ON THE GEOLOGY OF THE ALPUJARRIDE COMPLEX IN THE WESTERN SIERRA DE LAS ESTANCIAS (BETIC CORDILLERAS, SE SPAIN)[1]

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ABSTRACT

Akkerman, J. H., G. Maier & O. J. Simon 1980 On the geology of the Alpujarride Complex in the western Sierra de las Estancias (Betic Cordilleras, SE Spain) – Geol. Mijnbouw 59: 363-374.

The Alpujarride Complex in the western Sierra de las Estancias comprises a pelite-psammite sequence and an overlying carbonate sequence. A Ladinian to Late Triassic age seems most likely for the carbonate sequence, while a Middle Triassic and possibly older age is inferred for the remaining part of the section.

The tectono-metamorphic evolution took place during the Alpine orogeny. No indications have been found for pre-Alpine metamorphism and deformation. The rock sequences have been affected by plurifacial metamorphism during three metamorphic events. The first event (M_1) involved an increase in temperature under low to intermediate pressure, resulting in a prograde metamorphism up to amphibolite facies. M_1 seems related to the intrusion of hot ultramafic masses. This event was followed by retrograde metamorphism (M_2). Renewed increase of temperature, without a change of the existing low-pressure conditions, locally caused a third metamorphic event (M_3).

The plurifacial metamorphism was accompanied by polyphase deformation. The first phase (D_1) resulted in mainly isoclinal, similar folds. During the second phase (D_2) important translations gave rise to the superposition of at least three major overthrust masses. Associated folds have a vergence to the north, indicating a northerly direction of transport. Subsequently the rock sequences have been deformed into S to SE vergent folds, N to NW dipping reverse faults, E-W trending subvertical faults and into NNW trending wrench faults.

INTRODUCTION

The Betic Cordilleras – the Alpine foldbelt of southern Spain – is usually divided into the External Zone in the north and the Internal or Betic Zone in the south. The E-W trending Sierra de las Estancias in the province of Almería forms part of the Internal Zone. This zone consists of a number of mountain ranges, mainly comprising Triassic and older rock sequences, separated by intramontaneous basins filled with Miocene and younger sediments.

In the Internal Zone polyphase deformation and plurifacial metamorphism took place during the Alpine orogeny. The structure is characterized by superposition of a number of overthrust masses. Their presence is inferred from gaps and repetitions in the stratigraphy and/or marked discontinuities in grade of regional metamorphism.

On the basis of lithostratigraphic development of (Permo-) Triassic sequences and tectono-metamorphic evolution, the overthrust masses are usually grouped into three major tectonic complexes. In ascending order these are the Nevado-Filabride Complex, Alpujarride Complex and Malaguide Complex (Fig. 1).

In the central and eastern Internal Zone a fourth tectonic complex, the Ballabona-Cucharón Complex, has been distinguished between the Nevado-Filabride and Alpujarride Complexes (EGELER & SIMON, 1969).

Opinions differ as to the palaeogeographic arrangement of the rock sequences constituting the tectonic complexes and on the direction of overthrusting (EGELER & SIMON, 1969; KAMPSCHUUR & RONDEEL, 1975; TORRES-ROLDAN, 1979).

By far the major part of the Sierra de las Estancias consists of rock sequences of the Alpujarride Complex. In the area studied three Alpujarride overthrust masses can be distinguished. They are, in ascending order, the Partaloa, Oria and Montroy overthrust masses. In the northern part rock sequences of the Malaguide Complex occur. In this paper the

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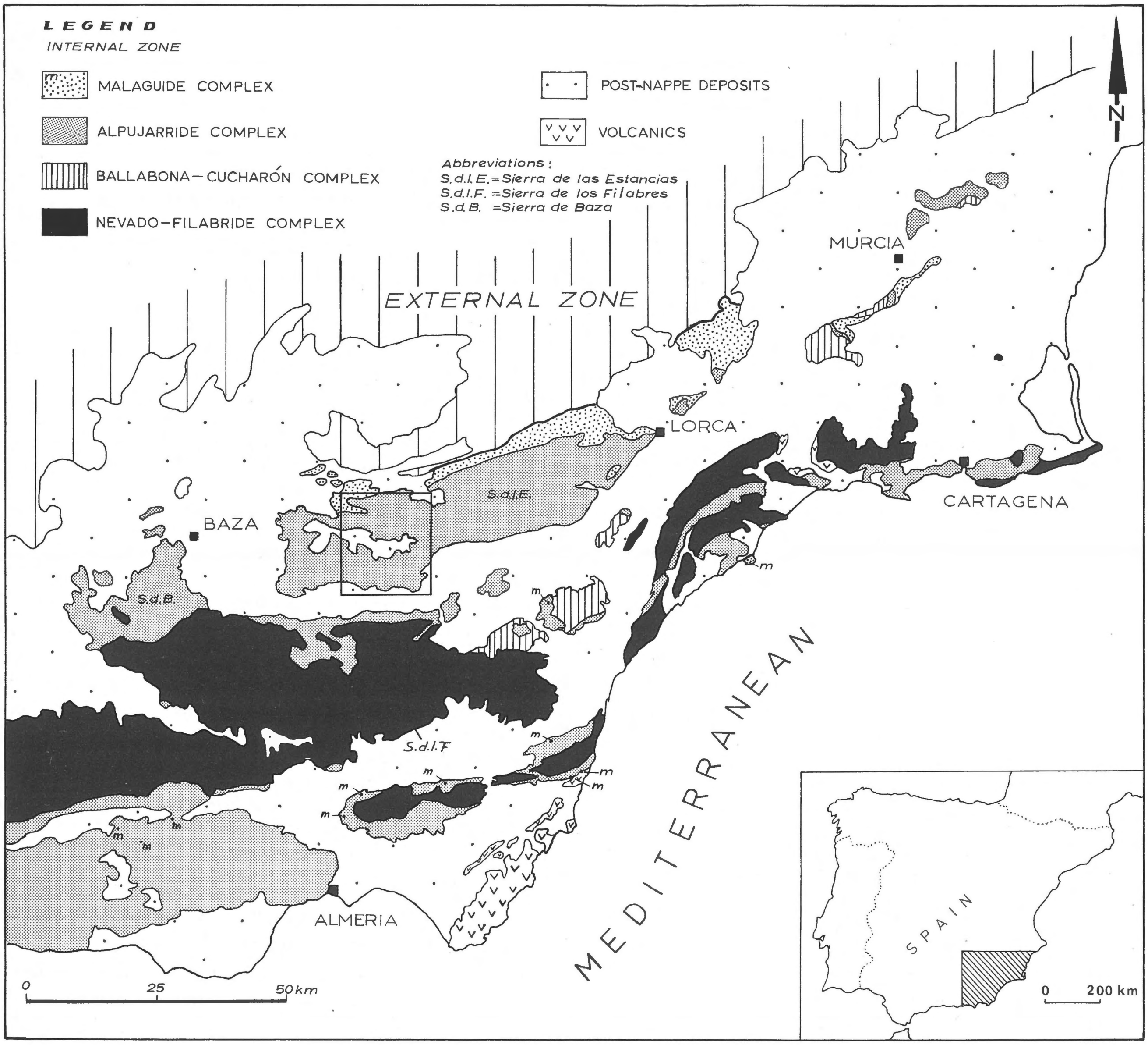


Fig. 1
Tectonic map of the central and eastern Internal Zone, showing the location of the area investigated.

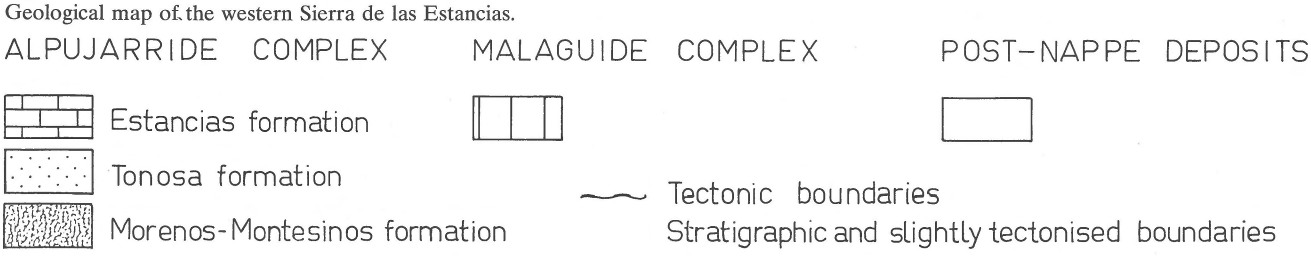
lithostratigraphic development and the tectono-metamorphic evolution of the Alpujarride rock sequences from the western part of the Sierra de las Estancias are treated. The results are based on studies by post-graduate students and staff of the Department of Structural Geology of the University of Amsterdam. This paper is a contribution to the 'Alpujarride Project', which intends to study the Alpujarride Complex. Geologists from the universities of Amsterdam, Bilbao, Granada, München and Salamanca participate in this project.

LITHOSTRATIGRAPHY

In the Alpujarride rock sequences of the western Sierra de las Estancias a lithologic subdivision can be made into a pelite-psammite sequence and a stratigraphically overlying carbonate sequence. The carbonate sequence (Estancias Formation) is exposed in a number of mountain ranges, the Sierra Partaloa (1106 m) in the south, the Sierra de Lúcar (1634 m) in the west and the Sierra de Oria (1431 m) in the north. Within the pelite-psammite sequence a lithologic subdivision can be made into the lower, dark-coloured Morenos-Montesinos Formation and the overlying, light-coloured Tonosa Formation. The names of these formations have been derived from DE VRIES & ZWAAN (1967). For the extent of the formations, the reader is referred to figure 2 and for the lithostratigraphic columns to figure 3.

As will appear from the following, the lithostratigraphic

Fig. 2
Geological map of the western Sierra de las Estancias.



section in the southern part of the area, belonging to the Partaloa overthrust mass, shows some differences with respect to that of the remaining part, belonging to the Oria and Montroy overthrust masses.

The *Morenos-Montesinos Formation* is built up of alternating metapsammites and metapelites with transitions between both types. The quartzites are thin- to thick-bedded and dark-grey to dark-brown in colour. The schists and phyllites are dark-blue. Dark-coloured garnet-bearing quartzites and schists predominate in the lower part. This colour is mainly due to the presence of fine-grained graphite. The stratigraphic thickness of this formation could not be established with certainty because of strong deformation; it is estimated to be of the order of 500 to 600 metres.

The overlying *Tonosa Formation* mainly consists of metapsammites and metapelites, and is generally lighter coloured than the underlying formation. Gradations between the Morenos-Montesinos and Tonosa Formations have been observed at some places. Usually, however, the contact between both formations is of a tectonic nature, due to Alpine fault movements. In the Tonosa Formation three members can be distinguished. They are in ascending order: (1) variegated quartzite member, (2) blue phyllite member and (3) light-coloured quartzite member. The members grade into each other. The lower member is built up of alternating thin- to thick-bedded quartzites and laminated to thin-bedded phyllites with transitions between both types. The quartzites generally are grey and green; the phyllites have a greyish-blue and greenish-grey colour. The lower part of this member contains banded quartzites. The banding is due to an alternation of dark-green layers mainly consisting of epidote, amphibole and carbonate, and light-grey layers rich in quartz. In this part of the member conglomerates occur locally. The pebbles consist of amphibole and carbonate. In the Partaloa overthrust mass the quartzitic rocks are predominantly reddish-brown and the phyllitic rocks green, blue and purple coloured. In addition very thin-bedded, yellowish-brown calcareous intercalations occur. Banded quartzites and conglomerates have not been found.

The blue phyllite member comprises bluish-purple phyllites with some intercalations of very thin- to thin-bedded, light-grey quartzites and brown-yellow carbonates.

The light-coloured quartzite member consists of thin- to thick-bedded, light-grey and reddish-purple quartzites, characterized by the common occurrence of cross-bedding. Thin carbonate intercalations in the uppermost part of this member represent the transition to the overlying Estancias Formation. The higher part of the light-coloured quartzite member locally consists of multi-coloured phyllites. In the Partaloa overthrust mass, the lower part of this member contains intercalations of gypsum. The estimated maximum stratigraphic thickness of the Tonosa Formation amounts to 450 metres.

The *Estancias Formation* mainly consists of thick- to very thick-bedded and massive, poorly bedded, greyish dolomites. Intercalations of thin- to thick-bedded, bluish-grey limestones occur, which locally have a marbly aspect. The basal part of the formation is characterized by a few metres of laminated to thin-bedded, yellowish and greyish limestones. The maximum stratigraphic thickness is of the order of 300 metres. In the Partaloa overthrust mass a tripartite subdivision can be made in the Estancias Formation. The lower part (about 50 metres) consists of a few metres of yellowish-brown limestones, overlain by thin- to well-bedded and massive, poorly bedded, dark-grey dolomites. The middle part (about 60 metres) is built up of laminated to well-bedded, yellowish and greyish limestones and dolomites with a few intercalations of phyllites and quartzites. The higher part of the formation, with a maximum thickness of 90 metres, consists of thin- to thick-bedded dolomites with intercalations of bluish-grey limestones.

FOSSILS AND AGE

In the Alpujarride rock sequences of the Sierra de las Estancias fossils are rare. Until now they have only been found in the Estancias Formation:

(1) In the lower part of the Estancias Formation of the Partaloa overthrust mass *Teutloporella triasina* (det. Dr. K. Ewert) has been found. Outside the Sierra de las Estancias this alga is present in Alpujarride carbonate rocks, which on basis of accompanying microfauna, have a late Ladinian to early Carnian age (see a.o. SIMON & KOZUR, 1977). In the Alpine Triassic *T. triasina* indicates the latest Anisian to earliest Ladinian.

(2) In the middle part of the Estancias Formation of the Partaloa overthrust mass undeterminable crinoids and lamellibranchs occur.

(3) In the central Sierra de las Estancias, outside the area studied, *Diplopora annulata* and some poorly preserved remnants, which probably represent *Teutloporella* cf. *herculea,* have been described by DE VRIES & ZWAAN (1967). According to these authors the algae-bearing samples are exposed at about 200 metres above the base of the Estancias Formation. In the Alpine Triassic *D. annulata* and *T. herculea* range respectively from the latest Anisian to the latest Ladinian and from the latest Anisian into the Late Triassic (OTT, 1972).

In order to establish the age of the Estancias Formation with the aid of microfossils, some 75 carbonate samples have been dissolved in diluted formic acid. In the residue of one sample, from the middle part of the Estancias Formation of the Partaloa overthrust mass, *Reubenella fraterna* has been found (det. Dr. H. Kozur). In the Internal Zone, this ostracode is characteristic of the *Mostlerella blumenthali* ostracode zone, indicating an early Carnian age (KOZUR et al., 1974; SIMON & KOZUR, 1977). In some of the other residues foraminifera

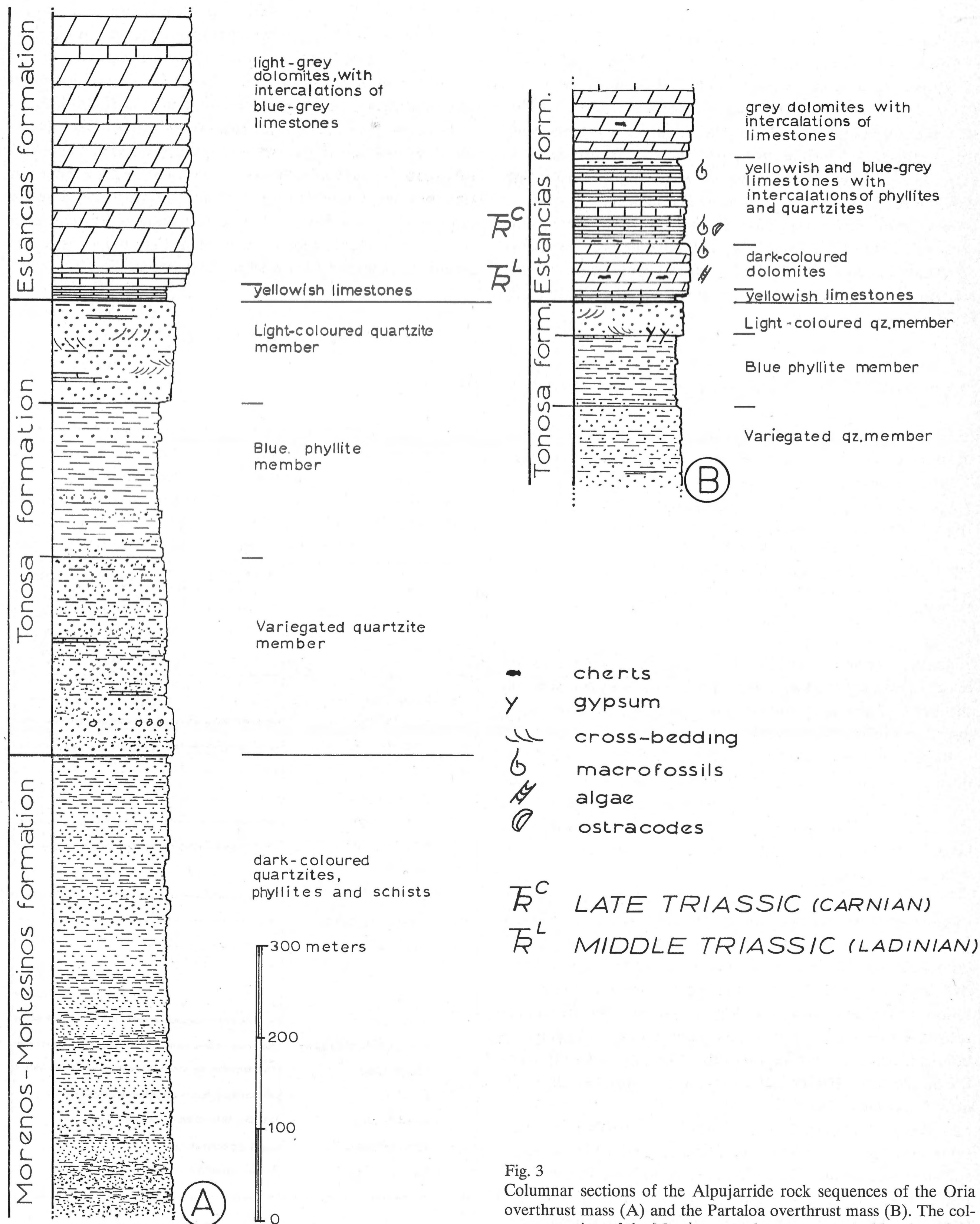


Fig. 3
Columnar sections of the Alpujarride rock sequences of the Oria overthrust mass (A) and the Partaloa overthrust mass (B). The columnar section of the Montroy overthrust mass resembles that of the Oria overthrust mass. However, due to tectonism, parts of the section are missing.

(a.o. *Ammodiscus* sp.), echinoderm fragments and fish remains without specific age value occur.

On the basis of the presence of *T. triasina* and of *R. fraterna*, respectively about 25 and 60 metres above the base of the Estancias Formation, and taking into account the probability that the above-mentioned dasyclad algae indicate younger ages in the Betic Cordilleras than in the Alpine Triassic (see also FALLOT et al., 1954), a Ladinian to Late Triassic age seems most likely for the Estancias Formation.

In view of the stratigraphic relationship between the Tonosa and Estancias Formations, a Middle Triassic age is inferred for the higher part of the Tonosa Formation. A Triassic and possibly older age is tentatively assigned to the remaining part of the section.

CONSIDERATIONS ON THE LITHOSTRATIGRAPHY

DE VRIES & ZWAAN (1967, p. 445) established the following stratigraphy of the Alpujarride Complex in the central Sierra de las Estancias:

Estancias Formation ....Middle and Late Triassic
Tonosa Formation ....'Permo-Triassic'
angular unconformity
Los Morenos Formation ....Siluro-Devono-Carboniferous
angular unconformity
Montesinos Formation ....earlier Palaeozoic and/or Pre-Cambrium

These authors concluded that an angular unconformity exists between the Montesinos and Morenos Formations on the basis of stronger folding and a higher degree of metamorphism of the Montesinos Formation.

Regarding the contact between the Morenos and Tonosa Formations, DE VRIES & ZWAAN (1967, p. 449) state: 'the angular relationship between the 'Permo-Triassic' rocks and the older rocks appears from the irregular distribution of the latter in the field as compared with the overlying 'Permo-Triassic' sequence'.

The present investigations have shown, however, that the number and succession of the metamorphic events and phases of deformation are the same for the entire pelite-psammite sequence. In view of the Triassic age of the upper part of this sequence, it implies that the tectono-metamorphic evolution took place during the Alpine orogeny. No arguments are available which support the existence of pre-Alpine metamorphism and deformation in the Alpujarride Complex of the Sierra de las Estancias (see also KAMPSCHUUR et al., 1973; I.G.M.E., in press a,b).

DE VRIES & ZWAAN (1967) allotted a Siluro-Devono-Carboniferous age to the Morenos Formation because of a conspicuous resemblance with the dated Palaeozoic Piar Formation of the Malaguide Complex in the northern Sierra de las Estancias. However, comparison of the lithostratigrafic section of the Piar Formation (GEEL, 1973) with that of the Morenos Formation shows considerable differences. For instance, sedimentary structures, indicating deposition by turbidity currents, as well as fossiliferous carbonate rocks and conglomerates, are common in the Piar Formation, but absent in the Morenos Formation. Therefore a correlation between the two formations in our opinion is not justified.

Consequently the age of the Morenos-Montesinos Formation remains a matter of debate. Taking into account that this formation stratigraphically passes into the Tonosa Formation -of which the upper part has a Middle Triassic age- and the absence of pre-Alpine metamorphism and deformation in the Morenos-Montesinos Formation, a (Permo-) Triassic age cannot be excluded for the latter formation.

METAMORPHISM AND DEFORMATION

Introduction

Study of the metamorphism and deformation has been focused on the pelitic and psammitic rock sequences, as carbonate rocks in general are poorly suited for this kind of study.

The Alpujarride rocks of the Sierra de las Estancias are characterized by plurifacial metamorphism of low- to medium-grade. On the basis of mineral assemblages, three me-

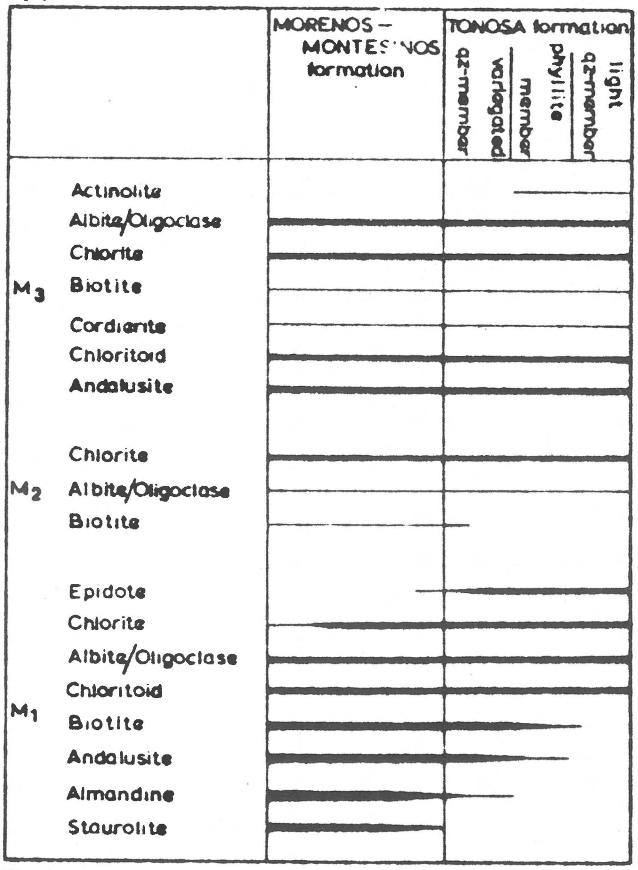


Fig. 4
Diagram showing the distribution of metamorphic minerals, formed during the three metamorphic events, in rocks of the Morenos-Montesinos and Tonosa Formations.

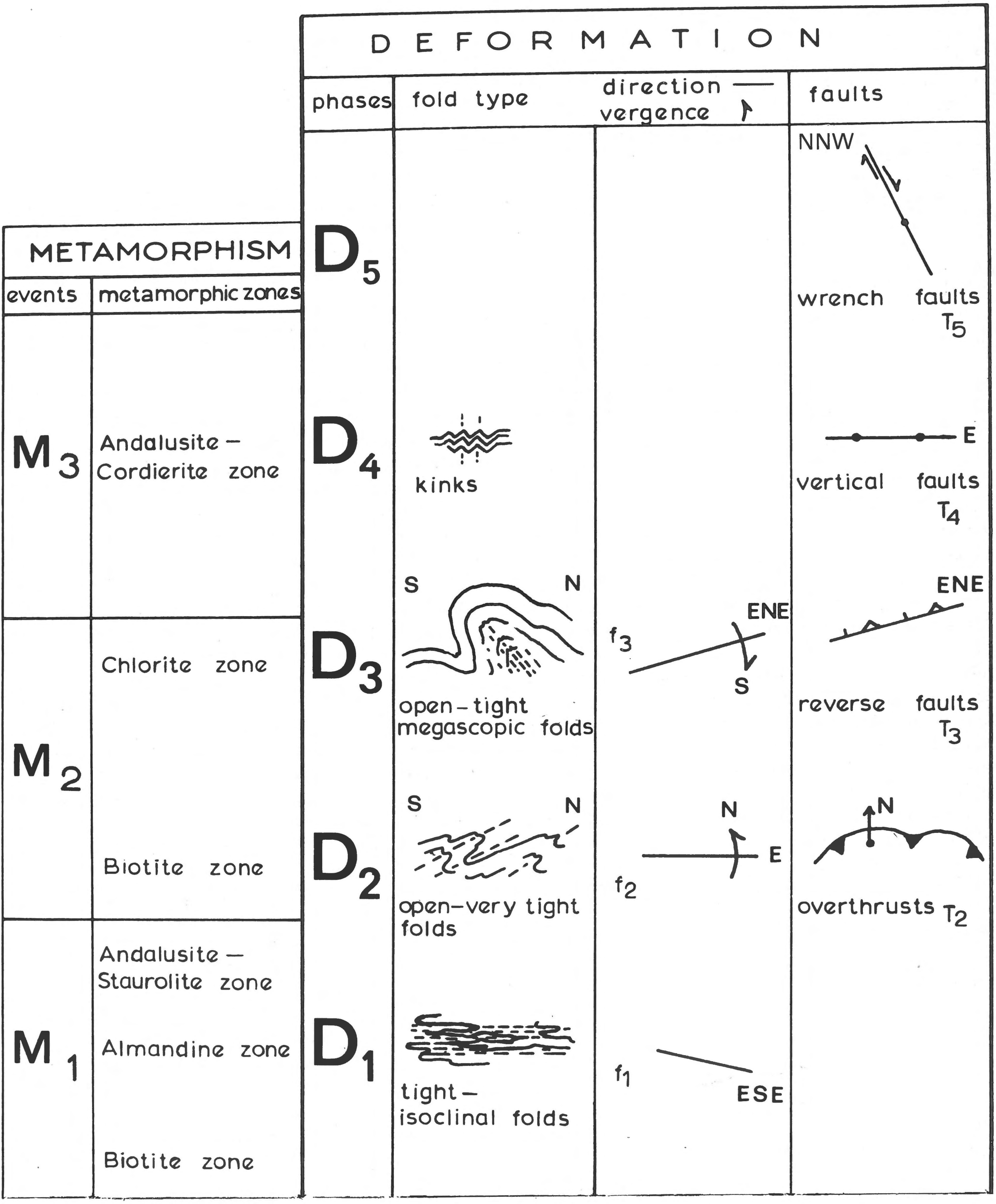


Fig. 5
Tectono-metamorphic scheme, presenting the relation between metamorphic events (M_1-M_3) and phases of deformation (D_1-D_5).

tamorphic events can be distinguished in rocks of the Morenos-Montesinos Formation as well as in the Tonosa Formation:

(1) a first event of prograde metamorphism up to amphibolite facies;
(2) a second event of retrograde metamorphism in the greenschist facies;
(3) a third event of low-pressure metamorphism up to amphibolite facies.

The distribution of minerals formed during these events is shown in figure 4.

Structural and petrological analysis revealed that the pelite-psammite sequence has been affected by five phases of deformation.

The different metamorphic events and phases of deformation are given in figure 5. The distribution of deformational structures is presented on tectonic maps and cross-sections (Fig. 6).

Metamorphism

First metamorphic event (M_1) – During this event the following prograde sequence of mineral assemblages -described in terms of metamorphic zones- can be distinguished: (1) biotite zone of the greenschist facies (biotite, chlorite, chloritoid); (2) almandine zone of the greenschist facies (almandine, biotite, chloritoid); and (3) staurolite-andalusite zone of the amphibolite facies (almandine, andalusite, biotite, staurolite). By combined structural and petrological analysis it appears that the three zones represent a succession in time.

The afore-mentioned mineral assemblages are representative of the lower part of the Morenos-Montesinos Formation. In the higher part of the pelite-psammite sequence, mineral assemblages occur which indicate a gradual upward decrease of the metamorphic grade. This is reflected, for example, in the presence of garnet in the lower part of the Tonosa Formation, and its absence in the higher part (Fig. 4).

The mineral assemblages, developed during the first metamorphic event, are characteristic of a metamorphism caused by an increase of temperature, under low to intermediate pressure, up to amphibolite facies (MIYASHIRO, 1973).

Second metamorphic event (M_2) – During this event the changing succession in time of mineral assemblages -described in terms of metamorphic zones- is as follows: (1) biotite zone of the greenschist facies (biotite, chlorite); and (2) chlorite zone of the greenschist facies (chlorite). During this event a retrograde metamorphism took place.

Third metamorphic event (M_3) – A third, low-pressure metamorphic event can be distinguished, during which mineral assemblages were formed, indicating the andalusite-cordierite zone of the amphibolite facies (andalusite, cordierite), and the greenschist facies (actinolite, chloritoid, talc). The minerals formed during this event are found in restricted areas, for instance in the region to the north of Somontín. They are characteristic of metamorphism under low-pressure and medium-grade temperature conditions. The cause of this metamorphism cannot yet be assessed on the basis of available data.

Deformation

During and after the metamorphic events, the Alpujarride rock sequences have been affected by several phases of deformation. For the relationship between the metamorphic events and phases of deformation the reader is referred to figure 5.

First phase of deformation (D_1) – The oldest phase of deformation is characterized by similar, tight to isoclinal folds on microscopic and mesoscopic scale, with a well developed axial-plane schistosity. At most places this schistosity is the most prominent metamorphic fabric. The folds are of the intrafolial type. The fold axes have a weak preferred orientation in WNW or ESE direction.

On microscopic scale it can be seen that during D_1 an older planar fabric has been folded. It consists of metamorphic minerals (biotite and chlorite) orientated parallel to the sedimentary bedding. No folds related with this fabric have been found and it seems most probable that it developed from a sedimentary fabric by diagenesis and metamorphism during the early stage of the first metamorphic event.

Second phase of deformation (D_2) – The second phase of deformation is represented by open to very tight folds on microscopic, mesoscopic and macroscopic scale with an axial-plane crenulation cleavage. Folds have an E or W trend and are asymmetric with a vergence towards the north where the stratigraphic succession is normal. The style of the F_2-folds and related cleavage strongly depends on the competency of the rocks. In the pelitic rocks this phase is characterized by close, angular folds, with a well developed crenulation cleavage. In the psammitic rocks concentric folds with a weakly developed crenulation cleavage are present.

During D_2 faults (T_2) have been formed on mesoscopic and macroscopic scales, subparallel to the axial planes of F_2-folds. The fault planes on mesoscopic scale are anastomosing. Along the fault planes on macroscopic scale the rocks have been strongly deformed. These faults are most obvious where medium-grade metamorphic rocks of the Morenos-Montesinos Formation overlie low-grade metamorphic rock sequences of the Estancias and Tonosa Formations. Along the macroscopic fault planes important translations took place, resulting in the superposition of a number of overthrust masses. In the western part of the Sierra de las Estancias at least three major overthrust masses are distinguished. They are, in ascending order, the Partaloa, Oria and Montroy overthrust masses. The geometry of the associated F_2-folds indicates a northerly sense of transport.

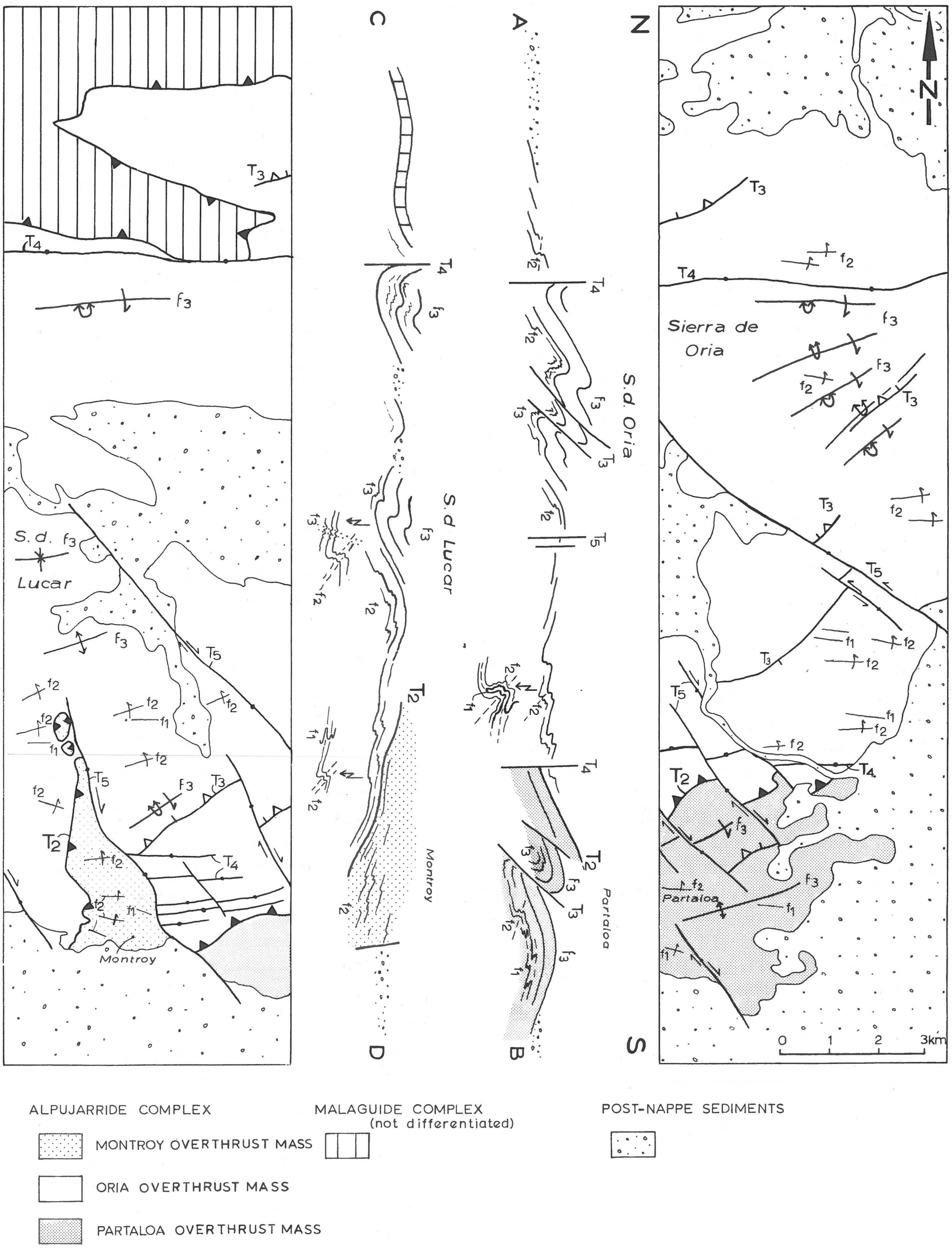


Fig. 6
Structural maps and schematic, composite cross-sections of the eastern (A-B) and western (C-D) parts of the area studied. For structural symbols see Fig. 5.

Third phase of deformation (D_3) – In a later stage of the second metamorphic event, the rock sequences have been influenced by a third phase of deformation. This phase caused open to tight, concentric folds with E-W to SW-NE trend. The folds are symmetrical or asymmetrical with N to NW dipping axial-planes (see Fig. 6, cross-sections). Especially in the Sierra de Oria and Sierra Partaloa they can be observed on a macroscopic scale. Angular folds on microscopic and mesoscopic scales, with a widely spaced axial-plane crenulation cleavage, have been developed in the cores of the macroscopic folds.

In a late stage of D_3 a number of N to NW dipping reverse faults (T_3) have been formed. They occur mainly in the overturned limbs of S- to SE-vergent F_3-folds. Displacements along these faults are of the order of some tens of metres.

The third phase of deformation has not affected the post-nappe deposits of Tortonian age (Mr. W. Dubelaar, pers. comm.).

Fourth phase of deformation (D_4) – This phase is characterized by a system of E-W trending, subvertical faults (T_4). Disharmonic folds and kinkbands on mesoscopic and microscopic scale developed simultaneously with, and in the direct neighbourhood of, these faults. On the basis of the geometry of the folds and kinks, it can be concluded that movements along these faults were essentially vertical. Some examples of T_4-faults are:

(1) The E-W trending fault north of the Sierra de Oria. This fault can be traced over a distance of at least 20 kilometres, and separates rocks of the Estancias Formation from rocks of the Morenos-Montesinos Formation. Locally, rocks of the Tonosa Formation are found in this fault zone.

(2) The E-W trending fault zone north of Somontín. In this region the fault zone is characterized by the occurrence of large quantities of talc. This mineral has been formed in a late stage of M_3.

Fifth phase of deformation (D_5) – During the last phase of deformation NNW trending subvertical faults (T_5) were formed. They are wrench-faults, mostly with dextral displacements of the order of some hundreds of metres. They affected also the post-nappe sediments of Tortonian and younger age.

CONSIDERATIONS ON THE TECTONO-METAMORPHIC EVOLUTION

Up to now, a systematic study of the tectono-metamorphic evolution of the Alpujarride rock sequences outside the Sierra de las Estancias has only been made in a small number of areas. It has been essentially based on the relation between metamorphic minerals and deformational structures in thin sections.

From the regions to the north of the Sierra Nevada and Sierra de los Filabres, NAVARRO-VILA (1976) and DELGADO (1978) described low- to medium-grade Alpujarride rock sequences. On the basis of successively formed mineral assemblages they concluded that metamorphism, up to amphibolite facies, resulted from an increase of temperature under intermediate-pressure conditions, followed by a decrease of pressure without a significant loss of temperature. This metamorphism can be correlated with the first metamorphic event (M_1) in the Sierra de las Estancias.

In the westernmost Internal Zone (Serrania de Ronda), low- to medium-grade Alpujarride rocks, as well as high-grade Alpujarride rocks occur. These rocks form part of polymetamorphic aureoles, caused by the not emplacement, during the alpine orogeny, of ultramafic rocks (peridotites) from the upper mantle into the crust. Metamorphic conditions in the contact zone of the composite aureole series changed from HP-HT to LP-HT (WESTERHOF, 1977). On basis of radiometric age determinations, PRIEM et al. (1979) concluded that the hot emplacement of the ultramafic masses in the Serrania de Ronda terminated in the Late Oligocene/Early Miocene.

Outcrops of ultramafic masses in the Serrania de Ronda and also in northern Morocco (Beni Bousera) coincide with positive Bouguer anomalies (Fig. 7). Ridges of positive anomalies continue eastwards along the Moroccan and Spanish coasts. The latter correspond with outcrops of Alpujarride rocks in the southern Internal Zone. According to WESTRA (1969; Sierra Cabrera) and TORRES-ROLDAN (1974; Sierra de Almijara) metamorphism in these rocks resulted from an increase of temperature towards high temperature under intermediate pressure, followed by a decrease of pressure. This metamorphic evolution shows strong affinities with that of the aureole rocks of the Serrania de Ronda, indicating that it was probably also controlled by ultramafic intrusions.

In view of the similar metamorphic evolution of the Alpujarride rock sequences to the north of the Sierra Nevada and Sierra de los Filabres, it seems that the metamorphism in this part of the Internal Zone is likewise related to the intrusion of ultramafic rocks. In order to explain the lower metamorphic grade of the Alpujarride rock sequences in the northern Internal Zone, we suggest that they represent the outer parts of the aureoles.

After this period of metamorphism a major phase of overthrusting took place in the Alpujarride Complex (a.o. ALDAYA, 1969; TORRES-ROLDAN, 1974; NAVARRO-VILA, 1976; DELGADO, 1978). This phase can be correlated with the T_2 overthrusts from the Sierra de las Estancias. They led to the superposition of a number of Alpujarride overthrust masses, usually referred to in literature as 'Alpujarride units' of 'nappes'. The overthrust masses differ in lithostratigraphic development and grade of metamorphism. Up to now a satisfactory correlation between the different overthrust masses, the number of which varies from region to region, has not been established.

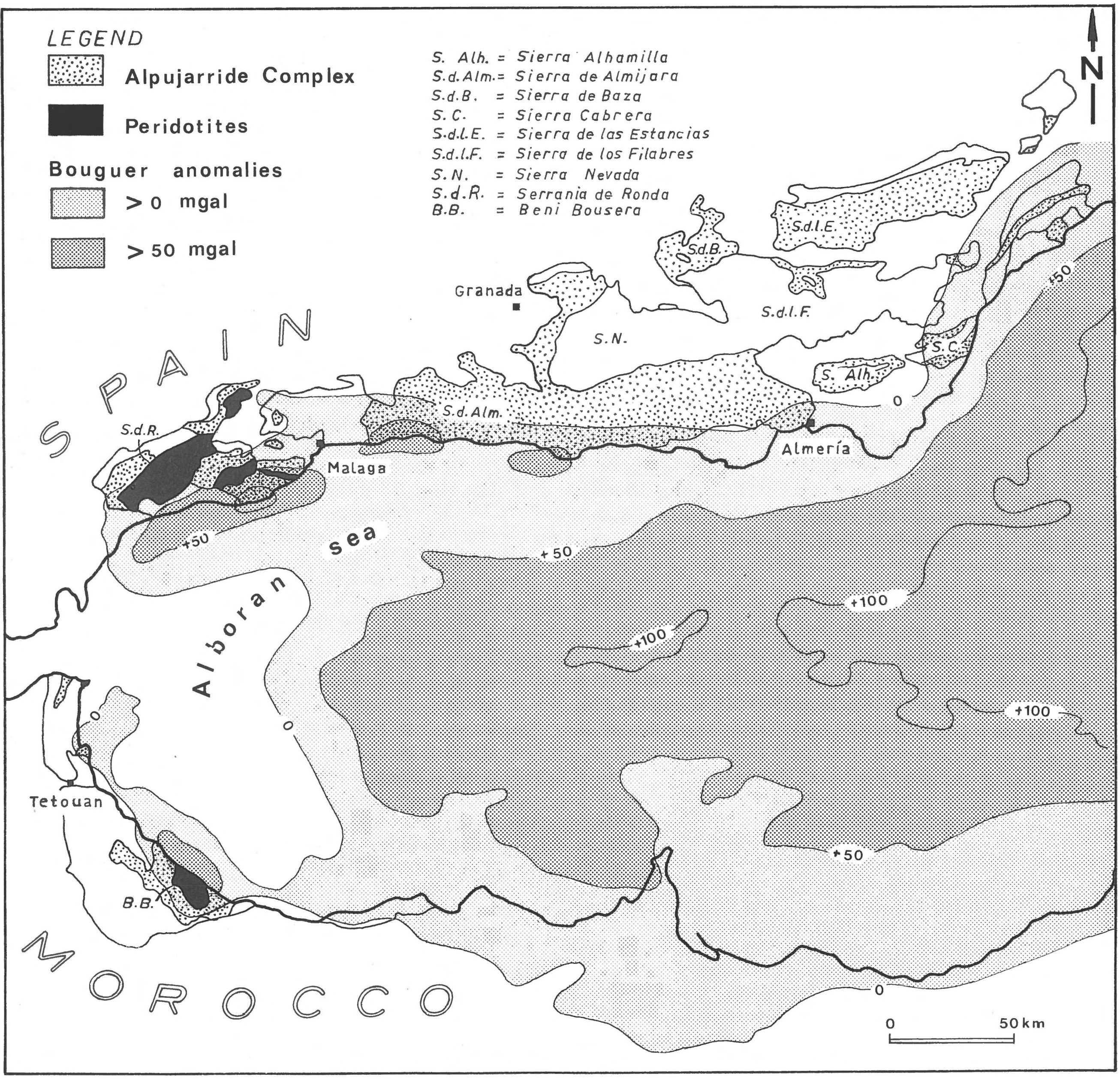


Fig. 7
Map showing positive Bouguer anomalies (after Van den Bosch, 1974) in relation to the distribution of ultramafic rocks (peridotites) and Alpujarride rock sequences.

On the basis of geometry of associated folds we have concluded that the T_2 overthrusts had a northerly sense of transport. In the Sierra de Baza DELGADO (1978) arrived at the same conclusion on the basis of similar criteria.

In the Sierra Alhamilla the lowest Alpujarride overthrust mass is a macroscopic north-closing, recumbent, isoclinal fold with a highly attenuated lower limb. This geometry has been demonstrated by PLATT (1979) using small-scale structures, and indicates a northerly sense of transport.

In the northern Betic Zone, NAVARRO-VILA (1976) and DELGADO (1978) described S-vergent folds and reverse faults which have been formed after the final emplacement of the Alpujarride overthrust masses. They can be most probably correlated with the folds and reverse faults of the third phase of deformation in the Sierra de las Estancias.

Elsewhere in the Internal Zone no metamorphism has been described which can be correlated with the third metamorphic event in the Sierra de las Estancias.

Summarizing we are of the opinion that:

(1) The Alpujarride rocks of the Sierra de las Estancias were metamorphosed due to the intrusion of hot ultramafic masses as described by WESTERHOF (1977). They represent the outer parts of the polymetamorphic aureoles.

(2) After the intrusion which terminated in the Late Oligocene/Early Miocene, the Alpujarride rocks were transported to their present position in the Sierra de las Estancias.

(3) In the Sierra de las Estancias the Alpujarride overthrust masses were deformed during the third phase of deformation and locally metamorphosed during the third metamorphic event, before the deposition of post-nappe sediments of Tortonian age.

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REFERENCES

Aldaya, F. 1969 Los mantos alpujárrides al Sur de Sierra Nevada-Thesis Univ. Granada: 527 pp.

Delgado, F. 1978 Los Alpujárrides en Sierra de Baza (Cordilleras Béticas, España) – Thesis Univ. Granada: 483 pp.

De Vries, W. C. P. & K. B. Zwaan 1967 Alpujarride succession in the Central Sierra de las Estancias, province of Almería, SE Spain – Proc. Kon. Ned. Akad. Wetensch. 70: 443-453.

Egeler, C. G. & O. J. Simon 1969 Orogenic evolution of the Betic Zone (Betic Cordilleras, Spain), with emphasis on the nappe structures – Geol. Mijnbouw 48: 296-305.

Fallot, P., L. Solé Sabaris & L. Lemoine 1954 Observations sur le Trias Bétique et ses Algues Calcaires – Mem. Comuns. Inst. Geol. Barcelona 11: 23-60.

Geel, T. 1973 The geology of the Betic of Málaga, the Subbetic and the zone between these two units in the Vélez Rubio area (southern Spain) – GUA Pap. Geol. 1 (5): 179 pp.

I. G. M. E. (in press, a) Mapa geológico de España, 1:50.000, Hoja Cantoria (23-40).

—— (in press, b) Mapa geológico de España, 1:50.000, Hoja Vélez Rubio (24-39).

Kampschuur, W., C. W. Langenberg & H. E. Rondeel 1973 Polyphase Alpine deformation in the eastern part of the Betic Zone of Spain – Estud. Geol. 29: 209-222.

Kampschuur, W. &. H. E. Rondeel 1975 The origin of the Betic orogen, southern Spain – Tectonophysics 27: 39-56.

Kozur, H., W. Kampschuur, C. W. Mulder-Blanken & O. J. Simon 1974 Contribution to the Triassic ostracode faunas of the Betic Zone (southern Spain) – Scripte Geol. 23: 1-56.

Miyashiro, A. 1973 Metamorphism and metamorphic belts – George Allen & Unwin (London): 492 pp.

Navarro-Vilá, F. 1976 Los mantos alpujárrides y maláguides al Norte de Sierra Nevada (Cordilleras Béticas, Andalucia) – Thesis Univ. Granada: 288 pp.

Ott, E. 1972 Zur Kalkalgen-Stratigraphie der Alpinen Trias – Mitt. Ges. Geol. Bergbaustud. Österr. 21: 455-464.

Platt, J. P. 1979 Emplacement of the Alpujarride Nappe, Sierra Alhamilla, S. E. Spain – Abstr. Tectonics Studies Group, Meeting Nottingham (Dec. 1979).

Priem, H. N. A., N. A. I. M. Boelrijk, E. H. Hebeda, I. S. Oen, E. A. Th. Verdurmen & R. H. Verschure 1979 Isotopic dating of the emplacement of the ultramafic masses in the Serrania de Ronda, Southern Spain – Contrib. Mineral. Petrol. 70: 103-109.

Simon, O. J. & H. Kozur 1977 New data on the (Permo-) Triassic of the Betic Zone (southern Spain) – Cuad. Geol. Ibérica 4: 307-322.

Torres-Roldán, R. L. 1974 El metamorfismo progresivo y la evolución de la serie de facies en las metapelitas alpujárrides al S. E. de Sierra Almijara (Sector central de las Cordilleras Béticas, S. de España) – Cuad. Geol. 5: 21-77.

—— 1979 The tectonic subdivision of the Betic Zone (Betic Cordilleras, southern Spain): its significance and one possible geotectonic scenario for the westernmost Alpine belt – Amer. J. Sci. 279: 19-51.

Van den Bosch, J. W. H. 1974 Quelques principes généraux de l'interprétation gravimétrique illustrés par des exemples empruntés à la carte gravimétrique du Maroc (structure du Rif et intrusions granitiques au Maroc central) – Notes Serv. géol. Maroc 35 (255): 117-136.

Westerhof, A. B. 1977 On the contact relations of high-temperature peridotites in the Serrania de Ronda, southern Spain – Tectonophysics 39: 579-591.

Westra, G. 1969 Petrogenesis of a composite metamorphic facies series in an intricate fault-zone in the south-eastern Sierra Cabrera, SE Spain – Thesis Univ. Amsterdam: 166 pp.