relieve son los siguientes (Fig. 14). a. Pendientes débiles (Fig. 9—11), en mayor parte al pié de pendientes menos débiles (y por eso llamadas „glacis"), se encuentran sobre rocas profundamente meteorizadas (Fig. 12). Son cubiertas estos parcialmente por coluviones (Fig. 12, 13) y a veces por depósitos de pendiente estratificados (Nonn 1964). Aquellos se extienden como capas de arcilla caolinítica bajo el nivel actual del mar (Fig. 15—17).
b. Colinas residuales redondeadas (Fig. 18).
c. Macizos montañosos con pendientes bastante escarpadas (Fig. 20, 21) y superficies menos inclinadas, los cuales pueden ser restos de una penillanura (Fig. 22—24).
La distribución de todos estos elementos del relieve ha sido indicada en un mapa geomorfológico.
La red fluvial ha sido influida mucho por las lineas de fractura antiguas y por fallas que datan del Terciario reciente (Fig. 27—29). Estas fracturaron la penillanura terciaria y dieron lugar a la larga fosa hundida (Fig. 1, 3), bordada de fallas, que se extiende a través de toda la Galicia occidental del Sur al Norte. Estas influyeron también en la costa asi como el relieve submarino alrededor de la llamada „Galicia Bank" (Black et al. 1964, Fig. 31).
Los rios principales mantuvieron sus direcciones sur-occidentales al cruzar la fosa hundida (Fig. 1). En estos sitios sus perfiles deben ser hundidos. Sus valles bajos, ahora ocupados en parte por las rías, pueden haberse hundido al mismo tiempo, pero es más probable que ellos se hicieron más anchos y hondos sólo por medio de denudación y erosión, es decir que son valles antecedentes encajados en el bloque al W de la fosa (Fig. 26). Estos procedimientos de todos modos continuaban también en los fondos de las rías actuales durante los períodos glaciares cuando el nivel del mar estaba más bajo. Las rías deben de haber existido a lo menos durante los dos últimos glaciares y probablemente ya mucho antes (Mensching 1961). No han tenido lugar movimientos tectónicos desde entonces.

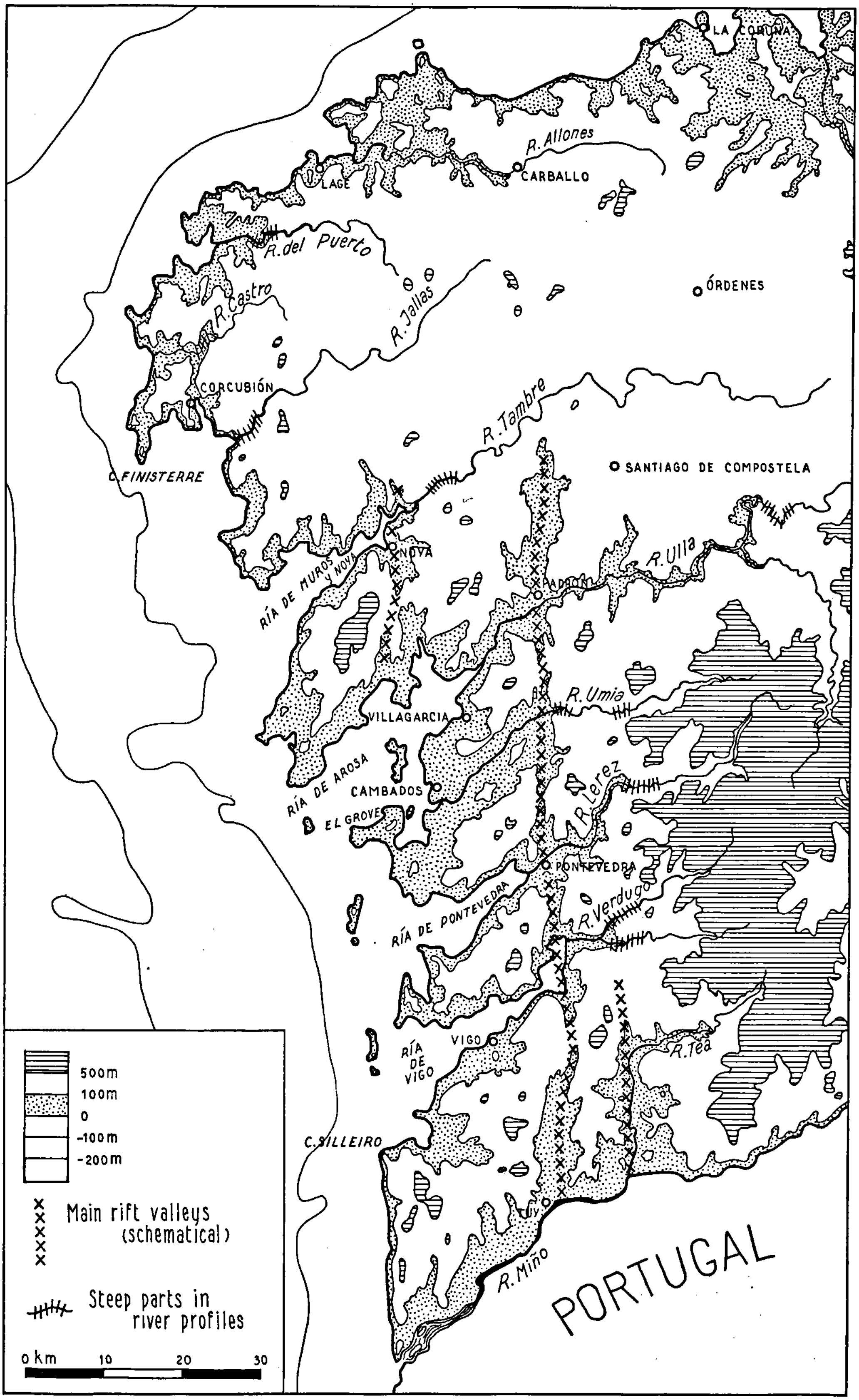

Fig. 1. Western Galicia. Topography. Scale 1 : 800 000.
Topografía de la Galicia occidental. Escala 1 : 800 000.

I. THE RELIEF OF WESTERN GALICIA AS A WHOLE

Western Galicia can be roughly subdivided into three regions, each with a different type of relief (Fig. 1).

(a) The Northern area is an extensive undulating plateau (Fig. 2) at a height of more than 300 m, with culminations reaching just over 500 m. Birot & Solé Sabaris (1954) consider the plateau to be a true peneplain („pénéplaine principale" or „surface d'érosion de Chantada"); it may, however, consist of more than one peneplained level. The upper courses of the main rivers (Tambre, Jallas) run almost at the level of this peneplain (Fig. 14A) and are not intrenched in it. Some information as to its age is given by Nonn & Médus (1963), who established a Tortonian or Tortonian-Pontian age for the flora contained in the lignites of Puentes de García Rodriguez (45 km east of La Coruña). These lignites are warped, and occur in a tectonic depression of the peneplain. This is an indication that tectonic movements have deformed the latter at or after the end of the Miocene; the peneplain itself must be older.

(b) South of a line running from the Ría de Noya to the upper course of the river Ulla we can distinguish an eastern region lying further inland, called by Birot & Solé Sabaris (1954) the Galician backbone mountains („dorsale galicienne"), and, to the west of it, a coastal area (c). The mountain range runs from S to N from the river Miño towards the Umia and then turns more to the E. Its highest culminations reach more than 1000 m.

(c) The coastal area encloses the Ría de Arosa and the three other main rias, those of Noya y Muros, Pontevedra, and Vigo. This area is characterized by isolated mountain blocks, reaching heights of over 600 m and separated by low depressions.

The most conspicuous feature is the long, straight depression running from S to N through the whole area (Fig. 1, 3). This depression starts on Portuguese territory, runs parallel to the coast, from which it is separated by some 20 km, then touches the upper edges of the rias of Vigo and Pontevedra, crosses the valleys of the Umia, Ulla, and Tambre, and can even be followed, although it is here less deeply depressed, through the northern peneplained area to the north coast. It has been considered as a rift zone of Tertiary age by Carlé (1947), Parga Pondal et al. (1953—1956, in Explanations to Mapa geol. de España), Torre Enciso (1958), and others. This view is supported by the occurrence, within the rift zone north of the river Miño, of Tertiary lignites containing remains of palm trees (Nonn & Médus 1963); locally these lignites are deformed, probably by tectonic movements [1]. Along this and other tectonic zones, moreover, numerous thermal wells occur. The formation of the rift zone may have accompanied an uplift of Galicia as a whole (Carlé 1947).

Other rectilinear depressions run parallel to the main N-S depression, for instance that of the lower course of the river Tea (Fig. 1), a tributary of the Miño; this zone can be followed for some distance northward and, more clearly, southward on Portuguese territory. Much farther inland there are the rift zone of Chaves-Verín, the latest movements of which are supposed to date from the older Quaternary (Neiva 1950), and the series of Tertiary basins of Lugo, Sarria, Monforte, etc. (map in Lucas et al. 1963).

The coastline of northern Portugal and the adjoining part of Spain (south of the Ría de Vigo) also forms a conspicuous N-S line. It, too, has generally been interpreted as a fault of late-Tertiary age.

II. REVIEW OF PREVIOUS INVESTIGATIONS

The west coast of Galicia with its deep bays, known as rias, became famous in geological and geographical literature when Ferdinand von Richthofen (1886) took it as type area for a specific kind of coast. He defined a ria coast as a coast on which mountain ranges run at nearly right angles (transverse) to the coast, and drowned valleys between them penetrate deep into the land.

[1] I am indebted to Mr. Nonn for showing me this locality in 1962.

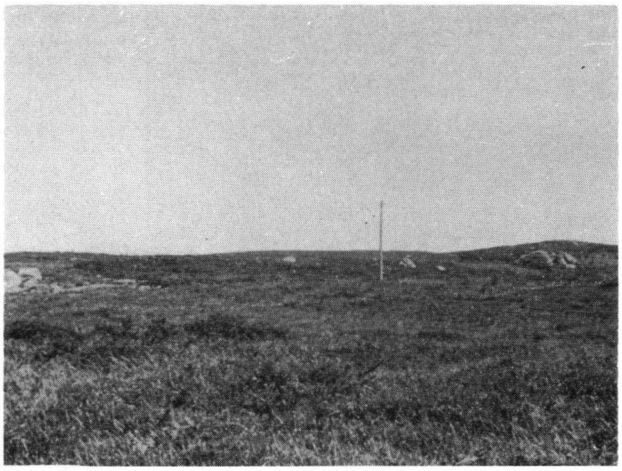

Fig. 2. Galician peneplain, 10 km ENE of Noya.
Penillanura gallega, 10 km ENE de Noya.

Fig. 3. N-S rift zone looking north towards Pontevedra.
Fosa central. Vista hacia el norte en la dirección de Pontevedra.

In most cases such parallel ridges and valleys are the consequence of unequal resistance of the rocks and therefore follow the strike of the rocks, which is, in these cases, also transverse to the coast. Von Richthofen was well aware of the fact that this condition is not fulfilled in western Galicia: the strike of the metamorphic rocks is, in fact, nearly perpendicular to the direction of the rias, although the rias themselves and the ridges between them are transverse with respect to the coast. Nevertheless, he chose the rias as prototypes because only in Galicia do such bays have a specific name; the real prototypes are to be found, for instance, in western Brittany and southwestern Ireland.

Later authors (A. Penck 1894, de Martonne 1926; see also Cotton 1956) had a tendency to differentiate between transverse coasts where the strike of the rocks is actually nearly at right angles to the coast (conforming to Von Richthofen's original definition of ria coasts), and real ria coasts where the inlets are unrelated to the strike of the rock, as in western Galicia. Others have extended the term ria coast to all coasts with drowned valleys (fiords alone being excepted), whatever the strike of the rocks or of mountain ranges may be, and even to those in regions with horizontal beds (Johnson 1919, Guilcher 1954). Later Cotton (1956) undertook a rehabilitation of the Galician rias us true rias when he became aware of the work of Birot & Solé Sabaris (1956), who tentatively assumed that the rias follow the strike of younger (Pliocene?) faults nearly transverse to the coast, thus conforming more to Von Richthofen's definition than was previously thought.

After Von Richthofen's time many decades passed before a more detailed description of the rias was undertaken by Scheu (1913). He recognized the peneplain character of northern Galicia and the importance of tectonic movements, especially along the N-S zone, but failed to take into account eustatic oscillations of the sea-level.

Afterwards the rias were briefly mentioned in papers on other coasts or on coasts in general (Lautensach 1928, Bourcart 1936), but it took a long time before new work on the rias was undertaken. Only shortly before 1940. Carlé made observations on coastal details along the rias (1940, 1941) and in 1947 he published an outline of the ria problem, in which he considered the N-S zone as a graben and the rias as similar sunken zones between rising blocks.

More became known about the morphology of adjoining areas: northern Portugal (Lautensach 1932, 1941, Teixeira 1944, 1949, and others) and the northcoast of Spain (F. Hernández-Pacheco, 1950 and later papers), both of which regions have some bearing on western Galicia. The phenomena of granite weathering and their importance for the relief features of Galicia also began to attract attention (Lautensach 1950, Birot 1952, more recently Schermerhorn,1959, on northern Portugal).

In 1953 a series of papers dealing with weathering phenomena, the geomorphology of Galicia, and the ria problem written by Parga Pondal (1953, 1958) and Torre Enciso (1955, 1958) began to appear, emanating from the former's private laboratory at Lage. The year 1953 also saw the publication of the first of the geological 1 : 50 000 sheets of western Galicia, with their extensive explanations by J. M. Lopez de Azcona, I. Parga Pondal, the late G. Martín Cardoso, and E. Torre Enciso, containing valuable geomorphological observations.

The most important geomorphological contribution of the fifties was, however, that of Birot & Solé Sabaris (1954), who gave an outline of the geomorphological evolution of the whole of Galicia. Although in many respects admittedly provisional and leaving many problems unsolved, this work is full of valuable ideas stimulating further research.

The latest phase in geomorphological work in Galicia is represented by a contribution of Mensching (1961) who stressed the importance of eustatic movements for the ria problem, and by papers of H. Nonn (1958, 1960, 1963, 1964); they are the fruits of an extensive investigation of the whole of western Galicia, intended to result in a geomorphological monograph of this interesting region.

Our own observations (see also Pannekoek 1966) concern a more restricted area, the direct surroundings of the Ría de Arosa, and also have a much more restricted object, i.e. to give an outline of the relief features in which the sedimentological processes are enacted. This paper does not claim to unravel the whole history and all the processes by which the present relief came into being. That aim can be accomplished only by the thorough investigation of a much larger area, and for this we will have to wait for the completion of Nonn's work.

III. WEATHERING AND ITS TOPOGRAPHIC EXPRESSION

Although weathering phenomena (Lautensach 1950, Birot 1952, Parga Pondal 1958) are the subject of a separate contribution in this series, by E.B.A. Bisdom, some introductory remarks on this topic are necessary for a better understanding of the relief features.

Spheroidal weathering (Chapman & Greenfield 1949) is most conspicuous in the course-grained parts of the intrusive Caldas granite, which contain large phenocrysts of potash feldspar. This granite occupies a large area east and southeast of the Ría de Arosa, and probably extends below it to appear again on the western shore.

In quarries it can be seen that weathering in this rock starts along the widely-spaced joints, first producing brown zones along these joints through mobilization of iron, partly derived from biotite. The iron forms concentric bands encircling the rounded unweathered cores of the blocks (Fig. 4) and prefigures the spheroidal weathering of the coarser rock types.

In a later stage the outer zones around each block are decomposed into granules, each consisting of a few crystals or of single crystals of mainly feldspar and quartz. Near the core the crystals still hold weakly

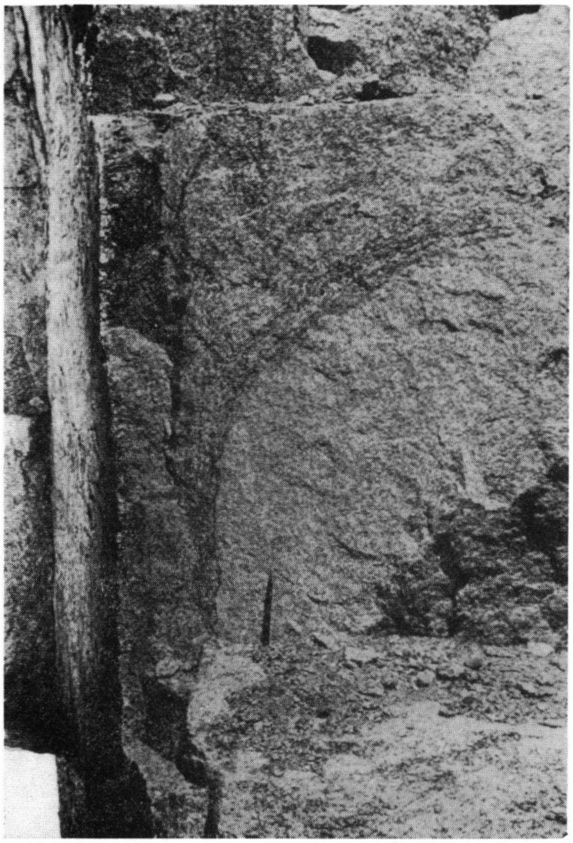

Fig. 4. Concentric rings of iron hydroxide in granite, north of Cambados (length of pencil 12 cm).
Zonas concéntricas de hidroxide de hierro en granito, al norte de Cambados (el lapiz tiene 12 cm de largo).

Fig. 6. Desintegrated porphyric granite with ghosts of former spheroidal boulders, Nogueira.
Desagregación del granito porfídico, con huellas de bolas esferoidales, Nogueira.

together so as to form concentric shells (Fig. 5), which, however, easily break into granules. In an outward direction the feldspars are increasingly subjected to sericitization and kaolinitization. The unweathered cores, in this stage, float as huge rounded boulders

Fig. 5. Spheroidal weathering in porphyric biotite granite, Villagarcía de Arosa.
Disyunción esferoidal en granito biotitico porfídico, Villagarcía de Arosa.

or corestones in a coarse, angular, arkosic sand (see also Fig. 18).

If the sandy weathering product is not removed, the process continues till the cores, too, are decomposed, though the spheroidal structure remains visible for some time as a ghost structure (Fig. 6). Along the former joints the process has often reached a more advanced stage, resulting in a finer grained and more clayey material, sometimes of a darker brown. The whole of this decayed weathering product is known as „rotted rock" (Linton 1955) or truncated regolith (Ollier 1965).

In many road cuts and some quarries in the low hills it can be observed that there the sandy decayed rock is still present to considerable depth; at some places 10 m can be measured without the base being disclosed[1]; it is expected that along major joints the weathering zone extends much deeper. Often, however, it contains floating unweathered boulders or corestones (remainders of the largest blocks left over where the spacing of joints is unusually wide), and at unexpected places unweathered rock pierces through the weathered mantle (see Fig. 12). As a result, a single

[1] Lautensach (1950, 1964) mentions thicknesses of more than 20 m; Ollier considers 20 m as normal for Australia, in exceptional cases exceeded by many times this amount.

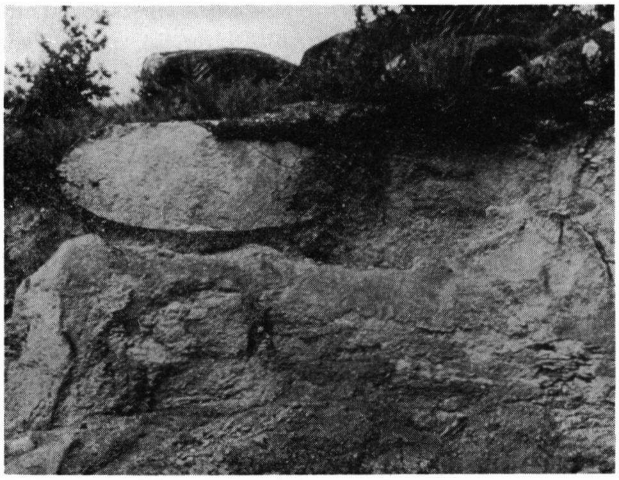

Fig. 7. Granite boulder partly at the surface, partly in rotted rock, Nogueira.
Bola de granito en parte a la superficie, en parte rodeada de granito desagregado (xabre). Nogueira.

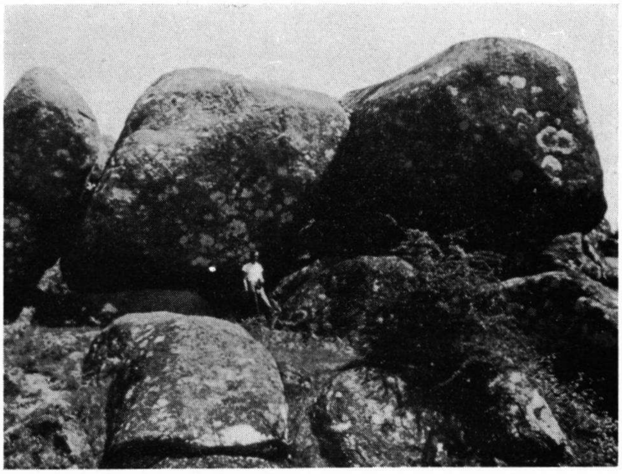

Fig. 8. Granite boulders at the surface. Top of Mt. Lobeiro.
Bolas de granito en la superficie. M. Lobeiro.

quarry (see Fig. 18) may supply fresh granite blocks as well as arkosic sand, which is locally known as *xabre* or *giabre*, in Portuguese *saibro* (etymologically related to the French word *sable*, although in France the term *arène* is used for decomposed granite).

If, however, the sandy material is removed by rainwash or otherwise, the boulders of fresh rock come to lie at the surface (Fig. 7). The weathering process then changes completely and is considerably retarded. Whereas the surface of the boulders embedded in the weathering mantle is continually kept wet by capillary water, which enables the weathering process to proceed rapidly, the exposed surfaces of the boulders and outcrops in contact with the air dry quickly after each shower. Weathering on these exposed surfaces is mainly effected by lichens and algae growing on the bare rock (Bakker 1960, Rondeau 1958), and proceeds much more slowly. This means that the rock, once removed from the weathering zone, is much more resistant, and is preserved at the surface as boulders and tors (Fig. 8).

In the chapter on relief features we will see that, accordingly, the low-angle slopes still have a thick weathering mantle, that smaller hills mostly have a core of unweathered rock and are often crowned by boulders and tors, and that the steeper slopes consist to a large extent of unweathered rock except where weathered material is preserved in joints.

So far we have considered only the intrusive, mainly coarse-grained granitic rocks. Gneisses and migmatic granites (den Tex 1961) are more resistant to weathering, making the process slower, and the jointing is often closer so that there is less tendency to form huge boulders. Nevertheless, the weathering process is similar to that in the discordant granites and, though conspicuous tors are less frequent, the surface expression is not very different.

Micaschists behave, of course, very differently. On relatively steep slopes (very steep slopes do not survive in this rock) the particles bordered by schistosity planes easily wander downslope, which causes a rounded topography, but on moist low-angle slopes weathering can again proceed to great depth and produce a thick cover of rotted rock, partly consisting of mica flakes.

A last remark concerns the clay minerals, about which more will be said in Bisdom's contribution to this series of papers. It is remarkable that in the great majority of samples of weathered Caldas granite the dominant clay mineral is halloysite, including poorly-crystallized kaolinite, with chlorite often taking second place. Gibbsite is mostly present in small amounts or traces, but is sometimes second, and in a few cases dominant; illite and dioctahedric vermiculite occur only as minor constituents. The formation of these kaolonitic minerals must have continued up to the present day because they are found everywhere, at the surface as well as at greater depth.

The dominance of minerals of the kaolonite group may be caused by a combination of conditions. One of these is the climate (Lautensach 1951, 1960). The annual precipitation is high (1455 mm for Pontevedra, 2430 mm on the exposed Cape Finisterre) and, though there is a minimum in summer, the driest months still show amounts of rainfall of about 40 mm and a high moisture content of the air. Summer temperatures are moderate (19.3 °C for Pontevedra) and do not favour strong evaporation, whereas winter temperatures are relatively high (9 ° C). This climate must be considered marginal as regards the formation of kaolinite (although the differences from Virginia, for instance, are not too great). The dominance of kaolinitic minerals, or even gibbsite, will therefore partly be due to other favourable circumstances. An important factor is probably the leaching of alkali ions from the decayed granite, as a result of which pH values are low: between 4.3 and 6 (see later contribution by Bisdom).

In a later chapter we will see that much kaolinite (including halloysite), probably produced in inter-

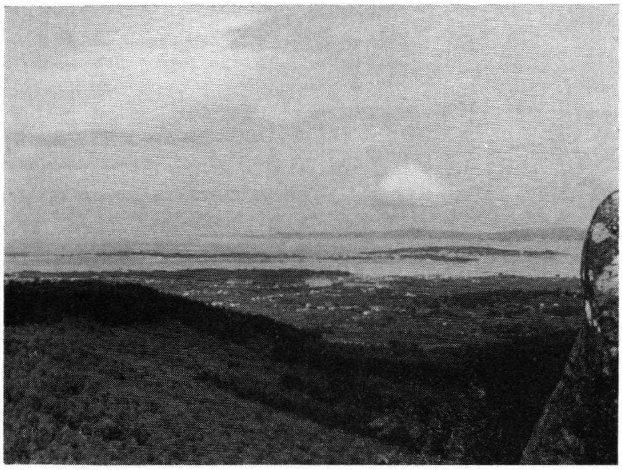

Fig. 9. Low area around the Ría de Arosa, seen from Mt. Lobeiro. Middle distance, Villanueva; behind it Isla de Arosa; in the far distance, peninsula of Ribeira.
Comarca baja alrededor de la Ría de Arosa; vista desde el M. Lobeiro. Se ve Villanueva, la Isla de Arosa y en el fondo la península de Ribeiro.

glacials or even earlier, was washed together and now locally forms a thick deposit near the shore of the Ría de Arosa. Some of the kaolinite in deep fracture zones may, however, have originated by hydrothermal alteration of the bedrock.

IV. REMARKS ON THE GEOMORPHOLOGICAL MAP

The accompanying geomorphological map has been compiled from aerial photographs and widely-scattered observations in the field. A few examples of every class of relief features that could be distinguished on the photographs and is shown on the map, were more carefully studied; a greater number was observed in the field in passing, but many have been classified solely from the photographs on the basis of their similarity with features seen in the field.

In some recent studies on the principles of preparing geomorphological maps (e.g. Klimaszewski 1956, Tricart 1963, Problems Geom. Mapping 1963) it is urged that besides a classification of relief forms, they should also contain (a) an indication of the age of every relief feature; (b) an indication of the processes by which each such feature was formed.

These requirements, however justified they may be from a theoretical standpoint, are often difficult to comply with when actually compiling a geomorphological map, for the following reasons. In the first place, many older relief features, supposing that they could be dated, have been so much modified by later events that many ages would have to be assigned to them. Secondly, various terrain forms have been shaped by the combined action of different processes and must consequently be represented on the map by an intricate pattern of combined symbols, as is seen, for instance, on Tricart's maps.

Because of these difficulties neither ages nor processes are given on the accompanying map, which merely registers terrain features according to some adopted classification. The map is, therefore, morphographical rather than morphological. The characteristics of the adopted classes of relief features will be described in the next chapter, with the addition, as far as possible, of remarks on the processes by which they were formed.

Some features known to be present in the area will be found missing on the map, for instance fluvial and marine terraces. On the aerial photographs these terraces could not be distinguished from flat parts of the low-angle slopes, occurring where weathering products or colluvium is preserved on the up-slope side of a hard-rock mound (see Chapter V). The only criterion for distinguishing fluvial terraces would have been their sediments.

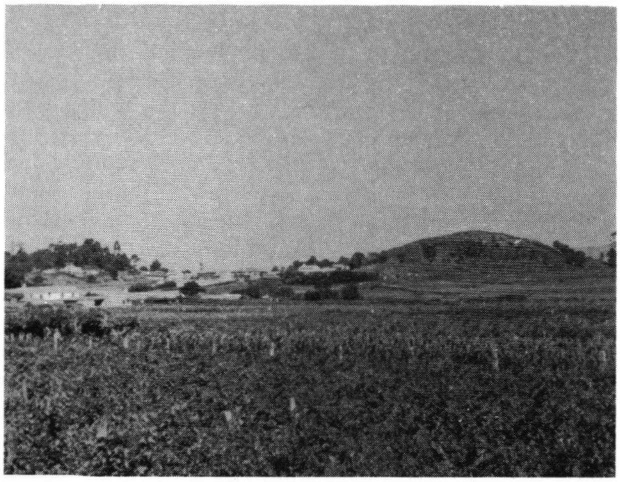

Fig. 10. Circular residual hills surrounded by low-angle slopes, south of Cambados.
Colinas residuales circulares, rodeadas de pendientes débiles, al sur de Cambados.

Fig. 11. Concave break of slope between northern extension of Acibal massif and low-angle slopes.
Linea entre pendiente escarpada y pendiente débil, al norte del macizo del Acibal.

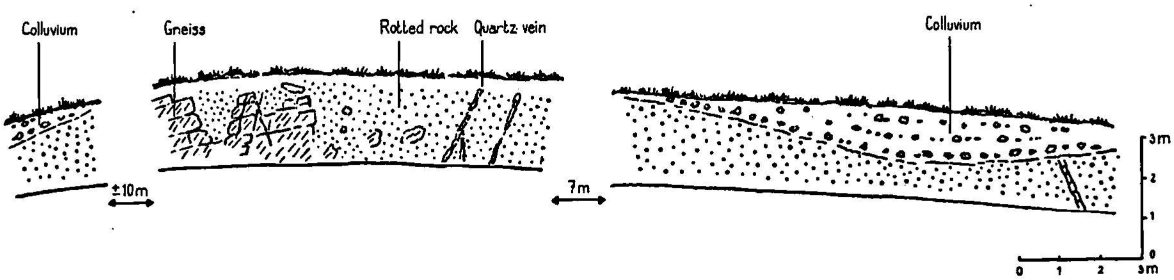

Fig. 12. Section through low hill with low-angle slopes, Poyo.
Corte a través una colina con pendientes débiles (punteada: roca desagregada), Poyo.

V. RELIEF FEATURES

A. Low-angle slopes

The low-angle slopes and low hills occupy an extensive low area around the Ría de Arosa, much larger than any around the other rias (Fig. 9). They are attached as foot-slopes (*glacis* in the French terminology) to most of the larger mountain blocks (Fig. 11), to many of the steeper rounded hills or groups of hills (Fig. 14C) and lastly to insignificant hills (Fig. 14B) which are often no more than a few granite blocks or boulders. In the last cases the low-angle slopes are not so much foot slopes as parts of a gently rolling relief (a similar type of relief on weathered granite is described by Ollier, 1965, from Australia).

The slope angles vary between wide limits: especially in the lower parts and in the gently rolling country just mentioned, they amount to 1—2°, whereas in the upper parts, from which steeper hills or mountain slopes rise up, the slope angle may be 5° or even 6—7°. These low-angle slopes are never uninterrupted inclined planes. In the first place, they are always dissected by shallow valleys (Fig. 14B), often with a rounded cross-profile and usually varying in depth between some 2 and 10 metres, generally at distances of 200—1000 m. Extensive cultivation with terracing and irrigation has, however, often modified the original shapes of these minor valleys.

In the second place, the low-angle slopes are irregular because they are often interrupted by small mounds (Fig. 11), consisting of unweathered crystalline rock or of a few boulders of unweathered rock piercing through the waste mantle (Fig. 12). This causes the slightly hummocky surface of many low slopes. The geomorphological map gives only the main mounds showing up clearly on the aerial photographs or conspicuous in the field (Fig. 10).

The material on which the low-angle slopes have developed is, as far as we could observe, either decayed rock or colluvium on top of rotted rock, and never hard rock except where the latter pierces through the waste mantle to form the small hillocks. This is shown in various road cuts and some quarries, though they are seldom deep enough to disclose the base of the decayed rock.

The example shown in Fig. 12 is a road-cut through a low-angle hill on gneiss. In the centre there is a remainder of hard rock, which may explain why there is a hill, whereas on the flanks soft decayed rock is exposed, with colluvium on the lower slopes.

Among the numerous profiles examined and sampled by E.B.A. Bisdom (see later contribution) there are examples in which the decayed rock is uncovered up to the surface, as well as examples in which it is covered by one or even several sheets of colluvium, some with a layer of angular gravel at their base (Fig. 13) and sometimes containing angular stones up to 15 cm long. The rotted rock below the colluvium is mostly devoid of a complete soil profile, so that it must have been truncated before the colluvium was deposited on it.

The nature of the process or processes by which the

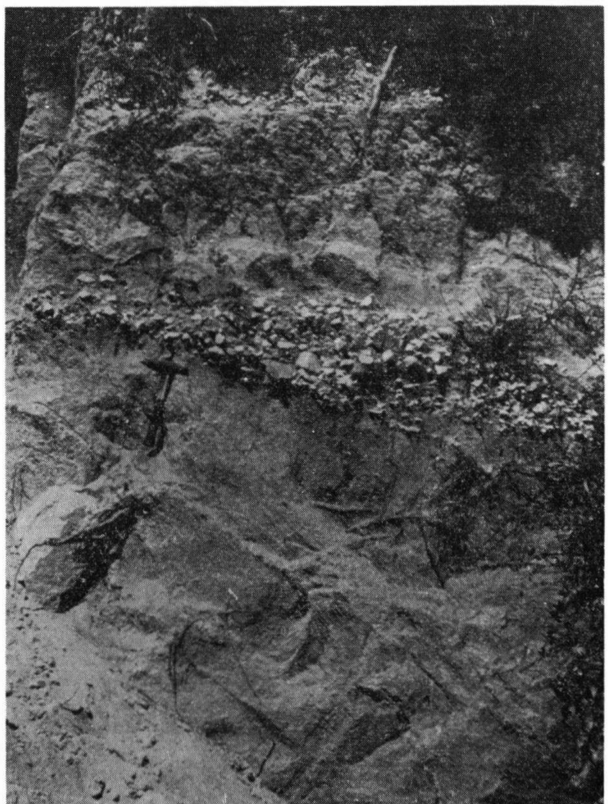

Fig. 13. Colluvium on top of rotted rock, northeast of Cambados.
Coluviones encima de granito desagregado, al NE de Cambados.

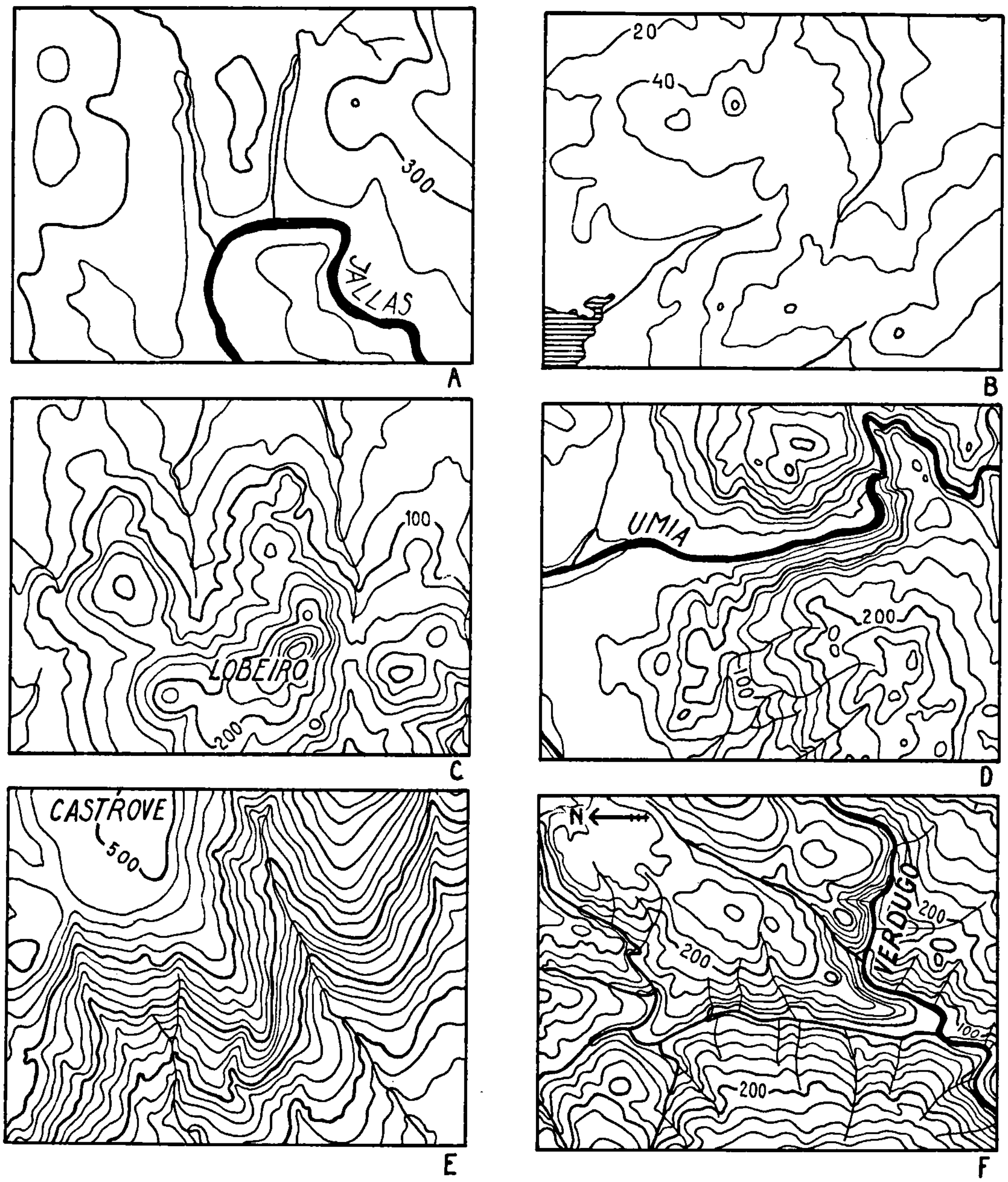

Fig. 14. Relief types. Scale 1 : 50 000.
Tipos de relieve. Escala 1 : 50 000.

A. River Jallas on the Galician peneplain near Brandomil (sheet 68).
Rio Jallas en su curso en la penillanura gallega, cerca de Brandomil (*hoja* 68).

B. Low-angle slopes surrounding small residual hills (sheet 152).
Pendientes débiles alrededor de unas colinas residuales al sur de Cambados (*hoja* 152).

C. Large, conical residual hills in Caldas granite, with low-angle footslopes and concave break. Mt. Lobeiro (sheet 152).
Largas colinas residuales cónicas en el granito de Caldas. M. Lobeiro, con pendientes débiles al pie (*hoja* 152).

D. Flat-topped hills of medium height. River Umia crossing the N-S rift zone at Caldas de Reyes; intrenched valley upstream (sheet 152).
Colinas cubiertas de una superficie de altura media. A la izquierda el río Umia cruza la fosa central, a la derecha el río está encajado (*hoja* 152).

E. Steep slope of Castrove massif, with flat surface at its top, and low-angle slope at its foot (sheet 185).
Pendiente escarpado del macizo del Castrove. Encima se ve la superficie alta, al pie un pendiente débil (*hoja* 185).

F. Rectilinear valley pattern, east of Mt. Taboadela (sheet 185, north is to the left).
Cursos fluviales rectilíneos al este del M. Taboadela (*hoja* 185, *el norte está a la izquierda*).

Fig. 15. Bedded slope deposit near Noalla.
Depósitos de pendiente estratificados cerca de Noalla.

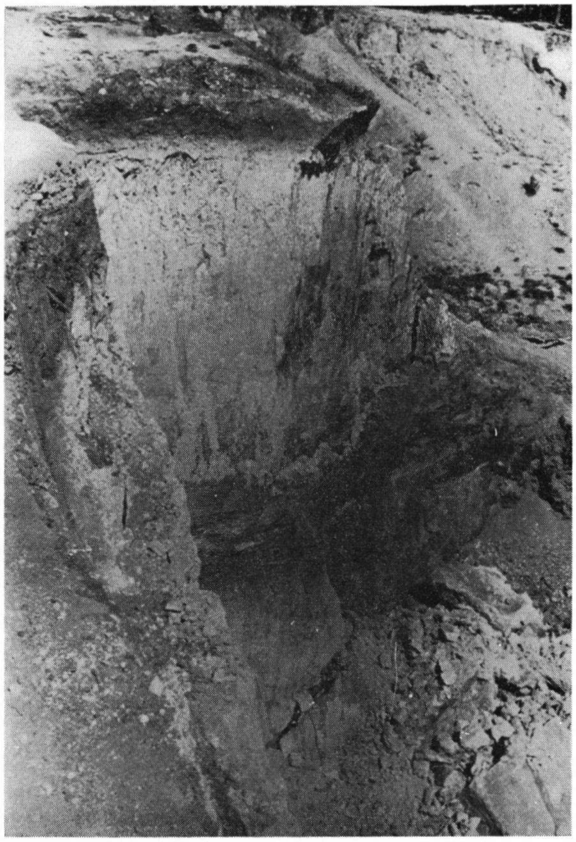

Fig. 16. Bedded kaolinite deposit near Fianteiro.
Depósito de caolinita estratificado cerca de Fianteiro.

colluvium was transported and deposited is difficult to establish, and was not yet investigated (some information on this subject will be given in a later contribution by Bisdom). It may have been rain wash combined with some soil flow. These processes could have been active only if the vegetation was much scarcer than now. We are inclined to assign them to the cold periods of the Quaternary. Similar processes are recorded from the glacials in the Mediterranean area (de Vaumas 1964, Butzer 1964).

This is not to say that the low-angle slopes themselves on which the colluvium rests, and which consist mainly of rotted rock, are exclusively products of the same processes, though this is possible. Supporting argument is that the bottom topography (see Chapter IX A) of the Ría de Arosa resembles that found on land, and this bottom topography could only have been shaped by these processes if the sea-level was much lower than it now is, i.e. in the glacial periods. We will see, however, that part of the lower slopes already existed before the last glacial, and probably earlier. Accordingly, various slope processes acting during the Quaternary, if not before, may have contributed to the formation of the low-angle slopes.

Low-angle slopes also occur at higher altitudes, but they are included on the geomorphological map in the high surfaces and the intermediate surfaces of mountain massifs and hill ranges.

Bedded slope deposits. — At some places the low-angle slopes are covered by deposits that are distinctly though irregularly bedded, and consist of sand and mostly subangular pebbles in alternating layers, albeit rather mixed, and lenses or beds of kaolinitic clay (Fig. 15). Nonn (1964) described these deposits for various sites (near Puentecesures, Meaño-Dena, Noalla) and applied to them the term „torrential". Because a torrent suggests a linear mode of transportation and these deposits cover larger surfaces, I would rather suggest strong slope wash to have been responsible for transporting the finer deposits, occasionally alternating with sheetfloods or muddy flows that were also able to transport the pebbles (or even boulders); the exact nature of the process could not be decided.

The bedded deposit at Noalla (Fig. 15) covers a long, pediment-like slope of a hill of only moderate height (Montefaro near Vilalonga, 168 m), mostly consisting of weathered mica schist, with some granite intrusions.

The deposit becomes more clayey downslope and probably grades into the thick kaolinite deposit of Fianteira (Fig. 16), which covers at least 6 sq. km and is extracted in many pits for brick making or transportation overseas to ceramic industries. The exposed thickness is at least 8 m, and at various levels there are streaks or layers of angular quartz gravels. The deposit continues beyond the coast and underlies the thin tidal flat deposits of the bay of El Grove.

It is difficult to assign an age to the bedded deposits, which contain no plant remains or other fossils. The following facts may help to form at least some idea about this point.
(a) According to Nonn (1964), elements of the bedded deposits occur in Monastirian beaches, so the bedded slope deposits must be older than last interglacial.
(b) Locally, a typical colluvium is found lying on top of the bedded deposits.
(c) The clayey deposits of Fianteira are partly situated below the present sea-level; it is not known to what depth they continue.
(d) A slope deposit directly east of Villagarcía, containing large granitic and quartz boulders (Fig. 17), occurs on the southern slope (and reaching up to very near the top) of a low hill (28 m) and overlies rotted schists with small granite dykes. It is unlikely that the hill itself can have produced the numerous granite boulders (up to 40 cm long). This means that the deposit was laid down before a wide, shallow valley separated the hill from the granitic hills further north. Some of the granitic boulders have completely weathered to sand, obviously after their transportation. Both facts are indicative of a considerable age of the deposit.
(e) A bedded deposit near Dena overlies what is probably a paleosol in clayey rotted rock, red-yellow in patches.
From these facts it follows that the bedded slope deposits must be older than the last part of the Quaternary. Nonn (1964) suggests, as one of two possibilities, assigning them to the older glacials: Günz, Mindel, or even Riss. During these periods rainfall could well have been intermittent but intense (pluvials) and vegetation perhaps less dense than now, which would have favoured strong slopewash with occasional sheetfloods. The lowered sea-level would have allowed the deposits to extend below the present level of the sea; it is not necessary, then, to resort to subsequent tilting to explain their location below the sea-level.
This would mean that at the time of deposition the low-angle slopes were already in existence, at least in places, and that the major features of the relief must have been formed before at least the middle part of the Quaternary, however vague this term may be. The weathering below the bedded slope deposits and below some terrace deposits may then date from the oldest interglacials and earlier.
Another possibility suggested by Nonn is the formation of the low-angle slopes with their deposits in the drier Villafranchian, which would make the relief still older and refer the deep weathering to a more humid phase of the Villafranchian or to the Pliocene. This corresponds with Tricart's opinion (1964) when he correlates *glacis* deposits in southern Galicia (near Tuy and Porriño) with the Villafranchian *ranha* déposits in Portugal. The evidence is not conclusive, however, because similar slope deposits can have been formed at various times during the Quaternary, and granite weathering has continued ever since, up to the present. Neither is there any indication of the extensive area of low-angle slopes around the Ría de Arosa being a subsided part of a Tertiary peneplain, as was suspected by Birot & Solé Sabaris (1954, p. 50, 54). It is rather a product of denudation on easily weatherable rock, a denudation having been active, under various modifications, since Tertiary times to the present day.

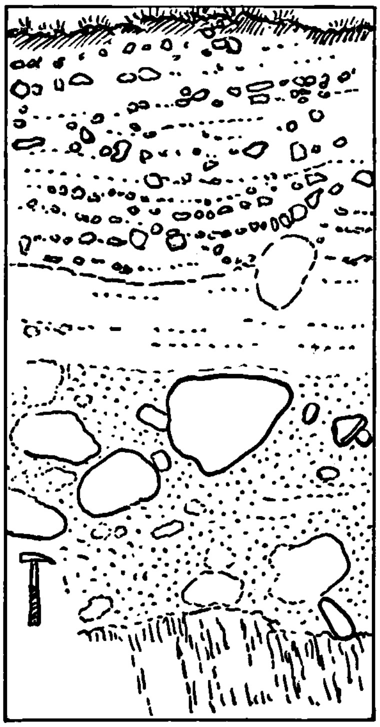

Fig. 17. Bedded slope deposit with granite boulders on top of weathered schists, east of Villagarcía de Arosa. *Depósitos de pendiente estratificados con cantos de granito, encima de esquistos meteorizados. Al este de Villagarcía de Arosa.*

B. Rounded hills.

Under this heading we collect a variety of relief features, all of which have the character of residual hills. This group may be subdivided, according to form and size, into the following subgroups (this subdivision is, however, rather artifical because actually there are gradual transitions between them):
(a1) small isolated conical hills with a rounded top and concave base (Fig. 10, 14B), often crowned by tors of crystalline rock or groups of boulders; the lowest and smallest are not shown on the map and form parts of the low-angle slopes;
(a2) irregular groups of such conical hills which together form small ranges;
(b) larger ranges of hills, with heights of up to some 250 m, and several kilometres long, whose individual tops are again rounded and mostly crowned by boulders, tors, or domes of unweathered crystalline rock (Fig. 8, 14C);
(c) larger hill ranges crowned by a flatter surface, to be described in the next paragraph.
The hills of this group pass at their base into the low-angle slopes, sometimes gradually but more often with

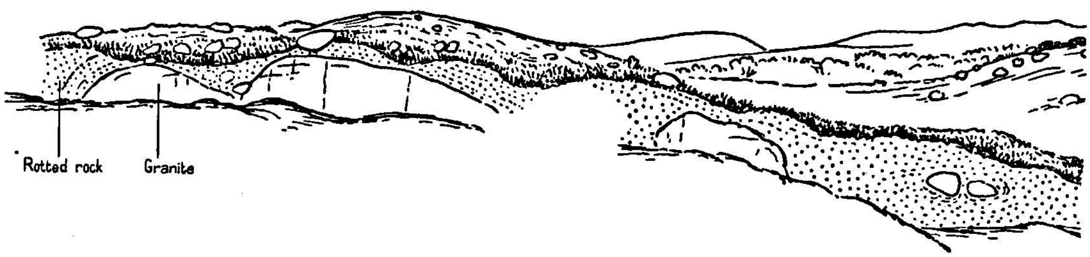

Fig. 18. Section through residual hill in granite near Nogueira.
Corte a través una colina residual de granito (punteado: granito desagregado), cerca de Nogueira.

a convex break of slope (Fig. 11); for the larger ranges this break is indicated on the geomorphological map by a line.

Some road cuts and quarries permit observation of the material composing such hills. As an example, we show in Fig. 18 a hill in Caldas granite near Nogueira, disclosed by a long quarry. The fresh granite rises to near the surface in two rounded masses, topped by some loose boulders that reach the surface, but on both sides the whole quarry wall, about 10 m high, again consists of rotted rock weathered to coarse sand, containing some floating granite boulders. The fact that so much sandy rotted rock is preserved here is in this case due to the circumstance that the hill forms part of a group: in the space between the rock cores of the individual hills more sandy material could be preserved than in the case of an isolated hill.

The steeper slopes of individual hills often show more of the unweathered rock, either as large boulders or as outcrops of the bedrock, but between them the sandy rotted rock is always present, fixed by vegetation.

In most cases the hill core consists of a single granite dome. At such places exfoliation (or sheeting) can sometimes be observed, for instance in some larger granite quarries near Villagarcía. Near the surface, however, weathering in the vertical joints causes most of the exfoliation sheets to fall apart into blocks and boulders.

Fig. 19. Inner part of Ría de Arosa, surrounded by mountain massifs (left: Barbanza, right: Muralla). Seen from Mt. Lobeiro towards Villagarcía de Arosa and Cortegada Island.
Parte interior de la Ría de Arosa, rodeado de macizos montañosos (Barbanza a la izquierda, Muralla al derecho). Vista del M. Lobeiro hacia Villagarcía de Arosa y la Isla de Cortegada.

C. Mountain massifs

The main mountain massifs are characterized by steep flanks and a flatter undulating surface, mostly at an altitude of between 500 and 600 m. A number of them surround the Caldas granite and the Ría de Arosa in a wide circle (Fig. 19). They are found on gneisses, other metamorphic rocks, and migmatic granites, but not on the intrusive Caldas granite itself, which is always topographically lower. The names by which they are indicated on our map are taken from those of conspicuous tops according to the topographical map sheets, and are mostly in accordance with those used by Parga Pondal, although other authors sometimes use different names.

As a separate sub-group we have included some smaller and lower mountains, rising up to less than 300 m, which have already been mentioned with group B under c. They differ from the rounded hills of group B.b only by their rather flat undulating top surface.

The s l o p e s of the higher massifs form in their steeper parts (Fig. 20) slope angles of about 20°, but they are much less steep (7—10°) at the spurs where the slope becomes much more gradual. On the steeper slopes much unweathered rock is exposed, but on closer

Fig. 20. Steep regular slope of Mt. Giabre.
Pendiente escarpado y regular del M. Giabr..

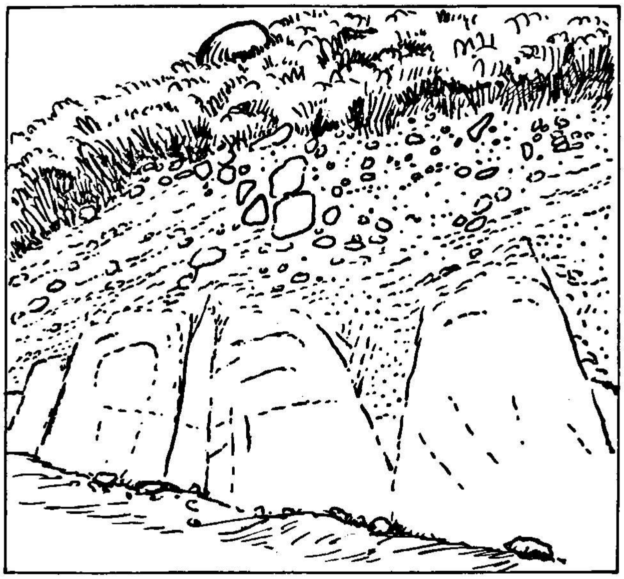

Fig. 21. Slope deposit on northern slope of Mt. Castrove (in medium-grained two mica granite).
Deposito de pendiente sobre el pendiente septentrional del M. Castrove (en granito de dos micas de grano medio).

inspection and in road cuts this rock is found to belong only in part to the rock core; many parts consist of boulders and blocks between which, in widened fractures, some rotted rock still remains, overlain by colluvium and slope debris (Fig. 21).
Where the mountain slopes are bordered at their base by a low-angle slope there is often a concave break, and when there is a distinctly flatter top surface, there is a convex break at the upper margins (Fig. 14E).
Although the bare rock outcropping on the steep slopes itself weathers only slowly, the occurrence of numerous detached blocks on these slopes shows that they must be capable of receding considerably. Weathering proceeds in the joints, including those parallel to the surface, and as soon as a block is loosened it can move

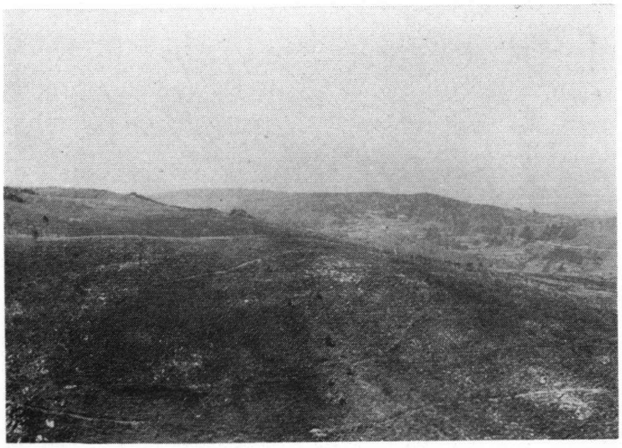

Fig. 22. Top surface of San Mamed, western part of Castrove massif.
Superficie de San Mamed, parte occidental del Macizo de Castrove.

slowly downward because it is lying on weathered material. Much of the weathered material, however, is washed down more rapidly towards the lower part of the slope, where it accumulates for some time. This cover of waste material furthers weathering of the underlying rock until it can easily be washed away. This process could have led to the formation of the flatter foot-slopes.
On the map the mountain massifs show irregular indented outlines in many places. The re-entrants are in part narrow erosion valleys, in part wide bays (called „*alvéoles*" by the French) probably resulting from differences in the velocity at which the slope receded, though helped by erosion. It is, therefore, not to be expected that the steep slopes can still be found anywhere at the places where they originated, whether as fault scarp or as valley wall.
The t o p s u r f a c e s of the mountain blocks, though in various cases conspicuously flatter than the steep flanks (Fig. 22), are actually undulating, often with slope angles of between 3° and 7° and rarely less

Fig. 23. Hills on top surface of Castiñeira massif.
Colinitas en la superficie superior del macizo de Castiñeira.

(Fig. 23). Occasionally, somewhat steeper steps separate two flatter parts with different heights, and often larger rounded hills rise out of the flatter undulating surface. Moreover, on these plateaus there occur many smaller rocks (Fig. 23, 24) which, as can be seen on the aerial photographs, are determined by major fractures between them (see also Fig. 29).
Small valleys run over the larger top surfaces, in directions also clearly determined by fractures, and they are often dry because the water infiltrates through the deeply weathered fractures. They have flat longitudinal profiles until they approach the flank of the massif, from which they run down steeply as sharply V-shaped valleys, whose directions are again determined by those of main fractures or zones of weaker rocks.
Fracture patterns, which show up so clearly on the aerial photographs (see Fig. 29), are much more frequent on the top surfaces and flanks of the mountain blocks than in the low hills and lowlands. In these

latter areas they are to a large extent obliterated by the thick mantle of rotted rock. On the steeper slopes and mountain tops, however, the fresh rock between the fractures is often cleared of waste material, the latter being preserved only in the fracture zones where it can penetrate deeply between the fresh rock. These zones carry a somewhat denser vegatation appearing as dark lines on the photographs.

It is a familiar experience to photo-geologists that on the terrain, when covered by vegetation, no pattern can be distinguished (Rondeau 1961), no more than a fly would be able to recognize the pattern of a Persian rug when walking over it. When, however, a steep mountain slope cleared of trees is seen from a distance, the pattern is as distinct as on an aerial photograph (see, for instance, Fig. 11). It is still clearer on bare mountain slopes and even low hills facing the ocean, where waste material is more rapidly washed down, or sometimes swept inland, during strong western storms (as for example on the Pindo granite or on Mt. Silleiro, both outside our map-area, or on the peninsula of Ribeira).

The parts of the mountain massifs consisting of metamorphic schists differ from those in granites and gneisses. Their surfaces are much more rounded and there is no clear boundary between a steeper slope and a flatter top surface. The parts with such rounded forms are indicated by a different colour on the map.

Another subgroup is that of the lower hills with steep slopes and a flatter top surface already mentioned. Examples are the range SE of Caldas de Reyes (Fig. 14D), the hill (Monte Celo) NW of Pontevedra, and the Chandelore NE of Sangenjo. In all three cases, the undulating top surfaces are at a height of about 250 m. On the geomorphological map the same colour is used for flatter surfaces at between 250 and 350 m, which are often found leaning against higher massifs but are themselves bordered by steeper slopes at a lower level. Sometimes, however, the transitions are so gradual that an intermediate level cannot be clearly distinguished.

The question has been raised (Birot & Solé Sabaris 1954) as to whether the flat-topped surfaces of at least some of the higher mountain-massifs were once parts of the same peneplain still covering northwestern Galicia, from which they were separated by either erosion or subsidence of the intervening areas. The heights are, indeed, not very different. The hypothesis seems to us by no means impossible, and we will return to this point later.

The same authors presume a tilting of some of the massifs situated between the rias, by which the top surfaces became inclined. Slightly inclined surfaces, however, are common features on peneplains, and as yet the arguments for tilting are not conclusive.

If the top surfaces of the higher massifs could be remnants of a peneplain, it is equally possible that the surfaces of the lower massifs (250—350 m) are remnants of a lower peneplaned surface, one which perhaps also exists in northern Galicia. It may once have covered large areas, also on the Caldas granite, but

Fig. 24. Bedrock and boulders on a hill on the top surface of the Castrove massif.
Afloramiento y bolas en una colina en la superficie superior del macizo de Castrove.

been destroyed by continued denudation and erosion in most places. Our finding of a few well-rounded pebbles in a soil at about 250 m, near the top of Mt. Lobeiro, may be indicative for the existence of a former river at this level, but is not conclusive. Only observations from a much larger part of Galicia may bring evidence whether or not such an intermediate erosion level once existed.

D. Valley forms

Only a few special valley forms are distinguished on the map by separate symbols. They are:

(a) the most conspicuous sharply V-shaped valleys that run steeply down from the mountain massifs;

(b) steeply-walled valleys of larger rivers when intrenched in a flatter relief on one or both sides;

(c) alluvial valley floors, including those in which the river is slightly incised so that they are not flooded during high water. The same colour has been used for former coastal lagoons now silted up by rivers or small streams, or in some cases by eolian sand or by the sea when it occasionally flooded the plain.

Not represented by separate symbols are:

(a) the numerous shallow valleys with rounded cross-section dissecting the low-angle slopes;

(b) smaller valleys coming down from mountain slopes;

(c) the valleys of the larger rivers, because their slopes are for the most part indicated by the symbols for the various slope types.

VI. LONGITUDINAL PROFILES OF THE MAIN RIVERS AND THEIR IMPORTANCE FOR THE RIA PROBLEM

Upper courses of the main rivers of the Galician „peneplain" in the north are not incised in narrow valleys but, as mentioned in the first chapter, flow in wide shallow depressions on the peneplain (Fig. 14A). Only on approaching the coast do they descend steeply in gorges with rapids. This is most conspicuous in the case of the Jallas River, which less than 1 km upstream from its mouth is still at a height of 100 m[1]. The descent of the larger Tambre River is less sudden: it takes 6 km, measured along a straight line, to overcome a difference in height of 100 m.

Most of the rivers more to the south also have a section with a strong slope where the river is becoming intrenched in a narrow valley or gorge. These steeper parts, however, are always situated to the east, i.e. upstreams from the N-S rift zone.

The Ulla passes through such a narrow gorge east of Padrón (Fig. 25), though the steeper slope in this case has receded much farther upstream. The Umia runs in a gorge east of Caldas de Reyes (Fig. 14D), in which it overcomes a difference in altitude of 100 m in 2 km. In the case of the Lerez the steeper part has again retreated more upstream: the river passes the 100 m contour 13 km upstream from its mouth; but in the narrow valley of the Verdugo the 100 m point lies only 6 km from the mouth. The large Miño River, as can be expected, behaves differently: it has a long lower course, and steeper stretches are only found far upstrean, some 100 km from its mouth.

The steep descent of the northern rivers (Jallas and Tambre) from the peneplain surface down to their mouths has been explained by most authors by assuming a relatively recent subsidence of the area now occupied by the sea (Birot & Solé Sabaris. 1954, even consider a relative upwarp of a zone near the coast, which zone is slightly higher than the area more inland, and which the rivers had to cross).

For the southern rivers the same role could have been played by the subsidence of the N-S rift zone. This brought a certain point or section of the river to a lower level, but apparently so slowly that erosion downstream from it could keep pace with the subsidence. These downstream parts became, so to speak, antecedent courses. Otherwise the rivers would have been diverted into the subsiding N-S rift. The upstream parts must at that time have had steep sections at the subsiding rift zone, but these sections eventually receded upstream over distances in accordance with the magnitude of the rivers: farthest in the cases of the Miño and Ulla, less far in the Lerez valley, and over short distances in the smaller Umia and Verdugo Rivers.

This explanation cannot be applied to the Ría de Muros y Noya, which does not reach the main N-S rift zone, but in the next chapter some arguments are given for the existence of a smaller N-S rift near the upper end of this ria that may have played a comparable role.

Various authors (Carlé 1947, Birot & Solé Sabaris 1954) have presumed that at the time of the subsidence of the N-S rift zone the lower river valleys, now partly filled by the rias, also subsided individually with respect to the mountain massifs between them. This is, indeed, a possibility, and we will see that there are indications for rather young movements outside the main N-S rift zone too. There is, however, much evidence in favour of the other possibility: that the lower sections of the main rivers simply followed their ori-

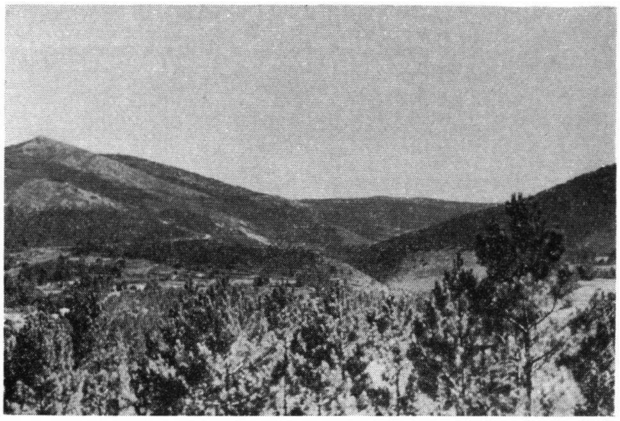

Fig. 25. Intrenched valley of river Ulla east of the N-S rift zone, looking upstream.
Valle encajado del Río Ulla al este de la fosa central. Vista hacia arriba.

ginal courses, perhaps prefigured by older fault or fracture directions, through the uprising block west of the rift zone, and eroded wide antecedent valleys in them (Pannekoek 1966). These antecendent valleys would have been situated at a low level, not much above the sea-level of that time, because an upstream point, namely the crossing of the N-S zone, had subsided. This possibility is shown schematically in Fig. 26. The erosion of these valleys and the denudation of their valley slopes must then have continued during low stands of the Quaternary sea-level. In that case the rias would owe their existence to a filling with sea water, in interglacial times, of the wide valleys eroded during the successive glacials. It implies that Quaternary erosion and denudation must have been intensive, especially during the glacial phases; similar conclusions for the Mediterranean area were drawn by, for instance, De Vaumas (1964) and Butzer (1964).

These processes, however, must have acted anyhow, even if a subsidence of the ria zones is accepted. This follows from the occurrence of kaolinitic bedded slope deposits below the present sea-level and from the similarity of the bottom topography of the Ría de Arosa with that of the surrounding land (compare bathymetric map in the foregoing contribution).

The lower course of the large Miño River is completely different from that of the other rivers more to the north. There is no ria, and the lower course is accompanied by thick interglacial terrace deposits. Nevertheless, the Miño, too, must have eroded a lower valley below the present sea-level in glacial times[2]. The reason for the difference must be found in the great amount of sediment then carried by the river Miño. This may have been supplied partly by the

[1] For this river the resistance to erosion of the Pindo granite near its mouth has been cited as an additional cause of the steep section (Birot & Solé Sabaris 1954, p. 55).

[2] Lautensach (1964, p. 459) mentions that 49 km upstream from the mouth the Pleistocene valley floor was encountered at a depth of 38 m.

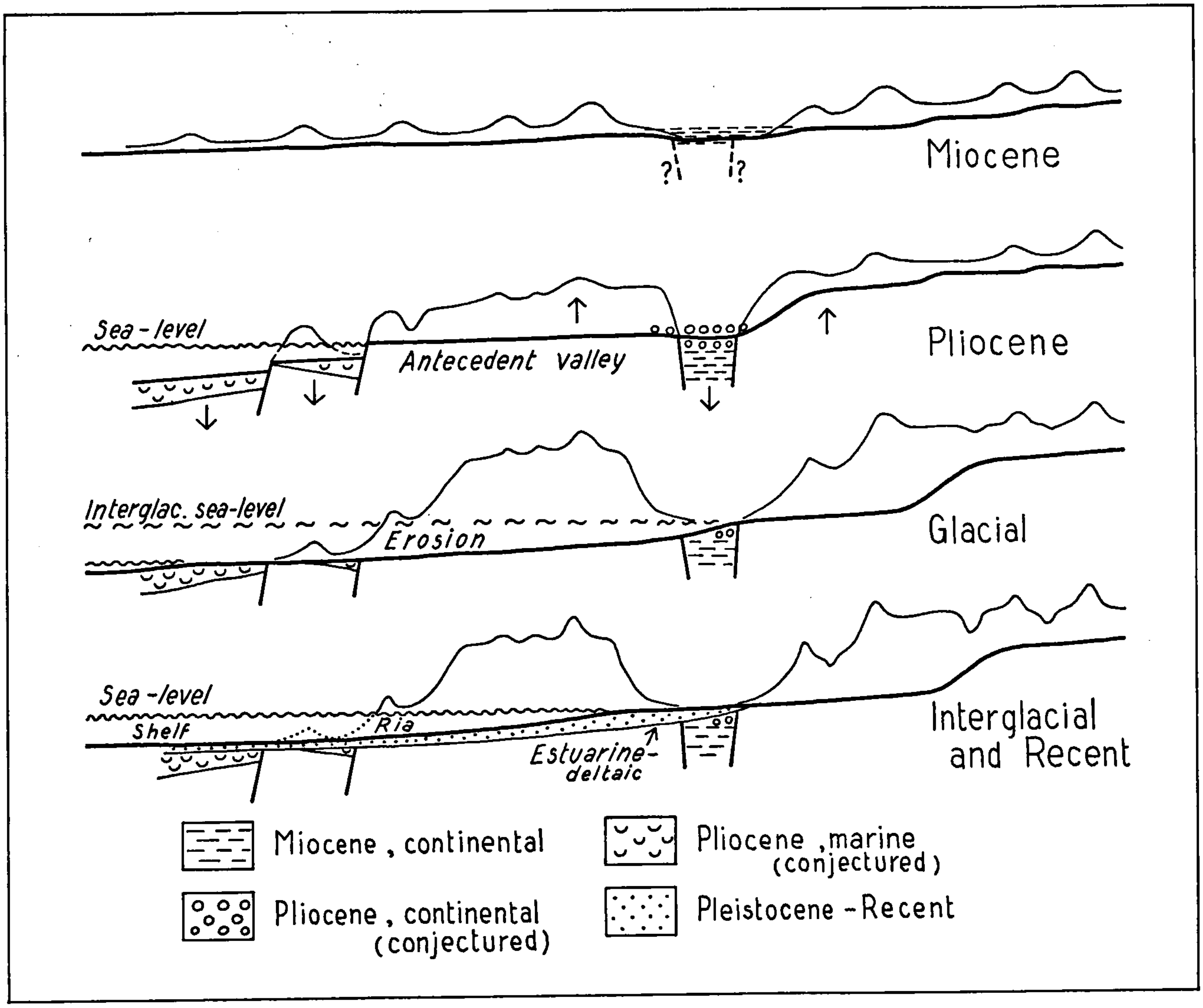

Fig. 26. Hypothetical development of the East-Galician rias (after Pannekoek 1966).
Desarrollo hipotético de las rías bajas gallegas (segun Pannekoek 1966).

rapid erosion of the poorly consolidated Tertiary sediments of the basins of Monforte, Ponferrada and others along the upper course of the Miño and its tributaries (Birot & Solé Sabaris 1954, Sluiter & Pannekoek 1964). These sediments must have filled up any initial ria of the Miño soon after every successive rise of the sealevel.

VII. DRAINAGE PATTERNS AND THEIR STRUCTURAL CONTROL

Direction of the main rivers. Considering the drainage of western Galicia and northern Portugal as a whole the most conspicuous feature is that the main rivers all run nearly in parallel, and flow roughly towards the WSW (Fig. 1), at least in their middle and lower courses. The same applies to the four main rias of the west coast, which are in line with four of these rivers (Verdugo, Lerez, Ulla, and Tambre). Only in the north, where the coast turns from a northerly to a northeasterly direction, does the river direction (Río Grande or del Puerto, Río Allones) turn to the W.
This WSW direction is not limited to the sections where the rivers are enclosed in deep valleys, as are most rivers south of the Umia. It also holds for the northern areas where some of the rivers flow on the so-called Galician peneplain, as for instance the upper course of the Río Jallas or of the Ulla S. of Mellid, both at about 300 m above sea-level.
This may be taken as an indication that the WSW direction is an old one, proper to the peneplain, and not a consequence of late-Tertiary movements. Later we will see that this direction does coincide with a major joint or fault direction, but the fact that all these rivers, even where they meander on the peneplain, flow in the same general direction is rather indicative of an original slope of the land surface.
The N-S rift zone. It is remarkable that not one of the main rivers follows for any appreciable distance the

N-S rift zone mentioned earlier. Only medium-sized or very small tributaries of the main rivers occupy this N-S zone. The largest are the Louro, a tributary of the Miño, and the Sar, a tributary of the Ulla. It looks as though at the time when this N-S rift was formed, the main rivers could maintain their courses, and that smaller tributaries sufficed to erode the fault zone until it became a long N-S depression. It must once have been partly filled with Tertiary deposits, which are now preserved in the Louro valley to a depth of at least 50 m (Explicación Hoja 261), and partly with strongly decayed rock and Quaternary deposits.

Directions of smaller valleys in relation to the fracture pattern. Whereas the meandering parts of the larger rivers seem largely independent of the structure of the basement, the smaller ones often appear to be control-

Fig. 28. Main fracture directions in granite north of Cambados, seen from above; north is towards upper margin (length of pencil 12 cm).
Direcciones principales de las fracturas en un granito al norte de Cambados; vista vertical. El norte está hacia el lado superior (el lapiz tiene 12 cm de largo).

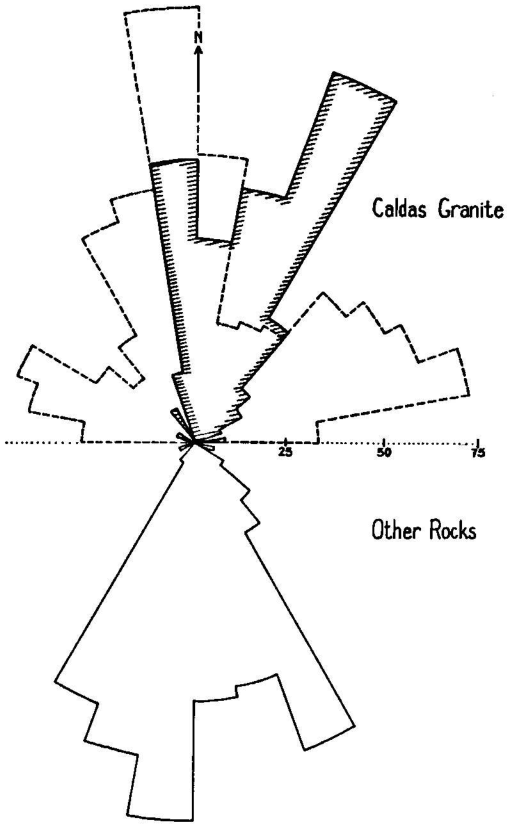

Fig. 27. Upper half, stippled: frequency of fracture directions in Caldas Granite (after E.B.A. Bisdom); drawn and hachured: frequency of rectilinear river directions in Caldas Granite.
Lower half: freqoency of rectilinear river directions in metamorphic and migmatic rocks.
Arriba, en lineas punteadas: frecuencia de direcciones de fracturas en el granito de Caldas (según E.B.A. Bisdom).
En lineas tiradas y rayadas: frecuencia de direcciones de ríos rectilineos en el granito de Caldas.
Abajo: frecuencia de direcciones de ríos rectilineos en rocas metamórficas y migmáticas.

led by major joints, faults, or differences in resistance of the crystalline rocks. Many are remarkably rectilinear (Fig. 14F), and often two streamlets or valleys running in opposite directions are exactly in line. These conspicuous rectilinear sections have been indicated by a special symbol on the map. But actually, many short sections of meandering rivers and of apparently dendritic drainage systems, and many small valleys as well, each follows a fracture[1] direction for a short distance and then curves into another, though these details are not indicated on the map.

The rivers have not, however, used all the available joint directions indiscriminately. In the Caldas Granite, for instance, there are three main joint directions, roughly in the directions N-S, N 60—70° W, and N 60—70° E. But even in a small outcrop (Fig. 28) it can be seen that each direction shows considerable variation: the joints are not strictly parallel, longer joints are often somewhat curved, and there are nearly parallel ones intersecting at very small angles. If a great many joint directions are measured (Fig. 27 upper half, stippled) the variation is found to be considerable.

The rectilinear rivers in the Caldas Granite (Fig. 27, upper half, hachured) do in part follow the N-S direction but not the N 60 W or N 60 E directions. On the other hand, they show a maximum frequency in the direction N 20—30° E that is not a maximum in the fracture frequency.

A similar picture arises when the river directions in the metamorphic and migmatic areas surrounding the Caldas Granite are considered (Fig. 27, lower half). There is again a maximum in the directions between N and N 30° E, but a second maximum appears in the direction N 20—30° W, the strike of the metamorphic rocks; this latter maximum is

[1] The term fracture is used in a general sense, including various types of joints, cleavage, foliation, and faults.

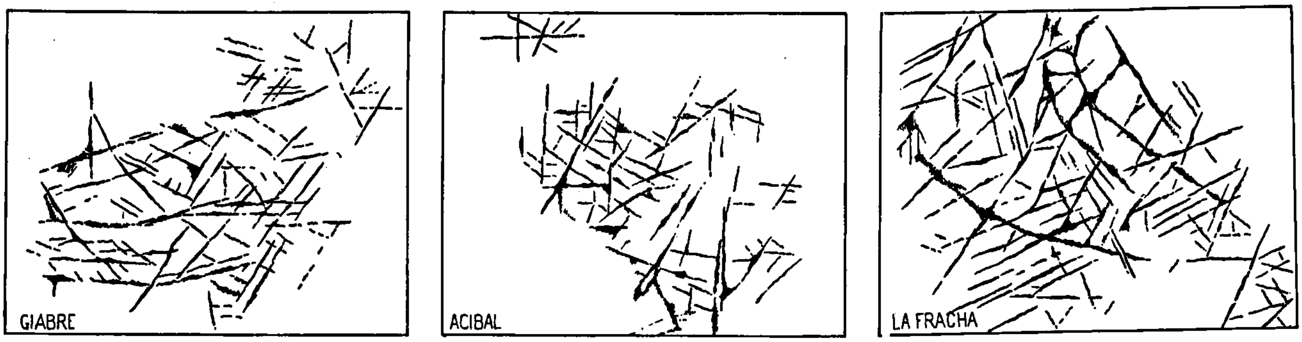

Fig. 29. Fracture patterns on three mountain massifs. Scale 1 : 57 000. The width of the lines indicates approximately the width to which a fracture has weathered at the surface.
Lineas de fractura en tres macizos montañosos. Escala 1 : 57 000. *La anchura de las lineas indica la anchura que las fracturas han obtenido por meteorización.*

caused by rivers following weaker schist zones between the more resistant migmatic granites or gneisses. Here again the rivers seem to ignore the other fracture directions that can be taken from, for instance, Von Raumer's (1963) diagrams; he found maxima in the directions N-S, NE-SW, and, albeit less pronounced, E-W, although he adds: „The result is a confused picture, because locally one or the other direction may prevail".

The great variability is also apparent from an analysis of fracture patterns on aerial photographs, such as those in Fig. 29 for three surfaces of mountain massifs. Some directions occur frequently on all three diagrams, but others are much more conspicuous in one area than in the other. The preferred river direction of N 20—30° E is clearly represented, but the more northerly directions are less numerous than would be expected.

From these facts taken together it appears that the rivers show a preference for particular fracture directions, especially those between N-S and N 30° E, and ignore others (see also Murawski 1964). It may be that the joints along these preferred directions are of another kind, more open and therefore more suited to erosion, and that the others are more compressed. But this is not quite in accordance with the presumed Hercynian stress pattern, which should show a compression directed N 50—70° E. Another possibility is that the preferred river directions are partially determined by later reactivation of certain fracture directions, in conjunction with the reactivation of certain faults in Tertiary times.

It is noteworthy that the described stream pattern differs from that in northern Portugal (Feio & Soeiro de Brito 1950), where the rectangular or triangular drainage patterns mentioned in so many textbooks are more nearly realized.

Fault directions. Among the faults having been active in Tertiary times there need not be much doubt concerning those bordering the N-S zone. They seem to have been for a part wrench faults in Hercynian times, but there are as yet no indications for horizontal displacements during their Tertiary reactivation. Although as a whole the rift zone runs N-S, in detail it is not as straight as it seems at first glance: various sections deviate from this direction (see map), and the fault pattern is probably somewhat more complicated than could be expected if it consisted of two straight and parallel faults. This gives support to the assumption that conspicuous river valleys in the direction of N 20—30° E may also be determined by reactivated faults even though these faults are not directly observable in the field.

There may be still other faults whose presence can be presumed from geomorphological evidence, implying that they may have been active in late-Tertiary times, if not later. In dealing with the mountain massifs we mentioned that some authors, particularly Birot & Solé Sabaris (1954), consider some of the steep slopes of the massifs to be fault scarps, especially on one side, causing a tilting of some of the massifs. This may be so, but, as we have already said, these slopes have been so much altered that the problem cannot be decided. Moreover, most of the massifs are bounded by steeper slopes on all sides, which is not indicative of tilting.

There, are, however, some features that conform better to what might be expected of fault scarps of relatively recent origin. One of these is the rectilinear slope bordering the Barbanza massif in the east, with a direction of 20° E. This slope is only dissected by small ravines where it crosses weak zones of metamorphic schists, and is nearly parallel to other faults assumed from geological evidence. It may be part of a downfaulted zone east of the Barbanza massif, as supposed by Carlé (1947) and Birot & Solé Sabaris (1954). The depression continues northward past Noya, where it is occupied by a northern extension of the Ría de Noya and by a deep valley. If this is indeed a tectonic depression it may have played a role in the formation of the Ría de Noya similar to that of the main rift zone in the formation of the three other rias (Chapter VI). Similar rectilinear slopes occur locally in various massifs, including parts of the western slope of the Barbanza massif. They, too, generally deviate somewhat from the N-S direction.

VIII. MARINE TERRACES

This chapter mainly concerns a discussion of some general problems related to marine terraces. More detailed information about the particular terraces around the Ría de Arosa as well as along the ocean shore is contained in later contributions to this series.

Various authors have commented on the relative paucity of marine terraces around the west-Galician rias. The lower ones, up to about 25—30 m, are generally present though not extensive, but higher levels are doubtful or absent. This is rather unfortunate, because such higher terraces could have served as evidence for possible differential movements and could have brought the ria problem nearer to its solution.

Lautensach (1932), Teixeira (1944, 1949), and Dias (1949), for instance, state that higher terrace levels recognized in Portugal become lower in a northern direction, i.e. towards the ria area. Birot & Solé Sabaris (1954), Llópis Lladó (1957), and F. Hernández-Pacheco & J. Asencio Amor (1959, 1963) mention that the high „rasa"-level of the Asturian coast descends in a western direction towards the ria area; all these authors consider these phenomena to be indications of a subsidence of Galicia after the formation of the oldest terraces; this subsidence would then have caused these terraces to be much lower in western Galicia, and have favoured the formation of the ria's.

For the apparent absence of terraces higher than about 30 m around the „rias bajas" there are, however, some reasons inherent in the erosional processes themselves. One is that wave action is obviously much weaker in the rias than on the shores of the open ocean. Scheu (1913) and Carlé (1947) already observed the narrowness of the present abrasion platforms in the rias. Moreover, some of the coasts along the open ocean are directly bordered by high mountain ranges of wave-resistant rocks and these coasts are also not favourable for the formation of broad terraces like those in Portugal, where a rather complete series is well developed.

For the granite areas, especially the Caldas granite around the Ría de Arosa, an additional reason is the weatherability of the rock, which causes an effective removal of the decayed rock and with it any terrace that may have been deposited on it. Actually, the bedded slope deposits already mentioned contain, together with badly rounded pebbles, some well-rounded ones which Nonn (1964) attributes to having been derived from such higher marine terraces, now removed.

It is therefore difficult, on the basis of the altitude of higher marine terraces, to answer the question of whether the ria area subsided with respect to Portugal or Asturia in Quaternary times. Mensching (1961) thinks it did not, at least since the early Quaternary, because he found a complete succession of levels around the Ría de Foz in northern Galicia.

Along the shores of the Ría de Arosa and the adjoining rias, the following levels can often be recognized (Nonn, 1958). (a) A widespread level only a few meters above sea-level, which sometimes grades upward into (b), a level at about 12—15 m. The deposits are already weathered and have locally been reworked by soil flow. Both levels probably belong tot the Monastirian (Tyrrhenian II—III). The lower terrace is, consequently, not of post-Würm or Flandrian age but corresponds to the Epi-Monastirian which occurs at the same level on the Mediterranean shores (Butzer & Cuerda 1962, Butzer 1964). (c) Some remnants of deposits at about 30 m altitude, considered as Tyrrhenian I. These are mostly estuarine deposits (Samil, Pontevedra, Cambados). These terrace deposits can be traced around the rias without encountering signs of tilting, which testifies to the absence of differential movements since at least the Mindel-Riss interglacial. Moreover, Mensching (1961) and Von Raumer (1963) mention a marine terrace level near 60 m at the Ría de Muros y Noya.

Lautensach (1941) thought he had observed a warping of the interglacial fluvial terraces of the river Miño. Feio (1948), however, opposes this view as being based on mistaken correlations, and most later authors agree with him. At the time of the highest terrace level, some 70 m above the present river, the southern end of the N-S depression was filled with thick gravel deposits showing no deformations, even though the underlying Tertiary sediments in this rift zone are probably warped. This also argues that differential tectonic movements had stopped at least in about the middle of Quaternary times.

The foregoing observations lead to the conclusion, as pointed out by Mensching (1961), that the west-Galician rias were in existence at least during the later half of the Quaternary. They must even have extended, during periods of high sea-level, farther inland than now, thereby flooding those parts of the N-S rift that had by then sufficiently been lowered by erosion (as can be seen at present at the inner end of the Ría de Vigo). There remains, however, the possibility that in the oldest Quaternary or the late Pliocene the uplift of Western Galicia was less than in the areas to the east or south of it.

IX. SUBMARINE TOPOGRAPHY

A. Ria bottom

In the introductory paper, which is accompanied by a bathymetrical chart, it has already been stated that a central channel more or less follows the median line of the Ría de Arosa in its outer and middle parts, though it is crossed by a transverse ridge less than 50 m in depth. On both sides of the channel the bottom appears to rise slowly in many places, resembling the low-angle slopes on land, but under water too these slopes are interrupted by steeper hills, many of which rise above sea-level as islands or small rocks. The bottom topography therefore seems to be a perfect replica of the granitic lowland and the granitic hills of the adjoining land, except for the marine sediments deposited on the former.

If this is indeed the case it can be argued that the bottom relief was formed by the same agents as the corresponding parts on land. This means that the bottom relief came into being during the times in which the ria was dry, i.e. in the colder episodes of the Quaternary. This accords with what we presumed about the colluvium on the land, which we are inclined to assign mainly to the glacial phases of the Quarternary.

The main channel must have been the course of the river Ulla of that time and actually been eroded by it. Its cross profile is not unlike the present one downstream from Puentecesures.

The central channel becomes shallow and even indistinct in the upper part of the ria near the estuary of the Ulla; this may be attributed to sedimentation at the outer end of the estuary. Also, the bottom configuration of the other wide shallow margins of the ria is probably much more the consequence of recent sedimentation than of denudation, with the exception of hills rising from the bottom (cf. Koldijk's contribution in this series). Some smaller gullies in narrow places may be due to tidal currents.

There is as yet no certainty about the nature of the transverse ridge crossing the main channel SE of Ribeira. Scheu (1913) tentatively explained it as a tectonic deformation, but nothing in the surrounding bottom topography nor that on land (which had not yet been accurately surveyed in Scheu's time) favours this explanation, so that a sedimentary origin seems more likely. It might perhaps have been a transverse dune ridge when the sea stood 70 m lower than now, afterwards flattened out by the sea during the transgression, or an area of stronger sedimention owing to a decrease in current velocity where the ria widens.

The other rias all have a similar central channel of nearly the same depth, so that a similar origin may be assumed.

B. Shelf

In contrast to the rias, the contour lines of the shelf, to judge from the more widely scattered sounding figures of the charts, show no traces of deeper channels before the mouths of the rias. The 50 fathom line (85 m), for instance, runs as a nearly straight line, with only minor curves, parallel to the main direction of the coast, including the islands.

This can only be interpreted as an indication of a great sediment transport on the shelf, mainly parallel to the coast. Because during the Riss glacial the sea was considerably lower than the 50-fathom line, one might expect that the lower river courses of that time would have made some sort of channel in the shelf. If so, it has been completely filled up since then. [1]

The same reasoning can be applied for consideration of tectonic movements along the coast. Most authors agree on interpreting the straight and partly steep coastline of northern Portugal and southern Galicia (south of the Ría de Vigo) as a fault along which a western block has subsided into the present sea. This fault is thought to extend in some way along the coast (to near Cape Finisterre) where, though not along a a straight line, the plateau-like land also suddenly breaks off. It is not to be expected that all the sunken blocks would have subsided to exactly the same depth so as to form a uniform gently sloping surface, some 35 km wide. Here again it is reasonable to assume that sediment transport filled up any depressions, together with some abrasion of higher parts. These processes could have acted during the whole of the Quaternary with its fluctuating sea-level, which caused every point of the shelf (above a depth of some 150 m) to be alternately at various depths below the level of the sea.

The sediment may to some extent have derived from the larger rivers Miño and Duero more to the south. At present, the main wind direction is north-west, but heavy storms come from the south-west; the sediment may thus have continually been moved to and fro along the coast.

There are as yet no refraction or reflection measurements or echograms available giving information on the thickness of the sediment cover on this shelf.

C. Continental slope

The continental slope in the section where the rias are situated (Fig. 30) is rather different from the section farther south along the Portuguese coast (compare Fig. 31, the latest bathymetric map in Black et al., 1964). In the Portuguese section it is sinuous and is sculptured by various submarine canyons, the largest being that of Nazaré, cutting deeply into the shelf notwithstanding its situation at a point where no large river flows or ever flowed into the sea (Andrade 1937). At the base of the slope graded deep-sea sands of continental origin have been found (Duplaix et al. 1965).

The Galician section off the ria coast descends for some 1200 or 1500 m, after which the slope decreases from 8° to about 3° and gradually passes into an undulating platform. Moreover, this section of the continental slope contains no submarine canyons [2] except a small one opposite the mouth of the Miño (Fig. 30). The reason for their absence can only be guessed. It may be that the Galician rivers north of the Miño are too small to have brought much sediment near the outer edge of the shelf, also in glacial times with their lower sea-level. The sediment now covering the Galician shelf may partly be derived, as we have said, from the larger rivers more to the south.

[1] Even the lowermost sections of the Würm rivers must have extended somewhat beyond the 50 fathom line and caused a shorter channel on the shelf, but this may not show on the charts because of the great distances between the sounding figures. Also in Japan (Hoshino 1965) the ria bottoms terminate in flat parts of the shelf of corresponding depth (80—120 m for the Würm Glacial).

[2] According to bathymetric charts of Brenot & Berthois (1962), Berthois et al. (1965), and Black et al. (1964). Their results have been supplemented by sounding lines of the Netherlands' hydrographic vessel „Snellius" (Fig. 30). The author wishes to thank the Hydrographic Office of the Royal Netherlands Navy for permission to make use of these data.

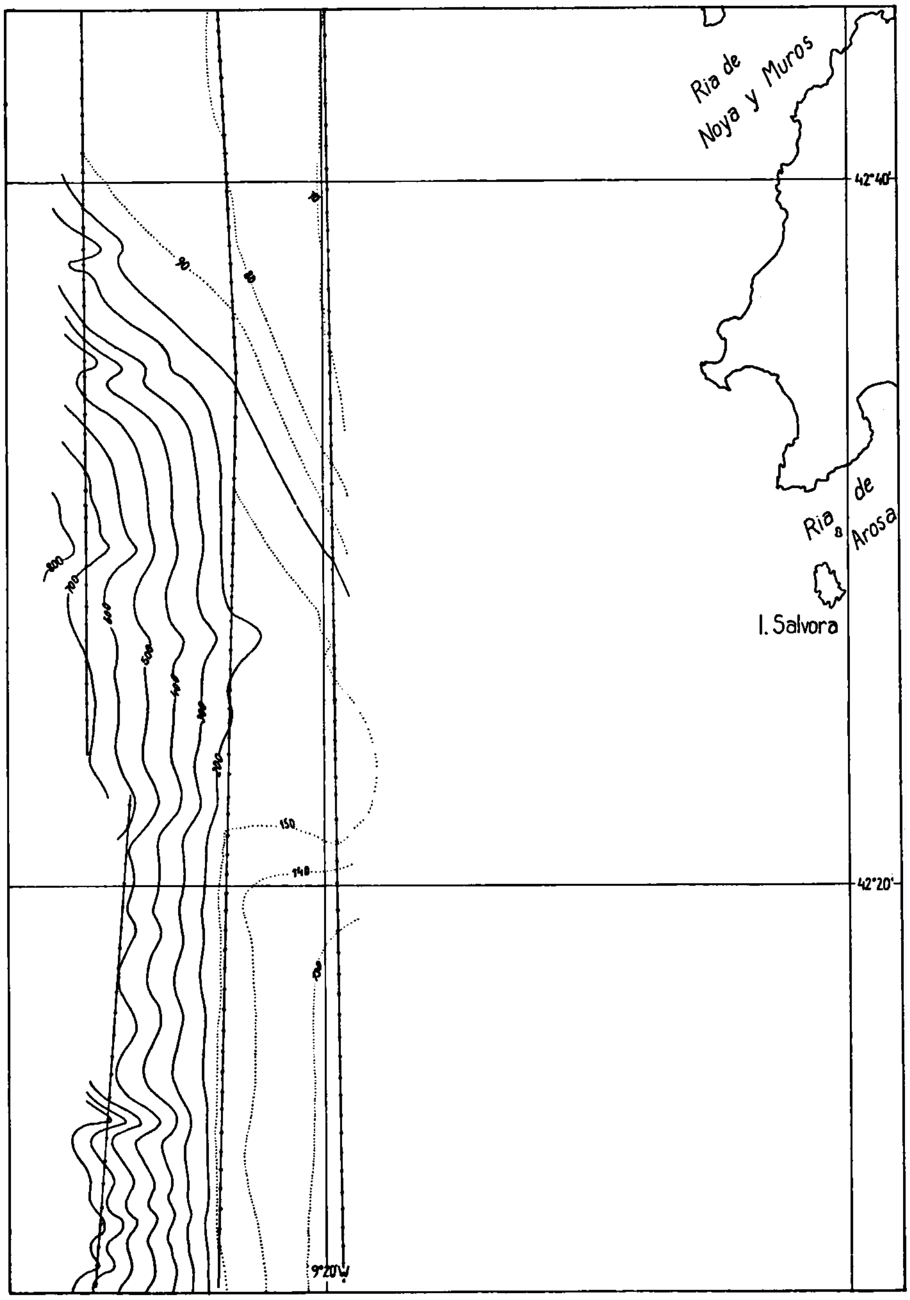

Fig. 30. Part of shelf and continental slope west of the western rias. Scale 1 : 400 000 (after soundings of the Netherlands hydrographic vessel „Snellius" 1964).
Parte de la plataforma continental y del pendiente continental al oeste de las rias bajas. Escala 1 : 400 000 (*segun sondas del buque hidrográfico holandes „Snellius"* 1964).

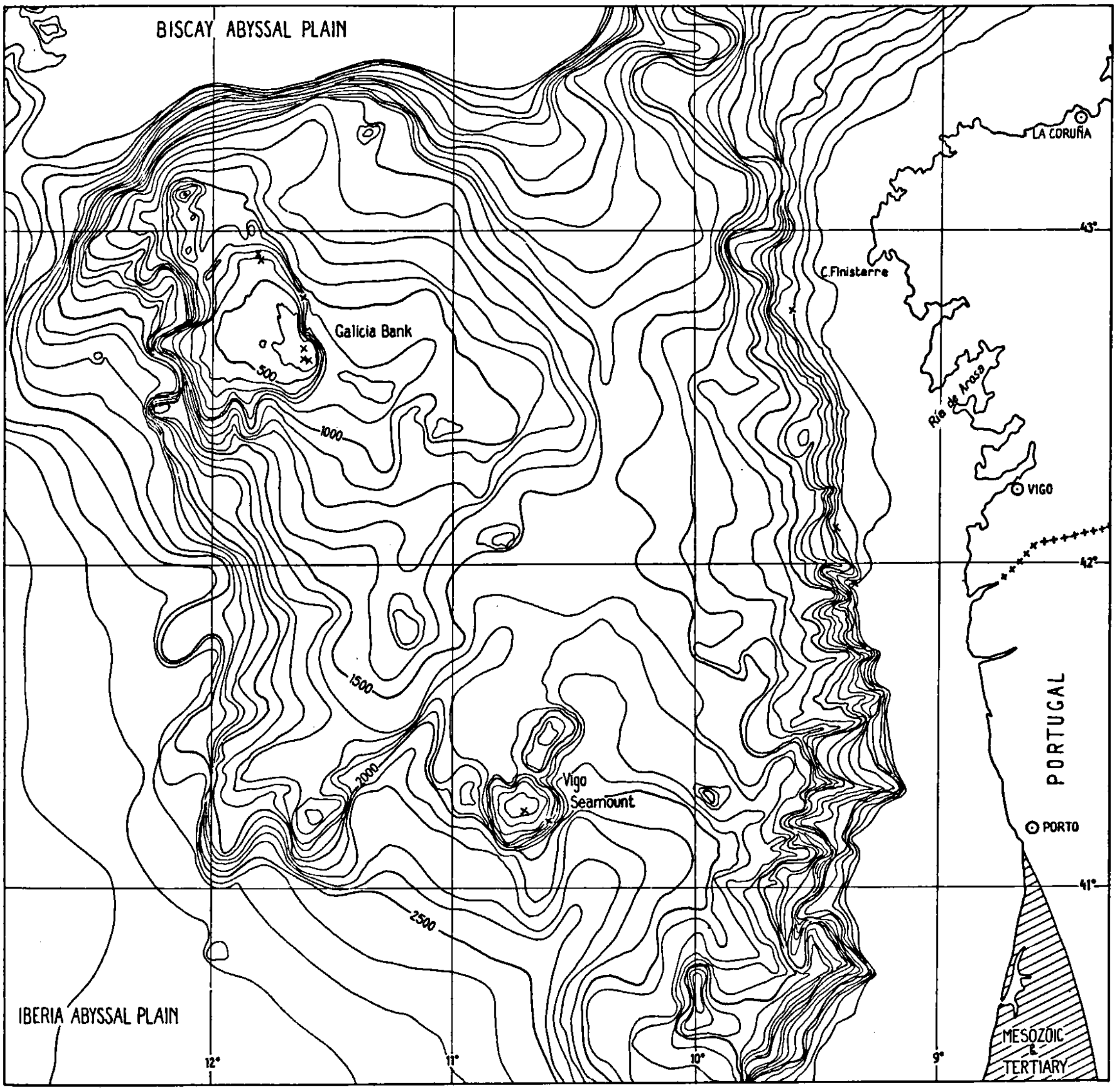

Fig. 31. Galicia Bank and its surroundings, after Black et al (1964). Scale 1 : 2 500 000. The crosses indicate locations of dredged Mesozoic or Tertiary rocks or fossils.
Banco de Galicia y sus alrededores, según Black et al (1964). *Escala* 1 : 2 500 000. *Las cruces indican localidades de rocas o fosiles mesozoicas o terciarias.*

D. Ocean floor

The above-mentioned extensive submarine platform lying before the Galician coast, has a gently undulating surface (Fig. 31, Black et al. 1964). West of the continental slope of Galicia the sea floor first has a westward slope towards a depth of 2500 m (with two deeper embayments north and south of it), after which it rises until, near the outer end, the steep-walled Galicia Bank is reached. This bank has a flat top at a depth of about 700 m (shallowest point 550 m); it is bordered on the east by a rather straight wall striking about 20° W; on the west the outline is more angular with strikes of some 20° W and 60—70° E. These steep slopes and also the linear features of the flat top suggest faults, fractures or flexures in these directions (as tentatively drawn by Bourcart, 1964, p. 99).

The platform itself[1] is separated from the Biscay Abyssal Plain on the north by a steep rectilinear slope, whereas the other slopes, towards the Iberia Abyssal Plain, are more irregular. Besides some smaller culminations the platform bears two seamounts near its southern margin.

Fortunately, some rock specimens dredged from this platform (Fig. 31) give information about the geological structure. Colom (1954) mentions the occurrence of Eocene foraminifera at three localities at the upper margin of the continental slope (i.e. 35—40 km out from the coast), respectively situated off the mouth of the Miño, opposite the southern end of the Ría de

[1] It has not in its entirety as yet received a name. I would suggest Finisterre platform, the name of Galicia already having been given to the bank. The name is, moreover, suggestive of the ending of the continent.

Vigo, and west of the Ría de Noya, at depths of 215 m, 500 m, and 600 m. Separate microfossils might, however, have been derived from land, for instance from the Basque coast, but this possibility is excluded when freshly broken rocks are dredged up. The Vigo seamount supplied such limestone fragments of possible Jurassic age, the Galicia Bank Upper Cretaceous limestone of shallow-water origin, and possibly Lower Cretaceous limestone, all of them more related to a West-Mediterranean than to a northern facies (Black et al. 1964). At both localities soft limestones with Eocene microfossils were also found. According to seismic data, the sedimentary rocks are 4 km thick (ibid.).

If the straight flexure, in Portugal separating the Mesozoic and Tertiary area in the west from the crystalline basement in the east, is traced northward along the same direction (15—20° W) it follows the coast from Porto to Viana and then runs over the shelf to west of Cape Finisterre. All the dredged rocks of Mesozoic and Tertiary age fall west of the line, and it may be presumed that the Finisterre platform is a counterpart of the Mesozoic belt of Portugal (F. Hernández-Pacheco, 1963). Hill & Vine (1965) even suggest a connection with the Mesozoic trough in the „Western Approaches" of the English Channel. The whole of the plateau need not be composed of Mesozoic and Tertiary rocks only; in Portugal, too, the basement pierces through them (Berlenga Islands). The Portuguese part of this Mesozoic-Tertiary shelf area eventually rose up, lastly after the Miocene (the marine Miocene is warped and faulted in Portugal), whereas the Finisterre platform off Galicia subsided to greater depth, perhaps also lastly in the Pliocene [1]. This subsidence may have been compensated by the uplift of Galicia, especially of the main chain.

This is in accordance with what is known from the mainland. There, too, the dislocations which affected the Miocene deposits and created the N-S rift zone probably date from the Pliocene, and the same may be presumed of the faults along the coast.

X. CONCLUSIONS

Various conclusions, already mentioned in the preceding chapters, may now be briefly summarized.

1. A Tertiary peneplain, large parts of which still exist in northwestern Galicia, has been affected by faults and broken-up in southwestern Galicia, i.e. in the area where four of the largest rias are situated. These movements caused the subsidence of a long N-S rift zone in which warped Tertiary sediments occur. Some of the vertical movements may have continued into the early Quaternary.
2. There are also indications of other (contemporaneous?) vertical movements along faults, including those along the coast. Along these a former Mesozoic foreland may have subsided in the course of Tertiary times, now forming a large submarine platform from which the Galicia bank rises up (Black et al. 1964).
3. At the points where the main rivers crossed the subsiding N-S rift zone they maintained their original southwestern directions and were not diverted. These points will, however, have been lowered, and with them the downstream parts of the rivers now partly occupied by the rias. These lower valleys may have followed subsided zones, but more probably they were simply antecedent valleys, eroded and widened by strong erosion and denudation in the course of the Quaternary. The drainage patterns of the smaller rivers are, to a great extent, controlled by some directions of fractures and faults of the basement rocks, especially by those between N 30° W and N 30° E.
4. Between the lower valleys (the present rias) mountain massifs having steep slopes and flatter top surfaces were preserved, perhaps as remnants of the former peneplain. The steep slopes have, however, receded considerably.
5. Large areas, especially in the coarse-grained granites around the Ría de Arosa, are occupied by low-angle slopes, many of which are foot-slopes (glacis) surrounding the numerous rounded residual hills and the larger mountain massifs.
6. These low-angle slopes occur mainly on deeply weathered rock now decayed into an unconsolidated mantle consisting of granitic granules or arkosic sand-sized particles mixed with kaolinite. Boulders or core-stones, being residuals of spheroidal weathering, are embedded in it or occur at the surface where the decayed rock has been removed.
7. The low-angle slopes are partly covered by colluvium, sometimes in various superposed sheets, and occasionally by older and more extensive bedded slope deposits (Nonn 1964) passing into kaolinite deposits. The latter continue below the present sea-level. This indicates that strong denudation occurred during the successive glacials of the Quaternary.
8. Consequently the present bottom topography of the rias is due at least in part to subaerial denudation and to erosion during these times of lowered sea-level.
9. The occurrance of probably Tyrrhenian marine or estuarine terrace deposits indicates that no movements have occurred since that time, and that the rias existed at least during the last two interglacials (Nonn 1958, Mensching 1961) and probably much earlier.

ACKNOWLEDGEMENTS

The author is indebted to Mr. H. Nonn, professor E. den Tex, Dr. J. D. de Jong, and Mr. E. B. A. Bisdom for critically reading the text and for their valuable comments, to Mr. Bisdom also for having supplied data for Fig. 27, to Mrs. I. Seeger-Wolf for correcting the English text, to Miss C. Roest, Mr. J. J. Bink, and Mr. B. Lieffering for the final draught of the maps and some figures, and to Miss Paula Bitter for typing and retyping the manuscript.

[1] The possibility of these movements having been accompanied by horizontal displacements should not be excluded.

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