REFOLDING IN THE THRUST FAULT ZONE OF SAN MARTIN DE LOS HERREROS
(Prov. Palencia, Spain)

by

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ABSTRACT

The thrust fault zone of San Martin de los Herreros is a narrow E-W trending zone, which on lithological as well as structural grounds is different from the adjacent areas. The lower part of the Upper Carboniferous developed in the Culm facies, whereas directly north and south of this narrow trough thick bedded and massive limestones of the Caliza de Montaña facies laterally replace the shale-subgraywacke series of the Culm facies.

The major folds were formed during two distinct periods of movement. The first generation of WNW-ESE trending recumbent folds had axial planes which were dipping gently to the south-southwest. The folds were accompanied by low-angle overthrusts with movement towards north. Incompetent red shales and nodular limestone of Upper Visean age served as detachment horizon. The second set of isoclinal major folds, the

E-W refolding, has axial planes which dip 30-50 degrees to the north. They are superimposed on the earlier folds and determine the present day geometry of the folding pattern. They distort the primary fold axes and axial planes. On the other hand their trend is influenced by the first set of structures. North of San Martin a N-S orientation can be distinguished in the minor folds, which were contemporaneous with the E-W refolding.

INTRODUCTION

The area mapped in 1954-1960 lies between the villages San Martin de los Herreros, Rebanal de las Llantas and Santibañez de Resoba, on the southern slope of the Cantabrian mountains and the northern part of the province of Palencia. The Rio Rivera, a tributary of the Rio Pisuerga, has eroded a wide valley, mainly in soft rocks at an altitude of 1.100 meters. To the south, the regions is bounded by the Sierra del Brezo, formed by massive limestones of a Namurian age. These mountains have a maximum altitude of 2.000 meters.

To the north occurs another ridge of limestone mountains of the same age which reaches an altitude of 1846 m. in the summit of the Santa Lucia mountain, west of Santibañez de Resoba. A geological map made by Quiring (1939) gave only the broad outlines of the lithology of the area. Kanis (1955) studied the geology of the area between San Martin and Ventanilla. From the very complicated structures around Can Martin he made a detailed map on 1:10.000 scale. The present study links up directly with the western margin of the detailed map of Kanis. A description by de Sitter (1957) of a folded thrust plane near the San Martin anticline indicated the discovery of a more complicated structural history than was supposed by Kanis. From the present described area de Sitter remarks: "In the complicated structures north and west of San Martin and in the recumbent syncline below Santibañez a similar intensely folded thrust plane can now and then be detected" (de Sitter, 1957, p. 278).

STRATIGRAPHIC SEQUENCE

The rocks outcropping in the area are of Devonian and Carboniferous age. The Devonian is exposed only in an anticlinal core, outcropping on the eastern slope of the Peña Negra. This anticlinal fold can be traced between San Martin and Ventanilla and is named the San Martin anticline. East of San Martin the oldest rocks in the San Martin anticline are limestones of Emsian age, whereas west of the Rio Rivera the oldest outcrop in the core are the ferruginous San Martin sandstone of the Givetian age. Eight hundred meters south of the village of San Martin this hematite-rich sandstone has been exploited for several years. The sandstone is overlain by a 50 m thick-bedded coral limestone. The few fossil determinations do not give sufficient indications for an exact dating. However, field mapping indicates that the limestone can be correlated with calcareous shales and black shales in adjacent areas belonging to the Upper Givetian and Frasnian. This formation is known in the Valsurvio dome as the Valcovero formation Koopmans, 1962. A 2 m thick quartz-sandstone overlays the Valcovero formation with a sharp boundary. Erosion phenomena can be seen on the boundary plane, indicating a break in the sedimentation. An age determination of this white quartz-sandstone is not possible, because of the lack of fossils. A probable Famennian age is suggested here and the beds are correlated with the top of the Camporredondo quartz-sandstone in the Valsurvio dome.

Carboniferous sedimentation starts with a transgression in the Upper Visean. The deposits consist of red shales or radiolarites and a red or green nodular limestone, "griotte". The griotte horizon, which has a large lateral extent over nearly the whole Cantabric-Asturian mountains, serves as a stratigraphic marker horizon. The total thickness of red shale and nodular limestone reaches a maximum of 20 m. The proportions of the griotte layer have been exaggerated on the maps and sections in order to show this important marker clearly.

On top of the griotte follows 10-40 m. of blue-grey, fine crystalline limestone. Upwards the limestone grades into shales and calcareous shales, followed by a thick series of several hundreds of meters of shales, mudstones, pebbly mudstones, subgraywacke and conglomerates of the Culm facies. The development of the Culm facies is in strong contrast with what we find a few kilometers to the south in the Sierra del Brezo and to the north in the Santa Lucia mountain (west of Santibañez de Resoba), where the Namurian is represented by a thick sequence of massive limestones in the Caliza de Montaña facies (Calcaire des Canons of Barrois, 1882). These facies changes are restricted to a narrow E-W trending zone, which runs from Cervera de Pisuerga over the Pantano de Ruesga, San Martín de los Herreros and Pantano de Camporredondo in the direction of Riaño. Facies changes in the Devonian are related to this same zone (Fig. 1). The Upper Devonian Camporredondo quartz-sandstone is several hundreds of meters thick and grades gradually downwards into the shales of the Valcovero formation in the Valsurvio dome (Koopmans, 1962). In the thrust fault zone of San Martin the Camporredondo formation is only represented by a 2 m. thick quartz-sandstone which lies with a disconformity upon the Valcovero formation. Changes in lithology affect the type of deformation in the area. In the present paper further details of these rapid facies changes will not be discussed.

The Carboniferous sequence older than the Curavacas folding phase will be referred to as the Ruesga group.

STRUCTURAL OUTLINE

The study of the thrust fault zone of San Martin is based on detailed field work, great attention being paid to top and bottom criteria in the Culm facies. Mapping was carried out on 1:10.000 scale (Fig. 2) and the orientations of the axial planes and fold axes of the minor folds, developed particularly in the griotte and Carboniferous limestones, have been analysed. Cleavages are developed faintly in the incompetent rocks, e. g., the shales of the Culm facies, but they are difficult to study in detail, due to the lack of exposures. Fig. 3 represents a structural map, showing the major fold trends and the traces of the low angle overthrusts.

An analysis of the structural relations indicates that at least two folding phases have affected the area. The first generation fold structures are trending WNW-ESE. The isoclinal folds are overturned towards the NNE and many overthrusts are developed in this folded sequence.

The second folding has deformed the first generation folds and thrust planes. This fold trend makes only a slight angle with the previous structures. The most striking difference between the first folds and the later refolding structures is the opposing orientation of their axial planes. Whereas the former have axial planes dipping gently south, the latter have axial planes which dip 30-50 degrees towards the north. The structures developed during the refolding period are clearly visible in the field, as for example the 'S' shaped fold on the Peña Negra, whereas the first generation structures are obliterated by the refolding.

FIRST GENERATION MAJOR FOLDS.

The great lithological differences between the sediments of the Valsurvio dome (south of the area described here) and the Zone of San Martin de los Herreros have caused a completely different type of deformation in these two areas. In the

Valsurvio dome the type of deformation has been dictated by the competent Upper Devonian quartz-sandstone and by the massive Carboniferous limestones of the "Caliza de Montaña" facies (Koopmans, 1962). The thickness of the competent quartz-sandstone decreases suddenly to the north in the area of San Martin. The 2 m. thick Camporredondo quartz-sandstone no longer dictates the folding style. Together with this change there is a facies change in the Ruesga group. The massive limestones of the Caliza de Montaña give way to highly incompetent shales and mudstones of the Culm facies towards the north.

With this change the folding style has adapted itself. The stress field which has caused large isoclinal folding in the competent beds of the Valsurvio dome, does not encounter the same resistence against deformation in the incompetent series of the San Martin zone. This results in the development of a large number of low-angle overthursts with a thrust direction towards the north. The incompetent nodular limestone and red shales (griotte horizon) on the base of the Carboniferous served as the main detachment horizon. Sometimes we find a few meters of Upper Devonian quartz-sandstone still preserved above the thrust plane.

The existence of the thrust planes can only be deduced from the repetition of the stratigraphic sequence. No mylonite, fault-breccia or signs of other disturbance occur on the thrust planes.

Together with the low-angle overthrusts a few isoclinal folds are developed with gentle SSW dipping axial planes. Mostly these folds show thrusting in the core and a thinning of the overturned limb.

Going from south to north through the area we encounter the following first generation structures (Fig. 4).

South of Rebanal limestones and griottes of the base of the Ruesga group are thrust over shales and mudstones of the Ruesga group which are stratigraphically higher. Thrust movement was towards the north. At present this thrust plane

(1)* is in an inverted position due to the later refolding. It is followed to the north by an isoclinal syncline (2), the Peña Negra syncline, which has in its core a thick series of shales, mudstones and a 30 m. thick conglomerate. The conglomerate bed can be easily traced on the southern slope of the Peña Negra, forming a 'S' shaped structure (refolding structure). The northern limb of the Rebanal syncline with limestones and griotte at its base is thrust to the north over an isoclinal anticline, the San Martin anticline (4).

This anticline can be traced from the Pantano de Ruesga in the east, via San Martín to the Peña Negra in the west. De Sitter (1957) has described this fold structure in the region between San Martin de los Herreros and Ventanilla. The northern limb of this first generation structure is strongly reduced and squeezed out at many places and shows evidences of local thrusting near Ventanilla.

North of the San Martin anticline a tightly compressed syncline (5) occurs. In the overturned limb of this syncline, the limestone and griotte horizon of the base of the Carboniferous sequence is again thrusted over the shales of the Culm facies (6). Further north more similar low-angle overthrusts (7, 8, 9, 13) and recumbent folds (10, 11, 12, 14) occur.

All these WNW-ESE trending structures are a result of large horizontal translations towards the north. The folds are developed as isoclinal folds, overturned to the north and with the inverted limb strongly reduced by shearing. The low-angle overthrusts are formed in the same way, and either the middle limb has been completely sheared out, or thrusts replaced the folds without a middle limb being formed.

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* The numbers between brackets, noted behind the first generation structures in the text, are related to the numbers of the trend of the folds and thrust faults on Fig. 3 and 4.

E-W MAJOR REFOLDING

The WNW-ESE trending structures described above were refolded during a later period of deformation along an E-W trend. This E-W refolding dictates the present-day geometry of the fold pattern. The axial planes of the isoclinal folds are dipping 30-50 degrees to the north, and opposite to the axial planes of the first generation structures. The originally southerly dipping strata are all overturned and dip to the north as a result of the refolding. The two generations of folds are of about the same scale and identical in shape (isoclinal). Moreover the directions of the fold axes make only a small angle with each other. Thus it is rather difficult to separate the two generations of fold structures from each other.

The sections of Fig. 5 showing the refolding, are to some extent idealised, because the triclinic symmetry of the superimposed fold structures make constructions in two dimensions almost impossible.

The most important E-W trending cross-folds are the Rabanal anticline and syncline, which intersect the whole series of first generation structures. The syncline can be traced over a distance of about five kilometers from west to east. Complications occur where the Rebanal syncline is superimposed on the thrust plane (1) and the Peña Negra syncline (2) in the West of the region. The Carboniferous limestone and griotte above the thrust plane (1) can be followed in an anticlinal and a synclinal bend, northwest of Rebanal, broken by a few transverse faults. The bending must be due to the refolding by the Rebanal anticline and the Rebanal syncline, because the original flat thrust plane (1) is folded in the same way. Similarly the primary Peña Negra syncline is refolded. Following the southern limb of this syncline (2), by tracing the conglomerate bed from the northwest into the bend of the secondary Rebanal syncline, the limb is seen to be cut by an underthrust, which partly follows the already existing first generation thrust plane (1). The reactivation of this thrust plane is contemporaneous with the inversion of the plane. The relative direction of movement is the same. The small anticlinal nose in the conglomerates, against the reactivated thrust plane, 300 m. north-northwest of Rebanal, is not the secondary Rebanal anticline, but the inverted synclinal nose of the first generation Peña Negra syncline (2).

This interpretation is confirmed by top and bottom criteria (small scale cross lamination, load casts, flame structures, washouts and other sedimentary features). The series between Rebanal and the above mentioned conglomerate can be shown to have been repeated at least three times.

Further towards the east, on the southern slope of the Peña Negra, the conglomerate bed can be traced into a 'S' shaped curve. This curve represents the second generation structures (Rebanal syncline) superimposed on the northern limb of the Peña Negra syncline. The Rebanal syncline has been split towards the east into two synclines. The plunge and direction of fold axes of the superimposed fold structures are controlled by the attitude of the limbs of the first generation folds and change from a north-westerly direction with a plunge of about 40° on the southern limb of the Peña Negra syncline to a west-northwesterly direction with a plunge of 20° to 30° on the northern limb.

West of San Martin the Devonian and Carboniferous limestones on the Peña Negra show a snake-like trend, due to E-W refolding by the Rebanal syncline and anticline.

Where the road from San Martin to Rebanal turns from a south-westerly direction into a west-northwesterly direction, a small Devonian anticline core is visible on the west side of the Rio Rivera (Kanis, Fig. 20). This is the easterly continuation of the Rebanal anticline.

North of San Martin the structures become more complicated. Tight isoclinal first generation fold structures are intensively refolded. The scale of the folds decreases. Along its axial trend towards the northeast the Rebanal syncline becomes inverted near the Arroyo de Agueras. The second generation fold is formed around an axial plane that dips gently to the NNW. The axis plunges approximately down the dip of the axial plane and as it swings from one side of the dip direction to the other side in the axial plane, the fold changes from a synform into an antiform.

MINOR FOLD STRUCTURES

Minor folds are developed on both sides of Arroyo de Agueras, especially in the well-bedded limestone and griotte, but also in the shale-sandstone alternation. In the incompetent shale layers and occasionally the griotte, folds have developed an axial plane cleavage. Incipient traces of axial plane cleavage are sometimes visible in the folded well-bedded limestones, but accordeon folds or concentric folds are dominant. In the fiel a succession of the several minor folds is seldom distinguishable.

Fold axes and the poles to the axial planes of the minor folds are plotted in an equal area lower hemisphere projection (Fig. 6). Diagram A shows the orientation of the fold axes, the poles to the axial planes (π diagram, Weiss 1959) and a few poles to the axial plane cleavages, measured in the griotte and limestone in the first generation structures 7-11. The orientations of the fold axes can be separated into two groups. One group with a direction of N10E-N20W and with a mean dip of 20°, and a smaller group in the direction N80E-N120E with a dip of 0-20°. The poles to the axial planes which belong to the N-S directed folds are situated more or less on a girdle. The B axis (the pole of the girdle or great circle in a π diagram) is roughly in agreement with the maximum of the corresponding group of the fold axes. This is a common picture we can expect in a stereographic projection of parasitic minor folds. However, indications of a deformation of one group by the other group of folds is not evident in this diagram.

The other diagrams of minor folds (Diags. B and C) developed in the limestone hills formed by the first fold structures (13) and (14), show a much greater divergency of fold axes of minor folds than those in diagram A.

The E-W folds show a great variation in the orientations of the axial planes, the axes of these folds are nearly horizontal (diagram C).

The N-S fold directions are spread over the northern half of the diagrams B and C, meanwhile the orientations of the axial planes vary in dip between east and north at various angles. A clear relation of the orientation of these minor folds with the attitude of the fold limbs of the major folds does not exist.

The stereographic projection of the fold axes and the axial planes, does not help us to unravel the succession of folding periods. The orientation of the stress field, causing the concentric minor folds, is dependent on so many factors (bedding, differences in competention, earlier fold structures, etc.) in this complicated fold pattern, that it gives no regular geometric pattern.

The E-W minor folds appear synchronous with the WNW-ESE major folds as demonstrated by the local cleavage development. The northerly plunging minor folds, which have axial directions throughout the northern quadrant, are synchronous with the E-W trending refolding. E-W folds with vertical axial planes (diagram C) are developed locally at a later date and do not occur as major folds in the described area.

CORRELATION OF THE TECTONIC SEQUENCE WITH THE ADJACENT AREAS

As shown in the preceding pages, there are two generations of major folds developed in the thrust fault zone of San Martin de los Herreros. In the Palaeozoic of the province of Palencia three important folding phases can be distinguished:

3. Post Stephanian - Pre Triassic phase.
2. Asturian phase, dated as Westphalian D or Stephanian A.
1. Curavacas phase, dates as pre-Westphalian A - post Namurian.

The recumbent folds with their flat overthrusts of the first WNW-ESE folding generation developed during the Curavacas phase. This can be proved further westwards near the lake of Camporredondo, where the flat overthrusts are overlain unconformably by sediments younger than the Curavacas folding phase. The dating of the E-W refolding is more difficult. There are, however, indications which justify a dating of folding during the Asturian phase (Koopmans, 1962).

The N-S direction, developed in the minor folds, was formed simultaneously with the E-W refolding. Indications of a third folding phase with E-W direction and a vertical axial plane of probably post Stephanian-pre Triassic age occur locally, but in adjacent area this last folding phase is quite strong.

An interesting correlation with folding data can be made more to the west, in the valley of the Rio Esla. This river is situated in the zone of the Leonides (de Sitter, 1959, 1961). In this zone large low-angle overthrusts have been developed, which have been thrusted from south (or south-west) towards the north (northeast). The dimensions (some tens of kilometers) justify their description as nappe structures. The detachment horizon is, just as in the thrust fault zone of San Martin, a griotte horizon, however, in these cases it is the Cambrian "griotte and dolomite de Lancara" (Comte, 1959). The thrust series is much thicker, containing the whole sequence from the Cambrian up to and including the Carboniferous Ruesga group. Further west in the valleys of the Rios Torio and Curueño a whole series of such thrusts occur. The nappe structures are dated by de Sitter (1959) as a result of the Curavacas folding phase. In the Esla region refolding of the nappe structures has been effected by.

1. NNE trending folds of the Asturian folding phase.
2. E-W trending folds of a post Stephanian - pre Triassic folding phase.

In the valleys of the Curueño and the Torio this refolding has caused a beginning of inversion of the nappes, although they are affected less than those of the San Martin area.

The folding pattern of the Esla-Bernesga region and that of the thrust fault zone of San Martin are very similar, although the thrust structures of San Martin are on a much smaller scale.

Other differences are:

1. a faint development of axial plane cleavage in the thrust fault zone of San Martin, which is lacking in the Esla-Bernesga region;
2. the refolding structures of San Martin are tight isoclinal folds, whereas further west these folds are mostly open folds, although often with a vertical or partly inverted limb.

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RESUMEN

La Zona de San Martín de los Herreros está situada en las laderas meridionales de las montañas Cantábrico-Astúricas, en el norte de la Provincia Palencia.

Cuando se pasa de sur a norte, a la zona de San Martín, la litología cambia a corta distancia y, conjuntamente, el tipo de deformación. La conversión S-N de la facies "Caliza de Montaña" en la de "Culm", dió en la zona de San Martín origen a corrimientos de ángulo bajo, contrastando con lo que se encuentra en el domo de Valsurvio (Koopmans, 1962), a saber los grandes pliegues isoclinales. Estas cobijaduras casi horizontales, empujadas aproximadamente de sur a norte, con rumbo ONO-ESE, han sido replegadas en pliegues asimétricos E-O, cuyos planos axiales tienen un buzamiento norte. Especialmente en las pizarras se ha encontrado localmente un replegamiento tardío en dirección E-O, con planos axiales verticales.

En resumen, encontramos las siguientes fases de deformación: (a) Cobyaduras de ángulo bajo, con rumbo ONO-ESE de la fase de plegamiento de Curavacas (Westfaliense A); (b) Replegamiento en dirección E-O de la fase de plegamiento Astúrico (Estefaniense A-B); (c) Localmente replegamiento tardío en dirección E-O con planos axiales verticales de la fase post-Estefaniense-pre-Triásica.

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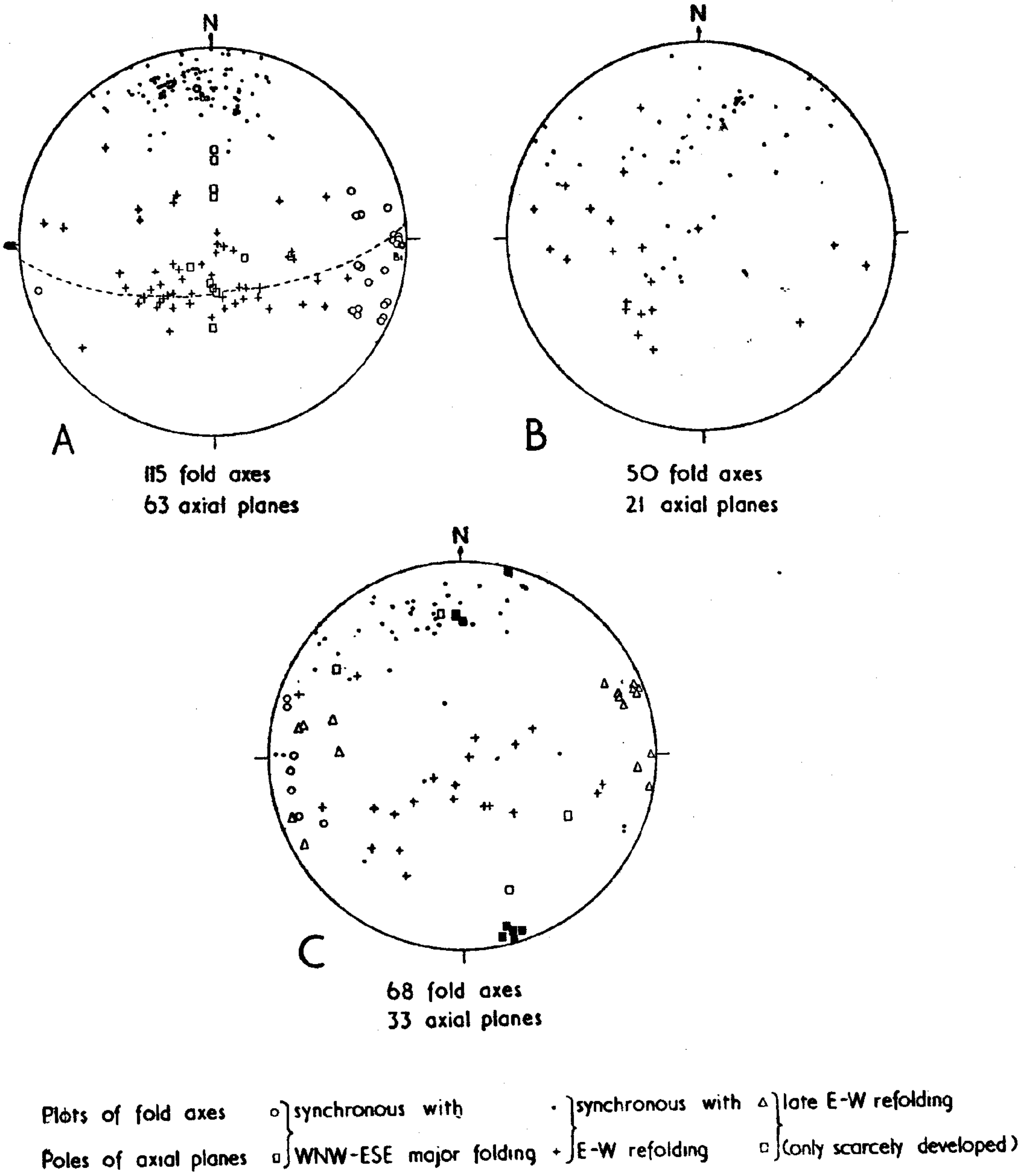
LIST OF ILLUSTRATIONS


N
A
115 fold axes
63 axial planes
N
B
50 fold axes
21 axial planes
N
C
68 fold axes
33 axial planes
Plots of fold axes ○ } synchronous with WNW-ESE major folding
Poles of axial planes □
· } synchronous with E-W refolding
+
△ } late E-W refolding (only scarcely developed)
□