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Northern part of the Sierra de Carrascoy

Sheet ALCANTARILLA

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Introduction

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The Sierra de Carrascoy - together with the Sierra del Puerto forming its north-eastern prolongation - is an isolated mountain range trending approximately WSW-ENE. Its geology has recently been studied in considerable detail by W. Kampschuur, a member of the team from the Geological Institute of the University of Amsterdam, working in the eastern part of the Betic Cordilleras. Kampschuur's studies included the mapping of the Sierra de Carrascoy on a scale 1 : 10.000. His results will be published before the end of 1972, in a thesis entitled: ' Geology of the Sierra de Carrascoy (SE Spain), with emphasis on alpine polyphase deformation '. The geological map 1 : 50.000, the cross-sections, the illustrations and the description of the geology, given in the present manuscript, are either based on or copied from Kampschuur's manuscript. The adaptation was made by C.G. Egeler.

Geological setting. - The Sierra de Carrascoy forms part of the internal zone of the Betic Cordilleras, which is generally indicated as the 'Betic Zone'. A recent summarizing publication by Egeler & Simon (1969a, see also 1969 b) gives the general outlines of this zone. Within its eastern part four major tectonic units are distinguished, i.e. (from below to above): (1) the Nevado-Filabride complex, (2) the Ballabona-Cucharón complex, (3) the Alpujarride complex, and (4) the Malaguide complex. Kampschuur's investigations in the Sierra de Carrascoy have resulted in the distinction of four separate units, i.e. (from below to above): (a) the Romero unit, (b) the Carrascoy unit, (c) the Pestillos unit, and (d) the Navela unit. Following the foregoing tectonic scheme of the Betic Zone, the Romero and Carrascoy units may be referred to the Ballabona-Cucharón complex, the Pestillos unit to the Alpujarride complex, and the Navela unit to the Malaguide complex.

Previous work. - When Kampschuur started mapping the Sierra de Carrascoy in 1967, no detailed investigations within this region had yet been carried out. Older writings reveal, however, considerable difference of opinion concerning the stratigraphy and the tectonics. Some examples may be mentioned. Fallot (1930) originally described the Sierra de Carrascoy as consisting of 'crystalline of the Sierra Nevada' with a cover of Penibetic, but in a later publication (1948) referred the sequence to the Betic of Malaga. Blumenthal, on the other hand, first referred the rocks to the Betic of Malaga (Blumenthal, 1933), but later (1950) ranged them with the 'Alpujarrides'. Staub (1934) believed a single nappe to be represented, with an Hercynian basement and a Mesozoic cover. Patijn (1937), in his turn, referred the rocks of the western Sierra de Carrascoy to the Betic of Malaga, but left open the possibility that Alpujarride elements are present in the east. Lastly, Durand Delga & Fontboté (1960) ranged the Sierra de Carrascoy within the Alpujarride complex.

In 1964 Simon forwarded the hypothesis that the Sierra de Carrascoy, at least partly, represents the Almagro unit, a major tectonic element distinguished by him in the Sierra de Almagro (1963). The presence, within the Sierra de Carrascoy, of more than one tectonic unit was pointed out by Azéma et al. (1965), who distinguished five separate elements. Bodenhausen & Simon (1965) gave the following tentative correlation between these elements and the units distinguished by Simon (1963) in the Sierra de Almagro:

Sierra de Almagro	Sierra de Carrascoy
Betic of Malaga	element 5
Variegato unit	element 4
Ballabona-Cucharón unit	elements 3 and 2
Almagro unit	element 1

Later investigations led Simon (1966 a) to conclude that the elements 1 and 3 of Azéma et al. (1965) form part of a single tectonic unit - the Almagro-Cucharón unit - with a continuous stratigraphic succession (see also Simon, 1966 b).

Stratigraphy

Romero unit

General statement

According to Kampschuur (1972) this lowermost tectonic unit of the Sierra de Carrascoy embraces two formations:

top: Fuente Aledo formation
carbonate rocks; intercalated slates; locally quartzites, gypsum and rauhwackes*)

Pocito formation
argillites and slates; quartzites; local intercalations of carbonate rocks

Within sheet Alcantarilla only the Pocito formation is represented.

Pocito formation

Lithology. - The rock sequence of the Pocito formation consists essentially of an alternation of red, greyish-purple, yellow and green argillites, and purple, grey, green and brown quartzites. Brownish-yellow, mediumly bedded carbonate rocks are locally intercalated.

Fossils. - With the exception of burrow-structures in the argillites and quartzites, no fossils have been found.

*) The rock sequences of all four tectonic units distinguished in the Sierra de Carrascoy contain rauhwackes. In a recent monograph on rauhwackes Leine (1968) discussed the genesis of these rocks and their distribution within the Permo-Triassic to Triassic rock sequences of the Betic Cordilleras. He claims that the rauhwackes are weathered carbonate breccias of tectonic origin (see also Leine & Egeler, 1962) and distinguished two main types, i.e. (a) monomict rauhwackes formed, in the first place, by fragmentation of only one type of rock, and (b), polymict rauhwackes, formed by fragmentation and mixing of two or more types of rocks. Both types of rauhwackes are usually developed in zones parallel to the general stratification and are mostly closely associated with evaporites.

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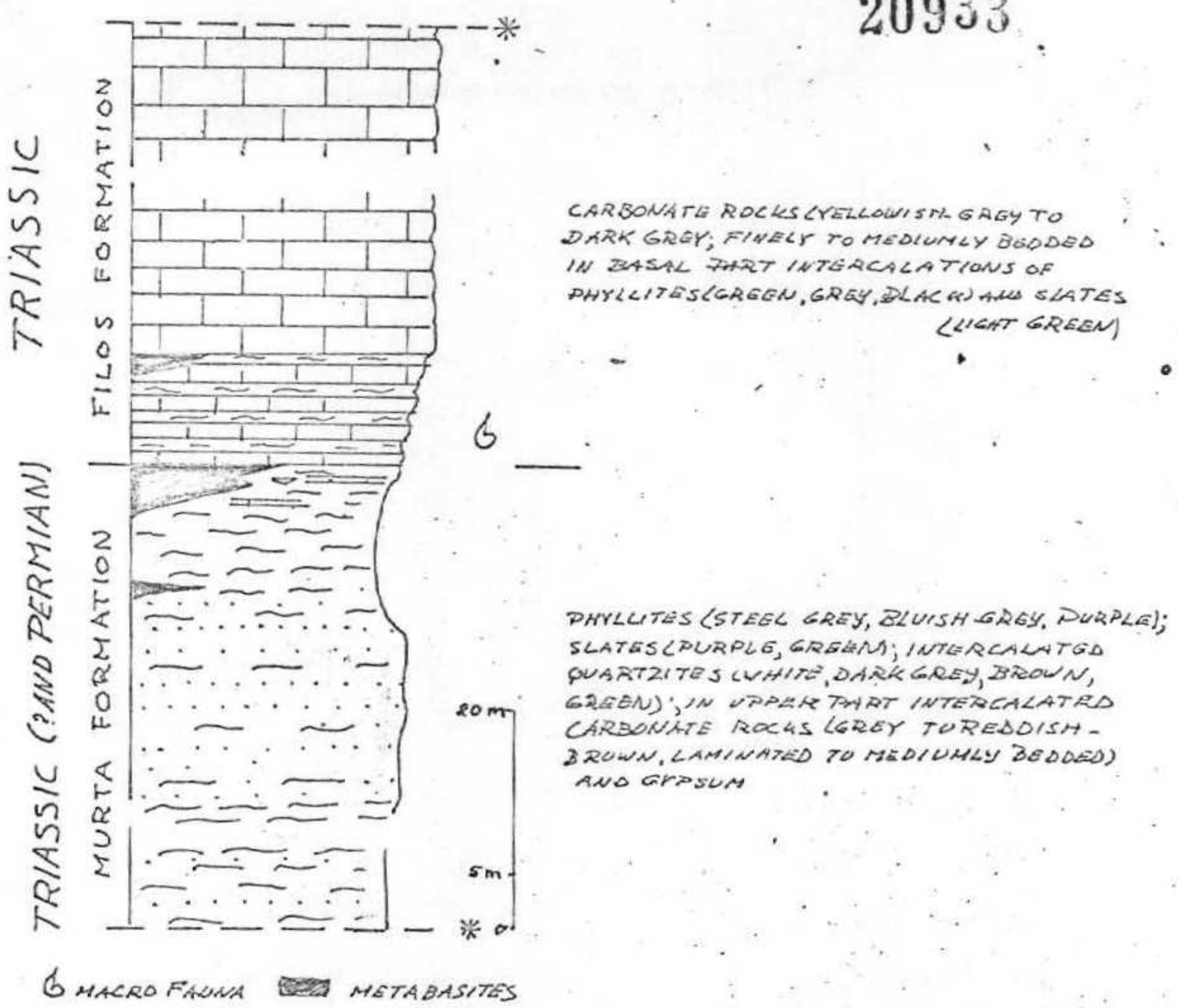

Fig. 1 - Composite columnar section of the Carrascoy unit

Contact relations. - The base of the formation is nowhere exposed. In the part of the Sierra de Carrascoy lying within sheet Alcantarilla the Pocito sequence is commonly overlain by 'post-nappe deposits' and locally by rocks of the Carrascoy unit. Further to the east, in the Sierra del Puerto, rocks of the Pocito formation are found in tectonic contact with rocks representing the higher part of the Fuente Aledo formation.

Thickness. - No more can be said than that the minimum exposed thickness amounts to 40 m.

Age

The combined data on the macro- and microfauna from the Fuente Aledo formation of the Romero unit in the southern part of the Sierra de Carrascoy (sheet Totana) suggest that this sequence is essentially of Ladinian age. The rocks of the underlying Pocito formation of the Romero unit may be tentatively referred to the Ladinian (? and older).

Carrascoy unit (see Fig. 1)

General statement

The Carrascoy unit, which tectonically overlies the Romero unit from a regional point of view, comprises two formations (Kampschuur, 1972):

top: Filos formation
mainly carbonate rocks (partly rauhwackes): in basal part intercalations of phyllites and slates

Murta formation
alternation of phyllites, slates and quartzites; in upper part intercalations of carbonate rocks (partly rauhwackes) and of gypsum.

The upper part of the rock sequence of the Murta formation locally contains basic sills, represented by metabasites.

Murta formation

Lithology. - The rock sequence of the Murta formation mainly consists of phyllites, with colours varying from steel grey to bluish-grey, dark grey and purple. There are local gradations into slates, characterized by purple and greenish colours. Laminated to mediumly bedded quartzites, exhibiting white, dark grey, brown and green colours, are present as intercalations, Gypsum occurs in the topmost part of the Murta sequence, which also contains intercalations of laminated to mediumly bedded carbonate rocks.

The presence of gypsum within the rock sequence of the Murta formation calls for attention, as this is a very characteristic feature. Layers showing a banding parallel to the general stratification indicate that the gypsum is partly normally intercalated. However, gypsum also occurs as irregularly shaped masses (up to 100 m thick) with a chaotic structure and obviously resulting from tectonization.

Locally the formation is exclusively represented by gypsum. Abundant foreign blocks are enclosed, exhibiting a random orientation. They mainly consist of rocks of the Murta or the Filos formation, but at the contact with rocks of other tectonic units fragments derived from the latter may also be present. The gypsum masses, both laterally and vertically, grade into mega-breccias, containing polymict rauhwackes as main constituent.

Fractures in quartzites may contain malachite and azurite (± 700 m E of Casas de la Fuente del Pino).

Fossils. - With the exception of burrow-structures no fossils have been found.

Contact relations. - The base of the Murta formation is formed by a major thrust-plane. The boundary with the overlying Filos formation is of normal stratigraphic nature; the contact is conveniently drawn where carbonate rocks become predominant.

Thickness. - The exposed thickness of the Murta sequence varies from 0 - 150 m.

Filos formation

Lithology. - The rocks of the Filos formation give rise to scarps. The rock sequence mainly consists of yellowish-grey to dark grey, finely to mediumly bedded carbonate rocks. Intercalations of greyish-black and green phyllites or of light green slates are found in the basal part of the succession. The presence of pyrite cubes is characteristic. Monomict rauhwackes are of widespread distribution; they form discontinuous layers which sometimes pass abruptly into non-brecciated carbonate rocks. Haematite is present in the basal part of the Filos sequence.

Fossils. - Indeterminable shell remains are found in some of the carbonates. Green slates from the basal part of the formation contain well-preserved Aviculopecten (Dr.Fr.Hirsch, pers.comm.).

Contact relations. - The Filos formation is tectonically overlain by the Pestillos unit.

Thickness. - The maximum exposed thickness amounts to 190 m. The formation wedges out locally.

Igneous rocks. - The principal body of metabasite is located at the top of the Murta formation, where it attains a thickness of 70 m.

Age

An exact dating of the sedimentary rocks of the Carrascoy unit is rendered impossible by the lack of diagnostic fossils. If one assumes that the contact with the underlying Romero unit is merely a detachment plane (Simon, 1967; see also 1966 a) - i.e. that the rock sequences of the two units initially formed part of a continuous stratigraphic succession - the rocks of the Carrascoy unit are obviously younger than those of the Romero unit. If, on the other hand, the Romero unit and the Carrascoy unit represent two 'independent' nappes, the age of the Carrascoy sequence is entirely open. In that case one can only state that the lithology suggests a Triassic age.

Metabasites

As mentioned already, bodies of basic igneous rocks occur within the sequence of the Carrascoy unit (Murta formation). The general term 'metabasites' seems appropriate, in view of the low grade regional metamorphism which the rocks have suffered. Still, they have invariably retained their massive habit and textural and mineralogical relics of magmatic origin indicate that they are original diabases. The intrusive nature of the bodies is evidenced by the occurrence of finely granular 'chilled borders' and by metamorphism suffered by the adjacent sediments. The relation with the country rock is always concordant and the bodies are obviously sills.

Petrography. - Relict minerals of magmatic origin include: colourless clino-pyroxene, brown to greenish-brown hornblende, biotite, plagioclase (An 37-50) and granophyric intergrowths of quartz and potash-feldspar.

The minerals produced by metamorphism include: bluish-green actinolitic amphibole, crossite (rare), albite, essentially colourless mica, chlorite, quartz and minerals of the epidote-group.

All transitions are found from rocks with a practically intact ophitic texture and with abundant relict minerals, to rocks the igneous origin of which is barely recognizable under the microscope. Plagioclase is usually completely pseudomorphosed by aggregates of colourless mica and epidote minerals. Some slides contain chessboard albite, presumably formed by albitization of potash-feldspar.

The assemblage of minerals formed by metamorphism indicates the greenschist facies. However, the occasional presence of crossite suggests local transition to the glaucophane schist facies.

Contact phenomena. - Carbonate rocks at the immediate contact may exhibit a change in colour within a narrow zone (measuring up to several tens of centimetres in width) and further brownish spots, consisting of carbonate material, albite and ore, occasionally together with biotite, colourless mica, chlorite and epidote.

Kampschuur (1972) suggests that the absence of high temperature minerals at the contacts of the thick basic sills, combined with

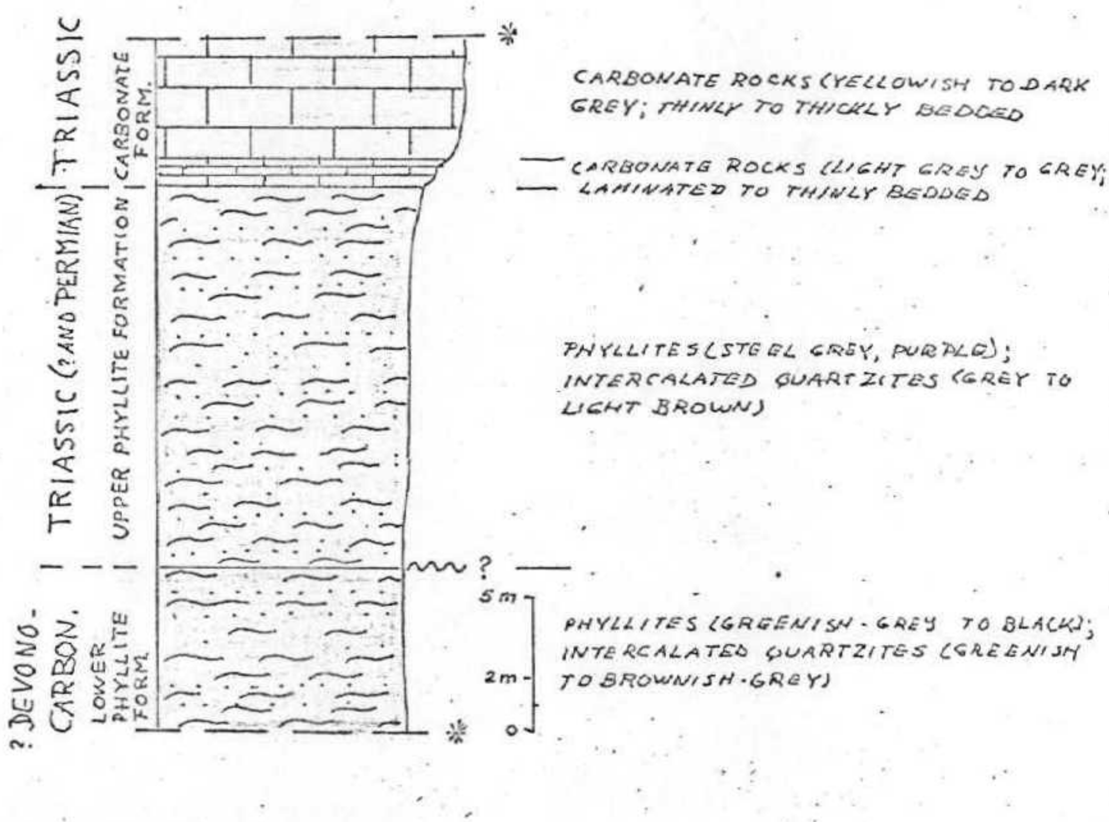

Fig. 2 - Composite columnar section of the
Pestillos unit.

the narrowness of the contact zone, indicates that intrusion took place in unconsolidated, wet sediments. This would obviously imply a Triassic age for the basic rocks.

Pestillos unit (see Fig. 2)

General statement

Tectonically overlying the Carrascoy unit is the Pestillos unit, for which Kampschuur (1972) gives the following scheme:

top: Carbonate formation
carbonate rocks; locally monomict rauhwackes

Upper phyllite formation
phyllites; intercalated quartzites

Lower phyllite formation
phyllites; intercalated quartzites

Lower phyllite formation

Lithology. - The Lower phyllite formation comprises greenish-grey to black phyllites with intercalated greenish to brownish-grey quartzites. Minor outcrops of black, more or less quartzitic schists, which according to Simon (1967) perhaps represent older rocks, are incorporated in the Lower phyllite formation, for want of conclusive criteria for distinction.

Contact relations. - The basal contact is of tectonic nature. The boundary with the Upper phyllite formation is very clear in the field, due to the conspicuous difference in colour. However, the true nature of the contact remains uncertain.

Upper phyllite formation

Lithology. - The Upper phyllite formation mainly consists of steel grey phyllitic rocks, with subordinate purple coloured varieties and intercalated brown quartzites. Numerous veins and lenses of quartz occur and appear to be characteristic of the sequence.

Contact relations. - The Lower phyllite formation is often absent, in which case the rocks of the Upper phyllite formation

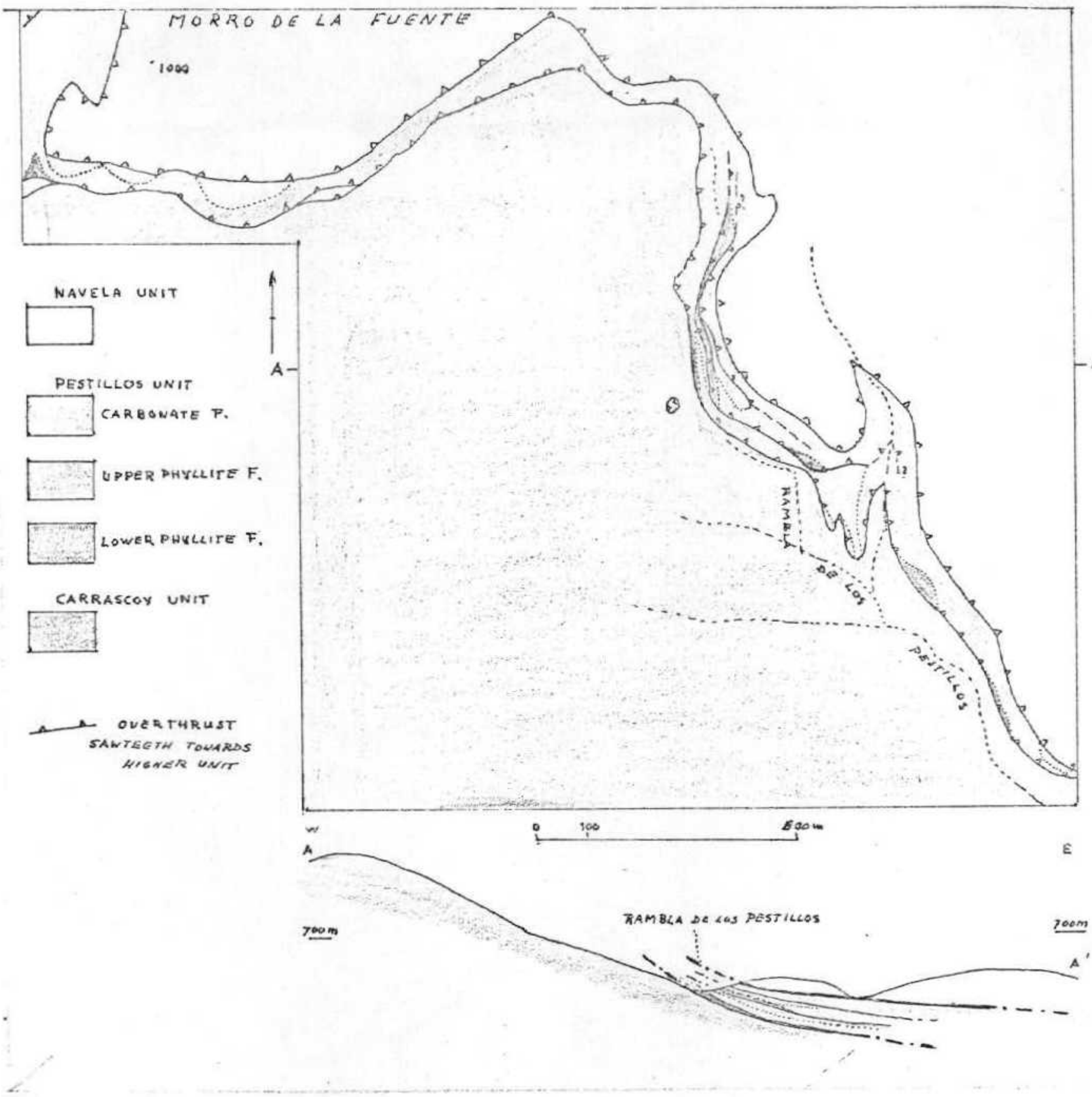

Fig.

Fig. 3 - Geological sketch-map and cross-section of the upper part of the Rambla de los Pestillos, showing distribution of the various rock sequences of the Pestillos unit (after Kampschuur, 1972).

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directly overlie rocks of the Carrascoy unit. The contact between the Upper phyllites and the rocks of the overlying Carbonate formation is of stratigraphic nature; it is invariably strongly tectonized. For complicated outcrop pattern see Fig. 3.

Thickness. - The maximum exposed thickness amounts to about 100 m.

Carbonate formation

Lithology. - The Carbonate formation is poorly represented within the northern part of the Sierra de Carrascoy; it is restricted to a small number of scattered outcrops. The sequence is mainly formed yellowish-grey to dark grey, thinly to thickly bedded carbonate rocks, partly developed as rauhwackes. Its basal part consists light grey, laminated to thinly bedded carbonates.

Thickness. - The maximum exposed thickness amounts to 5 m.

Age

Owing to absence of fossils the age of the rocks of the Pestillos unit has to be based on comparison with correlatable sequences from the Alpujarride complex elsewhere in the Betic Zone. This leads Simon to the following scheme:

Carbonate formation	Triassic
Upper phyllitic formation	Triassic (? and Permian)
Lower phyllite formation	Palæozoic (? Devono-Carboniferous)

Navela unit (see Fig. 4)

General statement

For this highest tectonic unit of the Sierra de Carrascoy the following tentative scheme is given (Kampschuur, 1972):

top: Carbonate formation
mainly dolomitic carbonate rocks

Argillite-quartzite formation
argillites and quartzites; locally slates, carbonate rocks, conglomerates and gypsum

Greywacke formation
greywackes and carbonate rocks

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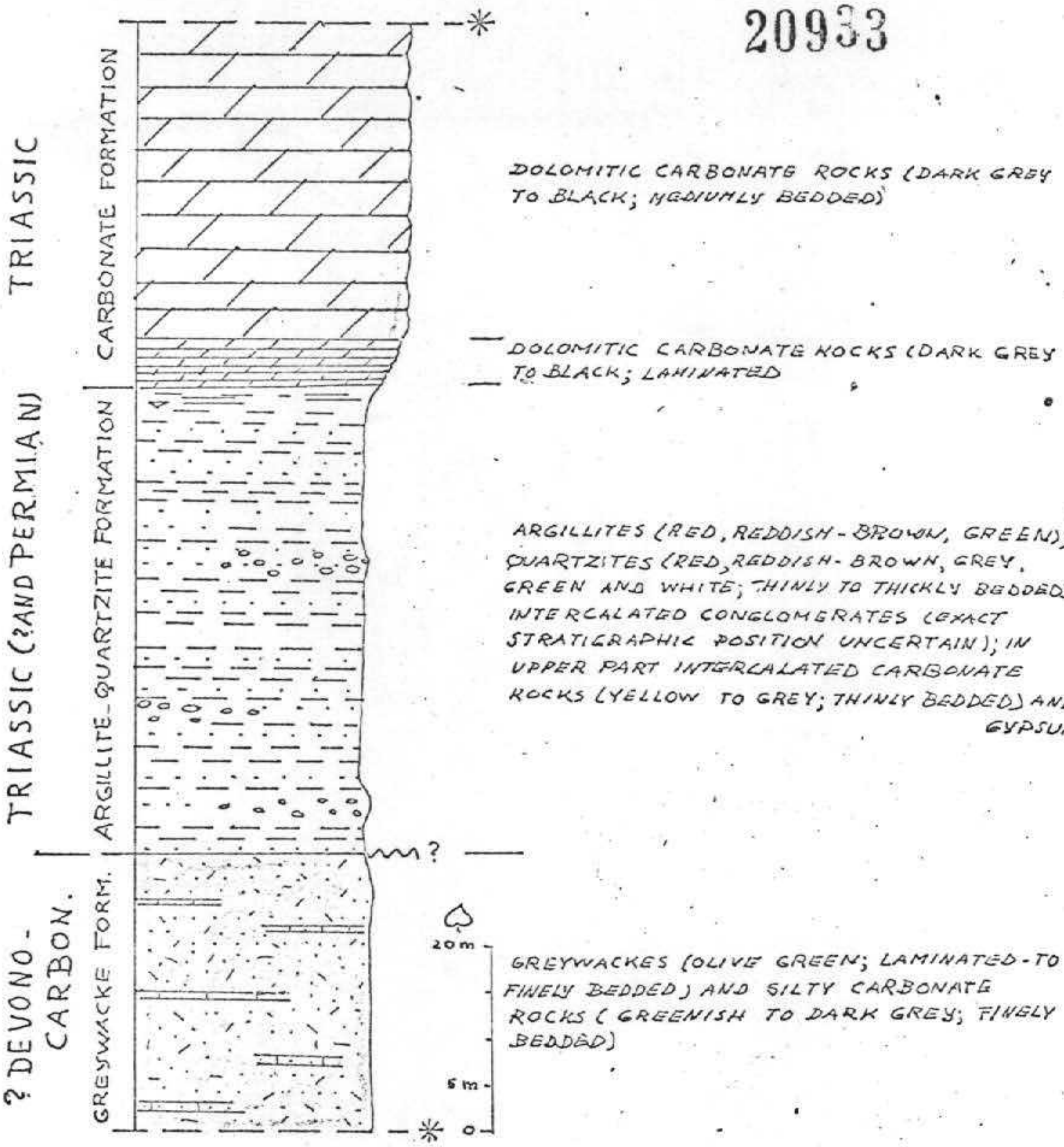

Fig. 4 - Composite columnar section of the Navela unit.

Kampschuur distinguishes four minor tectonic elements within the Navela unit.

Greywacke formation

Lithology. - The sequence mainly consists of laminated to finely bedded, olive-green greywackes, with intercalations of greenish to dark-grey coloured, finely bedded silty carbonate rocks. The greywackes sometimes exhibit a marked grading, as well as cross-lamination and sole-markings. Plant remains are linearly oriented. The rocks are interpreted as having been deposited by turbidity currents.

Rocks of the greywacke formation are only present at the base of the two higher tectonic elements (see above).

Fossils. - With the exception of plant remains no fossils have been found.

Contact relations. - The contact at the base of the Greywacke formation is always of tectonic nature. The contact with the overlying Argillite-quartzite formation is stratigraphic. It is sharp, due to the conspicuous difference in lithology. It should be noted that no evidence has been found of the angular unconformity which is usually assumed to occur at the boundary between the Greywacke formation and the overlying sequence.

Thickness. - The exposed thickness amounts to 25 m.

Argillite-quartzite formation

Lithology. - The sequence consists of an alternation of red to reddish-brown and green argillites and red to reddish-brown, grey, green and white quartzites. Gradations from the argillites to slates are of local occurrence. The upper part of the sequence contains intercalations of thinly bedded carbonate rocks and of layered gypsum. Conglomeratic layers occur in several levels. They are either red coloured and rich in well-rounded quartz pebbles or greyish and rich in well-rounded pebbles of carbonate rocks.

Fractures in the quartzites may contain malachite, azurite and jarossite (south of Colládo de la Fábrica).

Contact relations. - The Argillite-quartzite formation is conformably overlain by rocks of the Carbonate formation. The boundary seems to be gradational; the contact is conveniently drawn above the uppermost argillites. It is commonly strongly tectonized.

Thickness. - The maximum exposed thickness is 50 m.

Carbonate formation

Lithology. - The sequence consists of dark grey to black, mediumly bedded carbonate rocks, partly changed to monomict rauhwackes. The basal part is characterized by the occurrence of laminated dolomitic rocks, transected by numerous veins.

Fossils. - Shell-remains are locally present.

Contact relations. - The rocks of the Carbonate formation are unconformably overlain by 'post-nappe deposits'.

Thickness. - The exposed thickness amounts to 40 m.

Age

Owing to lack of diagnostic fossils the rocks of the Navela unit of the Sierra de Carrascoy can be only tentatively dated on the basis of lithologic correlation with Malaguide successions from elsewhere in the Betic Zone. This leads to the following scheme:

Carbonate formation	- Triassic
Argillite Quartzite formation	- Triassic (? and Permian)
Greywacke formation	- (? Devono-Carboniferous).

Tectonics

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General statement

As mentioned in the foregoing the Sierra de Carrascoy comprises four major tectonic units, i.e. (from below to above): (1 and 2) the Romero and Carrascoy units, representing the Ballabona-Cucharón complex, (3) the Pestillos unit, representing the Alpujarride complex, and (4) the Navela unit, representing the Malaguide complex In addition 'post-nappe deposits' are represented.

Kampschuur's studies reveal that the rocks sequences of all four tectonic units show the effects of six, apparently correlatable, phases of alpine deformation (D_1-D_6). In the part of the Sierra de Carrascoy lying within the sheet Alcantarilla the resulting structures are especially well-developed in the rock sequence of the Carrascoy unit; they are also found in the rock sequences of the Pestillos and Navela units.

Structures

In the well-bedded rocks sequences of the Murta and Filos formations of the Carrascoy unit D_1 has led to the formation of folds on all scales. Isoclinal folds predominate, but close and tight types were also formed. They are mostly characterized by a conspicuous axial plane cleavage. In the Pestillos unit folding attributable to D_1 has not been recognized. However, thist first phase is held responsible for the formation of the slaty cleavage in the phyllites of the Upper phyllite formation, and the same holds good for the local formation of a slaty cleavage in the rocks of the Argillite-quartzite formation of the Navela unit. In the latter D_1-isoclinal folds were formed in the well-bedded basal rocks of the Carbonate formation.

D_2 is held responsible for the final emplacement of the tectonic units in the Sierra de Carrascoy. The fact that the degree of syn-D_1 metamorphism of the rocks of the Navela unit is distinctly lower than that of the rocks of the underlying units, proves that this thrusting post-dates D_1. The internal imbrication of the Navela unit is presumably also a D_2-feature.

In the Carrascoy unit D_3 has produced folds on all scales, grading from open to isoclinal, with axial planes dipping at about

40° NE and with a well-developed crenulation cleavage. In the phyllites of the Pestillos unit most D_3-folds are tight to isoclinal. D_3-folds in rocks of the Argillite-quartzite formation of the Navela unit vary from open to tight.

D_4 produces meso- and macroscopic folds in rocks of the Carrascoy unit, varying from gentle to open, and with axial planes dipping at about 50° NW-NNW. The crenulation cleavage is weak. D_4-folds in the phyllites of the Pestillos unit are essentially of the same type. The Argillite-quartzite formation of the Navela unit shows folds on a mesoscopic scale.

The rock sequences of the Sierra de Carrascoy were further affected by southward-directed reverse faulting (D_5) followed by northward-directed reverse faulting (D_6).

Fig. 5 - Scheme illustrating structural evolution in Sierra de Carrascoy (based on Kampschuur, 1972)

normal faulting, related to updoming

D_6--> reverse faulting, N-NW-directed

D_5--> reverse faulting, S-directed

D_4--> folding with SE-vergence; crenulation cleavage

D_3--> folding with SW-vergence; crenulation cleavage

D_2--> overthrusting and imbrication, southward-directed, leading to present pile of nappes

D_1--> folding with SW-vergence; slaty cleavage; overthrusting, SW-directed, leading to 'initial pile of nappes'

Geological history

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The stratigraphic columns of the (Permo)Triassic rock sequences of the Pestillos and Navela units of the Sierra de Carrascoy - representing the Alpujarride and the Malaguide realm respectively - indicate an abrupt change in depositional conditions, presumably somewhere near the Lower Triassic - Middle Triassic boundary. Uncertainty as to the age of the rocks of the Carrascoy unit renders speculation on the conditions of deposition in the Ballabona-Cucharón realm hazardous. The fact that these conditions differed from the afore-mentioned, is shown by the stratigraphic column of the Romero unit, which reflects influx of terrigeneous detritus in Middle Triassic time.

Kampschuur's investigations have furnished ample information on the structural evolution during the Alpine orogeny. The resulting scheme (Fig. 5) shows that the pile of nappes now represented within the Sierra de Carrascoy is attributed to southward-directed overthrust movements, taking place during a second phase of deformation (D_2). The regional metamorphism is linked with earlier folding , during D_1 . According to Kampschuur this first phase is further responsible for major thrust movements, which led to the formation of an 'initial pile of nappes', in the sense of Egeler & Simon (1969). It may be recalled here, that these authors stress that the evolution of the nappe structure of the Betic Zone had a complex nature and that at least two major phases of overthrust movements of different character have played a role. Acceptance of the concept that regional metamorphism in alpine overthrust belts is related, in some way or other, with tectonic depth, leads them to postulate the development in an early stage of the orogenic evolution, of a pile of nappes with which the generation of the kinematic metamorphism was connected. The fact that this 'initial pile' was disturbed in a later stage, by translation of considerable magnitude, is i.a. evidenced by the discontinuity of the metamorphism at major thrust planes within the present pile.

It will be clear that the question whether Kampschuur's D_1 phase is responsible for the generation of the initial pile of nappes a very important but at the same time very delicate point, as definite evidence appears to be lacking. If correct, there seems to be no escaping the conclusion that the initial overthrust movements in the Betic Zone were southward-directed.

The dating of D_1 up to and including D_4 is necessarily very inaccurate, as the youngest rocks affected by these phases are of Triassic age and the oldest rocks not affected Middle Miocene. The 'post-nappe deposits' were affected by D_5 and D_6 faulting at some time between the Middle and Upper Pliocene. Subsequent normal faulting is assumedly related to the updoming of the Sierra.

Economic geology

In the north-eastern part of the Sierra de Carrascoy gypsum is of widespread occurrence as a constituent of the Murta formation of the Carrascoy unit. Notwithstanding good accessibility the gypsum is mined at one locality only, i.e. north of Fuente de las Palomas.

In the past some attempts have been made at exploitation of galenite, which is present in small quantities in brecciated carbonate rocks of the Navela unit, east of Caserio de Navela.

Finally the local occurrence of malachite and azurite may be mentioned, along joints of quartzitic rocks of the Murta formation of the Carrascoy unit and of the Argillite-quartzite formation of the Navela unit.

Metamorphism

The rocks of all four tectonic units distinguished in the Sierra de Carrascoy show the effects of low-grade alpine metamorphism. For the comparison of the degree of metamorphism within the respective units the pelitic rocks appear to be the most suitable. In the field a rough subdivision can be made into argillites, slates and phyllites. In the argillites metamorphism has resulted in neoformation of sericitic material, chlorite (?albite) and quartz and in the slates and phyllites in neoformation of colourless mica (muscovite, sometimes paragonite), chlorite, albite and quartz. According to Kampschuur (1972) the formation of these minerals is synkinematic and related to the first phase of deformation (D1), which is found te have affected the rock sequences of all four units (see below).

The degree of the metamorphism very seldom surpasses the greenschist facies. It may be recalled, however, that the presence of crossite in some metabasites suggests local transitions to the conditions of the glaucophane schist facies. Kampschuur found it impossible to range the rocks of the different tectonic units according to the degree of metamorphism, merely on the basis of microscopic study. He therefore used diffractograms of powder samples of rock specimens from the sequence of each unit, in order to establish the muscovite-paragonite coexistence, the illite crystallinity and the chlorite crystallinity. The results led him to conclude that: (1) the metamorphism of the rocks of the Romero unit is lower than that of the rocks of the Carrascoy unit, equal to or slightly lower than that of the rocks of the Pestillos unit, and equal to or slightly higher than that of the rocks of the Navela unit, (2) the metamorphism of the rocks of the Carrascoy unit is equal to or slightly higher than that of the rocks of the Pestillos unit, and higher than that of the rocks of the Navela unit, and (3) the metamorphism of the rocks of the Pestillos unit is higher than that of the rocks of the Navela unit.

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