THE LOWER PALEOZOIC METASEDIMENTARY BASEMENT OF THE COASTAL RANGES OF CHILE BETWEEN 25° 30' and 27° S

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RESUMEN

El basamento sedimentario de la Cordillera de la Costa del norte de Chile (Formación Las Tórtolas), entre los 25° 30' y 27° S, está constituido por una secuencia de turbiditas distales, con intercalaciones menores de calizas y cherts pelágicos. Esta secuencia se depositó en un ambiente submarino, de planicie abisal, con paleocorrientes de dirección SEE, probablemente paralelas a un margen continental, activo, del tipo cordillerano. La edad de las sedimentitas se ubicaría en el lapso Ordovícico-Devónico y su depositación fue acompañada por erupciones de basaltos alcalinos. Tanto las rocas sedimentarias como las volcánicas fueron deformadas y afectadas por un metamorfismo, que alcanzó hasta las facies de esquistos verdes, con anterioridad a la intrusión de monzogranitos del Pérmico Inferior. La existencia, en la región, de una importante zona de "mélanges" tectónicos ("mélange" de Chañaral) indica que este conjunto de rocas forma parte de un complejo de subducción de probable edad paleozoica superior.

ABSTRACT

The metasedimentary basement of the coastal ranges of Chile between 25° 30' and 27° S comprises a distal turbidite sequence, with minor limestones and pelagic cherts (Las Tórtolas Formation). The depositional environment was a deep-sea basin-plain, with palaeocurrents directed towards the south-southeast, possibly parallel to a cordilleran-type of active continental margin. The sediments are probably Ordovician to Devonian in age. Deposition was accompanied by eruptions of alkali basalts. The sedimentary and volcanic rocks were deformed and subjected to greenschist facies metamorphism prior to the intrusion of Lower Permian monzogranites. The presence of a major tectonic mélange (Chañaral mélange) indicates that the rocks formed part of a subduction complex of possible Upper Paleozoic age.

INTRODUCTION

This report details the lithology, provenance and depositional environment of the Lower Paleozoic metasedimentary and metavolcanic rocks of the coastal ranges of northern Chile between 25°30' and 27°S (Fig. 1). The strata have been subdivided into two units (Bell, in press): the Las Tórtolas Formation comprising clastic burbidites with minor pelagic cherts and basic lavas, and the Chañaral mélange. Trace fossils suggest an age between Ordovician and Devonian (written com. form V. Covacevich). The pattern of deformation (Bell, in press) and the presence of a tectonic mélange indicates that the rocks comprise a subduction complex produced by underthrusting towards the north and northeast. Posttectonic intrusion by Lower Permian monzogranites (267 ± 8 m.y.; Zentilli, 1974) indicates that the subduction complex probably formed in Devonian or Carboniferous times.

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LAS TORTOLAS FORMATION

The Las Tórtolas Formation (Ulriksen, 1979) is exposed over an area extending 160 km from north to south, and at least 50 km from west to east. It extends north beyond the area of the present investigation (Ferraris, 1978) and is probably equivalent to the El Toco Formation of the Antofagasta region (García, 1967; Harrington, 1961). Many exposures of Paleozoic metasedimentary and metavolcanic rocks are found farther south in Chile but few correlations between these isolated occurrences have yet been made.

The rocks of the Las Tórtolas Formation are a monotonous succession of interbedded fine-grained sandstones and mudstones with sedimentary structures, indicating a distal turbidite depositional environment. A few limestone and chert horizons are interbedded with the turbidites. No significant regional facies variations have been identified during the present study. Basic lavas at Pan de Azúcar are probably of a similar age to the sediments but their precise relationship is not known.

CLASTIC SEDIMENTARY ROCKS

Sandstones of the Las Tórtolas Formation are predominantly fine to very fine-grained and only very rarely medium to coarse-grained. Large detrital clasts were only observed at the southern end of Quebrada del Gritón, where scattered pebbles occur at the base of a 1 m thick sandstone. Scattered mudflakes, produced by contemporaneous erosion of cohesive beds, are common in the massive sandstones. In thin section the sandstones are seen to be immature and very poorly sorted, with angular to well-rounded clasts. The quartz content ranges from 20 to 60% with an average of 35%. Plagioclase (andesine and oligoclase) and potassium feldspar (often perthitic) comprise between 10 and 30%. The relative proportions and composition of the feldspars are, however, commonly indeterminate due to secondary altera-

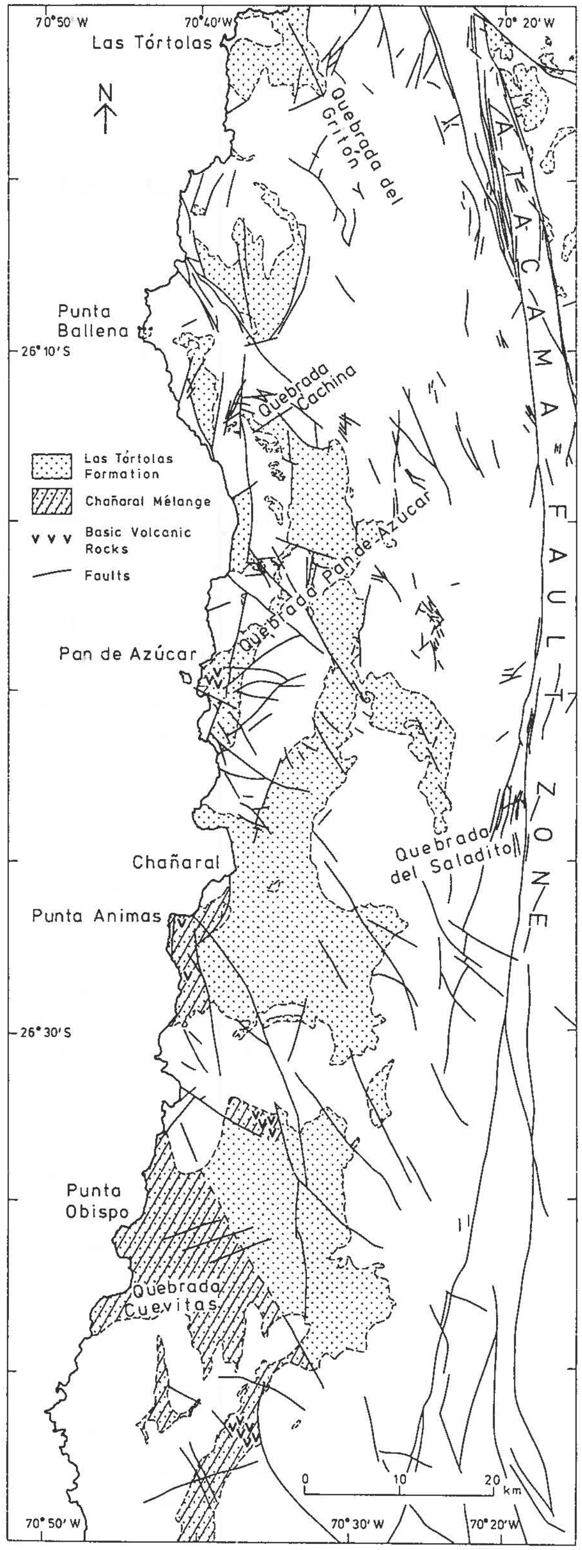

FIG. 1. **Geological map showing the distribution of Lower Palaeozoic sedimentary and volcanic rocks in the area between 25° 30' and 27° S.**

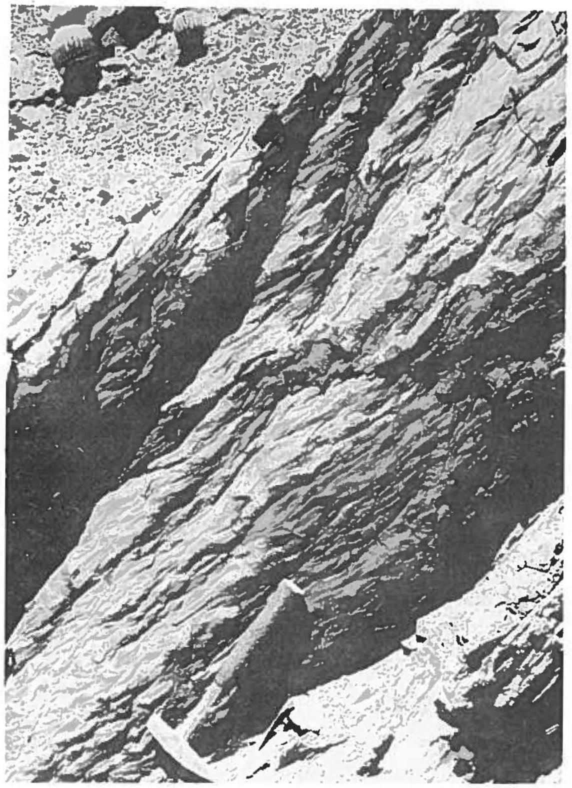

FIG. 2. Plan view of a bedding plane showing current scour marks deformed by subsequent folding.

tion. Other detrital minerals include muscovite, zircon, opaques, apatite, tourmaline, sphene, garnet and rutile. Some well-rounded detrital tourmaline crystals exhibit secondary euhedral overgrowths. Lithic clasts comprise up to 30% of the sandstones; andesitic and glassy volcanic fragments are the most abundant but low-grade metamorphosed sandstones and mudstones are also common. Diorite, granodiorite and granophyre have also been recorded. A study of the coarser-grained sandstones suggests that the abundant matrix (up to 40%) is predominantly secondary in origin, produced both by the compaction of mudstone clasts and by the alteration of feldspar and volcanic clasts. The sandstones are therefore classified as lithic and feldspathic arenites rather than as greywackes. Vein minerals include calcite, quartz, epidote and opaques. Calcite nodules up to several metres in length exhibiting cone-in-cone structures, were observed in the area southeast of Chañaral.

SEDIMENTARY STRUCTURES

Few sedimentary structures are preserved in the mudstones, which have been deformed and metamorphosed to phyllite, slate and spotted slate. Sedimentary structures in the sandstones and siltstones are also commonly distorted (Fig. 2) or destroyed by tectonic deformation and metamorphism. Beds are parallel and continous over the length of exposures (up to several 100 m). Bedding thickness is very variable, ranging from a few millimeters up to 3 m. Most beds are between 50 and 200 mm thick and beds thicker than 1 m are very uncommon.

Individual beds may be sudivided into divisions of the Bouma sequence. Massive or more rarely graded basal units of fine-grained sandstone grade up into or are overlain with a sharp contact by finely parallel or ripple cross-laminated siltstones and mudstones. Repeated ripple cross-laminated units with no massive basal unit are common, and the upper finely-laminated pelites are also frequently absent. The thickness and the proportions of sand to silt and clay in each unit is very variable. Due to the deformation, no sedimentary sequences were measured except for a 10 m section south of Quebrada Cachina, which comprised 25 thinly bedded units suggesting an upward fining cycle. In places the turbidites are predominantly pelitic but overall the proportion of sandstone exceeds that of pelite.

The contact between beds is usually parallel, with no current marks, but basal erosion structures have been observed at a number of localities. The most common are current scour marks (Fig. 2), normally between 15 and 20 mm deep but in places up to 70 mm deep. Grooves, bounce, brush and chevron marks have also been recorded. Ripple cross-laminations have lunate or cuspate crests. Load casts are commonly associated with the flute marks but other indicators of penecontemporaneous deformation, such as clastic dykes and convolute laminations, are very rare. Trace fossils are very common but are seldom well preserved.

LIMESTONE

Limestone beds are rare in the Las Tórtolas Formation. They are found at scattered localities in all but the northernmost areas but are apparently more abundant towards the south. Mercado (1978, 1980) subdivided the strata in the Pan de Azúcar and Chañaral areas on the basis of the presence of limestone (metacaliza) horizons. Field work during the present investigation has suggested, however, that this subdivision is inapplicable during detailed mapping. Limestone horizons are usually easily recognized from a distance due to their cover of a distinctive white lichen. Where this lichen is absent, the limestones are only distinguished with difficulty from the other fine-grained sediments. Beds are continuous and of constant thickness, normally up to 1.5 m thick with the thickest of 4 m. Beds occur either in isolation within the turbidite sequences or more commonly as parallel sets, often interbedded with phyllite and chert.

In most places the limestone is massive and structureless as a result of recrystallization. In a number of localities, particularly in the centre of the thickest beds, it can be seen to consist of broken shell fragments. These fragments are up to 10 mm in length and commonly 1 mm thick. They are usually flat or slightly bent but occasionally tightly curved. The fragments are tightly packed and lie parallel to the bedding. In thin section they can be seen to comprise long filaments of calcite divided into cells and orientated with the long axis of the filaments perpendicular or slightly inclined to the surface of the shell. Each filament is about 0.05 mm in diameter and up to 1 mm long. The filaments are closely packed with polygonal outlines. The centre of each cell is marked by a concentration of small dark impurities. R. Riding (written com.) has suggested that the shells resemble calcareous red algae such as the crustose Corallinaceae. Up to 5% of the limestones consists of secondary quartz, feldspar, muscovite, iron sulphide and iron oxide. No definite detrital grains have been indentified. The uniformity and close packing of the shell fragments are distinctive features of the limestone.

Two 1 kg blocks of the limestone were digested in dilute acetic acid and the resulting insoluble fraction was concentrated in heavy liquids. No conodonts were found but a number of small but well-preserved sponge spicule fragments were identified. These fragments consist of straight cylinders with a narrow central tube. The fragments range from 0.1 to 0.3 mm in lenth and are approximately 0.05 m wide. They have a smooth, shiny black exterior and a few show branches and spines. Most form discrete broken fragments but none show evidence of abrasion. The fragments are weakly magnetic and apparently consist of pyrrhotite as a replacement of opaline silica. The fragments closely resemble the spicules of glass sponges of the class Hexactinellida.

The origin of these limestones in a turbidite sequence is problematical. A pelagic origin is suggested by the association with chert horizons. However, the thickness, lack of detrital or chert content, together with the fragmented nature of the shells, strongly supports an origin by the influx of turbidity currents derived from a relatively pure carbonate sediment source area.

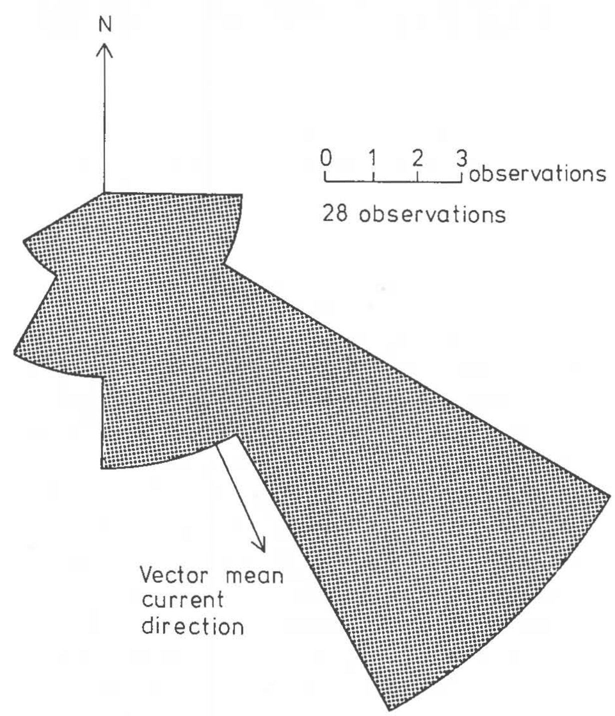

FIG. 3. Rose diagram indicating the palaeocurrent direction determined from flute marks. Vector mean towards the south-southeast.

CHERT

Rare chert horizons averaging 100 mm and up to 600 mm in thickness are interstratified with the limestones and the pelites. The strata are continous and of constant thickness. In thin section these rocks are extremely fine grained and they retain no recognizable organic structures. A very small proportion of the chert horizons comprise detrital grains of quartz and white mica with a preferred orientation parallel to the bedding. Secondary minerals include veins of quartz, calcite, iron sulphide and albite. The cherts are interpreted as pelagic deposits.

PALAEOGEOGRAPHY

Palaeocurrent determinations made on distinct flute marks at 28 localities (Fig. 3) indicate currents directed between the southwest and southeast, with a vector mean directed towards the south-southeast. The sedimentary structures and rock types described above are indicative of a deep-sea basin-plain environment (Mutti and Ricci-Lucchi, 1978).

The provenance was a mixed terrain of andesitic volcanic, plutonic and metasedimentary rocks. Immaturity and lack of sorting indicate relatively short transportation. These factors together suggest a cordilleran-type of active continental margin, similar to the present-day Andes.

METAMORPHISM OF THE SEDIMENTS

Metamorphism of the pelitic sediments has produced slates, phyllites and schists. Most specimens record a complex metamorphic history with a strog slaty cleavage deformed by a crenulation cleavage, itself superimposed by contact metamorphic porphyroblasts. The phyllites and schists comprise layers rich in orientated muscovite, stilpnomelane and chlorite alternating with quartz-rich layers. Other metamorphic minerals identified in thin section include almandine garnet (from one locality at Pan de Azúcar), plagioclase fledspar, clinopyroxene and tourmaline. Contact metamorphic porphyroblasts comprise andalusite, staurolite and sericitized cordierite crystals up to 2 mm in diameter. No distinct relationship between the plutonic intrusives and the areas of contact metamorphism was observed during the present investigation.

The sandstones show less metamorphic effects than the pelites but they do exhibit a similarly complex metamorphic history. In most sandstones the most prominent characteristic is the abundant matrix produced by alteration of feldspar and lithic clasts. Trains of fragmented tourmaline and feldspar provide evidence of brittle deformation in some sandstones. More common is the recrystallization of quartz and micas to form a schistose frabric. Quartz crystals are invariably strained and frequently show a mortar texture of deformed grains surrounded by smaller undeformed crystals produced by dynamic recrystallization. Plagioclase feldspars are also bent and strained in some specimens. Sandstones in close proximity to plutonic intrusive bodies have been completely recrystallized to form chlorite and muscovite schists.

The early metamorphic fabric in both the pelites and the sandstones is indicative of intense flattening and is probably related to the first phase of deformation described by Bell (in press). The crenulation cleavage was produced during the second phase of deformation, and the contact metamorphic spotting resulted from the intrusion of late Paleozoic plutons.

VOLCANIC ROCKS

Basic volcanic rocks become more abundant towards the south (Fig. 1) and all observations of volcanic rocks except those at Pan de Azúcar, were made within the mélange zone.

The basic volcanic rocks are black to dark brick red in colour. They are generally massive with metamorphism and tectonic deformation having masked most of the primary structures. Pillows up to 0.5 m in diameter were recorded at several localities. Some of the pillows exhibit chilled margins and concentrically zoned quartz and calcite-filled vesicles. Probable hyaloclastite breccias were observed at Pan de Azúcar. In thin section the lavas are seen to be greenschist facies amphibolites (metabasites) comprising up to 80% actinolite together with quartz, zoisite, white mica, epidote, sphene, albite and opaque minerals. Biotite is also present but partly altered to chlorite. In a few specimens a relict igneous texture of glomeroporphyritic albite laths can be distinguished. Extensive replacement by calcite is a feature of some of the rocks, elsewhere limonite or epidote rich patches can be observed. Falttening of the pillows at Pan de Azúcar provides clear evidence of tectonic deformation (Fig. 4) yet in thin section the rocks are non-schistose and the metamorphic minerals show no alignment. This suggests that the greenschist facies metamorphism post-dated much of the tectonic deformation.

Major and trace element analyses of six specimens of the volcanic rocks are presented in Table 1. Samples were crushed to less than 240 mesh in a tungsten carbide swingmill. Major elements were determined on glass fusion discs and trace elements on compressed powder briquettes using a Philips PW 1400 XRF at Bedford College, University of London. Calibration checks were maintained using accepted international and inter-laboratory standards. The extensive alteration of specimens CP 98.4 and CP 157.3 is reflected in the low total percentage of major oxides. The low Zr/Nb rations and the high Sr, Ni and Cr values indicate that these rocks resemble alkali basalts, rather than normal depleted mid-ocean ridge basalts (written com. from Dr. A.D. Sauders).

FIG. 4. Deformed pillow lavas at Pan de Azúcar.

MELANGE

The extraordinary assemblage of intensely deformed sedimentary rocks of the Chañaral mélange has been interpreted as the product of north and northeast directed subduction (Bell, in press). The rocks of the mélange are probably the stratigraphical equivalent of the Las Tórtolas Formation. Despite the great areal extent of the mélange, no significant regional variations have been observed.

The most typic?l rock type is a breccia comprising blocks of fine to very fine-grained feldspathic and lithic arenite in a pelitic matrix. The sandstone blocks are commonly lighter in colour and more resistant to erosion than matrix. Rare blocks of pillow lava (often extensively epidotized), limestone and deformed masses of turbidite have also been observed. Blocks very in size from grains up to many metres but there is no typical size. Th largest block observed was a mass of limestone approximately 150 x 50 m. Larger blocks than this may well exist but their recognition awaits more detailed studies.

The. small blocks are extremely irregular in shape, they are frequently rounded and may be pillow or lens shaped. Many are elongated parallel to the pervasive fabric of the matrix (Fig. 5), but this fabric, and hence the elongation, may well be a result of tectonic deformation superimposed on the mélange. Blocks seldom exhibit angular fractures indicative of brittle deformation. instead

TABLE 1: MAJOR AND TRACE ELEMENT COMPOSITION OF BASIC VOLCANIC ROCKS

%	CP82.1	CP98.3	CP98.4	CP98.5	CP102.1	CP157.3
SiO_2	46.03	42.38	34.34	44.47	51.34	51.06
TiO_2	2.62	3.19	4.07	2.50	2.41	1.01
Al_2O_3	12.06	14.22	14.92	15.20	12.49	14.73
Fe_2O_3*	13.39	15.97	19.37	13.07	10.78	8.19
MnO	0.22	0.20	0.27	0.20	0.18	0.26
MgO	10.00	9.26	12.52	6.73	7.29	4.53
CaO	11.94	9.68	8.02	13.83	10.22	6.40
Na_2O	1.07	2.12	1.73	2.24	3.26	2.50
K_2O	0.38	0.81	0.77	0.15	0.26	2.69
P_2O_5	0.25	0.21	0.24	0.58	0.21	0.11
Total	97.96	98.04	96.25	98.97	98.44	91.48
ppm						
V	251	297	405	285	252	262
Cr	332	500	689	331	387	380
Ni	271	253	391	117	187	120
Rb	14	27	22	3	11	150
Sr	162	327	193	215	338	294
Y	27	36	36	30	24	28
Zr	154	177	219	132	131	58
Nb	18	18	20	12	14	3

Localities CP82, CP98 and CP102 at Pan de Azúcar.
Locality CP157, 7 km south of Punta Animas.
Analyses carried out by Dr. A.D. Saunders at Bedford College, London.

gently curved surfaces indicate plastic deformation Some blocks are boudinaged, with pelitic material apparently intruding into the blocks, thus illustrating the marked ductility contrasts of the two materials. Folds are very rare, suggesting that much of the deformation was the product of tensile or shear rather than compressive stress. In places the blocks form interlocking masses with little matrix (Fig. 6), but elsewhere the matrix predominates, with whisps of sand in a pelitic mass. The contact between blocks and matrix is usually sharp but in places it is transitional with blocks merging into matrix.

In marked contrast with the typical mélange of sandstone blocks in a pelitic matrix (Fig. 5) is a dark-coloured breccia comprising well-sorted angular sandstone, siltstone and mudstone fragments. In the field this breccia has the appearance of a massive structureless sandstone, forming units up to 20 m in thickness. It grades imperceptibly into, and is interstratified with, the typical mélange. A distinctive feature of the breccia is the presence of scattered well-rounded clasts (quartzite, sandstone, andesitic volcanics and vein quartz) up to 200 mm in diameter. Detrital clasts of this size have been found nowhere else in the metasedimentary basement rocks in this area. Fragments in the breccia range from several millimetres up to a maximum of 1 m. The average grain size is that of a granule conglomerate. Little lithological sorting is apparent

FIG. 5. Mélange of sandstone fragments in a pelitic matrix. Fragments are elongated parallel to the pervasive fabric.

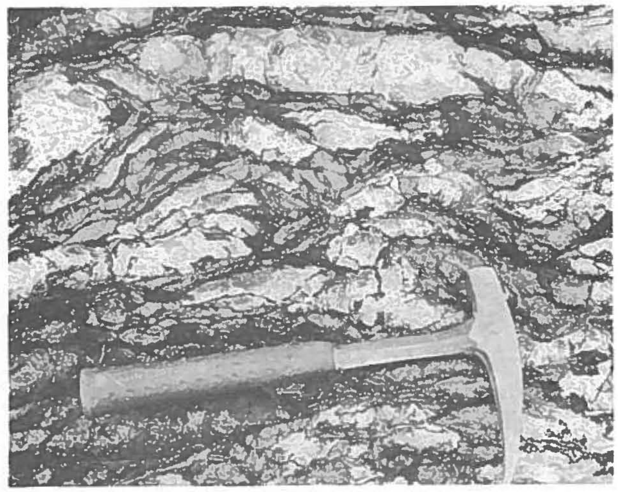

FIG. 6. Mélange comprising tabular sandstone blocks with little pelitic matrix.

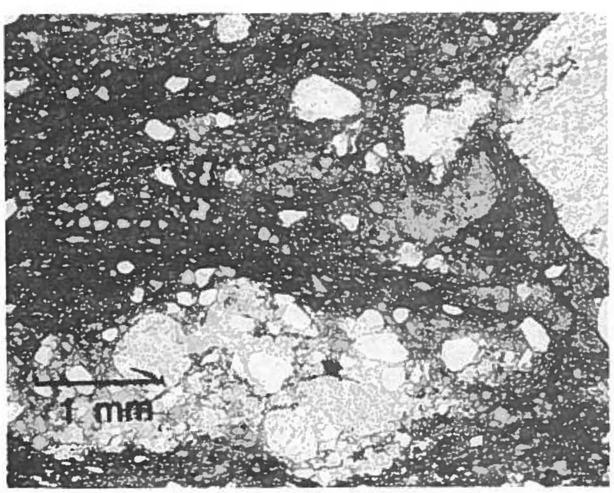

FIG. 7. Thin section of mélange breccia showing ill-defined fragments of poorly-sorted sandstone in a matrix comprising sand grains and small pelitic fragments.

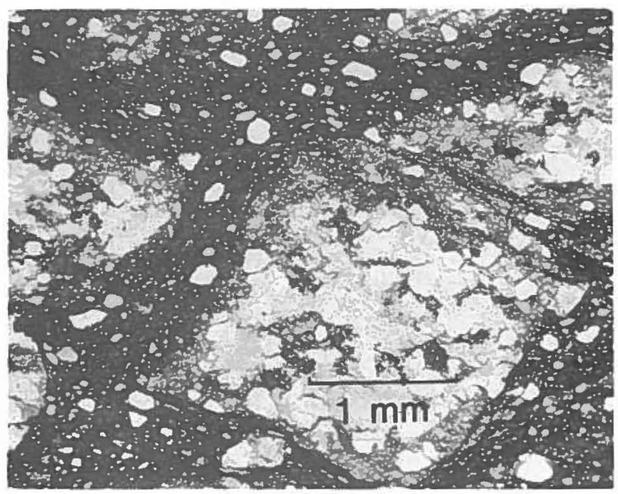

FIG. 8. Thin section of mélange breccia showing sandstone fragments with pelitic rims in a matrix of sandy mudstone. These fragments are believed to indicate recycling within the mélange.

but fragments of one size tend to be concentrrated in distinct layers which themselves grade into coarser and finer layers. With the exception of fine mud whisps, the fragments are seldom bent. In thin section these breccias can be seen to consist of compacted fragments of sandstone, siltstone and mudstone together with individual sand grains in an extremely ill-sorted matrix (Fig. 7). The mudstone clasts are generally rounded but many are deformed to fill the gaps between the less ductile fragments. Some of the fine-grained sandstone fragments are rounded but others are angular and may even be invaded by whisps of mud. In some specimens many of the fragments are themselves composed of an aggregate of small mud clasts and sand grains. There is commonly an increase in the proportion of fine-grained material towards the edges of these fragments (Fig. 8), providing evidence of the recycling of the component blocks of the mélange (Hibbard and Williams, 1979). There is no evidence of subaqueous erosion, sorting or deposition in the breccia, thus suggesting that it was produced by the breakdown of coherent, but not lithified, sediment in an intrastratal position. Therefore, the formation of the breccia is believed to have occurred during the subduction process.

DEFORMATION

Following the formation of the mélange, the rocks of the Las Tórtolas Formation were subjected to two phases of tectonic deformation (Bell, in press). The first phase is characterized by large-scale, tight chevron folds and an axial planar cleavage. The folds of the second phase are smaller and more upright, and are related to a crenulation cleavage. The fold axes of both phases trend between west-east and northwest-southeast, oblique to the present-day Andean structures. Folds are predominantly asymmetrically overturned towards the south and southwest, suggesting an origin by underthrusting directed towards the north and northeast (Bell, in press).

CONCLUSIONS

Distal turbidites in northern Chile were deposited in a deep-sea basin-plain environment during Ordovician to Devonian times. The sedimentary basin was situated adjacent to a cordilleran-type of continental margin. The presence of a tectonic mélange indicates that the rocks formed part of a subduction complex of possible Devonian or Carboniferous age (Bell, in press). The Upper Palaeozoic age deduced for the deformation coincides with that of the paired metamorphic belt in southern Chile (González-Bonorino, 1971; Hervé, 1977).

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