29. THE SARDINIA SLOPE BASEMENT

PREFACE

Metagraywackes and phyllites were sampled from Site 133, 39° 12'N, 7° 20'E, and Site 134, 39° 12'N, 7° 18'E, west of the Island of Sardinia. These rocks occur as clasts in a detrital sequence in Hole 133, but they represent the acoustic basement in Holes 134A-E on the upthrown block of the boundary fault bordering the Balearic Abyssal Plain. This chapter gives a petrographical description of these slightly metamorphosed rocks. A lithological comparison is made to similar rocks of lower Paleozoic age on the Island of Sardinia and to the basement rocks encountered in an exploratory well, Mistral 1, drilled in the Gulf of Lyon, 42° 59.6'N, 3° 53.9'E. Data on the radiometric dating of two Sardinia Slope basement samples are also presented.

29.1. COMPARATIVE PETROGRAPHY OF THREE SUITES OF BASEMENT ROCKS FROM THE WESTERN MEDITERRANEAN

K. J. Hsü, Geologisches Institut, Eidg. Technische Hochschule, Zurich, Switzerland
William B. F. Ryan, Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York
T. Cocozza, University of Cagliari, Cagliari, Sardinia
and
P. Magnier, Compagnie Francais des Pétroles, Paris, France

INTRODUCTION

Even a casual examination, while on board the *Glomar Challenger*, led us to recognize a similarity between the Sardinia Slope basement rocks recovered at Sites 133 and 134 and the lower Paleozoic rocks outcropping on the southwest coast of Sardinia. Accordingly, several samples of Ordovician graywackes and phyllites from Sardinia were sampled by Cocozza and made available to us for a comparative study.

Meanwhile, during a post-cruise conference with our European colleagues, we were informed by representatives of the Compagnie Francaise de Pétroles that in two exploratory holes drilled in the Gulf of Lyon, south of France, basement rocks had been encountered under a Tertiary sedimentary section. In one well, Sirocco 1 (43° 11.3'W, 4° 06.1'E), the basement consists of granite encountered at a depth of 1277 meters below sea level. However, when we learned that in a second well, the Mistral 1 (42° 57.6'N, 30° 53.9'E) some 17 miles to the southwest, a dark gray schist had been encountered at 3455 meters, we were curious to see if there is any similarity between this rock and the samples from the Sardinia Slope. One of the primary objectives of the drilling program in the western Mediterranean was to test a hypothesis first proposed by Argand (1922) that the areas drilled in the Gulf of Lyon and on the western Sardinia Slope were originally linked together prior to the counterclockwise rotation of the Corso-Sardinia block, a movement which created the Balearic Basin.

SARDINIA SLOPE BASEMENT SAMPLES

Several pebble-size rocks mixed with variegated silts were recovered in cores from Hole 133. Their origin is not certain, but they may represent channel-gravels deposited during the late Miocene dessication of the Mediterranean (see Chapters 25.1 and 43). These rocks were obviously derived from the basement, which was encountered *in situ* in five of the holes drilled at Site 134.[1] Five samples from the Sardinia Slope holes were examined in thin-section under the petrographic microscope and are described as follows.

13-133-3-1 Metagraywacke (gray)

The thin section consists of quartz and feldspar in a sericite-chlorite matrix. The maximum grain size is about 0.8 mm; sorting is very poor. Magnetite is common, and some muscovite flakes are present.

The quartz grains show some evidence of being flattened, and the recrystallized chert grains have been streaked

[1] Holes 134B and D, in particular, yielded large samples. For a discussion of the Site 133 and Site 134 drill cores and the geological setting of the western Sardinia slope, the reader is referred to Chapters 14 and 15 of this volume.

out as "lenticles." However, most quartz and feldspar grains are not particularly elongated.

A set of schistosity is distinguished by the preferred orientation of flat quartz grains and by the bands of sericitic matrix around such grains. A micro-shear zone inclined to this schistosity is marked by aggregates of finely pulverized quartz.

13-133-3-CC Metagraywacke (reddish brown)

The thin section identified as piece No. 3 and illustrated in Figure 1, consists mainly of lenticularly shaped quartz and feldspar grains in a sericite-chlorite matrix. The quartz "lenticles" range commonly from 100 to 150 microns. Sericite flakes are finer, but a few large flakes of muscovite (up to 0.5 mm long) are present. The black iron minerals have been largely altered to hematite and goethite, thus giving the rock a reddish brown color. Two sets of schistosity were recognized.

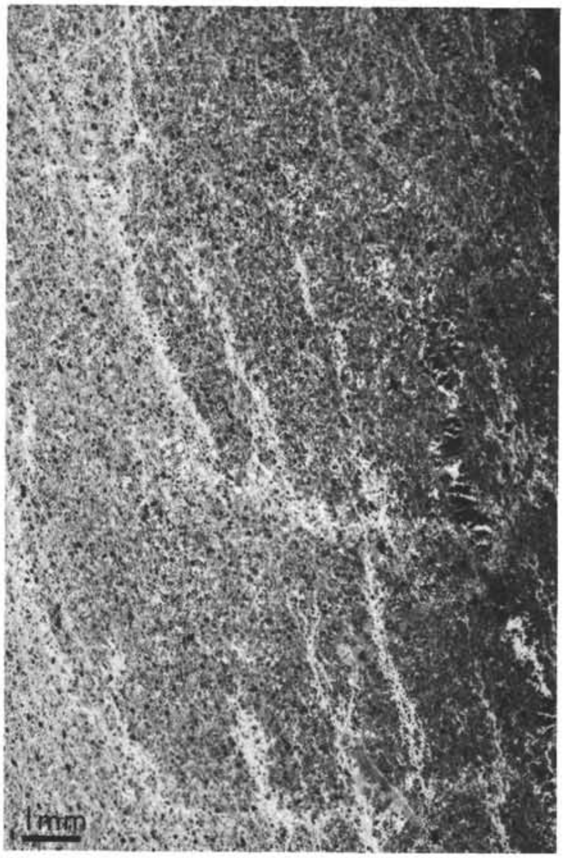

Figure 1. *Reverse print of a thin-section microphotograph of Sample 13-133-3-CC from the western Sardinia Slope. Note the orientation of the metamorphic fabric parallel to the elongation of quartz grains (black), and the quartz filled veins.*

13-134-B-1-CC Laminated Phyllite (dark gray)

The thin section illustrated in Figure 2(B), includes alternating laminae of light and dark gray phyllite. The individual laminae range from a fraction of a millimeter to a few millimeters thick. The lighter (darker in the photograph) laminae consist of sericite, chlorite (up to 10μ-long flakes), clay, and fine silt detrital grains. The darker laminae are even finer in grain size. Magnetite streaks are scattered throughout. A primary set of schistosity is parallel to the compositional layering. A second set of fracture cleavage is subparallel to the compositional layering while another set of fracture cleavages is subparallel to some annealed sheared fractures which cut the bedding plane at an apparent angle of 55 degrees.

The mineral assemblage suggests recrystallization under low greenschist-facies conditions.

13-134B-1-CC (A) Phyllite (gray)

This thin section illustrated in Figure 2(A), is cut from a specimen adjacent to 134B-1-CC and includes interlaminated metagraywacke and phyllite. Also present is a modified and sheared boring-tube which cuts across the bedding plane. Both sets of schistosity (parallel and inclined to bedding) are present.

The metagraywacke includes angular grains of quartz (up to 30μ) scattered in a sericitic-chloritic matrix. The phyllite is similar to that of Sample 13-134B-1-CC.

13-134D-3 CC Metagraywacke (gray)

The thin section illustrated in Figure 2(C) consists of quartz, potash feldspar, and plagioclase grains in a fine-grained sericite-chlorite matrix. The maximum grain size is approximately 1 mm. The sorting is poor. Magnetite is common. A few muscovite flakes are present.

The quartz grains (dark in the reverse print) are angular to subangular. Undulatory extinction is common. However, only a few quartz grains show signs of being flattened during the syntectonic crystallization. Recrystallized chert grains are present. Feldspars are twinned and somewhat sericitized. The schistosity is marked by crushed laminae of very fine-grained aggregates of quartz sericite, magnetite, and calcite; the laminae range from several microns to a fraction of a millimeter thick. This schistosity is inclined to a planar structure defined by the long axis of quartz (in thin-section), and may represent the secondary schistosity inclined to the original bedding plane.

Comments on the Sardinia Slope Rocks

The Sardinia Slope basement is a slightly metamorphosed detrital sequence. The chlorite-sericite assemblages suggest recrystallization under low greenschist-facies conditions. Yet, the abundance of detrital feldspar as stable relics indicates temperatures which are not sufficiently high to promote chemical equilibrium. The absence of typical shelf-carbonate sediments from the "basement" sequence suggests an affinity to rocks of the flysch facies. However, the radiometric dates (> 100 m.y.) argue against a correlation with the Tertiary Flysch of the Alpine System. The presence of schistosity inclined to the bedding suggests that the detrital rocks have been strongly deformed. This is typical of the rocks of the "slate belts" in various orogenic systems. The nearest examples are the lower Paleozoic Caledonides of Sardinia and South France (see Gignoux, 1960, p. 109-111).

SARDINIA ISLAND SAMPLES

On the Southwest coast of Sardinia, a series of graywackes and phyllites of lower Paleozoic age is exposed

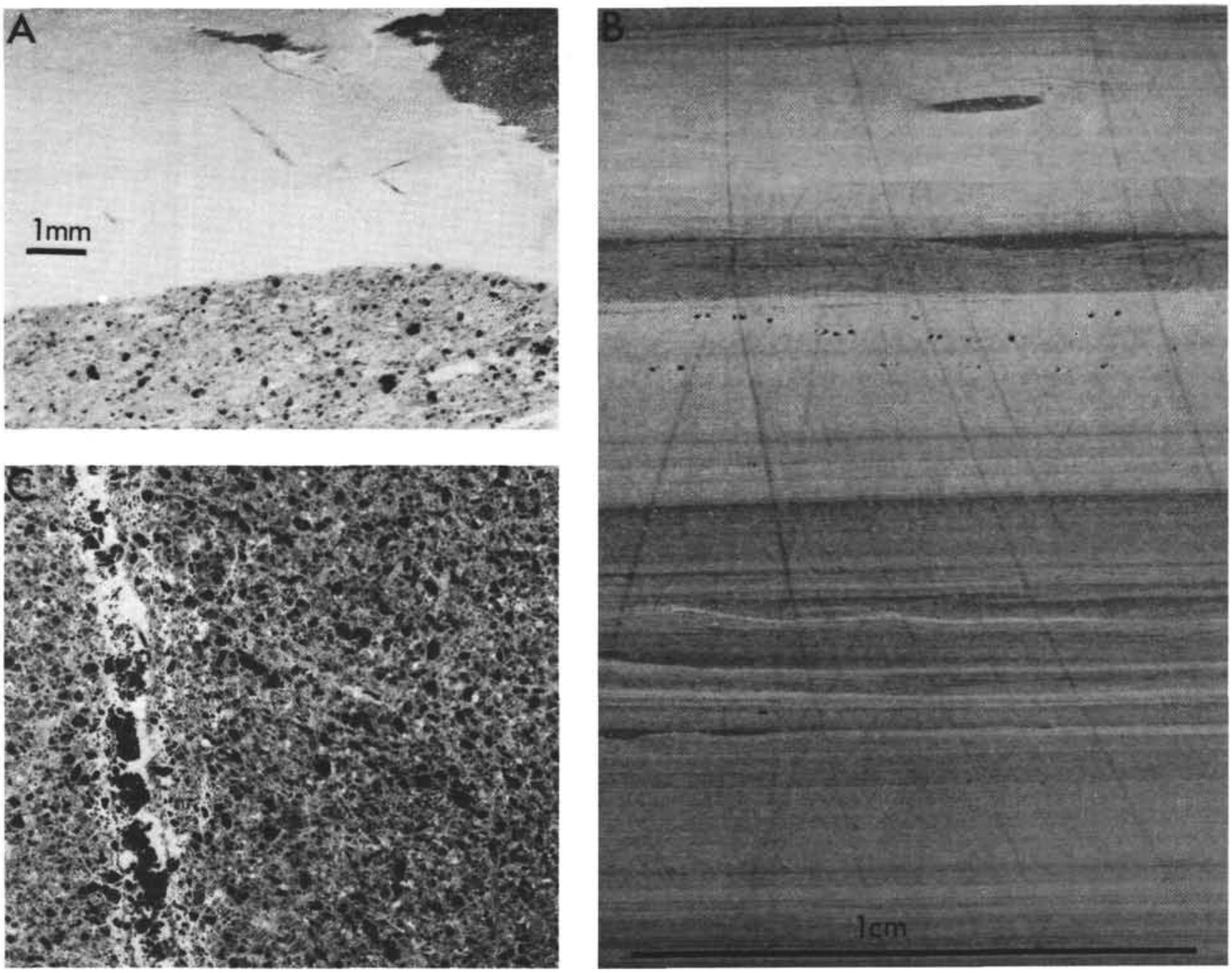

Figure 2. *Reverse prints of thin-sections of samples from Site 134–western Sardinia Slope. (A) Sample 134-B-1-CC (A), a specimen of interlaminated phyllite and metagraywacke. (B) Sample 134-B-1-CC, a fine-grained laminated phyllite. Note the scattered quartz grains (black) in the upper center and original cross-bedding structures. (C) Sample 134-D-3-CC, a poorly sorted metagraywacke with a quartz filled vein. The same scales apply to all the illustrations.*

(Gignoux, 1960). Two Ordovician samples were collected from the western slope of Monte Rosas (609 m a.s.l.), about 16 km southeast of Iglesias (Sulcis, southwest Sardinia). The Ordovician detrital strata lie uncomformably above a middle Cambrian "Scisti di Cabitza."

The Ordovician sequence has a polygenic pebbly mudstone at its base. The clasts are embedded in a reddish muddy matrix and are on the average several centimeters in size. This rock is overlain by an alternation of phyllites and metagraywackes; the latter show graded bedding. The silty beds show parallel or crossed laminations. The color of the rocks is purplish gray, but light green horizons are common. The two examples examined petrographically are described below.

SO-1 Phyllite and Metagraywacke (reddish brown)

The thin section illustrated in Figure 3(A), is mainly phyllite. A metagraywacke lamina 7 mm thick (a) is intercalated. Some scattered larger grains (some 50μ in size) can be identified as quartz and feldspars. Black iron minerals, considerably oxidized, are common and thus give the rock a reddish brown color. The sericite flakes, ranging up to 50μ long, mark a prominent schistosity which is inclined to the bedding plane.

The metasiltstone is similar to phyllite in mineralogy but lighter and coarser grained. Quartz and feldspar grains, up to 150μ in size, are common. They show some evidence of being flattened and streaked out during the low grade deformation and metamorphism.

SO-3 Metagraywacke (gray)

The thin section consists mainly of lenticular-shaped grains of quartz and quartz-aggregates in a very fine-grained phyllitic matrix. "Lenticles" of quartz aggregates range up to 5 mm long, but individual quartz grains are rarely larger than 0.5 mm. Sericite is the predominant matrix mineral; chlorite and magnetite are present. The matrix sericite flakes range from a few to a few tens of microns long.

The quartz grains show evidence of being flattened and stretched during the low-grade metamorphism and deformation. A few equidimensional grains are, however, present to betray the original outline of this detritus. Some deformed elongate phyllite components may represent shale chips in the original graywacke.

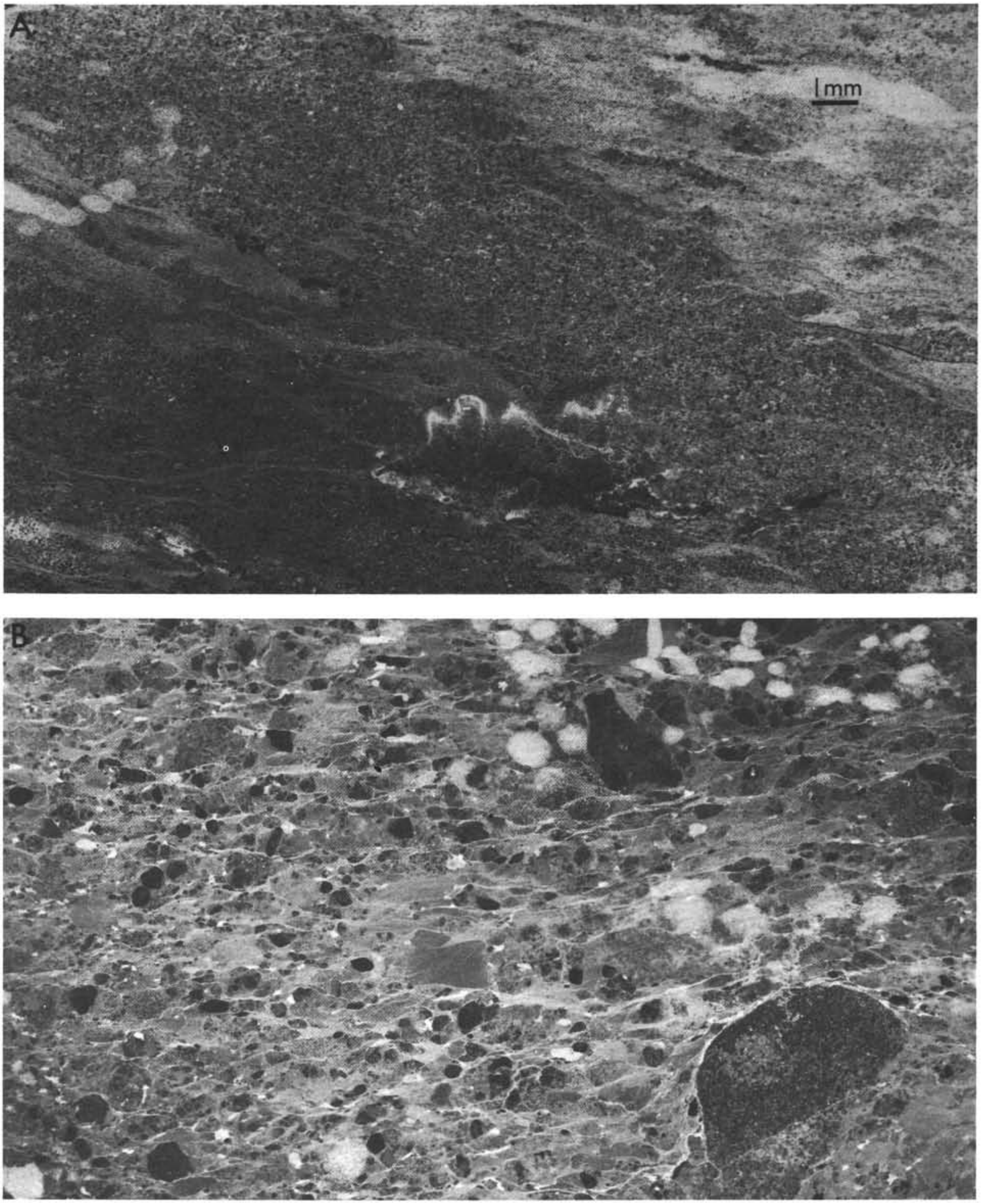

Figure 3. *Reverse prints of thin-sections of samples from the Ordovician of southwestern Sardinia. (A) Sample SO-1. Note the thick laminae of metagraywacke cutting across the phyllite. (B) Sample SO-3, a considerably coarser-grained metagraywacke with lenticular, shaped grains of quartz and quartz-aggregate. Sericite is the predominant matrix material.*

Comments on the Sardinia Island Samples

At the outcrop, the metagraywackes and phyllites constitute a well-bedded detrital sequence in the Caledonian orogenic belt of southwest Sardinia.

The samples examined are lithologically similar to the Sardinia Slope rocks, although here the rocks have larger grain-size components and seem to be somewhat more recrystallized and more severely deformed. Although the deformation of the Sardinia rocks is Caledonian, the mild metamorphism is believed to be related to a Hercynian thermal event.

GULF OF LYON SAMPLES

Two specimens from the basement suite of the drillhole Mistral 1 were selected for petrographic examination—one from Core 2 at 3491.5 meters subbottom and the other from Core 3 at 3567 meters subbottom. The basement rocks include fragments of dark gray laminated phyllites and metagraywackes. Thin-sections were made from each specimen and are described below.

MS-1-Core 2 Metagraywacke (gray)

The thin section illustrated in Figure 4(A), consists of quartz, potash feldspar, and plagioclase in a fine grained sericite-chlorite matrix. The maximum grain size is approximately 1 mm. The sorting is poor. Some muscovite flakes and traces of biotite are present, probably as recrystallized detrital constituents. Magnetite is common.

The quartz grains (dark in the reverse print) are angular, and show flattening parallel to primary schistosity. They are characterized by their almond shape in thin section and by the undulatory extinction. The flattening and streaking out of quartz grains are apparently related to syntectonic recrystallization. The other evidence of recrystallization is provided by the traces of inclusion bands within some quartz grains that are parallel to the enclosing schistosity. Quartz aggregate grains may have derived from chert, and carbonate aggregates from limestone detritus. Plagioclase grains are twinned, but the twinned grains are only rarely bent. The micaceous minerals in the matrix were wrapped around the coarser grains. Two sets of indistinct schistosity have been recognized.

MS-1-Core 3 Laminated Phyllite (gray)

The thin section illustrated in Figure 4(B) includes alternating light and dark gray laminae ranging from a fraction of a millimeter to about a millimeter thick. The light laminae consist of sericite, chlorite (up to 30μ long flakes), and silt-sized quartz grains. The darker laminae are slightly finer in grain size. At least two sets of schistosity (parallel and inclined to bedding) have been recognized. The rock is further fractured along microshear fractures and these were filled by aggregates of calcite and quartz.

Comments on the Gulf of Lyon Samples

The basement samples from the Mistral well are only slightly metamorphosed. The sericite-chlorite assemblage suggests metamorphism under greenschist-facies conditions. Yet, the presence of detrital feldspar as unstable relics indicates that chemical equilibration has not been achieved. Radiometric dating by Rb/Sr method (data not released by CFP) suggests that mild metamorphic changes occurred during the Paleozoic (305 m.y.) and were followed by a

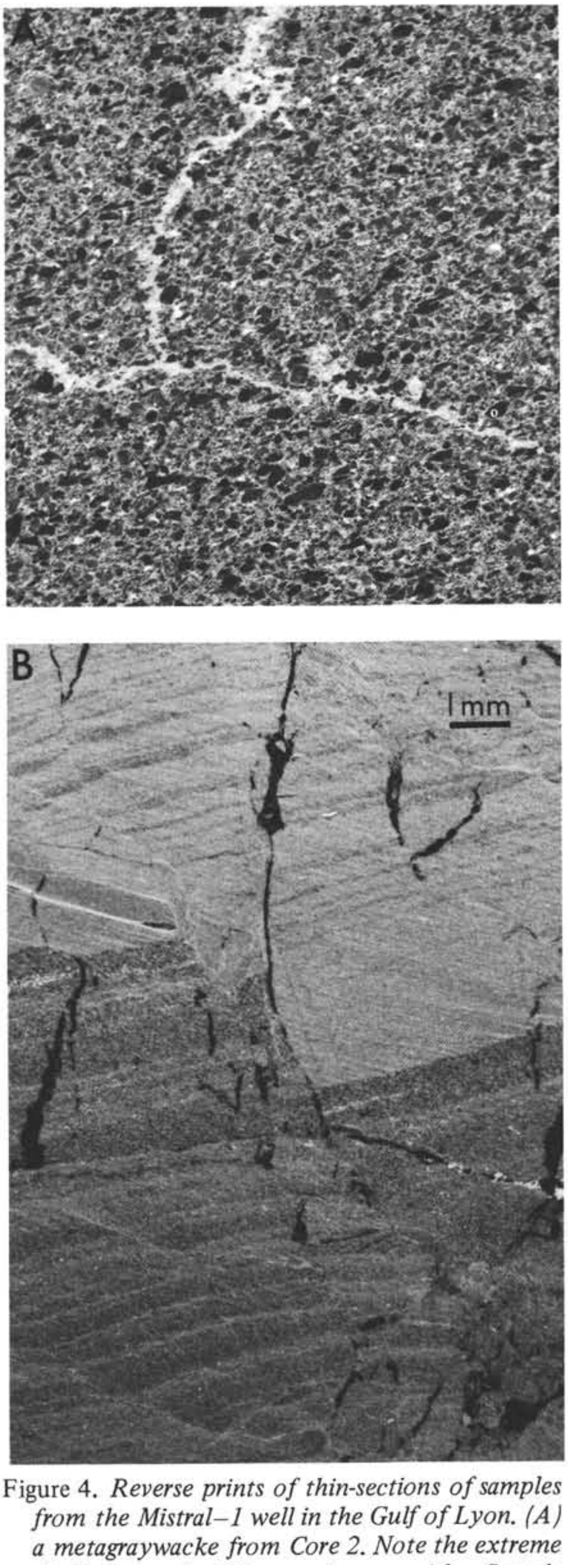

Figure 4. *Reverse prints of thin-sections of samples from the Mistral–1 well in the Gulf of Lyon. (A) a metagraywacke from Core 2. Note the extreme similarity of this specimen with Sample 134-D-3-CC in Figure 2 (C). (B) a laminated phyllite from Core 3, which except for fracturing and shearing is comparable to Sample 134-B-1-CC in Figure 28.*

Mesozoic (150 m.y.) event. The Mistral basement is probably related to the lower Paleozoic Caledonides of South France (Géze, 1960). Graptolite-bearing phyllites and sandstone are present in the Maures Massif on the coast between Toulon and Cannes and in the Montagne-Noire east of, and northwest of, the Gulf of Lyon respectively (Gignoux, 1960, p. 109-110). Like the rocks on Sardinia, the Cambrian-Ordovician series of the Montagne Noire seems to record a Hercynian tectonic and thermal event as well (Géze *et al.*, 1962; Mattauer *et al.*, 1967).

DISCUSSION

Samples from these three widely separate regions are sedimentologically very similar: all belong to the graywacke-suite and are derived from a similar source terrain. Their deformational and metamorphic histories also show remarkably parallel trends. All were mildly metamorphosed. The Sardinia samples seem to have undergone the most advanced metamorphism and have lost much of their original clastic textures. Sardinia Slope and Mistral samples are fine-grained and less recrystallized. Although the samples from all these regions include sericite and chlorite as metamorphic minerals, the existence of potash feldspar and plagioclases, more calcic than albite, indicate that the rocks have not yet been equilibrated under conditions of greenschist metamorphism; the detrital feldspar grains represent unstable relics. The development of slaty cleavage inclined to the bedding surfaces has been observed in all three suites of samples. This feature would place all suites in the slate belt of a mountain system.

The similarity of the offshore "basement" to the proximal Caledonides on land suggests to us that both the Sardinia Slope and the Gulf of Lyon basement belong also to the Caledonides. Southern France and Sardinia are now separated by the Balearic Basin. Nevertheless, an affinity between the French and Sardinia Caledonides was already noted by Gignoux (1960). Our Sardinia Slope and Gulf of Lyon samples now provide us with an even closer link. The metagraywackes and phyllites from our holes could well represent the western and offshore prolongation of the Caledonides of the Maures Massif if we accept Argand's geometrical restoration of the Carso-Sardinia block.

REFERENCES

Argand, E., 1922. Le Tectonicque de l'Asie, Congrés géol. intern., XIII, Belgium, Comp. rendus. 171.

Gèze, B., 1960. L'Orogenèse caladonienne dans la Montagne Noire (sud du Massif Central français) et les régions voisines. *Intern. Geol. Congr., 21st, Copenhagen, 1960, Rept. Session, Norden,* **19**, 120.

Gèze, B., DeSitter, L. V. and Trumpy, R., 1952. Sur le sens de deversement des nappes de la Montagne Noire. *Bull. Soc. Géol. France.* **6** (2), 491.

Gignoux, M., 1960. Geologie Stratigraphique. Masson et Cie., Paris. 759.

Jung, J., 1953. Zonéographie et âge des formations crystallophylliennes et des massifs hercyniens française. *Bull. Soc. Géol. France.* **235**, 1.

Mattauer, M., Arthaud, F. and Proust, F., 1967. La structure et la microtectonique des rappes herciennes de la Montagne Noire. **In** J. P. Schaer (Editor), *Colloque Étages Tectoniques,* Baconniere, Neuchatel. 229.

29.2. ISOTOPIC DATING, SARDINIA SLOPE BASEMENT

U. Frick, R. H. Steiger and K. J. Hsü, Geologisches Institute Eidg. Technische Hochschule, Zurich, Switzerland

Two samples from the Sardinia Slope basement, 13-134-D-3-CC and 13-134-B-1-CC, were sent to the Laboratory of Isotope Geochemistry and Mass Spectrometry, Swiss Federal Institute of Technology, Zurich, for isotopic dating. The first is a fine-grained metagraywacke, the second a phyllite. The rocks consist mainly of quartz, sericite, and chlorite; the very fine-grained sericite is the main potassium-bearing mineral. However, the graywacke specimen (13-134-D-3-CC) includes a few per cent of potash feldspar, which may represent unstable relics of detrital origin. The detailed petrographic descriptions of these samples are included in Chapter 29.1.

Because it was not possible to separate grains of sericite, which are only several microns in size, it was necessary to do whole-rock K/A dating. The analytical data are shown in Table 1.

The computed ages are derived from the ratio of potassium and radiogenic argon. The geological significance of the ages is very questionable since whole-rock dating of metamorphic rocks is a rather unsatisfactory method. There is the problem of inherited argon from detrital minerals in such mildly metamorphosed graywackes and phyllites.

TABLE 1
Radiometric Dating of Sardinia Slope Basement

	Sample No.	
	13-134-D-3-CC	13-134-B-1-CC
Lithology	Metagraywacke	Phyllite
Potassium content		
by isotopic dilution	2.32%	3.75%
by atomic-absorption	2.10%	3.69%
rad. Ar^{40} cc STP	$1.89 \pm 0.05 \times 10^{-5}$	$1.82 \pm 0.05 \times 10^{-5}$
Air argon	19.1%	18.4%
Computed age	210 ± 15	120 ± 5