The Precambrian Geology of El Cristo, Southern Tandilia Region, Argentina

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With 2 figures and 2 tables

Zusammenfassung

Tektonische, lithologische und geochronologische Daten der metamorphen und granitischen Gesteine der El Cristo Gegend im südlichen Teil des Tandilia Gebirges werden diskutiert.

Vor mehr als 2000 Ma wurde dieses Gebiet erstmals von einem tektonothermalen Ereignis erfaßt, gefolgt von einer zweiten Episode starker SW—NE gerichteter Faltung. Letztere wurde begleitet oder gefolgt von einer Almandingrad Metamorphose und starker syn- bis spätkinematischer Granitisierung während der Zeitspanne 1800 bis 1520 Ma.

Darauffolgende Metamorphosen und Deformationsereignisse waren weniger intensiv und endeten um 900 Ma in Lokaler Granitintrusion, Chloritisierung und spröder Deformation.

Abstract

Metamorphic and granitoid rocks of the El Cristo area, southern part of Tandilia Range, are considered in terms of structural, lithological and geochronological data.

The abovementioned area was affected before 2000 m. y. by a first tectono-thermal event that was followed by a second episode of intense SW—NE folding. The latter accompanied or followed by a metamorphism of almandine grade and strong synkinematic to latekinematic granitization during the span 1800—1520 m. y.

Succeeding episodes of metamorphism and deformation were less intense and culminated in the local development of a 900 m. y. granite, chloritization and some brittle deformation.

Résumé

Des roches métamorphiques et granitoïdes de la région de Cristo font ici l'objet d'une discussion sur la base de données structurales, lithologiques et géochronologiques.

La région mentionnée a été marquée d'abord, il y a plus de 2000 millions d'années, par une phénomène thermo-tectonique, suivi, dans une seconde phase, d'un plissement important dirigé SO—NE. Celui-ci a été accompagné ou suivi par un métamorphisme à almandin et par une intense granitisation syncinématique à tardicinématique au cours de la période 1800—1500 m. a.

Des épisodes de métamorphisme et de déformation moins intenses s'ensuivirent, qui aboutirent au développement local, vers 900 m. a., d'une intrusion granitique, avec chloritisation et déformations cassantes.

Краткое содержание

На основании тектонических, литологических и геохронологических данных о метаморфных и гранитных породах в районе Эль-Кристо на южном склоне гор Тандилия установили, что более чем 2000 миллионов лет тому

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назад в данном регионе происходили тектоно-термические процессы, которые привели к образованию мощных складок в направлении SW-NE. Это складкообразование между 1800 и 1520 миллионами тому назад лет подверглось альмадиновому метаморфизму и сильной гранитизации. Последующие процессы метаморфизма и деформации были менее интенсивны и сопровождались локальной гранитизацией, хлоритизацией и частичной деформацией и закончились примерно 900 миллионов лет тому назад.

I. Introduction

The southern Middle Precambrian rocks in the South American continent crop out in the Tandilian Range, within the province of Buenos Aires, in the Argentine Republic.

Geochronological research work has shown that the crystalline basement here had a long geological history that began 2.2 billion years ago.

The Precambrian in Tandilia occurs as a Middle and Upper Precambrian igneous-metamorphic complex forming a part of at least a single orogenic belt partially covered by a sedimentary sequence composed mainly of quartzites and limestones of Vendian to Lower Palaeozoic ages.

The complex is composed mainly of dynamothermal ectinites, migmatites, granitoids, acid and basic hypabyssal rocks as well as cataclastic products of granitic composition.

The ectinitic rocks are not well represented; they occur as gneissic rocks usually granitised, lenses and sheets of mica schist, amphibolitic layers and a few thin marbles. As a local variation, near the town of Tandil, there are low-grade porphyroblastic, slightly granitised meta-volcanites, some of which show hornfelsic characteristics.

The migmatites are widely represented as epibolitic types with local variations to embrechites as well as anatexites.

Emplaced in the metamorphic structure there are many synkinematic as well as late tectonic, poorly delineated granitic bodies ranging in composition from granites to tonalites. These rocks are referred to as of high silica content by Teruggi and Kilmurray (1975), who also postulate that the potassic-rich composition is characteristic of the southern and northern parts of the range, while the tonalitic-granodioritic composition prevails in the central part of the western border.

The cataclastic rocks were referred to by Backlund (1913). Later Villar Fabre (1955), González Bonorino et al. (1956) and Teruggi et al. (1958, 1962), described a variety of similar mylonitic rocks, originating mainly from granitoids. This cataclastic phenomenon developed intensively in a straightening zone, trending E—W along ten kilometers in the Azul Ranges, according to González Bonorino (op. cit.). Within the granitic pegmatites which are widespread along the basement complex, there are some almandinic varieties, either concordant with or cross-cutting the metamorphites. A few alkaline basalt dykes are represented in the central and northern part of the range (Teruggi et al., 1974 b). They can be almost 100 m wide, like the body cropping out in "Sierra del Tigre" and are little affected by low metamorphic grade and hydrothermal alteration.

Considering the radiometric data available in Tandilia, Martín García island and in Uruguay (Cazeneuve, 1967; Stipanicic and Linares, 1969; Halpern and Linares, 1970; Umpierre and Halpern, 1971; Teruggi et al., 1973, 1974 a;

DALLA SALDA, 1975), it is possible to state that Tandilia and the whole of the Rio de la Plata cratonic area presents evidence of a long igneous and metamorphic process that began 2200 m. y. ago (DALLA SALDA, op. cit.). TERUGGI et al. (1973) dated the main event of this process as 1800 m. y. within a metamorphic climax when granitization and granitic mobilisation took place at the beginning as synkinematic and later as latekinematic and postkinematic with ages in the range 1700—1500 m. y.; they also believe that the 900—800 and even the 600 m. y. old rocks of Tandilia represent small granitic intrusives and pegmatite belts emplaced towards the end of the cycle.

Both the older age and the younger one were correlated respectively with the Transamazonic and Caririan cycles of the Brazilian shield (STIPANICIC and LINARES, 1969).

It is important to note that in the Tandilian Range the end of the Transamazonic cycle is represented by the diabasic intrusions (1.75 b. y.) cropping out in the central area near Tandil. Obviously these basaltic dykes must have been intruded some time after a stabilisation episode of the orogenic belt.

Although the ancient granulitic metamorphic rocks are affected by a deformational nappe structure assigned to a first structural domain (A-domain, Teruggi et al., 1974), the regional gneissic and migmatic rocks show two other episodes. The first (B-domain) covers a wide area along the Tandilian Range with a deformational pattern of high angle axial-plane folds trending NE—SW. The second (C-domain) is assigned to local folds in the Tandil area and some straightening zones throughout the region, trending mainly NW—SE.

QUARTINO and VILLAR FABRE (1967) referred to the geological features of Tandilian rocks as resulting from a process that began with a pre-metamorphic and gneissification process associated with fold deformation. Later a postgneissic autobrecciation as postcrystalline deformational episode occurred. These authors referred to the emplacement of a late tectonic granitic magmatism, followed by post-granitic deformation that came to an end before the intrusion of basic dykes, trending roughly at right angles to the gneissic structure. TERUGGI and KILMURRAY (1978) divided the crystalline basement into a series of complexes according to a chronostratigraphical sequence as follows:

The Manuelian Complex — aged 1,2—0,6 b. y.
The Vasconian Complex — aged 1,4—1,5 b. y.
The Tandilean Complex — aged 1,7—1,9 b. y.
The Balcarcean Complex — aged 2,0—2,2 b. y.

Metamorphites, mylonites and metabasites confined to small areas at the end of the range were assigned to the Balcarce Complex by the same authors. The second complex dated between 1.7 and 1.9 b. y. is the main lithological group cropping out in the ranges and consists of granitised gneisses transitional to granitoids as well as mylonites. The third complex, characterized by a finegrained metamorphic unit injected by granitic material crops out as a narrow belt in the south-eastern area of Tandil as well as some small relicts amongst the rocks of the other complexes in the central part of Tandilia. In the Manuelian complex, the abovementioned authors have included the thick diabasic dykes and a suite of minor granitic bodies and veins.

II. El Cristo Region, Balcarce Area

A. Lithological Features

The rocks of the El Cristo area in the region studied by us (DALLA SALDA, 1975), represent the southern part of the exposed belt (see map Fig. 1). In this area we recognized three lithological units, taking the metamorphic and igneous activities into account, were arranged as follows:

1) Dos Naciones Gneiss,
2) Cerro Las Piedras Migmatites
and 3) Cerro Redondo Granitoids.

These units belong to the span of time between 2.2 and 0.9 b. y. and have been included in the following chronostratigraphical units:

	1) Cerro Redondo Formation: Late tectonic granites, dated as 1,55—0,90 b. y.
El Cristo Group	2) Las Piedras Formation: synkinematic granitisation, dated as 1,7—1,9 b. y.
	3) Dos Naciones Gneiss: Relict metamorphic climax dated as 1,9—2,2 b. y.

(i) "Dos Naciones" Gneiss

This unit is mainly composed of garnet-biotite gneisses with some hornblendic varieties, that are characterised by a penetrative foliation and a mineral lineation formed by thin pencil-like quartzo-feldspathic aggregates. The biotite-rich rocks also show some schistosity always parallel to the compositional banding.

In some places transitional changes can be seen between the gneissic and migmatic rocks, resulting from an increase of some granitic material in the leucocratic folia of the gneiss, as well as skialiths of amphibolitic composition.

These gneissic rocks show lepidoblastic to granoblastic texture, the garnet-rich varieties are porphyroblastic and all gneissic rocks were divided into two main groups:

a) garnet-biotite gneisses, and
b) hornblende-biotite gneisses (sometimes containing a little garnet).

The first group of rocks are composed of plagioclase, quartz, biotite, garnet, epidote and in some cases, only a little interstitial microcline. The felsic minerals dominante, especially andesine ranging in composition form An_{36} to An_{48}, although in some samples the plagioclase was determined as basic oligoclase and in other as labradorite. The plagioclase crystals are usually unaltered, but in some rocks they are strongly altered to a granular assemblage of muscovite, epidote and calcite. The quartz follows the plagioclase in abundance showing crenulate borders and abnormal extinction. Strong pleochroic brown biotite is usually present to the extent of 10 to 25 per cent in the form of isolated individual flakes or in polycrystalline aggregates associated with epidote, hornblende, titanite and ores. The garnet — mainly almandine — is pink to colourless, having a subordinate proportion of pyrope molecule. Sometimes it is coated by flakes of chlorite and biotite. Interstitially there is xenoblastic microcline (less than 5 per cent) as well as very few grains of epidote, titanite, apatite and ores (see modal analysis, Table 1).

Table 1. Modal Analysis of representative rocks from El Cristo area.

A — Gneisses

Sample No.	104	X—1	X—7	X—3	58	X4	X—9	13
% Plagioclase	44.2	43.3	49.8	53.4	42.8	51.0	53.1	35.6
% Quartz	33.2	25.4	24.5	29.4	36.9	28.7	25.7	43.2
% K-feldspar	—	0.7	0.4	4.7	0.3	3.8	1.0	11.4
% Biotite	22.6	25.7	15.7	11.4	13.0	13.0	8.3	9.8
% Amphibole	—	4.2	9.6	—	—	0.5	7.6	—
% Epidote	T	—	—	T	—	—	—	—
% Garnet	T	—	—	0.9	6.6	3.0	4.3	—
% Chlorite	—	Tz	—	—	—	—	—	—
% Interg. Albite	—	—	Tz	—	—	—	—	—
% Accessories	T	0.7	Tz	0.2	0.4	—	Tz	Tz
% An Plagioclase	46	46	40	52	30	42	38	26

B — Migmatites and amphibolites

Sample No.	105	55	56	97	111	51	27	2
% Plagioclase	45.4	45.9	46.3	23.0	41.2	41.9	44.7	44.0
% Quartz	35.4	40.0	41.7	58.5	41.7	T	T	5.0
% K-feldspar	T	1.0	0.4	5.7	9.2	—	—	—
% Biotite	16.8	4.0	11.6	11.1	2.0	—	—	3.0
% Amphibole	—	0.1	—	—	—	58.1	55.3	48.0
% Epidote	0.4	—	T	—	—	T	T	—
% Garnet	1.8	—	—	1.6	—	—	—	—
% Chlorite	—	—	—	—	—	—	—	T
% interg. Albite	—	T	—	T	—	—	—	—
% Muscovite	—	T	—	—	5.9	—	—	—
% Accessories	0.2	T	Tz	—	T	T	Tz	T
% An plagioclase	28	30	30	28	20	38	70	ind.

Table 1. (continued)

C — Granitoids

Sample No.	106	59	60	21 A	29	17
% Plagioclase	21.0	27.5	31.2	14.6	3.0	25.1
% Quartz	25.6	17.8	34.0	37.5	29.0	36.8
% K-feldspar	44.4	48.2	28.6	39.9	65.6	36.6
% Biotite	3.8	4.5	1.6	5.7	—	1.0
% Epidote	T	T	—	—	—	—
% Garnet	—	1.7	4.6	2.3	—	—
% Chlorite	—	—	T	—	—	—
% Interg. Albite	5.0	—	—	—	—	—
% Muscovite	—	—	—	T	2.4	0.5
% Accessories	0.2	0.3	T	T	—	—
% An Plagioclase	30	46	30	32	ind.	ind.

Note: The modal analysis was calculated after 1.000 point with automatic point counter
T = less than 0,1%. ind. = indeterminable

The hornblendic gneisses show similar structural and textural features since their composition is also like that of the garnet-biotite varieties, except for the replacement of garnet by a similar amount of hastingsite and a higher anorthite content in the plagioclase.

(ii) "Las Piedras" Migmatites

In the Balcarce area, as well as in the rest of the Tandilia region the migmatite outcrops are very well represented. Three main forms are recognized:

1. homogeneous anatexites
2. homogeneous embrechites
3. heterogeneous epibolitic varieties

The migmatites appear as striped light-grey to pale brown coloured rocks. Some of them have a plutonic appearance and are of granitic to tonalitic composition.

The embrechitic rocks contain large felsitic porphyroblasts, usually lying along a weak metamorphic planar structure. They are often seen to have dark lenticular biotite-rich sheets within the granitic layers.

There are some garnetiferous and feldspathic types showing pinch and swell structure; others are crossed by two pegmatoid vein sets striking 240° and 300° respectively.

The homogeneous varieties have porphyroblastic to granoblastic textures and are composed of plagioclase (An_{28-32}), perthitic microcline (20 per cent albite), biotite, almandinic garnet and some epidote, muscovite and chlorite. The pyrope content of the garnet is similar to the one in the garnet-rich gneisses. In some migmatites the biotite is associated with hornblende and pistacite; in these rocks the anorthite content increases to 48 per cent (see Table 1).

There are also some leucocratic varieties that contain only 5 per cent of biotite showing micropegmatitic relations.

It is noticeable that some microcline porphyroblasts have inclusions of plagioclase almost wholly altered to sericitic aggregates.

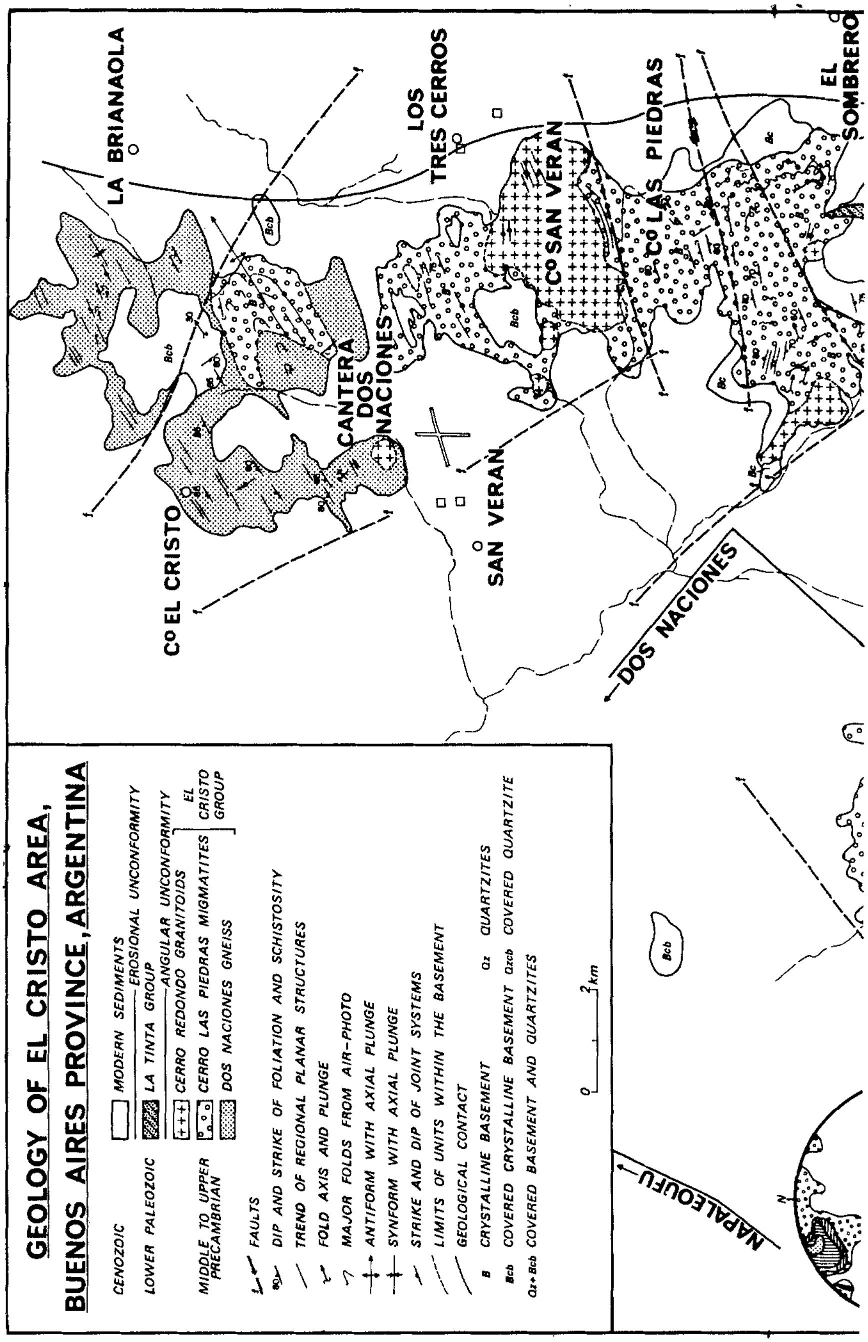
The heterogeneous migmatites are represented mainly by epibolitic varieties. These rocks present a marked foliation due to an alternation of felsic and mafic-rich striped bands, each several centimetres wide. The felsic bands often look like concordant pegmatitic veins. The dark foliae, generally of a finer grain size than the leucocratic ones, are composed of biotite and garnet, but these minerals were also observed in the leucosome.

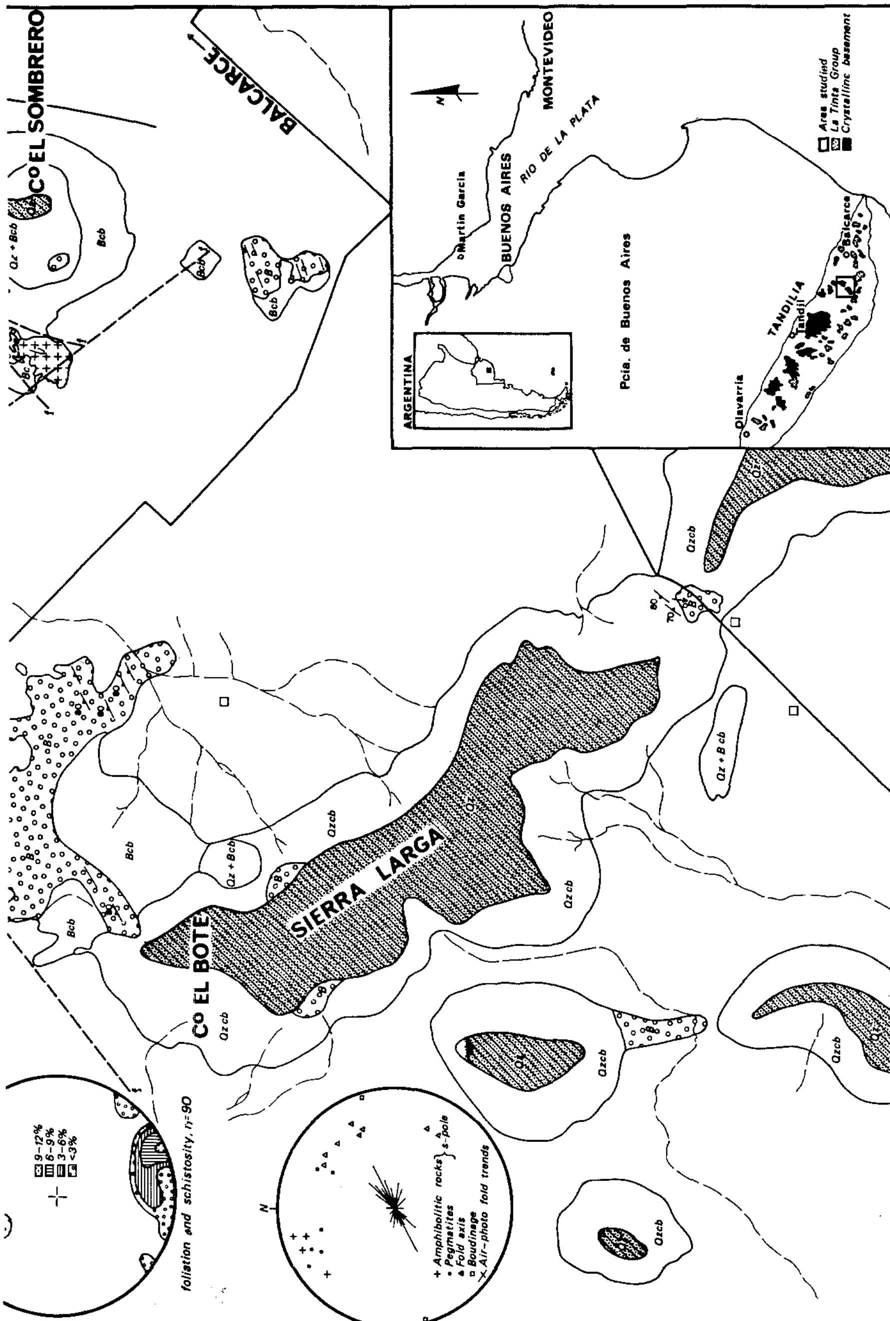
Porphyroblastic feldspar can usually be seen overlapping both the paleo and neosome.

The microscopic observation has shown that the Balcarce epibolites are tonalitic migmatites. The dark foliae are composed of brownish biotite and almandine garnet. It is important to note that there are two biotite generations, one paleosomatic and the other, together with some garnet, as the dark constituents of the neosomes. The plagioclase contains 35 per cent anorthite; the epibolites are quartzrich rocks and show little intergranular twinned microcline.

(iii) "Cerro Redondo" Granitoids

All acid plutonic rocks like the runitic granites of "San Veran" Hill, the small lenticular granitic bodies in the southern area of "Las Piedras" Hill that occur in


GEOLOGY OF EL CRISTO AREA,
BUENOS AIRES PROVINCE, ARGENTINA
CENOZOIC
MODERN SEDIMENTS
EROSIONAL UNCONFORMITY
LOWER PALEOZOIC
LA TINTA GROUP
ANGULAR UNCONFORMITY
MIDDLE TO UPPER PRECAMBRIAN
CERRO REDONDO GRANITOIDS
CERRO LAS PIEDRAS MIGMATITES
DOS NACIONES GNEISS
EL CRISTO GROUP
FAULTS
DIP AND STRIKE OF FOLIATION AND SCHISTOSITY
TREND OF REGIONAL PLANAR STRUCTURES
FOLD AXIS AND PLUNGE
MAJOR FOLDS FROM AIR-PHOTO
ANTIFORM WITH AXIAL PLUNGE
SYNFORM WITH AXIAL PLUNGE
STRIKE AND DIP OF JOINT SYSTEMS
LIMITS OF UNITS WITHIN THE BASEMENT
GEOLOGICAL CONTACT
B CRYSTALLINE BASEMENT
Qz QUARTZITES
Bcb COVERED CRYSTALLINE BASEMENT
Qzcb COVERED QUARTZITE
Qz+Bcb COVERED BASEMENT AND QUARTZITES
0
2 km
LA BRIANAOLA
LOS TRES CERROS
EL SOMBRERO
Cº LAS PIEDRAS
Cº SAN VERAN
CANTERA DOS NACIONES
Cº EL CRISTO
SAN VERAN
DOS NACIONES
NAPALEOUFU
Bcb


Cº EL SOMBRERO
BALCARCE
SIERRA LARGA
Cº EL BOTE
Qz + Bcb
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Qzcb
BUENOS AIRES
MONTEVIDEO
RIO DE LA PLATA
Martin Garcia
Pcia. de Buenos Aires
ARGENTINA
TANDILIA
Tandil
Balcarce
Olavarria
Area studied
La Tinta Group
Crystalline basement
9-12%
6-9%
3-6%
<3%
foliation and schistosity, n=90
Amphibolitic rocks
Pegmatites
Fold axis
Boudinage
Air-photo fold trends
s-pole

the core of antiforms whose axes plunge ENE and all concordant stratiform bodies within the gneissic and migmatic rocks, were included in this unit.

In the central area of "El Cristo" Hills, a small granitic stock (dated at 900 m. y.) 1.5 km long and 1.0 km wide, is emplaced in quartzfeldspathic epibolites. It is difficult to delineate the outer zone of the granite due to the presence there of some migmatites which are very similar in composition and texture.

The core is composed mainly of coarse granitic rocks accompanied by finer grained varieties. The granite is light grey when unaltered and contains many intergrowths of quartz-feldspathic structures like the runitic granites. Commonly the granite shows feldspar phenocrysts, veins and abrupt changes in the grain size giving the rock a pegmatic appearance.

It is important to note the presence of some relict metamorphic planes (schistosity and foliation) usually isolated and not very well defined as well as some reddish garnet with a random distribution within the granitic body.

Microscopically the granitoids of "El Cristo" area show granoblastic textures and average grain size of 5 mm, with some porphyritic variations. There are some rocks, as mentioned above, that present micropegmatoidal relations between the quartz and feldspar components.

All of them are composed of potassic feldspar, plagioclase, quartz and biotite, with some subordinate garnet, hornblende as well as muscovite (see Table I).

The potassic feldspar is perthitic microcline or microperthite with a 35 per cent albite content. The triclinicity of the potassic feldspar in the "San Veran" Granite and in the concordant granitic sheets within the gneisses and migmatites, was found to have a high to medium rate reaching the maximum in microcline.

The plagioclase, always ranges between An_{24-35} per cent, except in one rock (on 18 determinations) that showed An_{48}.

Quartz is present from 17.8 to 37.5 per cent as interstitial grains or polycrystalline assemblages, rarely as veinlets associated with epidote.

The dominanting dark constituent is pleochroic brown biotite that, in the "San Veran" Granite, is accompanied by five per cent chloritised pink garnet as well as some muscovite sheets in the microcline-rich varieties. The main accessory minerals are apatite, titanite and magnetite.

The pegmatitic veins within the granitic bodies have similar compositions, though they sometimes show quantities of garnet as well as epidote.

(iv) Amphibolites and Schists

These rocks are very poorly represented in the igneous and metamorphic complex, when compared to the gneisses and migmatites. They generally occur in thin stratiform sheets or lenses as well as xenolithic bodies within the gneisses and migmatitic rocks.

The amphibolites usually show a mineral lineation and some schistosity. They are fairly well represented in the "Dos Naciones" quarry within the hornblendic gneisses and epibolites. Microscopically they exhibit nematoblastic textures, some of them having decussate to granoblastic textures. They are composed of plagioclase and amphibole that can be accompanied by some epidote as well as some quartz, though some varieties may also have clinopyroxene.

The anorthite content of the plagioclase varies from An_{36} to An_{70}. The amphibole (about 50 per cent of total mineral) is a magnesian hornblende with a high hastingsite content. The clinopyroxene-bearing varieties show a hedenbergite-rich ferrosalite, a hastingsitic hornblende, some basic plagioclase and some zoisitic epidote (see Table 1).

The schists are not common in the "Balcarce" area or in the whole of the Tandilia region. These rocks are similar to those described by TERUGGI et al., (1974) in the "El Quebracho" Hill; they are mainly biotite-rich rocks sometimes containing garnet and felsic porphyroblasts with small quartz-feldspathic veins together with some segregations.

Under the microscope, they reveal lepidoblastic and porphyroblastic textures, being mainly composed by sodic plagioclase (basic oligoclase to acid andesine), quartz, brownish-green biotite (about 30 per cent), sometimes accompanied by subordinate amounts of green hornblende, red garnet and in some cases, pistacite associated with biotite.

B. Structural Features of "El Cristo" Area

The megascopic structural pattern and the regional distribution of the principal lithological units were established by photogeological interpretation of stereophoto pairs in a scale of 1 : 20 000. The abovementioned observation was carried out in conjunction with field determination of metamorphic planar and linear structures and fold modifications.

The aerial photographs and the mesotectonic analysis have shown a penetrative structural domain trending WSW—ENE marked by a persistent schistosity and foliation that coincides with the axes of the folds, with the main lithological changes and with one of the principal fault and joint systems. This structural domain was named "B Tectonic Domain" by TERUGGI et al. (1974).

A closer look at this important regional direction has shown that the northeast plunging folds, reaching up to 2 km from limb to limb, sometimes enclose a granitic core.

The mesoscopic folded structures reaching from a few centimetres to some metres across, are characterised as similar and disharmonic folds with asymmetrical limbs.

Accompanying the foliation, there is a mineral lineation due to a preferential orientation of hornblende as well as elongated quartz-feldspathic pencil-size aggregates.

It should be noted that there are some local modifications in the regional trend found in the crestal zone of the folds and also in the local disharmonic folding. Some of these changes may be due to rotation faults which are generally parallel to schistosity and which raise whole sections differentially to the surface. These sections present schistosity discordant at a high angle to the regional foliation.

It is important to mention that the deformation of the schistosity and foliation, suggests a previous planar structure, obviously produced by a previous tectonic phase. This older deformational phase (Fl) has been dealt with by TERUGGI et al. (op. cit.), who consider it as a folding phase of the nappe type, producing a foliation structure.

The same authors call the corresponding tectonic cycle "A tectonic domain", which is to be found principally in the Tandil area. As to the Balcarce area, the

E—W orientated structures are not abundant and are only to be found on "La Virgen" Hill, on "El Triunfo" Hill and in the "Punta Tota" district.

Therefore considering the E—W nappe folding and the "B-domain" structures mentioned above, we suggest a superimposed deformational pattern as shown in Fig. 2, in the "El Cristo" region.

The planar and linear trends are accompanied by a penetrative cleavage and by the main joint and fault system developed in a less intense and later phase. These structural features were considered by TERUGGI et al. (1973, 1974) as the "C-tectonic domain" which characterized them as planar structures of shear cleavage, fault-scarp alignments and persistent joints trending NW—SE in the granitoids.

There are three joint sets of which the appearance depends on the physical properties of the affected rocks, one trending NW—SE, the second NE—SW and the last being subhorizontal. The NE—SW set, trending parallel or at a low angle to the main fault system, as well as the NE—SW axial planes are considered as tensional joints, while the NW—SE set, normal to the most penetrative planar and linear structures, is an extensional joint type.

The SE—NW and SW—NE fault sets are considered to be gravitational faults.

C. Tecto-Methamorphic Evolution of "El Cristo" Region

The deformational history of nearly all of the world's orogenic belts such as the Alps, the Scottish Highlands, New Zealand and Tandilia, presents as a common feature an initial "nappe" structure, followed by one or several secondary fold

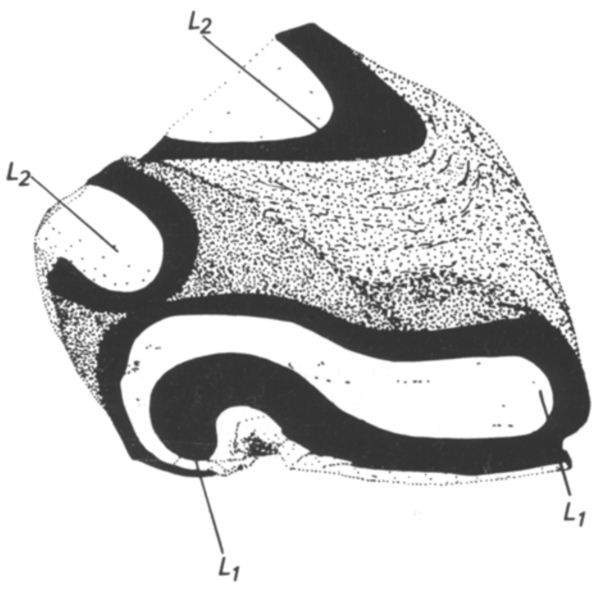

Fig. 2. Clay model showing F 1 and F 2 deformational phases and superimposed pattern. Taken from a photograph.

phases that have affected the previous planar and folded structures of the first tectonic episode and ending with late tectonic episodes represented by cleavage, crenulations and faulting.

This complex deformational pattern is accompanied by regional and local metamorphism and granitization.

On the basis of the structural and petrological features of the "El Cristo" region the sequences of the tectono-metamorphic events are as follows:

Table 2. Integrated calender of events of Balcarce area

Metamorphic events	Deformational phases	Igneous episodes	Age
M3 Local Diaphthoresis chlorite grade	F3 Faulting, jointing and cleavage	Postectonic granitic bodies	0.9 b. y.
M2 Regional. Almandine facies. Andesine grade.	F2. Intense folding. Planar structures and axes SW—NE, plunging gently NE	Strong synkinematic granitization and latetectonic granitic bodies.	1.52 1.66 1.69 1.70 1.73 1.80 1.87
M1 Regional. Almandine locally transitional to granulites. Ortho-pyroxene grade	Fl. Nappe folding, axes W—E		2.04 2.15

This series of episodes starts from a sedimentary basin older than 2.2 billion years. According to the petrological analysis carried out by ourselves together with Teruggi et al. (1962, 1973, 1974), the abovementioned basin was filled with wackes, alumina-poor pelites, a few limestones and some basic as well as ultra-basic igneous rocks. This igneous-sedimentary association underwent a first important deformational phase called Fl and is represented in the Balcarce area by subhorizontal axial plane folds and axes trending E—W. Synkinematically with this first phase, there occurred a first metamorphic event, called Ml; metamorphism that is considered regional by Teruggi et al. (op. cit.) who mentioned amphibolitic almandine facies transitional to granulites as indicated by the presence of orthopyroxene-bearing gneissic rocks. In the "El Cristo" region no high grade rocks are to be found, but it is understood that the presence of garnet and biotite in the gneissic rocks corresponds to the first step of the first metamorphic blastesis. The older ages of dated rocks accompanying this first metamorphic event are 2.04 and 2.15 b. y. A second deformational phase (F 2) took place afterwards producing SW—NE structures. The metamorphic event M 2 accompanied F 2 giving way to a Barrovian (B 21—B 22) type of dynamothermal metamorphism, a granitic event followed and the main penetrative planar structure as well as to the statistically meaningful mineral lineation were formed.

In keeping with the textural and structural evidence, the first microcline, plagioclase and quartz crystals were formed in the migmatites, growing in similar gneissic rocks and schists of the non-granitized areas and synkinematic with respect to F 2. The group of ages between 1.87 and 1.6 b. y., similar to those in the whole Tandilia region where there are also rocks of similar ages grouped between 1.8 and 1.5 b. y., represent this second metamorphic phase. It is important to point out that between these two age groups and that of the abovementioned

M 1 and F 1 episodes, there exists a meaningful stretch of time of nearly 170 m.y. After the deformation and the main metamorphic events, the complex was elevated, most likely due to block faulting, with local development of crenulations and minor F 3 cleavage, producing the partial diaphthoresis of rocks with the development of some chlorite and epidote during the M 3 episode. During these last orogenic pulses, the intrusion of minor bodies of granitic to tonalitic composition (900 m. y.) took place, representing the postectonic types.

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