

# Gradational development of slaty cleavage to schistosity

## — an example from the Iberian Pyrite Belt, Spain —

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The Iberian Pyrite Belt is an Upper Paleozoic succession which has been divided into the Phyllite-Quartzite Group, the Volcanic-Siliceous Complex and the Culm Group in ascending order from base to the top. The contacts among them are conformable. These Groups are tightly folded and metamorphosed under low-grade conditions during Hercynian times. The first stage folds of the Volcanic-Siliceous Complex and the Culm Group are associate with slaty cleavages(S1), while the Phyllite-Quartzite Group is associate with schistosities(S1). Fold analysis using cleavages and minor folds has been utilized in the analysis of the stratigraphy. This led to systematic horizontal collection of specimens(pelitic rocks). S1 texture is defined by parallel alignment of secondary platy minerals which tend to grow larger and together, forming zonal domains toward the Phyllite-Quartzite Group. The clay matrices change to recrystallized quartz toward the Phyllite-Quartzite Group. Textural modifications are evidenced by gradational changes from slaty cleavages to schistosities. This shows that recrystallization is the important deformation mechanism responsible for S1 development. It also reflects that the deformation was contemporaneous with metamorphism.

**Keywords:** Slaty cleavage, Schistosity, Recrystallization

## I. Introduction

The study of syn-tectonic cleavage has been carried out since the early 19th century. This reflects the development of the study of structural geology. Slaty cleavages and schistosities are formed by folding and lie approximately parallel to the axial planes of folds. They are defined by preferred alignment of platy minerals. It is therefore considered that the slaty cleavages and the schistosities are of the same origin. However, this idea has not been supported by evidence. Slaty cleavages are regarded as deformation texture, whilst schistosities are regarded as metamorphic texture. Fortunately, in the Iberian Pyrite Belt, the sequences which have slaty cleavages conformably overlie sequences which have weakly developed schistosities. The author visited the Iberian Pyrite Belt on four occasions and surveyed mostly around the Sotiel-Calañas area of Huelva Prefecture in Spain. The fold analysis using cleavages and minor folds in relation to the anal-

ysis of stratigraphy enabled the precise correlation of each outcrop and systematic horizontal sampling. In this paper, description of the horizontal change from slaty cleavages to schistosities has been made as well as discussion on the origin of the schistosity.

## II. Geology of the sotiel-calañas area

The Iberian Pyrite Belt belongs to the Southern Portuguese Zone in the southwestern branch of the Iberian Variscan arc. Oliveira (1990) divided the belt into two main branches; the southern part which consists of rooted structures and the northern part which forms a predominantly allochthonous belt. The study area is located in the southern part. The Belt is composed of Upper Devonian to Lower Carboniferous rock units which are lithologically divided into the Phyllite-Quartzite Group, the Volcanic-Siliceous Complex and the Culm Group in ascending order from base to top (Schermerhorn, 1971) (Fig.1). Schermerhorn (1971) observed that “there is complete conformity in the Pyrite Belt succession from the Phyllite-

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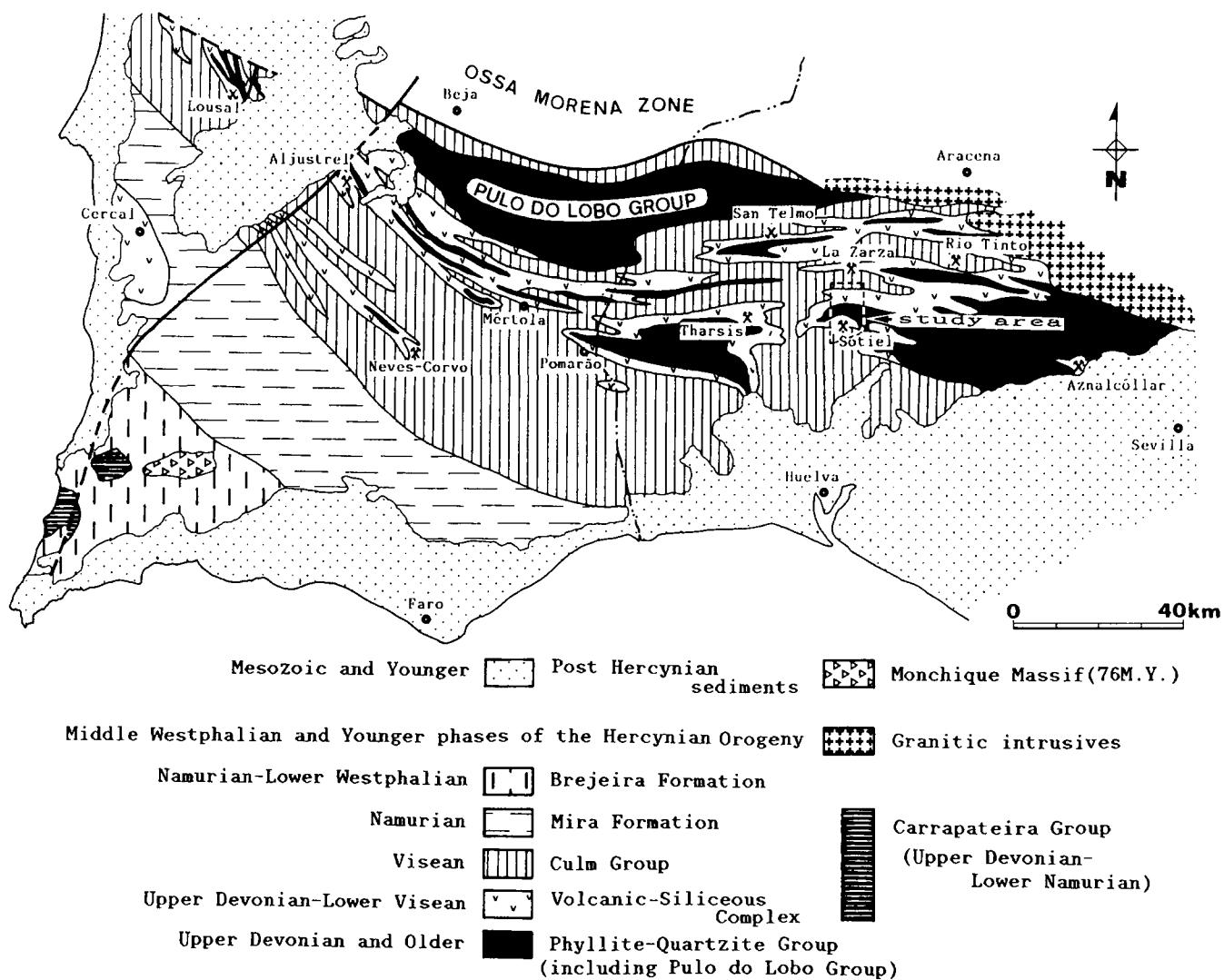


Fig. 1 General geology of the Iberian Pyrite Belt, showing the location of the study area. (after Carvalho et al., 1976)

Quartzite Group through the Volcanic-Siliceous Complex into the Culm Group," and also reviewed the ages of these Groups as described below. The base of the Phyllite-Quartzite Group is unknown but the contact between the Phyllite-Quartzite Group and the Volcanic-Siliceous Complex corresponds to the Devonian-Carboniferous boundary. The Volcanic-Siliceous Complex is of Tournaisian to Lower Visean in age. The age of the Culm Group is considered to be Upper Visean.

The Sotiel-Calañas area is occupied by the three Groups, and together they form one anticlinorium (Fig.2). The Phyllite-Quartzite Group is exposed in the axial part of the anticlinorium and consists mainly

of metapelites with minor amounts of sandstones. Metapelites are classified as phyllite and phyllitic slate and they have frequent intercalations of siltstone laminae. The sandstones are derived from quartzites and are composed chiefly of quartz with minor amount of mica. The matrix is recrystallized, and are therefore comparatively similar to psammitic schist. These sandstones occur as thin (1–30cm) beds and sometimes as slumped pebbles in the metapelites. The metapelite with slumped sandstone pebbles is dominant in the upper portion of the Phyllite-Quartzite Group in this area.

The Volcanic-Siliceous Complex occurs on both sides of the major axis of the anticlinorium in this area,

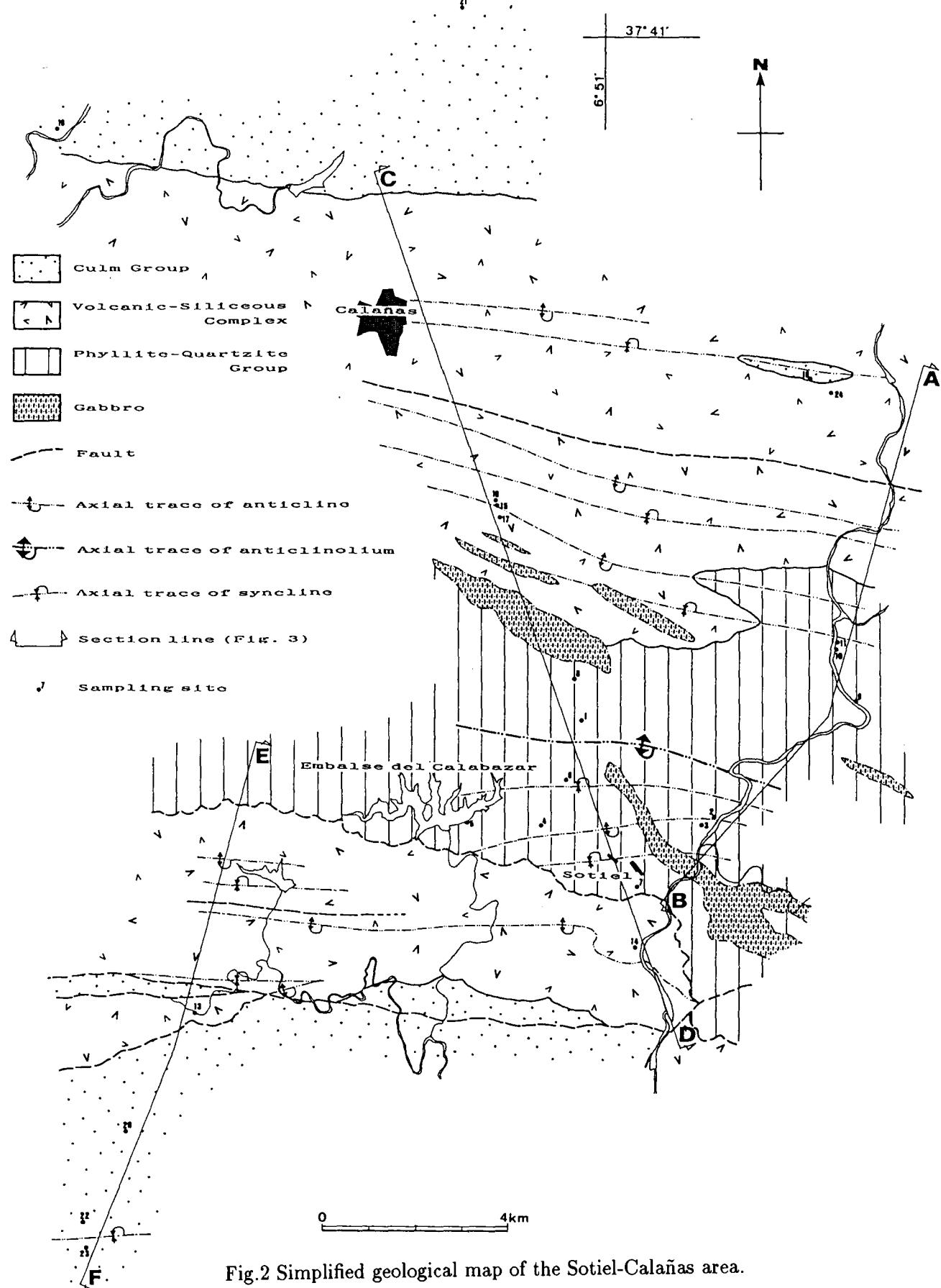


Fig. 2 Simplified geological map of the Sotiel-Calañas area.

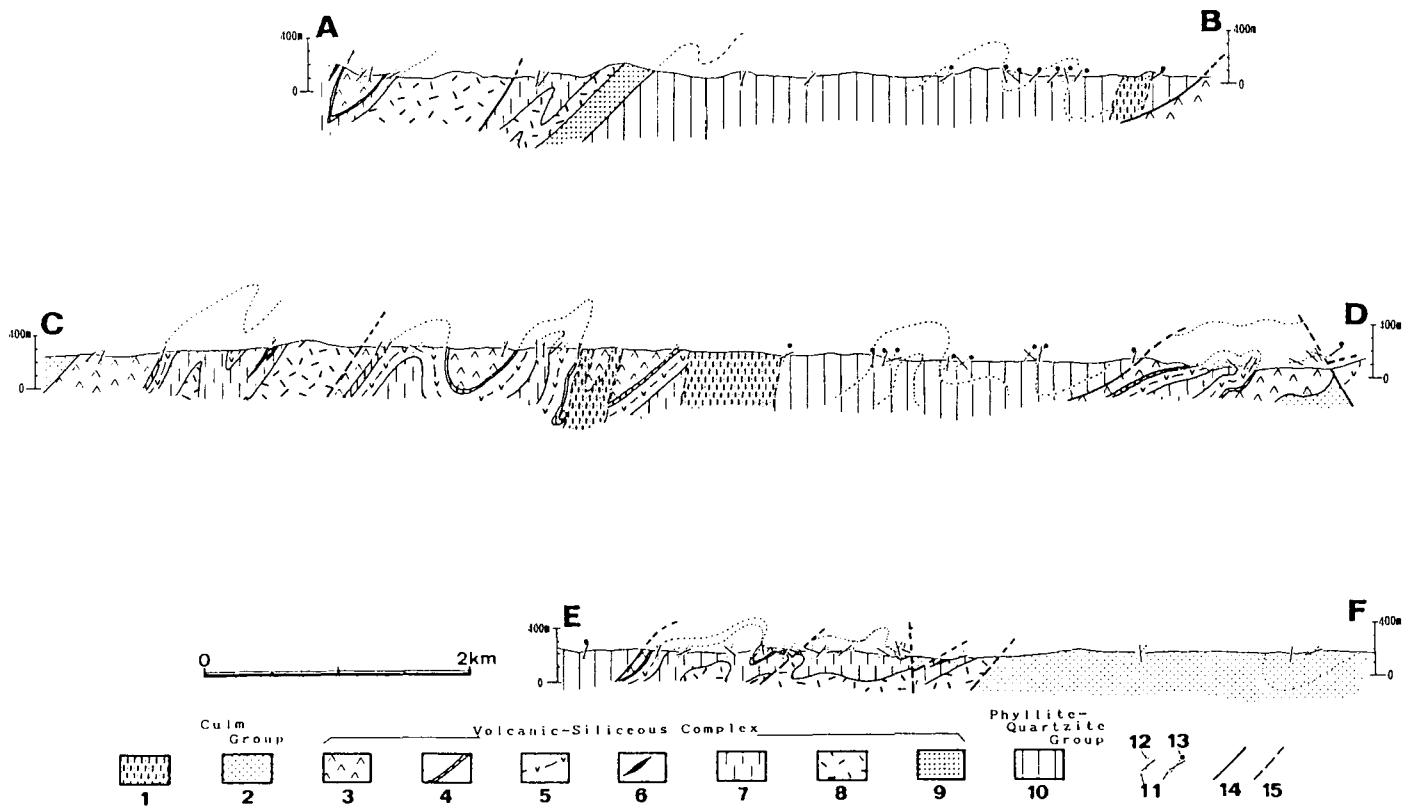


Fig. 3 Geologic profile across the Sotiel-Calañas area (1=Gabbro; 2=Sandstone and slate; 3=Intermediate tuff; 4=Purple slate; 5=fine-grained felsic tuff; 6=Jasper; 7=Black slate; 8=Mafic lava and tuff; 9=Felsic tuff and tuff breccia; 10=Metapelite and sandstone; 11=Dip of bedding; 12=Dip of slaty cleavage; 13=Dip of schistosity; 14=Fault; 15=Estimated fault).

trends E-W and is underlaid by the Phyllite-Quartzite Group. The Complex consists of felsic tuff and tuff breccia, mafic lava and tuff, black slate, fine-grained felsic tuff, purple slate and intermediate tuff unit in ascending order. The polymetallic pyrite deposits of the Sotiel mine is inferred to exist at a horizon between the felsic tuff and tuff breccia unit and the mafic lava and tuff unit. The Culm Group crops out in the northern part (corresponding to northern limb of the anticlinorium) and the southern part (corresponding to southern limb of the anticlinorium) of study area (the north of Calañas and the south of Sotiel). It consists of slates and sandstones. The slates are silty and are often interbedded with laminae of siltstones and fine-grained sandstones. The sandstones belong to lithic wacke.

The Phyllite-Quartzite Group and the Volcanic-Siliceous Complex were intruded by gabbros forming dikes and small intrusive masses. These intrusions resulted in contact metamorphic effects on the surrounding rocks, in a few tens meters.

Munhá (1983) defined four metamorphic zones in the Iberian Pyrite Belt. The metamorphic grade increases in a northward direction from zeolite facies through prehnite-pumpellyite facies to lower greenschist facies. A transitional facies however exist between the prehnite-pumpellyite and the lower greenschist facies. He also showed that the units of the Sotiel-Calañas area have been subjected to prehnite-pumpellyite facies metamorphism.

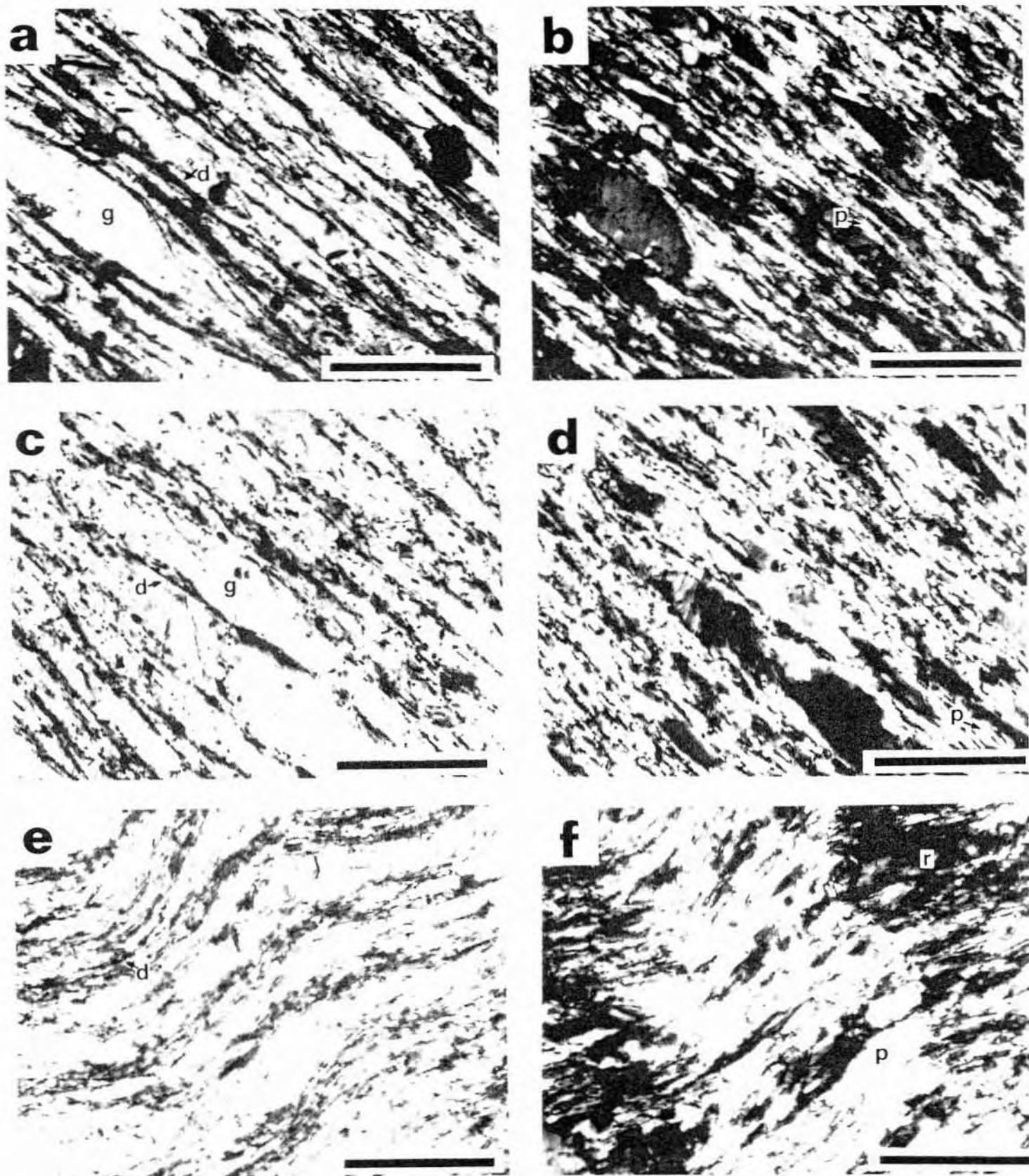


Fig. 4 Photomicrographs of S1. (a and b) S1 of the Culm Group (Loc. 21 in Fig. 2). (c and d) S1 of the Volcanic-Siliceous Complex(Loc. 24 in Fig. 2). (e and f) S1 of the Phyllite-Quartzite Group(Loc. 3 in Fig. 2). All scales are 0.05mm long. All sections are cut perpendicular to S1 and bedding. a, c and e were photographed under plane polarized light. b, d and f were photographed under crossed nicols. g: detrital grain, d: dusty seam, p: secondary platy mineral, r: recrystallized quartz.

### III. Folding and cleavage

Febrel (1965) studied the same area (Sotiel-Calañas area) and described three different S-surfaces (S1=bedding, S2=slaty cleavage, S3=strain slip cleavage) and recognized two stages of folding. Furthermore he demonstrated the presence of one anticlinorium (del anticinal del Sur de Calañas) which is associated with slaty cleavages and was formed by the first stage folding. Suzuki et al., (1990) also described the folded structures in the Iberian Pyrite Belt, and showed a geologic profile across the Embalse del Calabazar area in this study area. He recognized first stage folds of the Volcanic-Siliceous Complex and the Culm Group are associated with slaty cleavages, while those of the Phyllite-Quartzite Group is associated with schistosities. The first stage of folding produced overfold (F1) with north-dipping axial plane, and with axis trending E-W. F1 folds are associated with slaty cleavages (S1) or schistosities (S1) which lie parallel to the axial plane of the F1 folds. The geologic profiles of this study area (Fig. 3) show not only the style of folds, but also the relationship between F1 folds and S1 (slaty cleavages and schistosities) regionally. The slaty cleavages and the schistosities are weakly deformed by the second stage folding, even though they lie parallel to the axial planes of the F1 folds and the same F1 anticlinorium, suggesting that they formed contemporaneously during the same process.

The second stage of folding produces open to gentle folds (F2) with south-dipping axial plane, and with axis trending NW-SE to E-W. The crenulation cleavages (S2) lie approximately parallel to the axial plane of the F2 folds, which occur in the Phyllite-Quartzite Group and some parts of the Volcanic-Siliceous Complex. The S2 cuts the slaty cleavages and schistosities, and have tendency to be formed in the rocks which have schistosities and well developed slaty cleavages. The crenulation cleavages are defined by dusty seams and are not associated with platy minerals.

### IV. Horizontal relationship between slaty cleavage and schistosity

The slaty cleavages and the schistosities are defined by the parallel alignment of platy minerals. Many authors have stated that the slaty cleavages and the schistosities differ in grain size of recrystallized minerals (for example, Billings, 1972). In this study area, the textures of S1 (slaty cleavage and schistosity) show horizontal variation. The relationship between slaty cleavage and schistosity has been described below.

Fig.4 show the S1 in thin sections of pelitic rocks from the Culm Group[Figs.4a and b], Volcanic-Siliceous Complex (Figs.4c and d) and Phyllite-Quartzite Group(Figs.4e and f) in this study area. These pelitic rocks consist of detrital grains, secondary platy minerals, dusty seams and other very fine-grained silicate minerals. The detrital grains consist mainly of quartz, with mica, feldspar, rock fragment, heavy minerals and others. The secondary platy minerals and the dusty seams define the S1. X-ray diffraction data identify the platy minerals as illites and chlorites. The dusty seams occur as opaque lamellas which are composed of micrograined illites, chlorites and others (Oho,1981). The very fine-grained silicate minerals and fine-grained recrystallized quarts are regarded as matrices of the pelitic rocks.

S1 of the Culm Group is characterized by comparatively thick dusty seams and wide matrix domains. The platy minerals are less developed than that of the S1 in the Volcanic-Siliceous Complex. Morphological types of S1 texture is anastomosing. The continuity of S1 is not well developed. The matrix is weakly recrystallized and occurs as very fine-grained quartz (1-5mm) whereas very fine-grained (less than 1m) silicate minerals remain in the matrix. Pressure fringes occur in the matrix domains adjacent to detrital grains, and are generally composed of fibrous quartz, illites, or chlorites. The shape of the fringes are symmetrical and the fibre axis trend parallel to the S1. Grain boundaries of detrital grains which are in contact with dusty seams or secondary platy minerals(mostly illites) tend to be planer or smooth. It is inferred that detrital grains have undergone pressure solution. In the

Volcanic-Siliceous Complex, the dusty seams and the platy minerals tend to be planer and the degree of preferred orientation of platy minerals also increases. The dusty seams are less developed than that of the Culm Group. The grain size of matrix tends to be generally coarser than that of the Culm Group, and the size is about 5mm. The S1 of the Phyllite-Quartzite Group is characterized by the banding of platy minerals, which are more developed and coarser than that of the Volcanic-Siliceous Complex. The dusty seams tend to be wispy and remain a little. The matrix consists of recrystallized quartz with grain size between 5-10mm. These characteristics suggest that the S1 of the Phyllite-Quartzite Group has undergone weakly developed schistosity.

The features described above indicates that the slaty cleavages develop gradationally and change into schistosities in the Phyllite-Quartzite Group. Consequently, a point count analysis on the pelitic rocks was made to confirm the gradational relationship between the slaty cleavages and the schistosities. Detrital grains, secondary platy mineral, dusty seam and matrix were counted. Dusty seams of S1 were distinguished from that of S2. The modal composition was obtained by counting more than 500 points in one thin section for each specimen under the microscope with a magnification of  $\times 400$ . These sections were cut perpendicular to bedding and S1. As described above, the degree of development of the secondary platy minerals, dusty seams and matrix all changed from the upper horizon to the lower. Fig.5 shows the compositional domain of each Group. These domains overlapped each other, and therefore are characterized by different proportion of components. The pelitic rocks of the Culm Group have higher content of dusty seam and matrix, while those of the Phyllite-Quartzite Group have higher content of secondary platy minerals. Fig.6 shows a stratigraphic variation of the component of pelitic rocks. It also shows that the secondary platy minerals increase in proportion while the dusty seam and matrix decrease in proportion to the lower horizon. The change is gradational. From these facts, it is considered that the slaty cleavages gradationally change to the schis-

tosities. The textural change of S1 is summarized as follows; The development of S1 texture is defined by degree of preferred alignment and recrystallization of secondary platy minerals. As S1 texture developed, morphology of S1 texture changes from anastomosing to planer. The very fine-grained silicate minerals in matrix disappear and might have changed to become coarser quartz and platy minerals. The thickness of secondary platy mineral bands increases and also grain size of recrystallized quartz increases.

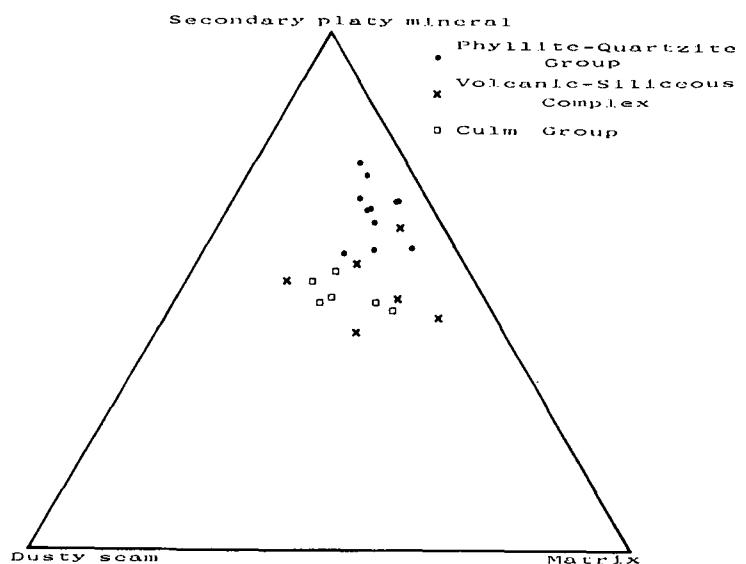


Fig. 5 Compositional diagram of S1 texture.

## V. Discussion and conclusion

Pressure solution, diffusion and recrystallization are thought to be important mechanisms of cleavage development. Gray (1979) showed that the solution-transfer is the dominant deformation mechanism responsible for crenulation cleavage development which was earlier believed to be of shear origin. Holeywell and Tullis (1975) studied at the Lehigh Gap Outcrop, Pennsylvania where a gradual transition from shale to slate exist. They indicated that the preferred orientation of micas associated with the cleavage appears to be a result of some solution and recrystallization process.

This study shows the textural change from slaty cleavage to schistosity. Illite and quartz grows coarser in the change. The study revealed that the recrystallization play an important role in this process. The

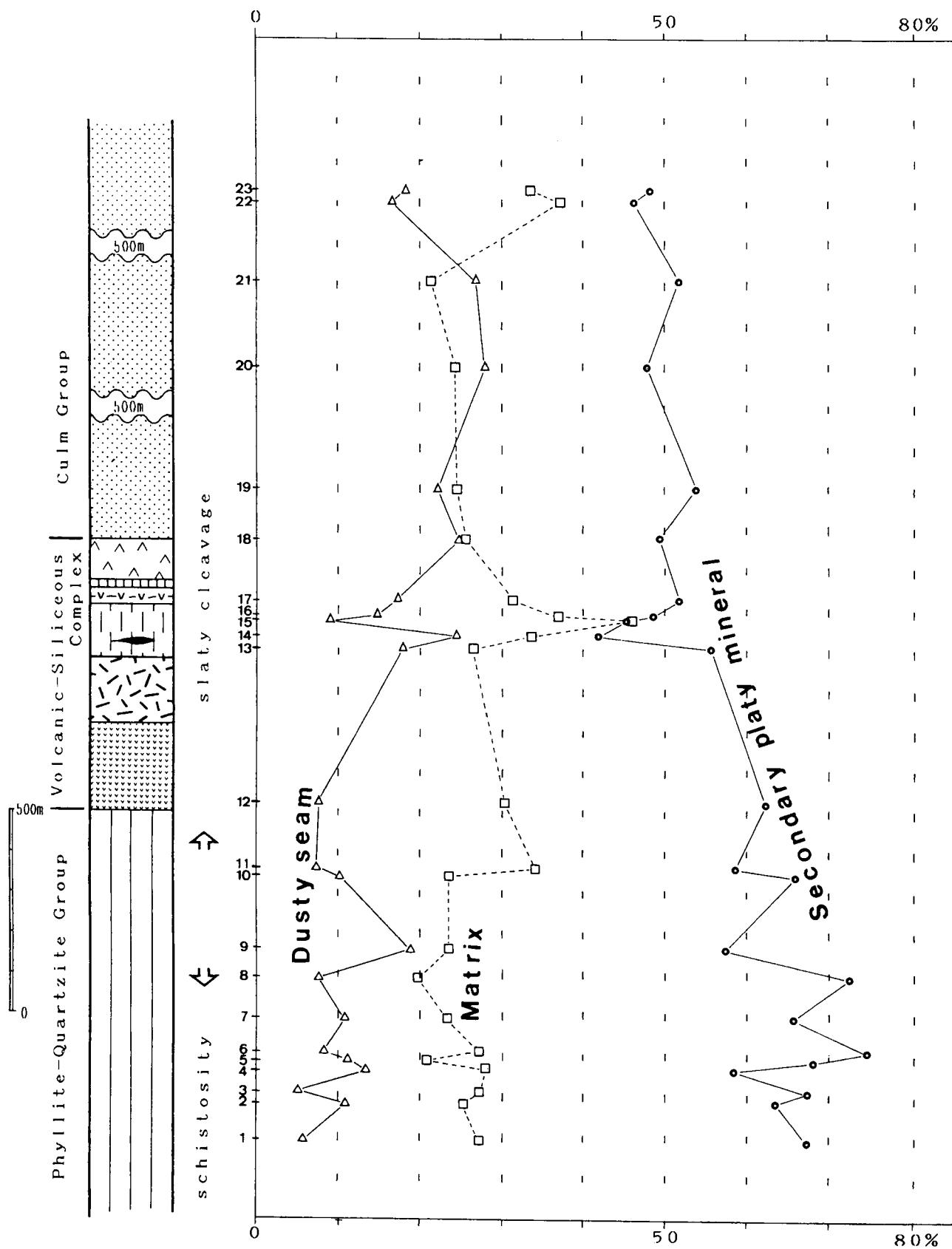


Fig. 6 Horizontal change of S1 texture. See the legend of Fig. 3. The specimen of 12 was taken from the Filon Norte, Tharsis mine, located about 23 km west of Sotiel. The numbers of other specimens correspond to that of Fig. 2.

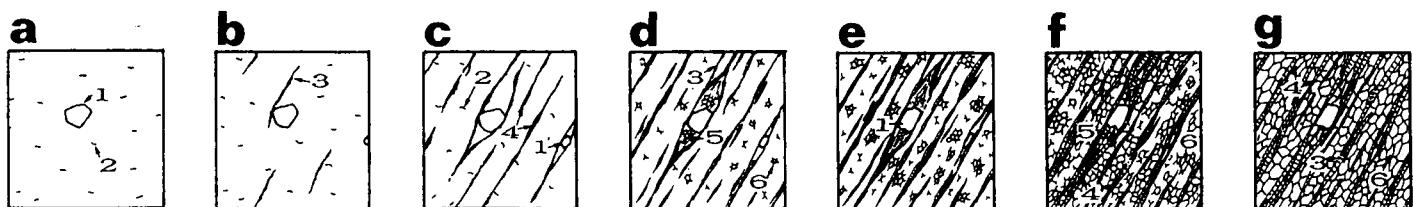


Fig. 7 Schematic development of S1 texture. d=the Culm Group; e=the Volcanic-Siliceous Complex; f=the Phyllite-Quartzite Group; g=the Pulo do Lobo Group. This Group is fault contacted with the Phyllite-Quartzite Group, is estimated to be lower Devonian in age (Oliveira, 1990). 1=detrital grain; 2=clay matrix; 3=dusty seam; 4=secondary platy mineral; 5=pressure fringe; 6=recrystallized quartz.

disappearance of the very fine-grained silicate minerals in the matrix indicates that solution-transfer might have occurred and notably activated recrystallization.

To sum up the result of this study and the work of early stage slaty cleavage (Holeywell and Tullis, 1975), the development of slaty cleavage and schistosity is generalized as follows; Non deformed pelitic rocks consist of detrital grains, very fine-grained silicate minerals and platy minerals. The platy minerals being sub-parallel to bedding are formed during compaction and diagenesis (Fig.7a). The earliest stage of slaty cleavages are defined by dusty seams and preferred oriented platy minerals (mainly illites). However the dusty seams are thin, short and sporadic. The platy minerals oriented parallel to bedding are transected by the platy minerals parallel to slaty cleavage (Holeywell and Tullis, 1975) (Fig.7b). As the slaty cleavages develop (Fig.7c), the platy minerals of diagenetic origin which are parallel to bedding disappear. The length and width of the platy minerals which are parallel to slaty cleavage increase. Illites being in contact with dusty seams tend to develop. Dusty seams become longer and larger and their spacing becomes gradually narrower. Fig.7d shows a typical example of the slate from the Culm Group. At this stage, recrystallized fine-grained quartz occur in the matrix, and pressure fringes also occur. The texture in Fig.7e corresponds to that of the Volcanic-Siliceous Complex. Secondary platy minerals grow larger and longer, and also recrystallized quartz grow larger. The domain of secondary platy minerals continue to increase but the do-

main of dark seams begin to decrease. Fig.7f shows an example of a weakly developed schistosity from the Phyllite-Quartzite Group. The domain of secondary platy minerals increase and the domain of dark seams and matrix decrease. Except for dark seams and detrital grains, constituents are clearly recrystallized and the S1 texture of this stage is referred to as schistosity. It is assumed that the dark seams at this stage consist of residual component of recrystallization. Fig.7g is an example of a typical schistosity from the pelitic schist of the Pulo Do Lobo Group, which is correlated with the Phyllite-Quartzite Group but are separated by a thrust. The Pulo Do Lobo Group corresponds to the greenschist facies (Munhá, 1983). The proportion of the constituent seems to be equal to that of the Phyllite-Quartzite Group. Therefore quartz grows larger and illites change to muscovite.

As mentioned above, F1 folds are associated with S1 (slaty cleavage and schistosity) which lie parallel to the axial plane of the F1 fold, suggesting that they are formed contemporaneously. The slaty cleavages gradationally change to the schistosities, suggesting that they were defined by the same foliation (S1) and the same origin. As was shown above, recrystallization played an important role in the formation of S1 texture, as well as metamorphism. It has been inferred that metamorphism and folding occurred in the same process.

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