GRAVITATIONAL GLIDING IN THE NORTHERN SIERRA DE LOS FILABRES (SE SPAIN)

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ABSTRACT

Evidence is given for rotatory movements of klippes in the northern Sierra de los Filabres. Use has been made of difference in the orientation of linear structural elements in the klippes compared with that of equivalent structures in the underlying 'basal succession'. The rotations indicate gravitational gliding, probably resulting from updoming of the mountain-range in a late stage of the orogenic history.

INTRODUCTION

The northern Sierra de los Filabres comprises a succession of four superimposed tectonic units, separated by regionally low-angle thrust planes. These units are, from below to above: the Nevado-Lubrín and Macael units (representing the Nevado-Filabride complex), the Ballabona unit (representing the Ballabona-Cucharón complex), and the Variegato unit (representing the Alpujarride complex). In the case of the three higher units a nappe character is indicated. The character of the Nevado-Lubrín unit remains uncertain, for lack of knowledge concerning its base. In the following the above-mentioned succession of units will be referred to as the basal succession (see also Voet, 1967, p. 89).

The units of the Nevado-Filabride complex have been subjected to at least five succesive phases of Alpine deformation, as witnessed by penetrative structural elements in the Permo-Triassic and younger rock-sequences (Langenberg, 1972). Subsequent to the last of these deformation phases, movements have taken place which caused tectonically lower units to be thrust over tectonically higher ones, i.e. Nevado-Filabride rocks over rocks of the Ballabona-Cucharón and Alpujarride complexes (Voet, 1964 & 1967; Leine, 1966; Egeler & Simon, 1969). Nevado-Filabride rocks occur in isolated klippes resting on rocks of the Ballabona and/or Variegato units of the basal succession. Voet (1967) suggested that these klippes result from gravitational gliding, initiated by the updoming of the Sierra de los Filabres in a late stage of the orogenic evolution. A chaotic or even a geometrically obscure structure may be an indication of gliding (de Sitter, 1956). In glide masses the lateral extension of the structure commonly has no connection with its surroundings. In order to verify Voet's gliding hypothesis one needs markers, the pre-gliding orientation of which is known. In this connection the work of ten Haaf (1957) in the Apennines may be mentioned, who proved rotations apparently resulting from gravitational gliding, with the help of current directions as orientation markers. In the case of the Sierra de los Filabres case use can be made of the orientation of pre-gliding structural elements, which are readily recognizable in certain rock-types of the Nevado-Filabride complex and are present both in the klippes and in the basal succession.

THE KLIPPES OF THE NORTHERN SIERRA DE LOS FILABRES

On the map accompanying the publication of Helmers & Voet (1967) various klippes (i.e. "late" thrust masses) are indicated on the northern side of the Sierra. The klippes investigated by the present author are shown in fig 1. They comprise two large ones (the Tejaras and Cerro Gordo klippes) and nine smaller ones (numbered V-XIII). They are essentially composed of a lower and/or higher Nevado-Filabride unit, probably correlatable with the Nevado-Lubrín and Macael units of the basal succession respectively.[2]

The lower Nevado-Filabride unit is essentially composed of marbles and mica schists belonging to the Triassic (and younger?) "Las Casas marbles and schists". The higher unit is composed of a pre-Permian base of dark coloured graphitic mica schists with some intercalated tourmaline gneiss layers and a cover of Triassic (and younger?) "Las Casas marbles and schists". The dating conforms with that proposed by Nijhuis (1964). The klippes VIII, IX, XI, XII and XIII probably consist of rocks of the higher Nevado-Filabride unit, though pre-Permian mica schists have not been found. The most prominent rocks present in all the klippes are Las Casas marbles.

The marbles in the klippes have been strongly folded

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[2] It should be noted that this interpretation differs from that given by Helmers & Voet (1967).

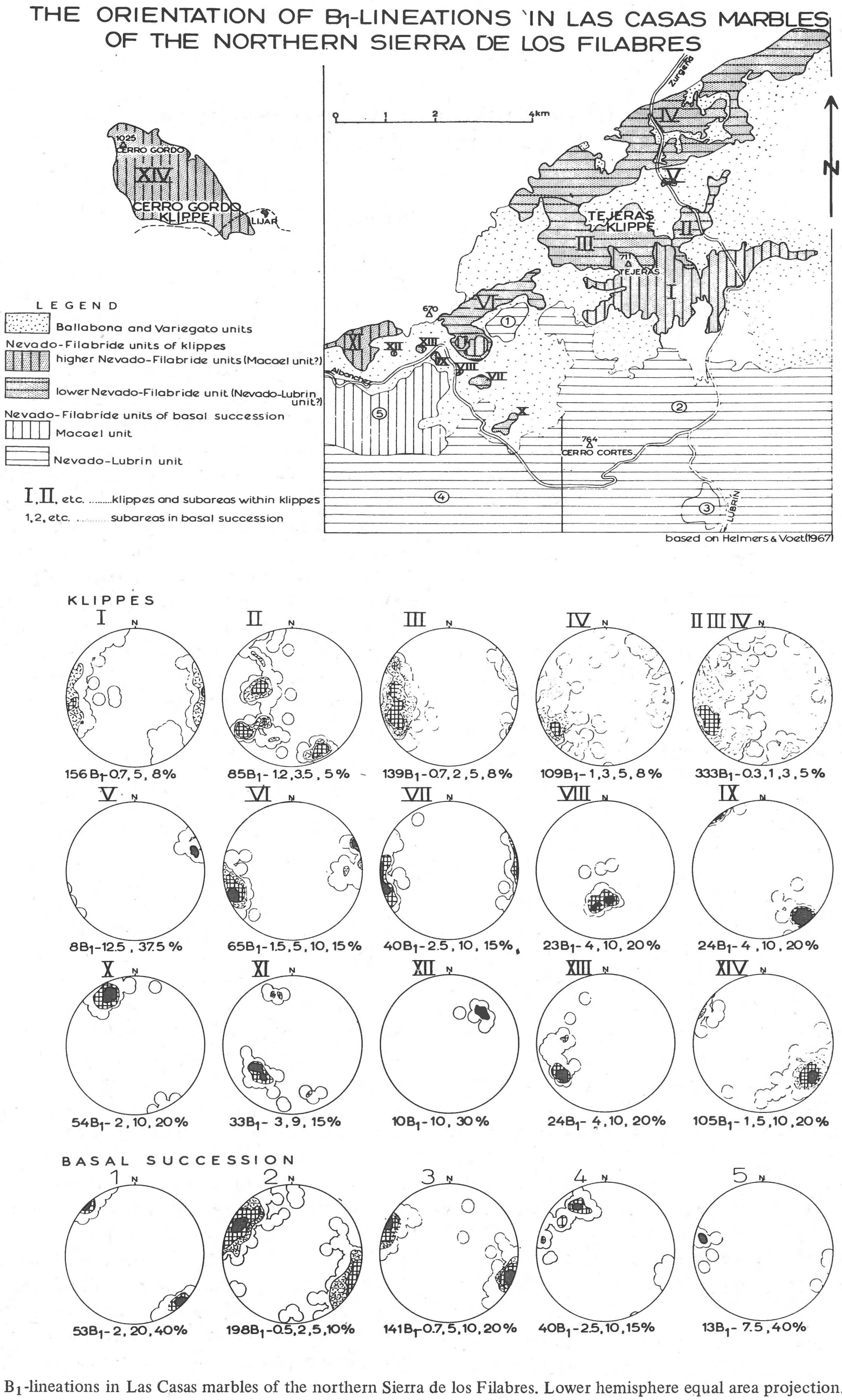

Fig. 1
Stereograms of B_1-lineations in Las Casas marbles of the northern Sierra de los Filabres. Lower hemisphere equal area projection. Contours per 1% area.

during the first deformation phase, often with transposition of bedding. The bedding planes frequently show mica lineations, resulting from the intersection of bedding and schistosity. The schistosity is parallel to the axial-planes of first phase folds, which prove to be tight to isoclinal. In cases of complete transposition the mica lineations represent the only evidence of the first deformation phase. Like the first phase fold-axes they are designated as B_1-lineations. During the second phase of deformation the marbles were refolded around axes which prove to be more or less parallel to those of the first phase. These B_2-lineations cannot be confused with B_1, since they are axes of more open folds; B_2 mica lineations have not been found. The effects of a third and fourth phase have been recognized, but they prove to be only of minor importance. The succession of deformation phases in the Las Casas marbles of the klippes conforms with that found in comparable rocks of the basal succession (L a n g e n b e r g, 1972).

ORIENTATION OF STRUCTURAL ELEMENTS IN THE KLIPPES

In order to study the mode of emplacement of the klippes the linear structural elements of the constituent rocks are used as orientation markers. Their orientation is compared with that of the equivalent structural elements in the basal succession, where the original structural pattern is assumed to be retained. A disadvantage is the lack of a significant sense of direction, owing to the bipolar nature of the linear structures. It is tempting to consider the measured differences in orientation to represent a direct indication for the sense in which the klippes were rotated, i.e. to interpret a westward deviation of for instance 60° with respect to the orientation in the basal succession, as an anti-clockwise rotation of 60°. If one assumes that the rotation was indeed minimal this is the most likely. Obviously however, a clockwise rotation of 120° leads to the same pattern. Moreover, it is clear that in the case of orientation differences around 90° nothing can be said about the sense of rotation. The author has refrained from any attempt to interpret the sense of rotation, in cases where the orientation difference exceeds 75°. Obviously this is a quite arbitrary delimitation.

For our purpose, the B_1-lineations present in Las Casas marbles were selected, as they represent the best developed structural element in the most prominent rock-type of the klippes.

Fig. 1 presents the area investigated and the stereograms of B_1-lineations in the various klippes and the basal succession. The mean orientation, the dispersion parameter (κ) and a measure of confidence on the mean (α_{95}) were computed for each domain (table I).

The majority of the mean B_1-orientations in the klippes lie at large angles to the mean B_1-directions in the basal succession, indicating rotatory movements. In some cases neighbouring klippes are found to be rotated through entirely different angles. This fact indicates that the klippes moved individually and not as a coherent thrustmass. Obviously the possibility cannot be excluded that the klippes started moving as a coherent thrustmass and that individual rotation only took place in a later stage.

The mean B_1-orientations of the various klippes are compared with the mean B_1-orientation of the adjacent subarea of the basal succession to the south, i.e. the assumed source-area. Table II presents the thus obtained rotation-axis, the amount of rotation and the interpreted sense of rotation of the klippes. Fig. 2 includes the stereograms of these rotations.

TABLE I - Means and dispersions of B_1-orientations in Las Casas marbles of the northern Sierra de los Filabres

Subareas	number of measurements	mean orientation	dispersion parameter (κ)	α_{95}
		K L I P P E S		
I	156	279/03	6.5	5°
II	85	282/36	2.9	not calculated
III	139	265/17	10.4	4°
IV	109	246/15	5.0	7°
II,III,IV	333	261/21	4.6	4°
V	8	067/12	41.0	9°
VI	65	257/08	14.6	5°
VII	40	270/03	13.7	6°
VIII	23	186/57	19.8	7°
IX	24	142/16	23.0	6°
X	54	332/16	31.3	4°
XI	33	207/28	5.1	12°
XII	10	045/35	42.5	7°
XIII	24	257/28	11.3	9°
XIV	105	123/18	14.0	4°
		B A S A L S U C C E S S I O N		
1	53	141/03	64.2	2°
2	198	299/05	9.3	4°
3	141	112/04	18.9	3°
4	40	311/17	10.0	8°
5	13	280/09	26.1	8°

TABLE II - Rotation of klippes as indicated by differences in B_1-orientations

Klippe or subarea within klippe	compared with subarea of basal succession	rotation-axis	amount of rotation	interpreted sense of rotation
I		140/84	20°	anti-clockwise
II		032/24	36°	anti-clockwise
III	2	039/66	35°	anti-clockwise
IV		046/74	53°	anti-clockwise
II,III,IV		040/62	40°	anti-clockwise
V		195/70	55°	anti-clockwise
VI	1	036/78	65°	anti-clockwise
VII	4	172/68	42°	anti-clockwise
VIII	5	017/32	86°	no interpretation
IX		024/58	48°	clockwise
X	4	137/73	20°	clockwise
XI		032/62	71°	anti-clockwise
XII	5	180/46	68°	anti-clockwise
XIII		020/45	29°	anti-clockwise

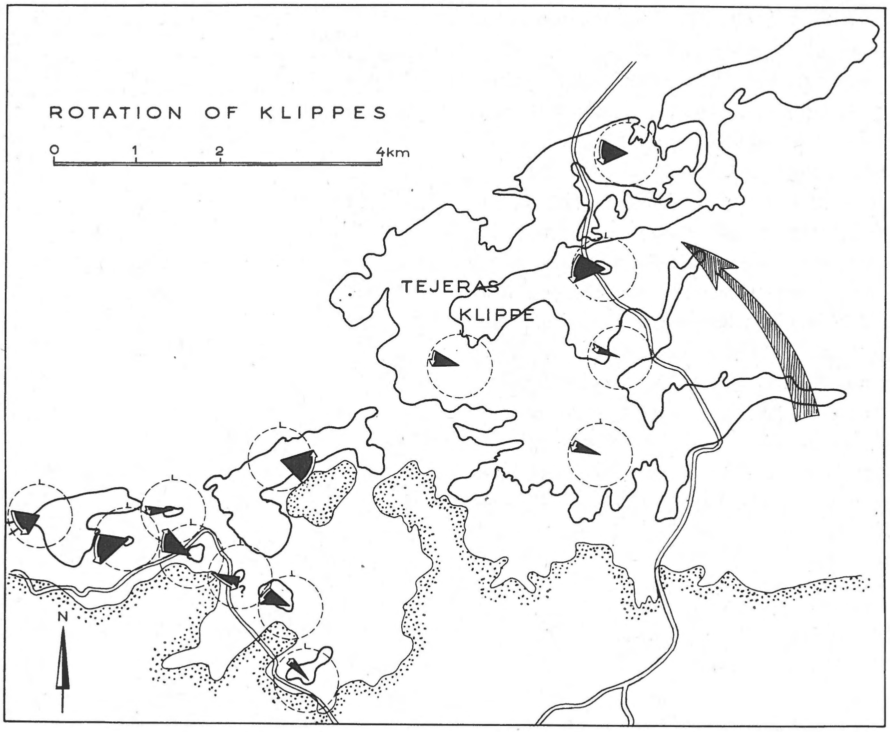

Fig. 2
Rotation of the various klippes, as suggested by the difference in orientation of b_1-lineations (see table II). Lower hemisphere equal area projection (some of the projections are extended outward to cover also the upper hemisphere).

The stereograms of the B_1-orientations in the Tejeras klippe (fig. 1) show that in this case movements have been more complex than simple rotation during translation. The stereogram of subarea II, for example, shows a girdle distribution, indicating contemporaneous folding and probably also faulting. Some angular folds and allied faults have indeed been found. This fact is also reflected in the dispersion-data of table I. The dispersions in the Tejeras-klippe are considerably larger (smaller dispersion parameter, κ) than those of the basal succession and those of the smaller klippes. A point, revealed by fig. 2, is the increase in amount of rotation, from south to north in the Tejeras klippe. This observation points to a pivotal movement, during which the northern part of the klippe rotated most. Probably the mass got buttressed in the west, while the eastern part continued gliding down. Pivotal movement is also indicated by the general strike, which in the north of the klippe clearly deviates from that in the south. This may be brought about by increase in décollement zone thickness, increase in dip, increase in depth of burial or decrease in décollement zone viscosity (see K e h l e, 1970). In the author's opinion in the present case increase in dip is the most likely, as it is difficult to envisage the other properties having changed that much. It is suggested that the increase in dip resulted from a greater upheaval of the Sierra in the east compared with its central part.

In the Cerro Gordo klippe near Lijar (fig. 1) some angular folds, among which monoclines, were found, clearly postdating first and second phase lineations. These structures have fold-axes plunging moderately in a NNW direction and axial-planes dipping steeply to the WSW. Though it cannot be excluded that these folds represent the third or fourth phase of deformation, they are tentatively linked with the gliding movements that resulted in the emplacement of the Cerro Gordo Klippe.

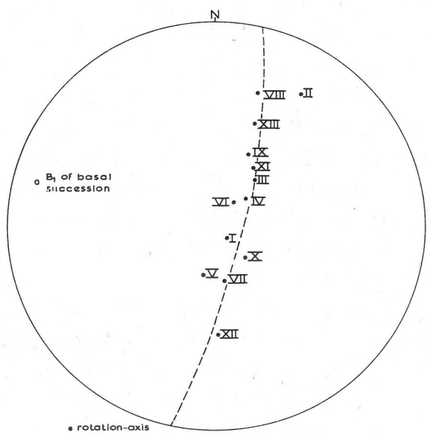

Fig. 3
Stereogram of the rotation-axes of the klippes.

The foregoing data suggest that in the larger klippes rotation was accompanied by folding and faulting. In the smaller klippes simple rotation seems to have prevailed.

The rotation-axes of the klippes presented in table II are situated in a plane normal to the mean B_1-orientation of the basal succession (see fig. 3). Most rotation-axes plunge more steeply than 60°. This indicates rotation over a relatively slightly inclined surface – probably the topography over which the klippe glided downwards. Subarea II and the klippes VIII, XII and XIII have rotation-axes with smaller plunges. In subarea II and XIII this is probably the result of contemporaneous folding. The klippes VIII and XII are the smallest. Their rotation may have been less controlled by the topography.

Most klippes have been tentatively interpreted as having been rotated anti-clockwise. As stressed already, definite proof of the sense of rotation is lacking. Klippe IX and X are assumed to have been rotated clockwise. It may be noted that the slight deviation of the general strike in the Cerro Gordo klippe, led Voet (1967, p. 92) to postulate a clockwise rotation.

CONCLUDING REMARKS

Evidence has been given of rotatory movements of klippes, in a late stage of the orogenic history. The rotation of large masses, sometimes measuring several kilometres in diameter, is considered as a strong indication of large scale gravitational gliding. The rotation of neighbouring klippes through different angles proves that they have moved individually as dislocated fragments, i.e. they are not just relics of a coherent thrustmass (the Cerillo del Sacristán thrustmass) as suggested by Helmers & Voet (1967).

About the origin of the gravitational movements nothing can be said with certainty. As stated by Voet (1967), updoming of the Sierra seems the most reasonable explanation. The northward increase in the amount of rotation, observed within the Tejeras Klippe, may reflect a difference in the amount of upheaval.

The updoming and consequently the gravitational gliding has been tentatively correlated with the conspicuous angular unconformity in the postorogenic deposits of the Vera basin, dated as middle Miocene (Völk, 1967b). However, the possibility cannot be excluded that the vertical movements responsible for erosional unconformities in the Mio-Pliocene sequence (Völk, 1967a) have played a role.

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