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Stretching normal to the regional thrust displacement in a thrust–wrench shear zone, Rehamna Massif, Morocco

J. L. LAGARDE

Faculté des Sciences, BP S 15, Marrakech, Morocco and C.A.E.S. (CNRS), 35042 Rennes, France

and

A. MICHARD

Laboratoire de Géologie Structurale, 1, rue Blessig, 67084 Strasbourg, France

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Abstract—The Hercynian Rehamna Massif of Morocco is located in the Meseta belt, on the sheared boundary between the weakly strained Western Meseta Coastal Block and an intensely deformed Carboniferous basin. Deformation may be related to three superposed phases. The most important phases (D_1 and D_2) result in a main composite S_{1-2} foliation and are related to westward thrusting. D_4 is contemporaneous with the emplacement of syn- to late tectonic granitic plutons. Fold asymmetry and microstructures (rotated garnets, *S/C* tectonites) suggest a dominant, westward thrusting in eastern Rehamna. In central Rehamna, along the thrust zone front, stretching lineations are almost normal to the regional, coeval thrust displacement direction, and microstructures (rotated garnets, shear bands, asymmetrical pressure shadows) observed along the λ_1 direction (stretching lineation direction) suggest dextral, reverse southward wrenching. This particular strain pattern is interpreted as a product of thrust–wrench shearing, combining ductile thrusting and wrenching during the progressive, synmetamorphic shortening of the area, along the frontal tip of the Central Meseta thrust units.

INTRODUCTION AND GEOLOGICAL SETTING

STUDIES of finite strain in thrust zones show numerous examples of large areas with longitudinal stretching lineations almost parallel to the thrust front and normal to the regional thrust transport direction. This longitudinal stretching is known in high-crustal level thin-skinned thrust zones such as the Caledonian Moine thrust zone (Fisher & Coward 1982, Butler 1982, Coward 1984) and also in deeper-level ductile thrust zones such as the Scandinavian Caledonides (Lisle, 1984) or the Variscan belt (Matte & Ribeiro 1975, Gapais & Lagarde 1977, Brun & Burg 1982). The interpretations of such longitudinal strains are varied. In the Scandinavian Caledonides, longitudinal stretching is related to a Silurian deformation superposed on an earlier, transverse strain (Lisle 1984). In the Variscan belt, Brun & Burg (1982) integrate longitudinal strain in a kinematic model combining two orthogonal shear components. Furthermore, Coward & Potts (1983) showed that longitudinal strain may be explained in terms of differential movements and are related to complex strain patterns developed at the frontal tips of thrust zones.

The present paper illustrates a case of longitudinal strain parallel to the front of a Variscan thrust zone, located in the SW Moroccan Meseta. After describing strain patterns, criteria showing the variations in deformation kinematics are examined. A model of thrust–wrench shearing is proposed. In this model, the major thrusting changes progressively into wrenching at the frontal tip of the thrust zone.

The Moroccan Meseta

The central and western parts of the Moroccan Meseta display a nearly complete Paleozoic sequence, folded during a Late Carboniferous (mainly Early Westphalian) tectonic event (Michard 1976, 1982, Hollard 1978). Deformation is concentrated within the central area (Fig. 1), a former Late Devonian–Early Carboniferous

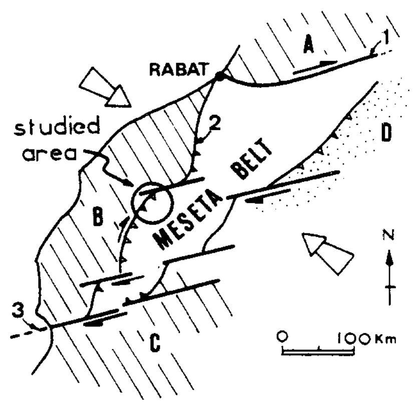

Fig. 1. Location of the studied area (Rehamna massif) in the frame of the Hercynian Meseta belt, Morocco. Ruled: relatively rigid blocks during Late Carboniferous orogeny. A: Caledonian block; B: Western Meseta block; C: Pre-Sahara foreland. Dots (D): Late Devonian fold belt. Large arrows: regional shortening direction. Half arrows: main transcurrent faults. 1: Rabat-Tiflet fault zone; 2: Western Meseta shear zone; 3: Tizi n'Test fault zone. Triangles: thrust faults.

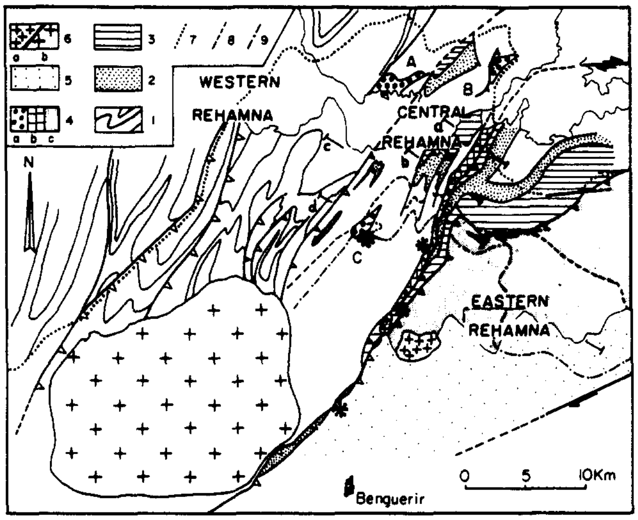

Fig. 2. Geological sketch map of the Rehamna massif (from Michard 1982). 1: Cambrian; 2: Lower Ordovician; 3: Upper Ordovician–Silurian; 4: Devonian (a: conglomerates; b: limestones and quartzites; c: shales and quartzites); 5: Visean; 6: Hercynian granites (a: leucogranites; b: calcalkaline granite); 7–9: Barrovian metamorphism isogrades (7: muscovite +; 8: biotite +; 9: garnet and staurolite +). Stars: kyanite occurrences. Triangles: thrust faults. A, B, C: areas for measurements of strained pebbles (Fig. 11). a, b, c: cross-sections, Fig. 3. d: cross-section, Fig. 10. Areas without ornament and with a serrated limit (south of A, east of B): Cretaceous cover.

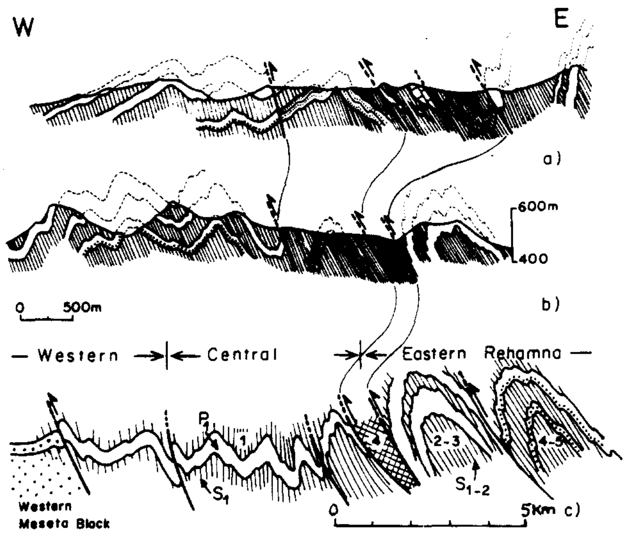

Fig. 3. Structural cross-sections in the Rehamna massif (location: Fig. 2); a & b: two cross-sections showing the evolution, from north (a) to south (b), from upright to reclined folds, in northern central Rehamna, and the westward-verging folds of eastern Rehamna (from Pique *et al.* 1982). c: schematic cross-section parallel to regional thrust movement; from east to west, the reclined folds of eastern Rehamna progressively change into nearly upright folds in the westernmost central Rehamna and in the Western Meseta Coastal block. 1 to 5: stratigraphic units, as for Fig. 2).

basin which was limited by uplifted, relatively rigid blocks on its N, W and S boundaries, and by a Late Devonian foldbelt to the E (Michard & Pique 1979, Marhoumi *et al.* 1983). In the central and western Meseta (Hercynian foldbelt *s.s.*), deformation is strikingly heterogeneous; narrow zones of strong deformation and high-grade metamorphism contrast with larger, moderately folded areas, with low-grade metamorphism. The narrow, deformed zones show a steeply dipping foliation and are commonly spatially associated with syn- to late kinematic granites (Pique 1979, Lagarde & Choukroune 1982, Lagarde & Roddaz 1983). The mean Hercynian shortening direction was NW–SE as indicated by foliation trajectories, major fold trends and syn-folding conjugate wrench faults. Folds usually verge westward, consistent with displacement on late thrusts (Guezou & Michard 1976, Michard *et al.* 1978, Cornee *et al.* 1982).

The Rehamna Massif

Synmetamorphic deformation of the Rehamna Massif occurred during the Westphalian. Three structural domains may be recognized (Figs. 2 and 3). The Eastern Rehamna massif (Ordovician to Late Viséan) is characterized by overturned, westward-verging folds. Their axes are frequently curved and the stretching lineation is down-dip. The central Rehamna (Cambrian to Middle Devonian) is a strongly folded area with moderately inclined folds. Fold axes are subhorizontal or slightly curved. Stretching is very intense and the stretching lineation is subparallel to fold axes. This area is a part of the western Meseta shear zone which extends from Rabat to the southwesternmost Meseta (Fig. 2) and has been shown to involve dextral displacements during the Hercynian compression (Pique *et al.* 1980). The Western Rehamna (Cambrian–Ordovician) belongs to the western Meseta coastal block where folds and associated cleavages of the more easterly zones are less important (Guezou & Michard 1976).

Recrystallization occurred during two main phases of metamorphism (Michard 1976, Hoepffner *et al.* 1982): (i) a prograde, Barrovian metamorphism grading up to amphibolite facies in the southernmost parts of central and eastern Rehamna (Fig. 2); (ii) a contact, high-temperature, low-pressure metamorphism around granitic plutons. These plutons consist of leucogranitic and calcalkaline granites, showing alkaline tendency (Fig. 2) (Cherotsky & Choubert 1973).

POLYPHASE DEFORMATION

Three main phases of syn-metamorphic deformation were recognized in the Rehamna massif (Pique *et al.* 1982).

First phase (D_1)

The D_1 deformation give rise to NNE-trending, WNW-facing folds, during prograde metamorphism in the greenschist facies. Outside the Barrovian metamorphic zones, D_1 forms the major deformation phase. F_1 folds show a variation in style from class 1C to class 2 (Fig. 4). S_1 cleavages, associated with F_1 folds, cross-cut bedding planes and cleavage fans related to lithological variations may be observed. Cleavage-bedding intersections form well-developed lineations parallel to fold hinges, which plunge gently to the N (Fig. 5a).

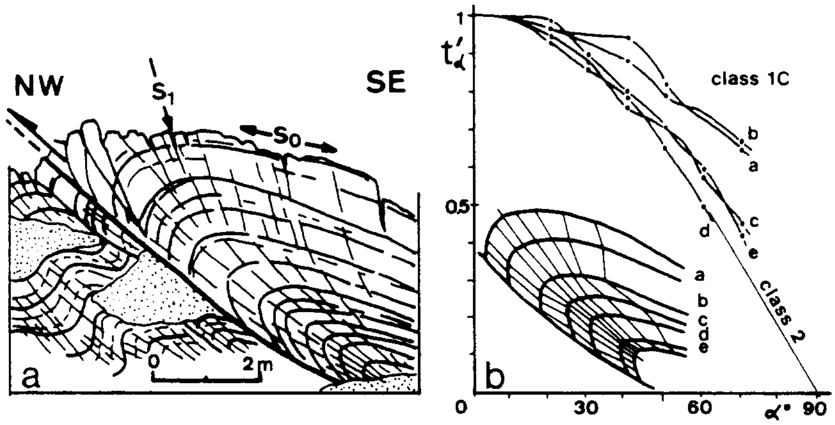

Fig. 4. D_1 folding. (a) NW facing F_1 folds in the Lower Ordovician quartzite, northern part of the thrust zone between eastern and central Rehamna (from Pique *et al.* 1982). (b) t'α plot (Ramsay 1967, p. 361) for some F_1-folded layers from (a), showing variation from class 1C to class 2. Inset shows dip isogons.

Second phase (D_2)

The D_2 deformation occurred mainly within the Barrovian metamorphic zones and accompanied the climax of the metamorphism. The increase of D_2 deformation may be correlated with the increase of metamorphic grade. In the eastern Rehamna units, D_2 is characterized by a ductile westward thrusting. S_1 cleavage and bedding are deformed by F_2 folds with an S_2 axial plane-foliation (Figs. 6a & b). The intensity of F_2 folding increases toward south central Rehamna, where F_2 folds become isoclinal and strongly sheared in the eastward-dipping S_2 foliation (Fig. 6c). F_2 fold axes are curved in the S_2 axial-plane foliation and show a great variation in plunge (Fig. 5b). Away from F_2 fold hinges, S_1 and S_2 form a composite S_{1-2} foliation which is ubiquitous in the highly metamorphic zone of eastern and central Rehamna.

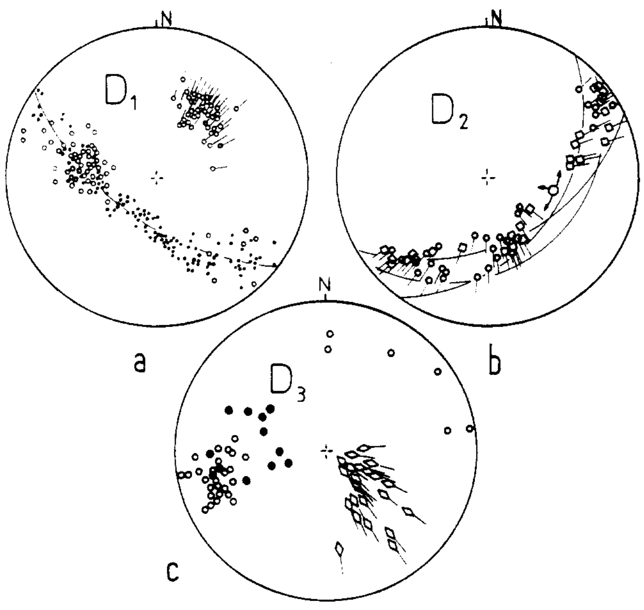

Fig. 5. Fold orientation data (Wulff stereonet, lower hemisphere projection). (a) D_1 phase in northern central Rehamna. Dots: bedding; open circles: S_1 cleavage; circle-and-line symbols: intersection lineations (F_1 fold axes). (b) dispersion of D_1–D_2 linear structures during D_2 thrusting in eastern Rehamna; circles: F_1–F_2 fold axes; squares: intersection lineations; circle with arrows: constructed slip line (Hansen 1971). (c) D_3 phase: two sets of small structures are distinguished: an S_3 crenulation cleavage (open circles), axial planar for F_3 upright folds (lozenges), and S_{3c} shear bands (closed circles), an extensional crenulation cleavage which develops in the vicinity of the granitic plutons (from Jenny 1974 and personal data).

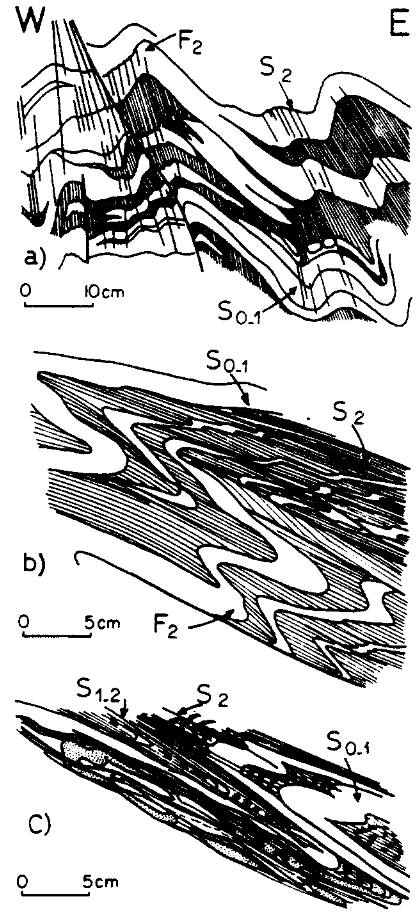

Fig. 6. Change in F_2 fold geometry related to increasing D_2 thrusting shear in the micaschists with quartzitic layers (white) from eastern Rehamna. (a) inclined F_2 folds with an S_2 axial plane cleavage oblique to the S_{0-1} tectonic bedding. (b) reclined, asymmetrical F_2 folds associated with discrete thrust planes, nearly parallel to the S_2 foliation; (c) reclined, isoclinal F_2 folds, strongly sheared along the S_2 foliation. Away from fold hinges, S_1 and S_2 form a composite foliation S_{1-2} (from Jenny 1974 and Pique *et al.* 1982).

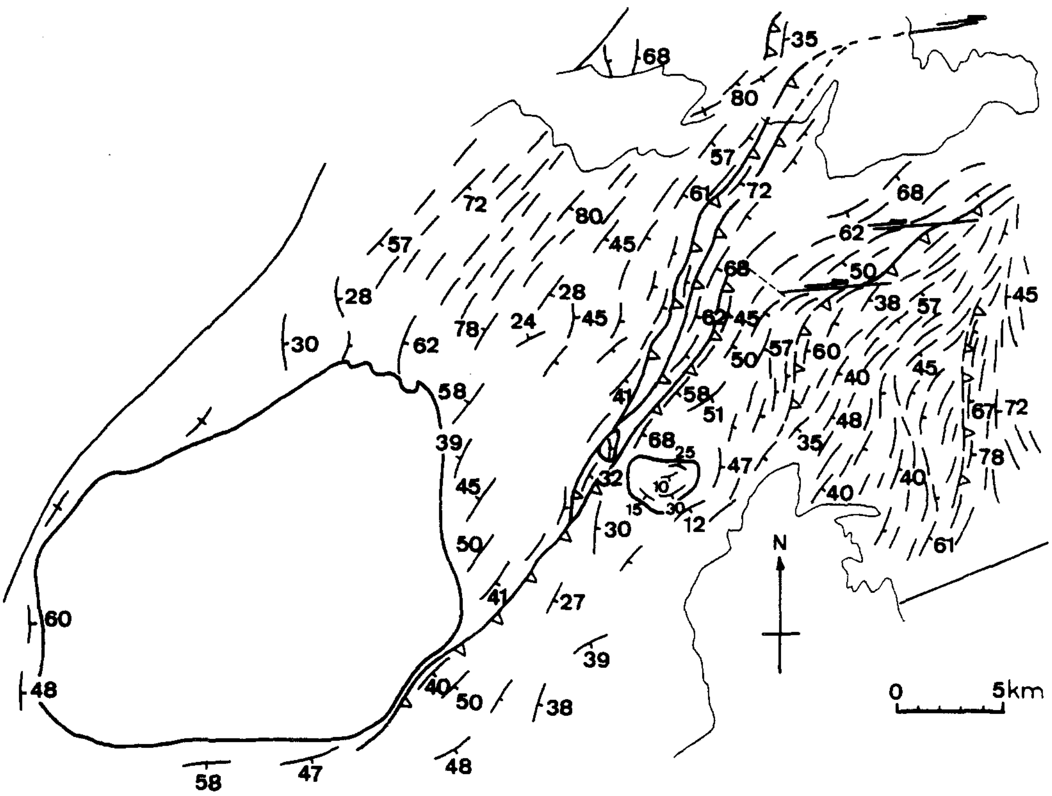

Fig. 8. Foliation trajectories map, showing the regional NE–SW trend and eastward dip of the foliation. Note its curvature along ENE–WSW trending, dextral strike-slip faults. Triangles: main ductile thrust zones. Geological limits: see Fig. 2.

Third phase (D_3)

The D_3 deformation is contemporaneous with granitic plutons emplaced during the late recrystallization of Barrovian metamorphism. D_3 is characterized by a weak S_3 crenulation cleavage, axial-planar to late upright folds. Around granitic plutons, in the strongly deformed central zone, the S_3 cleavage consists of shear bands (S_{3c}) indicating further extension parallel to S_{1-2}, in non-coaxial conditions of strain (Fig. 7e) (Platt & Vissers 1980, White *et al.* 1980).

STRAIN PATTERNS

Strain trajectories

Flattening-plane (S_1 or S_{1-2}) trajectories are characterized by (Fig. 8) a regional NE–SW trend, a general eastward dip, dextral curvature and sigmoidal patterns along dextral ENE strike-slip faults, and parallelism of S_{1-2} with the leucogranite boundary but local cross-cutting relationships with the western calc-alkaline pluton boundary.

Stretching directions (λ_1) are indicated by long axes of pressure shadows, long axes of strained pebbles or elongate, clastic or metamorphic minerals. λ_1 trajectories are characterized by (Fig. 9) a progressive decrease in plunge from E to W: λ_1 is steeply down-dip in the eastern Rehamna and shallow plunging in the central Rehamna. They have an arcuate pattern with northward plunges in the northern parts of central Rehamna and southward plunges in the southern parts and an increase in plunge along discrete westward thrust zones. However, the thrust zone separating eastern from central Rehamna (zone 4, Fig. 3) shows an intense subhorizontal stretching normal to the thrust transport direction.

Shear-strain gradients

In the strongly deformed zone including central Rehamna and westernmost zones of eastern Rehamna, synkinematic D_1–D_2 garnets are particularly suitable for strain-gradient analysis. Both the sense of garnet rotation and the asymmetry of the associated pressure shadows in the (λ_1, λ_3) sections (e.g. Malavielle *et al.* 1982) indicate a component of dextral, reverse shearing along the λ_1 direction (Figs. 7a & c). Values of shear strain γ_a were obtained from measurement of the rotation angle ω of the garnet porphyroblasts, assuming $\gamma = 2\omega$ (Rosenfeld 1970, Olensen 1983). The γ_a values were correlated with γ_b values obtained by comparing the actual length/width ratios for the pressure shadows in (λ_1, λ_3) sections with the calculated ratios for mathematical models (Malavielle *et al.* 1982).

From east to west, shear strain increases as the plunge of λ_1 decreases (Fig. 10): $\gamma \leq 2$ in eastern Rehamna ($\omega \leq 60°$) and $\gamma > 6$ in central Rehamna, where garnet rotation ω reaches 180° (Fig. 7c). In zones of intense subhorizontal stretching (strained metaconglomerates of central Rehamna, or the strongly deformed zone separating central from eastern Rehamna), the occur-

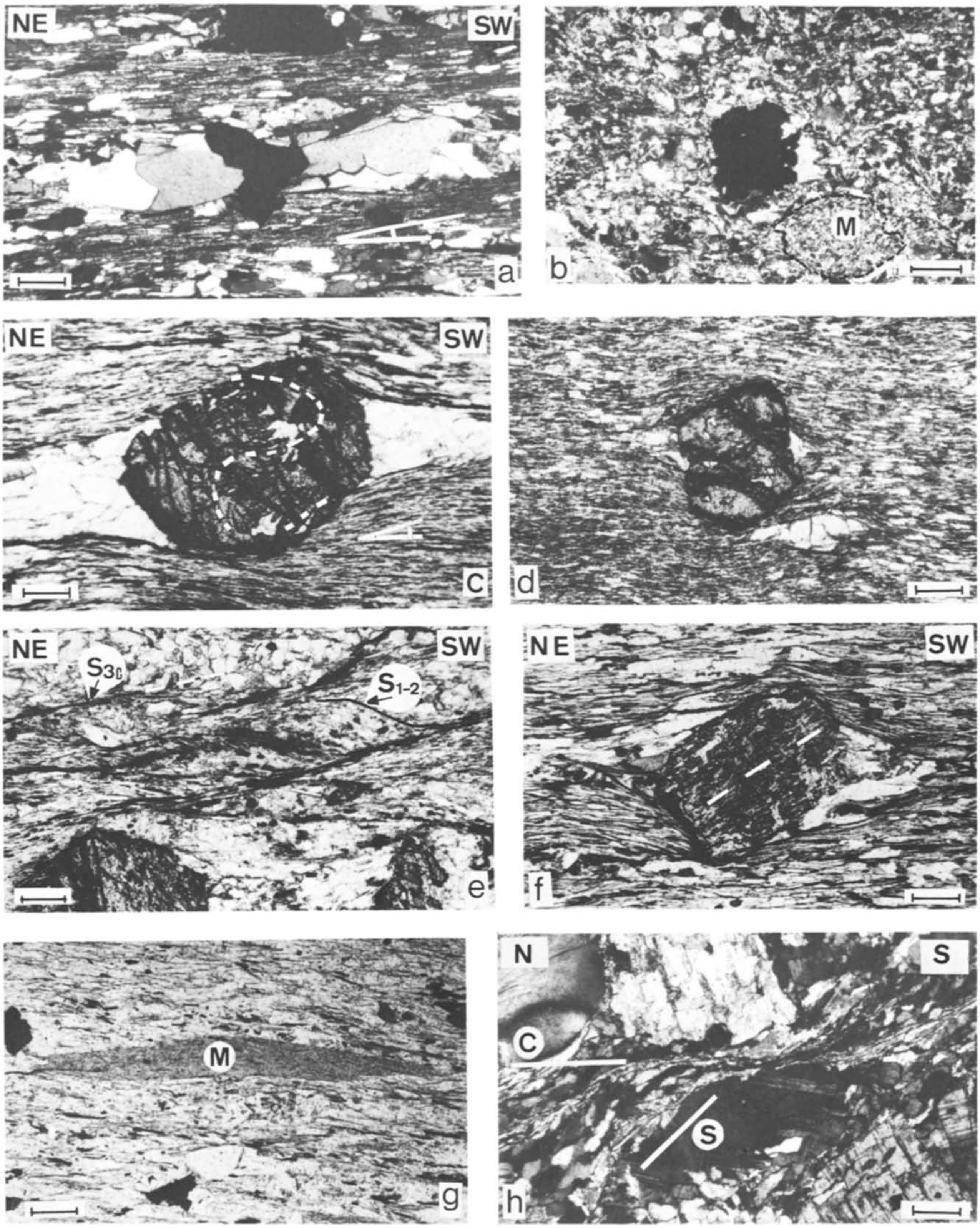

Fig. 7. Microstructures from central Rehamna. Scale bar: 200 μm. (a–d & g) D_1–D_2 phase, Devonian metaconglomerates and micaschists nearby. In $\lambda_1\lambda_3$ section (a, c & g), asymmetrical pressure shadows around framboidal pyrites (a) and helicitic garnet phenoblasts (c) indicate dextral wrenching. Micaceous clastic grains are elongated (g). In $\lambda_2\lambda_3$ section (b, d), cleavage is less developed, pressure shadows are much smaller and symmetrical around pyrite (b) and garnets (d), micaceous clastic grains are circular (b). (e, f & h) D_3 phase, close to or within the granitic plutons. (e) sinistral shearbands (S_{3c}) close to the eastern side of the western pluton; (f) sinistral rotation of a staurolite phenoblast from the country rock between the eastern leucogranitic plutons; (h) *S*/*C* surfaces within the easternmost pluton (6a, Fig. 2), indicating normal dextral shear, related to pluton emplacement.

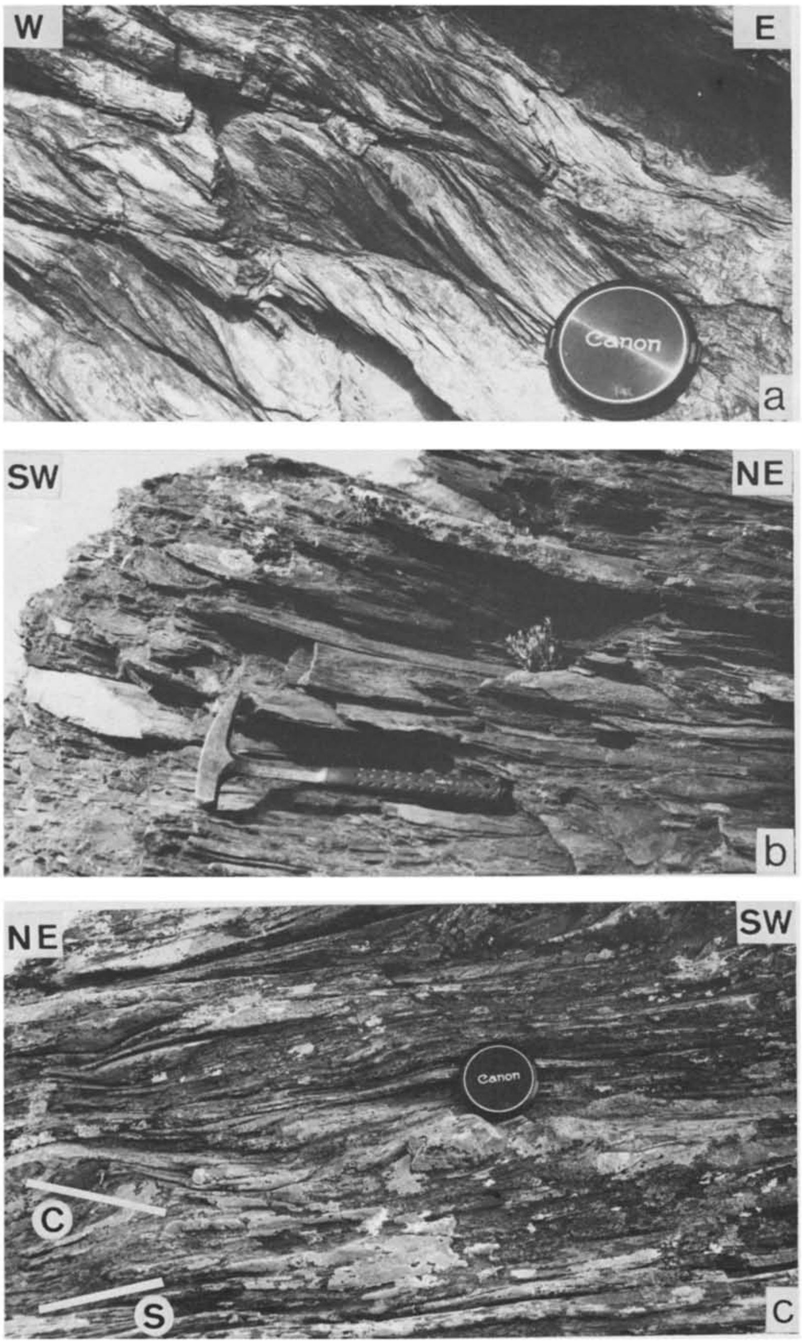

Fig. 12. Medium scale structures in central Rehamna metaconglomerates. (a) *S/C* surfaces (Berthé *et al.* 1979) indicating westward thrusting with extensional laminar flow. Area B, Fig. 2; the outcrop is roughly parallel to the $\lambda_1\lambda_3$ plane. (b) strongly stretched metaconglomerates, area C, Fig. 2. Hammer handle parallel to the stretching lineation. (c) *S/C* surfaces in the $\lambda_1\lambda_3$ plane, indicating, reverse, dextral wrenching. Same area as (b).

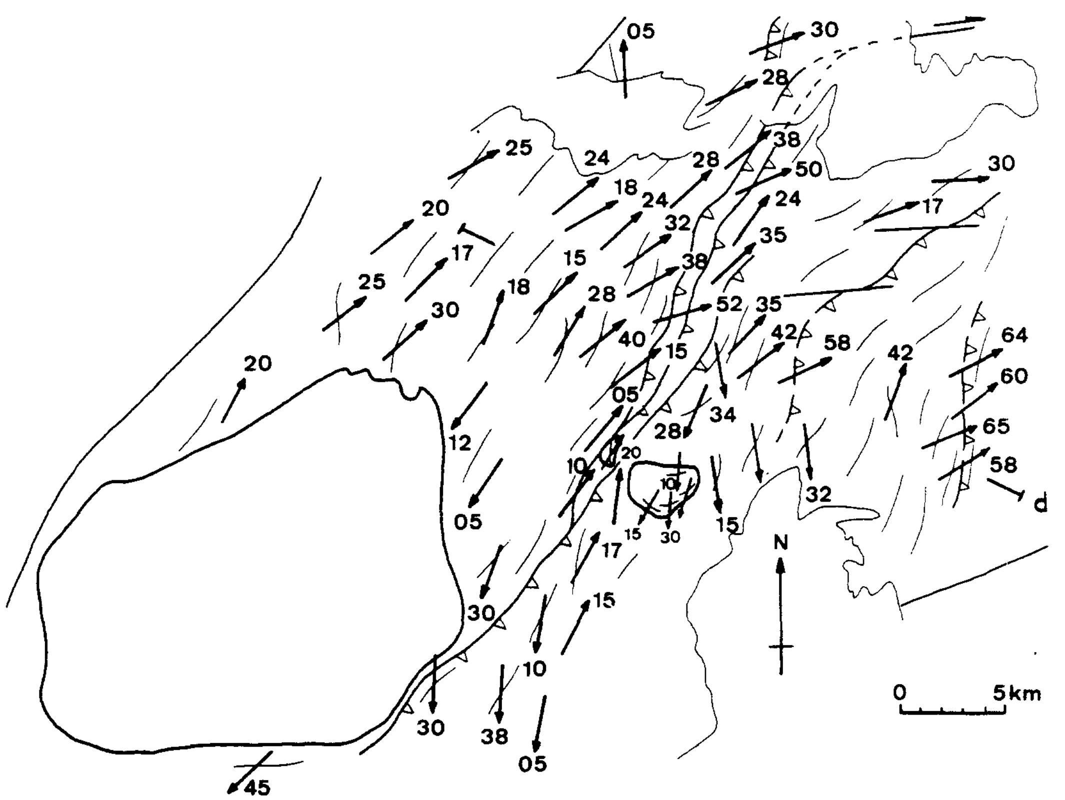

Fig. 9. Stretching lineation map. Note the progressive decrease of plunge from east to west. Arrows: stretching lineation. d: location of the cross-section, Fig. 10. Other symbols as for Fig. 8.

rence of dextral shear bands confirms the sense of shear and indicates an extensional laminar flow in conditions of non-coaxial strain (Platt & Vissers 1980).

In southern central Rehamna, the strain gradients and dextral sense of shear related to D_1–D_2 phases are locally perturbed during the D_3 phase, associated with emplacement of granitic plutons. Around and between these plutons, the dextral shear is locally converted into sinistral shear as shown by rotation of staurolite phenoblasts that crystallized during the D_2–D_3 interval (Hoepffner *et al.* 1982) and by numerous sinistral shear bands S_{3c} (Figs. 7e & f).

Finite-strain ellipsoid

The shape of the finite-strain ellipsoid was measured from various ellipsoidal markers, or approximated from microtectonic observations (Flinn 1965, Schwerdtner *et al.* 1977) and from the preferred orientation of micas, measured by X-ray goniometry. This method (Le Corre 1978) allows the planar fabric to be measured by two parameters: **S**, the schistosity index, and **R**, the fabric intensity index (Fig. 10). The results of this study can be summarized as follows.

In most places in eastern Rehamna, where suitable strain markers are lacking, we deal with $S > L$ tectonites (Flinn 1965) with a strong planar fabric of micas (Fig. 10) and chocolate-tablet boudinage of the competent layers. These suggest a shape parameter $k < 1$ for the finite-strain ellipsoid.

In thrust zones of eastern Rehamna and in southern central Rehamna **S** and **R** both decrease (Fig. 10). This decrease may be correlated with a change of fabric symmetry from $S > L$ tectonites to $L > S$ tectonites. In thrust zones, the main composite foliation (S_{1-2}) is crenulated parallel to the stretching direction. In southern central Rehamna, microscopic observations in (λ_1, λ_3)

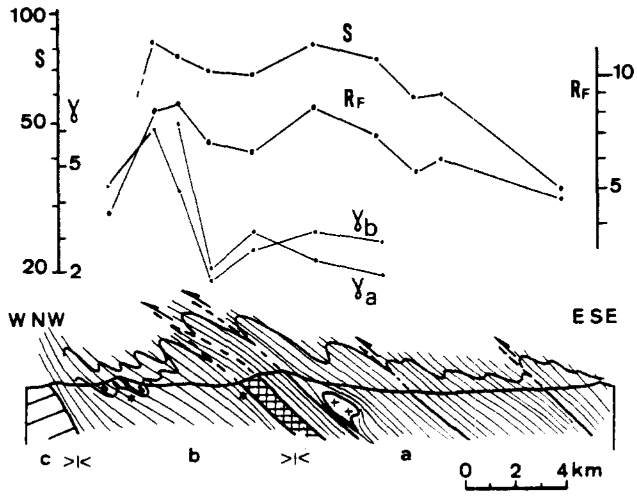

Fig. 10. Strain gradients and mica fabric intensity, along a cross-section parallel to the regional thrust transport (location of the cross-section: d, Fig. 2 and 9). (a) eastern Rehamna; (b) central Rehamna; (c) western Meseta block. **S** (schistosity index) and $\mathbf{R_F}$ (mica fabric intensity) parameters (Le Corre 1978) increase with increasing metamorphic grade, except in thrust zones, where $L > S$ tectonites develop. Shear values γ along the λ_1 direction (parallel, oblique or normal to the regional thrust transport: Fig. 9) increase from eastern to central Rehamna. γ_a values were obtained from garnet rotation ω, γ_b from length/width (l/w) ratios of pressure shadows (see text). 7 stations, 15 to 25 measurements/station (Mean values, from east to west: ω = 55°, 65°, 90°, 60°, 180°; l/w = 3.10, 3.47, 3.05, 2.00, 4.27, 6.27, 4.33).

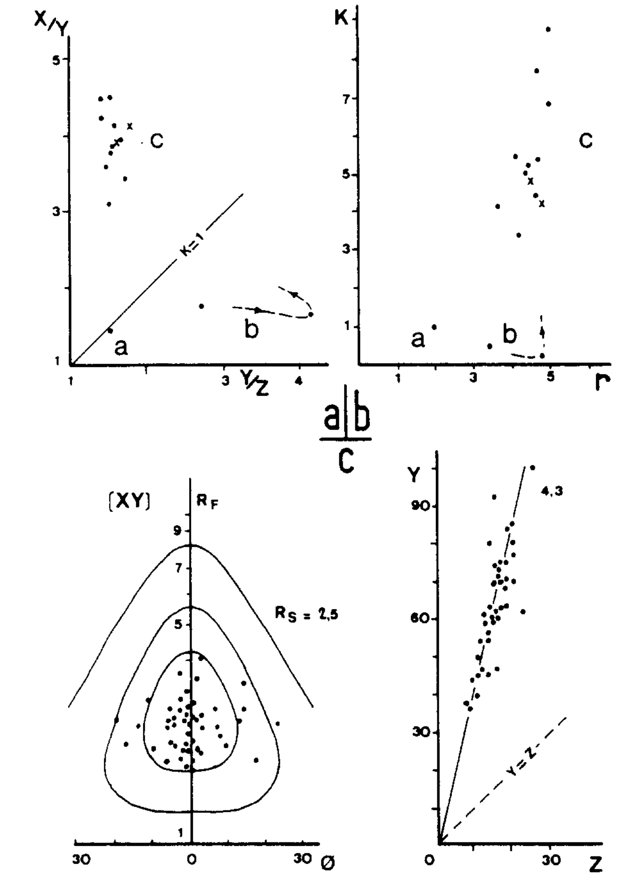

Fig. 11. Shape of finite-strain ellipsoid. Upper diagrams (a & b): central Rehamna metaclastics (a, b, c ellipsoids correspond respectively to measurements within the areas A, B, C, Fig. 2). Dots: pebble measurements (Pique 1973, 1975). x: quartz-porphyroclast measurements (40 to 150 measurements for one symbol). a: Flinn diagram (X, Y, Z are the finite strain ellipsoid axes ($\sqrt{\lambda_1}$, $\sqrt{\lambda_2}$, $\sqrt{\lambda_3}$). b: Plot of $k = (X/Y - 1)/(Y/Z - 1)$ vs $r = X/Y + Y/Z - 1$. Lower diagrams (c): contact metamorphism zone around the western granitic pluton (6b, Fig. 2). Measurements on contact metamorphism spots. Rf/ϕ diagram (Ramsay 1967, left) in the XY plane, and Y/Z plot (right) in the perpendicular plane, indicate an oblate ellipsoid, with $k = 0.45$.

and (λ_2, λ_3) sections are consistent with a constriction-type finite-strain ellipsoid. In (λ_1, λ_3) sections, pressure shadows around framboidal pyrites and helicitic patterns within garnets are conspicuous (Figs. 7a & c). Strain markers are strongly elliptical (Fig. 7b) and cleavage is well developed. In (λ_2, λ_3) sections, pressure shadows are virtually lacking, strain markers are nearly circular and cleavage is less obvious (Figs. 7b & c).

In central Rehamna, various ellipsoidal markers allowed more precise strain measurement to be done. Measurements on strained pebbles (Pique 1973, 1975) as well as on isolated quartz crystals indicate a change, from north to south, in the shape of the finite-strain ellipsoid. This change corresponds with strain and metamorphic gradients. In the northwestern part of central Rehamna, on the margin of the Western Meseta Coastal Block (Fig. 2, area A), Paleozoic formations are weakly deformed and recrystallized. Pebbles from Lower Devonian conglomerates are fractured and slightly stretched. λ_1 is subhorizontal and values of axial ratios lead to plane-strain ellipsoids ($k \simeq 0.9$) (Fig. 11a). In the northeastern part of central Rehamna, near the lateral tip of eastern Rehamna thrust (Fig. 2, area B), values of axial ratios of conglomerate pebbles give oblate finite-strain ellipsoids. Within this zone, flattening increases from north to south (from $k = 0.46$ to $k = 0.21$) as strain intensity increases (from $r = 3.46$ to $r = 4.82$) (Fig. 11a) (Pique 1975). To the south of this zone, a crenulation develops and affects the previously flattened pebbles. This crenulation, which is parallel to the thrust transport direction, indicates an evolution from an oblate to prolate finite-strain ellipsoid. In southern central Rehamna, at the frontal tip of the eastern Rehamna thrusts (Fig. 2, area C), strained pebbles and microscopic markers are strongly stretched (Fig. 12b), and indicate a constrictional-type finite-strain ellipsoid, with $3.5 < k < 8.7$ (Fig. 11a) (Pique 1975). The plot of k vs r for the same areas (Fig. 11b) shows that there is no simple relation between the shape of finite-strain ellipsoid (k parameter) and the increasing strain (r parameter): k increases from 0.2 to 8.7 with nearly constant values of $r \simeq 5$. The shape of the finite-strain ellipsoid may be interpreted with reference to the deformation history as discussed below.

Granitic pluton deformation

Granite emplacement took place during the D_3 phase, after the climax of Barrovian metamorphism. This emplacement post-dated most of the syn-metamorphic deformation, as shown by overlapping of contact andalusites on retromorphic staurolites (Michard 1976, Hoepffner *et al.* 1982). However, deformation is well developed in leucogranitic plutons (6a, Fig. 2). In contrast, the western calc-alkaline pluton (6b) is weakly deformed. The deformation can be summarized as follows: leucogranites present a planar fabric (Fig. 8) with S/C mylonitic zones (Fig. 7h) (Berthé *et al.* 1979). This fabric includes a stretching lineation which is parallel to the regional lineation of the country rock (Fig. 9) and contact metamorphic spots are stretched along the same direction. Finite-strain analysis near the top of the westernmost batholith indicates an oblate strain ellipsoid with $k \simeq 0.4$ (Fig. 11c), which is consistent with mathematical models for synkinematic plutons (Brun 1981). S_{3c} shear bands (Fig. 7e) are developed between the plutons and are explained, either by a thermal softening of the rocks close to the intrusions (Brun & Vigneresse 1981), and/or by increasing shear due to pluton ballooning (Brun 1981). This deformation pattern may be related to an interference between the regional strain field and pluton ballooning. Therefore, the granites of the Rehamna massif may be considered as syn- to late-kinematic plutons.

MOVEMENT HISTORY

Thrust–wrench shear criteria

A model of thrust–wrench shearing is proposed to account for the strain pattern (Fig. 13). Westward ductile

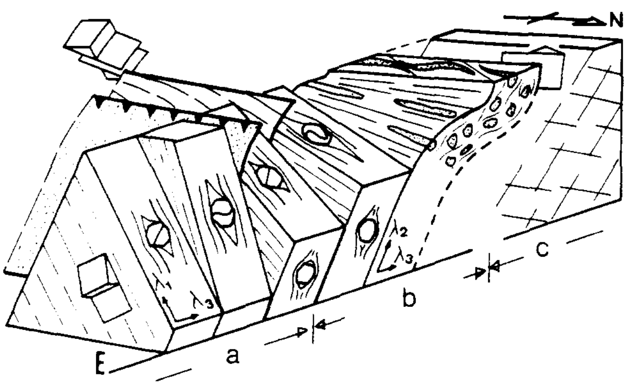

Fig. 13. D_1–D_2 kinematics in the studied area. (a) eastern Rehamna; (b) central Rehamna; (c) Western Meseta block (as on cross-section, Fig. 10, located on Fig. 9) Change in deformation kinematics within the curved S_{1-2} foliation ($\lambda_1\lambda_2$ plane) from westward thrusting to dextral wrenching is indicated by synkinematic garnets, stretched pebbles (dotted) and shear bands.

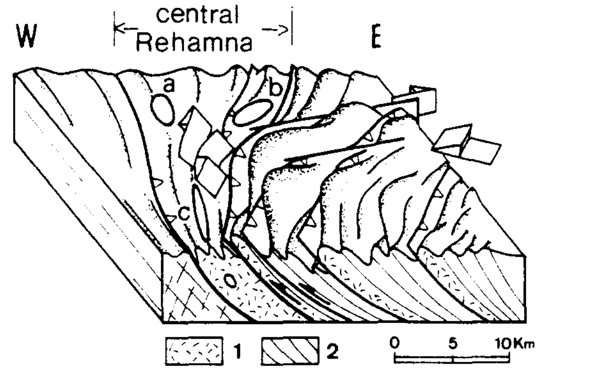

Fig. 14. Idealized model for strain-displacement relationships in the Rehamna massif. Central Rehamna folds are located at the frontal and lateral tips to eastern Rehamna thrust units and strained against the relatively rigid Western Meseta Coastal block. a, b, c: areas of finite strain ellipsoid measurements, Fig. 11 (same as A, B, C, Fig. 2). 1: $k > 1$ zones; 2: $k < 1$ zones (k = shape parameter for the finite strain ellipsoid, Fig. 11).

thrusting, dominant in the eastern Rehamna, is shown by (i) the general eastward dip of the foliation, (ii) overthrusting, at the map scale, of eastern toward central Rehamna and the consequent juxtaposition of different stratigraphic units (Figs. 2 & 3), (iii) overturned folds, of kilometric scale, verging to the west, (iv) the curvature of F_2 minor folds axes about a down-dip slip line (Hansen 1971) in the S_{1-2} foliation (Fig. 5b) (Pique *et al.* 1982), (v) the occurrence of ductile thrust zones with steeply plunging lineations and (vi) *S/C* surfaces indicating a westward sense of shear (Fig. 12a).

Dextral wrenching, dominant in central Rehamna, is indicated by (i) the parallelism of λ_1 to the shallow plunging axes of major folds, as expected in wrench tectonics (Odonne & Vialon 1983) and (ii) dextral, non-coaxial deformation criteria in the (λ_1, λ_3) plane (rotated garnets, asymmetrical pressure shadows and dextral shear bands) (Figs. 7a, 7c, & 12c).

Westward thrusting and dextral wrenching were combined during the same tectonic evolution as suggested by (i) the spatial continuity between zones with steeply plunging lineations and zones with horizontal lineation (Figs. 8 and 9) and (ii) the deformation chronology, for both types of zones, relative to the same metamorphic event. In this model (Fig. 13), the interpretation of relationships between displacement finite elongation and pattern must take into account the progressive change of thrusting into reverse wrenching. This change of movement along the same, curved composite foliation (S_{1-2}) is used here to explain the longitudinal stretching normal to the regional thrust direction, observed in central Rehamna.

Finite strain ellipsoid and differential movement

The variation in strain ellipsoid shape observed in central Rehamna (Fig. 11a) may be related to the combination of different movements at the frontal and lateral tips to a major thrust zone, as showed by Coward & Potts (1983). In zone a (Figs. 11 and 14; A in Fig. 2), the slight subhorizontal stretching and the $k = 1$ finite strain ellipsoid indicate a moderate finite simple shear. In this zone, dextral wrenching is the main component of strain. In zone b (Fig. 11 and 14; B in Fig. 2), the strain path is more complex as shown by the evolution from oblate to prolate strain ellipsoid. In this zone the major thrust shear is combined with a dextral transcurrent shear related to an ENE lateral thrust ramp. Such a combination occurs between the frontal and lateral tips to a thrust zone; it is normally associated with layer-parallel shortening and produces an oblate finite-strain ellipsoid (Coward & Potts, 1983). Further evolution from oblate to prolate strain may be related to an increase of the thrusting shear associated with an extensional laminar flow, as indicated by the occurrence of shear bands (Fig. 12a). Zone c (Figs. 11 and 14; C in Fig. 2) is located at the frontal tip of the thrust zone. The main component of shear is a dextral wrenching with an intense extensional flow (Fig. 12c). Thrusting shear is indicated there by the shallow eastward dip of the foliation and by fold asymmetry. Such a combination of displacements produced a prolate finite strain ellipsoid and gave rise to the longitudinal stretching lineation. This longitudinal extension along the thrust zone front accommodates a N–S material escape and was probably favoured by the increasing of central Rehamna shortening at the frontal tip to the thrust zones and the thermal softening of the highly metamorphosed rocks of southern central Rehamna and the consequent rheological contrast with the adjacent Western Block. For that reason, longitudinal displacements in central Rehamna were probably easier than transverse ones.

CONCLUSIONS

Superposed structures in the Rehamna massif result from a progressive non-coaxial strain history, which evolved as metamorphism and associated thermal softening developed. Southern central Rehamna is the most highly metamorphosed and strongly deformed area. The finite-strain pattern indicates westward thrusting, dominant in eastern Rehamna, and N–S dextral wrenching, dominant in central Rehamna. A longitudinal stretching lineation developed parallel to the thrust front, nearly normal to the regional thrust direction and was associated with a prolate finite-strain ellipsoid.

A model of thrust–wrench shearing is proposed to account for this complex strain pattern. In this model, the progressive change from thrusting into wrenching shear from east to west is related to variations in deformation kinematics at the frontal and lateral tips of a major westward thrust zone. The variation in shape of the finite-strain ellipsoid is related to the combination of different movements.

A similar complex tectonic history is already known in the European Variscan belt (Matte & Ribeiro 1975, Gapais & Lagarde 1977, Brun & Burg 1982). The Rehamna structure exemplifies the tectonics of the intracontinental Hercynian foldbelt of Morocco.

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