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Pleistocene cold-climate phenomena of the Island of Mallorca

by

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with 5 figures and 10 photos

In theory, the island of Mallorca is well-located to record the transition of Pleistocene geomorphic processes reflecting greater cold in higher latitudes, greater moisture in lower middle latitudes. This interplay of cold-climate („periglacial") and „pluvial" phenomena should be somehow recorded in what is an intermediate latitude (39° 16′—39° 58′ N.) and a fair range of altitude (sea-level to 1445 m) (Fig. 1). An I.N.Q.U.A. excursion in 1957 impressed the writer that numerous and diverse Pleistocene sediments are exposed both on the extensive plains and in the rugged mountains of Mallorca. Subsequently field work was carried out on Mallorca during 1959–62 with comparative studies on Ibiza, Formentera and in the provinces of Gerona and Soria[1]).

The field work showed that complex transitions of cold-climate and pluvial phenomena do indeed exist in the mountains of Mallorca, as well as in Catalonia and Old Castille. The use of the undefined term „pluvial solifluction" by H. MENSCHING (1953, 1955) and R. RAYNAL (1956) for Moroccan and Mallorcan features indicates that this realization is not entirely novel. But field analysis of features described by various authors in Spain suggests that a certain confusion exists between cold-climate and pluvial phenomena, and that unless careful field descriptions are published, caution must be used in the interpretation of references to „periglacial" phenomena in the western Mediterranean Basin.

[1]) The writer is pleased to acknowledge valuable field collaboration with J. CUERDA and A. MUNTANER DARDER on a number of occasions, the assistance of DIETER ROGGAN in surveying the Cueva de Cala Santanyí, and discussion or correspondence with O. FRÄNZLE, R. RAYNAL, and particularly R. A. NEILSON concerning problems discussed in this paper. J. M. JANSÁ kindly made unpublished meteorological data accessible. The maps were drawn by the Cartographic Laboratory of the University of Wisconsin, under the supervision of R. D. Sale. Financial support was provided by the Akademie der Wissenschaften und der Literatur (Mainz), the University Research Committee of the University of Wisconsin (Madison), and of the Geography Department of that university.

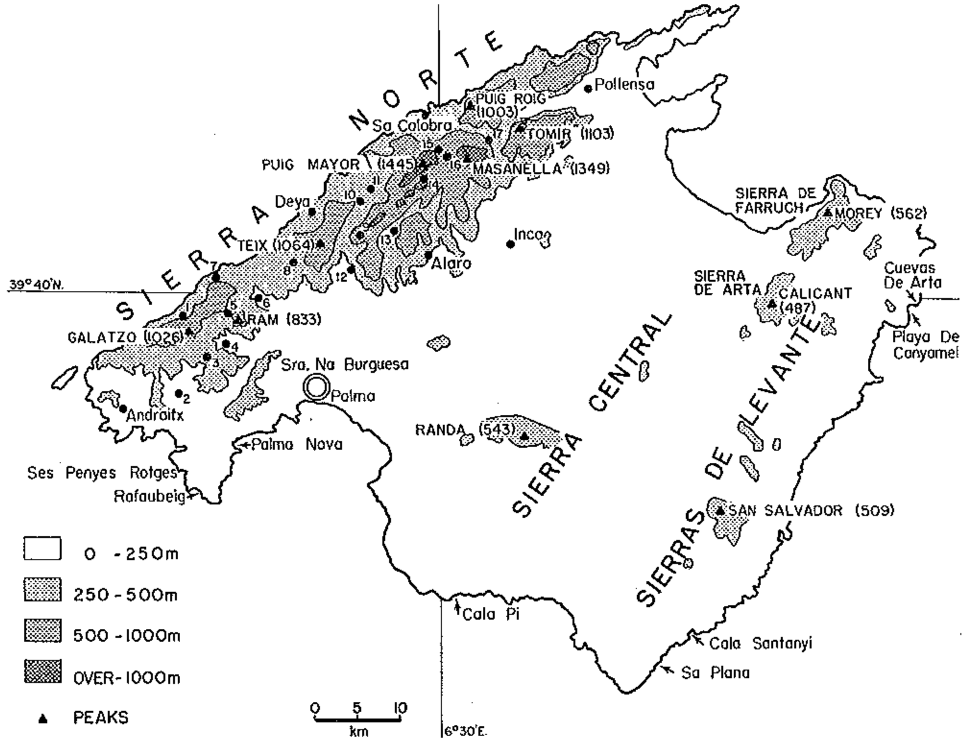

Fig. 1. *Relief and Topography of Mallorca.* Contour lines derived from the 1 : 100,000 series (1951—53), individual elevations from the 1 : 50,000 series (1959—60). Place names of the Sierra Norte indicated by number: 1. Estallench; 2. Capdellá; 3. Galilea; 4. Puigpunyent; 5. Cio. Son Vich; 6. Esporlas; 7. Banyalbufar; 8. Valldemosa; 9. Col de Soller; 10. Soller; 11. Fornalutx; 12. Bunyolas; 13. Orient; 14. Son Torrellas; 15. Cio. Ca'ls Reys; 16. Gorg Blau; 17. Lluch.

Modern Climatic Features

The present climate of Mallorca is that of a typical summer-dry mesothermal climate with hot summers and mild winters (Csa in the Köppen classification). The long-term January mean at Palma it 10° C., the July mean 24.5° C. (August 24.9° C.). The mean maxima and minima of January are 14·1° and 6.0° C. respectively, of July 27.5° and 19.6° C. The absolute minimum on record is —3.0° C. The annual precipitation at the same station is 482 mm, of which 91 % fall between September and May (Jansá and Jaume, 1944). There are 74.3 days a year with rain, 1.0 with snow, 3.7 with hail.

Although the climatic means of the sea-level station at Palma are typical for the lowlands of Mallorca, considerable differences exist in the higher country. Figs. 2 and 3 indicate respectively the distribution of precipitation and the number of days with snowfall. The data, for which provided by the Boletin

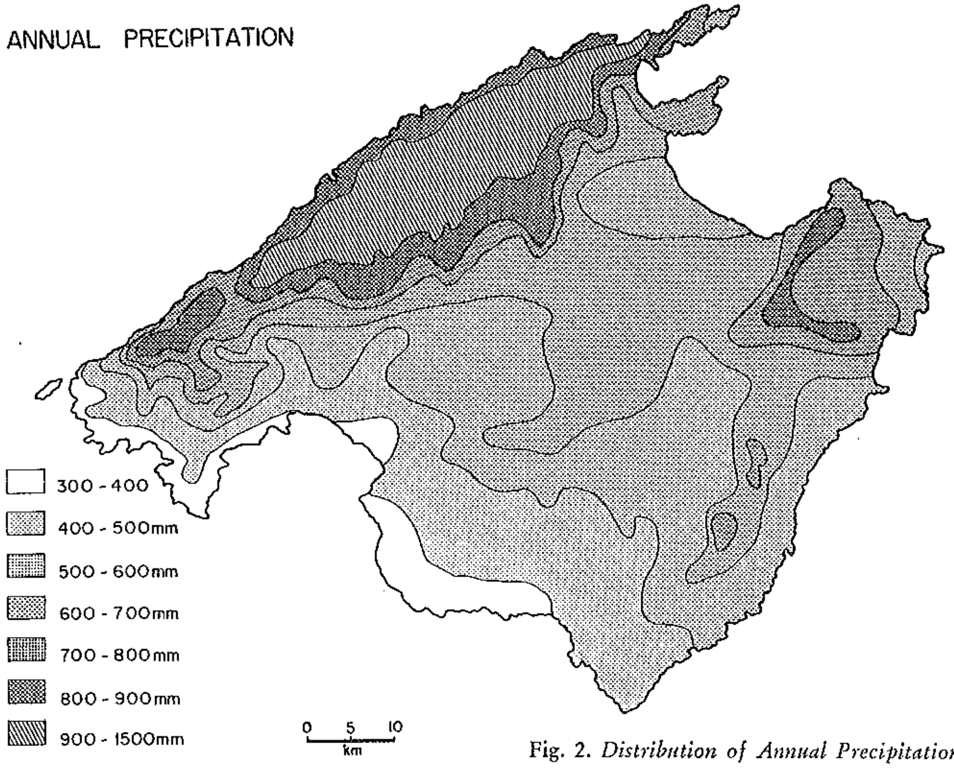

Fig. 2. *Distribution of Annual Precipitation*

mensual del Centro Meteorológico de las Baleares, is based on observations at 70 stations over the 4 year period 1954—57. Although this short-term record does not provide accurate absolute values, the vital regional differentiation is accurately portrayed. Significant is the high rainfall of 1000—1500 mm in the central parts of the Sierra Norte. Equally interesting is that although snow is practically unknown in the lowlands, 7—14 days with snow are common in the higher Sierra Norte. Even during exceptionally cold, snowy winters, however, snow does not persist for more than 1—2 weeks at above 1000 m.

Winter temperatures are mild, even in the mountains. The January mean for the Santuario de Lluch (480 m) (14 years, Jansá, pers. comm.) is 7.8° C., with the mean minimum 2.8°, mean maximum 11.3° C. At nearby Inca (120 m) these values (10 years) are 9.9°, 6.3° and 13.6° C. respectively, so that the January lapse rate in the central Sierra Norte is in the order of 0.8° C/100 m. If this value can be extrapolated, the Puig Mayor (1445 m) has a mean January temperature in the order of —1° C. Thus if the summer temperature was lowered by about 5° C., as is suggested by palaeo-temperature measurements made on Würm-age sediments from a deep-sea core in the eastern Mediterranean (C. Emiliani [1955]), theoretically only the higher mountain country of Mallorca would be removed from the mesothermal climate group.

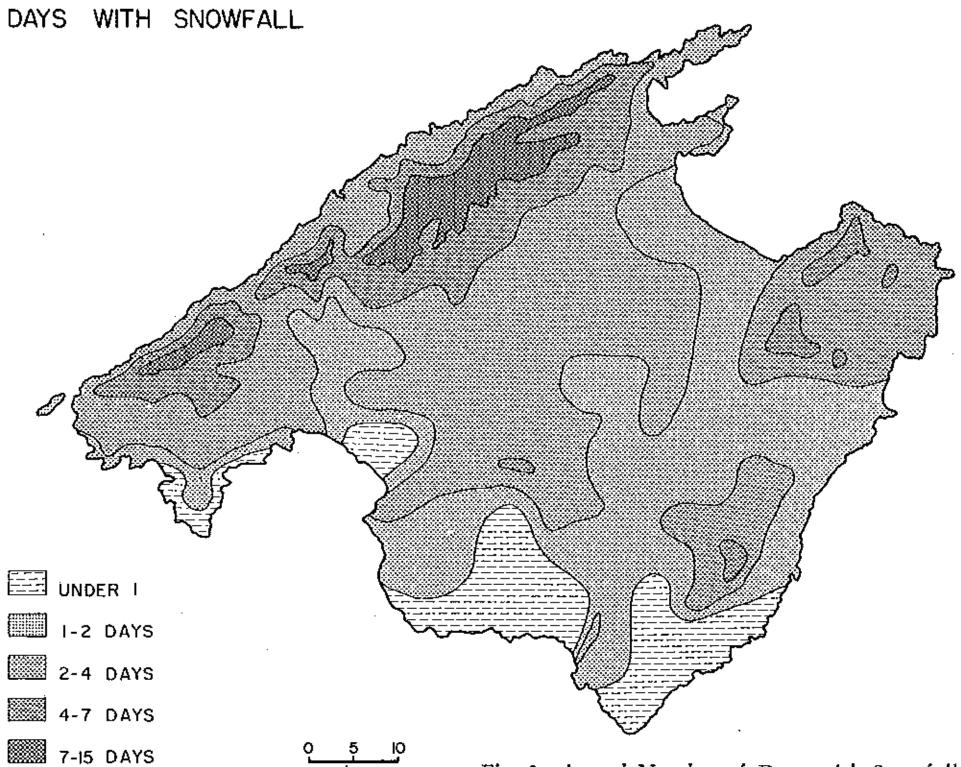

Fig. 3. *Annual Number of Days with Snowfall*

Previous Work on Cold-Climate Phenomena in the High Country

Reference to cold-climate phenomena on Mallorca has been made by MENSCHING (1955) and L. SOLÉ SABARÍS (1962).

MENSCHING'S stay in Mallorca during September of 1954 was apparently a brief one, and specific reference is only made to cold-climate features observed on the route Inca – Lluch – Gorg Blau – Sa Calobra. MENSCHING describes detrital mantles present on steeper slopes of the Sierra Norte, found above 500 m, and most frequent above 800—1000 m, sometimes reaching to lower levels in the larger valleys. The materials are angular and not thought to be fluvially transported. According to MENSCHING, they frequently permit recognition of solifluidal transport by the arrangement of rock fragments in the matrix of fines, although no details or sections are given. These detrital mantles, often several meters thick, are generally found under forest and show no relation to modern transport conditions. MENSCHING believes they resulted from Würm „pluvial solifluction", and the lack of similar deposits of pre-Wurm age is emphasized.

Solé Sabarís carried out incidental observations on cold-climate phenomena at various localities during several field seasons on the island. He reports an exposure of periglacial *brèches litées* at ca. 340 m between Palma and Soller, as well as possible cryoclastic formations at about sea-level at Rafaubeig, Cala Pí and Canyamel. The latter two sections are briefly described.

Types of Cold-Climate Phenomena observed 1959–62

During the writer's field study 1959–62 several types of cold-climate phenomena *sensu lato* were recognized, representing various degrees of intensity. These include:

(1) Fluvial and colluvial beds with mechanically-fractured pebbles. A number of lowland deposits contain appreciable proportions of pebbles that have been *mechanically fractured during or after transport*. In the former case they have been partly or fully rolled, and now show comparatively fresh fractures. In the latter case, the pebble is split *in situ*, with the parts in place or almost contiguous. Statistical studies performed by the writer on 100-specimen samples, obtained from pebbles of identical lithology and in beds having a similar degree of coarseness, showed considerable differences among sediments of different ages. The proportion of such fractured pebbles varied from 0—45 %. Although sheer mechanical impact during transport, as well as chemical weathering *in situ* may produce similar features, frost-action appears to be the most significant variable. With due restrictions, then, analysis of such fractured pebbles may give a certain index of frost-action. The method is limited to subangular and rounded gravel. The designation of „cryoclastic“ formations would seem to be justified for beds with moderate or high incidence of pebbles fractured after or during transport. A value of 30 % seems reasonable as a statistical criterion.

(2) Mechanically-fractured detritus in cave sediments *(éboulis secs)*. Mechanically-fractured rock fragments with fresh, jagged edges, and preferably flattish forms, have been considered *primarily* as the product of frost-action by various authors (particularly R. Lais [1941]). Many variables such as porosity and rainfall are involved. But the amount of fresh, fractured detritus in cave sediments (cf. E. Bonifay [1956]) bears a certain relation to congelifraction. Such *éboulis secs* are not forming in Mallorcan caves today, but did so during the last glacial. Frequent, modest freeze-thaw changes were probably more significant than intense frosts of longer duration.

(3) Colluvial deposits with evidence of contortions. Curious mixed pluvial-„periglacial“ phenomena may be observed in a large number of exposures in the lower mountain country. In transverse and longitudinal section such features often represent pockets, usually 1—2 m in diameter, in which sorting of fines according to colour bands may have taken place, and where pebbles or detritus are usually arranged in concentric, circular or semi-circular patterns (Fig. 4). In other cases, colour and stone patterns take the form of moderately convoluted beds, arranged in festoons or spherical cells, inclined downslope (Fig. 5). Such features were observed on slopes varying from 10 % to 40 %. The contorted sediment's texture varied from loam to loamy clay, the materials being derived from weakly consolidated Tertiary or Mesozoic sediments (particularly Burdi-

galian marls and Keuper siltstones) or weathered residual products. These are generally sediments that are prone to mass-sliding when lubricated. In most cases there is no noticeably different texture between bands of different colour.

Since many of these features are found as disconformable pockets excavated into otherwise undisturbed horizontal beds, running water must be partly responsible for their genesis. In some cases it was possible to show that the colour patterns only reflect the parent sediment. In all cases the slopes in question are also covered with conformable colluvia or colluvial screes (cf. analysis of such sediments by BUTZER [1963a]). However, the contortions can only be explained by viscous flow of lubricated clayey loams. The exact role of congelifluction as an accessory to colluviation and gravity movement is difficult to assess. The recognizable patterns of distribution of such features in the Sierra Norte supports the idea of frost intervention, so that the term „solifluctoidal phenomena" is suggested. Similar features have been described from Villafranchian beds at Casablanca in 100 m (RAYNAL [1956]).

(4) *Eboulis ordonnés, brèches litées,* or *grèzes litées.* Alternations of inclined strata of coarse openwork and fine beds — „sorted talus" in the sense of J. TRICART (1952), have been described in detail from Morocco by RAYNAL (1960) and occur in the Mallorcan Sierra Norte. Development is rather poor and atypical, however. In most cases there is only one 30—55 cm thick bed of 8—30 cm long limestone fragments or slabs, packed more or less parallel to the slope with little or no fine matrix. These are overlain and underlain by finer, often cemented, beds with 1—5 cm angular detritus in a matrix of silts with dispersed blocks (Figs. 6, 8). In some exceptional cases, several openwork beds were found. Such features are found on slopes of 15—40 %.

In the case of Moroccan „sorted talus", RAYNAL (1960) attributes genesis primarily to gravity and washing or sheetflooding, and only secondarily to congelifluction. Mechanical, and particularly frost-weathering produces the crude rubble. This rather qualified „cold-climate" interpretation seems to be suitable to explain these Mallorcan features as well. They are invariably found in slope breccias and colluvia – as incidental patterns which easily escape notice – so that colluviation must be considered as the primary agent. An indeterminable contribution of frost convinces the writer that the atypical Mallorcan *éboulis ordonnés* are only to be considered as cold-climate indicators in a very qualified sense.

Although large blocks and other coarse detritus may be found „stranded" and fixed on many slopes of over 20 %, particularly below sheer cliffs, the occasional linear downstream orientation cannot be considered as that of stone stripes. The orientation and spacing is irregular, and the fine and coarse materials are arranged according to sheetflood velocities as conditioned by the irregular slope surface. TRICART (1956) also attributes such aypical linear orientations to surface washing.

(5) Typical „periglacial" features. Well-developed slope sediments of outspoken „periglacial" character may be observed at one locality, on the southern face of the Puig Mayor. They suggest large-scale modeling of the relief by cold-climate agencies, represented by block streams, massive solifluction lobes of crudely stratified sorted detritus, and moderately developed *éboulis ordonnés.*

Cryoplanation-type features appear to be represented as well. These phenomena will be described below.

Soils as Stratigraphic Markers on Mallorca

The primary importance of stratigraphic dating of cold-climate phenomena hardly needs to be stressed. However, the overall lack of a coherent system of stream terraces in the Sierra Norte leaves only one general method of stratigraphic delimitation, namely soils stratigraphy. As a result of the distinctive soils developed on the Balearic Islands at various times, it is almost generally possible to recognize pre- and post-Upper Pleistocene sediments.

The Holocene climax soil on calcareous bedrock is a rendzina, while the *terra rossa* relicts or sediments are invariably pre-Upper Pleistocene (cf. KLINGE & MELLA [1958]; BUTZER [1962]; BUTZER & CUERDA [1961, 1962a, b]). Nowhere in southern Mallorca, where the writer mapped the soils and Pleistocene sediments of a 350 sq. km. area at 1 : 50 000, had any but xerorendzina soils developed on continental deposits (aeolianites and colluvial silts) of Upper Pleistocene age. The last minor phase of *terra rossa* or *terra fusca* development took place between the Tyrrhenian II and Tyrrhenian III transgressions[1]). The last major phase of *terra rossa* soil development is even older, and can be shown to precede a 4—5 m Tyrrhenian I transgression, antedating the penultimate major regressional complex of the Mediterranean Sea.

From aeolianite sections southeast of Palma, KLINGE and MELLA (1958) also concluded that the last phase of *terra rossa* development broadly coincided with the Tyrrhenian II. But they considered the *terra fusca* of the Sierra Norte as a recent soil. A few indications will be given here to show that these *terra fuscas* are also definitely relict: (1) Each of the semi-consolidated 1—4 m low terraces (pre-pottery and Upper Pleistocene) of the Sierran torrents has a rendzina soil development with moder or mulliform-moder humus, and brownish (10 YR 4-6/3-6) A-horizon colours[2]). (2) Each of the fossil Pleistocene colluvial screes or breccias of the Sierra Norte has a rendzina A-horizon of similar characteristics, whether or not the sediment itself is derived from *terra fusca* or *terra rossa* products. Most of the sediments derived from interglacial soils have a shallow moder horizon developed over deeper, fossil (B)-horizons (Fig. 7). The recent climax soil development under *Quercus ilex* woodland or grass definitely is a rendzina. (3) The friable *terra fuscas,* which are frequently preserved as sediments in karst pipes, have been altered by incipient rendzina development as is suggested by 10—25 cm of moder or mulliform-moder A-horizons of brownish (10 YR 4-5/3-4) colour on reddish yellow (5-7.5 YR 6/8) sediments.

As simplified as it may seem, a local rule for distinction of Upper Pleistocene and pre-Upper Pleistocene deposits is that *only pre-Upper Pleistocene sediments have (B)-horizons, usually with colours of 5-7.5 YR hue.* Upper Pleistocene sediments only have A-horizons, directly overlying C-horizons.

[1]) MENSCHING's (1955) suggestion that the Mallorcan *terra rossas* are of last glacial age is not based on stratigraphical or pedological evidence.

[2]) Soil colours given from dry samples according to the Munsell Soil Color Charts (Baltimore, 1954).

There are no Holocene sediments of note in the sierras, although some do occur in the lowlands.

The Lower Limit of „Solifluctoidal" Phenomena in the Sierra Norte

Northeastern Section (Lluch-Pollensa). Cold-climate phenomena are not notably developed in the northeastern Sierra Norte. Relevant sections are frequently exposed along the motor road from Inca over Lluch to Sa Calobra, or from Lluch to Pollensa. The southeastern foothills of the Sierra are masked by massive colluvial screes reaching up to about 320 m along the highway. At higher levels more or less bare Jurassic limestones are exposed, with little or no mechanically-weathered detritus. As the precipitous face is passed, colluvial deposits again assume importance above 450 m. These are nothing but angular, or subangular, fine to coarse screelike deposits, frequently crudely stratified (Fig. 7). Traces of atypical *éboulis ordonnés* are visible between KM21 and 22.5, at elevations above 650 m, and again from KM 27.5 to the Gorg Blau, above a similar lower limit. These modest features are normally confined to an irregular coarse, openwork bed in a mass of colluvial scree (Fig. 8). The stretch between Lluch and Pollensa is characterized by chemical rather than mechanical weathering, thus colluvial deposits are limited, solifluctoidal deposits absent. The same applies to the low but rugged hill country of the adjacent peninsula of Formentor.

On the northern face of the Sierra, below elevations of 600m, micro-karstic phenomena *(lapiés, Karren)* are dominant, with an almost total absence of sediments down to elevations of about 200 m. Karstic caves are present, although drainage definitely employs normal surface channels. Massive colluvial screes are also embanked against the cliffs up to 100—150 m above sea level. In many coastal exposures these contain large, well-rolled boulders. Unlike the colluvial beds of the sierran upland and on the Inca foothills, (B)-horizons are not distinctly recognizable on the Mediterranean coast.

Cold-climate features at levels above those intersected by the highway are difficult to find due to lack of exposures. However crude lines of colluvial „stone stripes" are common. On the Puig Roig (1003 m) three nivational or cryoplanational niches are excavated into the massif at about 800—900 m, with southwesterly exposure. Mobile and fixed talus fans fill their lower parts, which may coincide with structural lines. The full implication of these niches can only be determined by more intensive study.

In summary, solifluctoidal phenomena, represented by rather atypical *éboulis ordonnés,* do not occur below 650 m in the northeastern section of the Sierra Norte. Such deposits are characterized by (B)-horizons of interglacial date, and are usually fixed under *Quercus ilex* woodlands with thin rendzina soils. Extremely few colluvial or scree deposits of Upper Pleistocene age were found, except along the foot of the coastal cliffs. Cold-climate sculpture is recognizable at elevations above 800—900 m. Micro-karstic phenomena are limited to massive limestones, areas with westerly or northerly exposure, and below elevations of 600 m.

Central Section (Lluch-Soller). No sections exposing solifluctoidal features were observed in the Pla de Cuba — Gorg Blau synclinal valley at 650—800 m, since detrital beds are generally absent except for small alluvial terraces. In the valley rising beyond the Caserio Ca'ls Reys to Puig Mayor, evidence of cold-climate alluviation was observed above 750 m (Fig. 14).

On the southern face of the central Sierra Norte, alluvial beds of the piedmont alluvial plain of Palma rise to 240 m on the road from Alaró to Orient. At higher elevations bare limestone slopes are characteristic, and slope deposits, if any, are confined to colluvial or gravity screes. Colluvial deposits achieve importance at the 580 m pass between Orient and Bunyolas, and massive sediments grading onto an ancient 3—4 m stream terrace accompany the torrent downstream. Nowhere are solifluctoidal features apparent, and the mountain sculpture is not „periglacial" in aspect.

Conditions are different on the road Palma-Soller, over the pass or Coll de Soller at 470 m. Alluvial deposits spread from Palma to the foot of the mountains at ca. 250 m. Below 200 m exposures in Middle Pleistocene beds seldom or never show pebbles fractured during or after transport, although such features were observed in exposures at 230 m near the Caserio Alfabia. The alluvial plains go over into 2 m of colluvial deposits masking both the southern and northern ascents of the Coll. A section at KM 18.7 (320 m) for the first time exposes *éboulis ordonnés*, one 50 cm bed of coarse angular openwork, sandwiched between finer reddish yellow (5-7.5 YR 6/6) detritus (Fig. 6).

On the pass itself solifluctoidal phenomena could be observed in sections exposed next to the summit restaurant. Here over 80 cm of red (10 R 5/3) and yellowish gray (2.5 Y 7/4) loamy clays form parent material on which as much as 1.30 m of contorted colluvial scree, with traces of a 30 cm openwork horizon, follow a 20—30 % slope. The bizarre colour sorting of this bed undoubtedly reflects the parent material, but the well-corroded, unstratified detritus and angular blocks show definite although modest convolution. These solifluctoidal features are disconformably overlain by 30—50 cm of uncontorted colluvial scree under a rendzina-type soil.

North of the Coll at KM 22.6 (440 m) a 2 m pocket of concentrically oriented, colluvial scree is disconformably located within an otherwise undisturbed deposit. A (B) soil horizon is developed on the filling which consists of unstratified and unsorted angular detritus, much of it mechanically fractured *in situ*, within a matrix of consolidated reddish yellow silts (5 YR 6/6). This is another „solifluctoidal" feature.

At KM 23.95 (390 m) on a 25—30 % slope a 4 m section with more or less typical *éboulis ordonnés* is exposed. Three openwork beds of 50 cm each can be distinguished. A moderately developed *terra rossa* (B)- horizon is visible on top. At KM 24.75 (340 m) a section quite analogous to that at KM 18.7 is exposed on a 35 % slope. The single openwork bed was referred to by Solé Sabarís (1962). The last traces of crude sorting into coarse openwork beds are noticeable between 230—280 m, below which classical talus bedding becomes exclusive.

Northeast of Soller on the road to Fornalutx traces of openwork sorting begin at 140 m, and atypical *éboulis ordonnés* are frequent above 200 m. They are under *terra rossa* soils. Upper Pleistocene colluvial screes were also observed on the new military highway to Puig Mayor. They begin above 650—700 m elevation, and extend to the summit areas at about 1000 m without any trace of solifluctoidal phenomena or *éboulis ordonnés* (except in the form of artificial terraces!). They usually consist of fine, angular limestone rubble in a silt matrix, with moder humus and fine, polyhedral structure. The typical colour is dark brownish gray (10 YR 4/2). In fact nowhere on Mallorca were Upper Pleistocene solifluctoidal phenomena observed.

Thus it appears that the lower limit of solifluctoidal phenomena in the central Sierra Norte is at 650 m in the east and interior, 300 m in the Coll de Soller region, at 200 m in the Fornalutx region. The lower values in the west are proportional to the significance of colluvial deposits in the area. This asymmetry is partly related to the westerly and northerly rainstorms, to which the Soller area is quite exposed. Equally significant is that the thermally active slopes have more evidence of solifluctoidal features, something probably resulting from instability occasioned by alternations of temperature around 0° C. All of the features encountered are pre-Upper Pleistocene. Conspicuous „periglacial" sculpture of the high mountains can be recognized above 800—900 m, although it is always extremely difficult to distinguish between structure and sculpture in the Sierra Norte.

Western Section (Soller-Andraitx). On the road Palma-Valldemosa-Deyá a problematical feature of solifluctoidal character is exposed in a new 4 m road section near KM 15, at elevations of 260—290 m (Fig. 4). The base is formed by marly limestones (pale yellow, 5 Y 8/3) and residual loamy clays (light olive gray, 5 Y 6/2; weak red 10 R 5/3-4) with occasional coarse detritus. Remnants of a reddish brown (5 YR 5/3-4) loam, also with coarse polyhedral structure, may represent an older Pleistocene sediment or weathering zone near the surface. Great contorted pockets of reddish yellow (5 YR 5-6/6) colluvial breccias extend into these diverse sediments from the 20—25 % slope above. The irregular disconformity and contortions of the adjacent materials suggest some solifluctoidal mass-movement. Just upstream of these features an embankment of angular but crudely stratified, reddish yellow (5 YR 5/6) colluvial loam extends into an eroded pocket under the strata of marly limestone. Since traces of coarse openwork appear at 310 m nearby, the writer is inclined to evaluate these phenomena as „solifluctoidal".

Although massive colluvial screes at elevations up to 400—500 m cover the northwesterly slopes between Valldemosa and Deyá no solifluctoidal phenomena were observed. The ranges southwest of Valldemosa have few colluvial deposits, consisting largely of bare rock surfaces.

On the road Palma-Esporlas pseudo-solifluctoidal phenomena occur at KM 10 in 150 m. Some 80 cm of residual loamy clays from limestone bedrock have been crudely contorted together with fine detritus, and cemented in a sedimentary calcareous crust or *croûte zonaire* (cf. BUTZER [1963a]). The colour sorting into light gray (5 Y 7/2) clayey bands interspersed with pink to reddish yellow (5-7.5 YR 7/4-6) loams appears to reflect intermixing of inhomogeneous sediments. But the bizarre patterns of stratification still fall within the range of variation of bedding within *croûtes zonaires*. The vertical fillings of pale yellow (5 Y 8/3) or weak red (10 R 5/3) loamy clays may belong to subsequent desiccation cracks. This non-solifluctoidal feature (Fig. 9) is overlain by a brown (7.5 YR 6/3, 5/6) soil.

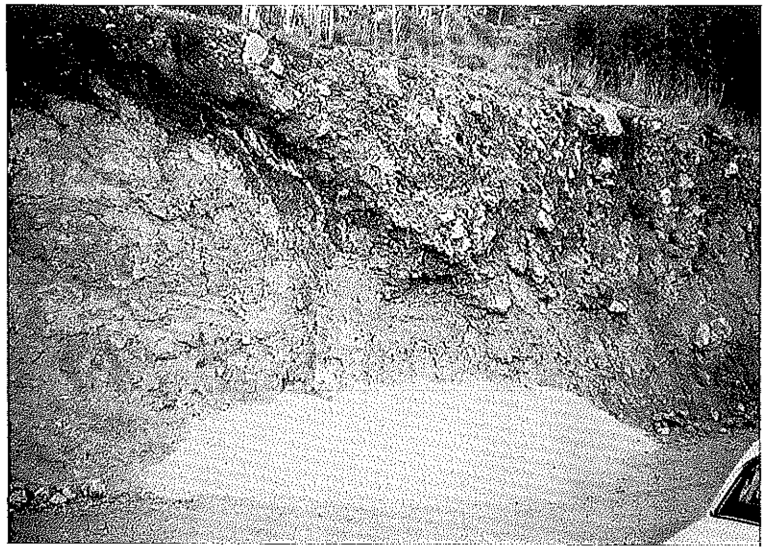

Fig. 4. "Solifluctoidal" feature near KM 15 of road Palma-Valldemosa (290 m). Description in text.

Fig. 5. "Solifluctoidal" feature near summit level between Puigpunyent and Galilea (420 m). Description in text.

Fig. 6. Atypical *éboulis ordonnés* at KM 18.7 on road Palma-Soller, on southern slope of the Coll de Soller in 320 m. The single, coarse openwork bed (without matrix) is overlain by fine colluvium and overlies slope breccia with fine matrix (see text).

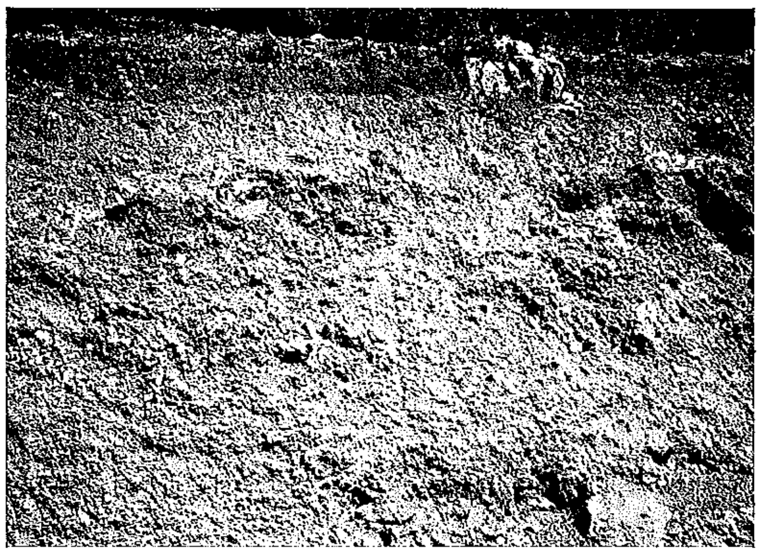

Fig. 7. Colluvial detritus with soil development at Cio. Ca'ls Reys (680 m). The black band at the surface represents a 20 cm rendzina A-horizon. This modern soil overlies a lighter coloured fossil (B)C-horizon of a *terra rossa*-type soil (10—35 cm below the A-horizon). The crudely stratified colluvium is derived from an interglacial weathering mantle.

Fig. 8. Irregular coarse "openwork" bed in colluvial scree, suggesting a rather atypical form of *éboulis ordonnés*. At Cio. Ca'ls Reys (680 m). Such marginal features are common to 100—150 m below recognizable *éboulis ordonnés* of the type shown in Fig. 6.

Fig. 9. Inhomogeneous residual and colluvial materials chaotically interbedded in a sedimentary calcareous crust *(croûte zonaire)* at KM 10 on the road Palma-Esporlas (150 m). The large white surface above hammer is a decomposed limestone block.

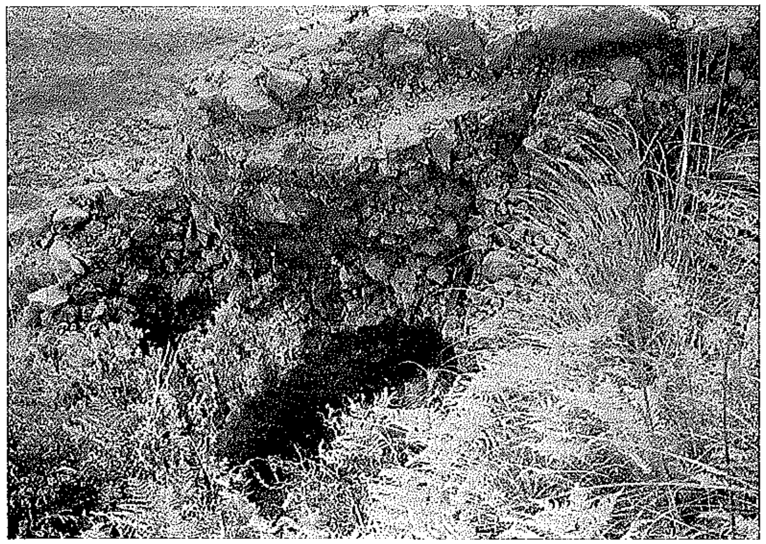

Fig. 12. Crudely stratified and sorted detritus of the solifluction lobe at Torrellas. Description in text.

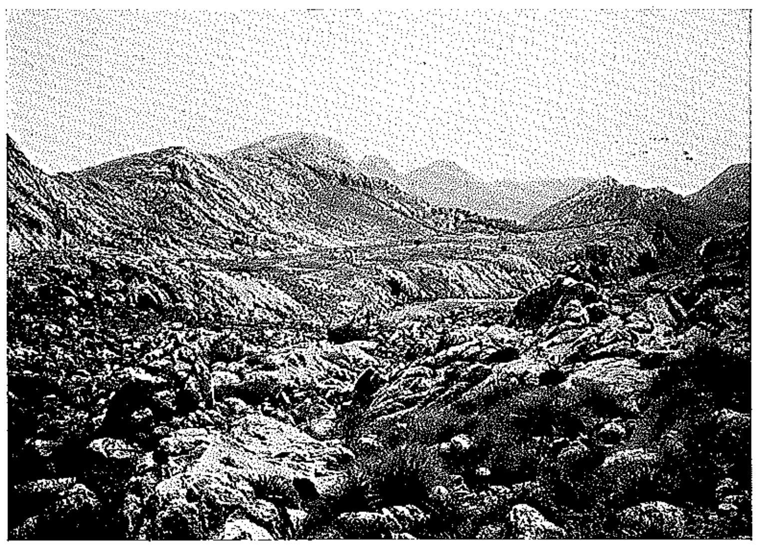

Fig. 13. Cryoplanation terrace (center) cut into Burdigalian marls and limestones at Son Torrellas, southwest of Puig Mayor (about 900 m). The Burdigalian beds here formed an anticlinal fold together with Liassic limestones, now exposed as the anticlinal ridge of S'Estret, on the left. Torrellas saddle in foreground.

Solifluctoidal forms appear above 200 m at KM 11—12, together with colluvial, linear orientations of talus on slopes in 250—400 m. Similar solifluctoidal features occur west of Esporlas at 280 m, and again on the road Esporlas-Puigpunyent, 1 km west of the Caserio Son Vich road at 380 m. On the western face of the Sierra del Ram (833 m) slopes of light brown (7.5 YR 6/4) colluvial scree show no solifluctoidal forms. These only reappear on the road Puigpunyent-Galilea at 380—430 m, where reddish yellow (7.5 YR 7/8) and light red (2.5 YR 6/8) colluvial sediments are noticeably contorted under 70 cm of very pale brown (10 YR 7/4) water-laid loam (Fig. 5). The 50 cm modern soil on the 40 % slope is a mulliform rendzina with medium granular structure. Analogous features are conspicuously absent in colluvial deposits on the road Galilea to Capdellá.

In the Sierra na Burguesa traces of atypical *éboulis ordonnés* occur down to 380 m. On the road Andraitx-Estallench-Banyalbufar noticeable *éboulis ordonnés* begin at the pass level of 360 m but descend down to 200—250 m on the seaward face of the mountains at Estallench. This lower limit again rises to 300 m at Banyalbufar as the amount of detritus decreases. Bare limestone cliffs dominate beyond the road junction Banyalbufar-Esporlas-Valldemosa.

In summary solifluctoidal features occur down to 200—250 m in the Valldemosa and Esporlas areas, as well as on the northwest face of the mountains between Banyalbufar and Estallench. However the same lower limit rapidly rises to about 400 m in the interior and on the southeastern slopes of the Sierra Norte. As far as can be said, all of these features are pre-Upper Pleistocene. A brief survey of the well-developed stream terraces of the major valleys at Esporlas, Puigpunyent and Capdellá confirms this: semiconsolidated 2—3 m low terraces (10 YR hues) contrast with cemented older conglomerates (5—7.5 YR hues). These conglomerates grade over laterally into the colluvial slope deposits. No colluvia equivalent to the low terrace exist. Noticeable „periglacial" sculpture of the high mountains is confined to elevations above 800—900 m, particularly to the Galatzó peak (1025 m).

„Periglacial" Phenomena in the Puig Mayor Region

The only true "periglacial" phenomena studied in Mallorca are located on the saddlepoint of Torrellas at 920 m, on the southeastern side of the Puig Mayor (1445 m). The features were noticed by G. Colom, A. Muntaner Darder and L. Solé Sabarís from the peak itself, but never examined. The writer studied the phenomena together with Sr. Muntaner, whose valuable collaboration is much appreciated.

Great talus fans inclined at 45 % are located at the foot of the limestone precipices of Puig Mayor. Some of these coarse talus aprons are recent and unconsolidated. Others however are semicemented with a matrix of reddish-yellow (5 YR 6-7/6) silts. These are in part truncated, exposing stratified sections of up to 5—8 m, some of which show sorting. These features are confined to the foot of the cliffs.

Further downhill various block streams with surface slopes of 12—18 % form partly dissected tongues extending down to about 850 m elevation on bedrock slopes of 25—35 %. At the saddlepoint itself a massive block stream, in part water stratified in thin horizontal bands of cemented detritus, is particularly conspicuous (Fig. 10).

Fig. 10. Blockstream with 14—18% surface on south face of Puig Mayor at Torrellas (930 m). A section of well-stratified and crudely sorted detritus is visible near the surface to the left of the larg block.

The most notable feature of the area however is a solifluction lobe (or overgrown block stream). The lobe is about 50 m long, 35 m wide, and up to over 15 m thick, and has created a kind of terrace at ca. 900 m. Contiguous with the fossil talus of the adjacent precipice the surface goes over from its concave upper margins onto a 15—20 % slope. The lower margins have been partly dissected by the small local torrent, but still largely reflect the morphology of the original lobe. The underlying bedrock slope is 30 % (Fig. 11). The material consists of crudely stratified beds of alternating coarser and finer, subangular detritus, showing moderate sorting recalling *éboulis ordonnés.* These alternating beds of mixed calibration are each about 50 cm thick. The materials are cemented by reddish yellow (5 YR 6/6) sandy silts, and contain dispersed coarse blocks aligned downhill (Fig. 12). Although the action of gravity and colluviation is obvious, the primary agencies also include gelivation and congelifluction. Together with the local block streams, these are the only sediments we can attribute primarily to morphologically active soil frost. A smaller, less characteristic lobe occurs just upstream. These features were not observed by MENSCHING (1955), who states that no detrital mantles occur around the Puig Mayor.

Downstream, „periglacial"-type stream aggradation led to alluviation of a 3—4 m terrace of well stratified, semicemented reddish yellow (5 YR 7/6) silts and fine to medium detritus, to elevations of about 750 m. The deposits decrease in elevation downstream and have been largely dissected and destroyed, and in part replaced by a semi-consolidated, 3—4 m terrace of Upper Pleistocene age extending downstream beyond the Caserio Ca'ls Reys. The dissection of the semicemented cold-climate phenomena of Torrellas leaves no doubt that they are pre-Upper Pleistocene, possibly even Lower Pleistocene.

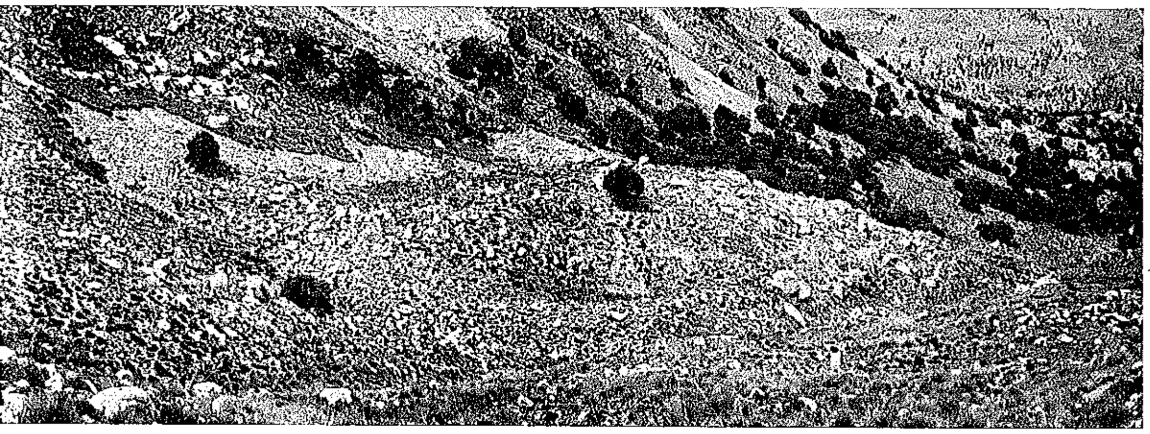

Fig. 11. Massive solifluction lobe forming a small terrace in ca. 900 m at Torrellas (Puig Mayor). Recent and fossil talus fans come in at 45% slopes on the left, a small gully dissects the terrace on the right. Blocks litter the surface (at 15—20%). Several blockstreams occur in the *Quercus ilex* woodlands downvalley (to about 850 m).

These depositional features northeast of the saddle are matched by what is frequently described as a cryoplanational terrace on the southwest side, at Son Torrellas (Figs. 13, 14). The S'Estret range here represents an anticlinal fold affecting massive Lower Liassic limestones and Burdigalian sandy marls or chalky limestones (P. Fallot [1922]). Whereas the tough Liassic has remained intact, the softer Burdigalian sediments have been planed off to a sub-horizontal surface at some 900 m. The presence of a shallow torrent channel, running parallel to the axis of folding, indicates that primary erosion was probably a result of fluvial erosion by a subsequent stream running below a hog-back ridge, at the contact between the Liassic and Burdigalian. The subsequent planation, however, can best be explained by protracted and active congelifraction.

The Possibility of Pleistocene Glaciation

With moderate effects of Pleistocene soil frost down to elevations of 250—650 m and of "periglacial" phenomena to elevations of 750—850 m, the question of Pleistocene glaciation arises. A feature of interest was noticed on the northern face of the Puig Mayor where a cirque-like form known as the Coma Freda has a floor level of about 1100 m. The morphology is that of a steep-sided valley, with a fairly well developed, steep headwall, but lacking a threshhold and without any other cirque requisites. It appears to be the result of fluvial erosion along structural lines, very probably aided by gelivation. It is certain that there has been no glaciation on the island of Mallorca.

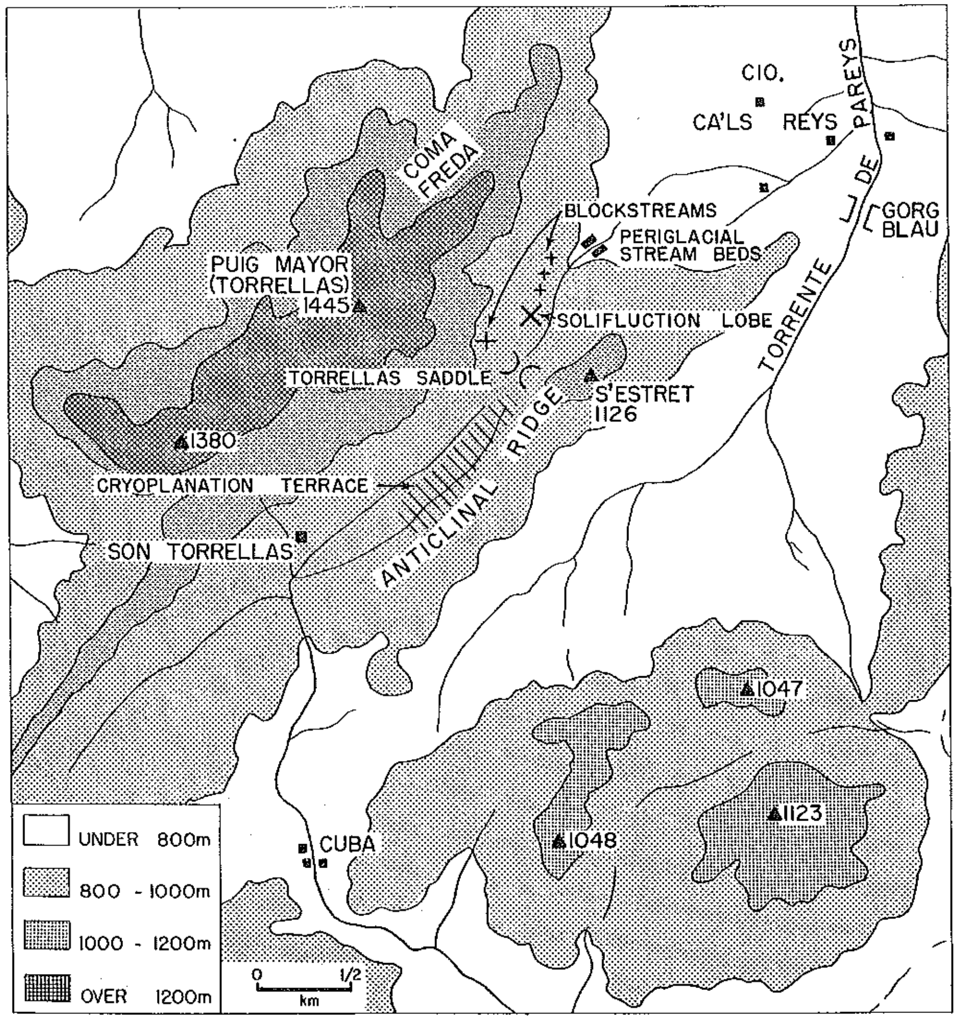

Fig. 14. Topographical situation of "periglacial" features in the Puig Mayor area.

Absence of Cold-Climate Phenomena in the Central and Eastern Sierras

The central sierra only has one mountain of importance, the Randa (543 m). The eastern sierras are subdivided into an older hill country in the south, a younger low mountain area in the north. The highest elevation of the southern section is San Salvador (509 m), while in the north the Sierra de Farruch attains 562 m, the Sierra de Artá 487 m.

In each of these minor highlands bare limestone, often with micro-karstic topography, is dominant. Colluvial breccias and talus are often absent, generally infrequent and poorly developed. Traces of dark xerorendzinas and *terra rossa* relicts may be found in crevices or fissures, while such slope deposits as do occur are generally fine and crudely stratified. Nowhere could a trace of congelifluction be observed. Not only are solifluctoidal features absent in the central and eastern sierras, but chemical weathering appears to have been more prominent than mechanical weathering during most of the Pleistocene. The minor highlands are not large enough to produce any appreciable altitudinal zonation of morphogenesis, so that features do not compare with those at similar elevations in the Sierra Norte.

Cryoclastic Deposits of the Mallorcan Lowlands

Although solifluctoidal phenomena are confined to the Sierra Norte, other less significant indicators of periodically colder climate may be found in the lowlands. These are (1) fractured pebbles, mainly of cryoclastic origin, and (2) *éboulis secs* deposits in caves.

Beds with pebbles, mechanically fractured during or after transport, are particularly common in the piedmont alluvial deposits at the foot of the Sierra Norte. According to information by Sres. CUERDA and MUNTANER, with whom many of the pertinent sections were visited, cryoclastic features were first recognized by SOLÉ SABARÍS (unpublished) in exposures at the new highway underpass near Inca, and at the cement factory just outside of Palma on the highway to Puigpunyent. Stratigraphic, pedological and gravel analysis of the Inca section by the writer showed the presence of twó, disconformable aggradation phases under a mature, red (2.5 YR 4/6 *terra rossa* of Tyrrhenian I age. Above that are younger gravels under another interglacial soil. The oldest gravels (with a mean rolling index ϱ of 50.3 % by the LÜTTIG (1956) method, and a coefficient of variation of 30 %) are mainly split *in situ*, but as a result of advanced decomposition and expansion of oxidized products. At best 14 % of the pebbles are mechanically fractured. The intermediate gravels (ϱ 48.4 %, and CV 24 %) are 36 % mechanically fractured, the younger gravels (ϱ 51.3 %, CV 13 %) only 4 %. The significance of this section is that maximum cold was attained during the Lower Pleistocene, before the Tyrrhenian I.

A similar section of the coast at Ses Penyes Rotges was first studied by Muntaner Darder (unpublished, except for brief reference in 1957). Over 30 m of pre-Tyrrhenian I deposits are exposed under sediments of a mature, red (2.5 YR 5/8) *terra rossa* and the fossil littoral dunes of two major regressional complexes. The lower gravel series (over 19 m) is strongly cemented at its base, where it could not be analyzed. It is at least 50 % mechanically fractured there, although subsequent corrosion has obscured this characteristic. The gravel of the upper parts of this series had 31 % mechanically fractured pebbles (ϱ 43.2 %, CV 38 %) and can still be considered as cryoclastic. The younger gravel series near the top of the pre-Tyrrhenian alluvial complex has 16 % mechanically fractured pebbles (ϱ 41.9 %, CV 39 %). The existence of cold climate during part of the Lower Pleistocene is again verified.

Genuine stream gravels of post-Tyrrhenian I date show little cryoclasticism anywhere on the island, and one of every two samples will show no mechanically fractured pebbles whatever. The incidence is considerably higher in colluvial gravels however, probably as a result of transport by only shallow and ephemeral waters. A stratigraphic section from Sa Plana, described in detail by BUTZER & CUERDA (1962a), shows the following incidence of mechanically fractured limestone pebbles:

	mean ρ	CV of ρ	mean 2r/L	mean (l+L)/2E	percent fractured
Holocene detritus	8.4%	106.2%	59.6	1.55	5
Upper Pleistocene (2)	9.3	129.0	—.—	—.—	(44)
Upper Pleistocene (1)	14.0	104.7	79.3	1.65	16
Middle Pleistocene (2)	11.0	72.3	81.1	1.58	4
Middle Pleistocene (1)	23.0	78.3	88.3	1.64	17

The abnormally high incidence in the younger Upper Pleistocene colluvial gravel may in part be due to chemical weathering. Considering that the Holocene detritus has 5 % fractured pebbles, low values may only be a result of mechanical impact during transport. But values of 16 and 17 % can be better explained by co-agency of frost-shattering.

Curiously, the two examples of cryoclastic formations described by SOLÉ SABARÍS (1962) are not quite valid. Solé refers to gray fine, angular, cemented detritus at Cala Pí, and gray, angular cemented deposits at the Playa de Canyamel. The Cala Pí beds in question however are nothing but large crumbs or fragments of calcified *braunlehm* embedded in a 90 cm massive, inconspicuously bedded calcite sediment (cf. BUTZER [1963a]) of the *croûte zonaire*-type (cf. DURAND [1959]). This bed is laterally conformable with true travertines. Microscopic and chemical study of a dozen such "pebbles" is conclusive to that effect. At Canyamel, fine limestone detritus is embedded in a typical *croûte zonaire*, but there is little or no evidence of fracture during or after sedimentation. The initial origin of the detritus may well have been frostweathering, but the sediment should not be called a cryoclastic formation. Stratified but unsorted, coarse slope breccias with reddish yellow (7.5 YR 7/6) silts extend up the slopes at 30—35 % angles to the cave of Artá above the Canyamel beach.

Cave deposits of the *éboulis secs*-type were studied at the entrance of the well-known cave of Artá (described by Faura y Sans, 1926) at about 45 m. and in the Cueva de Cala Santanyí. At Artá there are irregular beds of reddish yellow (7.5 YR 7/6) semicemented silty breccias with 0.5—3.0 cm long pieces of angular, limestone rubble. The silt is of aeolian derivation, and the deposit was accumulated by gravity colluviation. The detritus is typical thermoclastic detritus, although bedding is not typically that of *éboulis secs*. Scattered small bones of the extinct rupicaprine antelope *Myotragus balearicus* BATE and various birds occur within the breccia, which is analogous to continental sediments (also those of SOLÉ SABARÍS [1962]) overlying the Tyrrhenian II and III beaches at the coast below (BUTZER & CUERDA [1962b]). The deposits may be considered as evidence of greater frost action at the beginning of the last regression (glaciation).

The 1250 sq. m. Cueva de Cala Santanyí has one surface entrance at 15—16 m, presumably excavated during the Tyrrhenian I, and two subterranean entrances at at least 2 m below modern sea-level. Considerable sedimentation has taken place near the entrance, and the following sequence can be reconstructed (from top to bottom) (Fig. 15):

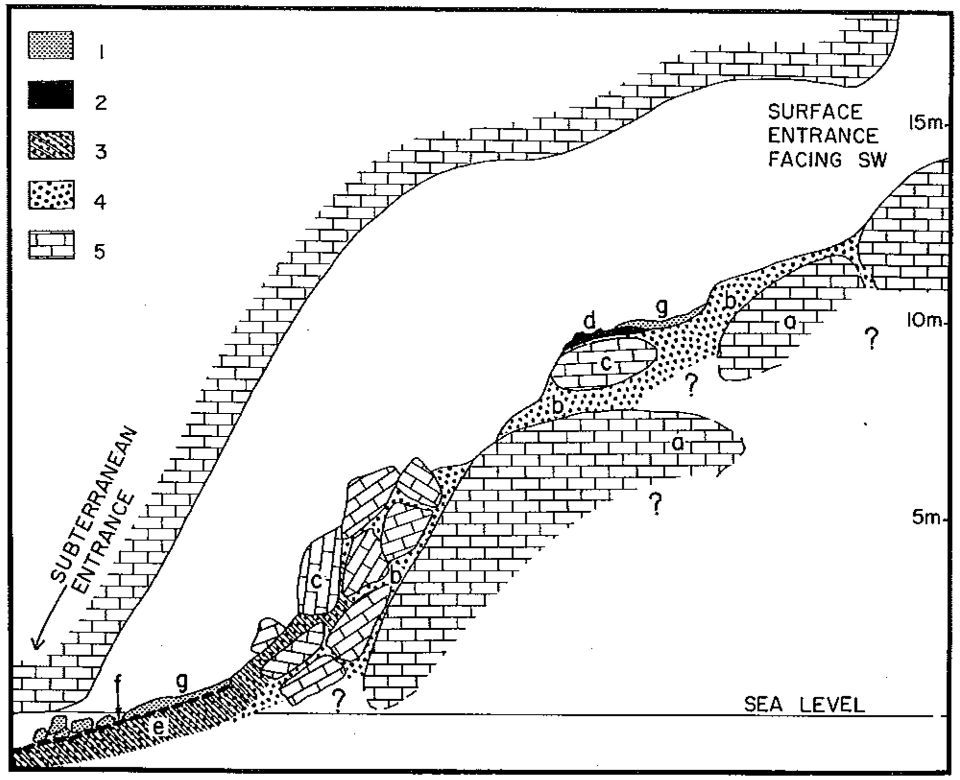

Fig. 15. Transverse section of the Cueva de Cala Santanyí. Legend: 1. recent scree; 2. stalagmites and dripstone; 3. marl; 4. grit and *éboulis secs;* 5. limestone bedrock and blocks. Letters refer to text profile. Approximately to scale.

(a) Massive limestone blocks from cave ceiling in part, surficially corroded. Pleistocene.

(b) 10 to over 80 cm unweathered, uncorroded, angular limestone grit and *éboulis secs*, with some limestone blocks. This unconsolidated, very pale brown (10 YR 7/3) detritus fills the hollows near the cave entrance, and has been transported downslope. The surface 15 cm have subsequently weathered to a light yellowish brown (10 YR 6/4). The lower part of (b) has been altered to bed (e). Upper Pleistocene (?)

(c) Great limestone boulders fallen from the ceiling surficially uncorroded. Contemporary with final part of (f).

(d) over 1.5 cm dripstone and various fossil stalagmites younger than the material of bed (e), contemporary with or older than the higher sea-level of 2–4 m. Early Holocene (?)

(e) 20- over 50 cm light brownish gray (10 YR 6/2) marl resulting from alteration *in situ* of Pleistocene sediments through intense corrosion by a marine transgression to +2—4 m.

(f) 1–1.5 mm marine clay with echinoderm spines and algal remains (identified by D. Roggan) extending up to about + lm (subrecent).

(g) Shallow surface fans of light brown (7.5 YR 7/6) limestone grit and rubble, derived from older, somewhat weathered deposits near the entrance (modern).

Beds (c) and (b) can with good probability be considered a consequence of a cold Upper Pleistocene climate.

In view of the almost total absence of frosts in the lowlands today (mean January minima at Palma +6.0° C), somewhat colder winter temperatures must have occurred during part of the Upper Pleistocene. Winter temperatures must have been at least equally cold during a part of the Middle Pleistocene, and certainly considerably colder during one or more phases of the Lower Pleistocene. No appreciable frosts of sufficient frequency can be expected unless the mean minimum temperature of the coldest month is at the freezing point. It is therefore suggested that a January temperature depression of at least 6° C is necessary to explain the cryoclastic features and *éboulis secs* of the Mallorcan lowlands during the Middle and Upper Pleistocene glacial phases. It is further suggested that a January mean of 0° C., i. e. a winter temperature depression of 10° C, would be necessary to explain the pre-Tyrrhenian I (Lower Pleistocene) phenomena of the lowlands. These are obviously crude estimates but they are on the conservative side. Appreciable winter temperature depressions, probably associated with semi-permanent inversions, have been variously suggested for Würm-age Europe (MORTENSEN [1952]; FLOHN [1953]) and may still have affected the Meditterranean area. Depression of mean annual or summer temperatures was probably less important.

Climatic-Geomorphologic Interpretation

Having completed this survey of cold-climate phenomena of various altitudinal and geographical zones of Mallorca, a more meaningful interpretation of the various classes of features will be attempted.

(a) Classical cold-climate phenomena in the form of block streams, solifluction lobes, *éboulis ordonnés*, cold-climate stream aggradation and apparent cryoplanational features are present but limited to the highest elevations about 750—850 m. The absence of ice-wedges and involutions in suitable sediments precludes the presence of permafrost on the high plateau region. The southerly or southwesterly exposure of these features suggests that frequent oscillations of freeze-and-thaw were more important than intense cold. A mixed diurnal-seasonal tjaele of subtropical type in the sense of TROLL (1948) seems to be an appropriate designation. These phenomena are definitely pre-Upper Pleistocene and possibly even Lower Pleistocene. It is suggested that such features were formed above the altitudinal woodland limit.

(b) Atypical cold-climate co-agency can be recognized in a range of "solifluctoidal" phenomena, including moderately contorted colluvial slope deposits and rather poorly developed *éboulis ordonnés*. Such features — invariably of pre-Upper Pleistocene age — occur down to 250—650, being some 200 m lower in areas exposed to the NW and W (major storms) or SW and S (most thermally active segments). This, and the correlation of intensive colluviation with solifluctoidal phenomena suggests that moisture and freeze-thaw oscillations are most significant for the distribution of such features. There is no correlation with the present distribution of absolute precipitation. The sedimentology of such beds is primarily that of colluvial slope deposits in each case. Many of the festoons and other solifluidal contortions observed are probably the result of nothing but pluvial saturation of clayey sediments with subsequent mass-sliding. In general, running water and gravity are beyond doubt the two major agents involved. Frost-weathering provided much of the material, but soil frost certainly played no more than a subsidiary role in sedimentation, mainly through loosening and promoting instability as a result of freeze-thaw alternations.

These "solifluctoidal" phenomena are then, not true cold-climate indicators but rather atypical colluvial features. While applying the term "pluvial solifluction" to features of this class, MENSCHING (1955) put major emphasis on the congelifluction aspects. Seen in the general perspective of this paper such features are only incidental and not reliable cold-climate indicators. Their delimitation does not contribute greatly to an understanding of the "periglacial cycle of erosion" in the sense of TROLL (1948). In fact such "solifluctoidal" phenomena have no direct relationship to "periglacial" morphogenesis. In this sense other references made to similar vague solifluction deposits elsewhere in subtropical latitudes may also be misleading, and may also require careful re-evaluation. The term "pluvial solifluction", as used in this Mallorcan case, is a misnomer if intended to carry significance for "periglacial" morphogenesis.

(c) The genetic class of colluvial deposits *(limons rouges)*, a characteristic Pleistocene element of the Mediterranean region, has been described in detail by the author in another publication (BUTZER [1963a]). These are predominantly fine, crudely stratified beds with a varying admixture of gravel and detritus, and frequently of interbedded tufaceous crusts. They form thin sheets on gently sloping surfaces but may attain over 5 m thickness at the bottom of moderate or steep slopes and in former topographic depressions (Fig. 7). Although aeolian components may be present, eroded *terra rossa*-type soils form the major constituent, together with a variable amount of angular to subrounded local detritus. A large number of gravel analyses from such colluvial deposits and synchronous, intercalated alluvial beds showed that both overall transport capacity and duration of effective water flow was equal to or greater than that at the same localities today. Torrential sheetflooding is considered to be the major geomorphic agency responsible, aided by gravity action in areas of accentuated slope.

Although colluviation does not occur in the Spanish Levante today, except in response to human activity, the garigue and heliophytic evergreen forests theoretically offer unlimited possibilities for violent sheetflooding to strip soil and transport detritus. The garigue has no sod grasses and little or no tuft grass while much bare soil is exposed. Even in the light oak or mixed oak-pine woodlands, dispersed coarse tuft grasses and a little sod vegetation also provide incomplete soil protection. Yet similar sod conditions exist in woodlands with less than 500 mm to more than 1000 mm precipitation today, so that a moderate change in rainfall amount would not alter the vegetation type. But an increase in rainfall amount coupled with an increase in intensity will lead to pluvial erosion and transport. Only prolonged, intensive rainfalls will saturate the dominantly coarser textured *terra rossa*-type soils to the point that they become impermeable.

This then is the primary genesis of the Mallorcan colluvial slope deposits of the Sierra Norte and its foothills, as well as of the colluvial silts widespread in the lower country[3]). Closer observation would convince any observer that there is no lower limit of 500 m to detrital mantles in Mallorca. The only lower limit of detrital spreads is that set where colluvial beds grade into alluvial deposits. The subtype of colluvial slope deposits with "solifluctoidal" phenomena marks the Pleistocene morphogenetic transition simultaneously recording both greater cold and greater moisture in the subtropics. It is suggested that these features were formed below the altitudinal tree-limit, with an open, lightly-stocked woodland on surfaces with less than 25—30 % slope. Unfortunately, corroborative paleobotanical evidence is lacking to date, as the one pollen core from Palma Nova (Menéndez-Amor & Florschütz [1961]) only extends back into the Atlantic period.

(d) Cryoclastic phenomena in lowland beds of alluvial and colluvial type certainly do not qualify as morphologically significant effects of soil frost. But these features provide valuable insight into the different intensity of cold during glacials of the Lower, Middle and Upper Pleistocene. Pluvial-colluvial phenomena of the Upper Pleistocene are rather limited in area, and the formation of the great piedmont alluvial plains adjacent to the Sierra Norte was completed during the Middle Pleistocene. It is possible to conclude that the Upper Pleistocene was the least effective of the Pleistocene morphodynamic phases of Mallorca. Maximum cold (January temperature depressions of 10° C ?) is recorded during one or more Lower Pleistocene glacials, which suggests that a fair part of the "solifluctoidal" features of the Sierra Norte may be older than the Middle Pleistocene — provided of course that such features were not destroyed during the penultimate glacial.

Comparative Observations on the Spanish Mainland

Although a review of analogous cold-climate phenomena studied on the peninsula would go beyond the scope of this paper, a few comparative remarks can be made.

In the Cordillera Costera (to 531 m) of the province of Gerona between the rivers Tordera and Ter, "periglacial" phenomena are absent (Butzer [1964]). "Solifluctoidal" phenomena of Lower Pleistocene age could be observed at elevations as low as 120 m however, and Pleistocene cryoclastic sediments variously occur down to modern sea-level. Younger "solifluctoidal" features are absent in the area. Pleistocene colluvial deposits occur at all levels, and alluvial deposits of regressional age are prominent. Conditions are then quite analogous to those of Mallorca.

In the Ebro Valley near Zaragoza, Johnsson (1960) has described an ice-wedge, as well as involutions and cryoclastic phenomena in Middle or Upper Pleistocene gravel terraces at about 200 m. The writer had opportunity to study the terraces of the Upper Jalón in some detail, and to check several kilometers of gravel pit exposures on the lower Jalón at Zaragoza, and on the south bank of the Ebro below Zaragoza. There are no traces of either "periglacial" or solifluctoidal

[3]) K. Wiche (1961) independently comes to similar conclusions concerning the genesis of colluvial deposits in Murcia, emphasizing the facility of confusion between colluvial and "periglacial" detrital deposits.

phenomena in the Upper Jalón terraces below elevations of 1000 m. Only occasional solifluctoidal phenomena could be observed in the Zaragoza area. Mechanically-fractured pebbles are present in some beds, but seldom constitute as much as 5 % of the specimens in samples counted. Similarly ice-wedges were conspicuously missing. The illustration of an "ice-wedge" provided by JOHNSSON (1960, Fig. 3) suggests several possible explanations. The writer is particularly disturbed by absence of deformation in the contacting sediments. In short the evidence presented to the effect of "periglacial" phenomena in the Zaragoza area is not convincing and requires detailed study.

In the southeastern part of the province of Soria, Upper or Middle Pleistocene colluvial slope breccias with traces of solifluction occur down to elevations of 1050 m on slopes of 20–40 %. Involutions are absent in regions up to 1300 m, as are block streams or *éboulis ordonnés* (BUTZER [1963b]). Although cryoclastic beds and certain evidence of congelifluction of Lower Pleistocene age occur (LYNCH *et al.* [1964]), ice-wedges are still absent in 1000–1200 m. FRÄNZLE (1959) describes detrital mantles *(Wanderschuttdecken)* from nearby Rello (1050 m) which he suggests as possible evidence of dominantly solifluidal transport. Such features are identical to what the writer considers as colluvial screes and products of pluvial aggradation on the basis of gravel analyses and macro-sedimentological field study. This again is the same problem of differentiating between "periglacial" detritus on the one hand, colluvial mantles on the other. There is little doubt however that the Sorian detritus was primarily derived from congelifracts.

Zusammenfassung

Eine Untersuchung der Quartärablagerungen und -stratigraphie Mallorcas führte zu folgenden Ergebnissen:

(1) Typische „periglazial" Morphogenese in Form von Blockströmen, Solifluktionszungen, *éboulis ordonnés* und mögliche Kryoplanationserscheinungen konnte oberhalb 850 m festgestellt werden, mit Anzeichen von „periglazialer" Flußaufschüttung bis etwa 750 m hinunter. Diese Bildungen sind jeweils vor dem Jungpleistozän anzusetzen, und weisen auf eine ehemalige gemischte tageszeitliche-jahreszeitliche Tjaele hin — oberhalb der Waldgrenze.

(2) Atypische solifluktions-ähnliche Erscheinungen, i. b. mäßig gewürgte kolluviale Hangablagerungen und wenig charakteristische, schwach ausgebildete *éboulis ordonnés,* haben eine Untergrenze von 250—650 m, sind aber auf die Nordsierra beschränkt. Diese Bildungen sind ebenfalls ausschließlich Alt- oder Mittelpleistozänen Alters, können aber nicht als Zeugen „periglazialer" Formenbildung gelten. Für die eigentliche Ablagerung waren Wasser- und Schwerkrafteinwirkungen sicherlich entscheidend, wobei der Bodenfrost — durch die Materialauflockerung — wohl eine Nebenrolle spielte. Die Bezeichnung „pluviale Solifluktion" wird als nicht befriedigend angesehen, da sie immerhin auf vorwiegende Kongelifluktion hinweist. Die Bedeutung dieser charakteristisch subtropischen Sedimente liegt darin, daß diese den morphogenetischen Übergang zwischen den Einwirkungen größerer Kälte einerseits, bzw. höherer und intensiverer Niederschläge andererseits, für das Eiszeitalter belegen.

(3) Diese solifluktions-ähnlichen Erscheinungen werden als Unterklasse der charakteristischen Kolluvialaufschüttungen *(limons rouges)* der mediterranen Pluvialklimate angesehen: Silts, Konglomerate und Hangbreccien, die auf pluvialzeitliche Erosion und Transport unter Trockenwald zurückzuführen sind.

(4) Gerölle, die während oder nach dem Transport mechanisch zertrümmert wurden, können als relativer Index der Frostsprengung dienen, und liefern daher — bei vorsichtiger Anwendung — wertvolle Information. Ablagerungen mit einer hohen Anzahl zersplitterten Gerölls sind auf das Altpleistozän (vor dem Tyrrhenien I) beschränkt; für diese Zeit ist eine Januar-Temperaturdepression von etwa 10° C anzunehmen. Die Bedeutung der mechanischen Zertrümmerung ist bei den jüngeren Ablagerungen geringer; für die Kaltzeiten des Mittel- und Jungpleistozäns kann eine Januar-Temperaturerniedrigung von etwa 6° C angenommen werden.

(5) Vergleichende Beobachtungen kaltzeitlicher Bildungen in den Provinzen Gerona, Zaragoza und Soria deuten auf analoge Verhältnisse zu denen Mallorcas. Auch gibt es dort ähnliche Schwierigkeiten bei der altitudinalen Differenzierung „periglazialer" und pluvialer Erscheinungen.

Résumé

L'étude des sédiments et de la stratigraphie du Pléistocène de Majorque conduit aux résultats suivants:

1) Une morphogénèse typiquement «périglaciaire» peut être prouvée au-dessus de 850 m, sous forme de coulées de blocs, langues de solifluction, éboulis ordonnés et, semble-t-il, phénomenès de cryoplanation, avec, jusqu' à 750 m, des marques d'alluvionnement de rivières «periglaciaires». Ces formations sont à chaque fois datées d'avant le Pléistocène récent. Elles témoignent d'un sous-sol gelé, mixte: saisonnier et diurne, au dessus de la limite de la forêt.

2) Des phénomènes atypiques à apparence de solifluction, comprenant des dépôts de versants colluviaux involutions modérées et des éboulis ordonnés peu caractéristiques et faiblement développés, ont une limite inférieure vers 250—650 m, mais sont limités à la Sierra du Nord. Ces formations sont aussi datées exclusivement du Pléistocène ancien et moyen, mais ne peuvent être considérées comme significatives d'une morphogénèse «périglaciaire». L'eau et l'action de la gravité furent visiblement les facteurs essentiels de dépôt, tandis que le gel du sol ne jouait qu'un rôle secondaire en ameublissant les matériaux. La dénomination «solifluction pluviale» n'est pas satisfaisante car elle dénoterait la prédominance de la congélifluction. Ces sédiments spécifiquement subtropicaux prouvent le passage latéral, dans la morphogénèse, au Pléistocène, entre les actions dues aux froids intenses d'une part, et celles dues aux précipitations plus importantes et intenses de l'autre.

3) Ces phénomènes à apparence de solifluction sont considérés comme un sous-type des sédiments colluviaux (limons rouges) caractéristiques des climats pluviaux méditerranéens (BUTZER [1963a]). Ces limons, graviers et dépôts détritiques sont le résultat de l'érosion lors de ces climats pluviaux et du transport sous forêt séche (sauf sur talus excédant 25—30 %).

4) Les galets qui ont été mécaniquement concassés pendant ou après le transport peuvent être considérés comme indicateurs relatifs de l'action du gel et peuvent fournir des informations intéressantes, moyennant prudence cependant. Les dépôts qui ont un fort pourcentage de galets éclatés se limitent au Pléistocène ancien (avant le Tyrrhénien I); il faut admettre pour cette époque un abaissement de la température moyenne de Janvier d'environ 10° C. Le concassage mécanique est moindre dans les dépôts plus récents. Un abaissement de la température moyenne de janvier d'environ 6° C pendant les glaciations du pléistocène moyen et récent est vraisemblable.

5) Les observations faites sur les formations des périodes froides dans les provinces de Gerone, Saragosse et Soria montrent des conditions analogues à celles de Majorque; là aussi se présentent des difficultés semblables dans la délimitation en altitude des phénoménes pluviaux et «périglaciaires».

Resumen

Los estudios verificados sobre los sedimentos y la estratigrafia del Pleistoceno de Mallorca, sugieren las siguientes conclusiones acerca de los procesos de clima frio:

(1) Morfogénesis "periglacial" típica representada por mares de bloques, lóbulos de solifluxión, *éboulis ordonnés,* y formas de crioplanación ocurridas por encima de los 850 m, con evidencia de aluviación "periglacial" que desciende hasta cerca de los 750 m. Estas acciones son cronológicamente anteriores al Pleistoceno Superior. Ellas suponen un tjaele diurnal-estacional, por encima del límite altitudinal de las zonas de arbolada.

(2) Fenómenos de solifluxión atípicos, incluyendo depósitos de escarpes coluviales moderadamente revueltos y *éboulis ordonnés* no característicos y pobremente desarrollados, se observan a elevaciones del orden de los 250—650 m, pero estan limitados a la Sierra Norte. Son también exclusivamente de edad anterior al Pleistoceno Superior, pero no son considerados como indicadores de morfogenesis "periglacial". Ello hace pensar que las corrientes de aqua y la acción de la gravedad fueron los dos principales agentes deposicionales y que el suelo de helada únicamente jugó un menor papel en sedimentación causando inestabilidad y soltura. La aplicación del término "solifluxión pluvial" para tales hechos debe considerarse inadecuada, en atención a su connotación a una congelifluxión dominante. La importancia de tales sedimentos característicos subtropicales estriba en que ellos registran la transición morfogenética pleistocena resultante por un lado de los más grandes fríos y por otro de las más intensas precipitaciones.

(3) Los fenómenos atípicos de solifluxión son considerados como un subtipo de los sedimentos coluviales (limos rojos) característicos de los climas pluviales en la región mediterránea. Estos limos, gravas y depósitos detríticos son el resultado de la erosión pluvial, y transporte en suelo de bosque (excepto en pendientes que excedan de 25—30 %).

(4) Cantos fracturados mecánicamente durante o después de su transporte, son considerados como un índice relativo de meteorización debida a las heladas.

Los depósitos con un alto componente crioclástico están limitados al Pleistoceno Inferior (pre-Tirreniense I) sugiriendo una depresión de temperatura media en invierno de al menos 10° C. Una mayor limitación de incidencia de cantos fracturados mecánicamente en depósitos posteriores, en varias partes de la Isla, sugiere que las fases glaciales del Pleistoceno Medio y Superior experimentaron en Enero depresiones de temperatura al menos de 6° C.

(5) Observaciones comparativas de fenómenos de clima frio en las provincias de Gerona, Zaragoza y Soria, sugieren que las condiciones fueron análogas, y que también existen dificultades como la de la delimitación altitudinal de los fenómenos "periglaciales" y pluviales.

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