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Structural development of Legoupil Formation at Cape Legoupil, Antarctic Peninsula

ABSTRACT: Rocks of the Legoupil Formation in the Cape Legoupil area were folded about a N7OE oriented axis. Later these rocks were affected only by brittle deformation which occurred in four stages: (1) jointing — set I, (2) dyking, (3) faulting and, (4) jointing — set II. Both, folding and subsequent brittle deformation, are hardly compatible with the Mesozoic-Cenozoic eastward subduction of the ancient Pacific ocean crust.

Key words: Antarctica, Legoupil Formation, structural geology.

Introduction

This paper describes some results of geological investigations carried out during the austral summer of 1987/88 during the 3rd Polish Geodynamic Expedition to West Antarctica led by Professor Aleksander Guterch (*see*: Birkenmajer 1988, Doktor *et al.* 1988).

The history of geological studies in the Cape Legoupil area (Fig. 1) is rather short. The area was first studied by Halpern (1964, 1965) who published its geological map and found numerous localities with macrofossils on Gandara and Kopaitic islands. Some remarks on the lithology and metamorphism in the Cape Legoupil area were published by Elliot (1965). Detailed observations of small-scale structures were made in the immediate surroundings of the Chilean station *General Bernardo O'Higgins* by Miller (1966). British Antarctic Survey personnel made further collections of fossils from localities found by Halpern (1964, 1965). These fossils were studied by Thomson (1975a, b).

Regional setting

The Legoupil Formation was distinguished by Halpern (1964, 1965). This Triassic formation (Thomson 1975a, b) belongs to the Trinity Peninsula Group (Hyden and Tanner 1981) of ill-defined (Permo-Carboniferous — Triassic?) age (Thomson 1975a, Pankhurst 1983). The group comprises largely turbidites.

The Trinity Peninsula Group is a part of the thermal orogen which includes the Antarctic Peninsula. The origin of this orogen had been related to the long-lived eastward subduction of ancient Pacific ocean crust (Suárez 1976, Smellie 1981, Burn 1984, Storey and Garret 1985). The rocks of the Trinity Peninsula Group were deposited within the active margin. Depositions within upper-slope (Smellie 1981) and trench-slope (Storey and Garret 1985) basins have been postulated.

The rocks of the Trinity Peninsula Group are considered to be affected by multiphase deformation (Hyden and Tanner 1981, Tanner *et al.* 1982, Dalziel 1984).

Lithostratigraphy

Principal rock units

The observations discussed in this paper were made on Schmidt Peninsula, on Toro[1], Kopaitic and Gandara islands, on Cape Legoupil, and at Mount Jaquinot Nunatak (Fig. 1). The rocks cropping out on Schmidt Peninsula, Toro Island, and at Mount Jaquinot are metamorphosed while those in the northern part of the area are not changed. In the whole area they show three facies: (1) massive argillite, (2) interlayered sandstone and argillite, and (3) thick-bedded and unstratified sandstone. Particular lithologies form bodies which pinch-out laterally and repeat in vertical section (Figs 2—3).

Massive argillite. — It comprises black and dark grey claystones and mudstones. These rocks form bodies up to 140 m thick. They contain less that 5% intercalations of grey, fine grained sandstones. These sandstones are usually thin bedded, however, close to locality 1 on Toro Island (Fig. 2) the sandstones are up to 2 m thick. Close to locality 2 on Kopaitic Island (Fig. 3) argillite contains clasts of fine grained sandstone (Fig. 4).

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[1] The name Toro Island has been introduced by the present author after Toro Point the unique named feature of the island.

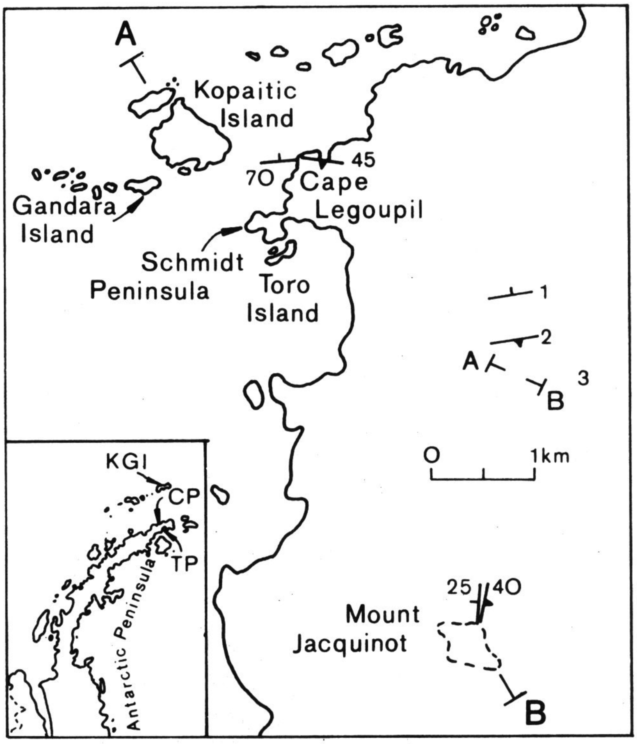

Fig. 1. Location map of the Cape Legoupil area. Inset shows location at Antarctic Peninsula. CP — Cape Legoupil, KGI — King George Island, TP — Trinity Peninsula, 1 — dip, 2 — cleavage, 3 — cross-section line (*cf.* Fig. 16)

Interlayered sandstone and argillite. — It comprises black and dark grey argillite and grey, fine grained sandstone in approximatively equal proproportions. Each rock forms beds up to 1 m thick. This facies form bodies up to 50 m thick.

Thick-bedded and unstratified sandstone. — It comprises grey, fine grained sandstone forming bodies up to 125 m thick. In places, *e.g.* at locality 3 on Kopaitic Island (Fig. 3), the sandstone includes irregular bodies of coarse conglomerate. The conglomerate (Fig. 5) consists of poorly rounded clasts of sandstone, mudstone and claystone in sandy matrix.

Contacts between lithological bodies are in places erosional. For example, at locality 4 on Kopaitic Island (Fig. 3). poorly bedded sandstone fills up a depression cut in argillite (Fig. 6). Close to the contact the sandstone contains numerous angular fragments of argillite.

Metamorphic rocks. — In the southern part of the studied area, all described lithologies are affected by dynamic metamorphism (Halpern 1964, 1965). The argillite is changed into phyllite while arenaceous sediments show less obvious effects of the metamorphism (Halpern *op. cit.*). In that area all rocks contain numerous bedding-parallel quartz veins up to few centimeters thick.

Other rock units

Conglomerate. — Indistinctly bedded sandstone at locality 5 on Gandara Island (Fig. 3) contains some layer-parallel lenses of conglomerate. These lenses are up to 15 m long and up to 1 m thick. Their boundaries are usually not sharp. The conglomerate consists of rounded and well rounded pebbles of mudstones, granitoides, basalts and altered basic rocks in poorly sorted sandy matrix.

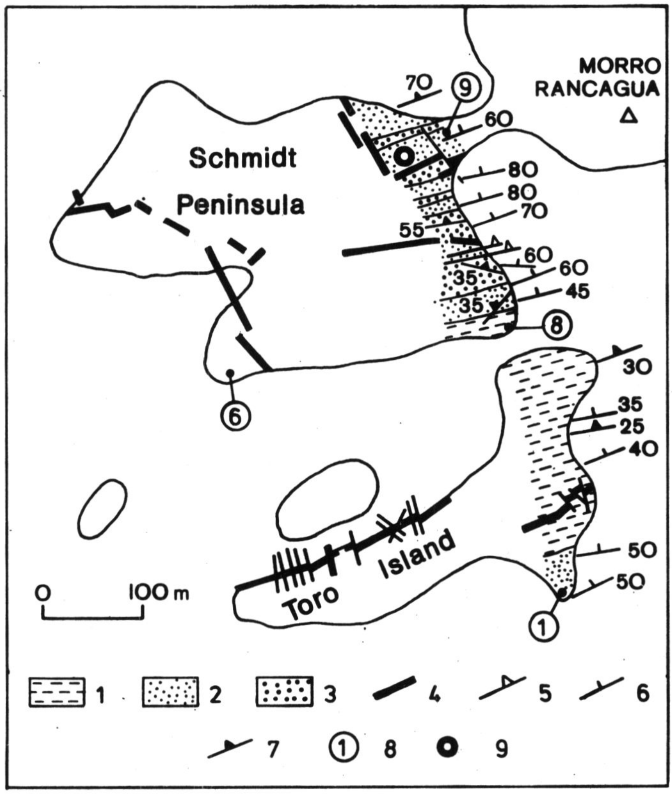

Fig. 2. Geological scheme of Schmidt Peninsula and Toro Island. 1 — argillite, 2 — interlayered sandstone and argillite, 3 — thick-bedded and unstratified sandstone, 4 — dyke, 5 — reversed fault with barb on uphtrown side, 6 — bedding, 7 — cleavage, 8 — locality discussed in text, 9 — centre of Station *General Bernardo O'Higgins*

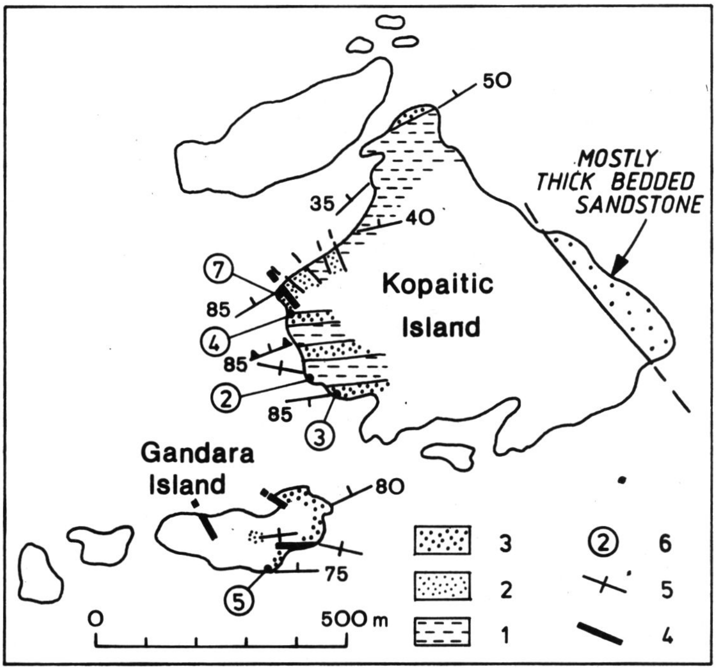

Fig. 3. Geological scheme of Kopaitic and Gandara islands. 1 — argillite, 2 — interlayered sandstone and argillite, 3 — thick-bedded and unstratified sandstone, 4 — dyke, 5 — vertical attitude of beds, 6 — locality discussed in text

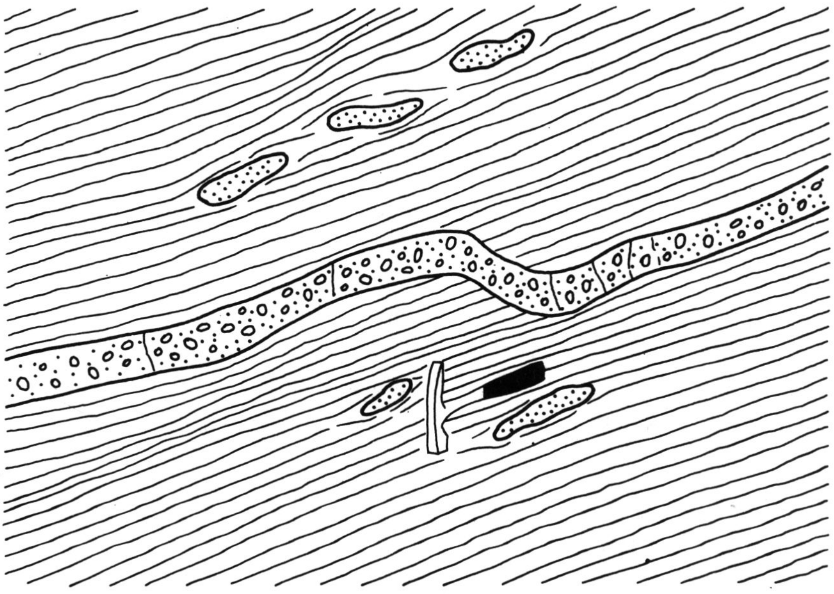

Fig. 4. Gravelly dyke and sandstone clasts in argillite at locality 2 on Kopatic Island. Drawn from photograph

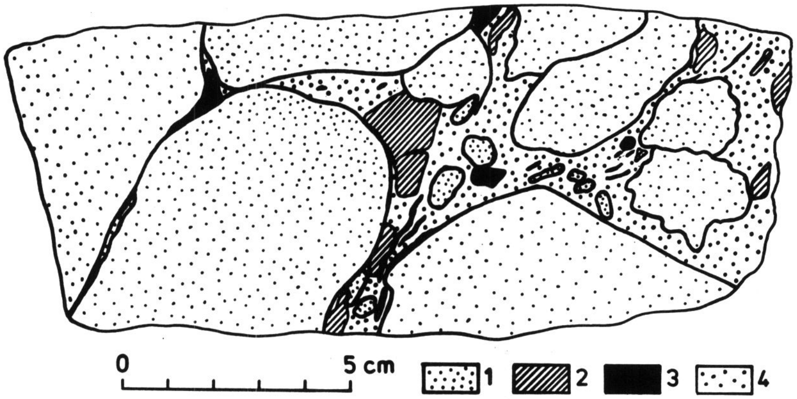

Fig. 5. Conglomerate from locality 3 on Kopaitic Island. Clasts of sandstone (1), mudstone (2), and claystone (3) in sandy matrix (4). Drawn from photograph

Clastic intrusions. — Several sheet-like clastic intrusions cut the argillite at locality 2 on Kopaitic Island (Fig. 3). The intrusions (Fig. 4) are up to 10 cm thick. They usually parallel the bedding but in places they cut the bedding. The intrusions consist of sandstone clasts in sandstone matrix.

Sedimentary breccias. — Patches of sedimentary breccias up to few square meters large crop out at locality 1 on Toro Island and at locality 6 on Schmidt Peninsula (Fig. 2). These are irregular bodies of breccia occurring inside undisturbed sections of interlayered sandstone and argillite. The breccias (Fig. 7) consist of parts in which bedding, though disrupted, is traceable and of parts which are chaotic.

Fossils

Numerous localities with macrofossils occur on Kopaitic and Gandara islands (*see*: Halpern 1964, 1965; Thomson 1975a, b). These fossils were determined by Thomson (*op. cit.*) as Triassic bivalves. At locality 5 on Gandara Island (Fig. 3) the fossils occur in indistinctly bedded sandstone. There, they form several layer-parallel bands which are up to 5 m long and up to 50 cm thick (Fig. 8). The fossils are oriented both, convexity upward and downward which may indicate that they are redeposited.

Pyrite mineralization

Pyrite veins occur at localities 2 and 7 on Kopaitic Island (Fig. 3). At locality 2 numerous pyrite veins up to 5 mm thick cut the black argillite.

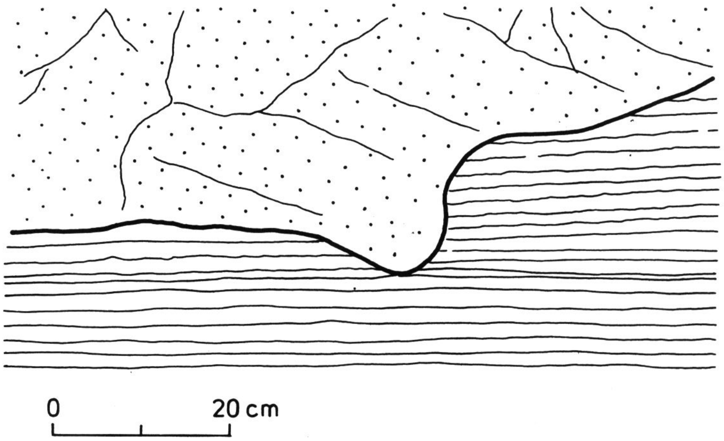

Fig. 6. Erosional contact between sandstone and argillite at locality 4 on Kopaitic Island. View from above. Both lithologies dip subvertically. Direction of younging is towards the top. Drawn from photograph

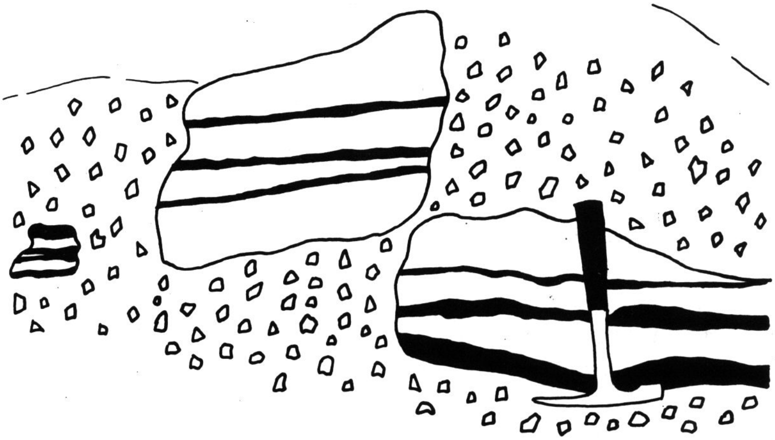

Fig. 7. Sedimentary breccia at locality 6 on Schmidt Peninsula. Stratified fragments with bedding surfaces lined by quartz veins (black) surrounded by chaotic breccia. Drawn from photograph

The veins show different dips but they strike parallel to the bedding. At locality 7 pyrite veins accompany a magmatic dyke. The veins are parallel to the segment of the dyke oriented 70/65 N. The veins, up to 5 mm thick, cut the dyke and its country rocks — interlayered sandstone and argillite, up to 5 m from the dyke.

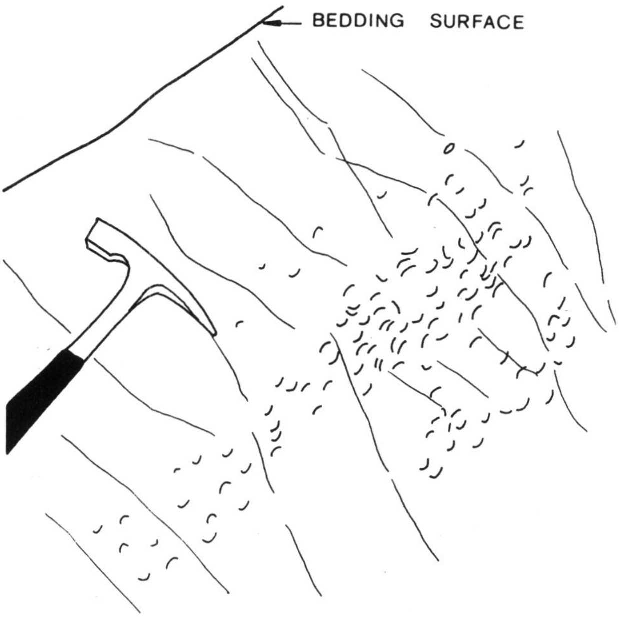

Fig. 8. Fossils in thick-bedded sandstone at locality 5 on Gandara Island. View from above. Beds dip subvertically. Direction of younging is toward the bottom. Drawn from photograph

Tectonic structure

Folds and associated structures

Description. — Rocks dip steeply toward NWN (Figs 2—3; 9A, B) in the whole studied area. In the southern part of the area the rocks are commonly cut by fracture cleavage which on Schmidt Peninsula and Toro Island is either bedding parallel or dips northward less steeply than the bedding (Fig. 9C). The cleavage is commonly lined by quartz veins up to few centimeters thick. More to the north, in unmetamorphosed rocks, cleavage occurs only exceptionally.

Phyllites on Schmidt Peninsula and Toro Island are folded in places into minor folds with amplitudes of few milimeters to few meters (Fig. 10) while sandstones rest unfolded. In the same area bedding surfaces are commonly affected by crenulation lineation and lineation resulting from intersection between bedding and cleavage surfaces. Tectonic striae occur commonly on quartz veins lining bedding and cleavage surfaces as well as on bedding surfaces in sandstones. In locality 8 on Schmidt Peninsula (Fig. 2), thick up to few centimeters sandstone intercalations in argillite are commonly boudined.

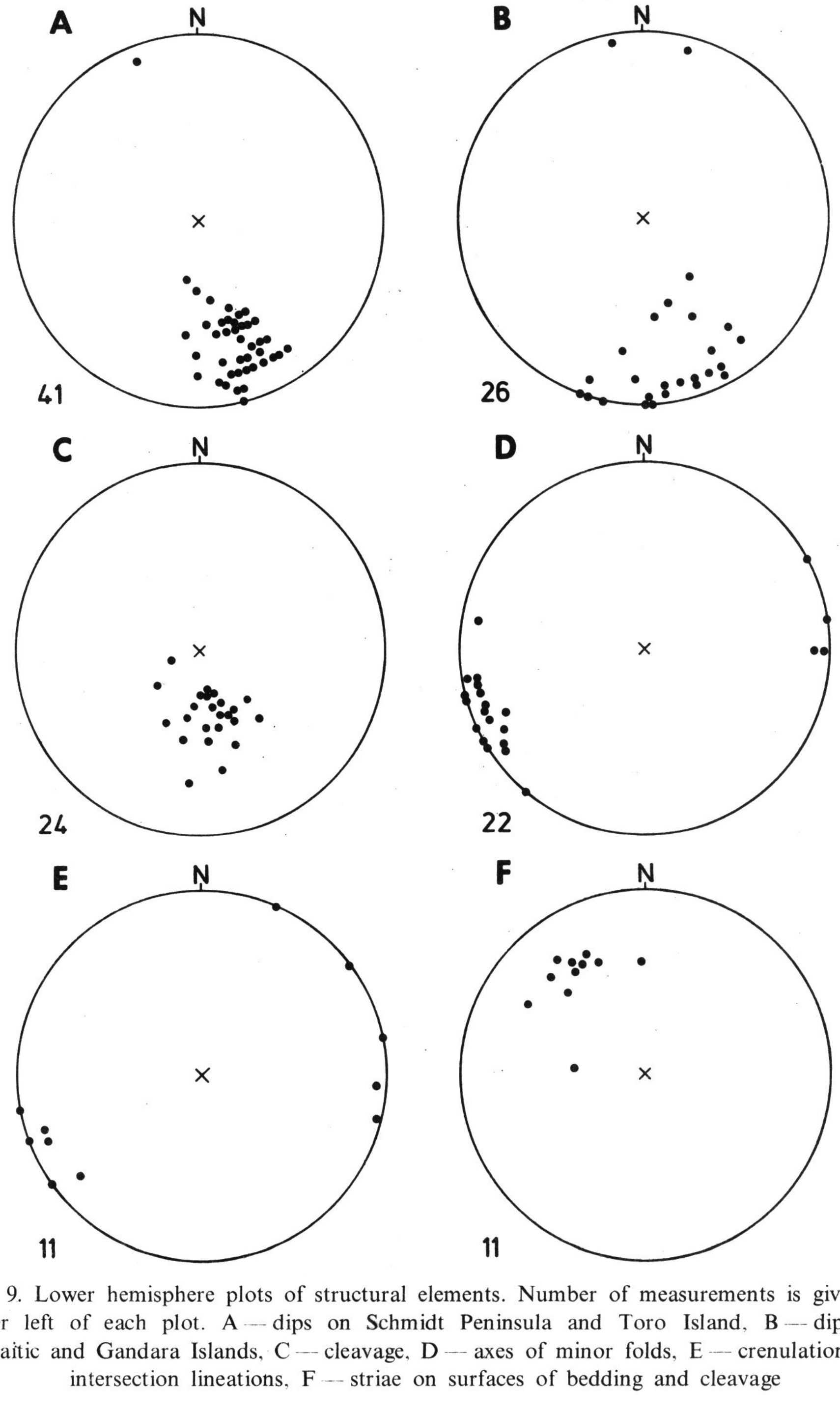

Fig. 9. Lower hemisphere plots of structural elements. Number of measurements is given at lower left of each plot. A — dips on Schmidt Peninsula and Toro Island, B — dips on Kopaitic and Gandara Islands, C — cleavage, D — axes of minor folds, E — crenulation and intersection lineations, F — striae on surfaces of bedding and cleavage

Discussion. — Axes of minor folds are oriented N7OE (Fig. 9D). The orientation of bedding on Schmidt Peninsula and Toro Island (Fig. 9A) appears to result from folding about the same axis, *i.e.* perpendicularly to σ_1 oriented N20W. Attitudes of bedding surfaces on Kopaitic and Gandara islands (Fig. 9B) are more dissipated but nevertheless appear to result from the same folding. It appears also that: (1) fracture cleavage (Fig. 9C), (2) crenulation and intersection lineations (Fig. 9E), and (3) bedding and cleavage surfaces striations (Fig. 9F) result from the same folding.

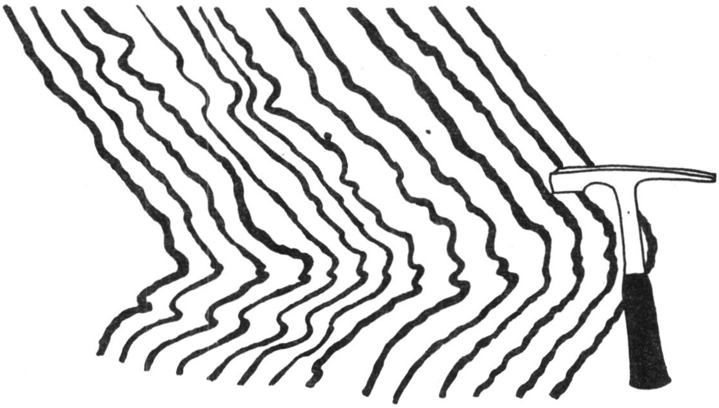

Fig. 10. Minor folds in argillite on Toro Island. Bedding surfaces lined by qùartz veins (black). Drawn from photograph

Joint and quartz veins

Description. — Joints were measured only at locality 8 on Schmidt Peninsula (Fig. 2). All measured joint surfaces (Fig. 11) are vertical or subvertical. They comprise two sets (I, II). Each of the sets is composed of two sub-sets (A, B).

Numerous vertical and subvertical quartz veins occur in the whole studied area. They occur commonly in swarms oriented en échelon (Fig. 12). Their all over distribution is bimodal (Fig. 13).

Discussion. — The majority of joints are not perpendicular to bedding (Fig. 11). This indicates that the jointing post-dated the folding. It appears that each joint set (I, II) comprises two sub-sets of shear joints conjugated under small angle. The bisectrisses of these angles are oriented N35W (set I) and N15E (set II). This interpretation is supported by the bimodal orientation of quartz veins with maxima oriented N20W (set I) and N25E (set II).

It appears that joints of set I were formed in a tectonic regime where

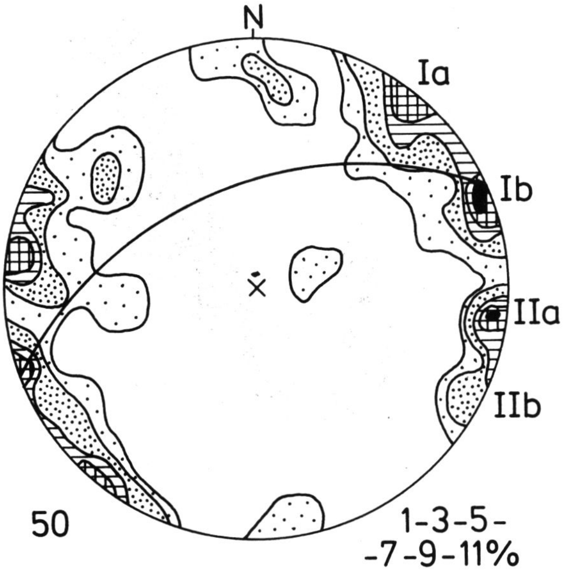

Fig. 11. Lower hemisphere plot of 50 joint surfaces at locality 8 on Schmidt Peninsula. Great circle denotes bedding

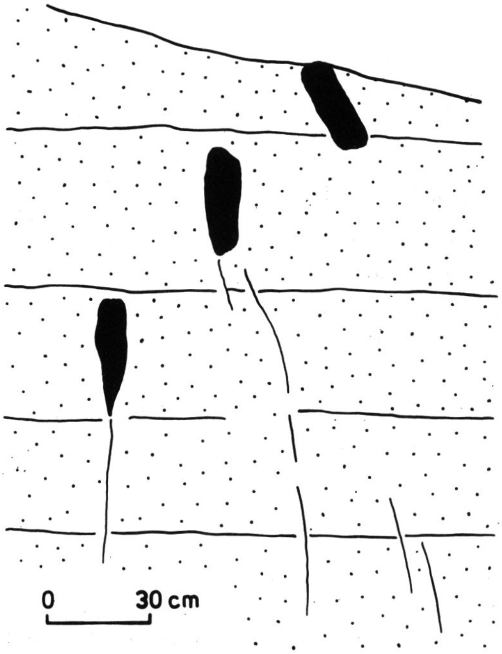

Fig. 12. Three quartz veins arranged en échelon in thick-bedded sandstone on Schmidt Peninsula. View from above. Bedding is subvertical. Drawn from photograph

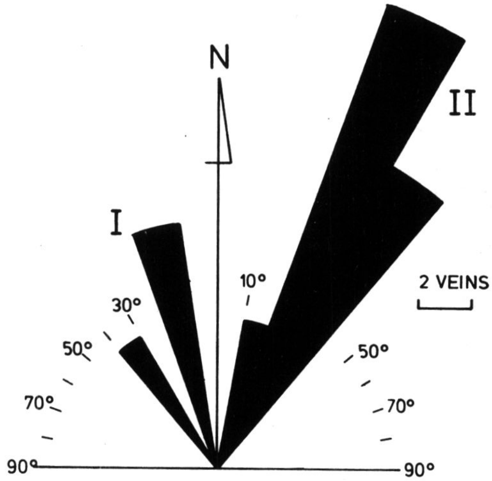

Fig. 13. Rose-diagram of 56 quartz veins

σ_1 was oriented NWN, *i.e.* similarly like during the folding. The joints and veins of set II were formed in a tectonic regime where σ_1 was oriented NEN.

Dykes and sills

Description. — Numerous magmatic dykes and sills cut the rocks of the Legoupil Formation in the whole discussed area (Figs 2—3). They are most numerous on Schmidt Peninsula. The distribution of these intrusions is bimodal (Fig. 14). Set I intrusions are parallel to joints of set I while those of set II are parallel to bedding or cleavage. There occur zigzag intrusions composed of segments belonging to either set, *e.g.* dyke on western shore of Schmidt Peninsula. Some of the intrusions on Schmidt Peninsula contain xenoliths of crenulated phyllite.

Discussion. — Both sets of dykes intruded at the same period of time — after folding and after formation of set I joints but before the formation of set II joints.

Faults

Description. — Twenty eight fault surfaces were measured in the studied area (Fig. 15). Large majority of them are parallel to joints of set I while only one fault surface is parallel to joints of set II. Cross-cutting relations (Fig. 2) indicate that some of the faults post-date the dykes.

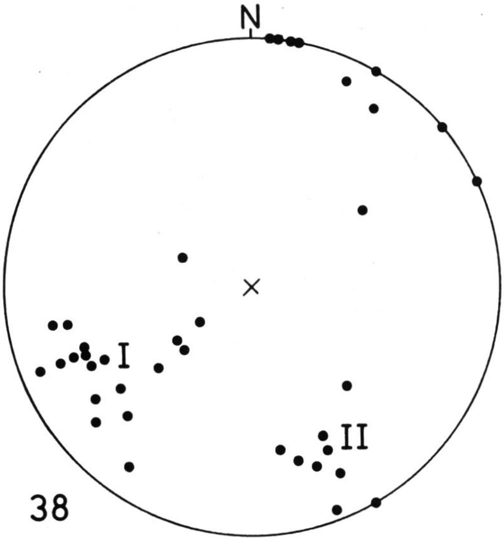

Fig. 14. Lower hemisphere plot of 38 dykes

Discussion. — Interpretation of the faults has been handicaped by the scarcity of striae which were found only on two faults, both of them normal ones. It appears that majority of the faults were formed later than joints of set I and majority of dykes but earlier then joints of set II.

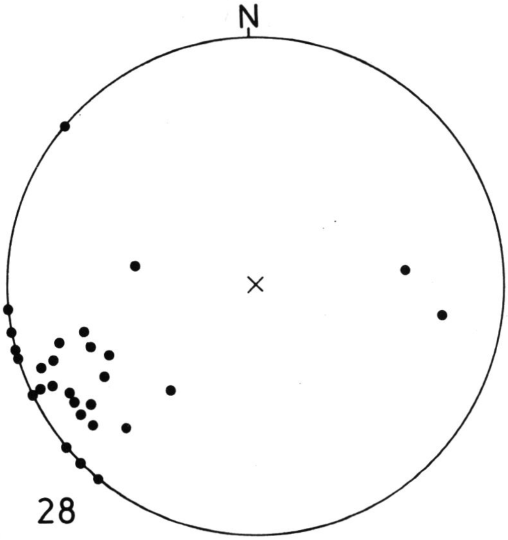

Fig. 15. Lower hemisphere plot of 28 faults

Structural evolution

It appears that the oldest tectonic deformation affecting rocks of the Legoupil Formation was related to the folding about a N70E oriented axis. Folds, cleavage, lineations, and bedding plane striae were formed in that period in a tectonic regime in which σ_1 was oriented N20W. Later, rocks in the discussed area were deformed only in brittle way. This brittle deformation occurred in four stages.

The oldest (1) brittle structures are joints of set I. They were formed when σ_1 was still oriented in the same way as during folding. This jointing was followed by intrusion (2) of dyke and sills. Two sets of these intrusions were formed simultaneously, parallel to the joints and to bedding or cleavage respectively. Then followed a period (3) of faulting. The majority of the faults are parallel to the joints of set I and some faults cut dykes and sills. The orientation of field of stresses during stages (2) and (3) is unclear but it seems that at least some of the dykes and faults were formed in a tectonic regime in which σ_1 was vertical. It is possible that successive stages (1)—(3) were at least in part overlapping. The youngest (4) structures are joints of set II. They were formed when σ_1 was oriented N20E.

Large-scale structure

The rocks of the Legoupil Formation in the studied area dip persistently to NWN. The beds are mostly overturned. This is indicated by sole marks occurring on Kopaitic Island, and orientation of cleavage on Schmidt Peninsula and Toro Island. There, the cleavage is either bedding-parallel or dips northward more gently then bedding (Figs 9C, 16). However, at Cape Legoupil and at Mount Jaquinot (Figs 1, 16) cleavage dips southward, opposite to the bedding. This indicates that in the studied area the rocks of the Legoupil Formation are folded into at least two anticlines and a syncline.

Discussion

Halpern (1964, 1965) interpreted the entire sedimentary section in the Cape Legoupil area as the north-dipping limb of a major anticlinal fold. He estimated the thickness of the Legoupil Formation at about 4000 m. This value seems highly exaggerated. Firstly, the sedimentary rocks in the discussed area seem to be refolded, and secondly, the section is not complete. There are possibly repetitions on reversed faults in the covered parts of the section. Two reverse faults of unknown amplitude occur on the eastern shore of Schmidt Peninsula (Figs 2, 16). The thickness of the Legoupil

Formation measured during the present study is about 800 m for the section of Kopaitic and Gandara islands and not more than 500 m for Schmidt Peninsula and Toro Island.

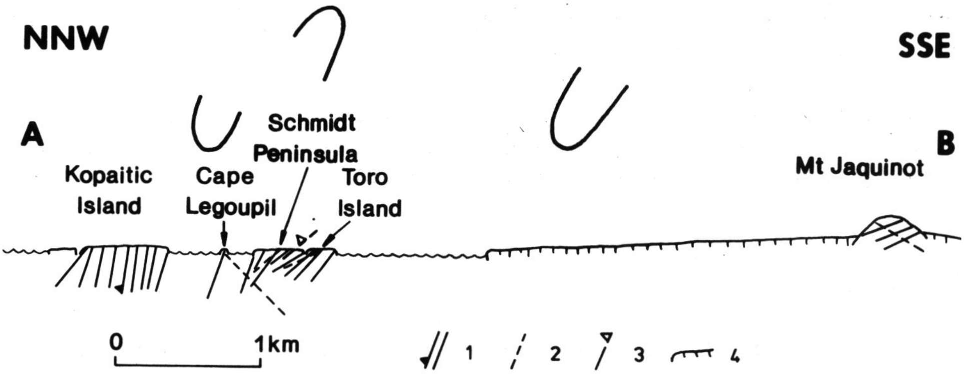

Fig. 16. Geological cross-section, 1 — dips with position of sole marks, 2 — cleavage, 3 — reversed fault with barb on upthrust side, 4 — glacier. Supposed position of fold hinges marked by heavy line

Miller (1966) concluded that the rocks of the Legoupil Formation in the immediate surroundings of the Station *General Bernardo O'Higgins* were folded three times about three differently oriented axes. However, in large majority of studied localities the rocks are affected by a single (oldest) folding about ENE oriented axis, while folds of the second and third generation occur only locally at Morro Rancagua and at locality 9 on Schmidt Peninsula (Fig. 2) respectively. No more than one generation of folds was ascertained at any studied locality. During the present study neither Morro Rancagua has been visited nor detailed observations have been made at locality 9 on Schmidt Peninsula. The present author believes that the anomalous orientations of fold axes at these localities are due either to local changes in the general field of stresses during single folding or to later rotations.

The Legoupil Formation as a part of the Trinity Peninsula Group is considered to form a part of the orogen related to the Mesozoic-Cenozoic eastward subduction of the ancient Pacific ocean crust. However, in the Cape Legoupil area, as well as in other parts of the Trinity Peninsula Group (Dalziel 1972, Elliot 1975, Hyden and Tanner 1981), the SES-verging folds are hardly compatible with this interpretation. Moreover, both reconstructed directions of σ_1 are also hardly compatible with the direction of the subduction. It appears that these incongruities may be explained alternatively. (1) The anomalous directions of σ_1 can be due to a local irregularity at plates boundary. (2) The Cape Legoupil area was rotated after subduction-related deformation. (3) The deformation predates subduction.

Conclusions

The rocks of the Legoupil Formation in the Cape Legoupil area appear to have been folded only once. The folding as well as the subsequent brittle deformation are hardly compatible with the Mesozoic-Cenozoic eastward subduction of the ancient Pacific ocean crust.

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Streszczenie

Skały formacji Legoupil w rejonie Przylądka Legoupil (fig. 1—8) zostały sfałdowane wokół osi zorientowanej N70E (fig. 9—10). Później, utwory te były deformowane wyłącznie w sposób kruchy (fig. 11—15). Deformacja krucha zachodziła w czterech etapach: (1) utworzenie ciosu zespołu I, (2) intruzje dajek i sillów, (3) uskokowanie, (4) utworzenie ciosu zespołu II. Orientacja struktur związanych z fałdowaniem (fig. 16) jak również orientacja młodszych kruchych deformacji wydają się wskazywać, że geneza tych struktur nie jest związana z mezozoiczno-kenozoiczną subdukcją skorupy oceanicznej dawnego Pacyfiku.

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