Mineral Res.Expl.Bull., 110, 77-87, 1990

PROGRESSIVE BRÜTLE-DUCTILE DEFORMATİON DM THE DEMİRKÖY PLÜTON OF THE STRANDJHA MASSIVE OF THRACE - TURKEY

M.Attila ÇAĞLAYAN*; Metin ŞENGÜN* and Ayhan YURTSEVER**

ABSTRACT.— Demirköy pluton, a Lower Cretaceous granitic body of the Strandjha massive of Thrace-Turkey, vary compositionally from a syeno-granite to quartz-diorite. The periphery of the granite has been converted to mortar gneiss and mylonite gneiss/schist. The host rocks, where they are of a pelitic origin, have been transformed into foliated contact schists comprising cordierite and andalusite. The intensity of shear shows a progressive diminution avvay from the periphery. The brittle-ductile deformation is ascribed to the emplacement of the granite causing multistage developments of multidirectional cleavage, king type folding and shear pods that are observable in macroscopic and microscopic dimensions. The deformation is not attributed to large displacements, but is rather interpreted as the cumulative result of en echelon shearing.

İNTRODUCTİON

This article aims at presenting details of peripheric macro and microstructures of the Demirköy pluton of the Strandjha massive (Fig.l).

The cataclastic deformation was interpreted as a product of thermo-dynamic metamorphism by Üşümezsoy and öztunalı (1981). This approach is fairly different from that of Aykol (1979) who defended an auto-cataclastic process resulting from rapid uprising of the pluton.

In Turkey, investigations on granite tectogenesis and related cataclastic processes have started in the last decade and may be considered fairly new in comparison to world-wide research on the subject since the beginning of the 19th century.

We have observed in the field that the structural elements of the pluton and those of the country rock are parallel. However, the detailed investigation of the microstructures suggests an outward push.

There has been a mechanical process during the emplacement, presumably through forceful injection, which has caused realization of shear zones leading to destruction and recrystallization of the granite as well as the country rock.

The area was mapped (Fig.2) to understand cause-effect relationship of the microscopically observed cataclastic deformation of the granite periphery and the country rock of the Demirköy pluton. We have tried to understand the deformational episodes; and relationship betvveen deformation and crystallization by field mapping, (Fig.3) collecting oriented samples and textural interpretation of these oriented samples.

MAIN CHARACTERISTICS OF THE DEMİRKÖY PLUTON

Demirköy pluton lies in the eastern segmen-r of the Strandjha massive. It has a slightly elongated shape, parallel to the general NW trend of the massive.

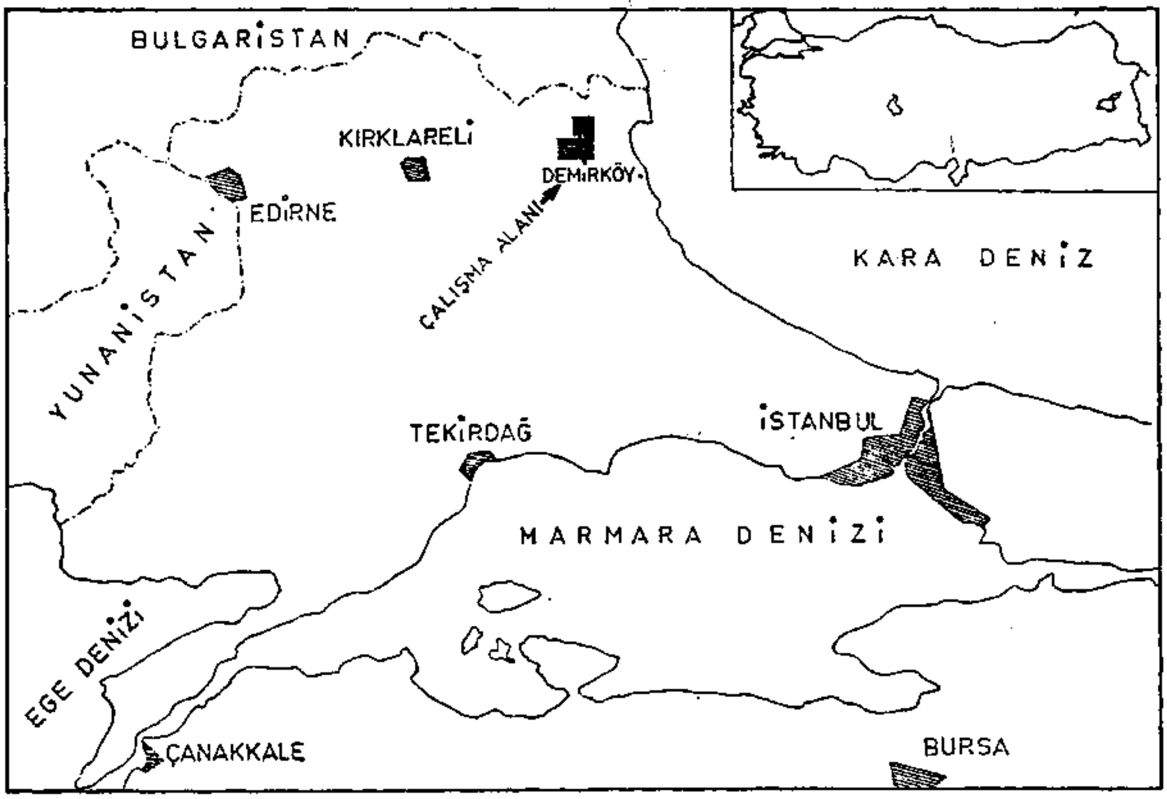

Fig.1— Location map.

The plutonic body was nomenclated as dioritic intrusions (Ksiazkiewicz, 1930), Demirköy magnetiferous granite lacolith (Pamir and Baykal, 1947), granite (Akartuna, 1959), granitic intrusions (Bürküt, 1966), Dereköy magmatic series (Aykol, 1979) and Demirköy pluton (Üşümezsoy, 1982; Aydın, 1982).

The pluton comprises a magmatic series varying compositionally from syeno-granite to quartz-diorite. It has intruded into basement rocks of the Strandjha massive that has generally suffered a metamorphism in amphibolite facieswith local migmatitic areas (Bürküt, 1966; Yurtsever et al., 1986). It intrudes the Dolapdere formation of Jurassic age (Kapaklı formation of Aydın, 1974,1982; Strandjha group of Üşümezsoy, 1982). It is covered by a sedimentary wedge starting with conglomerates and sandstones and minor volcanic intercalations.

K/Ar dating of the pluton (Aydın, 1982) gave an age of 83.1 + 2.0 and 83.5 + 2.5 ma from samples taken from the Dereköy pluton which Aydın (1982) considered a part of the Demirköy pluton. He suggested that the Coniacian age, thus found, is rejuvenated due to younger volcanic events. Tokel and Aykol (1987) claim a Santonian-Campanian age for the Demirköy granodiorite which, they suggest, is a part of the Srednogorie-Strandjha-Pontideschain.

Sharp contacts bervveen the pluton and the country rock, a fairly wide aphanitic margin and granophyric textures are suggestive for an epizonal emplacement (Buddington, 1959).

Formation of augens in the contact aerole, penetrative character of the lineations and foliations, formation of a conformable fold envelope through formation of strain-slip cleavage and marginal thrusting are structural

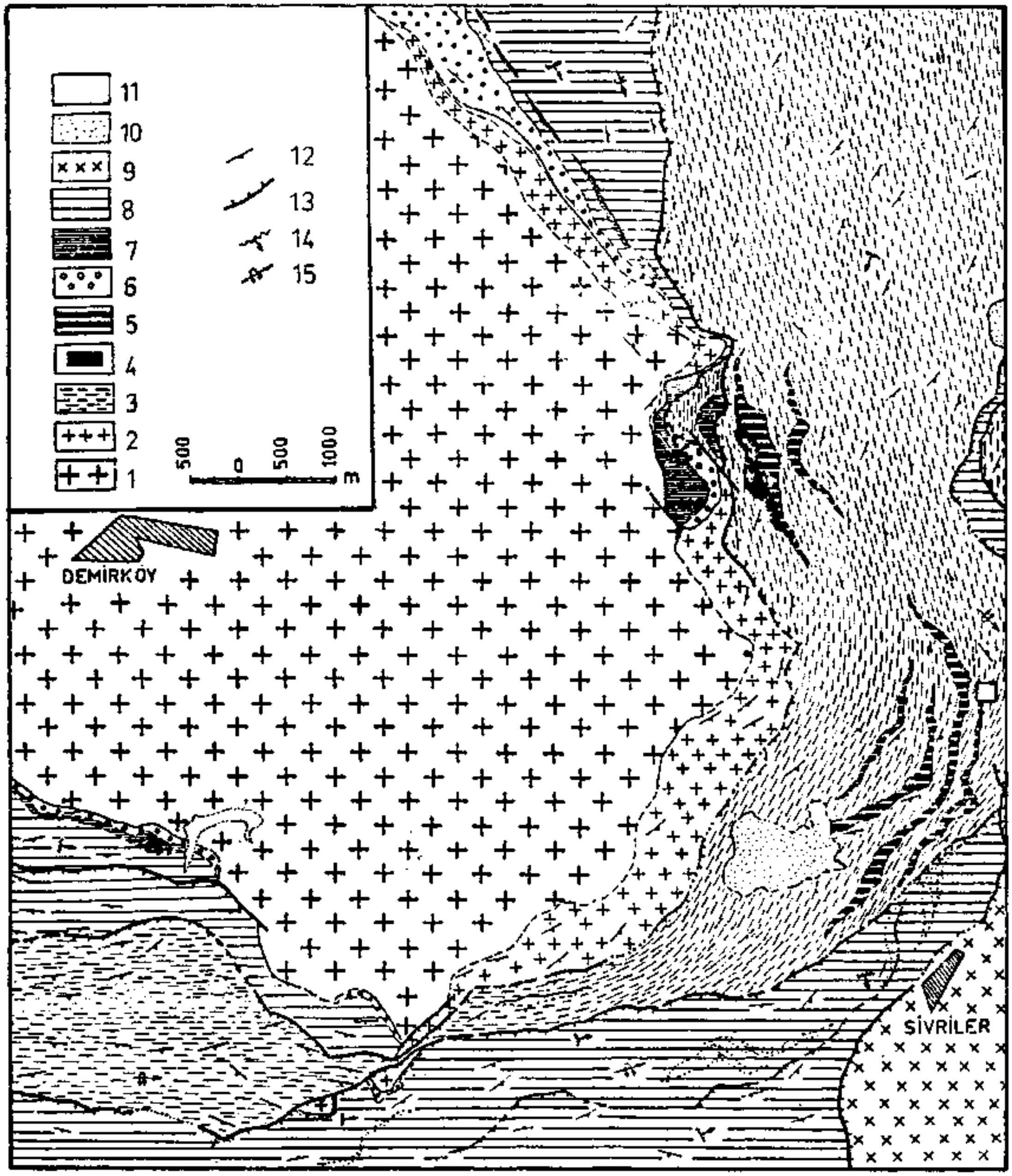

Fig.2— Geological map of the eastern and southeastern segments of the Demirköy plutone.

1-Demirköy pluton- 2- Microgranite, foliated granite; 3- Cataclastic granite; 4- Mylonite gneiss; 5- Mylonite schists; 6- Contact schists comprising cordierite and andalusitc; 7 Marble+ Skarn; 8- Phyllite, chlorite schist and quartzite; 9- Sivriler granite; 10-Plio-Quatemary sediments; 11-Alluvium; 12-Foliation; 13-Thrust fault; 14-Microfold; 15-Fold axis.

elements seen peripherically. These structural features of the Demirköy pluton resemble those of the Colville batholith as described by Higgins (1971).

MICROSTRUCTURESOFTHECONTACTAEROLE

Symetric and assymetric axial planes of the contact schists are parallel to the contact plane throughout the

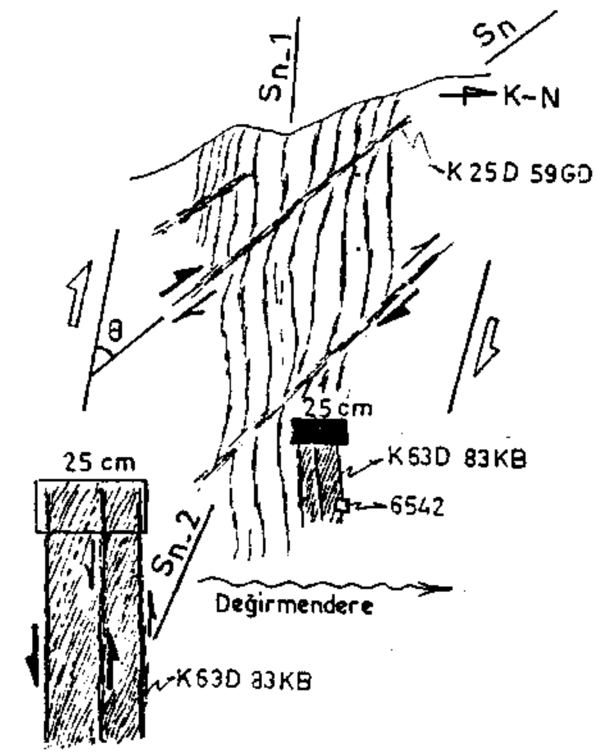

Fig.3— Mesoscopic structures. Early and late foliation, cross banding.

periphery. The observed microstructures consist of those produced by rotation of mineral grains such as garnet, pyrite, cordierite and andalusite, and, asymmetric pressure shadow areas.

Rotation of garnets and asymmetric pressure shadow areas

As it is seen in Plate I, fig.l, there is a marked difference between behaviour of the matrix and the grains of foliated rocks of the sheared zones, presumably due to different elastic behaviour. The matrix is fine grained so that it can flow around the grains while the clasts may have been broken up several times prior to and/or during shearing and consequent rotations. The fold axes of the mica flakes surrounding the garnet grains, as exemplified by the garnet in the lower part of Plate I, fig.l, defines the sense of rotation.Two asymmetric pockets,made up by a crushed quartz and feldspar mosaic, are seen in the upper-left and lower-right corners of the garnet grains. These are often seen as wings of durable feldspar porphyroclasts as a result of strain accumulation and thus brecciation of the grains. These asymmetric shadow areas are also known as "pressure tail" (Simpson and Schmid, 1983) and "pressure shadow wings" (Schoneveld, 1977). Pressure shadow areas can be used as a reliable indicator of the sense of rotation (Takagi, 1986)

Rotation in garnets as well as pressure shadow areas indicate a right-handed shear for the specimen.

Rotated crystals of andalusite and cordierite

Traces of rotation are very pronounced in the pinnitized cordierite porphyroblasts of the andalusite-cordierite schists (Plate I fig.2). The incipient foliation of these rocks are defined by orientation of the mica flakes. Andalusite is in the form of idiomorphic porphyroblasts and is occasionally seen to have been rotated. S shaped wave of the cordierite (Helisitic structure) is at an angle to the early foliation planes. Waving is due to rotation and is indicative of a multi-phase deformation. The spindle and flattened shape of the grains point to growth during blastesy.

The examples given above are microstructural features showing shearing during the emplacement of the granite. These examples certify a couple between the granite and the country rock. Deformation is progressive and directionally defined.

MICROSTRUCTURES IN GRANITIC ROCKS

The symmetric and asymmetric structures caused by shearing are "oblique incremental quartz elongation", "displaced broken grains", and "mica fish".

Oblique incremental quartz elongation

Deformational characteristics of quartzo-feldspathic veins or the geometry of the recrystallized quartz mosaic that fill up the fractures within a rock or a mineral can be used for interpretation of the sense of shear. A quartz vein extending inclined to the foliation plane in a fine grained quartzo-feldspathic rock in Plate I, fig.3; Fig.4. The grains have been recrystallized in an orientation roughly perpendicular to the apparent foliation plane. This example of oblique incremental elongation points to a right-handed shear.

Schmid et al. (1981), have pointed out that the c axes of calcite crystals are oriented perpendicular to the dynamically generated foliation planes. Brunei (1980) and Simpson (1980) have observed similar phenomena in grains between aggregates of mylonite or mylonitic gneisses and suggested that the preferred orientation of grains were achieved by a progressive shear in late stages of the deformational episode.

Displaced broken grains

Feldspar porphyroclasts are seen in Plate II, fig.l in a quartzo feldspathic, finely powdered matrix with

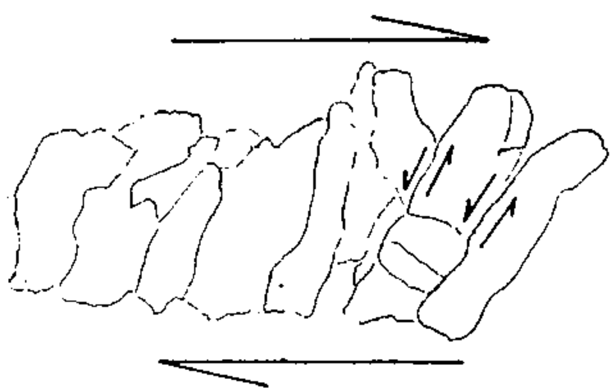

Fig.4 Sketch showing sense of movements that is opposite to that of the main shear in quartzo-feldspathic vein.

cohesion. The elongation'.and geometry of the grains, the simultaneous extinction, relative setting of crystal edges, or simply crystals being in the same optic orientation, show that all of the three pieces belong to the same clast. The interstitial area is filled by a recrystallized quartz matrix. This is often seen in mylonitic rocks, a rotational movement along micro-fractures that are oblique to the-foliation planes (Fig.5). The grain setting seen in this figure, point to a right-handed shear. The quartz mosaic filling up the fracture zones, has been re-fracturated and crushed in the peripheric zones (Plate II, fig.l; fig.5).

Recrystallized quartz mosaic following brecciation and formation of mortar gneiss in a typical sequence of events for progressive brecciation. Takagi (1986) points out that durable grains such as feldspar and pyroxene porphyroclasts in foliated mylonitic rocks are often observed to have extension fractures and broken grains with concurrent rotations.

Spindle-shaped micas (mica fish)

Foliated rocks of granitic origin and phyllonites often comprise spindle-shaped porphyroclasts (Plate II, fig.2), possibly of micro-pull apart origin (Hanmer, 1986). The spindle-shaped mica aggregates or "pockets" are

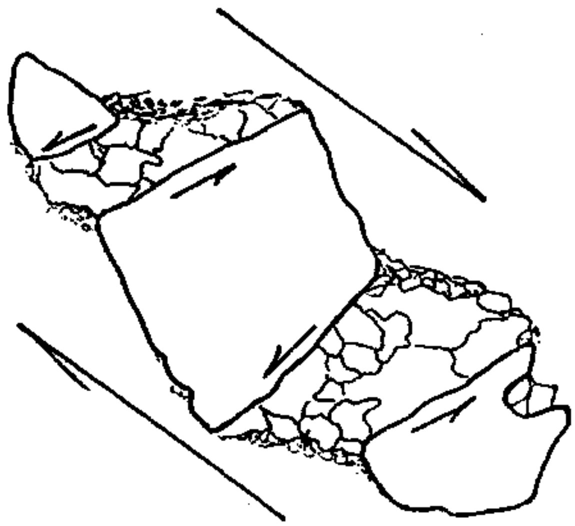

Fig.5— Sketch showing sense and direction of movements of rotated clasts.

often referred to as "mica fish" (Plate II, fig.3) and is used for determination of the sense of shear (Lister and Snoke, 1984). A large mica clast in a fine-grained quartzo-feldspathic matrix in Plate II, fig.3. The mica clast is oriented oblique to the incipient foliation defined by the elongation of fine grained crystals.The mica cleavage plane (001) makes an angle of 28° with the foliation plane. The direction pointed out by this acute angle, defines the direction of movement. A sinistral movement is suggested by the mica fish of Plate II, fig.3.

TEXTURAL ANALYSIS OF MACRO AND MICROSTRUCTURES

We have, so far, concentrated on microstructures formed by shearing of the granite and the host rock. We will, now, have a look on the macrostructures and dependent microstructures which are, again, consequences of shearing processes.

There will always be medium or large grains in the course of crushing and powdering of the granitic rocks in shear *zones* of the periphery, in addition to the clay-silt size, equigranular powder. This feature plays a role for confusion of a mylonitic granite with a sandstone. These rocks often display micro shear planes that resemble sedimentary structures such as lamination and cross-bedding.

The crystals are elastic within a given interval in the ideal case. However, beyond these limits, a stationary deformation is encountered. The grain is broken when the stress exceeds the amount required (Turner, 1968). The larger clasts are broken into small granules which tend to get dislocated in the slip planes that are apt to get parallel to the larger shear zones. There is a variety of distribution of trends of these zones and the broken grains in these crushed zones (Zeck, 1974).

The appearance of the rock specimen depends on the number and intensity of deformational episodes (Marker, 1950). As it is known, a mineral growth, formation of a cleavage plane or formation of a fold is defined as "late" for the proceeding and "early" for the following deformational episode (Spry, 1969). Three progressive deformational episodes were recognised through mesoscopic observation (Fig.3). On the other hand, five episodes was established from studies of thin sections.

Banded structure : definition and origin

The main mesoscopic and microscopic features (Plate III, fig.l) on the granite periphery are banded structures. These may be as wide as tens of meters and are in the form of narrow strips, they are continuous and have the appearance of an alternating sedimentary sequence. The medial sections of the bands preserve, generally, the primary characteristics of the rock. As the shear zones are approached, the grain size diminishes considerably and an incipient foliation is observed. The crushed grains of sheeted minerals are concentrated in the lamination of the cataclastic matrix. Fining up of grains and compositional changes have formed colour bands. Recrystallized micas are formed synkinematically. The mechanical wrenching that was formed by slip along grain borders, have contributed to formation of foliation planes (Fig.3). The schistosity planes are thin in the slip planes and gets thicker away from these zones.

This type of banding or foliation was defined as "flow structures" by Lapworth (1885) and Waters and Campbel (1935). These planes can be distinguished as continuous or discontinuous (Burg and Laurent, 1978) and are ascribed to segregation of material of different physical characteristics in different layers (Higgins, 1971). The mechanism of formation starts with generation of lenticular pods, and with progressing cataclasis, formation of subparallel shear planes are followed by laminar flow structures (Fig.3 : Higgins, 1971). This process was considered in four steps by Ramsay (1980): approach, curving tips, intersection and merging.

Cross-banding

Shear bands, defined by fine grained and mica-rich shear planes, joins obliquely to another foliation plane (Plate III, fig.l and Fig.6). These colour bands or compositional banding resemble cross-bedding, and join obliquely the foliation plane by drawing a sigmoidal path (Fig.6). Passchier (1986) has shown that there is an angle of 45° between cross-banding centre and late stage foliations.

The cross-banding referred as 'transfer zone" by Boyer (198 1), is defined by colour contrast and tectonic fabric and bears typical characteristics of a brittle-ductile deformation in the early period of formation of cleavage.

Relation of shear to folding

Folds, different in'dimension and geometry, asc observed to form along shear cleavage due to different behaviour of material in -the microlithons. Ductile faults (Ramsay and Graham, 1970), shear pods and button structures (Roper, 1972) are encountered along the shear cleavage and microlithons.

Isoclinal folds have been formed in overpowdered mylonite gneiss/schists (Fig.8) while assymetric and/or overturned conjugate folds (Fig.7) have been generated in the shsar bands of granitic rocks of quartzo-feldspathic composition. In bands rich in phyllosilicates, crenulations have developped in folds formed by flow. These structures are probably synchronous. The axial planes of these folds and attitude of'shear planes are conformable embracing the pluton peripherycally.

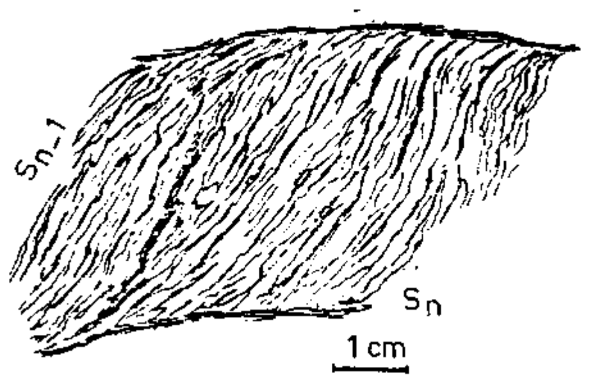

Fig.6— Early and late foliation in mesoscopic structures. Note that the foliation planes run at an angle of 45°

Thrusting will be realized due to relative movement of one band with respect to another if the stresses parallel the foliation planes. The relative movement of flow structures will fold the material in microlithons so that conjugate folds (Fig.7) and microfolds with flow cleavage will be formed (Fig.8). Differential movements between the walls of shear cleavages have resulted in offset of ductile fractures (Plate III, fig. 2). The prograde character of the movement will result in refolding or rupture in the wings of these ductile faults. There will be folds, formed perpendicular to those formed earlier (Fig.7), in addition to breakup and movement along fault planes, with consequent formation of microthrusts.

The axial planes of folds of the late stage cross-cut the foliation planes formed during the earlier phase of deformation. The material in the flanks elongates and thins with prograde deformation while thickening occurs in the apex (Fig.8). As the angle between the flanks is minimized, there will be flow to the apex and the boundaries get sharper. The apex is finally detached as the flanks thin out. Thus, the earlier foliation (S_{n-1}) is eradicated.

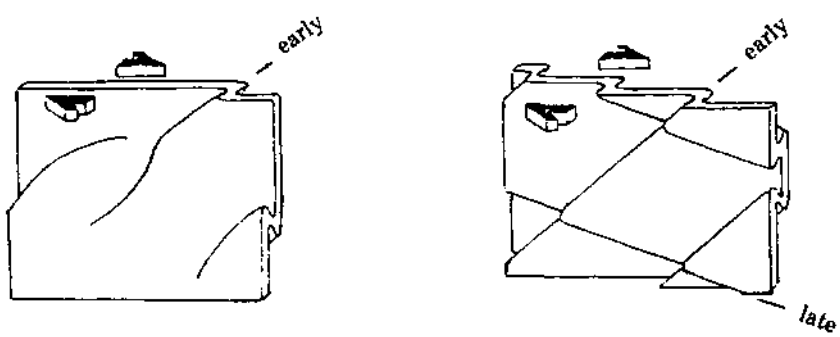

Fig.7— Schematised diagramme (after Berthé and Brun, 1980) showing formation of the conjugate folds in microlithons.

The new foliation planes (S) starts to conform with attitude of the earlier foliation planes. The relict structures from the early foliation are shear pods (Plate III, fig. 3). and mica buttons of the apex (Fig.8) (Roper, 1972) and trend generally at an angle to the banding.

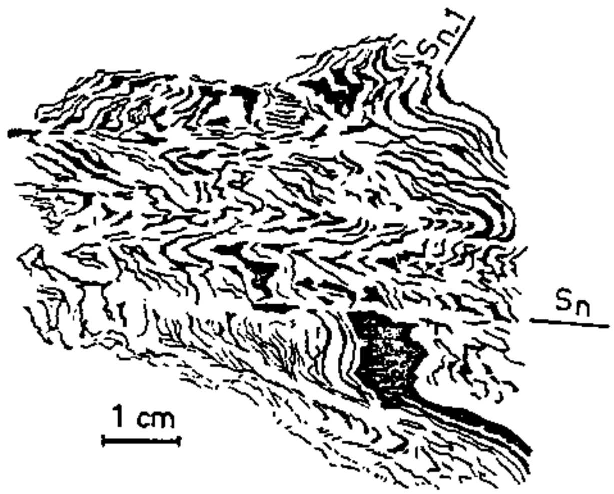

Fig.8— Tight and recumbent isoclinal folds. Button structure at crests of folds formed by the new foliation.

The translation along these flow structures have caused formation of thrust slices. These movements, which are the cumulative result of a prograde deformation, are responsible for enhancement of the movements of microlithons or shear bands.

DISCUSSIONANDCONCLUSION

The structural forms and events are consequences of deformation and rupture of granitic and host rocks during the emplacement.

The total displacement of the thrust slices is the cumulative result or vectoral addition of dextral and sinistral movements.

1— Contact metamdrphism of hornblend-hornfels facies is encountered in the country rocks.

2— The cataclastic zone, characterized by a brittle-ductile deformation, embraces the pluton with a peripheric attitude.

3— Andalusite-cordierite bearing contact schists encircle and embrace the granite periphery which is converted into a zone of mortar gneiss.

4— Rupture and'displacement in quartz, feldspar and micas of the granite and the country rocks; rotation and pressure shadow area in cordierite and garnet, oblique incremental elongation in quartz, displacement of broken grains leading to oblique rearrangement of-grains and mica fish are frequently observed microstructural features.

5— The micro.and-macrostructures seen along the granite boundary are conform,ble.

6— Multi dimensional banded structures-cross banded structures, plus folds and thrusts of various dimension and character are encountered.

7— Rupture and folding followed each other and ended up with convertion of shear slices into en echelon micro-thrusts.

8— The deformational process in mylonitic rocks, starting with undulatory extinction and ending up with micro-thrusts, is a direct consequence of multistage and progressive simple shear.

9— The cause of simple shear is emplacement of the granite. The steepness of the structural elements around the granite periphery have been realized in the latest stage of emplacement

10— The total movement observed along the granite periphery is the cumulative result of the described progressive deformation.

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PLATES

PLATE-I

Fig.1- Rotation in garnets. Note the microfolds defined by mica flakes and the asymmetric pressure shadow areas. Crossed nicols.

Fig.2- Pinitized ksenomorphic cordierite and idiomorphic andalusite in a contact schist. Crossed nicols.

Fig.3- Photomicrograph of grains with throw with respect to one another in a quartzo-feldspathic vein.

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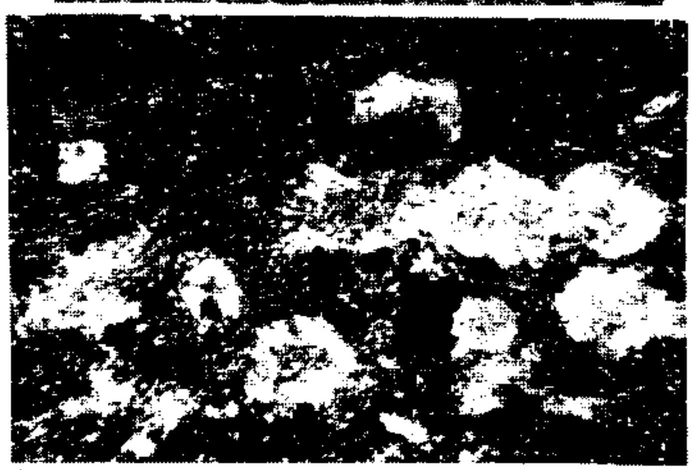

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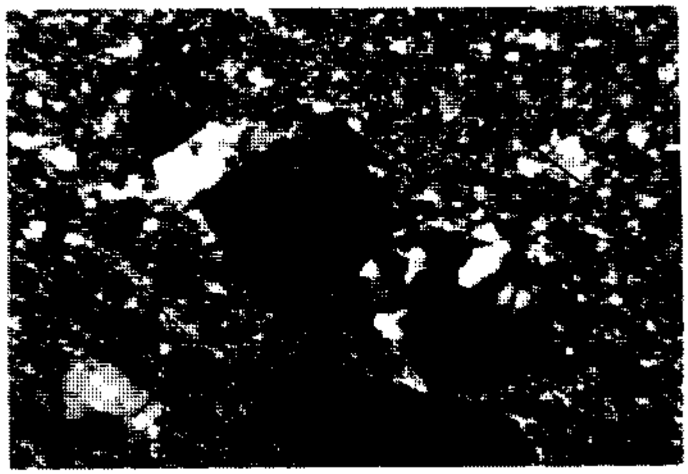
PLATE-II

Fig.1— Feldspar clasts of the same orientation. Note the throw is oblique to the direction of main shear.

Fig.2— Spindle shape quartz porphyroclasts produced by shear.

Fig.3— Mica-fish, oblique (28) to the foliation, indicating a left-lateral shear. Crossed nicols.



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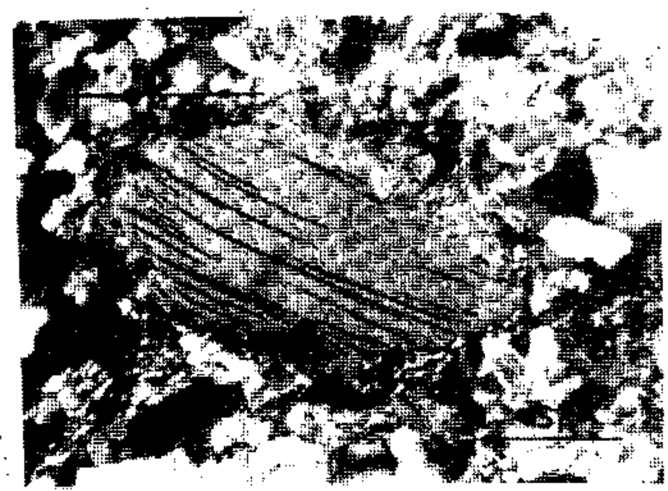

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PLATE-III

Fig.l— Shear clevage. Note the orientation of mica flakes that is oblique to the cleavage.

Fig.2— A ductile fault formed in a mica rich shear pod. Crossed nicols.

Fig.3— Mica pods denned by the early and late foliation. Note that the foliation planes are at right angles. The section passes through the crest.

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