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Geological Resources of Tierra del Fuego

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Foreword

The CADIC's Geological Resources Program will soon turn 40 years of fruitful development. During this period, many projects were carried out and others remain to be implemented. In the course of time, three generations of researchers have been formed. Mentioning names would be unfair to those that could be involuntarily omitted. There is still a long way to go. The eagerness for knowledge should not stop.

This book is a tribute to all those people who have worked in the different projects, of pure and applied science, and educational, and human resources training, granted to this foundational program and associated laboratories of the regional center of CONICET in Ushuaia.

Ushuaia, Tierra del Fuego, Argentina — Rogelio Daniel Acevedo

Preface

Ignacio Subías Pérez, our kindhearted partner Natxo, Head of Mineral Resources of the Zaragoza University, died prematurely in February, 2019. The contributions that follow this foreword are intended as a memorial to his devotion to science and friendship.

Some articles of the present volume concern polymetallic ore deposits, the study of which had given him a well-deserved international reputation throughout his career. In 2007, ISP led a grant about massive sulfides ores in Tierra del Fuego funded by the Spanish Ministry of Education and Science and that support not only consolidated the basis for the spirit of this book but also of former and future studies.

The collaborations that constitute the present work have been written by different authors and everyone hopes that it will prove a fitting and lasting memorial to our colleague, whose personal influence to our knowledge of the geology of the end of the world was outstanding.

Ushuaia, Argentina — Rogelio Daniel Acevedo

Acknowledgements

The editor is indebted to the *Centro Austral de Investigaciones Científicas* for the *Consejo Nacional de Investigaciones Científicas y Técnicas* and the *Instituto de Ciencias Polares* of the *Universidad Nacional de Tierra del Fuego* for give its facilities during the time it took to gather and organize the contributions received for this book.

Contents

An Introduction to the Geology of Tierra del Fuego

Luis Díaz Balocchi, Sebastián José Cao, and Erika Lorena Bedoya Agudelo

Abstract Tierra del Fuego is an island located at the southern tip of South America. It is one of the southernmost emerged lands on Earth, except for Antarctica. Its position is significant in terms of geologic environments both in the past and present times. During the Middle Jurassic, southern South America was exposed to regional extension and volcanism, associated with the breakup of the Gondwana supercontinent. In the Early Cretaceous, the Rocas Verdes back-arc basin (which included oceanic floor expansion) was developed. Contractional tectonics started in the Late Cretaceous, closing the back-arc basin and initiating the Andean orogeny. The crustal thickening led to the formation of the Austral (Magallanes) foreland basin. From the Late Cretaceous to the Eocene the Fuegian Andes went through a counterclockwise rotation that generated the bending of the South America–Antarctica connection and formed an orocline. Crustal extension responsible for the rupture of the continental bridge started at the Eocene and implied the relative displacement of South America to the north and Antarctica to the South. The contraction in the Fuegian Andes ended during the Miocene. Later, they were affected by a strike-slip faulting regime associated with transcurrence that started in the late Miocene. Nowadays, the island is placed over the South American and Scotia plates, separated by the Magallanes–Fagnano transform boundary (tectonically active) and is encircled by the Andes range to the west and south. Through the late Cenozoic, diverse agents sculpted the relief of Tierra del Fuego, mainly triggered by tectonic, climatic and eustatic action. Since the Late Miocene, the climate of southern South America entered the glacial cycles that are still active. Ice sheets covered the highest mountains in the southwestern portion of the island and fed four main ice lobes that occupied valleys in the lowlands. Late Pleistocene and Holocene glaciers were restricted to the higher and southern zones. Coastal landscapes of the island expose evidences of the oscillation of sea level through the late Cenozoic. Neotectonics related to the Magallanes–Fagnano

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Transform System is playing an important role in the landscape development in the central region.

Keywords Tierra del Fuego geology · Fuegian Andes · Rocas Verdes basin · Austral basin · Magallanes–Fagnano Transform System · Patagonian glaciations

1 Introduction

Tierra del Fuego is an island positioned at the tip of South America, in one of the southernmost emerged lands on Earth, except for Antarctica (Figs. 1 and 2). Enclosed by the Andes range to the west and south, and surrounded by the Atlantic, Pacific and Southern oceans, this location has unique significance in terms of climate, oceanography, ecology, human settlements and, indubitably, geology.

Its topography varies from gentle hills and plains in the northern part to a rocky mountainous environment in the south, with maximum elevations reaching over 2000 m a.s.l. Situated between 52° and 55° S, the climate is cold and oceanic,

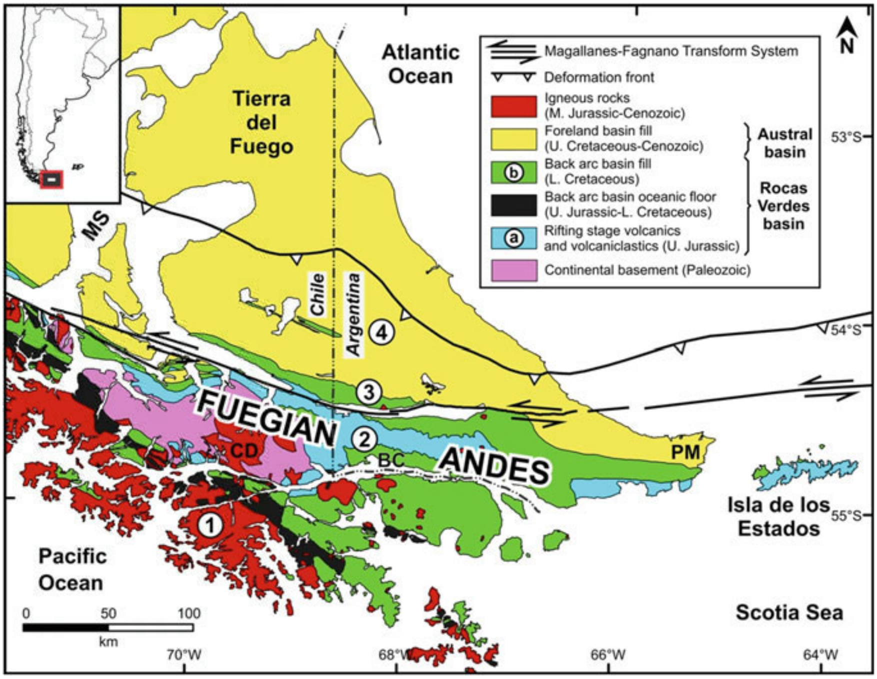

Fig. 1 Simplified geologic map of Tierra del Fuego and adjacent islands (modified from Torres Carbonell et al. 2014), indicating the main tectonostratigraphic units and structural elements. MS—Magellan Straits; CD—Cordillera Darwin; BC—Beagle Channel; PM—Península Mitre

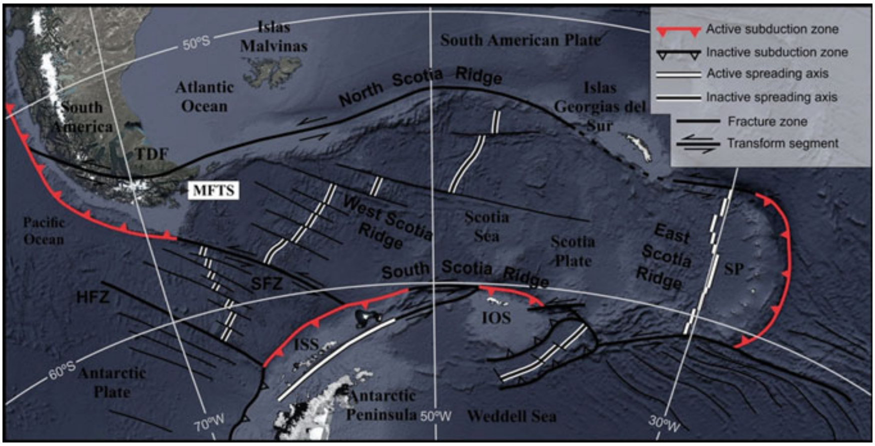

Fig. 2 Present-day geographic and tectonic situation of Tierra del Fuego with respect to the Scotia arc and the Antarctica Peninsula. TDF—Tierra del Fuego; MFTS—Magallanes-Fagnano Transform System; ISS—Islas Shetland del Sur; IOS—Islas Orcadas del Sur; SP—Sandwich Plate; SFZ—Shackleton Fracture Zone; HFZ—Hero Fracture Zone. Satellite image taken from Google Earth Pro. Structure based on Galindo-Zaldívar et al., Bohoyo et al. (2007), Dalziel et al. (2013) and Bohoyo et al. (2016)

with low thermal amplitude. Temperatures in winter usually fall below 0°C and not frequently rise above 20°C in summer. Winds coming from the west and southwest are constant and intense. Hydric regime shows a gradient from subhumid to humid in a southward direction (Coronato et al. 2008). All these differences induce a vegetation change from a grassy steppe in the northern zone to a deciduous *Nothofagus* forest with peat bogs in the Fuegian Andes further south (Coronato et al. 2008).

The island rests over the South American and Scotia plates, separated by the Magallanes–Fagnano transform boundary. During its geological history, Tierra del Fuego was affected by different tectonic regimes together with variations in paleogeography, sedimentary environments and climate that, in present times, configure a rich geology that we will try to briefly depict in the text below.

2 Mesozoic Rifting Stage and Back-Arc Basin Development

During the Middle Jurassic, southern South America was subjected to regional extensional faulting and associated volcanism, both related to the breakup of Gondwanaland. South of 50° S (present coordinates), crustal extension led to the opening of a submarine trough in Late Jurassic times, which by the Early Cretaceous evolved into a back-arc basin with oceanic floor development, known as the Rocas Verdes back-arc basin (Katz 1972; Dalziel et al. 1974; Bruhn et al. 1978; Gust et al. 1985).

The stratigraphy of the Rocas Verdes back-arc basin is best represented in the southern portion of Tierra del Fuego and in adjacent islands of the Fuegian Archipelago (Fig. 1). Exhumated relicts of the faulted continental basement are well exposed in Cordillera Darwin (Chilean Tierra del Fuego), encompassing greenschists to upper amphibolite facies metamorphic rocks, mostly Early Palaeozoic in age (Hervé et al. 2010). The Middle-Upper Jurassic Lemaire Formation (in Argentina), and its lateral equivalent, the Tobífera Formation (in Chile) comprise bimodal syn-rift lavas, shallow intrusive bodies and volcaniclastic successions deposited in a subaqueous environment (Hanson and Wilson 1991; Calderón et al. 2007; González Guillot et al. 2016) (unit "a" in Fig. 1). In southeastern Tierra del Fuego, the Lemaire Formation rocks portray very low to low-grade metamorphic grade, while in Cordillera Darwin the Tobífera Formation displays a wider range of metamorphic conditions, from lower greenschists to amphibolite facies, being higher in the southern sector of Cordillera Darwin (Nelson et al. 1980; Kohn et al. 1995; Maloney et al. 2011). The Lapataia Formation, restricted to the southwestern corner of Argentinian Tierra del Fuego, is thought to be a slightly higher metamorphic-grade equivalent of the Lemaire Formation (Olivero et al. 1997; Cao et al. 2018; Acevedo 2019). Between the latest Jurassic and the Early Cretaceous, oceanic crust generation took place. Rocas Verdes sea-floor remnants are preserved as incomplete ophiolite sequences, discontinuously distributed from the southern Patagonian Andes to the islands located south of Tierra del Fuego (Suárez 1977; Cunningham 1994; Stern and De Wit 2003; Calderón et al. 2012) (Fig. 1).

By the Early Cretaceous, the Rocas Verdes basin was rimmed by an active volcanic arc to the southwest and the South American continent to the northeast. Part of the Patagonian Batholith (labeled "1" in Fig. 1) is thought to represent the roots of this volcanic arc (Dalziel et al. 1974; Suárez 1979). Over a mixed crust of faulted basement blocks with partially developed oceanic crust and overlying the Upper Jurassic rift sequences, thick clastic and volcaniclastic deposits filled the Rocas Verdes basin during the Early Cretaceous (unit "b" in Fig. 1). In Argentinian Tierra del Fuego, the Yahgán Formation comprises Lower Cretaceous deep marine, flysch-like strata (very low-grade slates and meta-greywackes); while the Beauvoir Formation (black slates and mudstones) is considered its lateral equivalent to the north–northeast, representing outer platform sedimentary facies (Olivero and Martinioni 1996a; Olivero and Malumián 2008). The youngest fossil record known in the Rocas Verdes basin consists of late Albian inoceramids in the Yahgán Formation (Olivero and Martinioni 1996b), establishing a minimum age constraint for sedimentary activity, prior to tectonic contraction and the commencement of the Andean orogeny in Tierra del Fuego.

3 Late Mesozoic-Cenozoic Contraction: Back-Arc Basin Closure and Foreland Basin Development

The Fuegian Andes are the result of a long-lived, complex history of contractional tectonics, initiating in the Late Cretaceous. It has been proposed that the shift of tectonic regime (from extensional to contractional) responsible for the inversion of the Rocas Verdes basin and the beginning of the orogeny at the Pacific margin of southernmost South America was a consequence of global changes in plate kinematics, namely the increase in sea-floor spreading rates at the South Atlantic oceanic ridges (Dalziel 1986). Following structural criteria, the Fuegian Andes may be subdivided into an orogenic core or central belt of deformation (located hinterlandward, labeled "2" in Fig. 1), and a foreland thrust-fold belt—further subdivided into "internal" and "external," labeled "3" and "4," respectively, in Fig. 1 (Torres Carbonell et al. 2017a, b).

In a broad sense, the structure in the Fuegian Andes Central Belt domain reveals two main deformation phases, each related to different stages in the history of the Andean orogeny (Klepeis et al. 2010; Torres Carbonell et al. 2017a). The first phase of deformation initiated ca. 100 Ma, causing the obduction of the oceanic floor and volcanic/volcaniclastic fill of the basin to the northeast, and the underthrusting of the South American cratonic margin to the southwest (present coordinates). During this phase, the Rocas Verdes rocks experienced ductile deformation accompanied by regional metamorphism (Bruhn 1979; Klepeis et al. 2010; Torres Carbonell et al. 2017a). The second deformation event took place between the Late Cretaceous and the Miocene, and is characterized by brittle/ductile structures and the emplacement of regional-scale thrust systems, overprinting and crosscutting previous structures and metamorphic fabrics. This phase includes several deformation pulses, probably responsible for most of the uplift and shortening registered in the hinterland and the migration of the deformation front to the foreland (Klepeis 1994; Kohn et al. 1995; Gombosi et al. 2009; Torres Carbonell and Dimieri 2013). The crustal thickening achieved during the obduction of the Rocas Verdes basin exerted a tectonic load that caused the flexure of the lithosphere at the orogenic front; thus favoring sedimentation in the foreland region (to the northeast), with the adjacent growing orogen as the main source of detritus. This resulted in the initial development of the Austral (in Argentina) or Magallanes (in Chile) foreland basin (Biddle et al. 1986; Wilson 1991; Fildani and Hessler 2005).

The Fuegian thrust-fold belt is a thin-skinned orogenic wedge developed at the Fuegian Andes mountain front (Álvarez-Marrón et al. 1993; Torres Carbonell et al. 2011). According to differences in structural style, it has been subdivided into an internal thrust-fold belt and an external thrust-fold belt. The first one is located between the hinterland central belt and the external foreland thrust-fold belt, involves Upper Cretaceous (both Rocas Verdes basin and Austral basin) and Paleocene (Austral basin) strata, and marks the structural linkage between deformation and uplift in the orogenic core with the foreland propagation of structures toward progressively shallower structural levels in the external thrust-fold belt (Torres

Carbonell et al. 2017b). The latter comprises Cenozoic Austral basin units involved in a series of imbricate thrust systems with a predominantly brittle behavior. At least six contractional stages have been identified between the Maastrichtian-Danian and the Miocene in the Fuegian thrust-fold belt (Torres Carbonell et al. 2011).

From the uppermost Cretaceous through the Early Miocene, sedimentation in the Austral basin was accompanied by a significant tectonic control, evidenced in the occurrence of several synorogenic sequences with angular unconformities, as the foreland thrust-fold belt developed and the orogenic front advanced toward the foreland (Álvarez Marrón et al. 1993; Ghiglione and Ramos 2005; Rojas and Mpodozis 2006; Torres Carbonell et al. 2011). In Tierra del Fuego, the oldest sedimentary strata with clear provenance from an adjacent exhumed orogen are conglomerates in the Cerro Matrero, Río García (both localized in northern Cordillera Darwin) and the Bahía Thetis (in Península Mitre) Formations, all of them Campanian in age (Olivero et al. 2003; McAtamney et al. 2011). Overlying the Bahía Thetis Formation, the Policarpo Formation (Maastrichtian-Danian) is constituted by outer shelf and/or slope mudstones and sandstones (Olivero and Malumián 2008). The top of this unit shows an angular unconformity in the contact with the overlying strata, which may be Paleocene or Lutetian in different sectors of Tierra del Fuego (Torres Carbonell et al. 2011). The Paleocene and lower Eocene of the Austral basin are represented by the Río Claro Group, a regressive megasequence comprising turbiditic deposits at the base, and shallower facies to the top (Olivero and Malumián 2008). The La Despedida Group consists of a very thick clastic wedge (thinning to the north) that marks an extended transgression between the middle Eocene and the upper Eocene (Olivero and Martinioni 2001; Olivero and Malumián 2008), and the Cabo Domingo Group (Oligocene-middle Miocene) includes mostly subhorizontal strata, mainly exposed along the Atlantic coast from the thrust-fold belt deformation front boundary to the north (Olivero and Malumián 2008). The lower to upper Oligocene strata within the Cabo Domingo Group consist of folded marine conglomerates, sandstones and mudstones deposited below the calcite compensation depth; while the middle Miocene, upper part comprises shallow marine and deltaic mudstones of the Carmen Silva Formation and the chiefly fluvial deposits of the Cerro Castillo Formation (Olivero and Malumián 2008).

4 Oroclinal Bending and Rupture of the South America–Antarctica Continental Bridge

Although there is general consensus that the southern tip of South America and the Antarctic Peninsula where once joined forming a continuous continental "bridge," controversy still exists regarding the origin, timing and kinematics of their breakup and relative displacement (Diraison et al. 2000; Barker 2001; Dalziel et al. 2013; Torres Carbonell et al. 2014; Poblete et al. 2016; among many others). Paleogeographic reconstructions based on paleomagnetic data indicate that from the Late

Cretaceous to the Eocene the Fuegian Andes went through a large counterclockwise rotation, related to the closure of the Rocas Verdes basin (Poblete et al. 2016). Conversely, Antarctica experienced clockwise rotation with respect to South America, generating the bending of the South America–Antarctica connection and forming a cuspate orocline (Barker 2001; Torres Carbonell et al. 2014). Additionally, it has been proposed that from 110 Ma until 55 Ma both masses kept a similar relative position and a continuous southward displacement (Milanese et al. 2019).

The initiation of crustal extension and thinning responsible for the rupture of the South America–Antarctica continental bridge has been established at ca. 50 Ma (Livermore et al. 2005). This implied the relative displacement of South America to the north and Antarctica to the South, consistent with a northward thrust-front migration in the Fuegian thrust-fold belt recorded between the Eocene and the Miocene (Torres Carbonell et al. 2014). In that period, the Scotia Sea (Fig. 2) developed by extension at several spreading ridges, behind an east-migrating subduction zone at the boundary between the South American and Antarctic plates (Barker 2001). Contraction in the Fuegian Andes ended in the Miocene, coincident with a decrease in expansion rates at the West Scotia Ridge, which ceased definitely at around 7 Ma in the western and central Scotia Sea (Barker 2001).

5 Late Neogene–Recent Strike-Slip Faulting: The Magallanes–Fagnano Transform System

After contractional deformation ceased, the Fuegian Andes became subjected to a strike-slip faulting regime, associated with the Scotia plate northern transform boundary (Fig. 2). In Tierra del Fuego, a system of regional faults with an approximately east–west trend and sinistral kinematics is known as the Magallanes–Fagnano Transform System, located at the junction between the South American (to the north) and Scotia (to the south) tectonic plates (Figs. 1 and 2). The strike-slip displacement along the Fagnano system has been calculated at fairly 48 km (Torres Carbonell et al. 2008). Considering this value together with geodetic determinations of relative displacements documented at the plate boundary (Smalley et al. 2003; Mendoza et al. 2011), a maximum age between 7 and 11 Ma has been proposed for the initiation of transcurrence in Tierra del Fuego, which is still active (Torres Carbonell et al. 2008).

6 Late Cenozoic Landscape Evolution of Tierra del Fuego

Finally, through the late Cenozoic, Tierra del Fuego was affected by diverse agents that sculpted its relief (Rabassa et al. 2000, 2011; Coronato et al. 2008). Climatic and sea-level oscillations triggered different geomorphological events that left a footprint in the landscape. Since the Late Miocene, the climate of southern South America entered into the glacial cycles that are active until present (Mercer 1976; Wenzens 2006). The most prominent of these glacial episodes covered significant areas of the island, but is still in active discussion whether it has been fully covered at some time in the late Cenozoic (Malagnino and Olivero 1999; Rabassa et al. 2000; Coronato et al. 2004a; Bujalesky et al. 2001).

Over the highest mountains located in Cordillera Darwin, the ice sheets fed outlet glaciers and ice lobes that occupied lowlands. They dug wide valleys that follow an eastward direction taking advantage of depressions of tectonic origin (Diraison et al. 2000; Rabassa et al. 2000). The four main ice flow axes were the Magellan Straits, Bahía Inútil—San Sebastián, Lago Fagnano and Beagle Channel (Fig. 3). The several advances are recognized as a series of nested moraine ridges and belts that have been mapped and described since the nineteenth century (Darwin 1842; Nordenskjöld

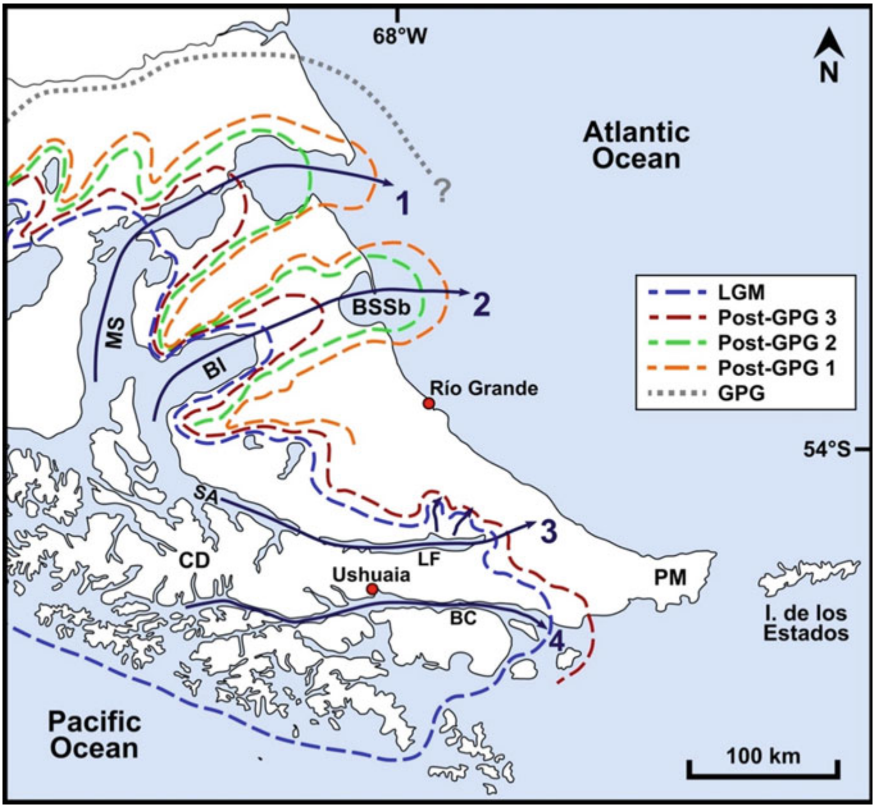

Fig. 3 Simplified map of Late Cenozoic ice flow axis and approximate ice lobes extension in Tierra del Fuego (based on Caldenius 1932; Meglioli 1992; Clapperton et al. 1995; Rabassa et al. 2000, 2011; Bentley et al. 2005; Glasser and Jansson 2008; Darvill et al. 2014, 2016). 1—Magellan Straits lobe; 2—Bahía Inútil—San Sebastián lobe; 3—Lago Fagnano lobe; 4—Beagle Channel lobe. MS—Magellan Straits; BI—Bahía Inútil; BSSb—Bahía San Sebastián; SA—Seno Almirantazgo; LF—Lago Fagnano; BC—Beagle Channel; PM—Península Mitre

1899; Caldenius 1932; Feruglio 1950; Auer 1956; Meglioli 1992; Clapperton et al. 1995; McCulloch and Bentley 1998; Rabassa et al. 2000, 2011; Coronato et al. 2004a, b; Bentley et al. 2005; Glasser and Jansson 2008; Darvill et al. 2014, 2016; among others).

The till plains and moraines of the oldest glaciations in Tierra del Fuego are found in the northern parts of the island (Meglioli 1992). They are possibly related to the Great Patagonian Glaciation (GPG, ca. 1.1 Ma BP, Mercer 1976), based on the correlation with landforms of known chronological age studied in continental Patagonia (Coronato et al. 2004a; Rabassa et al. 2011). The Post-GPG 1 (< 1 Ma, > 760 ka), 2 (< 760 ka, > 315 ka) and 3 (< 260 ka, > 150 ka) glaciations (Coronato et al. 2004b) are registered as well-defined morainic ridges and belts located on the margins of the northern ice lobes (Magellan Straits and Bahía Inútil—San Sebastián). Minor expressions of Post-GPG 3 advance are visible as moraines in the Río Fuego Valley, north of Lago Fagnano and in the Beagle Channel (Rabassa et al. 2011). Further field, mapping and dating studies over the central zone and the southeastern Atlantic coast are required to elucidate the extent and timing of glaciations prior to the Last Glacial Maximum (LGM) in these sectors.

The Late Pleistocene glaciations were restricted to the southern mountainous environments and the western coasts of Tierra del Fuego, surrounding the Magellan Straits, Bahía Inútil and Seno Almirantazgo (Fig. 3). The LGM (ca. 25 ka BP, Rabassa et al. 2011) ice limit is visible around the Chilean side of Tierra del Fuego, in the central Magellan Straits and Bahía Inútil, where minor readvances were identified (Bentley et al. 2005; McCulloch et al. 2005). Moraines produced by this glaciation are also located on the margins of the Lago Fagnano lobe, the Río Fuego and Ewan valleys (Coronato et al. 2009), the inner valleys of the Fuegian Andes (Coronato 1995), and in the coasts of the Beagle Channel (Rabassa et al. 2000, 2011). Moraines recording the Late Glacial minor ice readvances are found in inner and higher positions surrounding the same valleys affected by the LGM (McCulloch et al. 2005; Coronato et al. 2009; Rabassa et al. 2011).

Neoglaciation signals are limited to the higher sites of the Fuegian Andes, where climatic conditions allowed cirque glaciers to persist. Several Holocene and Little Ice Age moraines are preserved in the mountains located north of Ushuaia (Menounos et al. 2013).

During interglacial periods, the ice melting created vast gravel outwash plains and associated cut-in-fill terraces and fans. Examples of these landforms can be found in the proglacial zone of the Lago Fagnano lobe (Coronato et al. 2009) and in the steppes north and west of Río Grande (Codignotto and Malumián 1981; Bujalesky et al. 2001; Quiroga 2018). In these periods, the cold and humid climate together with the postglacial valleys topography led to the appearing of large peat bogs that dominate the southern and southeastern lowlands of the island (Rabassa et al. 1996; Iturraspe 2010).

The semiarid to subhumid conditions and westerly winds present in the northern part of the island allowed the aeolian modeling of the landscape. In the central portion of Tierra del Fuego, there are several examples of Holocene deflationary features. To the west of Río Grande, a group of ephemeral, brackish, shallow Lakes are set over blowouts (Codignotto and Malumián 1981; Coronato et al. 2011; Villarreal et al. 2014; Montes 2015; Villarreal and Coronato 2017; Quiroga 2018; Montes et al. 2020). They are encircled by depositional landforms formed by fine-grained sediments. Some of the recognized elements are sand and silt dunes (Coronato et al. 2011, 2020), lunettes (Villarreal and Coronato 2017; Montes et al. 2020) and sandy silt sheets (Villarreal et al. 2014). In the Bahía San Sebastián area, the interaction of aeolian processes acting over paleomarshes allowed the formation of ephemerally flooded pans, enlarged in an E-W direction (Arche and Vilas 1986, 2001; Villarreal and Coronato 2017).

Coastal landscapes of the island expose evidences of the oscillation of sea level through the Late Cenozoic, due to eustatic and tectonic processes (Bujalesky 2007; Ponce et al. 2011). These landscapes are found along the Atlantic coast as well as in the inner shores of the Magellan Straits and the Beagle Channel. They show a wide variety of landforms related to the emergence and submergence of the coasts at a local scale (Bujalesky 2007).

The northern Atlantic coast is part of a passive margin. It is dominated by cliffs that outline a straight wall positioned in a NNW–SSE orientation between Cabo Espíritu Santo and Cabo Nombre (Codignotto and Malumián 1981; Bujalesky 2007).

The Bahía San Sebastián (Fig. 3) is a wide bay (40 km diameter) of semicircular shape, developed over a glaciotectonic valley that was flooded during the early Holocene (Codignotto 1975). The northern part is characterized by supratidal fossil marshes and intertidal flats, the central and eastern shores are distinguished by Cheniers ridges, while the southern sector is recognized for its cliffs and sandy beach complexes (Vilas et al. 1986, 1999; Isla et al. 1991). The bay mouth is partially closed by El Páramo peninsula. It is a N-S oriented, 20-km long, gravel spit formed during the last 5 ka BP by the southward longshore drift (Codignotto 1975; Codignotto and Malumián 1981; Bujalesky 1990; Isla et al. 1991).

Southward, the central area of the Atlantic coast of Tierra del Fuego is defined by several Holocene gravel beach ridges plains. These landforms closed previous paleoembayments and estuaries, showing a relative sea-level descent (Bujalesky et al. 2001; Montes 2015; Bujalesky and Isla 2006). In addition, some of the southernmost Pleistocene raised beaches of the world are recognized there (Bujalesky 2007).

The Magellan Straits display diverse coastal landforms along its shores, related to glacial and eustatic oscillations. The coastal processes that affected its eastern mouth, in the north of the island, are similar to the ones that acted over the Atlantic margin. Thus, there appear cliffs, sandy beaches, spits, tidal mudflats, marshes and coastal dune fields (Simeoni et al. 1997). In the central section of the strait, there is a pattern of marine and glacio-lacustrine terraces and elevated shorelines (DeMuro et al. 2015, 2017).

The south and southwestern Tierra del Fuego shores, near Cordillera Darwin, Seno Almirantazgo and the western Beagle Channel (Fig. 3) were affected by tectonic and glacial processes different from the ones that acted in the eastern and northern part of the island (Bentley and McCulloch 2005), configuring coasts mainly occupied by fjords.

The central Beagle channel is surrounded by a rocky shoreline with cliffs and gravel beaches situated in the embayments (Gordillo et al. 1992). Several terrace levels are recognized along it, together with raised beaches of Holocene and Pleistocene ages (Gordillo et al. 1992; Rabassa et al. 2008). The coastline has suffered rapid modifications during the Holocene. The last postglacial flooding of the Beagle valley occurred about 11 ka BP, with a maximum sea-level rise of about 10 m above present day level at 6 ka BP (Bujalesky 2011), when low elevation Lakes were flooded and connected with the sea as paleofjords (Gordillo et al. 1993). The southeastern Peninsula Mitre (Fig. 3) shows rock cliffs and minor beaches, developed in bays and near river mouths (Isla 1994; Coronato et al. 2008).

Neotectonics related to the Magallanes–Fagnano Transform System is playing an important role in the landscape development in the central zone of the island. Several Quaternary fault scarps and pull-apart basins associated to strike-slip motion and transtension were recognized near Lago Fagnano (Costa et al. 2006; Perucca et al. 2016; Onorato et al. 2016, 2019).

To conclude, present-day active geomorphological processes are those inherited from the late Holocene, described above, in conjunction with fluvial, lacustrine, mass wasting, periglacial and anthropogenic activity (Coronato et al. 2008).

References

Acevedo RD (2019) Geological records of the Fuegian Andes deformed complex framed in a Patagonian Orogenic Belt regional context. 113p. Springer

Álvarez-Marrón J, McClay K, Harambour S, Rojas L, Skarmeta J (1993) Geometry and evolution of the frontal part of the Magallanes foreland thrust and fold belt (Vicuña Area), Tierra del Fuego, Southern Chile. AAPG Bull 77:1904–1921

Arche A, Vilas F (1986) Depósitos eólicos de grano fino en la Bahía de San Sebastián, Tierra de Fuego, Argentina. Acta geológica hispánica 21(1):261–266

Arche A, Vilas F (2001) Sedimentos eólicos de grano fino en la Bahía de San Sebastián, Tierra del Fuego, Argentina. J Iberian Geol 27:159–173

Auer V (1956) The Pleistocene of Fuego-Patagonia. Part I: the ice and interglacial ages. Annales Academia Scientiarum Fennicae, A, III 45:1–222

Barker PF (2001) Scotia Sea regional tectonic evolution: implications formantle flow and palaeocirculation. Earth Sci Rev 55:1–39. https://doi.org/10.1016/s0012-8252(01)00055-1

Bentley MJ, McCulloch RD (2005) Impact of neotectonics on the record of glacier and sea level fluctuations, Magellan Straits, southern Chile. Geografiska Annaler: Ser A Phys Geogr 87(2):393–402

Bentley MJ, Sugden DE, Hulton NR, McCulloch RD (2005) The landforms and pattern of deglaciation in the Magellan Straits and Bahía Inútil, southernmost South America. Geografiska Annaler: Ser A Phys Geogr 87(2):313–333

Biddle K, Uliana M, Mitchum R(Jr), Fitzgerald M, Wright R (1986) The stratigraphic and structural evolution of the central and eastern Magallanes Basin, southern South America,. In: Allen PA, Homewood P (eds) Foreland Basins. International Association of Sedimentologists Special Publication. Blackwell, pp 41–66

Bohoyo F, Galindo-Zaldívar J, Jabaloy A, Maldonado A, Rodríguez-Fernández J, Schreider A, Suriñach E (2007) Extensional deformation and development of deep basins associated with the

sinistral transcurrent fault zone of the Scotia-Antarctic plate boundary. Geol Soc Lond Spec Publ 290:203–217. https://doi.org/10.1144/sp290.6
Bohoyo F, Larter RD, Galindo-Zaldívar J, Leat PT, Maldonado A, Tate AJ, Gowland EJM, Arndt JE, Dorschel B, Kim YD, Hong JK, Flexas M, López-Martínez J, Maestro A, Bermudez O, Nitsche FO, Livermore RA, Riley TR (2016) Bathymetry and geological setting of the drake passage BAS GEOMAP 2 Series, Sheet 7. Escala 1:1.500.000. British Antarctic Survey
Bruhn RL (1979) Rock structures formed during back-arc basin deformation in the Andes of Tierra del Fuego. Geol Soc Am Bull 90:998–1012
Bruhn RL, Stern CR, De Wit MJ (1978) Field and geochemical data bearing on the development of a Mesozoic volcano-tectonic rift zone and back-arc basin in southernmost South America. Earth Planet Sci Lett 41:32–46
Bujalesky GG (1990) Morfología y dinámica de la sedimentación costera en la península El Páramo, bahía San Sebastián, Isla Grande de la Tierra del Fuego. Doctoral dissertation, Facultad de Ciencias Naturales y Museo
Bujalesky GG (2007) Coastal geomorphology and evolution of Tierra del Fuego (Southern Argentina). Geol Acta 5(4):337–362
Bujalesky GG (2011) The flood of the Beagle Valley (11.000 yr. BP), Tierra del Fuego. In: Anales del Instituto de la Patagonia, vol 39, no 1, pp 5–21
Bujalesky GG, Isla FI (2006) Depósitos cuaternarios de la costa atlántica fueguina, entre los Cabos Peñas y Ewan. Revista de la Asociación Geológica Argentina 61(1):81–92
Bujalesky G, Coronato A, Isla F (2001) Ambientes glacifluviales y litorales cuaternarios de la región del río Chico, Tierra del Fuego, Argentina. Revista de la Asociación Geológica Argentina 56(1):73–90
Caldenius C (1932) Las Glaciaciones Cuaternarias en la Patagonia y Tierra del Fuego. Geogr Ann 14:1–164
Calderón M, Fildani A, Hervé F, Fanning CM, Weislogel A, Cordani U (2007) Late Jurassic bimodal magmatism in the northern sea-floor remnant of the Rocas Verdes basin, southern Patagonian Andes. J Geol Soc Lond 164:1011–1022. https://doi.org/10.1144/0016-76492006-102
Calderón M, Fosdick JC, Warren C, Massonne HJ, Fanning CM, Cury LF, Schwanethal J, Fonseca PE, Galaz G, Gaytán D, Hervé F (2012) The low-grade Canal de las Montañas Shear Zone and its role in the tectonic emplacement of the Sarmiento Ophiolitic Complex and Late Cretaceous Patagonian Andes orogeny, Chile. Tectonophysics 524–525:165–185. https://doi.org/10.1016/j.tecto.2011.12.034
Cao SJ, Torres Carbonell PJ, Dimieri LV (2018) Structural and petrographic constraints on the stratigraphy of the Lapataia Formation, with implications for the tectonic evolution of the Fuegian Andes. J S Am Earth Sci 84:223–241. https://doi.org/10.1016/j.jsames.2018.04.002
Clapperton CM, Sugden DE, Kaufman DS, McCulloch RD (1995) The last glaciation in central Magellan Straits, southernmost Chile. Quatern Res 44(2):133–148
Codignotto JO (1975) Geología y Rasgos Geomorfológicos de la Patagonia Austral Extraandina, entre el río Chico de Gallegos (Santa Cruz) y la bahía de San Sebastián (Tierra del Fuego). Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, 76 p., unpublished doctoral thesis
Codignotto JO, Malumián N (1981) Geología de la región al norte del paralelo 54 S de la Isla Grande de Tierra del Fuego. Revista de la Asociación Geológica Argentina 36(1):44–88
Coronato A (1995) Geomorfología glacial de valles de los Andes Fueguinos y condicionantes físicos para la instalación humana. Tesis Doctoral. Facultad de Filosofía y Letras, University of Buenos Aires, 16 maps, 318p. Unpublished
Coronato A, Coronato F, Mazzoni E, Vázquez M (2008) The physical geography of Patagonia and Tierra del Fuego. In: Rabassa J (Ed.) The Late Cenozoic of Patagonia and Tierra del Fuego. Dev Quatern Sci 11:13–55
Coronato A, Fanning P, Salemme M, Oría J, Pickard J, Ponce JF (2011) Aeolian sequence and the archaeological record in the fuegian steppe, Argentina. Quatern Int 245(1):122–135
Coronato A, Meglioli A, Rabassa J (2004a) Glaciations in the Magellan Straits and Tierra del Fuego, Southernmost South America. Dev Quatern Sci Elsevier 2:45–48

Coronato A, Martínez O, Rabassa J (2004b) Glaciations in Argentine Patagonia, southern South America. Dev Quatern Sci Elsevier 2:49–67

Coronato A, Salemme M, Oría J, Mari F, López R (2020) Perched dunes in the Fuegian Steppe, Southern Argentina: Archeological Reservoirs of Holocene Information. In: Advances in Geomorphology and quaternary studies in Argentina. Springer, Cham, pp 58–91

Coronato A, Seppälä M, Ponce JF, Rabassa J (2009) Glacial geomorphology of the Pleistocene Lake Fagnano ice lobe, Tierra del Fuego, southern South America. Geomorphology 112(1–2):67–81

Costa CH, Smalley R (Jr), Schwartz DP, Stenner HD, Ellis M, Ahumada EA, Velasco MS (2006) Paleoseismic observations of an onshore transform boundary: the Magallanes-Fagnano fault, Tierra del Fuego, Argentina. Revista de la Asociación Geológica Argentina 61(4):647–657

Cunningham WD (1994) Uplifted ophiolitic rocks on Isla Gordon, southernmost Chile: implications for the closure history of the Rocas Verdes marginal basin and the tectonic evolution of the Beagle Channel region. J S Am Earth Sci 7:135–147. https://doi.org/10.1016/0895-9811(94)90004-3

Dalziel IWD (1986) Collision and Cordilleran orogenesis: an Andean perspective. Geol Soc Lond Spec Publ 19:389–404. https://doi.org/10.1144/gsl.sp.1986.019.01.22

Dalziel IWD, De Wit MJ, Palmer KF (1974) Fossil marginal basin in the southern Andes. Nature 250:291–294

Dalziel IWD, Lawver LA, Norton IO, Gahagan LM (2013) The Scotia Arc: genesis, evolution, global significance. Annu Rev Earth Planet Sci 41:767–793. https://doi.org/10.1146/annurev-earth-050212-124155

Darvill CM, Stokes CR, Bentley MJ, Lovell H (2014) A glacial geomorphological map of the southernmost ice lobes of Patagonia: the Bahía Inútil-San Sebastián, Magellan, Otway, Skyring and Río Gallegos lobes. J Maps 10(3):500–520

Darvill CM, Stokes CR, Bentley MJ, Evans DJ, Lovell H (2016) Dynamics of former ice lobes of the southernmost Patagonian Ice Sheet based on a glacial landsystems approach. J Quatern Sci 32(6):857–876

Darwin C (1842) On the distribution of the erratic boulders and on the contemporaneous unstratified deposits of South America. Trans Geol Soc Lond 2(2):415–431

DeMuro S, Brambati A, Tecchiato S, Porta M, Ibba A (2017) Geomorphology of marine and transitional terraces and raised shorelines between Punta Paulo and Porvenir, Tierra del Fuego, Straits of Magellan-Chile. J Maps 13(2):311–321

DeMuro S, Di Grande A, Brambati A, Ibba A (2015) Geomorphology map of the marine and transitional terraces and raised shorelines of the Península Juan Mazía, Tierra Del Fuego, Straits of Magellan-Chile. J Maps 11(5):698–710

Diraison M, Cobbold PR, Gapais D, Rossello EA, Le Corre C (2000) Cenozoic crustal thickening, wrenching and rifting in the foothills of the southernmost Andes. Tectonophysics 316:91–119. https://doi.org/10.1016/s0040-1951(99)00255-3

Feruglio E (1950) Descripción Geológica de la Patagonia. Dirección General de YPF 3:1–431

Fildani A, Hessler AM (2005) Stratigraphic record across a retroarc basin inversion: Rocas Verdes-Magallanes Basin, Patagonian Andes, Chile. Geol Soc Am Bull 117:1596–1614. https://doi.org/10.1130/B25708.1

Galindo-Zaldívar J, Balanyá JC, Bohoyo F, Jabaloy A, Maldonado A, Martínez-Martínez JM, Rodríguez-Fernández J, Suriñach E (2002) Active crustal fragmentation along the Scotia–Antarctic plate boundary east of the South Orkney Microcontinent (Antarctica). Earth Planet Sci Lett 204:33–46. doi:http://dx.doi.org/10.1016/S0012-821X(02)00959-7

Ghiglione MC, Ramos VA (2005) Progression of deformation and sedimentation in the southernmost Andes. Tectonophysics 405:25–46. https://doi.org/10.1016/j.tecto.2005.05.004

Glasser N, Jansson K (2008) The glacial map of southern South America. J Maps 4(1):175–196

Gombosi DJ, Barbeau DL, (Jr), Garver JI, JI (2009) New thermochronometric constraints on the rapid Palaeogene exhumation of the Cordillera Darwin complex and related thrust sheets in the Fuegian Andes. Terra Nova 21:507–515. https://doi.org/10.1111/j.1365-3121.2009.00908.x

González Guillot M, Urraza I, Acevedo RD, Escayola M (2016) Magmatismo básico jurásico-cretácico en los Andes Fueguinos y su relación con la Cuenca Marginal Rocas Verdes. Revista de la Asociacion Geológica Argentina 73:1–22
Gordillo S, Bujalesky GG, Pirazzoli PA, Rabassa JO, Saliège JF (1992) Holocene raised beaches along the northern coast of the Beagle Channel, Tierra del Fuego, Argentina. Palaeogeogr Palaeoclimatol Palaeoecol 99(1–2):41–54
Gordillo S, Coronato A, Rabassa JO (1993) Late Quaternary evolution of a subantarctic paleofjord, Tierra del Fuego. Quatern Sci Rev 12(10):889–897
Gust DA, Biddle KT, Phelps DW, Uliana MA (1985) Associated middle to late Jurassic volcanism and extension in southern South America. Tectonophysics 116:223–253. https://doi.org/10.1016/0040-1951(85)90210-0
Hanson B, Wilson T (1991) Submarine rhyolitic volcanism in a Jurassic proto-marginal basin, southern Andes, Chile and Argentina. In: Harmon R, Rapela C (eds) Andean magmatism and its tectonic setting, Geologic Society of America Special Paper. Geological Society of America, Boulder, pp 13–27
Hervé F, Fanning CM, Pankhurst RJ, Mpodozis C, Klepeis K, Calderón M, Thomson SN (2010) Detrital zircon SHRIMP U-Pb age study of the Cordillera Darwin Metamorphic Complex of Tierra del Fuego: sedimentary sources and implications for the evolution of the Pacific margin of Gondwana. J Geol Soc 167:555–568. https://doi.org/10.1144/0016-76492009-124
Isla FI (1994) Evolución comparada de bahías de la península Mitre, Tierra del Fuego. Revista de la Asociación Geológica Argentina 49(3):197–205
Isla FI, Vilas FE, Bujalesky GG, Ferrero M, Gonzalez Bonorino G, Arche Miralles A (1991) Gravel drift and wind effects on the macrotidal San Sebastian Bay, Tierra del Fuego, Argentina. Marine Geol 97(1–2):211–224
Iturraspe R (2010) Las turberas de Tierra del Fuego y el cambio climático global. Fundación Humedales-Wetlands International
Katz HR (1972) Plate tectonics and orogenic belts in the South-east Pacific. Nature 237:331–332
Klepeis KA (1994) Relationship between uplift of the metamorphic core of the southernmost Andes and shortening in the Magallanes foreland fold and thrust belt, Tierra del Fuego, Chile. Tectonics 13:882–904. https://doi.org/10.1029/94tc00628
Klepeis KA, Betka P, Clarke G, Fanning M, Hervé F, Rojas L, Mpodozis C, Thomson S (2010) Continental underthrusting and obduction during the Cretaceous closure of the Rocas Verdes rift basin, Cordillera Darwin, Patagonian Andes. Tectonics 29:TC3014. https://doi.org/10.1029/2009tc002610
Kohn MJ, Spear FS, Harrison TM, Dalziel IWD (1995) 40Ar/39Ar geochronology and P-T-t paths from the Cordillera Darwin metamorphic complex, Tierra del Fuego, Chile. J Metamorph Geol 13:251–270. https://doi.org/10.1111/j.1525-1314.1995.tb00217.x
Livermore R, Nankivell A, Eagles G, Morris P (2005) Paleogene opening of Drake Passage. Earth Planet. Sci. Lett 236(1–2):459–470
Malagnino EC, Olivero EB (1999) New evidence of the total glaciation of the Isla Grande de Tierra Del Fuego. J S Am Earth Sci 12(3):343–348
Maloney KT, Clarke GL, Klepeis KA, Fanning CM, Wang W (2011) Crustal growth during back-arc closure: Cretaceous exhumation history of Cordillera Darwin, southern Patagonia. J Metamorph Geol 29:649–672. https://doi.org/10.1111/j.1525-1314.2011.00934.x
McAtamney J, Klepeis K, Mehrtens C, Thomson S, Betka P, Rojas L, Snyder S (2011) Along-strike variability of back-arc basin collapse and the initiation of sedimentation in the Magallanes foreland basin, southernmost Andes (53–54.5°S). Tectonics 30:TC5001. https://doi.org/10.1029/2010tc002826
Mcculloch RD, Bentley MJ (1998) Late glacial ice advances in the Magellan Straits, southern Chile. Quatern Sci Rev 17(8):775–787
McCulloch RD, Fogwill CJ, Sugden DE, Bentley MJ, Kubik PW (2005) Chronology of the last glaciation in central Magellan Straits and Bahía Inútil, southernmost South America. Geografiska Annaler: Ser A Phys Geogr 87(2):289–312

Meglioli A (1992) Glacial geology and chronology of southernmost Patagonia and Tierra del Fuego. Lehigh University, unpublished doctoral thesis

Mendoza L, Perdomo R, Hormaechea JL, Cogliano DD, Fritsche M, Richter A, Dietrich R (2011) Present-day crustal deformation along the Magallanes-Fagnano Fault System in Tierra del Fuego from repeated GPS observations. Geophys J Int 184:1009–1022. https://doi.org/10.1111/j.1365-246X.2010.04912.x

Menounos B, Clague JJ, Osborn G, Davis PT, Ponce F, Goehring B, Maurera M, Rabassa J, Coronato A, Marr R (2013) Latest Pleistocene and Holocene glacier fluctuations in southernmost Tierra del Fuego, Argentina. Quatern Sci Rev 77:70–79

Mercer JH (1976) Glacial history of Southernmost South America. Quatern Res 6(2):125–166

Milanese F, Rapalini A, Slotznick SP, Tobin TS, Kirschvink J, Olivero E (2019) Late Cretaceous paleogeography of the Antarctic Peninsula: new paleomagnetic pole from the James Ross Basin. J S Am Earth Sci 91: 131–143. https://doi.org/10.1016/j.jsames.2019.01.012

Montes A (2015) Morfología y evolución de depósitos litorales del Holoceno en la zona del río Chico, Tierra del Fuego. Facultad de Ciencias Naturales, UNPSJB, unpublished doctoral thesis. 307p

Montes A, Santiago F, Salemme M, López R (2020) Late Pleistocene and Holocene evolution of Lake Las Vueltas, Tierra del Fuego (Argentina). Andean Geol 47(1) (in press)

Nelson EP, Dalziel IWD, Milnes AG (1980) Structural geology of the Cordillera Darwin - Collisional-style orogenesis in the southernmost Chilean Andes. Eclogae Geol Helv 73:727–751

Nordenskjöld O (1899) Geologie, geographie und anthropologie. Scwedischen Expedition nach den Magellansländern, 1895– 1897

Olivero EB, Acevedo RD, Martinioni DR (1997) Geología del Mesozoico de bahía Ensenada, Tierra del Fuego. Revista de la Asociación Geológica Argentina 52:169–179

Olivero EB, Malumián N (2008) Mesozoic-Cenozoic stratigraphy of the Fuegian Andes, Argentina. Geologica Acta 6:5–18

Olivero EB, Malumián N, Palamarczuk S (2003) Estratigrafía del Cretácico Superior-Paleoceno del área de Bahía Thetis, Andes fueguinos, Argentina: acontecimientos tectónicos y paleobiológicos. Revista Geológica de Chile 30:245–263

Olivero EB, Martinioni DR (1996a) Sedimentología de las Formaciones Lemaire y Yahgan (Jurásico-Cretácico) en Tierra del Fuego. Actas XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos 2:45–59

Olivero EB, Martinioni DR (1996b) Late Albian inoceramid bivalves from the Andes of Tierra del Fuego: Age implications for the closure of the Cretaceous Marginal Basin. J Paleontol 70:272–274

Olivero EB, Martinioni DR (2001) A review of the geology of the Argentinian Fuegian Andes. J S Am Earth Sci 14:175–188. https://doi.org/10.1016/s0895-9811(01)00016-5

Onorato MR, Perucca L, Coronato A, Rabassa J, López R (2016) Seismically-induced soft-sediment deformation structures associated with the Magallanes-Fagnano Fault System (Isla Grande de Tierra del Fuego, Argentina). Sed Geol 344:135–144

Onorato MR, Prezzi C, Orgeira MJ, Perucca LP, Coronato A, López R, Magneres I (2019) Geophysical characterization of Udaeta Lake as a possible pull-apart basin associated to quaternary tectonic activity along Magallanes-Fagnano fault system. Quatern Int 523:67–79

Perucca L, Alvarado P, Saez M (2016) Neotectonics and seismicity in southern Patagonia. Geol J 51(4):545–559

Poblete F, Roperch P, Arriagada C, Ruffet G, Ramírez de Arellano C, Hervé F, Poujol M (2016) Late cretaceous–early Eocene counterclockwise rotation of the Fueguian Andes and evolution of the Patagonia- Antarctic Peninsula system

Ponce JF, Rabassa J, Coronato A, Borromei AM (2011) Palaeogeographical evolution of the Atlantic coast of Pampa and Patagonia from the last glacial maximum to the Middle Holocene. Biol J Lin Soc 103(2):363–379

Quiroga DRA (2018) La incidencia de los agentes naturales y antropogénicos en la evolución geomorfológica de la región río Chico-río Grande, Tierra del Fuego. Universidad Nacional del Sur, unpublished doctoral thesis. 198p

Rabassa J (2008) Late cenozoic glaciations in Patagonia and Tierra del Fuego. In: Rabassa J (ed) The Late Cenozoic of Patagonia and Tierra del Fuego. Elsevier, Amsterdam. Dev Quatern Sci 11:151–204

Rabassa J, Coronato A, Martinez O (2011) Late Cenozoic glaciations in Patagonia and Tierra del Fuego: an updated review. Biol J Lin Soc 103(2):316–335

Rabassa J, Coronato A, Roig C (1996) The peat bogs of Tierra del Fuego. International Peat Society Publisher, Jyskä, Finland, Argentina, Global Peat Resources, pp 261–266

Rabassa J, Coronato A, Bujalesky G, Salemme M, Roig C, Meglioli A, Heusser C, Gordillo S, Roig F, Borromei AM, Quattrocchio M (2000) Quaternary of Tierra del Fuego, southernmost South America: an updated review. Quatern Int 68:217–240

Rabassa J, Gordillo S, Ocampo C, Hurtado PR (2008) The southernmost evidence for an interglacial transgression (Sangamon?) in South America. First record of upraised Pleistocene marine deposits in Isla Navarino (Beagle Channel, Southern Chile). Geol Acta: Int Earth Sci J 6(3):251–258

Rojas L, Mpodozis C (2006) Geología estructural de la faja plegada y corrida de Tierra del Fuego, Andes Patagónicos Chilenos. XI Congreso Geológico Chileno, Antofagasta, Chile, pp 325–328

Simeoni U, Fontolan G, Colizza E (1997) Geomorphological characterization of the coastal and marine area between Primera and Segunda Angostura, Magellan Straits (Chile). J Coast Res:916–924

Smalley R, Kendrick E, Bevis MG, Dalziel IWD, Taylor F, Lauría E, Barriga R, Casassa G, Olivero E, Piana E (2003) Geodetic determination of relative plate motion and crustal deformation across the Scotia-South America plate boundary in Eastern Tierra del Fuego. Geochem Geophys Geosyst 4:1070. https://doi.org/10.1029/2002gc000446

Stern CR, De Wit MJ (2003) Rocas Verdes ophiolites, southernmost South America: remnants of progressive stages of development of oceanic-type crust in a continental margin back-arc basin. Geol Soc Lond Spec Publ 218:665–683. https://doi.org/10.1144/gsl.sp.2003.218.01.32

Suárez M (1977) Aspectos geoquímicos del Complejo Ofiolítico Tortuga en la Cordillera Patagónica del Sur, Chile. Revista Geológica de Chile 4:3–14

Suárez M (1979) A Late Mesozoic island arc in the southern Andes, Chile. Geol Mag 116:181–190. https://doi.org/10.1016/j.tecto.2015.11.025

Torres Carbonell PJ, Dimieri LV (2013) Cenozoic contractional tectonics in the Fuegian Andes, southernmost South America: a model for the transference of orogenic shortening to the foreland. Geologica Acta 11:359–370. https://doi.org/10.1344/105.000001874

Torres Carbonell PJ, Dimieri LV, Olivero EB (2011) Progressive deformation of a Coulomb thrust wedge: the eastern Fuegian Andes Thrust-Fold Belt. In: Poblet J, Lisle R (eds) Kinematic evolution and structural styles of fold-and-thrust belts. Geol Soc Lond Spec Publ Geol Soc Bath:123–147

Torres Carbonell PJ, Dimieri LV, Olivero EB, Bohoyo F, Galindo-Zaldívar J (2014) Structure and tectonic evolution of the Fuegian Andes (southernmost South America) in the framework of the Scotia Arc development. Planet Chang, Glob. https://doi.org/10.1016/j.gloplacha.2014.07.019

Torres Carbonell PJ, Olivero EB, Dimieri LV (2008) Control en la magnitud de desplazamiento de rumbo del Sistema Transformante Fagnano, Tierra del Fuego, Argentina. Revista Geológica de Chile 35:63–77

Torres Carbonell PJ, Cao SJ, Dimieri LV (2017a) Spatial and temporal characterization of progressive deformation during orogenic growth: example from the Fuegian Andes, southern Argentina. J Struct Geol 99:1–19. https://doi.org/10.1016/j.jsg.2017.04.003

Torres Carbonell PJ, Rodríguez Arias L, Atencio MR (2017b) Geometry and kinematics of the Fuegian thrust-fold belt, southernmost Andes. Tectonics 36:33–50. https://doi.org/10.1002/2016tc004349

Vilas F, Arche A, Ferrero M, Isla F (1999) Subantarctic macrotidal flats, cheniers and beaches in San Sebastián Bay, Tierra del Fuego, Argentina. Marine Geol 160(3–4):301–326

Vilas F, Arche A, González Bonorino G, Isla F, Ferrero H (1986) Sedimentación intermareal en la bahía de San Sebastián, Tierra de Fuego, Argentina. Acta Geológica Hispánica 21(1):253–260

Villarreal ML, Coronato A (2017) Characteristics and nature of pans in the semi-arid temperate/cold steppe of Tierra del Fuego. In: Advances in geomorphology and quaternary studies in Argentina. Springer, Cham, pp 203–224

Villarreal ML, Coronato A, Mazzoni E, López R (2014) Mantos eólicos y lagunas semipermanentes de la Estepa Fueguina (53 S), Argentina. Revista de la Sociedad Geológica de España 27(2):81–96

Wenzens G (2006) Terminal moraines, outwash plains, and Lake terraces in the vicinity of Lago Cardiel (49° S; Patagonia, Argentina)—evidence for Miocene Andean foreland glaciations. Arct Antarct Alp Res 38(2):276–291

Wilson TJ (1991) Transition from back-arc to foreland basin development in the southernmost Andes: Stratigraphic record from the Ultima Esperanza District, Chile. Geol Soc Am Bull 103:98–111. https://doi.org/10.1130/0016-7606(1991)103%3c0098:tfbatf%3e2.3.CO;2. Acevedo RD, Radoszta AP (1987) Manifestaciones piríticas y anomalías metálicas en la costa sur de Tierra del Fuego, Rep. Argentina. X Congreso Geológico Argentino, II:227–230

Beatriz Mine: A Polymetallic Massive Occurrence in Tierra del Fuego

Silvia Ametrano, Ricardo Etcheverry, Horacio Echeveste, and Marta Godeas

Abstract The so-called Beatriz mine is located 15 km from Ushuaia and it was the first recognized polymetallic massive sulfide in Tierra del Fuego. The ore consists of a lens-shaped sulfide body with sedimentary and metamorphic textures, composed by chalcopyrite, sphalerite, galena and pyrite, and minor pyrrhotite, cobaltite, arsenopyrite, marcasite, magnetite and tetrahedrite. The lens is hosted in a volcano-sedimentary sequence of Jurassic age.

Keywords Polymetallic lens · Massive sulfides · Pyritic chert

1 Introduction

Many colored oxidized sulfide belts outcrops are known in Tierra del Fuego, which stretch along some 200 km within Andean Argentine territory. The first information regarding to metalliferous mineralizations in the region comes from Popper (in Kittl 1931) who assessed the auriferous placers discovered at Bahía Sloggett, which produced approximately 20,000 oz of gold. Kranck (1932) presented a systematic study of both sides of Canal de Beagle, where he surveyed different areas and found base metal sulfides (sphalerite, galena, chalcopyrite and pyrite). This author briefly refers to mineralizations located in Bahía Yendegaia, east coast of Lago Roca and Bahía San Juan. At the beginning and middle of 20´s century, some gold placer mining was developed in the Canal de Beagle and also rudimentary mining works were carried on in Beatriz mine. Since 1970, geological surveys (Caminos et al. 1981) determine several color anomalies (Arroyo Los Castores, Río Remolino-Túnel, Bahía Slogget, Bahía Aguirre). Many exploration and research works were also performed (Zubia et al. 1989; Broili et al. 2000; Biel et al. 2010; Biel 2011) that have allowed

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to typify these mineralizations as belonging to massive sulfide type, volcanic or sediments hosted (Acevedo et al. 2005).

The so-called Beatriz mine was the first recognized massive sulfide deposit in the area (Zubia et al. 1989), since the first geological surveys carried out by the Argentine Mining Geological Service (SEGEMAR) in the 70 s. Then the National University of La Plata (FCNyM) and the National Council of Science and Technology (CONICET) supported more studies. Nevertheless, others bigger colored zones and polymetallic lenses outcroppings, such as Arroyo Rojo, called the attention of companies for exploration surveys as well as research projects. The exploration has led to the recognition of several targets in the Sorondo and Alvear Range, which have reached the drill stage (Acevedo et al. 2005; Broili et al. 2000; Biel et al. 2010). This chapter summarized the knowledge reached on Beatriz polymetallic occurrence.

2 Regional Geological Setting

Beatriz mine is located in the western foothill of Monte Susana (54°51′30″ SL and 68°27′33″ WL) within Tierra del Fuego National Park (Fig. 1). This mineralization is 15 km from Ushuaia and 200 m from Bahía Ensenada in the Canal de Beagle. It is accessed through roads, although the last 1.5 km must be covered on foot.

The geological environment of Tierra del Fuego (Fig. 2) is characterized by a deformed metamorphic basement represented by accreted prisms, assigned to the Upper Paleozoic. In the southern part of South America, in Tierra del Fuego, during the Jurassic, there was an extensional episode (Dalziel et al. 1974; Bruhn et al. 1978), which originated a back-arc basin. During its evolution, a thick acid volcanism was deposited (Lemaire Formation, Borrello 1969), which was interbedded with marine sedimentary rocks. These sedimentary rocks correspond in their lower levels to high energy environments that evolved toward deeper environment facies represented by pelites and shales with no acid volcanic activity. These last sedimentary rocks with some rhyodacitic volcanic rocks correspond to Yahgán Formation (Kranck 1932).

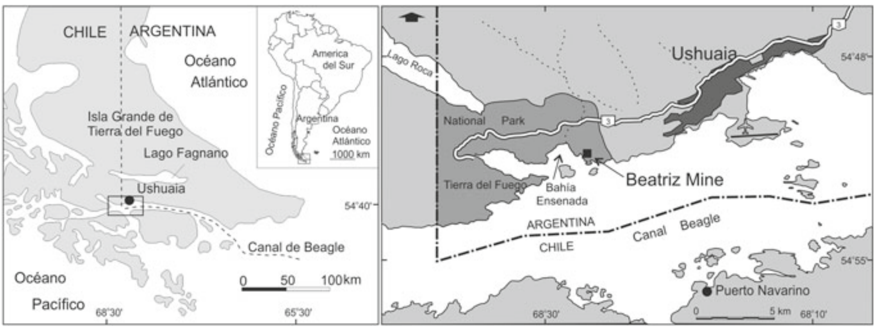

Fig. 1 Location of Beatriz mine

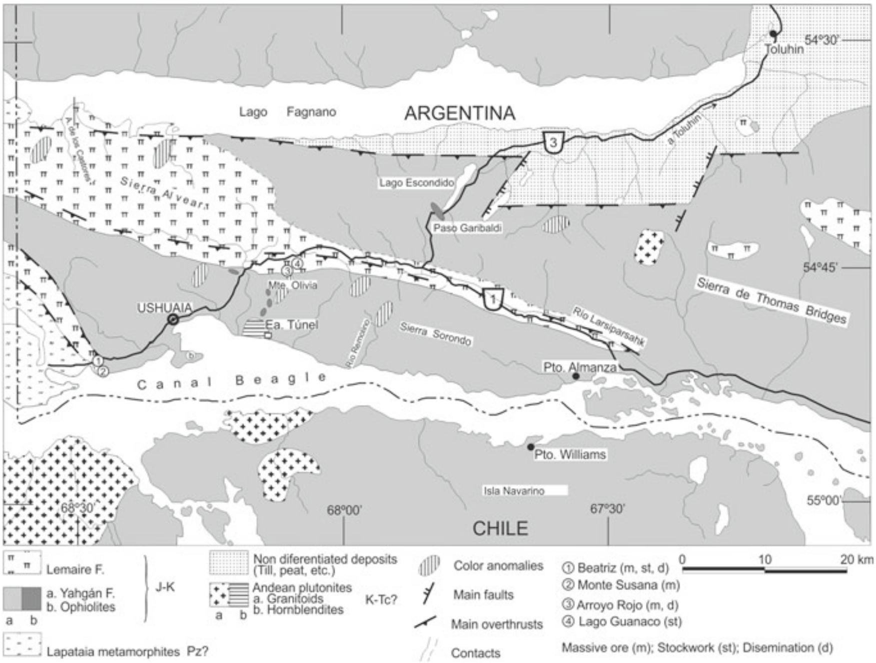

Fig. 2 Geology of Tierra del Fuego (compiled after Caminos et al. 1981; Kranck 1932; Suarez et al. 1985)

Later on, when attenuation and fracturing conditions were suitable, there was an overflow of basaltic dikes and bodies, which are the best exposure of the back-arc basin (Dalziel et al. 1987).

In the Argentine territory, the basement crops out only in the Argentine–Chilean border (Fig. 2) through the Lapataia Formation. The sedimentary and volcanic rocks of the back-arc basin were later affected by low grade and deformation metamorphism. It should be noted that the intercalation of the rhyolitic volcanic episode (Tuffaceous Series, Thomas 1949; Lemaire Formation, Borrello 1969, 1972) in the volcanic-sedimentary sequence of the back-arc is highly exposed in other sectors of the Andes. The age of the main units of this basin has been defined as Upper Triassic—Lower Cretaceous. Dark to greenish basic rocks, also metamorphosed, located at Paso Garibaldi and other sites represent the rift period according to Dalziel (1981); to the west, in Chilean territory, they have been named Rocas Verdes (Dalziel et al. 1974) and other authors relate them to Tortuga Complex (De Wit and Stern 1981).

The evolution is completed with a magmatic arc with plutonic rocks of the Late Cretaceous—Tertiary, when the closure of the basin is produced. These rocks form stocks and domes of various compositions (granite—syenodiorite—diorite—hornblendite). The current tectonic configuration is due to the Andean orogeny, whose compression effects appear in the different tectonic flakes, limited by reverse faults,