

The Mulhacen and Alpujarride Complex in the eastern Sierra de los Filabres, SE Spain: Litho-stratigraphy

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Abstract

The litho-stratigraphy of the Mulhacen and Alpujarride Complex, in the eastern Sierra de los Filabres, is described in detail. Well defined litho-stratigraphic units can be traced for tens of kilometres along strike, despite the complicated tectono-metamorphic history.

The Mulhacen Complex comprises three thrust-sheet units, formed by crustal-scale underthrusting. The thrust-sheets are composed of a dark-coloured series of Paleozoic age, covered by light-coloured metasediments of Triassic age. The most extensively developed unit from the Mulhacen Complex is the Nevado-Lubrin unit. The clastic base of the Triassic series is covered by a sequence dominated by carbonates. These basal clastics probably represent shelf deposits in an open marine environment. The overlying carbonate sequence marks an abrupt transition to a lagoonal environment, with reef and littoral facies. This abrupt facies shift might have been caused by regional crustal extension.

The Alpujarride Complex contains two tectonic units of light-coloured metasediments of Triassic age.

Introduction

The Sierra de los Filabres forms part of the Internal Zone of the alpine fold- and thrust-belt of southern Spain. The Internal Zone is dominated by large-scale overthrust units which are composed of dark-coloured Paleozoic and light-coloured mainly Triassic metasediments. The units are commonly grouped into four thrust sheet complexes (Fig. 1), based on differences in tectono-metamorphic evolution. In order of tectonic superposition: 1) the Veleta Complex, 2) the Mulhacen Complex, 3) the Alpujarride Complex, and 4) the Malaguide Com-

plex (Egeler & Simon 1969, Puga & Diaz de Federico 1978, Bakker et al. 1989).

In the northeastern part of the Internal Zone, Alpujarride thrust units overlie the Almagrider Complex, which shows strong stratigraphic affinities with Middle to Late Triassic rocks of the Subbetic of the eastern External Zone (Simon 1987; Fig. 1).

The P-T-t paths of the Mulhacen Complex and the Alpujarride Complex as discussed in this paper, reflect the essential features of the alpine tectonic evolution of the Betic Cordilleras (Bakker et al. 1989). Continental collision resulted in under-

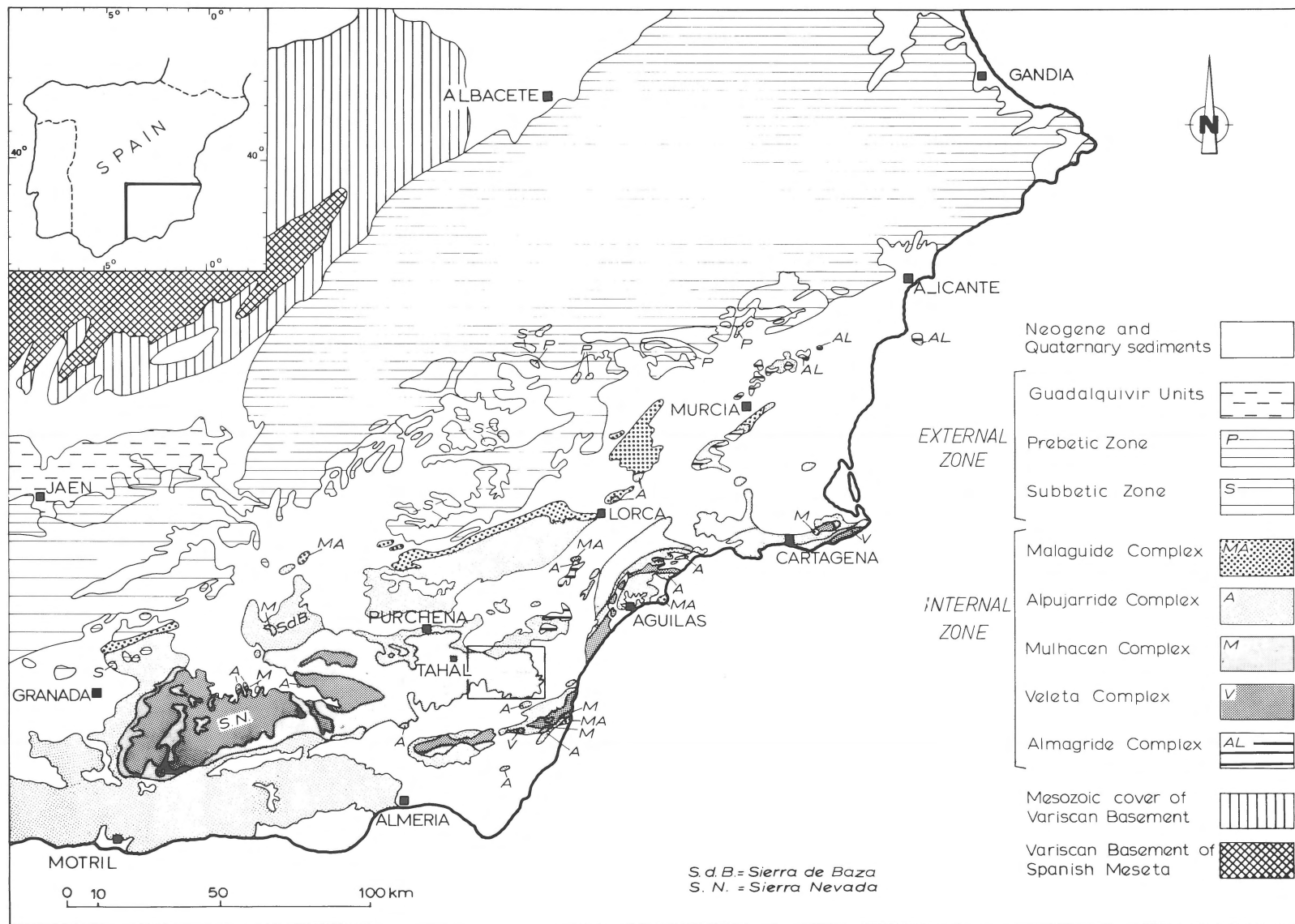


Fig. 1. Tectonic sketch map of the eastern Betic Cordilleras, showing the distribution of the major tectonic complexes, after Bakker et al. (1989). The studied area is outlined.

thrusting of the two Complexes to respectively 37 and 27 km depth, as expressed by HP/LT metamorphism. At these depths the first two phases of penetrative deformation took place (D_{x-1} and D_x). These are related to large scale thrust movements during continuing convergence. For this evolution a Cretaceous age is suggested. Late Oligocene to Early Miocene tectonics are characterized by heterogeneous extension and crustal thinning (D_{x+1}), which resulted in superposition of the Alpujarride Complex directly on top of the Mulhacen Complex. This extension might have been related to the earliest stage of continental rifting and ocean floor spreading, that affected the western Mediterranean from the Oligocene onwards. Subsequent folding and overthrusting (D_{x+2} and D_{x+3}) strongly modified the original superposition of tectonic units. Despite this complicated tectonic evolution, well-defined lithostratigraphic units from the Mulhacen and Alpujarride Complexes can be traced for several tens of kilometres in the Sierra de los Filabres.

The Mulhacen Complex in the area of the Sierra de los Filabres consists of three major thrust sheet units (Encl. I, II (inserted in the back of this issue); Fig. 2), which were formed during the earliest phase of penetrative ductile deformation (Bakker et al. 1989). These units are, in ascending order: 1) the Nevado-Lubrin Unit, 2) the Macael-Chive Unit and 3) the Huertecicas Altas-Almocaizar Unit (Helmers & Voet 1967, Bakker et al. 1989). On outcrop scale the tectonic contacts are parallel to the lithological layering. On a regional scale, however, the contacts truncate the layering as observable in the central part of the map area (Encl. I). The main planar structure is a transposition foliation parallel to the lithological layering. Deformed plagioclase porphyroclasts in metabasites on average demonstrate 75% flattening perpendicular to this foliation. The consequence of this deformation is that the original thickness of the sedimentary sequence might be four times larger than presently measured.

The Alpujarride Complex in the mapped area comprises two tectonic units, the Almanzora Unit and the Variegato Unit. These rocks also contain a

transposition foliation, parallel to the lithological layering with associated stretching lineations.

The lithostratigraphy and areal distribution of the rock sequences in the eastern Sierra de los Filabres will be described in this paper. In addition the depositional environment will be sketched for the top sequences of inferred Triassic age of the Mulhacen Complex.

Litho-stratigraphy

Mulhacen Complex

The three thrust sheet units of the Mulhacen Complex consist of a basal sequence of dark-coloured, graphite-rich clastics, covered by a top sequence of mainly light-coloured clastic rocks with calcareous intercalations. The rocks have not yielded any age diagnostic fossils. The basal sequences, of the two highest tectonic units, contain bodies of alpine gneissified granites, which yielded Permian ages (Priem et al. 1966, Andriessen et al. in press), indicating an older age for the country rocks. Lithological and geochemical correlations (Bakker & De Jong 1985) with metasedimentary rocks of the Veleta Complex, which contain Eifelian fossils (Lafuste & Pavillon 1976), make a Paleozoic age for the basal sequences of all three units most likely.

The gneissified granite and associated pegmatites in the country rock from the Macael-Chive Unit are locally directly covered by light-coloured clastics of the top sequence. The lower levels of the top sequence of the Nevado-Lubrin Unit contain detritus of granitic source, suggesting a post-Permian age. Based on geochemical similarities (Bakker & De Jong 1985) and a lithological correlation with biostratigraphical-dated rocks from the Alpujarride Complex (Simon 1987) a Triassic age is suggested for the marble containing top sequence of the tectonic units within the Mulhacen Complex.

Nevado-Lubrin Unit. The Paleozoic of the Nevado-Lubrin Unit (Velefique Schists; Fig. 2) is not exposed in the map area. The Triassic part consists

MULHACEN UNITS

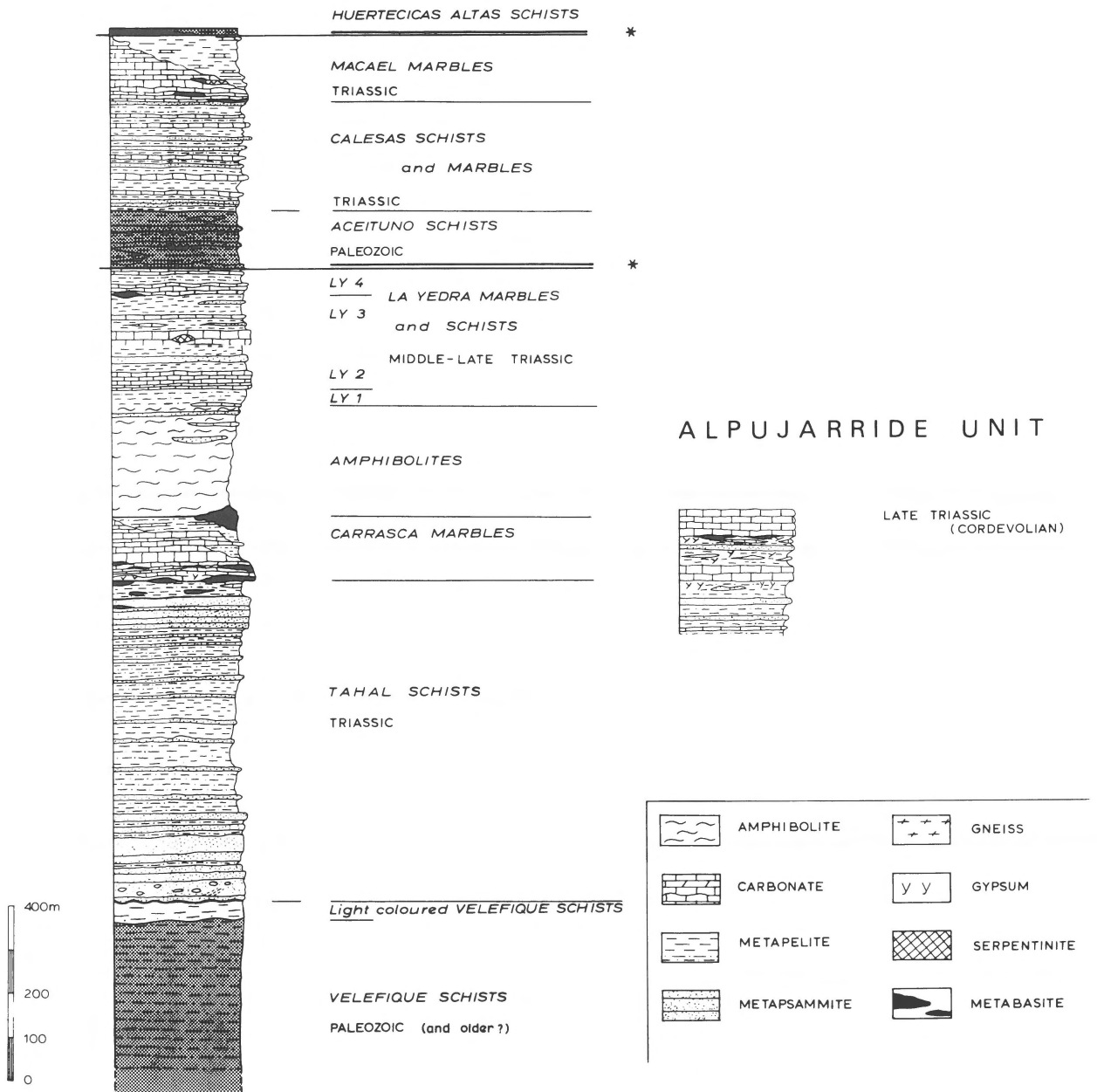


Fig. 2. Columnar sections of the litho-stratigraphy of the Mulhacén Units (Nevado-Lubrin, Macael-Chive and Huertecicas Altas-Almocaizar Unit) and of the Alpujarride Unit (Almanzora Unit) in the eastern Sierra de los Filabres.

of quartzites and micaschists (Tahal Schists) overlain by a sequence characterized by thick marble layers with intercalations of quartzites, schists and amphibolites (Carrasca Marbles and La Yedra

Marbles and Schists). Both sequences have been intruded by mafic and ultramafic rocks. However, by far the largest occurrences of these intrusives are

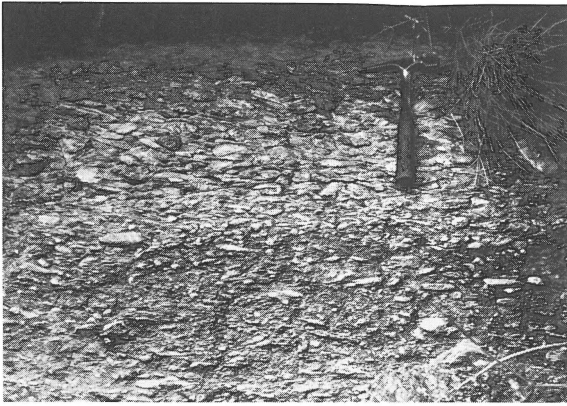


Fig. 3. Detail of deformed conglomerate lens in the lower part of the Tahal Schists (outcrop along road Tahal-Macael).

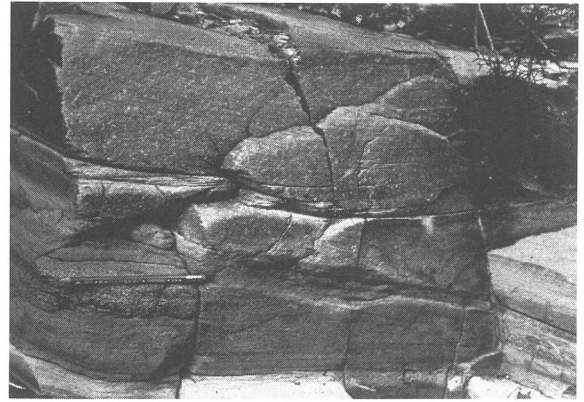


Fig. 4. Decimetre scale low-angle cross-bedded merge in white quartzites from the lower part of the Tahal Schists.

concentrated in the thin transition zone between both sequences (Fig. 2).

The total tectonic thickness, which is defined as the thickness perpendicular to the main tectonic foliation, amounts to 500–700 metres for the *Tahal Schists* (Nijhuis 1964). The lower part of the Tahal Schists consists of a sequence of thick-bedded quartzites, locally with lenses of strongly deformed metaconglomerate, which are not larger than several metres. The clast or matrix supported conglomerate is composed of quartzite and chert pebbles in a quartz-feldspar-biotite matrix (Fig. 3). The quartz is typically blue-coloured rutile-quartz of magmatic origin. This sequence is exposed just west of the mapped area, near Tahal (Fig. 1). It gradually changes upwards into a sequence of grey-blue, locally garnet-bearing, micaschists and quartzitic micaschists with thin quartzite intercalations. Towards the top, the quartzite layers become increasingly dominant. They mark the gradual transition to a quartzite series with some marble intercalations, the upper part of which consists of white coloured, almost pure quartzites. These beds usually form the top of the Tahal Schists. Locally they are covered by chloritoid garnet micaschists with yellow-brown marble intercalations.

Sedimentary structures are only scarcely preserved, due to severe deformation. In white quartzites from the lower part of the Tahal Schists a dm-scale low-angle cross-bedded merge has been observed (Fig. 4). The beds show swelling and

thinning and contain no slip faces. In the lower part of the overlying schist sequence an alternation of quartz and mica bands has been detected which resembles linsen and flaser structures. The white quartzites from the top of the Tahal Schists contain low-angle cm-scale cross lamination (Fig. 5) of non-elongated, short sets, that show a saucer shape in all directions. The laminae point to non-preferential current directions. Segregated laminae of heavy minerals and quartz indicate a high degree of mechanical sorting (Th. B. Roep, pers. comm.).

The *Carrasca Marbles* consist of calcite and dolomite marbles, calcareous schists, micaschists and garnet micaschists. These lithologies show rapid lateral and vertical variations. The Carrasca Marbles attain a maximum tectonic thickness of 150 metres. Most characteristically it is developed as a massive marble series. The lower part is composed of brown-grey to black coarse-grained marbles and brown calcareous schists. The marbles exhibit a conspicuously protruding mica lamination curving around carbonate boudins. The upper part is composed of coarse-grained, light-coloured almost pure calcite marbles. The entire marble sequence has been dolomitized to a varying extent, especially in the upper parts.

The lateral equivalent of the massive marbles is formed by black-coloured, fine-grained garnet micaschists with intercalated calcite and dolomite marbles. The graphite content of the schists varies laterally. Dark grey to black graphite-rich mica-

schists grade into graphite-free silver-grey coloured schists. Within the schists laminated gypsum occurs locally.

The Carrasca Marbles were previously included in the Huertecicas Brecciated Marble Zone (Nijhuis 1964, Langenberg 1972). They were considered to be the original stratigraphic cover of the underlying Tahal Schists (Linthout & Vissers 1979). This is confirmed by the present study. In the surroundings of Cobdar in particular, it can be observed that metabasite bodies have intrusive contacts with both the Tahal Schists and the Carrasca Marbles. However, in general the contact with the Tahal Schists is tectonic and is formed by a thick breccia layer, generated during D_{x+2} and further modified during D_{x+3} (Bakker et al. 1989). There are no indications that the contact acted as a detachment zone already during earlier deformation. Since the displacement along this contact is minor with respect to displacements along the D_{x-1} and D_{x+1} boundaries, it is considered unnecessary to further subdivide the Nevado-Lubrin Unit in distinct tectonic units, as suggested by Linthout & Vissers (1979).

The Carrasca Marbles are stratigraphically covered by the *Muñoz Amphibole Micaschists* (Nijhuis 1964), with a maximum thickness of 150 m. This series is dominated by albite-epidote amphibolites and amphibole micaschists. The schists show a compositional banding defined by epidote, amphibole and mica. Relict magmatic minerals have not been found. The upper part of the sequence contains an increasing number of marble and quartzite intercalations, marking the stratigraphic transition of the overlying La Yedra Marbles and Schists. Nijhuis (1964) suggested that the occurrence of metasedimentary intercalations and the high Ti-content of the amphibole micaschists point to a tuffaceous origin. Strongly sheared mafic intrusives of younger age, intruded in the metavolcanic rocks, have been included in the formation.

The *La Yedra Marbles and Schists* are composed of a 300 m thick alternation of marbles, schists and quartzites. This sequence includes, in its lower part, the Las Casas Marbles and Schists of Nijhuis (1964). Due to the remarkably constant stratigraphy and excellent exposure, the La Yedra se-



Fig. 5. Centimetre scale cross lamination in white quartzites from the upper part of the Tahal Schists. Sample collected by H.J. Nijhuis along road Lubrin-Uleila del Campo.

quence can be subdivided into four mapable units, in ascending order La Yedra 1 to 4, on the basis of characteristic marble horizons.

La Yedra 1 consists of dark grey-brown garnet micaschists and garnet-bearing calcareous micaschists with marble and quartzite intercalations. The basal part is composed of green-coloured epidote- and chlorite-bearing micaschists marking the gradual transition to the *Muñoz Amphibole Micaschists*. *La Yedra 2* consists of a lower series of platy, dark grey calcite marbles with intercalations of calcareous micaschists, grading upwards into a micaschist sequence with an intercalated white quartzite layer. The thickness of the marble series varies from 30 m in the western part to only a few metres in the eastern part of the studied area. *La Yedra 3* consists of a lower massive series of coarse-grained quartz- and mica-rich calcite and dolomite mar-

bles. The calcite marbles are blue-grey in colour with a white lamination. The series attains a maximum thickness of 20 m but abruptly dies out to the east and northeast. It is covered by a series of mica schists and chlorite schists with quartzite intercalations, marked by marble intercalations in the top and the lower parts. Due to the wedging out of the basal marble series, this unit can not be identified in the eastern part of the area. In that region the meta-siliclastic series of La Yedra 2 and 3 are mapped together, and the basal marble series of La Yedra 2 has been mapped separately as La Yedra 2' (Encl. I, Fig. 7). The base of *La Yedra 4* is marked by a 10–30 m thick marble sequence, which contains a conspicuous light-coloured dolomite marble layer of varying thickness. The marbles are covered by an alternation of chloriteschists, mica-schists and quartzites with marble layers in the lower parts.

Intrusives. The metasediments of the Nevado-Lubrin Unit are intruded by a group of rocks including olivine gabbros, blastophytic metabasites (when sheared transformed into foliated albite-epidote amphibolites) and serpentinites. These intrusives, that generally have preserved their magmatic texture, are largely concentrated in the transition zone between the Tahal Schists and Carrasca Marbles. Bodies have been found varying from one metre to several kilometres. Minor intrusives (mainly serpentinites) occur in the La Yedra 3 and 4. The intrusive nature of these rocks is indicated by cross-cutting contacts with the lithological layering of the metasediments, by apophyses and chilled margins (Fig. 6; Nijhuis 1964). The contacts are locally formed by albitites developed in the metabasites, whereas surrounding marbles suffered considerable Fe-enrichment. These contact rocks suggest the activity of localized metasomatic processes associated with the intrusion (Bicker 1966). Part of the mafic rocks, might have been intruded near the surface of the earth. This is suggested by fine-grained metabasites with flow structures of plagioclase crystals, carbonate-filled amygdals and cooling joints.

Non-altered troctolitic gabbro exhibits a cumulitic texture of anhedral to subhedral olivine,



Fig. 6. Apophyse of mafic rock (dark colour) in light-coloured Carrasca Marble (outcrop along road Lubrin-El Chive).

zonal plagioclase (An₇₀₋₄₇), apatite and ilmenite. Ti-augite, magnesio-kearsutite and biotite are present as intercumulus phase. Blastophytic metabasites locally contain relict magmatic minerals, including brown and green hornblende, clinopyroxene, biotite, plagioclase and apatite. However, these rocks are in general entirely composed of metamorphic mineral assemblages. The serpentinites frequently contain abundant pyroxene pseudomorphs and rare relict clino- and orthopyroxene. A troctolitic gabbro body has yielded a 146 ± 3 Ma Rb/Sr age (Hebeda et al. 1980), indicating a Late Jurassic age for the intrusion.

Macael-Chive Unit. The Nevado-Lubrin Unit is tectonically covered by the Macael-Chive Unit (Fig. 2). The tectonic character of the contact is expressed by a regional truncation of the lithological layering in the underlying La Yedra sequence (Encl. I). In the eastern part of the area the contact is with La Yedra 4; in the southeastern and western part it is with La Yedra 2 and 3 respectively. Within the Macael-Chive Unit three litho-stratigraphic units have been distinguished, in ascending order: 1) the Aceituno Schists, 2) the Calesas Schists and Marbles and 3) the Macael Marbles.

The *Aceituno Schists* consist of a monotonous series of graphite-bearing quartzitic mica-schists with quartzite and marble intercalations. The dark grey- to black-coloured schists are garnet-rich and typically devoid of albite. The series contains two

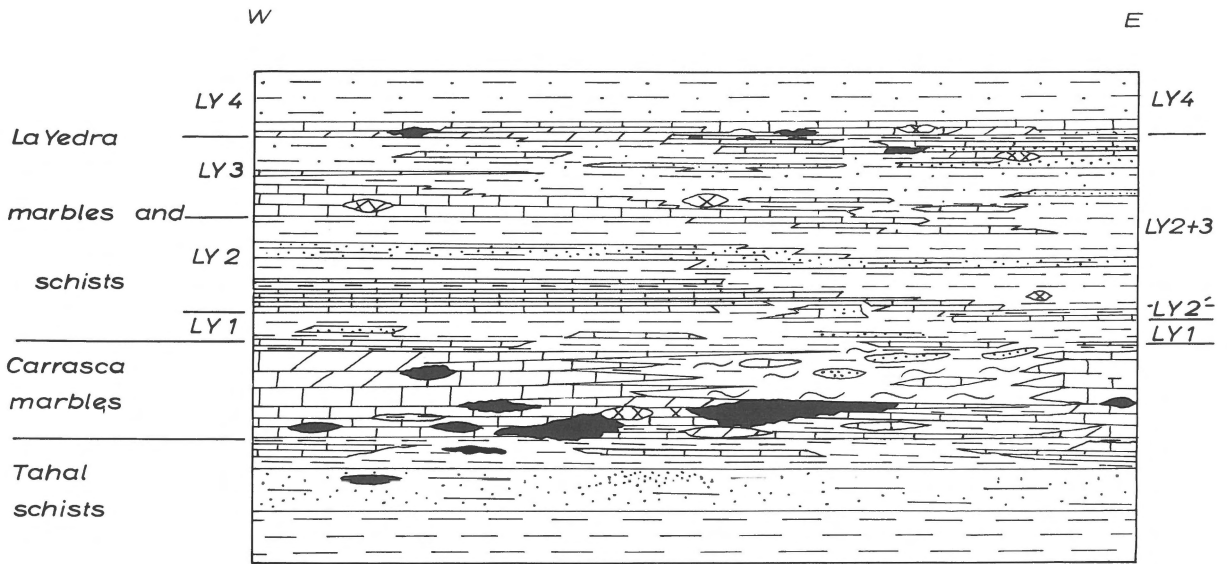


Fig. 7. Cartoon-like section illustrating the lateral distribution of the Carrasca Marbles, Muñoz Amphibole Micaschists (amphibolite notation), La Yedra Marbles and Schists and intrusives. Note the gradual eastward disappearance of the basal marble unit of La Yedra 3. Legend as in Fig. 2.

marble-rich sequences of approximately 10–15 m thick, one in the basal part and one in the upper part. The marbles are rich in detrital quartz and mica; they are grey-coloured and contain a cm- to dm-thick banding of varying graphite content. The schists of the upper part of the series are light-coloured and contain less garnet than their dark-coloured equivalents. The boundary between dark- and light-coloured schists is oblique to the marble sequence. In the easternmost part of the area it is located below the upper marble sequence; in the western part it is above this sequence.

The Aceituno schists have been intruded by granite of Permian age (Priem et al. 1966, Andriessen et al. in press). The granite is rich in tourmaline, accessory apatite, and locally contains abundant fluorite and topaz (Nijhuis 1964). Petrological analyses indicate that the rock represents a subsolvus granite, which crystallized at 2.5–3 kbar and 650°C. Associated skarn and calcsilicate hornfels bodies in the country rock point to intrusion conditions of 4 kbar and 575°C (Helmerts, pers. comm.). Due to severe alpine deformation a penetrative tectonic fabric developed and the granite has been nearly completely transformed into augen to even-grained gneiss. As a result the contact between the

gneiss and country rock is parallel to the main tectonic foliation S_x .

The *Caleas Schists and Marbles* consist of an alternation of quartzites, quartzitic micaschists, (chlorite)-micaschists and marbles, which unconformably overlie the Aceituno Schists. In particular in the area near Bedar the Caleas Schists and Marbles truncate and directly cover the orthogneisses and associated pegmatites (Helmerts, pers. comm.). The tectonic thickness of this alternation amounts to about 200–250 metres. The lower part is formed by platy light-coloured quartzites. The micaschists are commonly garnet-bearing and contain albite. Marbles and calcareous micaschists become predominant towards the top of the sequence.

This series marks the gradual transition to the 150 m thick *Macael Marbles*, the lower part of which is composed of well-bedded, grey- to blue-coloured marbles with intercalations of micaschists and quartzites. It grades upwards into massive to thick-bedded, light-coloured calcite and dolomite marbles. Coarse-grained, pure calcite marbles are extensively quarried near Macael just West of the studied area. The upper part of the series consists of calcareous garnet micaschists with minor marble

intercalations. Within the Macael Marbles there is a lateral transition of a single marble sequence into an alteration of calcareous garnet micaschists, marbles and quartzites. It is suggested that this transition is an original depositional feature.

Bodies of metabasites, metagabbros and serpentinites are locally present in the Macael Marbles. It is remarkable that the largest bodies are only present in alternations of well-bedded marbles and schists. In the massive-bedded marbles only small bodies occur.

Huertecicas Altas – Almocazar Unit. This unit is composed of albite- and biotite-rich augen gneisses associated with tourmaline-rich quartzites, graphite-bearing quartzitic garnet-micaschists, garnet-bearing epidote amphibolites and metabasites. In the southeastern part of the area gneisses are associated with calcsilicate contact rocks and marbles. Gneisses yielded a 267 ± 53 Ma Rb/Sr whole rock age (Andriessen et al. in press). This sequence is overlain by a succession of light-coloured albite-bearing micaschists and quartzites with marble intercalations.

Alpujarride Complex

The Alpujarride Complex is represented by two tectonic units, the Almanzora Unit and the Variegato Unit, which are exposed as a discontinuous band in the northern part of the area (Encl. I). This discontinuity is mainly due to D_{x+2} and D_{x+3} deformation (Bakker, in press), which produced relatively minor thrust sheets. As a result, the original litho-stratigraphy has been disrupted and the description hereafter is a compilation of several exposed sequences.

Almanzora Unit. The lowermost part of this unit (Fig. 2) consists of an alternation of light-coloured quartzites and grey to green phyllites to schists. The top contains intercalations of marbles and gypsum. A characteristic 8–15 m thick horizon of light-coloured quartzites is developed in this sequence. The quartzites exhibit swelling and thinning of the layers, cross lamination and bioturbation. This

metasiliclastic sequence is overlain by a 25–35 m thick marble series with intercalated phyllites and gypsum. Locally a conspicuous marble with dark grey to black carbonate nodules is present. In the Sierra de Almagro this carbonate has yielded the ostracod *Reubenella fraterna* (Reuss) (Van den Berg et al. 1987) indicative of a Cordevolian age (Kozur et al. 1974). This series is covered by a succession of phyllites, quartzites, marbles and gypsum. Metabasites occur mainly within the gypsum levels. These rocks contain a blastophytic texture of blue-green amphibole and plagioclase. Relict mafic magmatic minerals comprise brown hornblende and minor augitic pyroxene. Magmatic plagioclase is usually recrystallized to albite, sericite and saussurite. The plagioclase locally preserves a complex zonality inherited from the magmatic stage.

Variegato Unit. This unit is composed of a 60 metres thick succession of phyllites, gypsum, marbles and minor amounts of garnet-bearing micaschists. The micaschists might represent part of the Paleozoic sequence. The most distinctive horizon from this unit is formed by a phyllite sequence, which can be easily recognized because of its purple colour. The lower part of the Variegato Unit consists of brown, blue and purple phyllites with some quartzite intercalations and minor garnet-bearing micaschists. This series is overlain by 40 m of layered gypsum, with ochre-coloured limestones in the top. It contains lenses of fine-grained metabasite, varying in size from several centimetres up to several hundreds of metres. The metabasites locally contain carbonate-filled amygdaloids, which together with plagioclase crystals and opaques define a magmatic flow structure, indicating that at least part of the metabasites represent extrusive rocks.

Carbonates of the light-coloured top sequence of the Variegato Unit have been dated as Middle to Late Triassic by micro flora and fauna (Simon 1987). These rocks have been deposited in a shallow marine sea with waterdepths less than 150–100 m and generally in the order of 30–0 m (Simon & Kozur 1977). Hypersaline conditions are indicated by the occurrence of gypsum.

Depositional environment

The intrusion conditions of the granites in the Aceituno Schists indicate a cover of 6–10 km pre-Permian rocks. The Calesas Schists, of inferred Triassic age, rest locally directly on these granites. Deposition of these sediments has therefore been preceded by important erosion. It is suggested that the light-coloured graphite-poor schists in the uppermost Aceituno Schists, represents a paleo-weathering zone. Such a weathering zone has also been described for the top of the Paleozoic series (Velefique Schists) of the Nevado-Lubrin Unit by Linthout & Vissers (1979). The arkosic matrix of the conglomerates above this zone indicates erosion of granitic source rock, possibly similar to the Permian granites in the Macael-Chive and Huertecicas Altas-Almocaizar Units. The erosion products and the presence of a weathering zone indicate uplift and continental erosion before deposition of the Tahal Schists.

The small size of the conglomerate lenses in the quartzitic lower part of the Tahal Schists suggests deposition by braided rivers. Their limited occurrence excludes deposition as beach conglomerates. The hummocky cross-stratification in the quartzites in a higher level indicates shallow marine conditions. The upward change into micaschists represents a transgressive series with shelf muds deposited on coastal sands. Linsen and flaser structures from the lower part of these micaschist sequence indicate wave action, and a water depth of several tens of metres.

The upper part of the Tahal Schists is characterized by a regressive series with a coarsening upward trend and increasing mechanical sorting. The white quartzites in the top with variably oriented small-scale cross lamination, indicate high energy conditions and probably wave action, implying deposition above wave base (20–25 metres).

The predominant carbonatic deposition on top of the Tahal Schists might reflect the transition from an open marine into lagoonal environment. It could be due to a considerable reduction of topographic relief in the source area and consequently a drastically reduced supply of detritus. The Carrasca Marbles can be interpreted as reefs that

fringed a lagoon, in which local anoxic and hypersaline conditions resulted in deposition of bituminous muds, evaporites and dolostones.

The strong lateral and vertical variation in lithologies that characterize the La Yedra sequence reflects relatively rapidly varying depositional conditions in space and time. High energy white quartzites are intercalated with low energy pelites.

Geochemical analyses suggest an original aragonite composition for the marbles of this sequence (Bakker & De Jong 1985). A lagoonal environment seems to be most appropriate to explain the aragonite and the abrupt variations.

The Macael-Chive Unit, shows a similar lithostratigraphic development. The Macael Marbles at the top can be interpreted as reefal limestones, correlatable with the Carrasca Marbles. The lateral change from massive carbonates to alternating carbonate beds and siliclastics reflects a transition from reef to lagoon facies.

The Muñoz Amphibole Micaschists indicate a volcanic phase that occurred after sedimentation of the Triassic Carrasca Marbles, but before deposition of the La Yedra sequence. These Late Triassic synsedimentary metavolcanics are related to crustal extension, which might have caused a shallowing of the depositional realm and a concurrent reduction of the basin slope (Cloetingh 1988). This process can explain the abrupt transition from clastic to predominantly carbonatic sedimentation and the associated change in depositional environment.

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