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TECTONIC ANALYSIS OF LECHADA AND CURAVACAS SYNCLINES, YUSO BASIN, LEÓN, NW SPAIN

BY

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ABSTRACT

The structures along the southern boundary of the flysch-filled Yuso Basin bear witness to continuous epeirogenic activity during the Upper Carboniferous. The Cardaño Line foems the boundary proper but other structures, somewhat similar to this fundamental feature e.g. the Peña Prieta line, trend away into the basin subdividing it, demonstrating their control over deposition. Sedimentary structures indicate the instability of the deposits near the edge of this basin.
The present structures have grown out of initial subbasins most probably by a simple continuation of a similar type of epeirogenic movements. Recrystallization of the shales into slates accompanied some of this deformation, the other rocks though recrystallised show little sign of an oriented fabric. The slaty cleavage mainly developed as a concentric cleavage with a flatlying attitude dips on average 15° less than the bedding. Although some flap folds have such flatlying axial planes that it could be axial plane cleavage to them. The slaty cleavage deformation increased the dimensions of the bedding planes it seems as much, or even more, than demanded by the growing structures.
The west plunge corresponding to the slope of the basin reveals a spectrum of the structural developments at different levels. The Curavacas syncline, only moderately asymmetric in the extreme east, becomes rapidly steeper to the west. The north limb becomes overturned against the Peñas Matas fault causing complicated cascade folds in the Lechada Formation.
The Peñas Matas fault controls the box-form of the Lechada syncline to the west until it is lost in the Cardaño Line near Barniedo. The syncline is then more symmetrical but cross folding here and near Portilla divert the trend to NW-SE.
Westwards very complex cascade and flap folds develop on either flank of the syncline folded inwards towards the core. In the extreme west the southern fold is dominant even involving Devonian rocks, one slab of which has been let-down by recent erosion to form a slip sheet.
The slaty cleavage is generally cut by a fracture cleavage found in almost all slates often parallel to the axial planes of minor folds. These range from the Portilla structure to minute puckers. Overall shortening must have been brought about during this deformation but due to the usual inclination this does not need to be more than 10 %: all could have been brought about by block tilting.
The fracture cleavage deformation has had its orientation perhaps more directly controlled by the fundamental lines. Hence, it cuts across the trend of the major structure especially where it swings NW. Here very steeply plunging folds with axial faults have developed. Some of these like the Portilla fold show younger rocks faulted upon older—typical for drape folds and suggesting further underlying control.
The evolution of the Lechada and Curavacas synclines is a single line of descent from the movements forming the basin in which the sediments were deposited through all the stages of deformation. Vertical and tilting movements are all that are required to induce such structures.

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Fig. 1. Frontispiece; Northward view of Portilla de la Reina, built on a shale tongue within the Curavacas Conglomerate lens. Distinct bedding in the conglomerates becomes steeper and eventually overturned in the distant ridge. The overlying greywacke-slate sequence with one marked band of limestone are clearly nonconformable with the conglomerates, cutting out the western band.

INTRODUCTION

The present study has grown out of work with the group of students from the Geological Institute of the State University of Leiden mapping in the Cantabrian Mtns. under Prof. L. U. de Sitter.
Initial mapping in the summer of 1959 formed the basis of an M.Sc. thesis presented at the University of London in 1961. The detailed work for the present thesis was completed during the summers of 1963 and 1964.
Grateful acknowledgment is made for the opportunities afforded by the International Training Centre for Aerial Survey (I.T.C.), Delft, to study during tenure of a part-time appointment. I owe a great debt to Mrs. M. E. van Bokhoven-Planje for all the typing and assistance with the computations.
Sincere thanks are due to all members of the staff and students of the Institute, who have so greatly assisted the foreigner to make such progress in his studies. The kindness and hospitality of the local inhabitants of Castile, a byeword with our geologists, is very sincerely appreciated.

Geomorphology

The Curavacas and Lechada synclines lie just south of the watershed of the Cantabrian Mtns. The major part of the ground is drained by streams flowing south towards the Mesata where they feed into the Rio Duero system. In the northeastern part of the map area drainage is northwards to the Bay of Biscay. The grade length of these latter streams to the sea is only 40 km whereas it is over 400 km to the mouth of the Duero in Portugal. This difference in length of profile is vividly demonstrated by the difference in the landscapes. To the north the incredibly steep slopes testify to the strong, still-active erosion, whereas to the south streams often develop aggraded sections (Fig. 13).
The area shows undoubted evidence of glaciation although this would appear to have been of the cirque and valley glacier type. Some rock summits, notably that composed of Peñas Prieta granite, show typical ice-shattered forms and perfect rock cirques below them at Hoyos de Vargas. Cirques containing lakes are also to be found in Peña Prieta itself and the north slopes of Mura Mtn. to the west. The lakes of Hoyos de Vargas are in perfect hollows scooped out in the solid rock in the bottom of a cirque. However, other moraine-dammed lakes are also to be seen in the upper reaches of the Lechada drainage.
There has been an interesting diversion of drainage since the glaciation just east of Peña Prieta. The main headwater of the Rio de Lechada flowing NNW turns west at Bobia in the Curavacas Conglomerate scarp. The rocks in this saddle are scoured smooth and it is clear that the ice of the valley glacier plunged over the scarp into the Naranco valley to the north.
Lateral and terminal moraines are not usually well expressed topographically probably due to later modification. But these deposits are often to be seen in the valleys above an altitude of about 1400 m, where they have been primarily noted because they obscure the solid rock in many places. The upper valleys do show a much broader and open form than the lower reaches where the steep slopes close up very close to the streams with very typical V-shaped cross-sections. At Portilla de la Reina the Rio Yuso seems previously to have traversed the conglomerates somewhat north of its present course along the fault trace. This change probably formed part of normal headward stream-erosion for no evidence of glaciation has been found here.
The meanders in the Rio Yuso southwest of Portilla denote the aggrading of this segment of the river due to the resistance of the conglomerates around Barniedo which act as a local base level. Various terrace levels can be made out up to 50 m above the present profile of some streams so that quite a complex history of development lies behind the present stream pattern. The north-draining Rio Frio flows east through a very broad moraine-filled valley where at least one perfect intermediate moraine can be seen. The old headwaters of the Rio Frio have been captured by a stream flowing northeast at Pico Zamburria. Another branch of this stream to the east of that mountain has put a further large segment of the Rio Frio drainage in imminent danger of capture. In fact it is quite possible that, at times when rapid thaws induce floods in the flat-bottomed valley, the effective drainage of the Peña Prieta mass does flow via the northerly route. Glacial action and ordinary weathering is very distinctly more marked in north and east facing slopes than those of other aspects. This is characteristic of the very smallest as well as the larger features. The practical proof of this has come out of the search for continuously exposed sections.
Present erosion is still very rapid, extensive scree slopes being maintained below many of the prominent features of conglomerate and greywacke.

General Geology

The general geology of this area was first investigated in the modern phase by the Leiden group whose cooperative efforts have lead to the map picture here presented. The individuals and the areas they worked in are shown in the reliability diagram on the map sheet (Encl. 1).
The main problem investigated since and here reported is that of the detailed geometry of the structures, the order and manner of their development. During the process of these investigations the difficulties of correlation across the larger structures has forced recourse to the aid of biostratigraphic methods. Parallel research into the biostratigraphic sequence has already yielded highly significant results (e.g. van

Ginkel, 1965) but detailed application depends on more detailed work. It is hoped to publish some of the combined data in the near future.

The setting of Yuso Basin between the great limestone developments of the Picos de Europa to the north and the Older Palaeozoic rocks of Palencia to the east and León to the south has been described by de Sitter (1957, 1962, 1966). Subsequent work has laid stress on the continued tectonic activity within this region from the late Devonian to late Carboniferous time (Koopmans, 1962; Helmig, 1965; Rupke, 1965; van Veen, 1965; de Sitter and Boschma, 1966).

The present work emphasises and extends the notion of tectonic activity involved in the sedimentary process. And, in addition, that the resulting irregular distribution of bodies of sediment have then largely determined the manner of their later deformation.

A very high rate of subsidence must have been necessary to allow the deposition of such a thick sequence as has been found here, all of shallow water facies, in a relatively short time. Since there are neighbouring regions with different usually much thinner sections but also generally of shallow water deposits, there must have been quite large differential movements between them and the Yuso Basin.

The significance and activity of active zones or 'lines' have been described and discussed many times in recent literature over the Asturo-Cantabrian Mountains (e.g. de Sitter and Boschma, 1966 with full references). The work of van Veen (1965) has clearly defined one—the Cardaño line—forming effectively the southern boundary of the Yuso Basin sensu stricto. To the north the most obvious boundary is that with the Picos de Europa but this has yet to be worked out fully.

One difficulty in the application of the tectonic control over the sedimentation lies in the frequent overlapping of some facies across what should be the limiting feature. For example the way in which the Yuso facies of sediments overlap south to, and even beyond the León line. Another disturbing feature is the much more obvious and stronger influence of structures of purely local extent whose activity is often limited in time (here for example, the Peñas Matas fault).

The Yuso Basin was then an actively subsiding region with the most persistent positive area to the east and possibly west; also a much less actively subsiding area to the south. To the north, the Picos de Europa clearly also maintained a highly individual regime independent of the Yuso Basin.

The tendency to finer grained and better sorted deposits with more limestones in the uppermost sequence suggests perhaps the slowing-down of sedimentation. However, the manner of the final termination of this sequence is not to be found in this area because there are no younger Palaeozoic rocks. In the absence of the latter nothing can really be said about the latest possible date for the folding. However, it will be seen that there is evidence for a considerable amount of synsedimentary deformation. The most probable sequence of events would seem to be that the deformation was more or less continuous, if episodic.

CHAPTER I

STRATIGRAPHY

The Geological Map (Encl. 1) is restricted to the Carboniferous rocks of the area, the structural investigations having been carried out exclusively in the upper part of this sequence. The stratigraphy of these formations has been described by van Veen (1965) from the exposures in the eastern part of the map area and there is little to add to the general lithologic description given, apart from the very uppermost parts. Primarily it is a question of stronger lateral variations in the thicknesses of various formations. An attempt has been made to express these graphically in the Lithostratigraphic Column of Enclosure 1.

Ruesga Group

The Ruesga Group comprises here the lower Carboniferous rocks of the Vegamián Formation and Alba Griotte together with the Caliza de Montaña and Cervera Formations. These only outcrop along the Cardaño line which forms the southern boundary to the Yuso Basin and the map sheet.

The Vegamián Formation developed as 30 m of black shale in the best section of the Cardaño area, outcrops almost continuously along this line. Tectonic complications make it difficult to assess many of the thicknesses but there does seem to be a tendency for the formation to thin westwards. The culmination of this tendency is to be seen in Pico Redondo where the sequence must be less than 10 m. thick. This thinning seems to be accompanied by an increase in the amount of black chert and it is postulated that erosion and alteration of the black shales took place causing the thinning and their alteration to chert.

The Alba Griotte is rarely to be seen in a truly typical development but some characteristic colouration and texture variation is usually present at the base of the Caliza de Montaña Formation, indicative of the presence of the former. Both of these units are only to be seen in restricted outcrops WNW of Barniedo in the map area.

The Cervera Formation has been mapped from the type area of Frets (1965) into the area of Barniedo by van Veen (1965). However, it will be noticed that this formation has been given the same signature on the map as the overlying Lechada Formation. This is due to the fact that it is simply not possible to distinguish these units in the field on the basis of the lithological definitions given. Due to the structural complications the mapping of the unconformity that might have served to demarcate their boundary was also impossible.

The Triollo Member of the Cervera Formation is, however, quite typically and in some places massively developed, so that it has been delineated on the Geological Map (Encl. 1). The unconformable relation of the Triollo Member upon the Caliza de Montaña and the Vegamián rocks can be well seen in a number of places, e.g. in the Valponguero valley, 2 km ENE of Barniedo.

In the northern part of the map sheet the stratigraphic equivalent of the Cervera Formation can be seen unconformably overlain by the Curavacas Conglomerate. These rocks are known as the Potes Formation and extend far into the Potes area to the northeast where the structure and stratigraphy are still being worked out. (Dr. D. Boschma pers. comm.).

Yuso Group

The Yuso Group combines the clastic sediments of a flysch facies (shallow burial greywacke association, Krumbein and Sloss, 1963; turbidite basin, Potter and Pettijohn, 1963, p. 241) which form a clastic wedge stretching from the Arauz 'high' (van Veen, 1965) westwards as far as the Upper Esla area of older Palaeozoic units (de Sitter, 1962). A distinct contrast in thickness is evident from the immense thickness of conglomerates at Curavacas Mtn. (>1500 m) to the thin draping cover on older Carboniferous and Devonian rocks in the Upper Esla area.

The Curavacas Conglomerate forms the most clearly distinguishable major unit mappable throughout the basin. Other less continuous and often less easily correlated units comprise the mainly bioclastic limestones e.g. El Ves Limestone Member as well as the Panda Limestone Member together with pebble beds and some of thick greywacke beds. Because of its importance in mapping the Curavacas Conglomerate has been ranked as a formation interfingering with the Lechada Formation which includes the remainder of the clastic series and contains several members.

Curavacas Conglomerate. — The name Curavacas Conglomerate proposed by Oriol (1876) seems entirely appropriate since the massive sequence forming one of the highest and most imposing peaks in the region would seem to be very fully developed here. However, Kanis (1956) did not map this area and van Veen (1965) presents a section from the Las Lomas valley some 6 km to the west. The mapping demonstrates considerable interfingering and lensing of conglomerate with the greywacke association of the Lechada Formation between Las Lomas and Curavacas. Hence investigations in the latter locality would be of great interest for the possible definition of a better type section.

The previous authors all agree upon the illsorted, polymict character of the Curavacas Conglomerate emphasising the high proportion of argillaceous or greywacke matrix (e.g. Koopmans 1962; de Sitter and Boschma, 1966). Lenses of greywacke and even shale may occur completely enclosed within the conglomerate, while similar masses may widen out to tongues of the Lechada Formation. It is in fact remarkable how little variation there is to be seen in the lithology of the Curavacas Conglomerate throughout its extent despite the rapid changes of thickness (c.f. Sjerp, 1967, p. 97).

There is now no question but that these rocks in the western part of the basin have been deposited by a high density mud flow mechanism as demonstrated so clearly by exposures of some isolated lenses (Fig. 2 and 3).

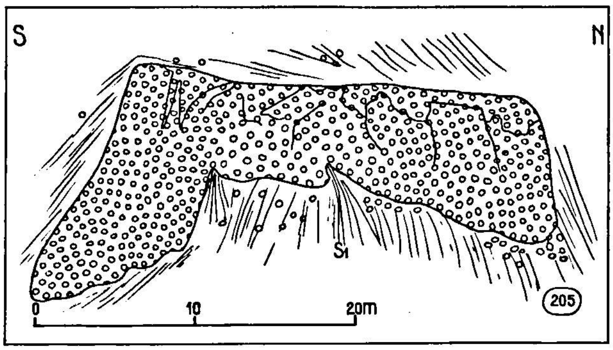


Fig. 2. Field sketch of slumped Curavacas Conglomerate lens 2 km south of Pico Redondo (St. 205, Section A). Slates strongly cleaved but with little sign of bedding, contain occasional pebbles the same as in the lens itself. Note the refraction of the slaty cleavage planes around the mass and especially into the flame structures at the base.

Fig. 3. Slumped mass of Curavacas Conglomerate, load casted in pebbly slate (mudstone) cutting off contemporaneous Lechada sediments, vertical with hammer along strike.

2 and 3). The fact that above the massive conglomerates at Portilla there follows a pebbly mudstone with pebbles gradually thinning out and the occasional limestone block completely out of scale, demonstrates the necessity for the mud flow mechanism in their genesis (Fig. 4). This despite the layering that can be seen in the Portilla lens (Fig. 1) which is remarkable in not showing imbrication of the pebbles in the layers. Similar pebbly mudstones are to be seen in Orpiñas mountain both above and below the main conglomerate so that it seems inescapable that the Curavacas Conglomerate has been primarily emplaced in the Yuso Basin in this way.

Fig. 4. Pebbly slate (mudstone) with a large limestone block and some angular fragments of limestone. Above Curavacas Conglomerate lens 2 km NW of Portilla.

It is very clear that the pebbles of the Curavacas Conglomerate have been eroded from and rounded in a milieu entirely separate from that in which they were eventually deposited. Hence it remains possible that evidence of these different conditions should be found elsewhere. Judging from the strong westerly lensing and the onlap onto Devonian rocks seen in the Arauz area to the east, such exposures might be expected there.

Certainly the discoveries of well preserved floras by Kanis (1956) and Mr. J. A. van Hoeflaken (in Kanis, 1956) in outliers of Curavacas Conglomerates well to the east of our mapsheet, confirm that terrestrial influence was perhaps closer there. However, there is an excellent flora at the base of the Curavacas Conglomerate in the Las Lomas valley (van Veen, 1965 and Stockmans, 1965). This together with the evidence of subaerial erosion below the Curavacas unconformity around Barniedo and to the southeast (also in Koopmans, 1962) suggest that there should have also been land exposed along the Cardaño line if only as small short-lived islands.

Lechada Formation. — The Lechada Formation was named to include the thick sequence of beds well exposed in a simple sequence in the valley of the Rio de Lechada (Sections D and E). It is hoped to publish data on the measured sections together with some more detailed stratigraphic data in the near future.

In the area of the Peñas Matas fault the basic turbidite facies is very clear, grading being particularly common. The regularity of this succession is interrupted by numerous slumping and sliding phenomena which no doubt owed their origin to the instability of the accumulations so rapidly deposited by the turbidity currents. One clear example of slumping is shown by the El Ves Limestone Member in the Lechada valley. The large mass just shown in Section D (Encl. 1) can be seen cutting across some 150 m. of section including the greywacke forming the extensive outcrop just west of it.

The sliding of beds in the Curavacas syncline are described in the detailed account of the measurement of that profile (Section F, p. 220). Sedimentary folds as well as slumping have also been recorded in the Guspiada valley (Fig. 5, Section B; p. 238). Many other examples have been so tectonized that it is only possible to state the strong likelihood that the initial deformation took place during sedimentation (e.g. Barniedo Road, Section C; p. 230).

Fig. 5. Slump folds in greywackes of the Lechada Formation, Arroyo de Guspiada: view towards north, folds overturned towards the east.

The faults trending NW near Grillo are clearly visible on the aerial photographs and it proved to be possible to measure the small throw (10 m) of two of them. Other essentially similar traces can be seen on the aerial photographs and these should mark similar structures. The oblique trend of these faults with their downthrow to the north conforms to the deepening of the basin in that direction. It is possible that this fault system may be, in part, synsedimentary recording the deformation of the basin boundary.

The Panda Limestone Member type section is in Peña Panda near the northern edge of the mapsheet which has been described by Mr. P. Kamerling (in van Ginkel, 1965). This member shows considerable variations in the comparatively small lateral extent included in the map sheet. Evidence of erosion of

Table 1. Flora and Fauna from Limestones of the Lechada Formation

Location									
Vegacerneja	(1 km E)	Algae [1]							
Barniedo	(2 km N)			Ostracods [2]	Fusulinids [3]				
Peña Prieta	(3 km W)	Algae [4]			Fusulinids				
Llanaves	(1 km S)	Algae [4]				Corals	Brachiopods		
Portilla	(1 km N)						Brachiopods		Crinoids
Panda Mt.			Bryzoans [5]		Fusulinids	Corals	Brachiopods	Cephalapods	Crinoids
Casasuertes		Algae [4]	Bryzoans [4]		Fusulinids [4]	Corals [4]		Cephelapods [4]	Crinoids [4]

1. Dr. L. Rácz 2. Mr. D. Zeilmaker 3. Dr. A. C. van Ginkel 4. Mr. G. J. B. Germs 5. Mr. P. Kamerling

the upper layers is to be seen near Casasuertes but the final lensing to the west is certainly due to non-deposition. Only the fusulinid fauna and the lithological column has as yet been published of these rocks (van Ginkel, 1965) but there is considerable evidence for a disturbed depositional environment (Mr. P. Kamerling, internal report, Leiden).

The most fossils frequently found in the Lechada syncline are plant stems. These occur throughout the sequence often covering bedding planes thickly, yet identifiable floras are uncommonly rare. Only two isolated leaf prints have been found in the main sequence although a flora has been collected from beds just below the Panda Limestone exposed in Coriscao Mt. just off the map sheet, 3 km N of Llanaves (Van Ginkel, 1965). The only other widely distributed animal traces are burrowing structures sometimes on bedding planes sometimes cutting through them.

In contrast to this relatively poor representation of the terrestrial flora the evidence of marine organisms though somewhat more difficult to find is much more extensive. Table 1 gives a general idea of the lateral extent and range of organisms encountered. It is most remarkable that the longest lists of marine fossils are from the Panda Limestone which overlies the beds having the most definite terrestrial affinities i.e. the flora at Coriscao and the coal layer at Casasuertes (Mr. H. Diederix int. rept. Leiden). Similarly the marine limestones in the slumped beds north of Barniedo also show more plant remains (not identified) in close association with the marine limestone there. These occurrences lend support to the opinion of Mr. G. J. B. Germs (pers. comm.) that the limestones of this sequence represent shallower-water conditions than the greywacke-slate. This concept may bear the solution to the interbedding of these limestones in an area receiving much clastic sediments.

Hence, we are forced to conclude that the marine environment was dominant during the deposition of the Lechada Formation. It is true that the depth of water must have been quite shallow so that slight eustatic or epeirogenic movements could result in emergence but the really rare evidence of subaerial erosion suggests this was not a frequent event. In fact the rapid accumulation of such a great thickness (> 2 000 m) of sediments over a relatively short period implies the dominance of down-warping.

The limestones are often also clastic but have largely originated in situ from biological activity apparently possible due to local shallowing preventing clastic material from being transported there.

It has to be admitted that the idea that flysch deposits can have been laid down in shallow water conditions is not universally accepted (Kuenen, 1964). However, more examples seem to be quoted in current literature and the facts have to be accepted that a) the lithologic sequence conforms to the holotype flysch and b) that all sedimentological and palaeontological data to date point to shallow water conditions.

The rocks that have been investigated in detail in this paper comprise the clastic wacke-slate alternations of the Lechada Formation. The more massive types such as the Curavacas Conglomerate on the El Ves and Panda Limestone members of the Lechada Formations are not amenable to this type of analysis.

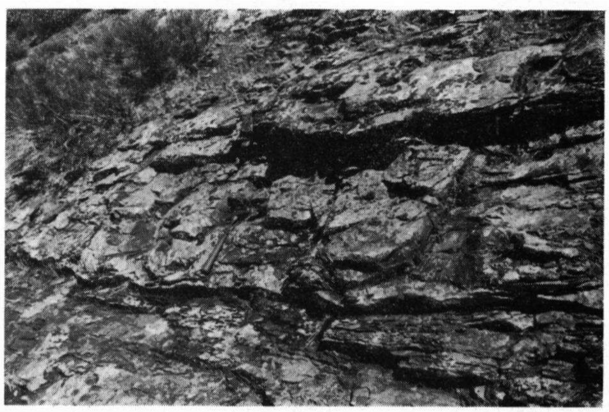


Fig. 6. Rhythmic graded turbidites with load casts at the coarse base of the lithic wacke. Note the notches due to the more rapid erosion of the most argillaceous layers at the top of the cycle.

The rapid alternations are generally between 3 and 20 cm. although thicker bands are not uncommon. There is a tendency for the finer grained clastics to increase over the coarser higher in the sequence.
The lithic wackes show much more obvious grading in the thicker developments where the grain size is usually coarser. Where such beds exceed 1 m there is occasionally a gritty conglomerate or flake conglomerate at the base. The underside of such larger beds frequently show diagnostic bottom structures such as load casting, groove casting and flute casting which are generally aligned E.—W. Grading is not usually fully developed to the shale grade, some kind of banding usually intervening in the uppermost parts (Fig. 6).
The Pebble Beds mapped at a number of different levels (Lithostratigraphic Column, Encl. 1) have provided the most useful marker horizons in the otherwise ever-changing sequence. Although they may vary considerably they are most usually a band 30—50 cm thick of small rounded pebbles (< 2 cm diameter) in an argillaceous matrix (Fig. 7). Shale pebbles have also been found although in the usual outcrop the rock has many holes where either shale or limestone pebbles have been weathered away.

Fig. 7. Pebble bed in the Lechada Formation, Lechada valley. Slates showing the typical field appearance of gently curving slating cleavage planes.

The typical pebble bed usually occur within the slates but may occur at the base of a very thick (2 m) graded lithic wacke bed. Sometimes they are replaced laterally by a pebble mudstone with much larger pebbles set wide apart in a much thicker band of unbedded slate. Such bands may even widen out, as in the Barniedo Road exposures (Section C, Encl. 1), to include limestone knolls and rafts of slumped bedded greywacke-slates which may be as much as 22 m thick (Fig. 39, p. 231).
The way in which the pebble beds can be traced laterally into the typical El Ves Limestone Member in the Curavacas syncline emphasises the general similarily of genisis of these two rock types. This is also reinforced by the frequent occurrence of quartzite and limestone pebbles in the El Ves Limestone Member. Similarly the main Curavacas conglomerate mass of Hoyos de Vargas can be seen to pinch out into just such a pebble bed before being lost entirely.
There would seem to be no doubt that some quite extraordinary event must have occurred to spread such a deposits so widely and yet so thinly over such a large area. Most likely this must have been a mud flow generated at the arrest of the much larger flows which deposited the Curavacas Conglomerates and some of the clastic limestones.
Attention has been concentrated upon these aspects of the sediments because of their utility in determining the attitude of the beds in the complex structures found. Sedimentological investigations have already begun and it is to be hoped that some of the interesting problems raised by these unusual sediments will be worked out in the future.

Intrusions

Acid igneous rocks form the intrusions throughout this area. Usually these rocks are very altered so that the fine-grained types in the small dykes and sills cannot be identified at all. The larger lopolithic intrusion has a granodioritic composition according to van Veen (1965). It has caused low-grade contact metamorphism in the country rocks and has apparently assimilated some limestone of the El Ves Limestone Member developing pink (almandine) garnets.
Occasional small gash veins and even casts of wood fragments are filled with fibrous quartz with sericite and less often crystals of goethite pseudomorphic after pyrite (ehrenwerthite).
The quartz fibres present the strange phenomena of the crystal axes at an angle to that of the fibre (Dr. P. Hartmann, pers. comm.).

CHAPTER II

STRUCTURE

STRUCTURAL TYPES

The investigation of the structures of the area has established the presence of definite types of folds. The understanding of these various types has been necessary before any useful synthesis of the geometric, and later the dynamic, model could be made.
Parasitic folds (fig. 8) are used for the type of asymmetric minor fold as defined by de Sitter (1958). This type of fold should theoretically only develop in beds dipping at less than 45° to the tectonic stress; steeper dips should lead to total thinning of the sequence with more comptent layers lensing out into

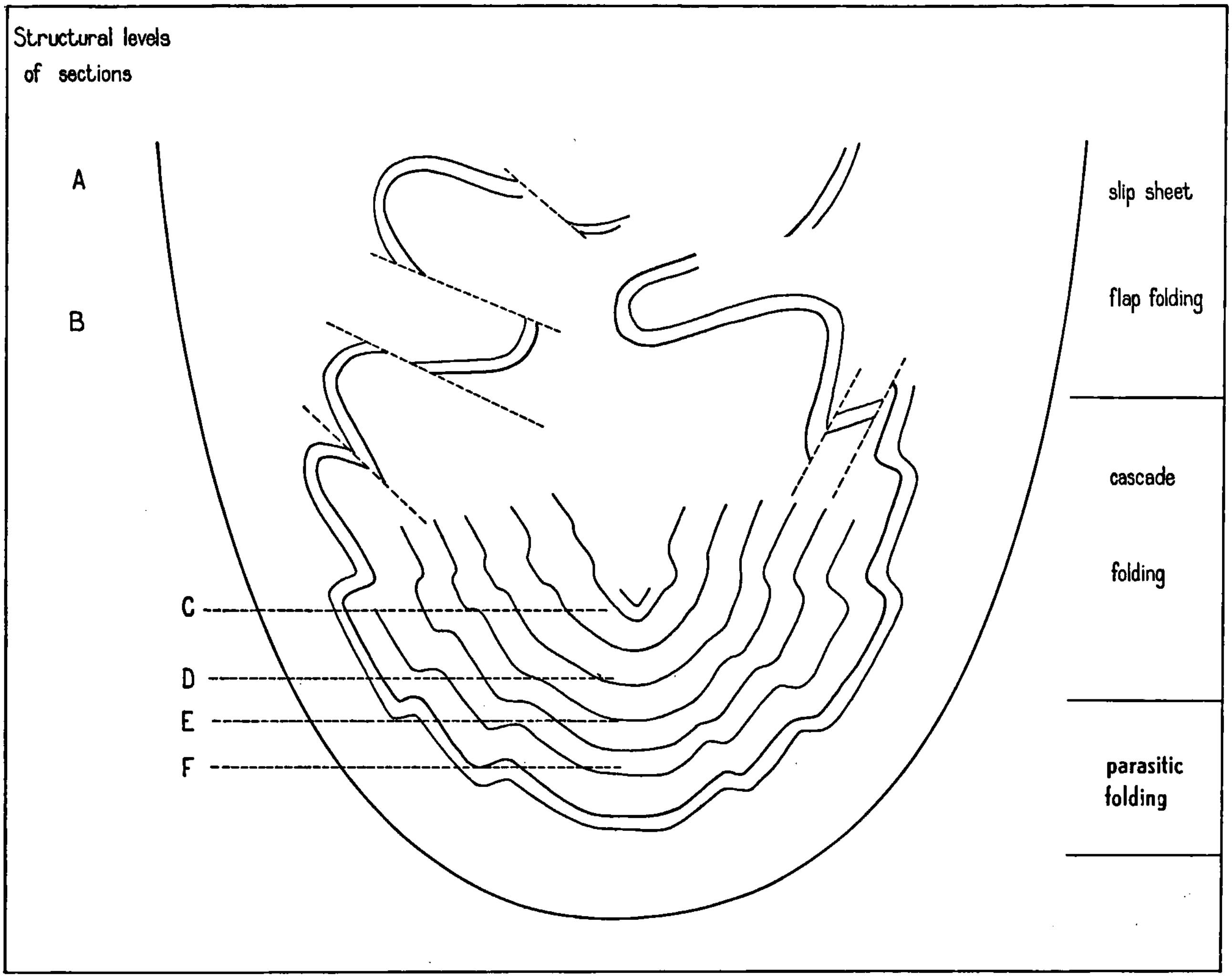


Fig. 8. Diagrammatic section illustrating the types of minor structures and the concept of their relation to the major synclines.

boudins. Yet despite the steep dips common in many parts of the map area little has been seen of even incipient boudinage.

Cascade and flap folds (fig. 8) are usually found where the bedding is relatively steep. Although they are developed in entirely different rocks, the geometric forms are precisely the same as those described by Harrison and Falcon (1934) in their definitions of these terms. In one place a slip sheet like those of Harrison and Falcon has also developed but this has depended upon the deep erosion of the nose of the fold to allow the core to slip down.

Although the geometric properties were strikingly similar the conclusion that these folds must be due to gravity was not directly assumed.

A principal argument follows from the usual preservation of the inverted middle limb of these folds even where strong axial plane faulting has occurred. This is considered to be a characteristic typical for recumbent gravity folds (de Sitter, 1954). Folds with exactly similar cross sectional shapes and having the same relation to the major structure has been illustrated by Schwan (1964). However, these 'aufbruch-falte' have the inverted middle limb sheared out where faulting has developed and seem to be quite a different type of fold.

All the types of minor folds may develop about axes with quite steep plunges; up to 70° are not uncommon. The bedding around such a fold, of course, must dip at a comparable angle and once faulting intervenes the normal size and frequency of exposures only yields an incomprehensible jumble of beds.

Faults are frequently developed in all types of minor fold. Some are purely bedding plane décollement allowing the folding to proceed disharmonically. Others develop in the axial planes frequently allowing the middle limb of a cascade fold to become detached to lie upside down at a discordant angle to a completely normal sequence, separated from it by faults above and below, Fig. 8. This can bring about the curious situation that older beds let down by a normal fault are thrown against younger beds.

Axial plane faults in parasitic minor folds may just allow the disharmony to be found below the centre of

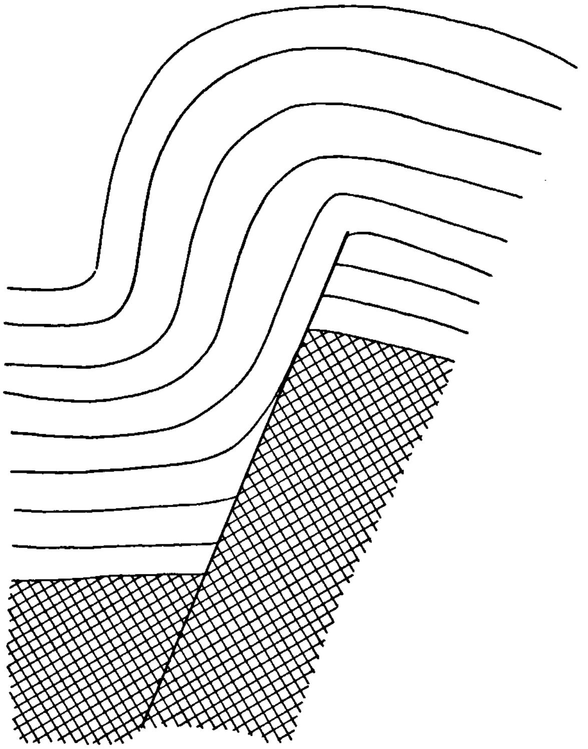


Fig. 9. Diagrammatic section illustrating the development of faulting in a draped anticline.

concentricity. However, some of these faults continue far beyond the possibility of concentric control, as a hinge about which the bedding changes in strike across the fault (Fig. 9). Since this type of fault usually takes up an attitude parallel to the bedding in one set of beds, one flank has practically the same horizon against it. The other flank, however, contains progressively lower beds of the sequence with depth so that another curious situation arises. That is, the beds apparently lying upon a parallel thrust plane are stratigraphically higher than those below the fault (Fig. 9).

The fact that there is an apparent reversal in throw mainly arises due to a considerable proportion of strike-slip in the faults as they appear on the map. These deep axial faults of the parasitic folds cannot be derived from the flexure of some highly competent bed. The folds are generally rather disharmonic upwards with the fault quite high in the arch. The most obvious conclusion is that these folds must be draped over some kind of a steep discontinuity below (Fig. 9).

The faults in the cascade folds are due to the upper part of the fold failing to remain in contact with the outer lower limb. This failure can only have been brought about by the weight of the column of rock supported on the upper limb. Whatever the stress-generating mechanism, gravity must have played a fundamental role in forming these folds for the principal direction of shortening is nearly vertical. The gravity hypothesis for all the structures was only accepted as a reasonable working theory after the analysis of the folding had proved other tectonic models inadequate.

GEOLOGICAL MAP AND SECTIONS

The general structure of the map area is very simple being a syncline largely outlined by the Curavacas Conglomerate. The outcrop of this formation emphasised on the Geological Map, illustrates the average WNW trend of the major structure. In addition the form of the closure at Curavacas Mtn. demonstrates very strikingly the westward plunging nose of the syncline. The aggregate west plunge for the whole structure is shown by the way in which the stratigraphically highest beds including the Panda Limestone Member, swing across the western extremity of the syncline. In the north the broad outcrop marking the closure across the parallel-trending, westward plunging nose of the Vallines anticline just appears. The map picture is disturbed by a number of departures from the simple east-west structural pattern. Firstly a zone of disturbance, the Peñas Matas fault, aligned ENE-WSW through the prominent Peña Prieta intrusion and secondly the NNW-SSE trends evident where the Río Yuso crosses either flank. Along the north flank the repetition of the Curavacas Conglomerate is tectonic due to the large Naranco strike fault (Fig. 10).

The Curavacas syncline previously described by de Sitter (1962) and van Veen (1965) is the most clearly defined because of the almost continuous outcrop of Curavacas Conglomerate around it. The breaks in this rim occur to the west along the line of disturbance, the Peñas Matas fault. In fact, the structure is essentially continuous with that of the main Lechada syncline to the west, however, it does have its own individual peculiarities.

The wedge-shaped outcrops of the Curavacas syncline narrowing westwards belies the idea of an axis plunging in that direction. However, the structure is much more tightly folded in the west; the dips of the north flank increasing from 50° S, through the vertical to overturned 60° N and the south flank from 25° N to 60° N from east to west, respectively. The decrease in the width of outcrop consequent on the increase in dip can, thus, account for the anomalous pattern. The smooth curve of the upper contact of the Curavacas Conglomerate with the Lechada Formation, the undisturbed nature of its unconformable base in the north, as well as the stratigraphic continuity to the south, all testify to the harmonic folding of the Curavacas Conglomerate with the adjacent rocks here.

Within the core of the Curavacas syncline many small folds have been measured in the beds of the Lechada Formation but these die out when projected to depth. Thus the trace constructed for the upper surface of the Curavacas Conglomerate is quite smooth and, in fact, closely approaches a purely circular arc (Section F, Encl. 1). The subtended centre of this circle lies above the measured profile so that theoreti-

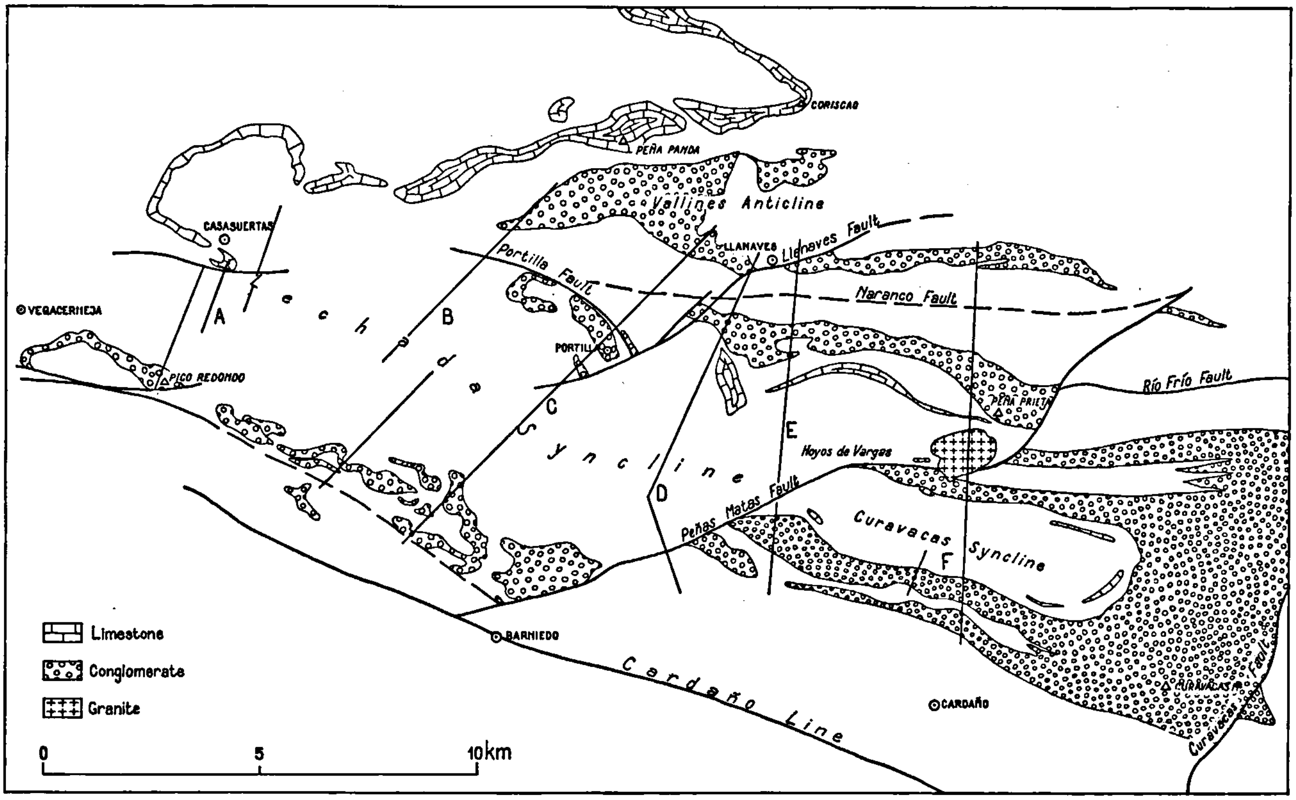


Fig. 10. Structural sketch-map showing the location of the cross sections.

cally the whole sequence above the Curavacas Conglomerate could have been concentrically folded harmonically with it. However, the series of complicated folds present in the core together with the strongly developed slaty cleavage and the occasional fracture cleavage mainly indicate a departure from this rule. In general the minor folds in the Curavacas syncline can be classified into two types belonging to a specific segment of the structure. At the southern hinge zone there are a series of minor folds with their axial planes and shorter limbs dipping north typically parasitic to the flatlying axial zone which dips gently south. In the steep north limb we find large and small cascade folds ranging from the smallest wrinkle to the final overturning of the Curavacas Conglomerate.

These two types of minor folds form a complementary set with respect to the bedding the southerly allowing shortening in the horizontal direction whereas the northern folds result in expansion in the same horizontal direction (Fig. 11). The net result has been to compress more rock into the core by transferring it from the oversteepened flank to the axial zone. It is quite remarkable that the slaty cleavage more or less parallel to the axial plane of the syncline takes part in both sets of folds with only the minimum of variation of attitude.

Where the syncline narrows to the west the north flank is overturned to dip north parallel to the plane of the Peñas Matas fault and the minor folding is even more chaotic than ever (Fig. 12). Nevertheless the same contrast persists, folds with flatlying axial planes only occurring in minor folds of the north flank and more vertical axial planes to the south.

The Lechada syncline proper, is taken to commence at the Peñas Matas fault across which there is a very noticeable increase in the breadth of the synclinal structure.

The effect is not, however, simply one of normal downthrow of the northern block across the Peñas Matas fault, for the Lechada rocks extending as far east as Peña Prieta are folded into a fully developed

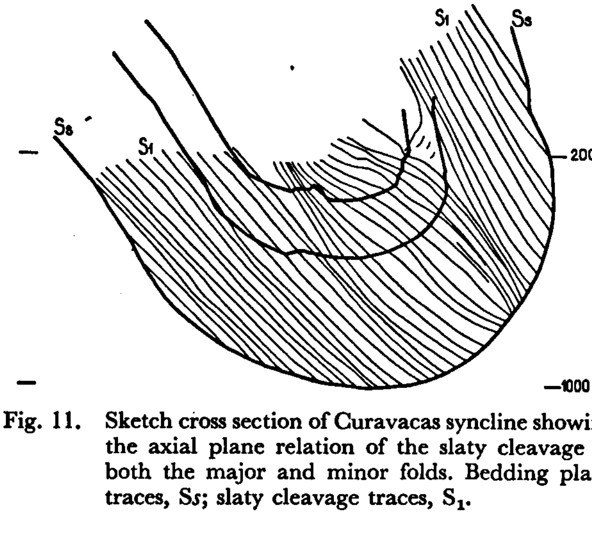


Fig. 11. Sketch cross section of Curavacas syncline showing the axial plane relation of the slaty cleavage to both the major and minor folds. Bedding plane traces, Ss; slaty cleavage traces, S_1.

Fig. 12. Cascade folds in south side of Hoyos de Vargas ridge in north flank of Curavacas syncline. Peñas Matas fault above and to right.

syncline plunging west parallel to the Curavacas syncline Section A, (Fig. 10). This structure merges into the north flank of the main Lechada syncline rather than its axial zone but there is no sign of seriously disharmonic structures at this point and it seems most probable that this fold is wholly dependent upon the Peñas Matas fault. This structure bringing up the uppermost Curavacas Conglomerate has the form of thrusted anticline and has been referred to by van Veen (1965) as the Hoyos de Vargas Anticline. The core of the extension of the Lechada syncline is penetrated by the Peña Prieta intrusion. This mainly concordant intrusion which may perhaps best be termed a lopolith, owes much of its extensive outcrop to the way the topographic slope has developed parallel to its boundaries. Accompanying dykes and sills are to be found at many other places especially near the Peñas Matas fault which strongly suggests that this important disturbance formed the plane of egress for the rising magma (Section F, Encl. 1). Moreover, it seems quite probable that the extensive development into the large intrusion here is to be related with the folding as postulated by van Veen (1965).

Only the practically planar north limb of the eastern nose is exposed along Section F and minor folding has only been found in the steeper south flank near Hoyos de Vargas. Most of these have a parasitic form and an axial plane fracture cleavage.

The structures further north are even less well-known although many complications certainly exist. The syncline shown in Section F is accompanied by smaller folds and faults which, though evident in exposures, it has not yet been possible to map. The one remarkable feature consistently repeated is the normal fault downthrown to the north with associated folding.

To the west the Lechada syncline though much broader is very much affected by the Peñas Matas fault which cuts out a great deal of the south flank for several kilometres down the Valponguero valley. At Peñas Matas the Curavacas Conglomerate is present south of the fault but it is most unlikely that it really takes part in the structure. In fact the way in which it pinches out stratigraphically east of the actual fault in the Valponquero suggests that it may not in fact persist as far as the fault even in a northward direction (Section E, Encl. 1). The conglomerates are entirely absent along the profile of Section D, south of Grillo, the higher Lechada Formation rocks being faulted directly against Devonian beds. This is certainly partially, if not totally, due to stratigraphic variations so clear in the exposures to the west as well. Due to the shortening of the south limb, the Lechada syncline here is dominated by the north flank forming a massive homocline dipping moderately south ($\approx$ 50°). This flank bears only the slightest suggestion of subsidiary folding and faulting perhaps intensifying to the west (compare Sections D and E). Both profiles reveal a remarkably flat axial zone giving a box-form to the fold here and the bedding on both flanks tends curiously to steepen in dip before curving sharply into it. This steepened segment is the only place in which cascade folds have been found in this part of the Lechada syncline.

The south flank is dominated by minor folds which by the way they increase in intensity toward it, must be dependent in some way on the fault. All of these are, of course, disharmonic and only project to a shallow depth. In any case, the Peñas Matas fault should cut out practically the whole of the north-dipping beds at the level of the top of the Curavacas Conglomerate as shown (Sections D and E, Encl. 1).

The Peñas Matas fault was active during sedimentation and it is possible that some of the normal movement, which may be as much as 1 000 m vertically, could have occurred at that time. Some very small isoclinal folds (Encl. 2) adjacent to the fault seem to have folded the slaty cleavage so that this type of movement seems to have continued until after that deformation. But the fracture cleavage and the associated parasitic minor folds of the south limb which increase in frequency towards the fault, indicate the cessation of normal movement and the possibility of reversal at the level of the profiles.

The almost complete lack of minor structures in the moderately dipping north limb and their concentration in the south limb is the mirror image of the deformation of the beds within the Curavacas syncline. Although the beds parallel to the Peñas Matas fault are not, of course, overturned and the minor folds associated with it are all parasitic to the main structure. Cascade folds have only been developed in the small oversteepened hinge zones bounding the flat-lying axial zone.

The distinct box-form of this part of the Lechada syncline is very marked and all projection methods produce this to depth usually implying an increase of influence as drawn in Sections B, D and E (Encls. 1 and 2). It is more probable, however, that this is disharmonic to the structure at the level of the Curavacas Conglomerate. The faults that trend NW near to Grillo may be part of such a mechanism as is suggested by the sudden changes in dip found at them.

These rocks may be either regularly flexed as in the Curavacas syncline or a simple fault block as is illustrated to the north of Orpiñas Mtn. along the Naranco fault. Even further north the Llavanes fault itself also displaced by a small fault, causes the break in the outcrop of the Curavacas Conglomerate ridge at Llanaves. This is probably a wrench fault as the plane can be mapped as vertical although the throw is equivalent to only 200 m of vertical throw. (Note: in Section D, Encl. 1, the signature showing Curavacas Conglomerate to be exposed south of the Llanaves fault under arrow Div., is in error, check map). The Llanaves fault forms a splay joining the northernmost bounding fault with the Naranco fault system and has probably been active together with these in various ways and at various times.

Further west the broad uninterrupted expanse of the Lechada rocks suddenly narrows where the Rio Yuso flows SW across the syncline. This is due to the NNW-trending Curavacas Conglomerate lenses in both flanks which jut across the usual WNW trend. North and northwest of Grillo the mapping of the pebble beds shows up to existence of minor folding possibly to be related with the faulted Portilla structure. In complete contrast the swing north-east of Barniedo is a perfectly smooth curve although there are many folds near the road where the swing is reversed.

One small fold outlined by a pebble bed 2 km due south of Portilla demonstrates the style of the Portilla folding simplified by not being broken by faulting. The sharply folded syncline and accompanying anticline plunge steeply WSW down the average dip of the north flank of the Lechada syncline. In the Portilla structure the swing in strike is mainly less but the dips vary more even to becoming overturned. The fault prominent 1 km south of Portilla has developed in the axial plane of the structure but dips parallel to the SW limb of the fold as far east as the Rio de Lechada. The way in which this fault brings the overlying rocks into contact with progressively older beds is very clear in the field as well as the Geological Map (Figs. 9, 13).

Fig. 13. West view along Lechada valley with south nose of the Portilla lens of Curavacas Conglomerate to left. E-W trending beds in foreground and lower slopes of distance cut off with conglomerate by fault, indicated (F), dipping west parallel to the bedding above. Typical flood plain terrace in bottom of V-shaped valley.

North of Portilla faulting is certainly present although the termination of the conglomerates is almost certainly primarily sedimentary. The C-shaped outcrop of the northernmost lens represents the extreme disharmonic development of this type of fold. The extreme internal deformation of the conglomerates in the sharp hinge is marked by a most extensive development of quartz veins, the large majority of which dip SW more or less parallel to the axial plane of the fold. Within the arc of conglomerate the slates and greywackes have undergone some very intensive deformation which is strikingly disharmonic with that of the rest of the Portilla structure.

The complex fault zone of the Naranco system cuts through the rocks north of Portilla probably absorbing the Portilla fault as a splay in the same way as it does the Llanaves fault. The exposures here emphasise only strong deformation and give little evidence of throw or even of location of the faulting. The greatest possibility is that some sort of faulted anticline and syncline might have been developed on analogy with some folds in the Naranco valley to the east. Finally the massive layer of Curavacas Conglomerate which forms the south limb of the Vallines anticline show the complete return to the regional strike. The pronounced swing in the upper contact of the conglomerates is due in the main to topography and not to folding in sympathy with the Portilla structure.

The strange outcrop shapes of the lenses of Curavacas Conglomerate north of Barniedo are primarily due to stratigraphic variations but the swing in the pebble beds outline some of the intricate minor folds here. It is not easy to portray the forms since the steeply plunging axes and the sharply dissected terrain combine to produce some quite bewildering outcrop patterns. These folds are strongly disharmonic and trend to plunge ENE down the dip of the south flank of the Lechada syncline.

As shown in Section C (Encl. 1) the overall structure of the Lechada syncline here is quite regular and symmetrical despite the complications on either flank. The flank project at almost exactly right-angles in cross section, the synclinal hinge being remarkably sharp at the level of the profile.

The effects of the Barniedo and Portilla folds are not very marked in Section C because the plane of projection is quite close to the axial planes of these folds. Nevertheless the clear shape of a parasitic fold can be seen in the conglomerate lenses to the south. The north flank shows on the contrary a flap fold with the axial plane fault vertical in the steeply dipping beds. Another cascade fold and a shallow syncline complicate the core of the Portilla structure before the beds finally tilt up against the Portilla fault.

The minor parasitic folding prominent in the exposures alongside the Portilla — Barniedo road are so small and disharmonic that they have very little effect at all on the form of the syncline.

The complex outcrops near to Barniedo undoubtedly owe much to the stratigraphic variations here with three unconformable sequences folded and faulted together. The splays of the Peñas Matas fault are intercepted by and in part diverted to a WNW trending system of structures. This complicated zone marks the Cardaño line; a zone probably active since early in the Devonian period (van Veen, 1965). The attitude of the faults is still remarkably parallel with the south limb of the Lechada syncline. To the west of the Río Yuso the ground rises rapidly so that higher parts of the structure are preserved. As might be expected the simple curve at the axis of the syncline found in the valley cannot persist and the beds found are strongly compressed in steep, often inverted, attitudes. Still further west where the profile of Section C has been investigated the syncline is somewhat broader and more complex structures seem to have been able to develop in the axial zone as a consequence. In outline the syncline is remarkably simple and regular although the apical angle is somewhat more acute ($\approx 80°$). However, complications are evident even in the extreme south where the Devonian rocks lie in inverted sequence upon the Vegamián, Alba Griotte, Caliza de Montaña and Cervera Formations. These formations can rarely be traced throughout a complete structure due to the unconformable relations and faulting, which is quite probably more intense than it has been possible to map.

To the north of the boundary structures along the Cardaño line, the Curavacas Conglomerate present in larger and smaller lenses lies in a planar segment of the fold. The regular north dip is only slightly disturbed by a few minor folds up to the family of faults shown in Section B (Encl. 1). Only one of these has been traced to any extent in the field (Geological Map) but the presence of the others has been established in the detailed profile (Section B, Encl. 2).

The flap fold illustrated in the air above Section B is much more complex in the terrain as described below (p. 236). However, the sum total of these flatlying cascade folds leads to an overall form of a large flap fold (Encl. 2).

The gently dipping upper flank of this flap fold is pushed against some vertical standing, complexly deformed beds forming an axial zone. The north flank of this axial zone is abutted by the overturned flank of a flap fold belonging to the north flank. The remarkable feature of two folds overturned from either flank towards the axis of a syncline makes this profile of outstanding interest.

The remainder of the north flank of the Lechada syncline comprises a steeply dipping sequence with a number of cascade folds mostly of fairly small amplitudes. The measurements show the presence of a steeply plunging anticlinal axis west of the C-shaped fold of Portilla. The folding is too tight for this to be a simple continuation of the latter. Rather it is considered as a comparable development dependent on the continuation of the Naranco-Portilla fault system just north of it.

Yet further north Section B shows the plunging nose of the Vallines anticline which has clearly reached the limit of concentric folding. It is quite possible that considerably more faulting attends this final disappearance of the Curavacas Conglomerate here while the isolated lenses speak of stratigraphic variations.

To the west the overturning of the south margin becomes even more pronounced the Devonian rocks lying subhorizontally upon the younger beds in places between Mura and Pico Redondo. The overturning can be traced far into the Lechada Formation in the ridge east of Pico Redondo but in the Guspiada valley the bedding conforms to the normal dip for the south limb of the syncline. The roll-over into the inverted limb of the major flap fold can be seen in the slopes of the ridge above the headwaters of Arroyo de Guspiada.

To the north two pebble beds overlain by two greywacke layers trace somewhat complex patterns demonstrating minor folding here. These are cascade folds with their axes plunging steeply west to northwest. The middle limb of these folds is often overturned but, as the continuity of the beds shows, little if any faulting has taken place here.

Folding in the north flank opposite to these folds also seems to be less intense. Exposures in this area are rare enough that — while the structural evidence found does not contradict the direct continuation of the known Vallines and Portilla anticlinal axes here — such a simple assumption must be considered somewhat rash. The undoubted north flank of the Vallines anticline is formed by the sequence topped by the thick development of Panda Limestone in the type section of this member.

The Lechada syncline at its western extremity presents its most extreme development as illustrated on Section A (Encl. 1). More than half the south flank is inverted, the beds sometimes even being folded completely over to dip north. The Devonian rocks to the north are here faulted against the Curavacas Conglomerate which cap Pico Redondo dipping inverted south. There is evidence of faulting in the axial plane of this recumbent anticline which, as constructed, follows the topography remarkably closely. The traces of the pebble bands demonstrate minor folding in this inverted limb by parasitic folds plunging west.

In the more normal limb further north (Section A″—A‴) clearly mappable cascade folds develop with overturned central limbs, complete and unfaulted. The uppermost sequence including the last lenses of the Panda Limestone Member and, the still massive, 'Quartzite' Bed, is quite a regular, dipping to the north right up to the axial zone.

The axial zone is probably more complicated than shown in Section A. Faulting is possibly more important and the fault shown certainly represents a rather wide zone of shearing in the Lechada Formation. Immediately north of the axial zone folding is quite intense, cascade folds being common but complicated by the superimposition of parasitic folds. Larger types of these folds dominate the structures in the valley of the Rio Orza the folding around axes plunging NW causing westerly and overturned dips.

North of the Orza valley E-W trends recur along the continuation of the trend of the Vallines anticline but the large number of minor folds here obscures the main structure. The average dip south is not very great but due to the asymmetry of the small folds the projection results in a more clearly defined anticline. Section A illustrates the disharmony that must exist between the minor folds and the Curavacas Conglomerate.

Near Casasuertes the Panda Limestone Member and the 'Quartzite' swing round in a great arc from north of the map boundary dipping quite steeply west between the north and south limbs in what can only be termed a dome structure. A considerable thickness of sediments is folded in this simple way but the core is filled by the complicated system of cascade folds and parasitic folds described above.

The two marker beds intersect the axial zone of the Lechada syncline just south of Casasuertes and become involved in complicated structures there. The Panda Limestone lenses out here and the mass seen against the axial fault has almost certainly been thickened tectonically. The sharp syncline just north of the fault is repeated in the 'Quartzite' which also shows the complete development of a subsidiary anticline in the core of the tightly apressed syncline. The massive outcrop of 'Quartzite' SE of Casasuertes represents the floor of the small syncline flanking the subsidiary anticline to the south, plunging westwards almost parallel to the topography.

The outcrop of the 'Quartzite' in the valley to the west is affected by the axial fault and several more subsidiary folds and, though the dips are often steep, it cannot be far from the axial zone of the main syncline axis. However, near Cuénabres the major fold is no longer recognizable and the stratigraphically higher rocks show complete disharmony with the structures traced from the east. Along the southern boundary the inverted Devonian rocks are reduced to a thin sliver by the convergence of the fault systems. These beds mostly seem to be dipping steeply between the faults as the Lechada and Curavacas rocks also tend to do. These faults are thought to have been responsible for detaching a core of Devonian Quartzite from its roots on the Pico Redondo ridge. This mass then slid down the axial plane of the major flap fold which had been carved out by relatively recent erosion, to its present position north of Vegacerneja (marked 'slide' on Geological Map).

The conglomerates of Pico Redondo swing down NW the inverted dip to the south steepening up to a final faulted and stratigraphic pinch out. These beds form the overturned limb of the fold which it is thought was probably detached by an axial plane fault from the upright limb above.

The most westerly lens of the Curavacas Conglomerate near Vegacerneja swings in a sharp C-shape strongly reminiscent of the northernmost fold at Portilla. However, the relation of this fold to the other rocks here, especially the limestone band with a gentle north dip just to the west, are difficult to understand. Insufficient evidence for the younging of the beds at various exposures have not allowed a definite picture to emerge. The influence of this structure can be seen along the roadside north of Vegacerneja where complex cascade folds plunging NW can be seen.

DEFORMATION

Internal Deformation

The very heterogeneous sequence within the simple structural framework of this region has been formed into folds of many shapes and size accomplished by quite variable types of internal deformation. The conglomerates generally do not take part in tight folds, rarely show greater sign of strain than jointing cutting through the pebbles not uncommonly lined by vein quartz. Sometimes the pebbles have been forced into contact and pressure pits can be seen in otherwise smooth surfaces. The much more extensive quartz veining and pebble crushing noted in the tightly folded conglomerate NW of Portilla confirms the correlation of these factors with the folding.

Fig. 14. (× 20) Slaty cleavage at an acute angle to the bedding of the sandy layer, crumpled and cut by fracture cleavage which curves with the grading of silty material. No cleavage of any kind to be seen in the sandy layer.

The greywackes often in quite massive beds similarly are usually merely jointed. However, the thinner beds are frequently involved in tight folds and then show very strong jointing with much quartz veining. The formation of boudins in steeply dipping beds by the development of quartz veins and stylolite surfaces has been observed. A quartz vein in the joint system perpendicular to the bedding is cut off by a stylolite vein parallel to it.

These beds are vertical so that the process of flattening horizontally and stretching vertically is clearly illustrated.

The argillaceous rocks of the Lechada Formation show the most obvious and extensive effects of deformation. Almost all have been recrystallized into oriented fabric of sericite and quartz yielding a typical slaty texture under the microscope (Fig. 14). The field appearance varies considerably the obvious planar partings sometimes being quite wide apart and usually curving (Fig. 7). This expression plainly depends upon the degree and type of weathering to which the rocks have been submitted as can often be seen where new cuts have been made in old exposures.

The argillaceous rocks of this greywacke association are never what may be termed completely pure and increases in the silty or sandy admixture affect the slaty cleavage development. Grading produces curved cleavage planes although this effect is generally not noticeable due to the irregularity of the feature seen in the field. The cleavage clearly curves too at the sharp contact with greywacke beds which are invariably uncleaved. Where this contact is complicated by sedimentary structures the cleavages are usually curved around the forms in the more competent rock generally tending to slope obliquely up to the contact (Fig. 15).

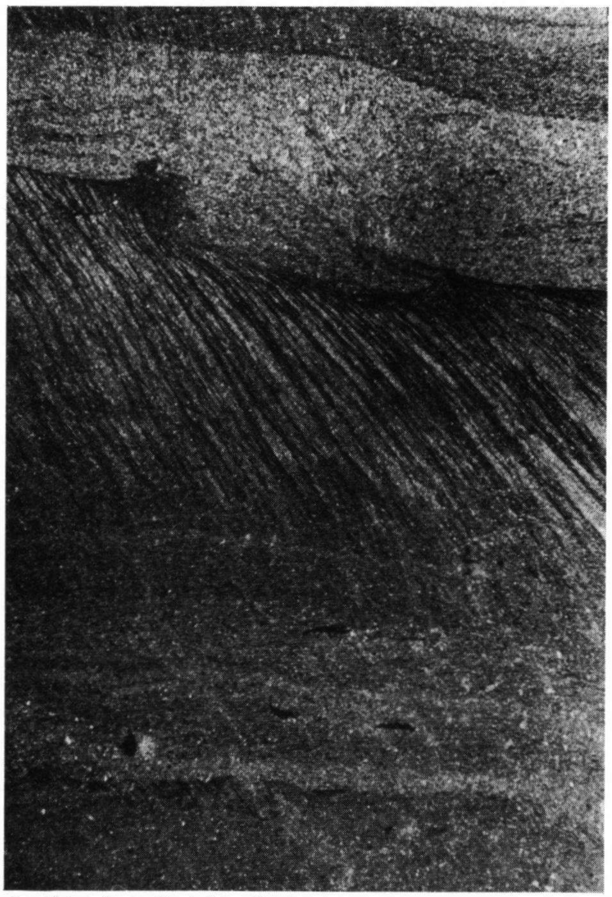


Fig. 15. (× 20) Thin lithic wacke layer with small load cast diverting the fracture cleavage planes in the surrounding slate.

Normally the slaty cleavage bears a concentric relation to the early, major folding usually showing a lower dip than the bedding. Some zones seem to have favoured the development of a steeper dip for the slaty cleavage and it even approaches the attitude of an axial plane cleavage to both major and minor folds in the axial zone of the tightly compressed Curavacas syncline. Elsewhere the slaty cleavage may be found more or less parallel to the axial planes of early flatlying cascade folds particularly in the extreme west. The relations to either set of folding can be established from the pattern formed by the cleavage planes and the coincidence of the cleavage/bedding intersections with the fold axis.

Usually the slaty cleavage planes are oriented in almost exactly the same way as the bedding planes – the typical fashion for concentric cleavage (de Sitter, 1964, p. 293). The resulting girdle thus defines the associated axis in the same way as the bedding. In folds with more or less planar limbs the intersections of the average (modal) attitude of either flank can also be used to define the axis and so can the intersection of the modal bedding and slaty cleavage planes as well as the cleavage/bedding lineation.

Since the lithology and bedding as well as the folding of this sequence is so irregular these measurements can only be evaluated statistically and, as might be expected, the combination of modal planes does not result in the best estimate of the relationship between all of these planes and the fold axis. It has proved much more reliable to analyse the relations of individual planes recorded at individual points, the distribution of these intersections being highly indicative of the orientation of the earliest structures as well as demonstrating the later folding.

The slaty cleavage is usually deformed by later fracture cleavage as well as minor folding throughout the Lechada syncline (Fig. 14). In some places the internal deformation has more truly the nature of an crenulation cleavage and the usually inferred passage between the two types is quite probable here. It is rare that all sign of fracture cleavage is absent from a slate although the planes curve strongly and die out quickly with an increase in the sand-silt content so that there is none in the greywacke beds. This indication of grading can be very striking (Fig. 14, 15).

The fracture cleavage usually dips quite steeply with a fairly constant E-W strike. It can be seen to be the axial plane cleavage to the very frequent small minor folds parasitic to the major syncline. The consistent occurrence throughout the structure even where no minor folds could be found emphasises that this de-

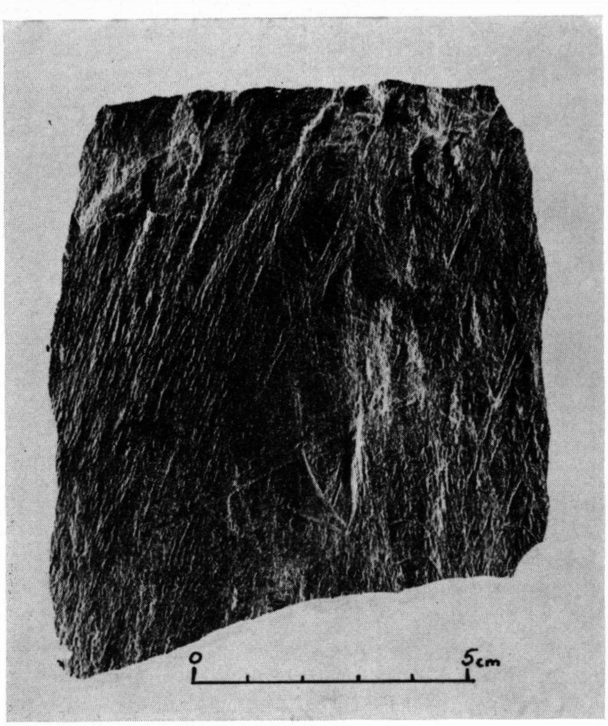


Fig. 16. Conjugate fracture cleavages in slates of the Lechada Formation.

formation affected the whole syncline and that much of the fracture cleavage development must be directly related to it.

Certain localities yielded examples of conjugate fracture cleavages (Fig. 16) and three intersecting sets have even been seen. Usually it has been possible to discover different minor folds associated with all attitudes of cleavage and it is claimed the development of essentially concentric folds has dictated these orientations. But one type of widely divergent conjugate fracture cleavage cannot be explained in this way (Fig. 51b).

The limestones found in the Lechada syncline have all been quite clearly recrystallized. It is very difficult to find any evidence of sedimentary or biological textures in these rocks. Only the smallest and most resistant forms such as fusulinids and crinoid ossicles have been found with any consistency although microscopic investigations have discovered traces of many other organisms.

The recrystallization is macroscopically more intense just where deformation seems to have been most severe. Hence the limestones appear to have yielded by flow although remaining relatively competent in relation to the slates. The limestones are not cleaved and the cleavage planes in the slates are diverted around some of the irregular sedimentary forms they show.

Total Deformation

The sum total of tectonic deformation of the Lechada syncline can be estimated from the internal deformation patterns found in the rocks of the Lechada Formation.

The statistic orientation of the cleavage planes is the most common evidence available. The average convergence angle between the bedding and the slaty cleavage is approximately 15° although there does seem to be a correlation between lower dips of the cleavage and larger convergence angles. Nevertheless the average is so low that we have to accept that the flattening process has largely effected only flattening of the sequence. This assumption implies of course, that extension took place parallel to the bedding, so that simply smoothing out our curves will result in an excessive estimate of the shortening undergone (cf. Hellermann, 1965).

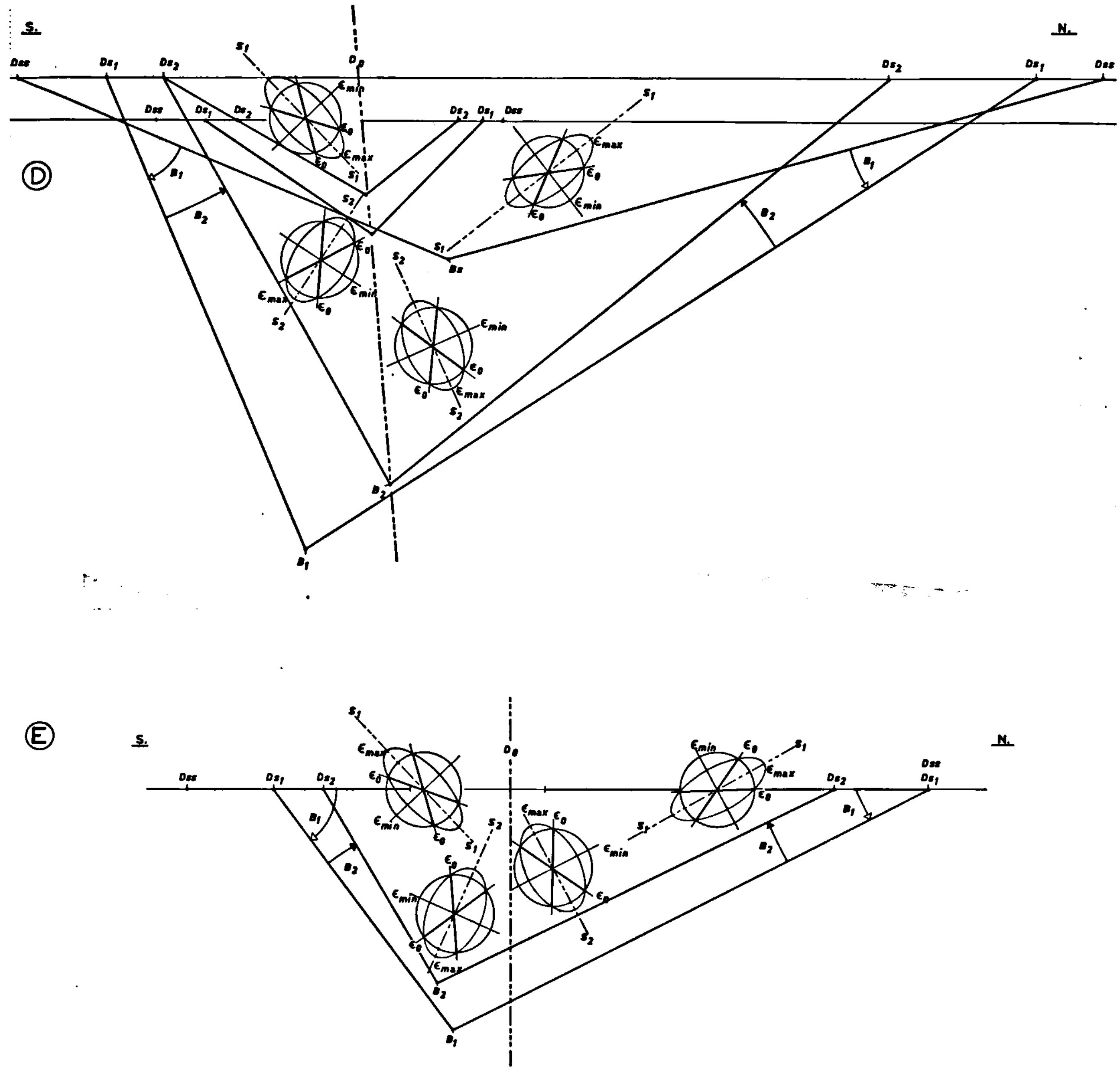
The circular arc constructed for the Curavacas syncline (p. 202) implies a shortening to 64 % of the lower beds concentrically folded with the underlying conglomerates. Furtak (1962) as well as Hellermann (1965) have calculated shortening values for argillaceous rocks undergoing recrystallization and slaty cleavage development of 35 % to 65 % perpendicular to the cleavage. On the assumption of conservation of volume this implies an extension in the plane of the cleavage to between 125 % to 200 %. It is quite remarkable that if we accept these average values, we find that the slaty cleavage deformation should have extended the bedding plane trace of the Curavacas syncline to about the average i.e. 160 %. Hence the shortening implied by the folding is almost exactly compensated by the extension due to cleaving (100 % $\times$ [1.6 $\times$ 0.64] $\approx$ 100 %).

The field occurrences make it quite clear that the fracture cleavage has in general a close relation to most of the minor folding especially of the parasitic type. As discussed in detail with the description of detailed sections can also be proved in the statistical analysis of the data (p. 213).

The minor folds are generally too complex to allow good estimates of the amount of shortening that they attain, to be made. In any case it cannot have been very large (cf. Hellermann, 1965) and the fracture cleavage is so ubiquitous that it will probably have had a greater influence.

The fracture cleavage planes are always rather steeply inclined and though they do vary considerably in azimuth throughout the syncline they are always highly concentrated in a given segment (see Orientation Diagrams, Encl. 3). In general they approach the attitude of the axial plane of the major syncline striking approximately E-W. However, where the major axis swings out of the regional trend as between Sections B and C the fracture cleavage orientation is clearly influenced but its trend changes to almost perpendicular to the axial direction (Figs. 37, 50). The relatively consistent trend of the fracture cleavage planes implies some regionally oriented constraint, the more so since local deviations can so often be related to local disturbing features.

In the Curavacas syncline the fracture cleavage development is not really comparable neither in the field



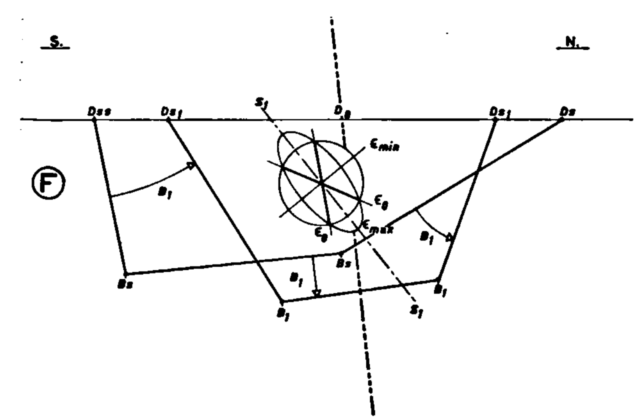


Fig. 17. Sketch Diagrams illustrating the deformation undergone by the beds within the syncline along profiles D, E, F. The strain ellipsoid is oriented with the axis of maximum deformation in the cleavage trace for the fracture cleavage (S_2) and slaty cleavage (S_1) (corrected for subsequent deformation). The resulting changes in attitude yield intersections with one another (B_2, B_1, B_3) and with the horizontal, D_2, D_1, D_s about the surface axes D_0. The construction is of the dimension changes in the bedding and the horizontal direction and is consequently not volume constant.

nor in relation to minor folds, to anywhere else in the Lechada syncline (p. 218). The minor folds in the Curavacas syncline (p. 218) are mainly associated with the slaty cleavage deformation but in fact demonstrate a significant deviation from it. The folding is parasitic to the gentle axial zone and cascade folds are typical for the steep north flank (Fig. 11). The sketch demonstrates that the deformation accomplished is of shortening horizontally and extension vertically in the axial zone; contrasting and complementing vertical compression and horizontal expansion in the steep flank. This pattern is associated with only a small deviation of the slaty cleavage or a minor development of the fracture cleavage.

The movement pattern implied by this arrangement is of a transfer of material from the upper part of the near-vertical north limb and to pile it up in the axial zone. The stresses appear to have been transmitted along the bedding planes and the model matches exactly that of gravitational pressures in the upended sequence inducing the downward sagging of the steep flank and crumpling in the core.

The analysis of the strain due to the slaty cleavage (Fig. 17) does not demonstrate the complete smoothing out of the bedding curvature because it has not been possible to reproduce the effect of the curving planes graphically. The curious asymmetric shape obtained illustrates the considerable amount of tectonic tilting that must have taken place (given by the positions B*s*). However, the effective transfer of a considerable amount of rock into the syncline from above and from the north to the south flank also influences this result. It is for this reason that constant volume diagrams were not constructed.

In the part of the Lechada syncline where the box-form is apparent, Sections D and E (p. 221), it is quite striking that the fracture cleavages are grouped fan-wise dipping north and south in the north and south limbs, respectively (Figs. 29, 32). Thus it is possible to postulate a correlation between the deformation of the box-fold and the fracture cleavage just as, in fact, with the slaty cleavage (p. 222).

The strain analysis of Section D and E (Fig. 17) shows that the greatest change in dip took place before or during the formation of the slaty cleavage only 20° dip being due to tectonic tilting in Section D. In Section E the effect of stretching the bedding planes by the slaty cleavage is more than adequate to account for the increase in length and the Peñas Matas fault seems to have been in active cutting out some.

The movement indicated by the development of the slaty cleavage is everywhere to increase the size of the syncline. In contrast the fracture cleavage gives a definite picture of compression, the apical angle of the fold being decreased but by only 5—10°. The total amount of horizontal shortening with constant volume is very small indeed ($\approx$ 10 %). The influence of the Peñas Matas fault seems to have been quite small and little rock has been lost or gained.

The lack of true shortening during such strong deformation can be seen to be due to the axes of principal strain of the deformation ellipses are inclined to one another. One of the pair of axes of no-strain tends towards the horizontal (at flattening to about 70 %) while at the same time the complementary axes of no-strain tend towards the vertical. Thus although the rocks have been flattened everywhere the orientation of this deformation is so laid out that the vertical and horizontal dimensions of the whole mass remain approximately the same (Fig. 17).

The change in shape of the rock mass in the syncline can be held to be responsible for the development of the cleavage. However, although the process can easily be visualized as shearing, it is clear that this is by no means necessary. Variable orientations of simple strain are quite adequate to attain the same geometric result.

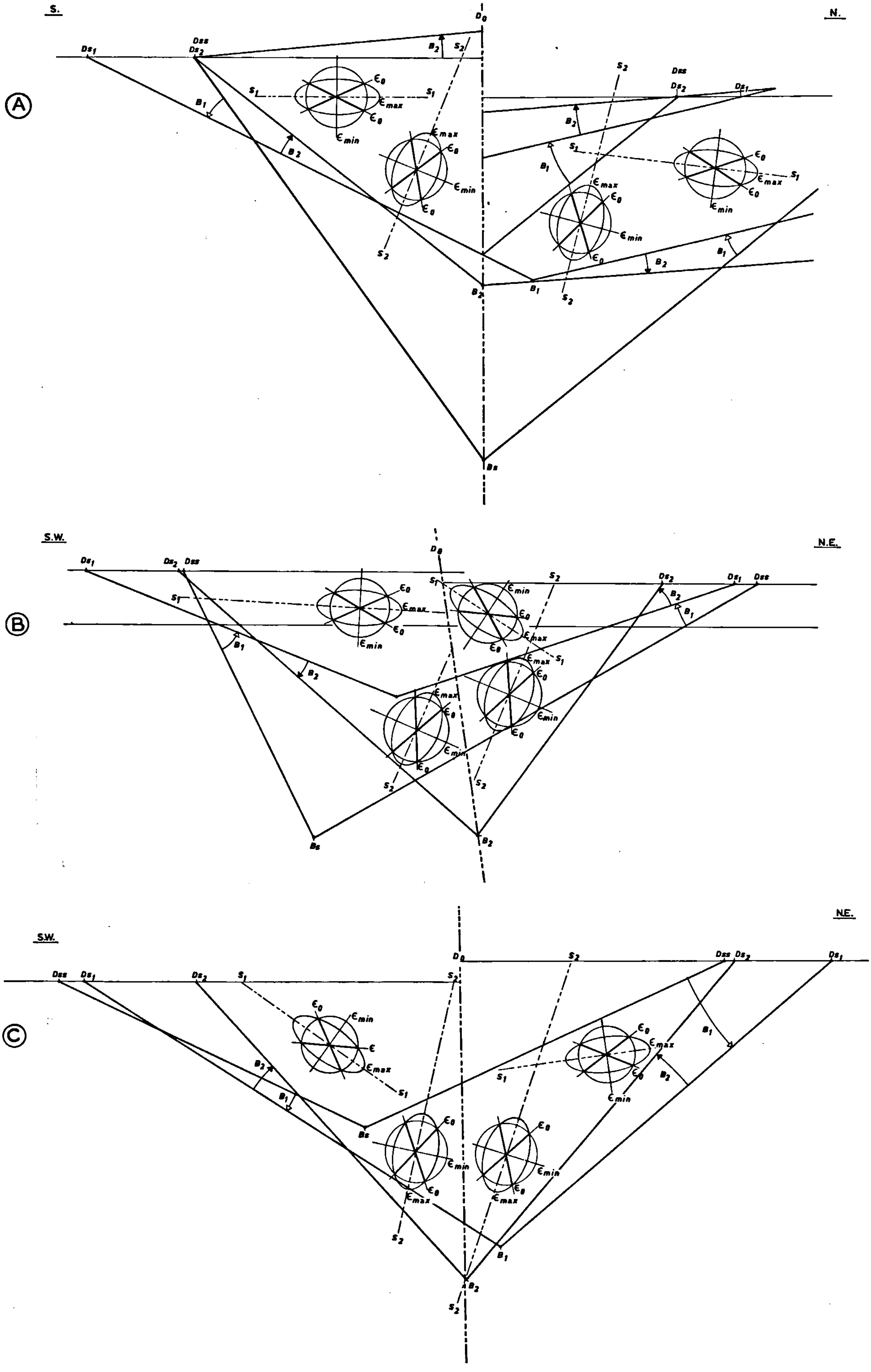
In Section D (p. 226) the fracture cleavage in minor parasitic folds is parallel to their axial planes and dips with them in the direction opposite to the modal fracture cleavage of their corresponding flanks (Fig. 32). This implies the complete dependence of the cleavage development upon the nearest fold. The orientation of these folds demonstrates different pattern of deformation involving the upward and outward expansion of the core of the syncline. The parasitic folds are in general so scarce as to account for only a small proportion of the total deformation. Their concentration near the Peñas Matas fault is most probably to be connected with the preceding complications along this zone.

The appropriate model is thus of cantling blocks which could as well have been faulted as folded, deforming but not compressing the syncline.

Between Sections B and C the major axis swings through a WNW to a NW trend while the fracture cleavage planes attain the ENE to NE trend (Diagrams, Encl. 3). The initial folding of the syncline during which formation of the slaty cleavage set in had developed many complex cascade folds increasing in severity to the west before the fracture cleavage deformation began.

The intersection of the undeviating planes of the fracture cleavage with the complex earlier structures yields a typical pattern. This pattern is exactly reproduced by the minor folds observed in the field to have axial plane fracture cleavage. Hence here there is no contradiction between the deformation assignable to the general fracture cleavage and that implicit in the minor folds.

The fracture cleavage in this part of the syncline usually shows a considerable deviation from the mode in a regular way. Hence the poles to the cleavage planes plot in well-defined partial girdles (Diagrams, Encl. 3). The cleavage/bedding intersections and the fold axes also form girdles which coincide precisely with the modal plane of the bedding so that the basic control of the pre-existing structure is quite clear. At the same time the similarity of the orientation of the minor fold and cleavage orientations demonstrates the fact, obvious in the field, that the fracture cleavage in them is wholly dependent on the fold.



S.
N.
A
Ds1
Dss
Ds2
D0
B1
B2
S1
S2
ε0
εmax
εmin
Bs
S.W.
N.E.
B
C

The strain analysis of Section C (Fig. 18) shows to a large degree tectonic tilting (B*s*) amounting to about 25° in either flank. During the formation of the slaty cleavage the structure developed considerably more, basically due to 15° increase of dip of the north flank. The movement to accomplish the fracture cleavage deformation has been an increase of dip of either limb by 10—15°; decreasing the apical angle by 25°. The result is a clear shortening of the section as would be expected from the constant orientation of the cleavage in either flank.

The evidence here is then of the bedding stretching with the formation of the slaty cleavage to accommodate at least 50 % more rock within the structure. The fracture cleavage shows the compression of this mass into something like its former volume but of a very different shape. The slaty cleavage event was accompanied by an increase of dip of only 15° on the north flank, while the fracture cleavage process involved even lower changes of dip on both flanks. These values would seem to be within the range of possible movements of cantling blocks as postulated above.

The only major structural feature known having the appropriate orientation to induce the fracture cleavage trending NNE in this NW-trending section of the syncline is the Peñas Matas fault. Late movement along this fault can be proved in the rocks near to it but such a through-going influence could hardly have been expected. Hence the concept binding the structures to the fault-lines is further strengthened.

The diagrams of the deformation in Sections A and B are very different to the others. They indicate the sedimentary dip at quite a steep angle having been lessened by the later movements. Tilting of as much as 30° on either flank may have accompanied the formation of the slaty cleavage but this was then a reversal of the movements bringing about the syncline. This interpretation may be somewhat falsified by the addition of material from above in the flap and the cascade folds of both flanks.

Nevertheless the deformation diagrams do indicate that the total shortening during the formation of the fracture cleavage was quite small in Section A where the apical angle reduced by less than 10°. This is in strong contrast to Section B where the difference is about 70°. The fracture cleavage is strongly oriented almost perpendicular to the bedding of the south flank tending to suggest that pressure was generated through the loading of the large flap fold which acted along the bedding.

At the western extremity of the Lechada syncline Section A illustrates the far-reaching effects of the slaty cleavage folding to the south and the fracture cleavage folding to the north. Here the greatest development of a flap-fold has taken place in the south flank in contrast to the mainly small NW-plunging back-folds in the south flank.

The fracture cleavage and the, generally small, folds associated with it are highly concentrated in both flanks with a steep south dip and an E-W trend. Thus we again obtain a deformation pattern of periferal uplift steepening the dip to allow sagging into back-folds to fill the axial zone. In contrast to the Section B only the north flank shows this to any great extent. The north flank is almost entirely absorbed by the plunging nose of the Vallines structures.

The strong orientation of the fracture cleavages in both flanks imply again purely vertical extension and horizontal compression in a structural situation comparable to that of Sections B and C. However, the different, almost exact E-W, orientation betrays a different controlling mechanism. It seems likely that the major E-W feature— the Pico Redondo fault may well have been the basic underlying feature.

Fig. 18. Sketch Diagrams illustrating the deformation undergone by the beds within the syncline along profiles A, B, C. The strain ellipsoid is oriented with the axis of maximum deformation in the cleavage trace for the fracture cleavage (S_2) and slaty cleavage (S_1) (corrected for subsequent deformation). The resulting changes in attitude yield intersections with one another (B_2, B_1, Bs) and with the horizontal, D_2, D_1, Ds about the surface axis D_0. The construction is of the dimension changes in the bedding and the horizontal direction and is consequently not volume constant.

DETAILED SECTIONS

Introduction

The rocks within the major syncline first mapped as seen in the exposures have obviously been subjected to complex deformations by minor folds and multiple cleavages. Exposures are quite plentiful, if patchy and it was quite clear that selection would be necessary to put some limit on the amount of work.

The method chosen for the detailed work was to run profiles selected for the best possible structural positions, perpendicular to the major fold axis, along which reasonably continuous sequences of exposured rock could be measured. Measurements were taken at fixed stratigraphic intervals apart from extra investigations to work out some more intricate folds. Initially a stratigraphic interval of 5 metres was selected (Section B, Encl. 2) but the results showed that this was not really necessary and all the other sections were made taking readings, as far as possible, every 10 metres of rock thickness.

Approximately every tenth station was identified on the aerial photographs (scale 1 : 28 000) and the whole profile plotted at 1 : 10 000 scale on a Wild A 6 Autograph. The resulting accuracy is considered to be far higher than could be obtained with the normal 1 : 50 000 topographic map (non-photogrammetric).

Previous work having shown the presence of both fracture and slaty cleavage deformation of the argillaceous rocks these phenomena were sought at each measurement station. Only after all of the bedding and cleavage features had been identified were the measurements made. Hence representative planes could be chosen as close together as possible having regard to cleavage refraction due to graded or irregular bedding.

The attitudes of the intersections of each individual cleavage plane with the bedding have been computed for all separate measurement stations and are presented as lineations (Encl. 3). The equal-area projections (Schmidt Net) show the measured or computed orientations as well as density contours. The method of contouring has been chosen to allow as far as possible for the variation in the number of points in different diagrams (see Encl. 3).

The stereographic analysis of the distribution of the bedding leads to an assumption of an axis (in the Curavacas syncline two axes) perpendicular to which right sections (Badgley, 1959) have been constructed. In fact the fold attitudes are so diverse that a single plane could never be completely satisfactory. Nevertheless the right sections constructed did show an improvement over the usual type vertical section first constructed. It should be noted that the elevations being also subject to projection, the profiles no longer match the actual topography so that the sections are only suited for visualizing the picture in depth. The right sections are presented at scale of 1 : 10 000 having been reduced from the plotting at 1 : 25 00. Each individual measurement has been corrected to the plane of the section and plotted to reproduce the intricacies of the folding and the fidelity of correlation was more impressive at the larger scale than at that reproduced in Enclosure 2.

The traces of the slaty cleavage as well as of the bedding have been plotted in the detailed Right Sections in order to demonstrate the varying attitude with the bedding. This has necessitated the use of a compact term to describe the cleavage/bedding relation.

The definition followed is that the cleavage converges on the bedding in the direction in which a cleavage plane approaches a bedding plane above it (Fig. 19). It will be seen that cleavage with a steeper dip than the bedding converge towards the axis of an anticline (the usual case) from either side so that the direction of convergence may be said to change. However, if the cleavage maintains the same relative angle to the bedding, clearly folded with it, the convergence does not change across the fold axis (Fig. 19). The advantage of this term is that inversion does not alter the sense during later folding.

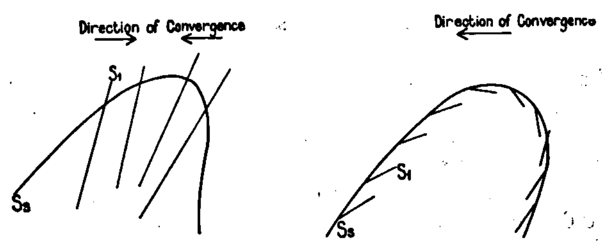


Fig. 19. Sketch cross sections illustrating the concept of converging between cleavage (S_1) and bedding (S_s) a) convergence changes in the contemporaneous fold; b) convergence does not change between the flanks, the cleavage having been folded with the bedding.

The projection to depth in the detailed right sections has been made using the Compensated Boundary Ray method of Gill (1953). This method allows for differential compression of the beds with increasing dip and is necessary in such mixed folding containing both cleavage and concentric properties.

In the absence of other information the compression factor for this construction has been determined by trial and error. Compression factors of 25 % and 50 % were incorporated in constructions for Section F (Encl. 2) through the Curavacas syncline. The correlation of the two identified pebble beds across the syncline was obviously much closer in the section resulting from using the 50 % compression factor.

According to Hellermann (1965) the greatest compression in the slates of Eastern Sauerland has been at right-angles to the slaty cleavage, increasing in severity with a decrease in dip. Consequently an attempt was made to allow for this by calculating the compression ratio as perpendicular to the modal slaty cleavage. Furtak and Hellermann (1961) also report compression factors for similar rocks of between 36% to 78 % so that an average of 50 % seemed appropriate. A test employing this orientation of the 50 % compression factor resulted in even poorer correlations than either of the previous ones.

Naturally the system yielding the best correlations has been used but the reason for this result can only be guessed at. It would seem likely that the majority of differential compression was attained before the onset of slaty cleavage recrystallization. The fact that some beds can be shown to have been inverted before the onset of the slaty cleavage (p. 242) demonstrates the possibilities. However, this should mean that the slaty cleavage has effected little differential compression which hardly seems likely.

Further work on this problem would be of great interest but tests by graphic construction such as carried out are far too laborious to be practical.

The use of photogrammetry to measure individual folds (Savage, 1965) and of electronic computation to test the possible models seems to offer opportunities to advance knowledge of these relationships.

Orientation Diagrams

The orientation diagrams have been constructed on an equal-area projection (Schmidt Net) subdivided into a grid that has allowed the calculation of densities of occurrence for areas 1 % of the total around a regular system of 441 centres (Fig. 20). This counting and plotting of points as well as the computation of the plane intersections have been carried out by the Zebra computer, I.T.C. Delft by kind permission of Drs. D. Eckhardt, the programmes having been written by Ir. J. W. J. Collet (modified from Robinson et al., 1963).

The contour values have been selected following the

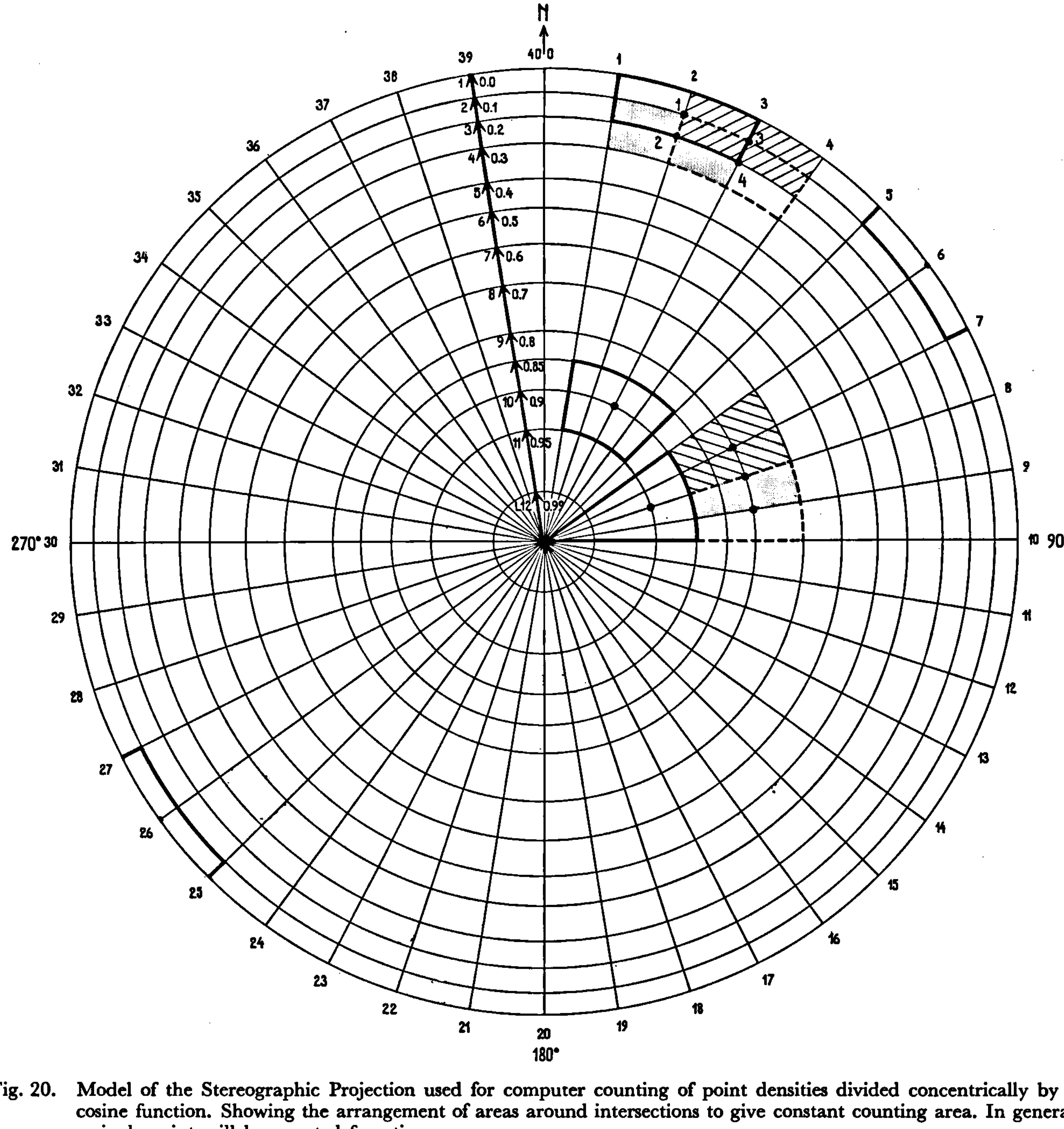


Fig. 20. Model of the Stereographic Projection used for computer counting of point densities divided concentrically by a cosine function. Showing the arrangement of areas around intersections to give constant counting area. In general a single point will be counted four times.

theory of Kamb (1959) to a certain extent. In fact this theory requires a counting circle varying in area with different total numbers of points. However, by calculating the expectation for the counting area in a fixed grid, as above, some allowance can be made for the variation in totals. Using Kamb's formula $\frac{\sigma}{E} = \sqrt{\frac{1-A}{NA}}$ and E=NA (where E is the expectation in the counting area; σ, the standard deviation for a random sample; A, the area of counting grid; N, the total number in sample). Values for σ and E can be found from the fixed A and the known N. It can be shown that for 441 points the area of the Kamb counting circle should be equal to the sampling grid used (i.e. where N=441, A=0.01).

Taking as a basis a confidence limit of 5 % (i.e. probability of 0.05) we can postulate that densities deviating by thrice the standard deviation from the expectation should not belong to a diagram obtained from a random population; i.e. densities $>E + 3\sigma$ or $<E-3\sigma$ should be significant. Although it does not seem likely that the confidence limit can be valid in exactly the

same way. In fact comparisons between values with a Kamb circle and the grid method confirm this.

Hence contours have been drawn to enclose the area of density values within E $+3\sigma$ which are hachured on the diagrams. Where the total number of points in a diagram is less than about 900 ($N<891$) it can be shown that a complete absence of points is no longer significant. Hence since all diagrams have lower total numbers of points, no limiting significant contour could be drawn. Here lies one of the great advantages of the Kamb method by setting $\frac{\sigma}{E} = 3$ the value E—3σ is therefore always positive. Thus the lower limiting contour can always be drawn so and empty areas, so often a very informative feature of the diagrams, can be evaluated.

Higher densities have been contoured in steps of equal to 6σ which has been made the standard contour interval. Numbering was not considered necessary because the total number of lines on any diagram is never large and the variation in the density of the actual points shown convey the sense of graduation.

It has been found that the values obtained by the grid method give lower values than obtained by Kamb's method except for very small total numbers of points. So in order to allow a more reliable comparison of densities between all diagrams the maximum density using the Kamb counter has been ascertained, the orientation of the centre being shown in the diagrams and the density given alongside.

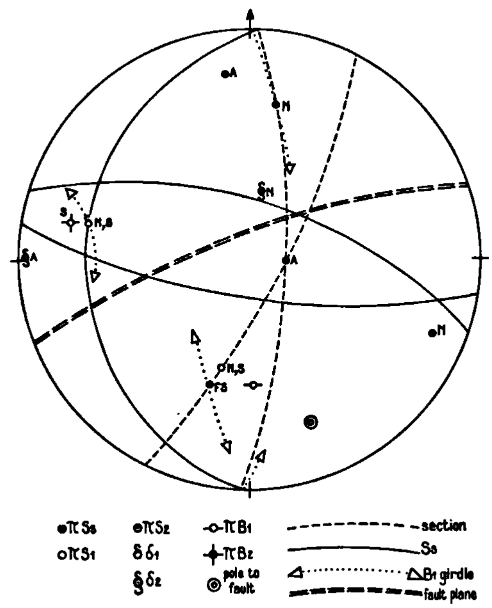


Fig. 21. Section F, Curavacas, composite stereographic diagram (Wulff Net), showing modal bedding planes and their poles (Ss, πSs) poles to modal slaty and fracture cleavages (πS_1, πS_1) as well as to the modal axial plane of minor folds (πB_1); the modal orientation of cleavage/bedding intersections (δ_1 and δ_1) together with the modal plunges of minor fold axes (B_1). The influence of the minor folds producing spread into partial girdles is also shown.

Section F, Curavacas

Introduction. — The Curavacas syncline was investigated in detail along a single line of measurements Section F (Encl. 2) which corresponds to a part of Section F (Encl. 1). The detailed Section F (Encl. 2) has been split into two segments in order to project onto planes as closely as possible perpendicular to the majority of bedding planes. The form of the fold in the beds along the profile is fairly simple being split into three main parts- two steep, near planar limbs and a flat, but somewhat folded axial zone. The orientation diagram (Diagram F; πSs; Encl. 3) shows clearly three maxima of pole concentrations corresponding to these parts. However, it is striking that these three maxima do not lie on a great circle (Fig. 21) implying that the structure as a whole is not cylindrical and cannot be projected onto a single plane without distortion.

Hence two projection planes have been chosen perpendicular to the intersections of the three planes so defined (Fig. 21). These planes do not, of course, meet in a line exactly perpendicular to the horizontal reference but the gap subtending an angle of only 8° was not considered worth demonstrating in the section.

As stated in the chapter on Structures (p. 202) the Curavacas syncline plunges to the west, yet the intersection of the two outer segments plunges toward the east. However, the intersections between the axial zone and the two outer segments plunge, diverging, toward the west. The hypothesis that these form the basic axes for the structure is strengthened by the map picture especially when the overturning of the northern flank is taken into account. Hence, the structure may be regarded as two separate opposing monoclines composed of the two flanks folded against the axial zone.

Section F (Encl. 2) shows that the southern limb of the Curavacas syncline is extraordinarily planar between Sts. 301 and 307 with a very slight tendency to flatten northwards; a curvature which is quite marked between Sts. 308 and 311 bringing the bedding into an attitude concordant with that of the axial zone between Sts. 311 and 312. This profile gives rise to a typical girdle in the bedding plane poles between the maxima corresponding to the south limb and the axial zone (Diagram F; πSs, Encl. 3). One short flat-lying segment between Sts. 311 and 312 represents the

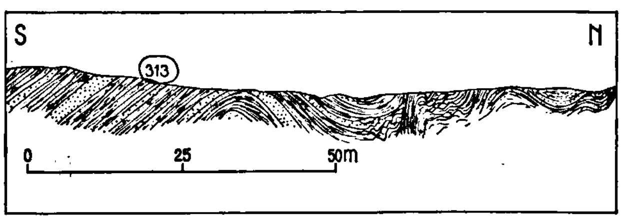


Fig. 22. Curavacas syncline, Sts. 312—313, Section F; intricate parasitic minor folding near the southern hinge in the axial zone. Note tendency for shorter, limbs to dip steeper northwards.

initial part of the axial zone but between Sts. 312 and 313 the bedding is quite intricately folded (Fig. 22). Beyond Sts. 313 the beds of the true axial zone lie with small southerly component to their generally western dip. At. St. 317 the south dip has already begun to steepen and at St. 320 it is overturned dipping steeply north with a minor cascade fold (Fig. 23) imitating the larger. This in fact forms part of a local back fold although the dip remains very steep throughout the remainder of the north limb becoming overturned from Sts. 324 through St. 326.

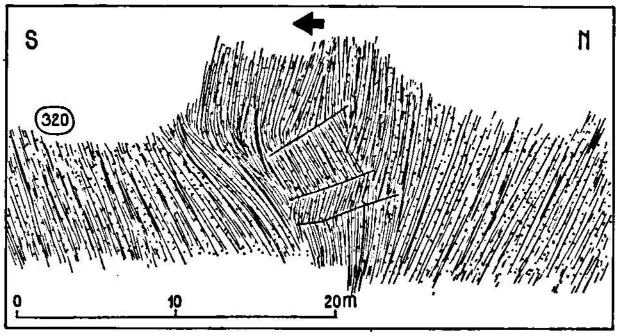


Fig. 23. Small cascade fold in north flank of Curavacas syncline arrow shows direction of younging.

Slaty Cleavage. — The slaty cleavage traces in Section F (Encl. 2) show that in the extreme south, near the massive conglomerate the slaty cleavage planes dip at an angle slightly lower than that of the bedding (10° modal difference and converge to north). Between Sts. 306 and 307 most of the cleavage traces are almost exactly parallel to those of the bedding mainly due to the gradual decrease in dip of the bedding. And as the dip of bedding decreases even more up to St. 311, the slaty cleavage lessens only slightly so that the cleavage attains a steeper dip than the bedding (Fig. 24). This tendency continues through Sts. 312 and 313 so that quite a large angle develops between the bedding and the slaty cleavage. In fact the cleavage here approaches the attitude of axial plane cleavage to the minor folds in this part of the axial zone. Within the flat part of the axial zone, Sts. 314—316 the slaty cleavage has generally quite a steep dip although the direction varies considerably in the northern segment. Between Sts. 318 and 319 the bedding curves sharply into the cascade-fold with its axial plane dipping north which is close to the dip of the slaty cleavage. But in the upper limb of this fold (St. 320) the cleavage suddenly reverts to a near-parallel attitude to the bedding through St. 321 and nearly to 322. Between Sts. 322 and 323 the cleavage attitude varies with respect to the bedding, which dips steeply south, some groups of cleavage planes dip to the north.

Fig. 24. Thin bedded greywacke-slate alternations typical for Lechada Formation in the Curavacas syncline, dipping north (St. 311) with slaty cleavage dipping slightly steeper than the bedding.

Beyond St. 324 where the bedding curves into a slightly inverted attitude the cleavage dips consistently north at a lower angle than the bedding i.e. converging south. This southerly convergence of the bedding and cleavage in a sequence younging south means that the relation is equivalent to the cleavage dipping steeper than the bedding in a normal succession (cf. St. 308 to 311, south limb).

Hence we see that the relation of the cleavage to the bedding varies throughout the cross section of the structure and though much may be compared, these variations are asymmetric from one flank to the other just like the syncline itself. The situation in the planar part of the south flank where the slaty cleavage dips at a lower angle tha the bedding is not repeated in the overturned north flank. However, for the rest of the structure a basic similarity can be made out between the cleavage, dipping at an angle 10—20° steeper than the bedding, in the curving part of the south flank with a similar angular difference but with an opposite direction of convergence in the vertical to overturned part of the north flank.

In the axial zone the slaty cleavage conforms to the asymmetry of the major structure by its general north dip throughout. It is also apparently related to the minor structures constructed from the measurements as axial plane cleavage and can often be found with this relationship to the smallest of modified sedimentary structures (see p. 220). These folds however tend to have a parasitic relation to the main fold, as described below so that the overall relation of the slaty cleavage to the main structure is not disturbed.

The slaty cleavage is, on the above evidence, to be related to the whole structure and its asymmetry and not to the individual monoclines of either flank. This suggests that the initial concentric folding controlled by the massive Curavacas Conglomerate layers took place around two axes. But that the later deformation with the slaty cleavage development and parasitic folding arose with the whole mass reacting as a single unit. The unimodal orientation of slaty cleavage planes shown in Diagram F; πS_1 (Encl. 3) contrast with the partial girdle, multi-modal in Diagram F; πSs (Encl. 3). Within the mass of course, the various inhomogeneties, asymmetries etc., due to previous sedimentary or early tectonic action, have influenced the local deformation pattern.

Fracture Cleavage. — The development of fracture cleavage is very irregular within the Curavacas syncline. Well expressed planes that could be certainly identified in the field were often difficult to find, the impression often being obtained that the fracture cleavage was parallel to the slaty cleavage. Since the slaty cleavage in this profile (Section F, Encl. 2) generally dips quite steeply north (Diagram F; πS_1: Encl. 3), which is more or less the average attitude of the fracture cleavages throughout the Yuso Basin, this idea was not surprising. However, it was not considered justifiable to plot such measurements dependent on rather a vague impression and treat them equally with those of positively identified planes.

The metamorphosing influence of the Peña Prieta intrusion may have something to do with rather different development of the cleavages here. The syntectonic character of this intrusion has been argued by van Veen (1965) and this seems very probable although little in the way of new data or ideas can be advanced. The argillaceous rocks near the contact have been hornfelsed in places but seem to bear a banding resembling relict slaty cleavage. Since van Veen (1965, p. 71) records the folding of a sill the emplacement probably occurred between the development of the slaty and fracture cleavages. The further recrystallization due to the contact metamorphism may well have inhibited the formation of fracture cleavage well beyond the zone in which the influence of the metamorphism is obvious.

In the southern flank of the syncline the planes measured between Sts. 301 and 308 were rather widely spaced 3—5 mm and not really strictly the same as the usual fracture cleavage with microlithons approximately 1 mm thick. Even these unsatisfactory planes were generally hard to find which was thought to be due to a higher psammitic content in these rocks. Most of the planes dip more of less steeply WNW, emphasising the difference with the usual fracture cleavage. These planes yield intersections plunging north down the dip of the bedding (Diagrams F; πS_2 and δ_2: Encl. 3) with no obvious relation to any known structures. Between Sts. 308 and 311 the fracture cleavage is quite well developed in a more normal way possibly because the slates here are purer. These fracture cleavage planes vary considerably in orientation all dipping steeply north or northwest but some even south. In strong contrast to the slaty cleavage no correlation could be made out between the few minor folds here and the fracture cleavage. Neither do the sedimentary structures appear to have had any influence upon it.

In the axial zone between Sts. 310 and 317 satisfactory measurements of fracture cleavage could only be made at three or four stations in contrast to the very strongly expressed slaty cleavage (Fig. 24), but beyond St. 317 and as far as St. 319 measurements could be made with reasonable frequency. These cleavage planes mostly dip steeply giving rise to a subsidiary maximum in the pattern of poles (Diagram F; πS_2: Encl. 3). The intersections of these planes with the bedding thus define a very different direction, the subsidiary maximum plunging west (Diagram F; δ_2: Encl. 3). Here these fracture cleavages can be seen parallel to the axial planes of some folds demonstrated by comparing the orientations of the fold axial planes and axes with the fracture cleavage planes and their intersections with the bedding, respectively (Diagrams F; $\pi B_{1,2}$, $B_{1,2}$, πS_2 and δ_2: Encl. 3).

Fracture cleavage is practically absent from the rest of the section approaching the Peña Prieta granite.

Minor Structures. — The large minor folds, large enough to be drawn at the scale of the cross section, are considered to be practically entirely tectonic; whereas many of the folds small enough to be directly observed in the exposure can be seen to be almost certainly more or less modified sedimentary structures (see p. 220).

The tectonic minor folds are practically confined to the two hinge zones between the three different segments of the box-structure and show differences to be related to the asymmetry of the whole. At the hinge of the south flank a series of sharply defined folds developed, whose axial planes (illustrated in Section F) dip consistently north. The slaty cleavage does not dip as steeply, on average, as these axial planes although near the fold hinges the former is often very nearly parallel to the latter.

The variations in the attitude of the slaty cleavage to be seen between Sts. 312 and 313 (Section F, Encl. 2) are wide enough to allow this and since the measurements have in fact been taken from points judged to represent the average of an interval extreme attitudes are not shown. It is most probable that the slaty cleavage has a statistical geometric relation, parallel to the axial planes of these folds as suggested by their orientation (Diagrams F; πB_1, πS_1: Encl. 3).

The asymmetry of the minor folds shown in the section can be described as having their shorter limb dipping north. This is a form of folds parasitic to the south-dipping limb of a fold although we can only regard them as occurring in part of the near-horizontal axial zone. However, as the stereographic analysis suggests, (Fig. 21) the hinge zone may be regarded as an independent monocline axis; then these folds may be regarded as truly parasitic to the almost flat, north limb of the southerly monocline.

The minor folds to be seen in the northern hinge zone on Section F have a very different form best seen between Sts. 320—321. The steeply dipping beds here roll over into a cascade fold with the short inverted limb dipping north. These folds belong to the steep northern limb of the structure and hence the asymmetry is exactly opposite to that of normal parasitic folds. The strong disharmony of these structures suggested by the construction of Section F illustrates rapid change and disharmonic nature of these folds, which makes isolated exposures in them so difficult to understand. The slaty cleavage is largely sub-parallel to the axial planes of these folds although rapidly reverting

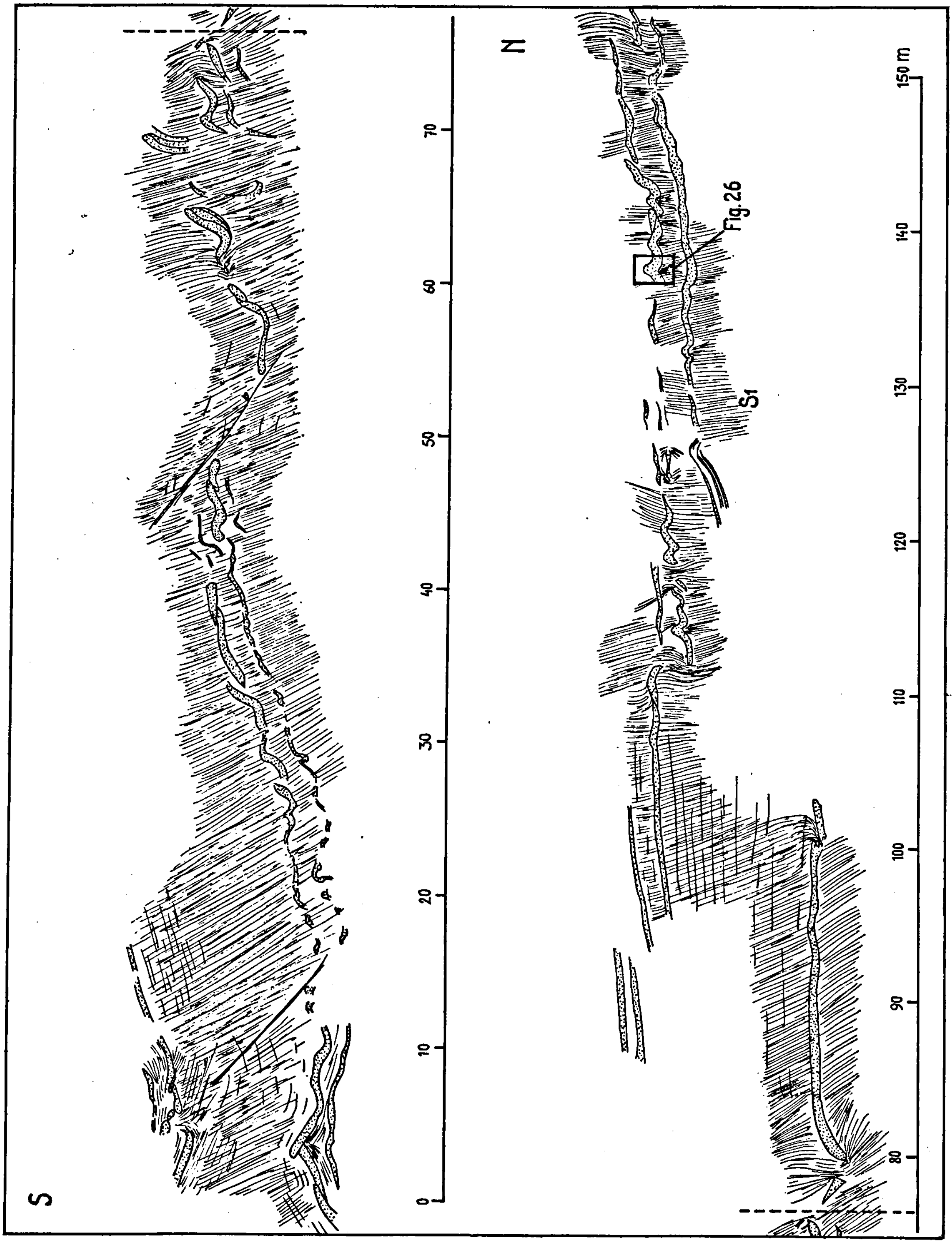


Fig. 25. Field sketch of slumped layers of greywacke in strongly cleaved slates, Sts. 314—315, Section F, Curavacas. Beds pulled out into lenses, crumpled into small folds and shoved together. The slaty cleavage planes (S_1) are clearly diverted around the ends of many lenses and into the axial planes of small folds (see also Fig. 26).

to a new bedding-plane attitude around St. 321. A further small fold near St. 322 seems to be responsible for the sharp reversal in the attitude of the slaty cleavage there.

Modified Sedimentary Folds. — Many of the smaller folds seen in individual exposures can be shown to be basically of sedimentary origin. Highly significant correlations of measurements as well as direct observation show that some relationship exists between the tectonic deformation and the folds but it must be accepted that this is rather more complex than it might be assumed.

Sequences are exposed on both the north and south flanks (Sts. 309—310 and 314—315), the latter being reproduced from the field sketch (Fig. 25). The general gentle southerly dip of the axial zone is very well shown by the sandy greywacke layers 10—30 cm thick. The argillaceous beds between the greywackes shows the typical slaty cleavage development with the planes dipping steeply northwards, fracture cleavage is absent. The most striking thing is that the greywacke layers frequently lens out as well as develop quite sharp folds despite the fact that these are some quite planar segments. It is quite clear that isolated slabs of rock like these could only receive tectonic pressures through the surrounding rocks. These slates were obviously much less competent than the greywackes as is shown by the refraction of the slaty cleavage around the end of a greywacke lens. This process cannot be boudinaging since the flattening associated with slaty cleavage is always perpendicular to the cleavage plane which is here almost perpendicular to the bedding. The interpretation of these deformations as sedimentary means that the forces will have been due to gravity, not requiring direct contact for transmission and that the close occurrence of compression and tension features (i.e. the thrusting and lensing below St. 314, Fig. 25), do not involve any difficulties.

A simple fold (Fig. 26) can be seen to consist of two adjacent load casts with the hinge having developed with much jointing and quartz veining between them. The slaty cleavage in the argillaceous rocks converges into the axial zone of this small anticline. The load casting clearly has been the root-cause for this fold; it is impossible to be sure how much the fold developed under the sedimentary slumping, demonstrated by the other beds but the cleavage and jointing have probably facilitated some further folding deformation during the tectonic activity.

In a similar way the deformation illustrated by van Veen (1965, p. 80, reproduced here Figs. 27, 28), are basically sedimentary in origin. Fig. 27 is at St. 310 on Section F (Encl. 2) and it can be seen that the hammer is resting on a flat massive greywacke bed about 30 cms thick. Above this there is a bed of slate almost as thick containing the row of separated rounded segments (pseudonodules) of a thinner (approx. 5 cm) bed of greywacke. This is again overlain by a greywacke band some 10 cm thick showing gentle undulations. The deformation has clearly been different within each of these three layers but there is no evidence in the exposure that such differential shearing accompanied the slaty cleavage formation. In any case the effect of pressures that would form the slaty cleavage would not boudinage a bed lying perpendicular to the cleavage.

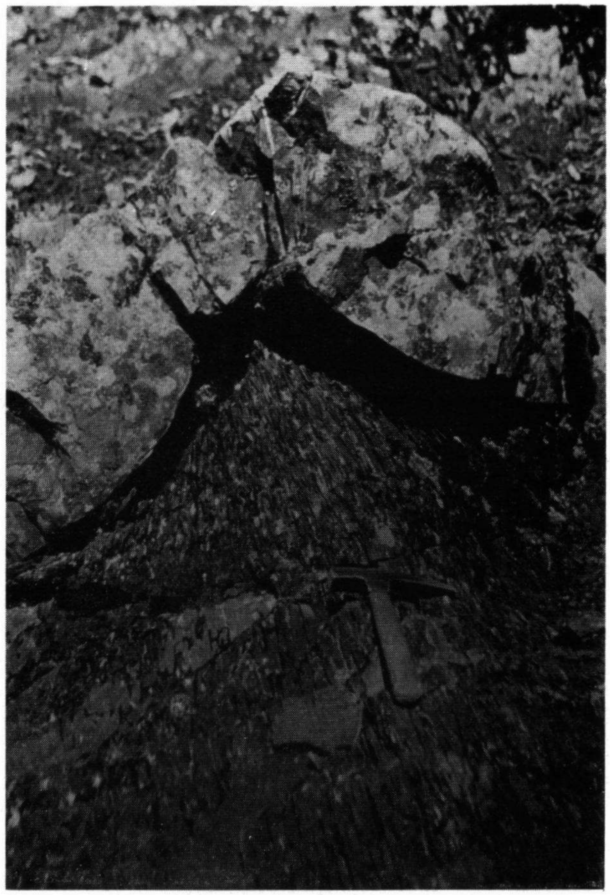


Fig. 26. Small fold in greywacke bed near St. 315, Section F, Curavacas syncline. The axis has developed between two load casts with fractures and quartz veins. The slaty cleavage is very strongly developed parallel to the hammer handle, in the axial zone.

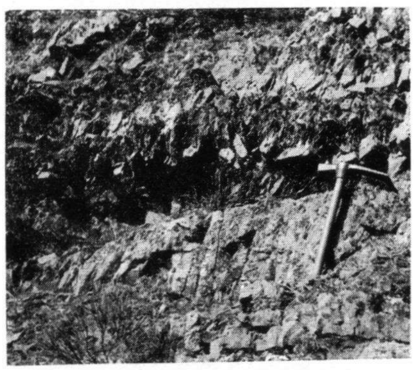


Fig. 27. Slumped sandstone slabs and balls with slaty cleavage concentrated between the separated blocks; cf. fig. 25. (After Van Veen, 1965.)

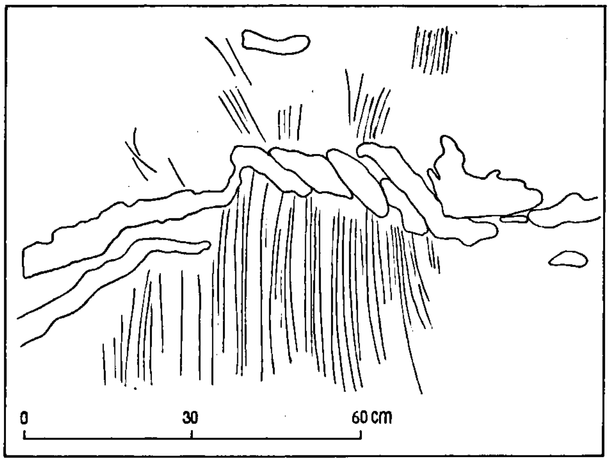


Fig. 28 Sketch from photograph (van Veen, 1965). Showing broken fragments of a thin graywacke layer piled on one another enclosed in slates with cleavage perpendicular to the bedding. Compression > 90% mostly due to sedimentary

The rounded fragments of the bed of greywacke in Fig. 28 have been piled on one another being rounded in a similar way to the pseudonodules at St. 310. Firstly the amount of compression represented by this imbricate structure is more than 90 % much more than that represented by most slaty cleavage (Hellermann, 1965). Secondly the slaty cleavage planes are remarkably unchanged between the parts of the structure where the greywacke is little deformed and the highly compressed parts.

Hence these examples demonstrate the need for pre-slaty cleavage deformation. The variations in form and mixed effects of compression and tension all point to a sedimentary slumping origin for this deformation. No doubt the greywackes were also deformed while the slates were being compressed but the effect can only have been that of emphasising pre-existing structures.

The cross section of the Curavacas syncline demonstrates the complexity of an apparently simple structure. Firstly no analysis yields a satisfactory single axis plunging west as demanded by the mapping. The rocks, at any rate along the profile examined show primary distributions suggesting folding about two axes forming a box structure.

The slaty cleavage in the steeply dipping flanks is the clearest type of concentric cleavage although the relation to the bedding seems to vary almost capriciously in some places so that in locations very close to one another the slaty concentric cleavage may vary from a steeper to a shallower dip than the bedding i.e. complete change of direction of convergence. However, within this same profile through the major syncline the slaty cleavage can be seen taking part in the further deformation of pre-existing sedimentary structures as well as becoming axial plane cleavage to some large cascade folds.

Despite the deviations noted above the pattern of orientation of the slaty cleavages is statistically very similar to that of the bedding planes justifying it being regarded as a concentric cleavage even here. The statistic indication of the individual slaty cleavage bedding intersections shows an even stronger preferred orientation which indicates unequivocally the orientation of the direction of least deformation plunging west.

The compression registered by the slaty cleavage was most probably perpendicular to the cleavage i.e. along a line plunging about 35° south. However, an attempt to use this to construct a geometrically correct section resulted in poor correlation of the marker beds from flank to flank. It is of course possible that the miscorrelation could be due to disharmonic folds deeper than the profile examined but the excellent correlation obtained using an horizontal compression factor does not make this likely. It must be assumed that other deformation differently oriented has affected these rocks. Again we find support for the notion that initial movements took place before the deformation associated with the slaty cleavage.

The evidence of cross-cutting fracture cleavage found here implies that some deformation occurred after the slaty cleavage but the poor, patchy development suggests that the effects were rather limited.

Consequently the emphasis in the Curavacas syncline is of early sedimentary deformation — note that the rocks here can rarely be identified as turbidites so that the slumping here may have been synchronous with turbidity flows to the west. Pre-slaty cleavage tectonic deformation of the main structure controlled perhaps more closely by fracturing in the Curavacas Conglomerate seems to have been the most important event before the slaty cleavage deformation with the final attainment of the major fold form together with the development of the complementary parasitic and cascade folds. After the formation of the slaty cleavage only minor structural developments took place together with the late development of fracture cleavage and of very few small folds.

Section E, Peñas Matas

Introduction. — Detailed Section E (Encl. 2) was made across the eastern nose of the Lechada Syncline where the structure pitches steeply upwards towards Peña Prieta. The major Peñas Matas fault here cuts into the south flank of the structure where the sequence above the Curavacas Conglomerate is about 600 m thinner than in the north flank. The precise structural significance of this change is difficult to define but stratigraphic variations are also postulated (p. 198).

The structure along the profile of Section E can be subdivided into 4 segments from south to north.

First the absolutely planar segment including the massive uppermost Curavacas Conglomerate and about 200 meters of sediments immediately overlying it which all dip at almost exactly 60° North.

Secondly the rest of south flank of the structure considerably modified by minor folds associated with the Peñas Matas fault as well as the hinge zone to the north.

Thirdly the gentle curving axial zone with a few gentle minor folds and two rather sharp hinges to the adjacent, steeper parts on either side.
Fourthly the moderately dipping north flank of the structure gently curved with a few minor folds, concordant with the massive Curavacas Conglomerate. The overall form is again essentially a box with two steep sides and a near planar floor. This is not so striking in Section E (Encl. 2) because the axial zone is relatively short. In addition rather fewer readings than usual could be taken here so that very little can be seen in the distribution of poles to the bedding (Diagrams $E_{N,S}$; πSs: Encl. 3).

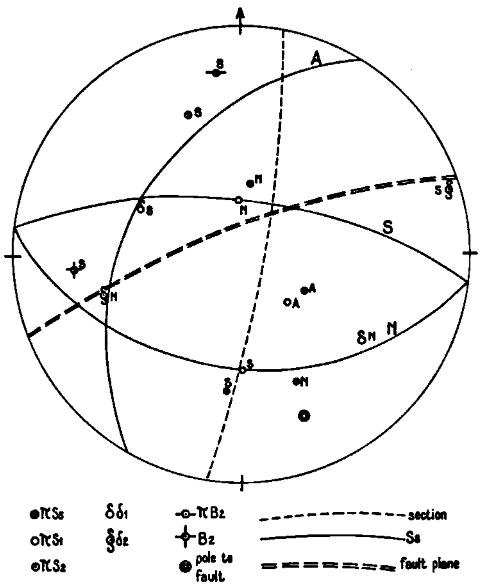


Fig. 29. Composite stereographic diagram (Wulff Net) for Section E, Peñas Matas: showing for each flank modal bedding planes (S*s*); poles of modal planes for bedding (πS*s*), slaty cleavage (πS_1), fracture cleavage (πS_2), and minor fold axial planes ($\pi B_{1,2}$); plunges of modal slaty cleavage/bedding intersections (δ_1), fracture cleavage/bedding intersections (δ_2), minor folds (B_1), (B_2); together with the girdle orientations associated with the B_1 and B_2 folds: the major fault plane and the plane of right section.

The composite diagram (Fig. 29) derived from the orientation diagrams shows that the maxima of bedding plane poles from both flanks do not lie on a great circle so that this part of the fold is also not cylindrical. However, the divergent maximum due to the short axial zone comprises a relatively small proportion of the measurements (40 from 260) so that little serious distortion would result from the use of a single projection plane compromising between the maxima of the flanks. The diagram illustrates, however, how strongly the axes between either flank and the axial zone must plunge (NW and WSW). The third constructed axis shown is that between the steeper and gentler segments of the north flank which also plunges steeply SW subparallel to the hinge.

The box-form barely detected in this relatively high section becomes more marked in depth by construction which compares closely with the forms obtained in Sections D and F (Encl. 2). This would seem to confirm the validity of the type of construction used while implying that this form is basic to this level in the structure.

Slaty Cleavage. — In detailed Section E, (Encl. 2) the slaty cleavage traces in the most southerly segment, Sts. 524—526 dip almost as consistently as the bedding planes but at a slightly lower angle (6°) i.e. converging north. The same sense of convergence is retained in the isoclinally folded sequence just south of the Peñas Matas fault (St. 524) as well as in the minor folds north of the fault as for as St. 521. Beyond, the cleavage/bedding relation varies, in the steeper dipping beds (Sts. 515, 516 and 520) they are practically parallel but in shallower dipping beds the slaty cleavage shows a much steeper angle to the north i.e. converging south (Sts. 521, 517—519 and 514—515).
The southerly convergence is part of the south limb and the axial zone persists even through the complex hinge fold north of St. 515 and on into the north flank. Here it means that the slaty cleavage has a lower dip than the bedding except for the minor few folds in this thick planar homocline sequence. Such folds are to be seen between Sts. 501—502, 511—512 and 512—513, where it is striking that the slaty cleavage maintains the same direction of convergence throughout these folds. At other places e.g. between Sts. 510—511, much of the cleavage is apparently parallel to the bedding.
The overall picture of this section of the Lechada syncline is quite closely comparable to that of the Curavacas syncline (Sect. F, Encl. 2, p. 217). The slaty cleavage of the south flank converges north in the lower part of the sequence varying to a southerly convergence in this flank which persists in general throughout the axial zone and the north flank. Hence only the lower parts of the sequence show an essential symmetry with respect to the structure as a whole. The locations where the slaty cleavage has been found to be practically parallel to the bedding are generally near the hinge zones where early deformation was probably concentrated.
The maxima of slaty cleavage/bedding intersections from the south flank coincides closely with fold axes generated by the various segments of this flank including the axial zone (Fig. 29). Hence, as postulated above, some of the folds here including the hinge to the axial zone, are confirmed as having been active during the slaty cleavage deformation. The few folds of this type that could be measured do indeed plunge NW but are too few to be significant (Diagram Es; $B_{1,2}$: Encl. 3).
The modal plunge for the slaty cleavage/bedding intersections in the north flank of Section E show a widely spread girdle although the maximum density is greater than of the found in the south flank (Kamb Maxima [$> 13\sigma$] : [$> 8\sigma$]). It would seem that this

orientation must be related to the structure as a whole—the near horizontal E-W axes defined by the steeper dipping limbs (Fig. 29). In fact the slaty cleavage/bedding intersections from the beds south of the Peñas Matas fault tend to plunge gently east forming a subsidiary maximum (Diagram Es; δ_1: Encl. 3). Thus while the indications are mainly of NW-SE fold axes in both flanks these were only subsidiary minor folds and the major fold seems nevertheless to have been E-W.

Fracture Cleavage. — This is very well developed in the rocks of profile Section E. The attitudes of the fracture cleavage planes are very strongly oriented in both north and south flanks forming sets dipping steeply NNW and SSE, respectively. Conjugate fracture cleavage has only been found in one or two isolated exposures. The association as axial plane cleavage to minor folds is obvious in numerous examples discussed below but the fracture cleavage has been detected throughout the north flank where practically no minor folding has taken place.

The modal fracture cleavage orientation in the south flank has exactly the same strike as the Peñas Matas fault the vertical angle between them being approximately 30°. This attitude seems appropriate for the compression of the wedge of rocks against the fault although this implies the tendency to reverse movement. The fracture cleavage planes of the north flank of the Lechada syncline in Section E similarly strike parallel to the Peñas Matas fault but they differ only by about 15° in dip. The correlation of the attitudes of these cleavages and the Peñas Matas fault is further brought out by the coincidence of the maxima of fracture cleavage/bedding intersections of either flank with the plane of the fault (Fig. 29).

It would seem that the fracture cleavage here can only be regarded as a whole enabling the movement of material into the core of the syncline with little or no vertical or horizontal component of compression. This means a change in shape of the rock mass without essentially overall compression (p. 209).

Minor Structures. — It is quite striking that the south flank of the Lechada syncline contains most of the minor folds as well as fault encountered in Section E (Encl. 2). Some, too small to be shown even at 1 : 10 000 scale used, occur just above the Curavacas Conglomerate near St. 525. They were quite possibly sedimentary in origin but they are now highly tectonized and no definite proof could be established. All others appeared to be wholly tectonic folds.

The isoclinal folds in the footwall of the main Peñas Matas fault near St. 524 are accompanied by many small folds of a somewhat different type which show axial plane fracture cleavage. The slaty cleavage, cut by the fracture cleavage and clearly folded by these folds, maintains a northerly convergence throughout. The axial planes of many of the isoclinal folds are broken by a fault rendering the strict visual determination of an axis difficult. However, the majority is almost exactly isoclinal so that the axial planes are practically parallel to the bedding, here dipping on average practically due north. In contrast most of the measured axial planes of parasitic folds dip south as does the axial plane fracture cleavage (Diagrams Es; $\pi B_{1,2}$ and πS_2 : Encl. 3). The Peñas Matas fault here dips to the NNW from the mapping but the fault planes measured in the exposure are practically parallel to the bedding, perhaps representing a local direction.

Hence we seem to have a mixture of folds here one set of which has no distinguishing cleavage. However, these isoclinal folds do fold the slaty cleavage while the fracture cleavage maintains its regional trend through them. Since the slaty cleavage/bedding convergence changes through each fold these folds must be earlier or synchronous with that cleavage. As the fracture cleavage cuts across the orientation these isoclinal folds it seems certain that they were earlier. The fact that the isoclinal folds have their axial planes parallel to the main fault plane here suggests a direct connection in mechanism. But no asymmetry indicative of the direction of fault movement could be found. They could quite easily have been generated by drag during the normal fault movements suggested by the stratigraphic correlations. However, the later asymmetric folds and their associated fracture cleavage reflect the condition of horizontal overpressure in the syncline which is incompatible with normal faulting (in these sediments).

So that after being active during sedimentation the Peñas Matas fault renewed active normal faulting during a stage after the slaty cleavage deformation. Conditions were reversed during the following fracture cleavage deformation which increases in intensity towards the fault suggesting its influence was important and that movement along it may have been reversed.

Towards the hinge with the axial zone, between Sts. 515—516 minor folds with oversteepened short north dipping limbs are evident in Section E. All the folds now show a similar orientation with rather flat axial planes dipping south and steep or overturned limbs dipping north (or south).

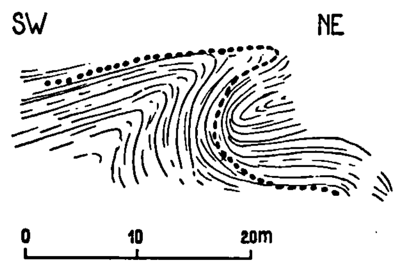


Fig. 30. Small cascade fold, St. 515, Section E, Peñas Matas; in the hinge zone of the north flank of the Lechada syncline outlined by thin pebble bed. Fold plunges 30° west; it seems to have folded the slaty cleavage but is earlier than the fracture cleavage (see Fig. 31).

The complex fold at St. 515 is strongly overturned towards the north and the axial zone of the Lechada Syncline. The continuous unbroken profile of the fold could be traced by the fortunate occurrence of one of the marker pebble bands in the exposure (fig. 30). This very tight fold clearly cannot persist through any great thickness of layers and varies considerably in form in the exposure. In fact complete disharmony must be expected at other levels and an axial plane fault has been assumed in the construction of Section E. It is, of course, impossible to describe this fold adequately in terms of axial planes and axes but most of the crests have a rather steep plunge (30°) to the NW.

Hence this fold axis is parallel to the plunge calculated for this hinge between the south flank and the axial zone as well as the modal slaty cleavage (Fig. 29). The slaty cleavage also approaches close to the axial plane orientation in the crest of the fold but there the fold is in any case near-isoclinal. Throughout the rest of the fold the slaty cleavage maintains the slight southerly convergence with the cleavage dipping steeper than the bedding (where right-side up), (Fig. 31). The reversal of the bedding/cleavage attitude in the fold where the bedding is inverted strongly suggests that the slaty cleavage has been folded. However, much of the fracture cleavage cuts across the orientation of the fold even in the crest so that the folding seems to have been earlier than the fracture cleavage. Hence we have again folding later than the slaty cleavage but earlier than the fracture cleavage deformations.

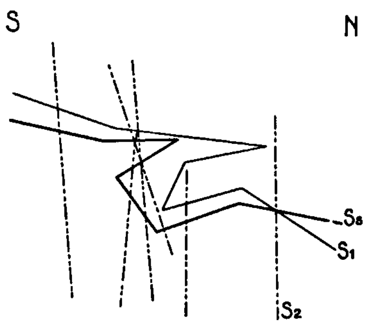


Fig. 31. Right section plot of the measurements of the cascade fold at St. 515, Section E, Peñas Matas. The bedding (S*s*) and slaty cleavage (S_1) have been folded together so that the convergence does not change. The fracture cleavage (S_2) cuts completely discordantly across the earlier structure.

The axial zone of the structure shows some very small gentle undulations which can be regarded as minor folds, barely visible on Section E. The constructed axes plunge quite steeply west at about 30° west down the dip of this almost planar zone. One distinct fold marks the inflexion between the axial zone and the north flank of the syncline although the form is in fact certainly much more complex than shown. In the field the bedding in the north flank of this anticline is extremely disturbed and the measurements that could be made cannot be wholly representative. The steeper dip of the slaty cleavage in the north-dipping flank means that the convergence does not change through this structure. Hence it is suggested that the slaty cleavage has been folded at the same time as the bedding. The later fracture cleavage here is parallel to the axial plane of the fold supporting the concept of post-slaty cleavage deformation.

Only few minor folds have been found in the gentler dipping part of the north flank. These have only been detected by variations in dip measurements but these indicate that the slaty cleavage has been folded. The convergence does not change through the fold so that where the bedding dips north the cleavage has a steeper dip. The relation to the fracture cleavage is not clear in the exposures but it is commonly subparallel to the calculated axial planes of these folds. Hence we see in Section E a fold again approaching a box form but with a steeper south flank abbreviated by a large normal fault of Peñas Matas and a north flank having a rather moderate, relatively undisturbed dip. The fault has apparently localized a considerable amount of deformation near it but only the isoclinal minor folds could possibly be related to the normal movement. The concentration of folds associated with the compressive fracture cleavage deformation near the fault suggests that the structure must have come into existence earlier. The slaty cleavage in the southern flank shows the same variations in convergence as seen in the Curavacas syncline from towards the synclinal axis (lower dip of cleavage) in the extreme south changing to convergence away (steeper dip of cleavage) from the synclinal axis as far as the core. In the north flank the situation is very simple with the convergence consistently towards the syncline (shallower dipping cleavage).

Section D, Grillo

Introduction. — The profile measured along the line of Section D (Encl. 1 and 2), has been chosen through the broadest part of the Lechada Syncline. This together with the relatively high altitude of this section (ref. St. 325 is at 1775 m *not* 1175 m as in Encl. 2), means that a thicker than usual sequence is exposed. The southern limit of the structure is here the continuation of the Hoyos de Vargas fault which throws the higher parts of the Lechada Formation against Devonian rocks (Encl. 1). The amount of throw remains somewhat in doubt because of the lack of certainty in the correlation of the various marker bands across the structure but may be as much as 1500 m downwards to the north as assumed in the section.

The composite diagram (Fig. 32) shows that the most likely axis should be one plunging gently west, so that Section D (Encl. 2) was projected onto a plane dipping 70° to the east because this also gave the best compromise passing closest to all maxima of bedding planes (Fig. 32). The spread of the maxima in both

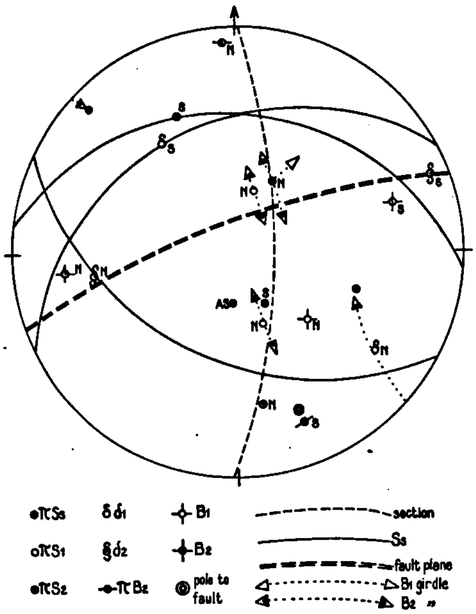


Fig. 32. Composite stereographic diagrams (Wulff Net) for Section D, Grillo: showing for each flank modal bedding planes (S*s*); poles of modal planes for bedding (πS*s*), slaty cleavage (πS_1) fracture cleavage (πS_2), plunges and minor fold axial planes ($\pi B_{1,2}$); plunges of modal: slaty cleavage/bedding intersections (δ_1), fracture cleavage/bedding intersections (δ_2), minor folds (B_1) and (B_2); together with the girdle orientations associated with the B_1 and B_2 folds: the major fault planes and the plane of section.

flanks (Diagrams DN,S; πS*s*: Encl. 3) can largely be accounted for by the effects of minor folds associated with fracture cleavage especially in the abbreviated south flank of the syncline.

The rocks immediately north of the Hoyos de Vargas fault are very highly deformed into very small folds impossible to plot accurately at this scale. Some attempt has been made to give an impression of the extreme deformation in Section D, (Encl. 2) as well as the general form of the bedding but the result can be only regarded as a very approximate realization. North of St. 333 deformation is much less intense and the bedding curves in a more continuous manner, first gently then more steeply and then again more gently. Thus the south flank of the Lechada syncline here has a near sigmoidal profile and the change of dip to the almost flat axial zone is a quite gentle curve. The two faults between Sts. 329 and 330 are normal faults (dipping 050/45 and 042/57) with a measured apparent vertical throw of 10 m down to the NE. Such movement is negligible in effect at the scale of the section but a marked change in dip takes place at each as if the fault-bounded block has been rotated as part of the above mentioned fold.

The almost exactly planar axial zone between Sts. 327—328 has a very low dip to the south while immediately north of the summit of Grillo (St. 327) the beds tilt sharply upwards into the steepest segment of the north flank. Faults have been found quite frequently in this flank although their precise role could not be established. Some may be associated with minor folds and probably have negligible throw at the surface. However, it is possible that others increase in throw to depth causing the failure of correlation of the pebble bands through this section, as illustrated Section D (Encl. 1).

North of St. 323 the bedding curves over a sizeable minor fold not regaining the same steep dip until St. 319. Once again a fault zone occurs at this hinge. Similarly there is another fault between Sts. 315 and 316 where the dip again lessens abruptly to the value of that of the rest of the north flank. Consequently the north flank shows a somewhat different profile having the steepest part of the limb adjoining the axial zone although beyond this the sigmoidal trace somewhat resembles that of the south limb.

The constructed profile demonstrates the disharmonic character of most of the minor folds which results in a much more nearly planar trace for the top of the Curavacas Conglomerate at depth. The construction also emphasises the planar, flat-lying axial zone so that the lower part of the profile strongly resembles that of Section E.

Slaty Cleavage. — The slaty cleavage in the most southerly part of Section D (Encl. 2) plots practically parallel to the bedding throughout the zone of intense minor folding (Sts. 331—336) except for the final stretch (St. 336) where there is a slightly greater dip south. Further north a distinct, consistent albeit very slight divergence develops with the cleavage dipping slightly less than the bedding i.e. converging north. At the hinge near St. 328 this direction of convergence changes, possibly indicating the major axis. The slaty cleavage then maintains a consistently lower dip than the bedding practically throughout the whole of the axial zone and the north flank i.e. converging south. Hence, this profile demonstrates the slaty cleavage having an almost ubiquitous lower dip than the bedding so that convergence is towards the axis of the syncline. The main departure from this rule is to be found in the south flank and the sequence of north convergence, parallel and south convergence has some similarity to the Curavacas profile (p. 217). In the southernmost part of Section D (Encl. 2) the slaty cleavage trace is almost exactly parallel to the bedding through two large minor folds. This parallelism is also shown by the close similarity of the bedding and slaty cleavage orientations (Diagrams Ds; πS*s* and πS_1: Encl. 3).

The intersections of slaty cleavage/bedding (Diagram Ds; δ_1: Encl. 3) are widely scattered along the great circle corresponding to the bedding and slaty cleavage planes although the concentrations reach reasonable values (Kamb Max $>6\sigma$). The spread seems to have been caused by the influence of minor variations and errors dominating the distribution because of the great angular shift caused by them at the narrow angles of intersection.

However, it appears that the modal plunge falls near the intersection of two groups of bedding planes corresponding to the segment adjoining the flat central box and the steeper dipping beds to the south. So that the faulted change in dip between Sts. 329 and 330 was probably an active fold axis during the slaty cleavage deformation. The tendency for the convergence of the slaty cleavage to change here also confirms this idea.

In the north flank of the syncline along Section D the bedding and slaty cleavage both have strong, closely similar preferred orientations (Diagrams DN; πSs and πS_1: Encl. 3). The form of the two concentrations of poles is so similar that their distribution must be attributed to the same cause. But as in the south flank the bedding/cleavage intersections show only a very weak maximum plunging gently SE which corresponds with the orientation of many larger minor folds associated with the slaty cleavage deformation (Diagram DN; $B_{1,2}$). However, the majority of intersections are spread widely in a partial great circle girdle defined by the intersection of two modal planes which are only 14° apart. It is remarkable how few intersections (25 %) points lie within the significant contour (≈ 20), despite their dependence upon such highly oriented features. In fact a much stronger orientation would have been expected from random intersections between planes from these two samples or a diagram of all possible intersections. Consequently the conclusion seems to be forced again that corresponding planes were so near to parallel that small variations due to inhomogenities in the rocks and measurement errors induce a large proportion of non-significant directions. Hence although the slaty cleavage has been strongly oriented during relatively simple folding the pattern of bedding cleavage/intersections may be widely dispersed.

Fracture Cleavage. — The fracture cleavage in the south flank of the Lechada syncline along Section D have quite a strong preferred orientation dipping steeply ESE (Diagram Ds; πS_2: Encl. 3). Where minor folds have been measured in the exposure the fracture cleavage is parallel to their axial planes despite the way in which majority of such folds are inclined toward the north (Diagram Ds; πB_2: Encl. 3). In fact a number of north-dipping slaty cleavage planes form a small subsidiary concentration (Diagram Ds; πS_2: Encl. 3) all of which were measured in the zone of small minor folds south of St. 334. This would seem to point to local compression near the fault.

In the north flank of the syncline along Section D the fracture cleavage planes have a very strong preference to a steep NNW dip (Diagram DN; πS_2: Encl. 3). Again in the field this cleavage was observed to be parallel to the axial planes of minor folds, which mostly dip steeply south. The group of cleavage planes corresponding to these folds form the subsidiary concentration dipping steeply south (Diagram DN; πS_2: Encl. 3).

Hence the fracture cleavage forms a normal fan opening out into the synclinal bend in the major part of the syncline but the attitude is tilted over with the development of minor folding where the fracture cleavage deformation was more intense.

Minor Structures. — The greatest concentration of minor structures in Section D (Encl. 2) is at the southern end immediately north of the Peñas Matas fault. Here both large and small structures are clearly to be related to the fault. The other minor folds in the north flank are rather widely separated and are usually quite gentle flexures except where associated with faults.

The two large minor folds in the south with their anticlinal crests at Sts. 333 and 335 are asymmetric to the south and clearly have a parasitic relation to the main fold. However, as mentioned above the close parallelism of the slaty cleavage and the bedding render the relationship of the minor folds difficult to ascertain. Since the convergence of the slaty cleavage and bedding is practically unaltered throughout these folds it seems most likely that the slaty cleavage has been folded by them. These folds being parasitic and later than the slaty cleavage must have formed later in the structural sequence of events. Their location near to the Peñas Matas fault clearly implies that there must have been some connection between them.

However, the stratigraphic picture shows that the fault was already active during sedimentation while there is only evidence for normal throw. Once again we find the contradiction of stress systems required— horizontal underpressure for the normal faulting and horizontal overpressure for the parasitic folding. So the concentration of minor folds here must be attributed to the effect of the fault already in existence having brought the different Devonian rocks directly against the Lechada rocks without the intervention of the massive competent Curavacas Conglomerate.

The large minor folds can be analysed to yield north-dipping planes (illustrated by the construction lines Section D) which corresponds to the orientation of the fracture planes here. Hence it seems entirely possible that these larger folds are also related to the fracture cleavage deformation although, as mentioned above, the field observations clearly relate the small minor folds to it. However, in view of the fact that the existence of the Peña Prieta fault here has dictated the orientation and development of cleavage and folds the coincidence of the constructed axial planes and the cleavage is not considered very conclusive. Rather it is thought, in analogy with Section E that the larger folds represent a somewhat earlier period of deformation here may be even syntectonic with the slaty cleavage deformation.

The very small minor folds in the southernmost extremity of Section D could only be sketchily illustrated at the scale of the section, the complex crumpling found often having wave-lengths of less than 20 cm. All of these small folds are asymmetric with their short limbs dipping south, i.e. with the typical parasitic form in relation to the major fold. Once again the anomaly of these compressive folds being obviously controlled by a normal fault can only be resolved by assuming an earlier date for the fault movement. The small fold barely visible in Section D near St. 326 has a near-vertical axial plane with the axis plunging steeply SE. This attitude is subparallel to the preferred orientation of slaty cleavage/bedding intersections for the north flank (Fig. 32, Diagram DN; δ_1: Encl. 3), although both the individual intersections for this fold are as widely dispersed as throughout the whole flank. This correlation together with the fact that the convergence changes from one flank to the other (cleavage dips less in both flanks) suggests a genetic relation i.e. that the slaty cleavage was a concentric cleavage developed with this fold.

The fracture cleavage planes maintain the same, regional ENE-trend throughout cutting across and evidently superimposed on the earlier fold.

The rather sharp curve in the bedding between St. 323 and 324 represents a complex fold too small to be shown at the scale used. This fold is just north of the fault also shown on the Geological Map (Encl. 1) that can be traced some 5 km obliquely (NW-SE) across the main syncline through at least 200 m of relief so that it probably represents quite an important structure.

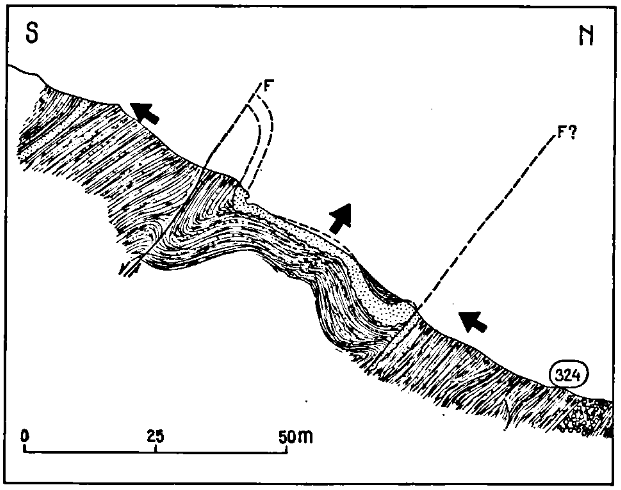


Fig. 33. Overfolded and overthrust parasitic minor fold plunging SE; St. 324, Section D, Grillo. Greywacke band really only 25 cm thick with good bottom structures forming a flat limb. Slates highly crumpled especially near the edges of the slab-like north limb.

The fold is outlined by a greywacke band somewhat thicker than usual here (25 cm) with good bottom-structures (Fig. 33). It has a curiously planar north limb flanked by two sharp hinges complicated by smaller puckering. The slates are even more disturbed, near-isoclinal folds developing at the hinges and some folding even in the axial zone. The constructed axis for the whole fold plunges steeply SE as do most of the minor folds (see Diagram DN; B_1, B_2: Encl. 3) and the axial planes dip south (although this concept is almost meaningless for the larger fold). Nevertheless it seems significant that the intersection of the axial planes and the fault coincide with the orientation of the axis and a direct genetic correlation between the folds and the fault is considered proved.

The slaty cleavage maintains a lower dip than the bedding even in the beds overturned near the hinge i.e. the direction of convergence of the slaty cleavage changes in the folds so that it seems probable that the fold is related to the slaty cleavage deformation. This idea is strengthened by the fact that the measured fracture cleavage throughout the west has an undeviating regional attitude (DN; πS_2: Encl. 3) which is almost at right-angles to this fold axis and so cannot have been influenced by it in any way.

The fault is oblique to the main syncline and would be expected to have some strike-slip motion if active during folding. The steep plunge of the folds indeed suggests some oblique lateral movement along the fault, so that a direct relation can be made out with the main folding and the slaty cleavage deformation. In a very general way the form is a parasitic fold to the major syncline with the short limb dipping away from the axis so that a comprehesive compatability can be made out for classification of the minor structures with the folding of the main syncline and the slaty cleavage deformation.

The minor structures around Sts. 321 are so large (wave length 200 m) that they show well in Section D. The form is that of the classic parasitic fold with the short limb opposing the general dip of the limb of the main fold. The section also shows clearly that the slaty cleavage maintains a consistently lower dip than the bedding throughout the folds so that the direction of convergence between them must change twice, at the synclinal and anticlinal axes. The partial gridles of bedding and slaty cleavage planes (Diagrams DN; πSs and πS_1: Encl. 3) suggest a fold axis plunging gently SE which is near to the direction of the majority of their intersections (Diagram DN; δ_2: Encl. 3). The later character of the fracture cleavages is proved by their orientation almost at right angles to this fold axis. Although some of the fracture cleavages do differ somewhat from the regional trend as it they have been diverted by the local disturbance here.

Near St. 321 on the north limb of the next syncline some small folds plunge SW down the general dip parallel to the intersection of a very small ENE striking reverse fault (Fig. 34). Here the axial planes of the folds and the fracture cleavage are clearly parallel while the slaty cleavage is folded. The fault dips at very little greater angle than the bedding and the sense of thrusting movement is clear from the deformation at the contact. Hence the attitude of the fracture cleavage and the minor folds is exactly what would be expected from the same stress field that produced the reverse fault (Fig. 34).

Another small fold at the fault between Sts. 319—320 has strongly developed axial plane fracture cleavage. The slaty cleavage can be clearly seen to be folded with the bedding since the direction of convergence stays the same throughout the fold. Whereas the frac-

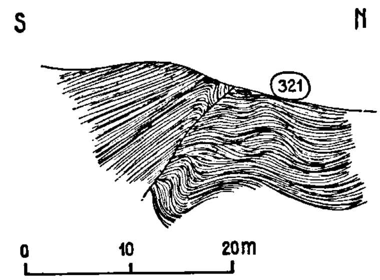


Fig. 34. Thrust fold in sequence mainly of slate, plunging SW; St. 321, Section D, Grillo. Parasitic form to the major syncline but clearly due to reverse movement along the fault.

ture cleavage and the fault are almost exactly parallel to the axial plane of the fold suggesting the fault is a crestal fracture associated with this fold. Such a fault would have relatively little throw and would die out with the fold which due to its small size must be very shallow. The fracture cleavage here is parallel to the usual trend throughout the main syncline connecting this structure with the final fracture cleavage deformation which is generally on a rather small scale.

Most of the remaining minor folds measured in the north flank of the Lechada syncline along this profile are also so small that they could not be shown in Section D. Their presence is sometimes betrayed by variations in the attitude of the slaty cleavage which is folded by almost all of them. One group occurs near St. 316 and another near St. 314 on the hinge between the steeper and gentler parts of the north flank. As usual these folds have axial plane, fracture cleavage but evidence can also be seen that sedimentary folding also took place here. A very similar set of folds occurs near St. 311 although no larger structure like the hinge zone has been found to account for them.

Another fold too small to show at the scale of Section D has been measured between Sts. 309 and 310 (Fig. 35). This corresponds to the abrupt termination just east of the section line of the greywacke band that stretches for some distance along the south bank of the Rio de Lechada (Geol. Map, Encl. 1). The rocks are completely exposed here and the smooth contact between the greywacke and slate can only be sedimentary. No definite evidence of intraformational erosion could be seen but a distinct variation in the strike affects the slates for a short interval. This fold diverts both the slaty and fracture cleavages although a conjugate set of two fracture cleavages almost at right angles is developed in places, one set of cleavages is almost parallel to the axial plane of the fold as well as approaching the regional orientation. This exposure illustrates the way in which sedimentary variations influence the tectonic deformation. The area affected is naturally small, proportional to the size of the sedimentary change but as has been shown in the stratigraphic chapter, considerably greater changes do exist in this region implying much larger tectonic influences.

Another intensely folded zone less than 10 m broad near St. 306 is again too small to show up on the Section D. These folds all have axial plane slaty cleavage and fold the slaty cleavage, one particularly clear example is sketched in Fig. 36. The fracture cleavage is parallel to the regional orientation although there is occasionally a conjugate set of fracture cleavages at an acute angle. The only other tectonic disturbance that could be found locally was the suggestion of strong bedding plane movements in the overlying rocks. It is not clear whether this could be a fault that could have caused the folds or that this detachment plane is purely local developed to accommodate the disharmony with the undisturbed beds above.

A fold between Sts. 302 and 303 is shown in Section D having the form of the classic parasitic fold to the major structure. The construction implies that the Curavacas Conglomerate is involved, but this seems highly unlikely and it is thought much more probable that a

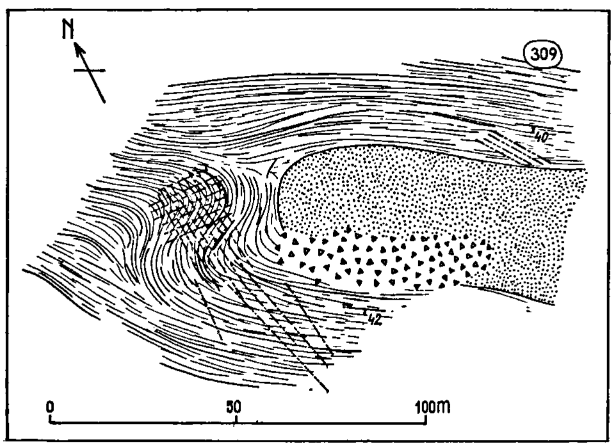


Fig. 35. Folding near the pinch-out of greywacke band in Lechada valley, St. 309, Section D, Grillo. Bedding and slaty cleavage curve around the nose of greywacke but these folds are cut across by fracture cleavage developed in two conjugate sets at the point of highest stress opposite the pinch-out.

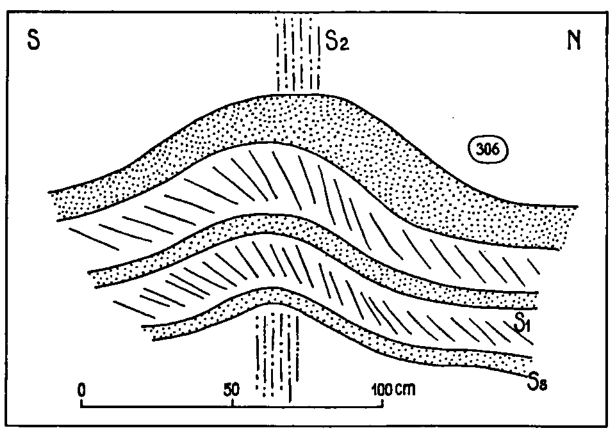


Fig. 36. Small minor fold folding the slaty cleavage in greywacke- slate alternation St. 306, Section D, Grillo. The fracture cleavage is parallel to the axial plane and the slaty cleavage maintains the same convergence throughout the fold.

stratigraphic change is present below. In fact the whole section in which measurements between Sts. 301—304 were taken is cut out 1—200 m to the west by the slumped limestone mass belonging to the El Ves Member. Some idea of this is given by the way the greywacke bed so prominent in the slopes of Orpiñas is cut off by the limestone here (Geological Map, Encl. 1). The fold clearly bends the slaty cleavage with it so that in the north-dipping flank the cleavage dips steeper than the bedding. The fracture cleavage deviates slightly from the regional E-W to a WNW trend sub-parallel to the axial plane of the fold. Measurements vary quite widely here due to variations in the sequence, either lack of greywacke for bedding or lack of slate in which to measure cleavage.

The overall box-form of the Lechada syncline along Section D (Encl. 2), is still evident although less so than in Sections E and F.

The total apparent thickness (2 500 m) encountered in the north flank of this profile is nearly twice that in Section E, forms a massive homocline only occasionally disturbed by minor folds and associated faults. The faulting may be responsible for some thickening but insufficient detail could be mapped to ascertain this. It seems more than likely that the Lechada Formation has thickened at the expense of the Curavacas Conglomerate.

Parasitic folding can be seen to have commenced during the slaty cleavage deformation some influenced by faulting. The normal faulting exemplified by the Peñas Matas fault took place before the development of slaty cleavage although the presence of this large structure has influenced the later phenomena, even the fracture cleavage.

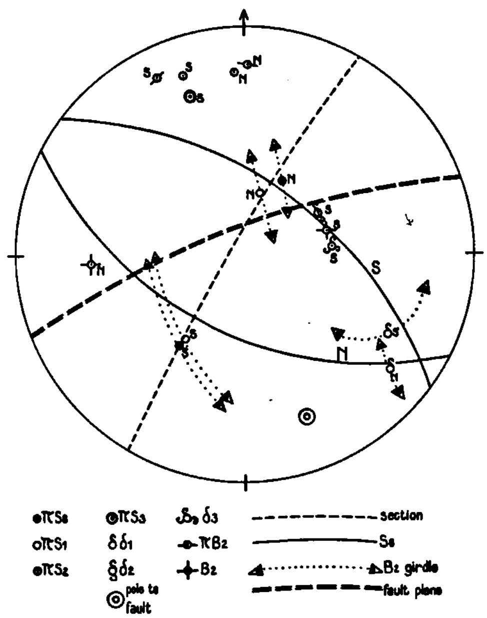


Fig. 37. Composite stereographic diagram (Wulff Net) for Section C, Barniedo Rd: showing for each flank modal bedding planes (Ss); poles of modal planes for bedding (πSs), slaty cleavage (πS_1) fracture cleavage (πS_2, πS_3), and minor fold axial planes ($\pi B_{2,3}$); plunges of modal: slaty cleavage/bedding intersections (δ_1), fracture cleavage/bedding intersections (δ_2, δ_3), minor folds (B_2); (B_3); together with the girdle orientations associated with the B_2 folds: the major fault planes and the plane of section.

Section C, Barniedo Road

Introduction. — The trace of the detailed Section C was determined primarily by the excellent exposures along the road following the Rio Yuso. Nevertheless this part of the Lechada Syncline is very interesting since the whole structure makes a northward swing here (See Geol. Map, Encl. 1). The general trend of the structure at the line of the road would appear from the trends on the map to be WNW-SSE although the Portilla structure introduces some N-S trends on the north flank. It has, in fact, been necessary to deal with this structure as a separate sub-area in this detailed account.

The distribution of the bedding planes clearly demonstrate the WNW trend in both limbs of the main syncline despite considerable subsidiary maxima. The intersection of modal bedding planes from the north and south flanks intersect in a line plunging gently ESE which has been taken as the major axis perpendicular to which detailed Section C (Encl. 2) has been drawn (Fig. 37).

The general form of the Lechada Syncline along the line of Section C is remarkably symmetrical, although subsidiary folding and faulting do increase the length of the northern limb. The syncline has an extremely sharp hinge consequent upon the planar limbs, with an apical angle of 77°. The lowermost 500 m of the sequence above the Curavacas Conglomerate of the southern limb almost parallel at about 60° N. Above there are series of minor folds between Sts. 227 and 211 some not adequately represented in the section because their axes diverge too widely from the perpendicular to the projection surface.

However, the exposures and the construction lines show that these folds are strongly disharmonic although all have parasitic form to the major structure. The remainder of the south limb dips slightly less than the outer segment but is also remarkably planar up to the principal axis.

The north flank is again remarkably planar immediately north of the major axis forming a very sharp hinge and the dip remains constant in the first 250 m to the first fold-fault complex at St. 278. The folds here are rather oblique to the section but also die out disharmonically quite quickly as suggested by the construction lines. Beyond St. 277 as far as the faults at St. 244 the dip remains generally steep but interrupted by a number of minor folds all having the general parasitic form to the major structure. Between the two faults, Sts. 244 and 268 there is a rather complex syncline with some beds inverted near to the fault. North of this fault the beds really take part in the Portilla structure although when projected onto this plane it is striking how regularly this extends the form of the major structure despite the violent swing in the strike. Nevertheless the dip does plot somewhat lower than nearer to the axis and a considerable amount of minor folding is also apparent.

Slaty Cleavage. — The orientation of the slaty cleavage planes is strikingly similar to that of the bedding planes in their respective limbs of the syncline (compare Diagrams CN; Cs; πSs with Diagrams CN; Cs; πS_1 Encl. 3). However, there is a small consistent difference resulting in modal cleavage planes dipping slightly less then the corresponding bedding (Fig. 37). This difference is very well brought out in the detailed Section C (Encl. 2) where the consistent convergence of the slaty cleavage trace up to the bedding towards the axis is clear in both flanks. This is the type section of concentric cleavage as designated by de Sitter (1964, p. 292—3). The hinge formed by two modal cleavage planes lies within a few degrees of that derived from the bedding planes which is considered typical for concentric cleavage (Fig. 37). The modal orientations of the slaty cleavage bedding intersections while not so highly concentrated are very close to the major axis as defined above.

Fracture Cleavage. — The fracture cleavage in the Barniedo Road section is better developed, or at least, better expressed in these exposures than anywhere else in the Yuso Basin. In fact this is the only place where a sufficient number of conjugate sets of cleavages could be found to produce a separate diagram (Diagram Cs; πS_3: Encl. 3).
All of the fracture cleavage planes are highly oriented with a very steep dip south (Diagrams Cs; πS_2 and Cs; πS_2 and S_3: Encl. 3), which reflects the asymmetry of the main structure. However, the cleavage planes in the south flank are spread considerably, the diagram showing a partial girdle of dips through the quadant SSW to ESE, so that complete direct control by the major structure here is not likely. In the field the fracture cleavage is usually found parallel to the axial planes of minor folds as is strikingly illustrated by the similarity of their orientations (Diagrams CN; πS_2, πS_3, and πB_2). The intersecting lineations of such sets of cleavages on the slaty cleavage planes are very clear in certain places (Fig. 16).

Minor Folds. — As has been noted above the form of all the minor folds large enough to appear in Section C (apart from the Portilla structure) is typical of folds parasitic to their position in the respective flanks of the main structure. There are, however, many other smaller folds, especially for example, near St. 327, which probably are basically due to stratigraphic variations. All of these minor folds have a well developed, axial plane fracture cleavage, the slaty cleavage being cut and folded by the later deformation. Despite this strong tectonism it has still been possible to prove the control of the pre-existing sedimentary features over at least some folds and their cleavage.
The most southerly minor folds in the south flank are, in fact, below the main conglomerate and hence not in the detailed Section C (Encl. 2) at all. These folds are developed in the steep north slopes of the Guspiada valley just near the junction with the Rio Yuso, below the tip of a Curavacas Conglomerate lens there (Geological Map, Encl. 1).
The finely banded sequence (greywacke/slate) is only gently folded to the west but near the conglomerate the complex of folds sets in (Fig. 38). The parasitic form (short limb dipping south) and axial plane fracture cleavage is very clear in the exposure although in the tighter near- isoclinal folds the folded slaty cleavage is also practically parallel. One strong detachment plane intruded by a quartz vein allows the disharmonic development of various groups of the folds above and below it (Fig. 38). These folds form a very highly oriented set plunging ENE very much like those of the west of the south flank (Diagram CN; B_2: Encl. 3). In the same way the axial planes and axial plane cleavages (not plotted) are parallel to the general attitudes in the south flank of the Lechada syncline here.
Within the most southerly planar part of the section there is some indication of very small folds near St. 327. This is the part of the section consisting of slumped rafts of sediments within the complex of pebbly mudstone and conglomerate bands discussed on p. 197 (see

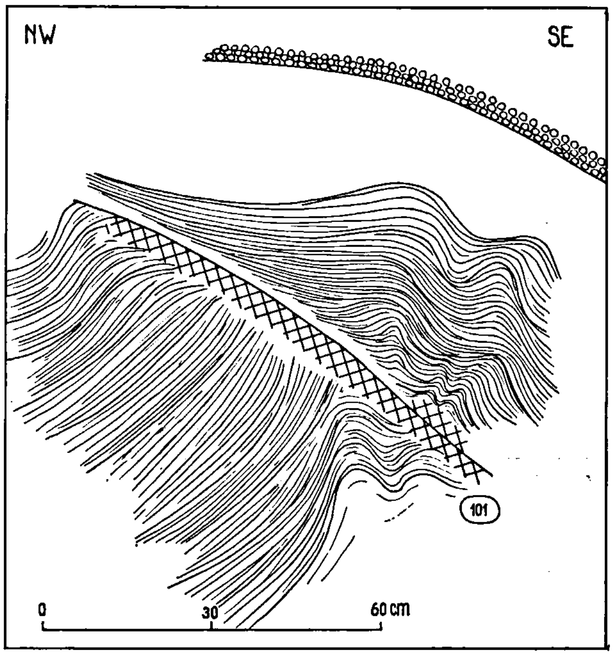


Fig. 38. Disharmonic folds below the nose of Curavacas Conglomerate at the mouth of the Guspiada valley, St. 102, Section C, Barniedo Road. Small parasitic folds with axial plane fracture cleavage disharmonic to each other and to the mass of conglomerates. Décollement intruded by vein quartz.

also Sect. C, Encl. 1). Thin bedded layers in these rocks are puckered into innumerable small folds (Fig. 39) which plunge more or less steeply eastwards largely spread throughout the area of the general distribution. However, most of the axes plunge gently east here forming the maximum for the whole flank (Diagram Cs; B_2).

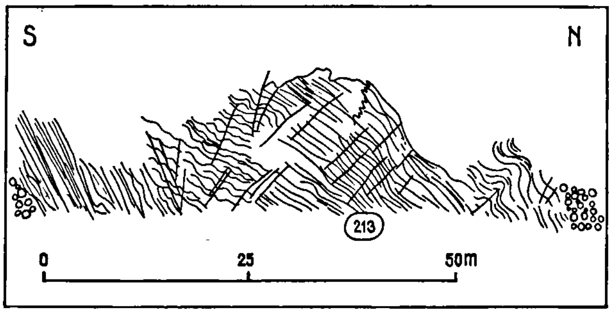


Fig. 39. Road-cut in thin bedded greywacke-slate alternations forming a raft slumped in pebbly mudstone, Sts. 327 and 213, Section C, Barniedo Road. Innumerable very small dishormanic folds of many widely differing orientations usually with axial plane fracture cleavage as many as three intersecting sets.

All of these small folds show well developed axial plane fracture cleavage which is often an intersecting conjugate set here. Some folds parallel to the different cleavages can be seen to interfere but actual folding of a recognisable fold could not be made out. Neither is it really possible to decide which cleavage of the set cuts the other although some classification has been attempted this has often been solely based upon similarity of trends.

The visual appearance of these cleavages and their geometric relationship makes it seem certain that these are a true conjugate set developed simultaneously. The angle between the two sets of cleavages measured average 34°, which is bisected by the regional trend. In this exposure (St. 327) the tendency is for the second fracture cleavages to dip NNW as opposed to the almost due south dip of the first fracture cleavage. However, the diagrams (CN; πS_2, πS_3) for the whole flank demonstrate no such preference, so that this is a purely local phenomenon.

This intensive development of minor folding is typically restricted to finely laminated layers in this isolated mass of rock. Where the rocks are thicker bedded there are also larger folds yet in neighbouring exposures of the same types of rocks little or no folding is to be seen. It has to be concluded that the isolated nature of this lens has been in some way responsible for the intensive deformation and hence, of course, controlled the various orientations within it. Just a little to the north of St. 327 a much smaller thicker-bedded lens is also strongly deformed (Fig. 40). The folds here are much larger, up to 20 m wavelength which is practically the length of the exposure. The anticline exposed is overturned towards the north and a thrust fault has devel-

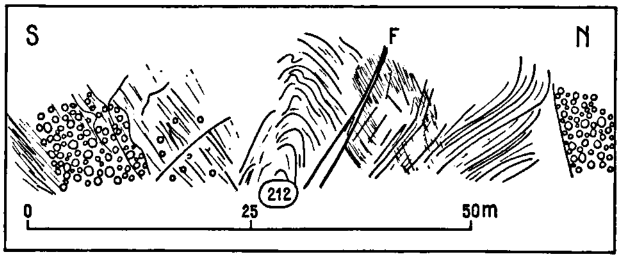


Fig. 40. Overturned folds in thick bedded greywacke-slate alternation in raft in pebbly mudstone, Sts. 326, 212—213, Section C, Barniedo Road. The fault, F, bears sulphide mineralization.

oped in the steep flank which has been subjected to later sulphide mineralization. The measure and constructed axes of the folds plunge eastwards between 20° and 40° below the horizontal. The axial planes mostly dip as usual steeply to NNE but the cascade fold developed near the conglomerate at St. 212 has a very flat-lying axial plane. There is a very unusual development of fracture cleavage parallel to the flat-lying axial plane of this fold though the fracture cleavage orientation curves rapidly to a more normal attitude near the other folds.

The next zone of complications in Section C is met with between Sts. 226 and 230. The construction method implies that these are disharmonic, a fact that can also often be seen in the field (Fig. 41). A large number of very small folds very similar to those of St. 212—214 are also present here and at St. 226 they also form a prominent topographic feature implying that this type of deformation must raise the resistance to erosion of these slates. But it is also quite possible that some sort of sedimentary control also existed.

The small folds all plunge very steeply (60°—70°) eastwards and have a well developed E-W axial plane cleavage. They are parallel in every respect to the larger fold between Sts. 227 and 228 and are concentrated in the axial zone of this fold. Due to the scale and the angle of projection onto the plane of the section this fold does not show up as the tightly folded structure seen in the field. The main fold comprises an anticline and syncline with apical angles of 85° and 72° respectively. Yet within 50 m along the axial trace in the steep hillside the fold has died out almost completely upwards and the pebble band marker can be traced in a smooth curve representing an apical angle greater than 150° (Fig. 41). Higher in the section, at St. 228, the fold has again changed, plunging if anything even more steeply 60°—70° E and having an apical angle of 113°.

The outline of this fold can be seen traced by the pebble bed marker in the Geological Map. It must be remembered that this fold is plunging steeply at a considerable angle to the slope of the ground. The topography is certainly partially the cause of the difference in shape shown by the following pebble bed on the north side of the small valley. The projection into the plane of Section C also shows a considerable change in the fold between the two pebble bands.

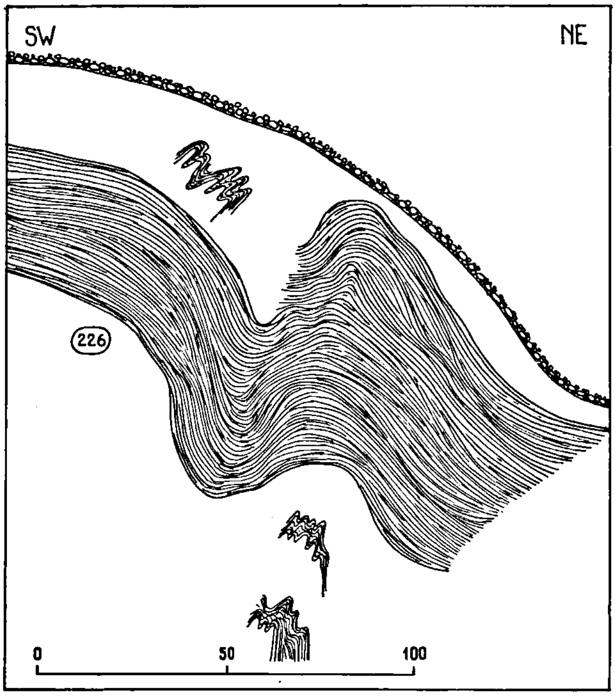


Fig. 41. Disharmonic minor folds, St. 226, Section C, Barniedo Road. Overlying pebble bed completely independent of the fold system in the underlying beds where very small disharmonic folds have developed in the core of the larter.

However, the plunge of the minor folds does fluctuate through this part of the section too; rather shallower at first, (40°—50°) between Sts. 230 and 224 but steepening again (55°—75°) at St. 231—232. The main fold is interrupted by so many smaller folds: that this sort of disharmony is to be expected.

A few examples of sedimentary folds have also been found in the slumped beds above the first pebble bed and one other with axial plane slaty cleavage. All other folds have a near vertical E-W axial plane with a well developed axial plane fracture cleavage; rarely a conjugate set of fracture cleavages. The next fold complex between Sts. 285—286 is much more faithfully represented in Section C because the plunge is generally quite low here (25°—35° E).

The smaller folds have the same type of parasitic asymmetry as shown by the larger fold in Section C and all have axial plane fracture cleavage. However, much of the fracture cleavage has a trend parallel to their E-W axial planes and some form a conjugate set with the axial plane cleavages (subtended angle 30°—40°).

One small anticline has an axial plane fault with quartz vein filling. The major synclinal bend of the Lechada syncline along this profile is quite sharp (apical angle, approx. 90°) yet there is remarkably little evidence of crumpling in the core. However, between Sts. 201 and 205 there are a number of small folds parasitic to the major structure. Almost all have axial plane fracture cleavage and one clearly demonstrated in the exposure the folding of the slaty cleavage (Fig. 42).

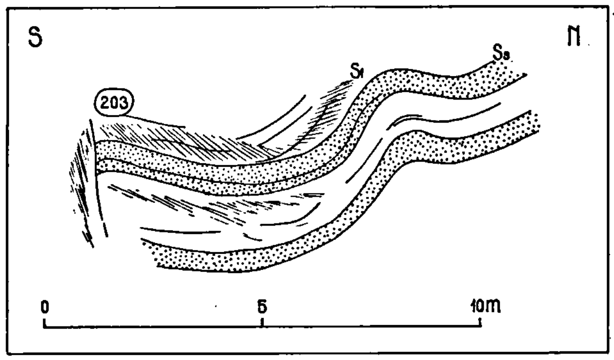


Fig. 42. Small folds near the axis of the major syncline, folding the slaty cleavage, St. 203, Section C, Barniedo Road.

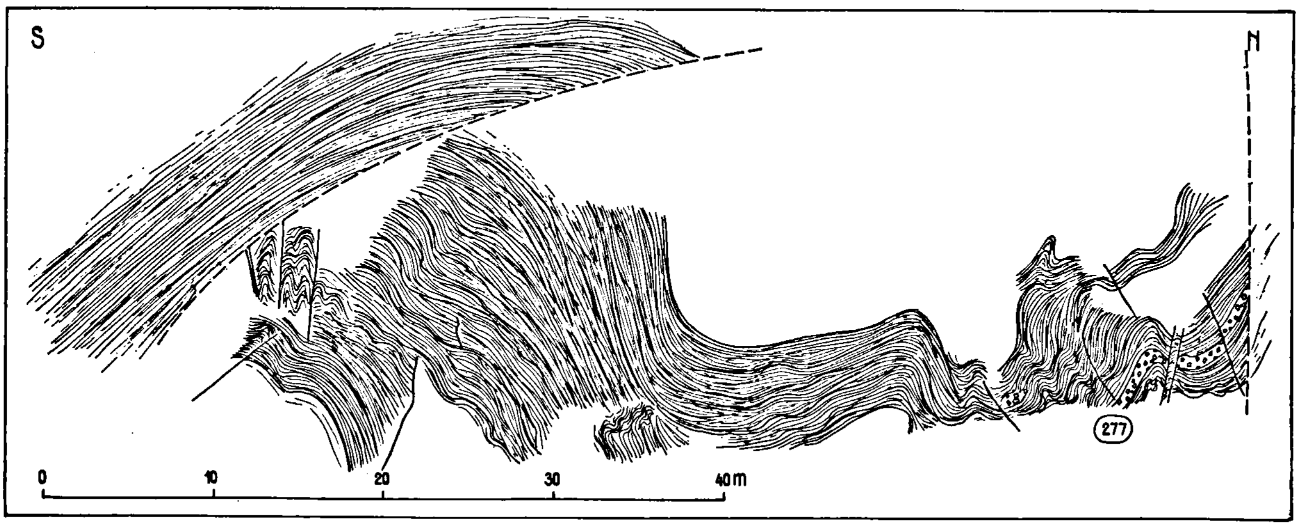


Fig. 43. Fold/fault complex Sts. 215 and 216, 277 to 279, Section C, Barniedo Road. Large and small disharmonic folds with axial plane fracture cleavage folding the slaty cleavage (Fig. 44).

The majority of these parasitic folds plunges quite steeply westwards (40°—50°) although there is a tendency for the folds nearest to the major hinge, Sts. 203—204, to plunge much less steeply, (see Diagram CN; $B_{1,2}$: Encl. 3).
The fault fold complex between Sts. 277—279 comprises a system of large and small parasitic folds many of them disharmonic to each other (Fig. 43). The largest attains an amplitude of at least 25 m and a wavelength of possibly 50 m and there are folds of every size down to microscopic puckers. All these folds tend to plunge gently eastwards (30°) making up a subsidiary maximum in the Diagram (CN; B_1: Encl. 3). They all have axial plane fracture cleavage which is responsible for the corresponding maximum of bedding/fracture cleavage intersections (Diagram CN; δ_2: Encl. 3). The folding of the slaty cleavage is demonstrated by their steeper dip in the north-dipping flanks of some folds which does not show up very well in Section C (Fig. 44). However, exceptions to this rule make the demonstration less convincing than usual although the most probable expanation is that part of the folding started here during the slaty cleavage deformation.

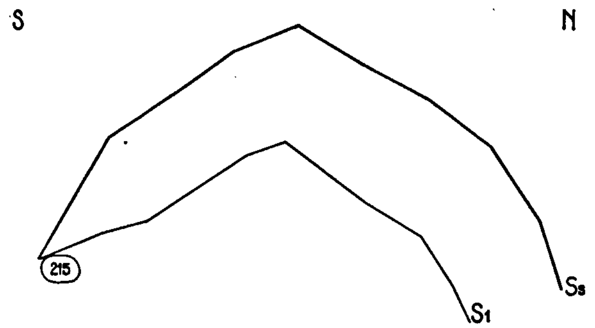


Fig. 44. Right section of bedding (S*s*) and slaty cleavage (S_1) traces St. 215, Section C, Barniedo Road. The convergence is almost consistently south.

The minor folds in this complex are clearly still concentric in part their size being related to thickness of the competent greywacke bands they deform. The slaty and fracture cleavages here can be seen curving in the slates with the gradual increase of silty material but no true cleavage has been seen in really psammitic rocks (Fig. 45). Some greywacke beds are rather intensely jointed but in typical rectangular systems of sets rarely directly referable to the cleavage system in the adjoining slates.
Beyond the fault to the north St. 272—277 exposures are not continuous so that there may be more folding than shown in the Section C. A considerable amount of fracturing the occasional occurrence of a second fracture cleavage and the number of small folds all suggest that larger folds probably exist. All the folds seen have an axial plane fracture cleavage and the typical parasitic asymmetry to the major fold. The slaty cleavage in a few exposures here dips at a steeper angle than the bedding reversing the convergence to-

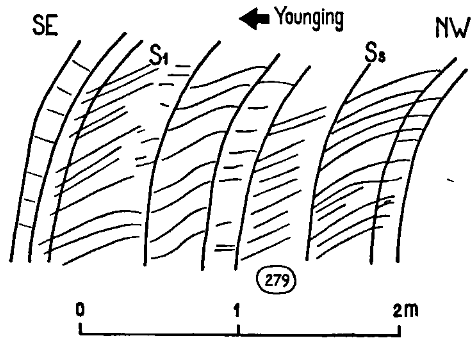


Fig. 45. Curving slaty and fracture cleavage planes refracted by grading of coarser material, St. 279, Section C, Barniedo Road.

ward the synclinal axis implies some folding related to the slaty cleavage deformation. However, in the small fold near Sts. 272 and 245 the convergence does not change so that the north dipping limb has the slaty cleavage dipping steeper than the bedding demonstrating the folding of the two together.
The folds measured plunge quite steeply westwards (30°—50°) corresponding to the maximum of the (Diagram CN; B_2: Encl. 3) and the greatest concentration of bedding/fracture cleavage intersections plunging steeply WSW (Diagram CN; δ_2: Encl. 3).
In the faulted syncline to the north, Sts. 268—271 a system of small folds often of tightly compressed accordion form and frequently broken by fractures are found. These folds are difficult to measure satisfactorily though one or two seem to plunge very steeply west as is confirmed by a bedding plane plot.
Beyond St. 268 the measurements have been included in the Portilla structure. The rocks between the faults Sts. 226—268 are not all well exposed near the road and the main evidence has been found some 200 m higher in the ridge above. A number of gentle folds and small wrinkles apparently plunging steeply south parallel to the fault plane warp the beds and the fracture cleavage can be seen to be diverted near them but not parallel to their generally N-S trend.
The Lechada syncline exposed along the Barniedo Road and shown in Section C shows the basic simplicity of the major structure here. At the scale of the drawing the complications seem to be quite minor but they do affect many of the exposures. The role of the slaty cleavage concentric with the fold in the bedding planes is very clear and its later deformation by the minor folding and fracture cleavage can also be plainly demonstrated.

Section C, Portilla

The Portilla structure is strikingly shown on the Geological Map (Encl. 1) by the very divergent trends of the rocks, especially the Curavacas Conglomerate lenses, around the village of Portilla de la Reina (see frontispiece). This structure is traversed by the Portilla-Barniedo road and so the profile data have been incorporated in detailed Section C (Encl. 2). How-

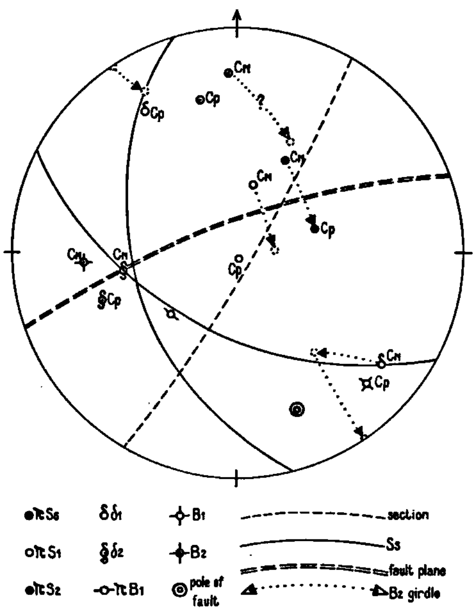


Fig. 46. Composite stereographic diagram (Wulff Net) for Section C, Portilla, of Barniedo Road: showing for each flank modal bedding planes (S*s*); poles of modal planes for bedding (πS*s*), slaty cleavage (πS_1) fracture cleavage (πS_2), and minor fold axial planes ($\pi B_{1,2}$); plunges of modal: slaty cleavage/bedding intersections (δ_2), fracture cleavage/bedding intersections (δ_2), minor folds (B_1), (B_2); together with the girdle orientations associated with the B_1 and B_1 folds: the major fault planes and the plane of section.

ever, apart from the complicated faulted syncline marking the axial zone of the structure, there is little to suggest a fold in the detailed section. This is due to the fact that the main fold axis basically plunges SW parallel to the projection plane of the cross section (Fig. 46).

The dominantly NNW trend of the bedding is very clearly illustrated by the orientation of bedding plane poles (Diagram Cp; πS*s*: Encl. 3). The quite strong partial girdle suggests subsidiary folding or flexuring about an axial direction plunging gently just east of south (Fig. 46).

The major features are quite clear; the sigmoidal curve of the bedding on top of the structure to the SW swinging out of and then back into, the main trend ESE-WNW of the Lechada syncline here.

Within the structure the NNW-trending core is mainly separated from the regionally-trending limbs by faults: to the north the vertical Portilla fault and to the south the south-dipping Lechada fault. Other faults of lesser importance often associated with complex folds divide up the core. The dip of the bedding tends to steepen from west to east even becoming overturned north of Portilla which gives rise to the partial girdle of bedding plane poles (Diagram Cp; πS*s*: Encl. 3), although the minor folds adjacent to the faults are generally much more striking.

The problem of the stage at which the Portilla fold developed can be analysed only with the aid of the cleavage relations. The calculated major axis corresponds closest to the orientation of fracture cleavage/bedding intersections both plunging SE (Fig. 46; Diagram Cp; $\delta_{2,3}$: Encl. 3). The slaty cleavage/bedding intersections plunging gently NNW correlate much more satisfactorily with the axis of the partial girdle of bedding planes within the structure (Fig. 46, Diagrams Cp; δ_1, and πS*s*: Encl. 3).

If the major fold is to be correlated with the fracture cleavage deformation then the slaty cleavage must have been folded as well. Rotating the attitude of the slaty cleavage planes of the north flank of the Lechada syncline of Section C (Diagram Cp; πS_1: Encl. 3), about the major axis, we obtain an orientation dipping gently west very similar to that of much slaty cleavage in the Portilla fold (Fig. 46; Diagram Cp; S_1: Encl. 3). Even more striking is the result of rotating the slaty cleavage/bedding modal intersection of the Lechada syncline about the calculated Portilla axis: the direction plunging gently SE swings to a gentle plunge NNW only 2° from the modal direction found (Fig. 46). Hence the operation of the Portilla axis after the slaty cleavage deformation and probably during the fracture cleavage deformation here can be taken as proved. Considerable spread from all the modal directions must be anticipated because of the existence of early folds here but there are none really contradicting this theory.

Slaty Cleavage. — Although the slaty cleavage planes are quite highly oriented (Kamb maximum $>14\sigma$) a girdle comparable to that of the bedding plane poles is lacking, implying that this cleavage must be later than or contemporaneous with the development of the NNW folds. The dominantly flat-lying attitude of the slaty cleavage is emphasised in Section C (Encl. 2) where the trace plots at a much lower dip than that of the bedding, converging south. There is a suggestion that the slaty cleavage is folded between Sts. 91 and 92 where the cleavage steepens with the bedding and again decreasing with it. However, an even more detailed study has been carried out to conclusively demonstrate this (p. 235).

The most striking feature of the slaty cleavage in this structure is the orientation of the intersections with the bedding which are quite highly concentrated (Kamb Maximum $>15\sigma$) plunging gently NNW (Diagram Cp; δ_1: Encl. 3). This is so divergent from the major fold axis plunging steeply SE that no direct connection can be possible between them. However, this orientation is quite near to the axis derived from the girdle of bedding plane poles (Fig. 46) so that it seems quite probable that these flexures should be related to the slaty cleavage deformation.

Fracture Cleavage. — The fracture cleavage planes in the Portilla structure are quite strongly oriented with the modal plane dipping steeply SSE (Diagram Cp; $\pi S_{2,3}$), which is closely comparable to that throughout the Lechada syncline. This attitude is the same for most

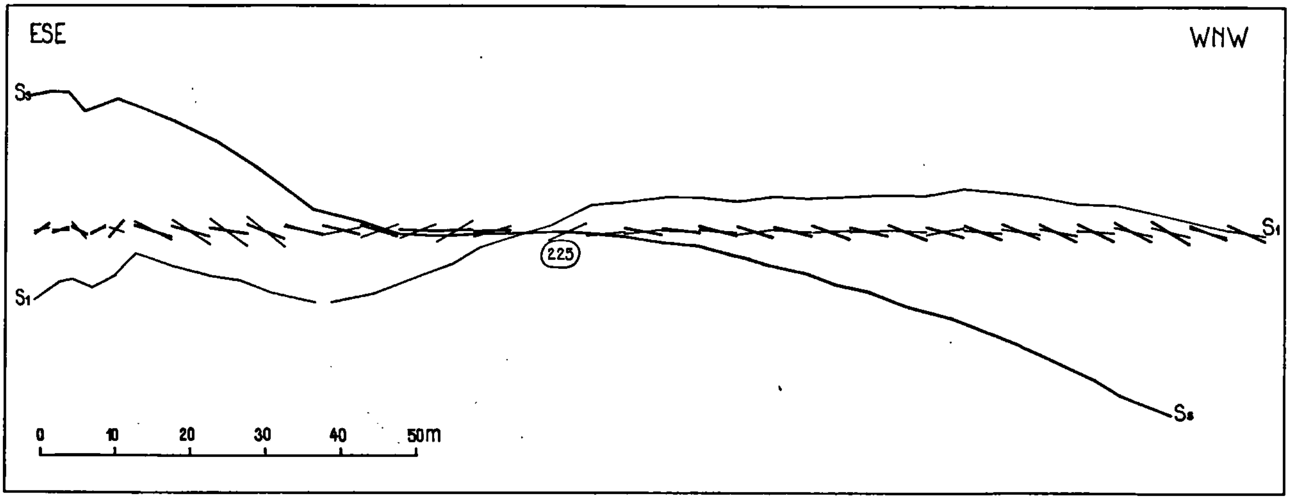


Fig. 47. Right Section of the gentle flexure in the Portilla fold, Section C, Barniedo Road. The traces of bedding (S*s*) and cleavage (S_1) show exactly the same form retaining the same convergence confirming that they have been folded together.

of the second fracture cleavage planes (πS_3) found in a conjugate relation to others that form part of the small partial girdle of planes dipping SE or NW. Such conjugate sets of cleavage mostly occur in severely deformed rocks and a definite order of precedence was often difficult to determine. Once again the true simultaneous conjugate relation must be assumed.

The fracture cleavages are often seen to be parallel to the axial planes of small minor folds. However, the attitude of these folds does not conform to the modal fracture cleavage and their axial plane cleavages form part of the rather large proportion of scattered planes (contrast Diagrams Cp; $\pi S_{2,3}$ and $\pi B_{1,2}$: Encl. 3). However, the axis calculated for the major folds lies very close to the modal fracture cleavage plane and though the calculated axial plane diverges somewhat from this (Fig. 46), it seems most likely that the major fold and the fracture cleavage are to be related. Certainly the near-regional attitude of the majority of fracture cleavage planes could hardly have allowed the development of the major fold after their formation, since the operation of the fold would have produced a widely diverging orientation (Fig. 46).

Minor Folds. — Minor folds of every dimension, from the Portilla fold itself which is subsidiary to the Lechada syncline, down to the smallest crumpling have been found. The larger folds tend to be rather gentle so that there is relatively little effect upon the detailed Section C, as is, of course, true of the smaller folds.

One larger fold in the core of the structure has been subjected to a more detailed survey to ascertain the relation of the slaty cleavage in it. A right section of the fold (Fig. 47) shows very clearly the gentle flexure with some small folds plunging to the ESE. The trace formed by the bedding planes, projected normal to themselves forms a smooth gently sigmoidal curve. The trace of the slaty cleavage often dips opposing those of the bedding but the curve is equally smooth and of essentially the same form. The exact reproduction of the fold in the bedding planes can only be reasonably interpreted as meaning that the slaty cleavage has been folded together with them. The same is then just as clearly true for the smaller folds although these indications are not conclusive here.

Small minor folds often have axial plane fracture cleavage which, cutting the slaty cleavage, clearly establishes the deformation of the latter. Sometimes the folded form of the slaty cleavage is even self-evident in the field (Fig. 48).

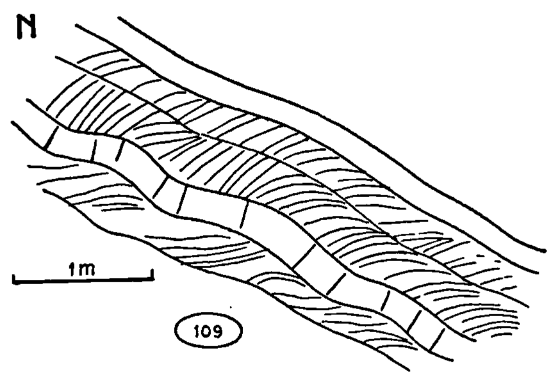


Fig. 48. Slaty cleavage folded by gentle minor folds, St. 109, Section B, Barniedo Road, Portilla fold. Similar angle and direction of convergence of the slaty cleavage on the bedding throughout the small folds.

However, as postulated above, some folding contemporaneous with the slaty cleavage deformation is also present. The partial girdle of bedding planes (Diagram Cp; πS*s*) only implies relatively gentle flexuring but some actual folds have been found. In the relatively planar part of the section near St. 248 there are a number of

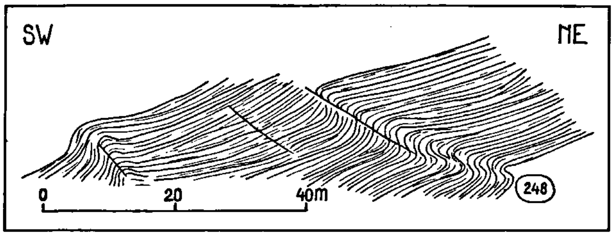


Fig. 49. Small cascade folds with small faults in the overturned limb, St. 248, Section C, Barniedo Road, Portilla fold.

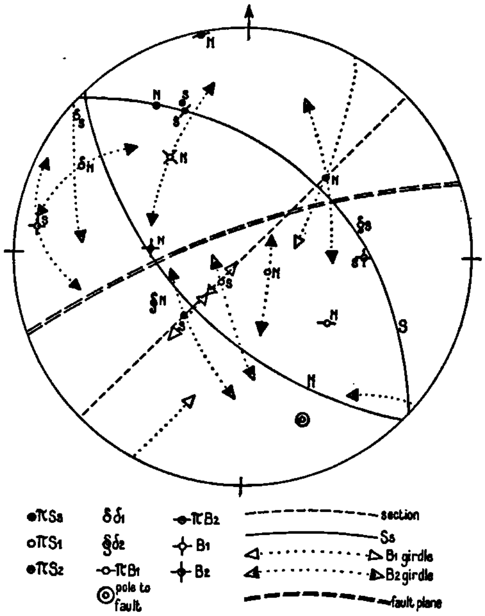


Fig. 50. Composite stereographic diagram (Wulff Net) for Section B, Guspiada: showing for each flank modal bedding planes (S*s*); poles of modal planes for bedding (πS*s*), slaty cleavage (πS_1) fracture cleavage (πS_2), and minor fold axial planes ($\pi B_{1,2}$); plunges of modal: slaty cleavage/bedding intersections (δ_1), fracture cleavage/bedding intersections (δ_2), minor folds (B_1), (B_2); together with the girdle orientations associated with the B_1 and B_2 folds: the major fault planes and the plane of section.

small cascade folds with flatlying axial planes (Fig. 49). The symmetry of these folds is exactly opposite to that of a parasitic fold and the fracture cleavage cuts across almost at right-angles to them. The orientation of the axes of these folds is almost exactly parallel to that of the modal slaty cleavage/bedding intersections but perpendicular to those of the fracture cleavage/bedding (Diagrams Cp; $B_{1,2}$; δ_1 and δ_2). The orientation of the axial planes of these folds tends to dip quite steeply NE quite divergent from the modal slaty cleavage. Hence it would seem that the slaty cleavage is concentric to these folds.

The Portilla structure has, therefore, a parasitic character with respect to the Lechada syncline in that it has developed out of a flank of a pre-existing larger fold, despite the strongly divergent trend of fold axes and strikes. This is emphasised by the simple continuation of the average dip of the north flank of the Lechada syncline through the Portilla fold in Section C. However, this structure is in fact a cascade fold with dips increasing to the NE even becoming overturned north of Portilla. Another typical feature of the cascade fold is also developed in the slopes of the south bank of the Rio Lechada. The fault here cuts off the steep NNW trending beds but is parallel to the bedding of the rocks above it. This represents the axial zone if the fold deformed beyond the limit of concentricity.

Section B Guspiada

Introduction. — This profile was chosen in the broadest part of the Lechada syncline west of the Rio Yuso and since in addition the relief exceeds 600 m the total sequence included is very thick (approx. 1800 m) The measurements were made as near to a NE-SW line as possible, perpendicular to the dominantly NW-SE strike (Diagrams Bn, Bs; πS*s*; Encl. 3).

The two flanks combine with an horizontal hinge taken to be the major fold axis (Fig. 50) so that a vertical NE-SW projection plane has been used for Section B (Encl. 2). The fold constructed has an apical angle of 90° very similar to that obtained for the Barniedo Road (Section C, Encl. 2) measured much lower in the structure. This result is quite remarkable in light of the complicated structures of the axial zone along Section B.

The composite diagram (Fig. 50) also shows that the slaty cleavage has a much lower dip than the bedding. However, those of the north flank tend to dip northwest and so do not conform to the usual attitude of concentric cleavage and their relation to cascade folds is shown by the correlation with the axial planes of the latter.

The axial plane character of the fracture cleavage to the minor folds is very clear both in the field and in the way their poles and plunges correspond (Fig. 50).

In detailed Section B (Encl. 2) we see the southernmost 900 m of section form a gently undulating flank dipping at about 40° N. North of St. 115 however, steepening of the dip heralds the development of a series of complex flatlying folds with limbs inverted towards the axis of the main syncline. Together with these folds we see a series of flatlying faults parallel to their axial planes which make detailed correlation of the stratigraphic sequence impossible. The gradual development of these faults out of a cascade fold as can be seen in the field suggests that the sense of movement may be normal; that is down-thrown in the direction of dip.

The zone of intensive folding and faulting extends to just north of St. 120 but between the fault here and that at St. 138 a gently dipping sequence more than 250 m thick of almost unfolded beds form a contrasting cap. The extremely deformed axial zone between the faults of Sts. 138 and 148 cannot be fully depicted at the scale of Section B. But in fact the exposures, though extensive, are not adequate to give a complete picture of the fold geometry. The beds are largely vertical, deformed by folds having rather flatlying axial planes as illustrated by the construction lines in Section B.

The north flank includes in its most central section a flatlying sequence up to 250 m thick between Sts. 146 and 163: then the beds dip steeply (60°—70°) SW only occasionally steepened by folds with flatlying axial planes. The final section north of St. 187 consists of beds dipping NW, perpendicular to the line of section which forms the commencement of the Portilla and Vallines anticlines.

Slaty Cleavage. — The traces of the slaty cleavage in Section B (Encl. 2) almost invariably dip less than the bedding so that convergence is toward the main synclinal axis except where the beds are overturned. They show the really typical attitude of concentric cleavage only in the south flank of the Lechada syncline and even here there is a noticeable tendency for the cleavage and construction lines to be parallel higher in the structure. This parallelism is the rule throughout most of the north flank where cascade folding also predominates. Only in the extreme north can the usual narrow angle be again observed between the bedding and cleavage traces.

The difference in the attitudes of the slaty cleavage and the bedding planes is clearly shown by the distribution of poles in the Diagrams (Bn, Bs; πS_s and πS_1: Encl. 3). In the south flank the two partial girdles are approximately the same length and orientation with the slaty cleavages having a consistently lower dip. But the distributions for the north flank show a much wider difference: the girdle of bedding planes dipping steeply SW whereas the slaty cleavages tend to dip very gently west.

The most remarkable feature is that the slaty cleavage shows no sign of simulating the steepened or overturned segments so prominent in both flanks of the main syncline. For example the slaty cleavages in the overturned beds between Sts. 120—121 and Sts. 156—160 have traces almost parallel to that in the upright beds between Sts. 121—129 and Sts. 154—156, of their respective folds. Hence they can only be regarded as an axial plane cleavage to these cascade folds.

Fracture Cleavage. — Fracture cleavage is practically ubiquitous in the slates of Section B, despite the fact that the minor folds with which it is associated as an axial plane cleavage, are relatively restricted in distribution. This cleavage tends to dip very steeply to the SSE and SE in south and north flanks, respectively (Diagrams Bn, Bs; πS_2: Encl. 3), which means that many are perpendicular to the major folds axes here (Fig. 50). Consequently the intersections of bedding with fracture cleavage tend to plunge quite steeply ENE and WSW in the south and north flanks, respectively (Fig. 50) (Diagrams Bn, Bs; δ_1, δ_2: Encl. 3). Near the minor folds of the south flank the situation is complicated by the frequent development of conjugate sets of fracture cleavages one of which is usually asociated with a fold as an axial plane cleavage. Usually the angle between these cleavages is quite

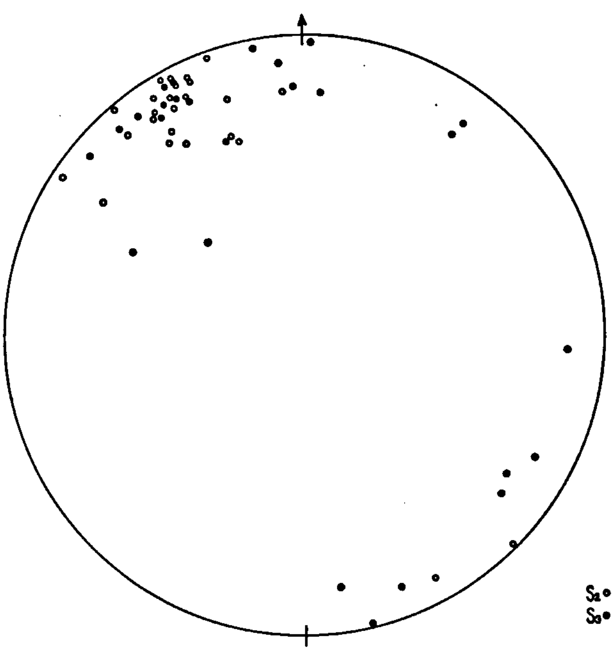


Fig. 51a. Stereographic plot (Schmidt Net) of poles to conjugate fracture cleavages (πS_2, πS_3); none seen to be associated with minor folds, Section B (south), Guspiada.

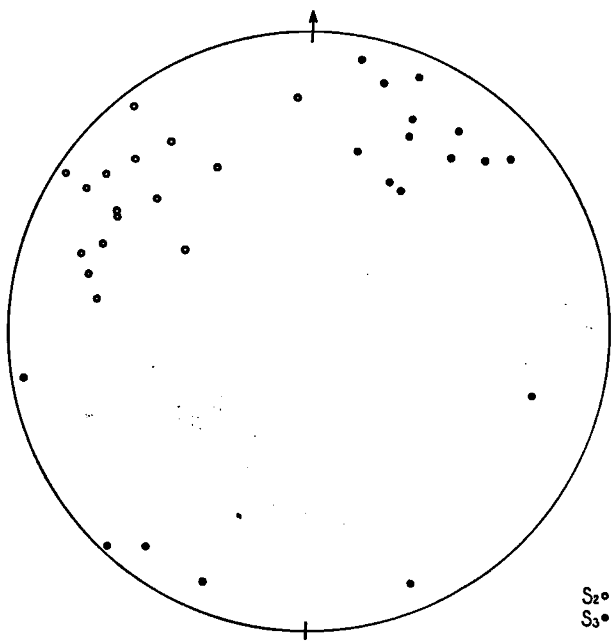


Fig. 51b. Stereographic plot (Schmidt Net) of poles to conjugate cleavages (πS_2, πS_3); observed to be associated with minor folds, Section B (south), Guspiada.

small (10°—20°) although they tend to dip very steeply almost due SE (Fig. 51a). Yet another type of conjugate fracture cleavage has been found in the south flank of the main structure subtending a very wide angle (up to 90°) and symmetrically placed about the mode of all fracture cleavages (Fig. 51b, Diagrams Bs; S_2, S_3). These can generally be classified as first and second by definite crosscutting features, the first tend to dip steeply SE and the second SW (Fig. 51b). Such developments seem to be in some way related to the large flatlying minor folds although the cleavage is clearly not parallel to their axial planes and, as has been mentioned above, these folds are probably contemporaneous with or earlier than the slaty cleavage deformation.

Thus the fracture cleavage in this part of the Lechada syncline demonstrates a wide divergence in the orientation of deformation to that of the major structure here. However, in detail it can also be demonstrated that pre-existing inhomogeneities have influenced the deformation pattern of the fracture cleavage locally.

Minor folds. — Almost all of the minor folds visible at the scale at which Section B (Encl. 2) is drawn, have flatlying axial planes ranging in size from the smallest to those involving almost one half of a limb of the main syncline, as in the north flank. These large folds are often broken by faults which makes direct measurement of axes and axial planes practically impossible. Consequently the symmetry of a number has been constructed from measurements of their flanks (Diagrams Bn, Bs; B_1 and πB_1: Encl. 3). Measurements were made on smaller folds generally parasitic with axial plane fracture cleavage (Diagrams Bn, Bs; B_2 and πB_2: Encl. 3). In addition measurements were made in the south flank of a number of unquestionable sedimentary folds some of which now have an axial plane slaty cleavage (Diagram Bs; πBs and Bs, *Bs*: Encl. 3; Fig. 5).

The axes of the sedimentary folds plunge gently NNW and do not coincide with any known tectonic direction here. The directions all lie outside the significant contour of slaty cleavage/bedding intersections and almost all of them in the area are significantly lacking in intersections. Hence, it is clear that the axial plane slaty cleavage to these folds has an extraordinary orientation and has been diverted to take advantage of the sedimentary fold, and not vice versa (Contrast Bs; πBs and Bs; πS_1: Encl. 3).

The flatlying folds in the south flank tend to plunge gently either ESE or WNW forming a good correlation with the partial girdle of slaty cleavage/bedding intersections (Diagrams Bs; B_1 and δ_1: Encl. 3). Thus they account for the westerly concentration of intersections that do not match the major axis (NW). The axial planes of these folds are not so satisfactorily defined but nevertheless their orientations may be compared with that of the slaty cleavage planes for both flanks (Diagrams Bn, Bs; πS_1 and πB_1: Encl. 3). In the north flank the fold axes plunge somewhat steeper NW but the correlation is reasonably good between these directions and that of the slaty cleavage/bedding intersections (Diagrams Bn; B_1 and δ_1: Encl. 3). Similarly the orientations of the axial planes compare quite well with those of the slaty cleavage planes (Compare Diagrams Bn; πB_1 and πS_1: Encl. 3). Hence the relationship of the slaty cleavage to the cascade folds here generally seems to have been as axial plane cleavage.

One or two small parasitic folds can be seen in Section B e.g. between Sts. 238 to 240 and 180 to 182, in the south and north flanks, respectively. The slaty cleavage appears to be folded with the bedding maintaining the same angle and direction of convergence but the folds are too gentle to be conclusive. However, there are a number of smaller folds where the field appearance as well as the cross cutting axial plane fracture cleavage make it clear that the slaty cleavage has been folded.

The thick planar sequence forming the lower part of the structure contains a number of minor folds so small as not to be visible at the scale of the Section B. At first, between Sts. 103—134 and 239—240 there are a series of small minor parasitic folds between 20 cm. to 3 metres in wavelength. All of these folds belong to the group plunging ENE (Diagram Bs; B_2: Encl. 3). These are the folds developed variously parallel to conjugate sets of fracture cleavages cutting each other at acute angles generally quite near to modal orientation of all fracture cleavages planes (Diagram Bn; πB_2: Encl. 3). Evidence of crosscutting can rarely be made out and even then often proves inconsistent between different samples so that these two sets of cleavage are almost certainly contemporaneous as elsewhere. Higher in the sequence between Sts. 103 and 105 there are a series of sedimentary folds some modified by tectonics plunging NW (Diagram Bs; *Bs*: Encl. 3). Nearby, between Sts. 105 and 106 there is a series of ordinary parasitic folds plunging

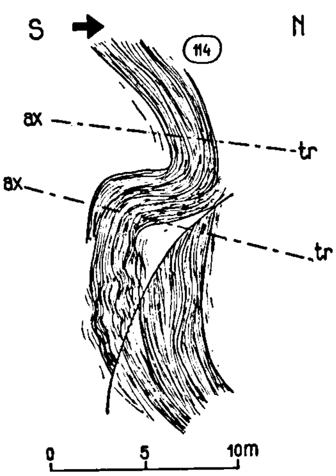


Fig. 52. Small cascade fold in steep part of south flank, St. 114, Section B, Guspiada. Note the axial trace (tr) does not coincide with the apical traces in the exposure due to the oblique angle of the exposed surface. Arrow indicates direction of younging.

east with axial plane fracture cleavage and folded slaty cleavage (Diagram Bs; B_2: Encl. 3). So as might be expected the thicker beds between Sts. 106 and 114 have not developed small folds despite the considerable stratigraphic variations noted in the sequence.

Beyond St. 114, however, the precursors of the main axial zone deformation were found. The first is the development of a perfect cascade fold showing exactly the reverse symmetry to the major structure as proper to a parasitic fold (Fig. 52). Measurements made at the various limbs allow the derivation from a β-plot of axes of folding plunging approximately northwest down their axial planes dipping approximately north. The slaty cleavage attitude reflects to some extent the same structure but except in one case inverted bedding also dips steeper than the cleavage. Hence the direction of convergence of the slaty cleavage to the bedding changes through this fold which is taken as evidence of the simultaneous development of the slaty cleavage and the folding.

The fracture cleavage is very strong in the slates here but its steep dip and generally E-W trend precludes any direct relationship with the cascade fold. However, this is one of the places where the fracture cleavage is represented by a conjugate set approximately at right-angles. Generally these sets are oriented with one bisectrix oriented near the strike of the modal fracture cleavage, as described above (p. 237). But in the fold itself the two sets are oriented nearly N-S and E-W, so that this NW-plunging fold axis bisects the angle between them. This would seem to imply that the fracture cleavage system has been deviated from the regional orientation by the existence of this fold as a pre-existing discontinuity or perhaps even by continuance of folding.

A little higher in the section between Sts. 116 and 117 a comparable larger size version of the fold at St. 114,

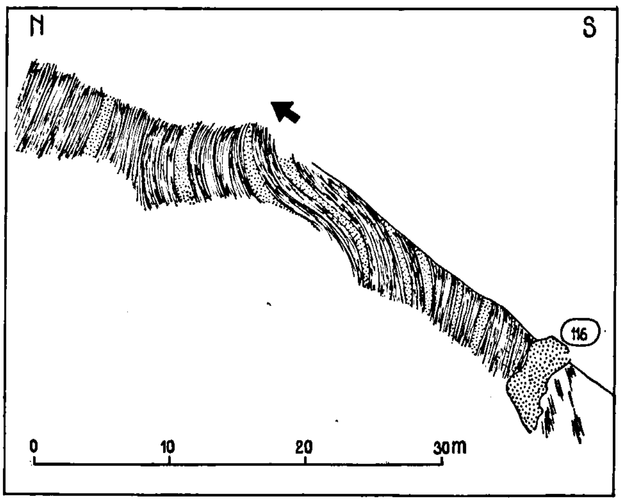


Fig. 53. Medium-sized unbroken cascade fold completely exposed St. 116, Section B, Guspiada. The mass of greywacke at St. 116 is a large slumped lens. Arrow indicates direction of younging.

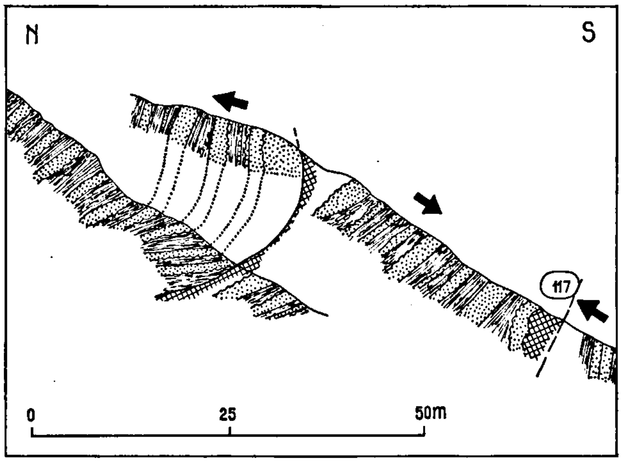


Fig. 54. Overturned limb of cascade fault isolated by faults, Sts. 117—118, Section B, Guspiada. Thick quartz veins follow the fault planes which are subparallel to the bedding. Excellent bottom structures on the greywacke layers confirm directions of younging (arrows).

with a very flat axial plane and an axis plunging very gently east (Fig. 53) is found.

Beyond St. 117 the sequence as shown is broken by faults marked in the field by extensive quartz veining and here by an abrupt inversion of the beds (Fig. 54). Between these faults an inverted segment about 20 m thick dips between 30 and 50° W. The overlying beds in places dip very steeply and may even reach a slightly overturned attitude but even then they curve rapidly into the general attitude of this flank of the major syncline. This structure can only be understood as a result of tightening of the type of cascade fold of St. 114 until axial plane faults developed. These faults would have a normal type of movement downward down the dip of the fault face to continue the movement picture of the fold. Since the axial planes are usually so flatlying these faults perhaps would be better termed lag-faults.

A very similar structure is to be seen between Sts. 119 and 120 where a fault is in fact present cutting across both axial zones (only the upper one has been drawn in Section B for simplicity's sake). However, the profile also shows the preservation of part of the antiform and synform shapes below the upper thrust (Fig. 55). The attitudes of the bedding planes can be analysed to yield an axis tending to plunge gently SW although it is more likely practically horizontal E-W.

Beyond the fault between Sts. 120—121 and as far as St. 130, the sequence is relatively planar, dipping much more gently than below (Section B, Encl. 2). The strike is also rather different tending very much nearer to E-W giving a rather discordant relation to the rest of the structure. Between Sts. 130 and 131 the dip begins to steepen and at St. 136 there are vertical and overturned beds belonging to the disturbed axial zone.

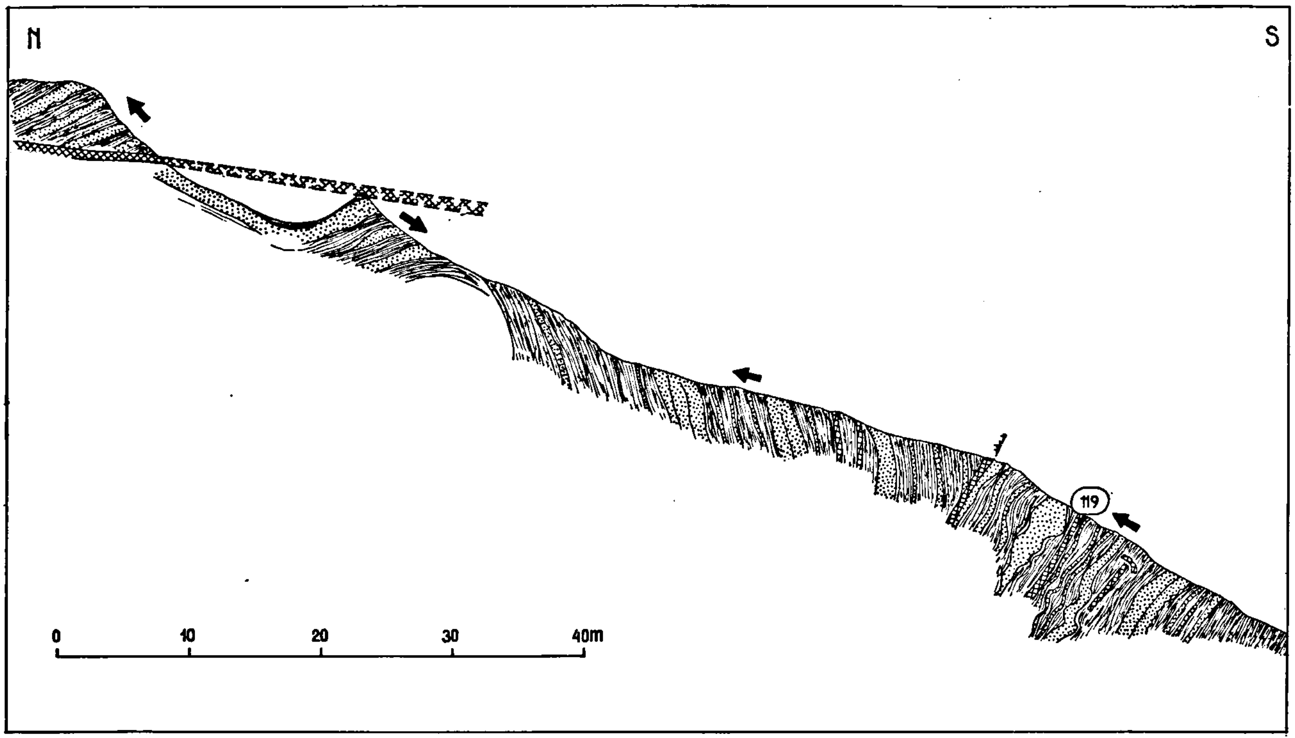


Fig. 55. Faulted cascade fold the fault cutting across both hinge zones, Sts. 119—120, Section B, Guspiada. Fault planes are all intruded by quartz veins but the lower ones do not appear to be of great movement. Arrows indicate younging.

It has not been possible to portray in Section B the true nature of the complications of folding and faulting found in the axial zone between Sts. 136 and 146. The scale of presentation is one handicap but it is also due to the lack of complete knowledge. Even though exposures are quite good folds and faults are so frequent that evidence of younging of the beds is always inadequate to control the sense of the structures sufficiently. Generally, of course, the near-vertical beds are deformed by folds with flat-lying axial planes. However, a few small parasitic minor folds have also been found with fracture cleavage parallel to their near vertical axial planes but these tend, of necessity, to be near-isoclinal so that both cleavages as well as the bedding become practically parallel.

The flatlying folds are generally so gently curved that it was not possible to measure axes or axial planes in the field. Constructions from π-diagrams yield a distribution mainly plunging gently east and west with axial planes dipping north (Diagram Bs; B_1: Encl. 3). No direct correlation with the slaty cleavage is possible although the shallow dip of the latter is in striking contrast to the near-vertical bedding. Hence it seems that the slaty cleavage tended to be an axial plane cleavage to the early flatlying folds here but the synchronous and perhaps subsequent, complications together with the difficulties of measurement mask this relationship. The best example found is illustrated in Fig. 56 where the slaty cleavage does give the impression of being parallel to the axial plane.

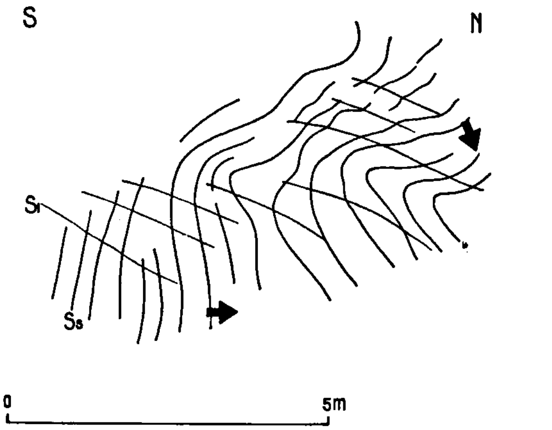


Fig. 56. Small cascade fold with axial plane slaty cleavage (S_1), St. 138, Section B, Guspiada. The fold plunges gently west and the bedding (*Ss*) has bottom structures showing it to be inverted (arrows indicate younging).

The small parasitic folds with axial plane fracture cleavage are also generally E-W and although some are almost horizontal other have quite steep plunges down the generally south-dipping axial planes (Diagram Bs; B_2: Encl. 3).

North of St. 146 the attitude of the beds changes abruptly across quite a narrow transition zone very disturbed with much quartz veining. In contrast to the near-vertical axial zone the sequence beyond is a

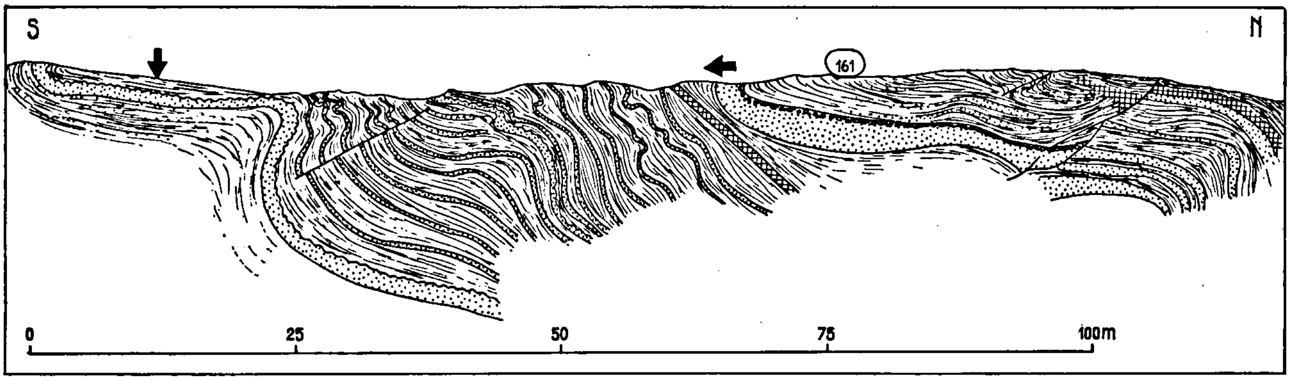


Fig. 57. Inverted limb of the large flap fold just north of the main axial zone, Sts. 160—162, Section B, Guspiada. Folded and refolded structures, many disharmonic and divergent. Strange upcurl of the more competent layers in exposure. Younging (indicated by arrows) confirmed by excellent bottom structures and grading.

gently dipping sequence which continues from St. 162 as far as St. 160 (Fig. 57). Excellent bottom structures confirm that this sequence is inverted so that it logically forms part of the north flank of the main structure. This is confirmed by 'roll-over' accomplished with very few complications between Sts. 156 and 157 where complete the stratigraphic continuity can be seen. The recumbent cascade fold here has a flatlying axial plane dipping WNW with the axis plunging NW almost down the dip. This then correlates with the SW dip of the construction lines in Section B here. The extraordinary situation in the core of this structure has been discussed above but no question can be raised about the field data from which the section has been constructed.

The trace of the slaty cleavage through this fold plots parallel to the constructed axial trace (Section B, Encl. 2), which shows a curious upward tilt to the north to the inverted beds flattening nearer to the hinge (St. 156). However, the slaty cleavage shows a distinct tendency to simulate the structure, albeit with lower dips in either flank. Thus the convergence changes between the flanks of this fold so that the slaty cleavage must be synchronous or later. It seems likely to have been connected with the folding so that the similarity of the bedding and slaty cleavage orientations would suggest a concentric cleavage relation.

It seems rather unlikely that the fanning of the slaty cleavages in this fold could be due to further folding since it would involve opening-out the limbs. Still such a process might have been effected as part of the minor folding since the inverted limb has been subsequently highly deformed whereas the upright sequence shows only a moderate development of fracture cleavage and very few smaller folds.

Some of the small minor folds measured in the inverted flank are clearly related to the slaty cleavage which is sub-parallel to their flatlying axial planes. The fracture cleavage being near vertical cuts completely across these minor folds but is often parallel to the axial planes of other minor folds. The upright attitude of these latter folds enables them to be easily distinguished in good exposures (Fig. 57). However, where only isolated patches of bedding are exposed the effect can be extremely confusing.

North of St. 156 a normal sequence dips south at a moderate angle until St. 152. Here the dips are steeper and in places the beds are inverted to dip steeply north. The beds curve gently and it was not possible to measure any axes or axial planes. Constructed directions are very variable plunging W to NNW, most likely to be related to the slaty cleavage which is generally very flatlying here. It seems quite possible that the slaty cleavage here could have been a concentric type during the formation of these folds. Again the fracture cleavages maintain their regional trend throughout the folds evidently post-dating them.

The same type of cascade fold occurs again in the sequence as far as St. 167 although many of them are not large enough to show effectively in Section B. Generally the axial planes of these folds seem to have quite a steep dip, nearly perpendicular to the average bedding as indicated in Section B by the construction lines. No really satisfactory evidence to connect these folds and the slaty cleavage could be found. However, the slaty cleavage has clearly not been folded with the bedding, yet the fracture cleavage deformation clearly postdates both the folds and the slaty cleavage. Hence the slaty cleavage and these cascade folds must have been quite closely related in the tectonic history.

Between Sts. 167 and 171 the sequence is quite planar but further north a number of small cascade folds are encountered. These are usually seen as gentle rolling over of the beds with no sharp inflexion points. The axial planes of these flexures are approximately perpendicular to the bedding, with shallow to moderate dips to NNW so that the fold axes plunge W or NW. The flatlying nature of these axial planes here, is illustrated by the construction lines in Section B.

Sometimes the attitude of the slaty cleavage demonstrates the presence of one of these folds by deviating much more than the bedding as for example near St. 176. But the actual orientation of the slaty cleavage cannot be related directly to the folds. A number of smaller minor folds, usually of the parasitic type, with axial plane fracture cleavage occur in this steep limb of the north flank. Usually the axial planes are parallel to the regional trend of the fracture cleavage but occasionally a fold and its cleavage cut at right angles to the modal cleavage attitude.

Beyond St. 186 the strike swings considerably to NE-SW nearly parallel to the line of the section. Hence although the dip remains quite steep the bedding trace plots nearly horizontal in the section. The slaty cleavage shows this effect sooner and more markedly so that the plotted trace even has a NE dip. This then forms the nose of a steeply plunging anticline such as is outlined by the Curavacas Conglomerate lens NW of Portilla (Geol. Map, Encl. 1). It is not likely that the same axis and axial plane could be effective for these two folds but their orientations are strikingly similar. It is thought more probable that the form and attitude of these folds have both been dictated by the extension of the Portilla-Naranco fault system that must run just to the north of them.

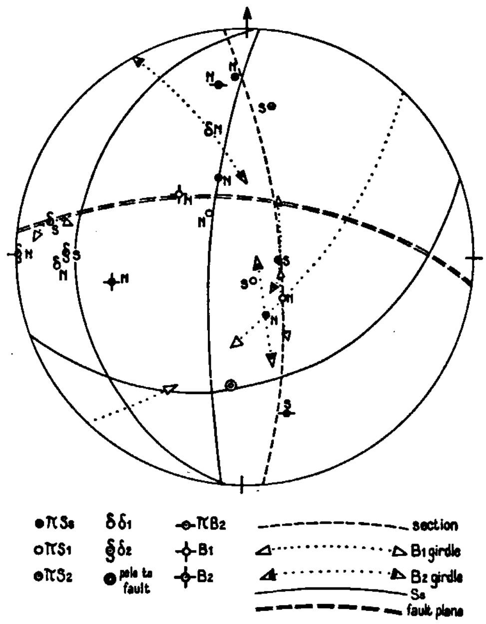


Fig. 58. Composite stereographic diagram (Wulff Net) for Section A, Pico Redondo showing for ezch flank modal bedding planes (S*s*); poles of modal planes for bedding (πS*s*), slaty clealage (πS_1) fracture cleavage (πS_2), and minor fold axial planes ($\pi B_{1,2}$); plunges of modal: slaty cleavage/bedding intersections (δ_1), fracture cleavage/bedding intersections (δ_2), minor folds (B_1), (B_2); together with the girdle orientations associated with the B_1 and B_2 folds: the major fault planes and the plane of section.

Section A, Pico Redondo

Introduction. — The Redondo profile, Section A was chosen through the western extremity of the Lechada syncline where the mapping of the Panda Limestone Member implies that the axis plunges sharply westwards. The trend of the axial trace on the map is approximately WNW which is amply confirmed by the girdle of bedding plane poles for the south flank of the structure although those of the north flank show a very wide dispersion (Diagrams AN,S; πS*s*: Encl. 3). The best-fitting plane through these groups of points dips east also confirming that the prime axis here still plunges west (Fig. 58). This has therefore been used as the projection plane for Section A (Encl. 2). The most southerly part of Section A shows a completely inverted trace dipping gently south between Sts. 148 and 214. In fact this part of the sequence dips almost due west, as do almost all the flatlying beds (Diagram As; πS*s*: Encl. 3). The average is quite constant but considerable small fluctuations measured could be seen to be related to small minor folds.

Further north between Sts. 214 and 208 the south dip of the bedding trace steepens suddenly due in part to a swing in the dip to a more southerly direction but also somewhat to an increase in the true dip. This fold girdle of bedding plane poles (Diagram As; πS*s*: Encl. 3) yields a hinge plunging gently west.

To the north of St. 208 the bedding is folded over, still inverted to dip N for the short interval to St. 207. As can be seen from the irregularity of the trace minor disturbances are also much in evidence here so that no significant concentration of poles of this attitude has resulted (Diagram As; πS*s*: Encl. 3). The best fitting axis plunges WNW almost parallel to the previous one. The bedding attains an upright position for the first time in this flank between Sts. 207 and 128 where the dip is quite steep NNE. The steeply inverted beds of the much lower profile above St. 203 form the nose to this drooping fold that constitutes more than half of the south flank of the major syncline here. Once again the axis derived for this fold plunges gently WNW.

Beyond the upright northerly dipping beds between Sts. 204 and 202 the trace again becomes inverted in the standard profile of a cascade fold. This flatlying axial plane again intercepts the rising profile between Sts. 223 and 224 both locations yielding axes plunging gently just north of west. The bedding attitude from St. 224 to axial zone north of St. 228 curves gradually to a gentler dip but data around the axis itself are difficult to obtain. It seems quite probable that faulting is important although the aggregate throw of the faulting and folding across the zone, as indicated by the Panda Limestone Member, is probably less than 200 m.

The hinge lines for most of the flatlying folds coincides with the preferred orientation of the slaty cleavage/bedding intersection (compare Diagram As; B_1 and δ_1: Encl. 3). This together with the way in which the slaty cleavage poles coincide with the constructed axial planes of the folds, confirms that the two are to be genetically related here (Diagram As; πB_1 and πS_1). The axial zone of the Lechada syncline is nowhere well exposed near this profile and the complications are quite possibly more intense than plotted. For example, the sharp syncline at St. 147 is almost certainly faulted but very little further evidence could be found closer to the axis.

The correlation constructed in detailed Section A (Encl. 1) is confirmed by the return of the Panda Limestone Member just to the north of the end of the section (Geological Map, Encl. 1).

The overall dip of the north flank of the main structure here only projects as 10° south in Section A. This is largely due to the extensive development of quite large minor folds up to 200 m wavelength. It is difficult to reconstruct the original attitude of the main flank but there seems to be no reason to assume the dip was greater than the average now found. This anomaly is no doubt connected with the folding of the large dome of Casasuertes which forms such a change from the acutely folded Vallines anticline along the strike to the east.

Slaty Cleavage. — The trace of the slaty cleavage planes in the south flank of the Lechada syncline simulates remarkably the structure of the bedding in Section A (Encl. 1). However, the folds are much more subdued as is also demonstrated by the distribution of poles; those of the slaty cleavage being in a much shorter partial girdle (compare Diagrams AN; πSs and πS_1: Encl. 3). The most unusual feature here is that in the overturned beds the slaty cleavage converges towards the south whereas in the upright part of the sequence the convergence is to the north. This leads to the general correlation of the slaty cleavage with the recumbent folding as a concentric cleavage.

The overturned limb of the southernmost part of Section A largely yields a trace dipping very gently north, converging southwards into the bedding. Like the bedding the slaty cleavage generally has a westerly component of dip so that the modal plane dips gently NNW (Diagram As; πS_1: Encl. 3). Between Sts. 214 and 212 where the south dip of the bedding abruptly steepens, the slaty cleavage also, curves into a southerly dip although not so steep as that of the bedding. Hence the southerly convergence is not changed suggesting the possibility of later folding. The numerous small variations in the trace of the slaty cleavage illustrate the effects of the later small folds just the same as on the bedding.

Between Sts. 208 and 207 the slaty cleavage trace steepens in the upright beds maintaining the southerly convergence for some distance. Then this trace becomes parallel to the bedding dipping quite steeply north as through the two underlying cascade folds. Just as argued earlier the steepened cleavage with the same sense of convergence suggests later folding of the nose of this drooping recumbent fold. In fact the rocks here are quite severely deformed with much quartz veining and the form of the fold constructed also seems too acute for complete continuity so that a fault has been interpreted here (Section A, Encl. 1).

The way in which the slaty cleavage trace cuts with scarcely any deviation across the cascade fold of St. 203 suggests a late- or post-kinematic stage for its development. Yet directly below the reversal of convergence in the inverted beds between Sts. 202 and 223 gives the clearest demonstration of a concentric relation to this cascade fold.

Throughout the simply dipping sequence between Sts. 223 to 228, the slaty cleavage maintains a lower dip than the bedding, converging toward the main axis of the Lechada syncline. This resembles the attitude in other profiles and in analogy probably represents a cleavage concentric to the main structure.

In the north flank the slaty cleavage trace in Section A (Encl. 2) shows a continual southerly convergence towards the major synclinal axis complementing the relation in the northern half of the south flank as far as St. 234. Beyond this the bedding and cleavage traces are either parallel or vary in convergence suggesting the axial zone as also derived from the mapping.

The effects of both large and small minor folds can be seen in the slaty cleavage trace just as well as in the bedding. Hence considerable folding must have taken place after the slaty cleavage deformation.

Fracture Cleavage. — The fracture cleavage in the slates of the profile of Section A are strongly oriented as is shown by the dense maxima of planes dipping very steeply south (Diagrams AN,s; πS_2: Encl. 3). In the field this cleavage has been frequently observed parallel to the axial planes of very small folds a relationship confirmed by the correlations between the attitude of measured axial planes and cleavage planes (Diagrams AN,s; πS_2, πB_2: Encl. 3) as well as between the fracture cleavage/bedding intersections and the fold axes (Diagrams AN,s; δ_2 and B_2: Encl. 3).

Conjugate sets of fracture cleavage have been found very occasionally in this profile. The angle between such sets varies widely and usually the cause is very obvious in a local inhomogeneity such as faulting or complex sedimentary variations.

Minor Folds. — The folds found in Section A (Encl. 2) show every gradation from the smallest micropuckering of the slaty cleavage to the scale of the Lechada syncline itself and no significant subdivision can be made. As defined above, the limit between major and minor folds has been taken as that of folds occurring complete in a natural exposure. However, in this section the completely artificial character of this limit became very obvious. Very little certain sedimentary influence on folding can be demonstrated from this profile. At St. 211 in the inverted limb of the south flank there are some near-isoclinal folds in a greywacke band which could have been asymmetric to the main structure but not to the present attitude of the overturned south limb (Fig. 59). On the contrary the somewhat larger fold to the north has axial plane fracture cleavage and a typical parasitic symmetry to the present attitude of the beds here.

The sedimentary folds are very tightly apressed with the slaty cleavage curving into their axial planes and the fracture cleavage cutting across their flatlying axial planes. Although no conclusive feature was noted,

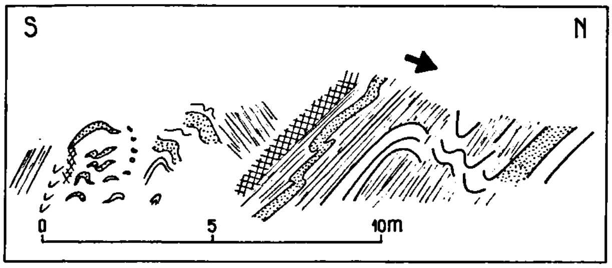


Fig. 59. Sedimentary (?) folds in thin greywacke band of the major flap fold, St. 211, Section A, Pico Redondo. Other fold of opposite symmetry just north could be parasitic to present attitude or an inverted cascade fold. Good sedimentary structures younging north (arrow).

the underlying sequence is of mudstones with occasional deformed lenses of greywacke, quite evidently slumped. The axes of these folds plunge gently west and only the rather flatlying axial plane distinguishes this fold from the normal tectonic folds (Diagram As; B*s* and πB*s*: Encl. 3).

The hinges of the flatlying cascade folds prominent in Section A have been directly observed in the rollover. This is usually accomplished by such gentle flexing that the fold is only evident from the measured bedding attitudes. However, one exposure not on the line of Section A, shows the nature of the hinge of the main recumbent fold of Pico Redondo. Measurement here showed that the slaty cleavage reversed its convergence direction across the limbs of the main fold suggesting a concentric relation as postulated above (p. 243). However, other folding also seems to be present in which the convergence is not affected. Hence as has also been discussed above, later folding of this hinge zone is evident.

At St. 209 at the hinge on the line of Section A there is another rather unusual fold (Fig. 60). The beds are all inverted and this near-isoclinal fold has slaty cleavage fanning outwards to the hinge of the antiform. This is the only example of a fold with axial plane slaty cleavage and the unusual development must be due to the severe deformation nearby, although all the other folds have axial plane fracture cleavage.

In the south flank of the Lechada syncline in Section A (Encl. 2) the most obvious effect of minor folding is in fact that of small folds producing minor wrinkling of the bedding and slaty cleavage traces. These folds and many more, too small to draw at the scale of the section, have an axial plane fracture cleavage, proving the late stage of the deformation. This is also emphasised by their asymmetry which is parasitic to the present dip of the beds. Of course, completely inverting a fold does not introduce a change in the direction of the sense of asymmetry, but the consistent attitude of the associated fracture plane cleavage everywhere does not allow later large overturning movements.

The close relation between the majority of minor folds and the fracture cleavage is well brought out by the similarity of the orientations of the axial planes and fracture cleavage planes as well as the fracture cleavage/bedding intersections and axial plunges (compare Diagrams As; πB_2 with πS_2 and δ_2 with B_2: Encl. 3).

The north flank of the Lechada syncline along the profile of Section A is really a series of minor folds of all types and sizes. Unfortunately these are not so well exposed as to allow all the interacting features to be investigated.

Near to the axial zone the first well defined fold is a cascade fold traversed twice between Sts. 152 and 240. The axial plane of this fold dips north as indicated by the construction lines in Section A (Encl. 2) and the axis plunges NW down this plane. The oblique attitude to the projection plane is responsible for the foreshortened shape of this fold. The slaty cleavage trace is partly parallel to the axial plane of the fold near the core but diverges widely in the limbs. The change in convergence of the slaty cleavage from one limb to the other suggests a concentric relation to the fold. Since the fracture cleavage maintains its regional attitude throughout the fold it does not seem likely that later folding can explain this.

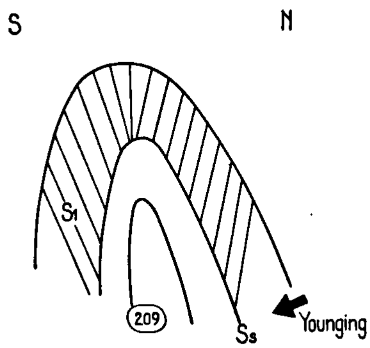


Fig. 60. Small antiform apparently with axial plane slaty cleavage (S_1) St. 209, Section A, Pico Redondo. The slaty cleavage planes fan out from the axial plane of the antiform.

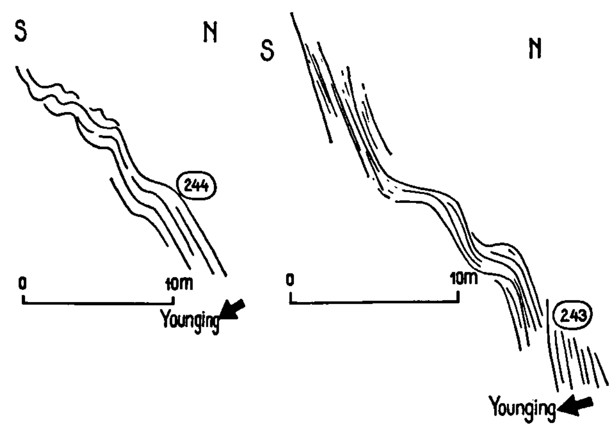


Fig. 61a, b. Small parasitic folds in the overturned limb of the cascade fold between Sts. 243 and 244, Section A, Pico Redondo.

The small folds with axial plane fracture cleavage found in the overturned central limb of the cascade fold have a parasitic asymmetry to the inverted bedding and not to the major structure (Fig. 61). Further north at St. 231 in Section A a series of very small cascade folds have been recorded (Fig. 62). The axial planes of these folds dip between north and west the axes plunging consistently NW (Diagrams AN; $B_{1,2}$ and $\pi B_{1,2}$: Encl. 3). The slaty cleavage is also flatlying here but not really parallel to the axial planes as can be seen by comparing the measurements (Diagrams AN; πS_1 and πB_1: Encl. 3). The lack of any strong preferred orientation is most emphatically brought out by the distribution of slaty cleavage/bedding intersections (Diagram AN; δ_1: Encl. 3).

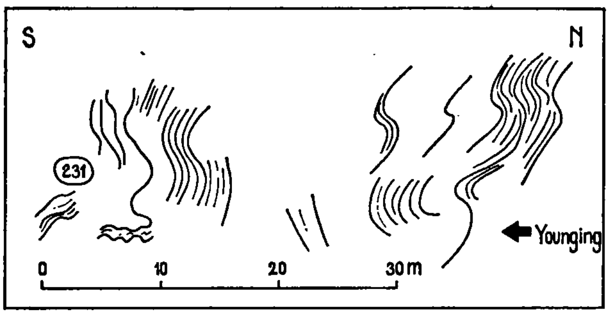


Fig. 62. Small cascade folds in steeply dipping beds of the north flank of the main syncline, St. 231, Section A, Pico Redondo.

This situation is assessed as meaning that the slaty cleavage here has developed as a concentric cleavage to the minor as well as the major folds.
North of St. 232 individual folds are seldom exposed and can only be reconstructed from measurements in their flanks. The readings were so variable that it was not possible to arrive at good estimates but the overall orientation of the bedding dipping either NNE or SW gives the impression that NW plunging axes must dominate. This distribution has no really significant pattern but the suggestion of a girdle in the bedding plane poles is also oriented NE-SW (Diagram AN; πSs: Encl. 3).
The construction lines of the north flank in Section A suggest that the axial planes of the NW folds must be quite steep to near vertical but this could not be confirmed. The consistent southerly convergence of the slaty cleavage onto the bedding through most of these folds suggests they are later than the slaty cleavage deformation. However, the reversal of convergence around St. 236 does imply at least some folding during that stage.
Small parasitic folds are to be found throughout this part of the north flank, all with axial plane fracture cleavage. This relationship so clear in the field is also brought out by the comparison of the attitudes of the axial planes with those of the fracture cleavages as well as the axial plunges with the fracture cleavage/bedding intersections (Diagrams AN; πB_2 with πS_2 and B_2 with δ_2: Encl. 3).
The consistent south dip of the fracture cleavage planes does not seem to allow for the development of NW trending folds during the deformation. True, one exceptional NW plunging axis has been observed although the axial plane fracture cleavage dips south here. Since this is an exceptional attitude for the cleavage it follows that the associated fold attitude probably be equally exceptional.
The Redondo profile yields a form that can hardly be described as a syncline. The recumbent part of the south flank seems to be quite plainly concordant with the cascade folding in the rest of the south flank. The relation with the slaty cleavage as a concentric cleavage to most of this folding is quite clear, although the cleavage appears to have formed after the beds had been inverted. The intricate topography here has allowed the following up of a flatlying axial plane demonstrating the validity of the concept. The huge recumbent syncline of the south flank is faced by an intricately folded sequence which shows only rather small scale effects of the slaty cleavage deformation. Once again the remarkable feature of the cascade folds allowing the development of overturning on *both* flanks of the major structure *towards* the synclinal axis is to be seen.
The fracture cleavage deformation can be clearly seen to be later than the slaty cleavage and the inversion of so much bedding. In addition to the innumerable small folds a number of larger ones are also suspected but the complexity of the earlier deformation was so great that confirmation by analysis is not possible.

SUMMARY

The Lechada and Curavacas synclines have developed along the southern boundary of the Yuso Basin. The Upper Carboniferous flysch deposits which fill it, bear, in the mixture of turbidites, polymict conglomerates as well as often clastic, limestone, the record of epeirogenic tectonic activity. The numerous bottom structures characteristic of these rock types enable the younging of strata to be read through most complicated folds. Basic control of sedimentation was effected by fundamental linear features such as the Cardaño line forming the margin of the basin proper, as well as others such as the Peña Prieta line (Peñas Matas fault), which strike out into the basin.
The structural developments formed a continuation of the activity during sedimentation, some perhaps having commenced to form while the uppermost strata were being laid down. The synclines are directly related to the same fundamental lines as the sedimentation. Although this may have been a direct result of the mechanical influence of the shape of the sedimentary bodies, it seems quite certain that the structural features are also attributable to gravity so that

a continuation, perhaps intensified, of the epeirogenic movements could have been the cause.

The argillaceous rocks in the sequence have been recrystallized to slates but the greywackes and limestones, though recrystallized show no oriented fabric. The concentric slaty cleavage usually dips at a lower angle than the bedding (average 15°) echoing the major structure, emphasised by the same concentric cleavage. The relation between this cleavage and the major fold axis is also borne out by the statistic modal cleavage/bedding intersection which is usually parallel to the major axis even where the trend swings. In certain isoclinal or recumbent folds the slaty cleavage resembles an axial plane type as it also may do in previously formed sedimentary folds.

The slaty cleavage has been cut by one, sometimes two, and even exceptionally three, fracture cleavages. Again the cleavage planes do not cut the coarser clastics or limestones. They are obviously parallel to the axial planes of many minor parasitic folds. These folds involve the more competent greywacke or limestone layers so that the deformation of the slates has been accompanied by some adjustment in the uncleaved rocks.

The major structures trend basically WNW-ESE plunging on average quite steeply west. These trends are interrupted by the Peñas Matas fault dividing the Curavacas from the Lechada syncline, as well as deviating trends along the line of the Rio Yuso, where the major axis also jogs north. The control of the Cardaño line upon the southern limb is very clear although it has been offset by the Peñas Matas fault. This southern limb maintains a fairly consistent dip of about 60° north except for those segments involved in the large flap folds developed east of Barniedo.

The north limb of the Curavacas syncline is quite gentle to the east but where the Peñas Matas fault cuts across, it is warped upside-down parallel to the north-dipping fault-plane. To the north of the fault the beds are also bent towards the fault plane so that the Lechada syncline has a type of nose en echelon with the Curavacas syncline. The structure in the Lechada Valley is more like a massive homocline with the southern limit rounded in a rather flat-bottomed box-form, terminated by the Peñas Matas fault.

The structurally higher sections to the west appear more compressed, developing more minor folding and beyond the Rio Yuso extensive, faulted cascade folds with some very large flap folds occur. The largest flap fold of Pico Redondo has involved Devonian rocks and some of these have been undermined by erosion to slide into the valley north of Vegacerneja. The cascade and flap folds typically have a completely preserved inverted limb, characteristic of gravitational folds. The development of opposing flap folds in either flank seen in the Guspiada valley would appear to exclude any other tectonic mechanism.

The strain recorded by the slaty cleavage has been largely one of stretching the bedding planes and thinning the layers. It is remarkable that the standard values for slaty cleavage deformation yield the same order of expansion as the folding does of shortening. So that there need be no significant approach of the outer flanks to produce the internal deformation seen. Again the fracture cleavages east of the Rio Yuso are so inclined, fanning downwards in the syncline, that no appreciable horizontal or vertical compression of the major structure occurred. The deformation corresponds to changes in the shape of the incompetent wedge which could have been induced by quite small rotational and differential vertical, movements.

The flap folds, of course, do imply shortening but only from beds that have been tilted up into a position of instability. The fact that slaty cleavage has developed in gravitational folds seems unusual but since the cleavage is only developed in the slates between competent, uncleaved strata it has depended upon their deformation. Since this type of folding of such rocks is quite generally accepted, the formation of the cleavage is not really extraordinary.

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