Evolution of the Gondwana margin in southern Chile, as revealed by U-Pb SHRIMP detrital zircon dating

FRANCISCO HERVÉ A. Departamento de Geología, Universidad de Chile, Casilla 13518 Correo 21, Santiago, Chile
e-mail: fherve@cec.uchile.cl

Summary

The low grade metamorphic complexes of southern Chile between 43^o and 53^o S. Lat., crop out in two belts, east and west of the >100 km wide Mesozoic-Cenozoic Patagonian Batholith. Previously considered as parts of a single accretionary complex developed during the Late Paleozoic on the southwestern margin of Gondwana, new petrological and detrital zircon SHRIMP U-Pb ages point towards different ages of the protoliths and different metamorphic environments for the two belts. There is no record in the considered segment of the Andes of high P/T accretionary complexes or of magmatic arc rocks older than Late Triassic, as is the case in the Chilean coastal areas to the north. If older subduction complexes and magmatic arcs existed, they were either transported laterally southwards, or eliminated by subduction erosion of the continental margin. Late Triassic sedimentation age in the Chonos Metamorphic Complex and Early Late Jurassic crystallization age of parts of the Diego de Almagro metamorphic complex bear witness of Mesozoic development of high P/T subduction complexes at the continental margin

INTRODUCTION

The Patagonian Andes extend along the South American plate margin, south of 42 S. Lat. They are mainly composed of the Late Jurassic to Cenozoic Patagonian Batholith, flanked by low-grade metamorphic complexes that crop out semi-continuously west and east of the batholith. Late Jurassic to Cenozoic volcanic and sedimentary units unconformably overlie these metamorphic complexes, particularly east of the batholith. (Fig. 1). The remoteness of this vast area has hindered detailed geological studies, and on the basis of limited data, both complexes have usually been mapped and considered as parts of a single subduction complex developed in the southwestern Gondwana margin during, broadly, the late Paleozoic. Recent petrological and geochronological investigations have permitted better constraints on the depositional and metamorphic ages of the different complexes, and on the P-T conditions of their metamorphism, thus relating them better to subduction processes.

THE EASTERN ANDES METAMORPHIC COMPLEX

The metamorphic rocks that crop out east of the Patagonian batholith will be referred to as the Eastern Andes Metamorphic Complex (EAMC, Hervé 1993). This vast unit is composed predominantly by a sandstone–shale assemblage, with minor conglomerate, diamictite, limestone and intraplate alkaline pillow basalts and their low grade metamorphic equivalents. The rocks have experienced polyphase deformation and metamorphism prior to the unconformable deposition over them of the acid late Jurassic volcanic rocks, which cover large areas in the mountain belt and adjacent extra-Andean Patagonia (Pankhurst and Rapela 1995).

The only fossils in this unit are Late Devonian to Early Carboniferous pollen and Tetrapod tracks, recorded in very low grade facies at Bahía de la Lancha, Argentina. The youngest concordant U-Pb SHRIMP ages of detrital zircons vary between 451 Ma in the easternmost sampled outcrop, to 254 Ma in the west. This suggests a younging of sedimentation towards the west, and that the depositional environment was a prograding sedimentary fringe, west of the inland continental areas of Gondwana (the present Patagonia and South Africa at the considered latitudes), which are the most probable sources the detrital material in the sediments. Imprecise Rb-Sr errorchrons in low-grade schists indicate ca.300 Ma, a possible age range for the metamorphism. . Fission-track dating of detrital zircons indicates healing ages (260°C?) of 300 and 265 Ma (S. Thomson, written communication 1999). These data indicate that metamorphism and exhumation of the complex were taking place in the late Paleozoic, in accordance with the field relations observed. Metamorphic conditions, at Valle de Chacabuco and Lago O'Higgins have been estimated at ca. 4 kbar and 375+-25°C from illite crystallinity determinations, b_o measurements and phengite geobarometry (Hervé *et al.* 1998). Metamorphic conditions seem to be higher to the north and lower to the south and east of these localities. These metamorphic conditions are not typical of subduction zone metamorphism, but more of an extensional setting with rather high geothermal gradient.

The Patagonian Batholith has developed a contact aureole in the EAMC, which south of Golfo de Penas is quite continuous, several kilometres wide, and shows distinct biotite, andalusite and sillimanite mineral zones approaching the batholith. Mesozoic components of the complex form part of the contact aureole.

THE WESTERN COASTAL COMPLEXES

The metamorphic complexes that crop out west of the Patagonian batholith will be referred to as the Chonos Metamorphic Complex north of the Golfo de Penas, and the Madre de Dios and Diego de Almagro complexes between the Golfo de Penas and the Strait of Magellan. They differ significantly from the EAMC in that they contain frequent MORB-like metabasite rock bodies and metalliferous and radiolarian cherts, they are usually more complexly deformed, and that their metamorphic regimes were high P/T ones, characteristic of subduction zones.

The Chonos Metamorphic Complex

It is composed of an eastern turbidite series with well-preserved sedimentary structures, which grades west into a highly deformed micaschist and greenschist assemblage. MORB-type pillow basalts and radiolarian cherts are also part of the complex, which has well-developed sheets of "broken formation".

The eastern turbidite series has provided marine fossils and detrital zircons of late Triassic age. As it is intruded by Early Cretaceous plutons, which cut across the metamorphic structures, the age of metamorphism is probably Jurassic, as previous Rb-Sr and K-Ar ages had suggested. The metamorphic conditions vary from 5.5 kbar / 250 – 280°C to 8-10 kbar / 380 – 500°C from east to west (Willner *et al.* 2000). Older components could be present towards the northern extension of the complex.

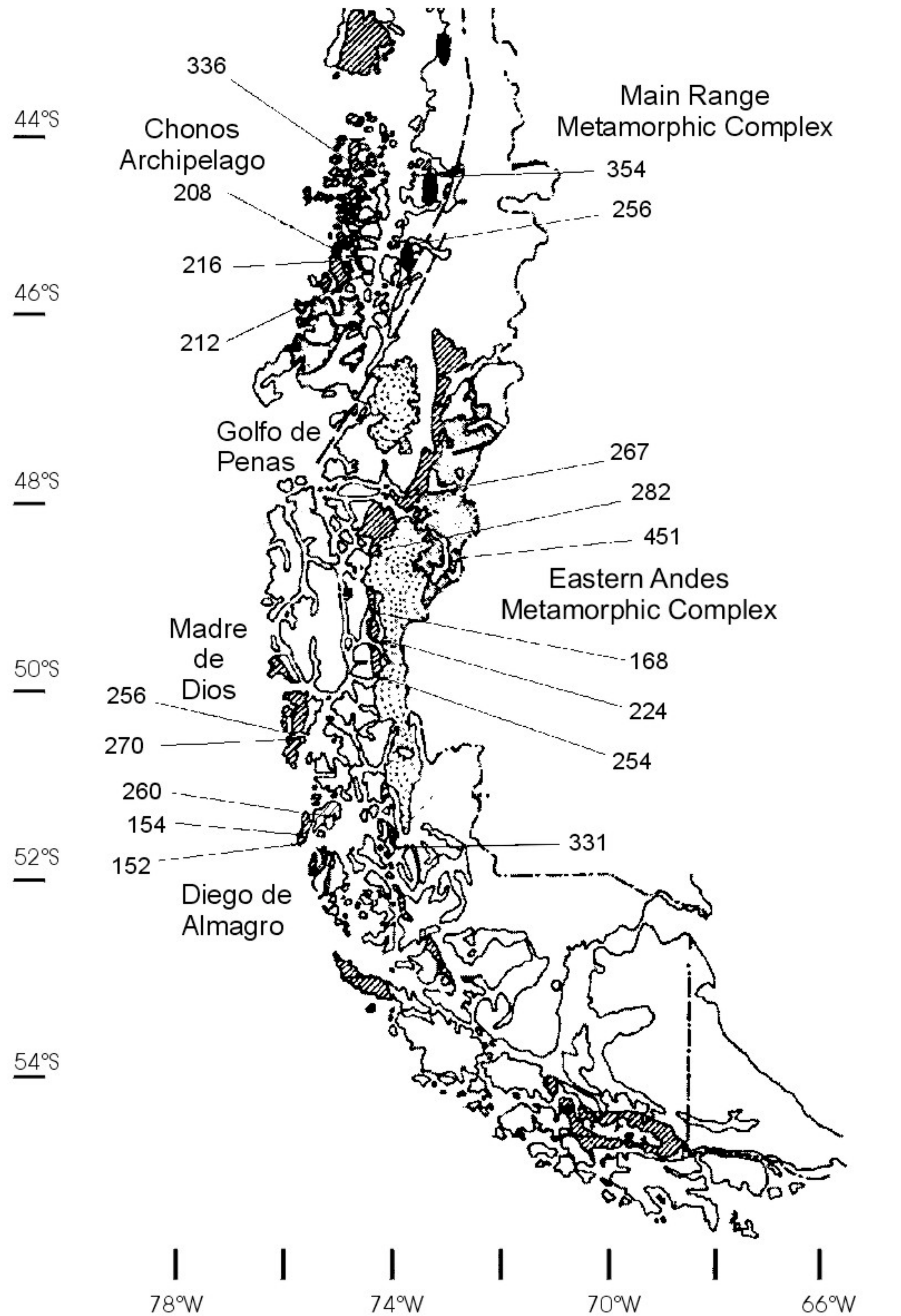

Figure 1. Youngest concordant U-Pb SHRIMP detrital zircon ages (in Ma) from metasedimentary rocks in Southern Chile. These represent maximum possible depositional ages for the host rocks. Ages from the Diego de Almagro metamorphic complex are from a metarhyolite (152 Ma) and a mylonitized granite (154 Ma). Key: cross-hatched = mica-schist, greenschist, metachert and marble; dotted = turbidite sequences; solid black = schist and amphibolite. Patagonian ice-fields are indicated by concentric dotted lines.

The Main Range Metamorphic Complex

Isolated outcrops of amphibolite facies andalusite- and staurolite-bearing metamorphic rocks, located within the Patagonian batholith and east of the Chonos metamorphic complex, are older than the latter and probably formed part of the backstop region during the Jurassic high P/T event.

The Madre de Dios metamorphic complex

In the Madre de Dios archipelago, the presence of three lithostratigraphic units has been established (Forsythe and Mpodozis 1979). The Denaro complex of pillow basalts associated to metalliferous and radiolarian chert is interpreted as representing the oceanic basement to the Tarlton Limestone. This second unit is composed exclusively of massive limestone and marble interpreted as having been deposited in open-ocean volcanic island environment. Finally, the Duque de York complex is composed of a conglomerate-bearing continent-derived turbidite sequence.

The Tarlton limestone and the Denaro complex have fossils of late Carboniferous to Early Permian age (Ling *et al.* 1985), while the Duque de York complex, which stratigraphically overlies the other two, has detrital zircons of late Early Permian age (256 - 270 Ma; Hervé *et al.* 1999a). Maximum metamorphism is in the pumpellyite actinolite facies. The three units were tectonically interleaved at the Gondwana continental margin prior to the late Jurassic intrusion of the Patagonian Batholith.

The Diego de Almagro metamorphic complex

In this archipelago, the same three units described in the previous section are in tectonic contact through the Seno Arcabuz shear zone, with the Diego de Almagro Metamorphic Complex to the southwest. The latter complex is composed mainly of metabasites (greenschists and blueschists) and metapelites in varying metamorphic grades, but also contains mylonitic granites and meta-rhyolites. In the latter lithologies, early Late Jurassic (152 and 154 Ma) igneous zircons are present (Hervé *et al.* 1999b). This is an indication that rocks of continental origin were carried down the subduction zone and metamorphosed in conditions akin to the blueschist facies.

Ar-Ar spot laser dating of phengite reveals Early Cretaceous ages for coarse low silica white micas and late Cretaceous ages for finer grained more phengitic ones. These two generations of mica are present in the blueschists, the meta-granite, and the meta-rhyolite, and record different stages of their subduction with peak pressures of 8 to 10 kbar in the late Cretaceous.

GEOLOGICAL EVOLUTION

If continuous subduction since the late Paleozoic is supposed to have been active in this area (i.e. Veevers *et al.* 1994), the diversity of ages and metamorphic conditions exhibited by the present outcrops, as detailed above, could be explained by a paucity in the preservation of originally continuous subduction complexes generated in the continental margin. Preservation is conditioned by the extent of tectonic mass transport along the margin and down the subduction zone. The first process is controlled by oblique subduction and associated strike-slip fault zones, the second by the subduction of topographic relief in the subducting oceanic lithosphere, which produce tectonic erosion in the continental margin. Such events may have been frequent along the margin of southwestern Gondwana during the considered time span. Varying paleoclimatic conditions may also account for the patchy existence in space and time of turbidite complexes along the margin.

The presented age and petrological data constrain some aspects of the geological evolution of this segment of the Gondwana margin. It appears that at least part of the Eastern Andes Metamorphic Complex is older, in age of sedimentation and metamorphism, than the western complexes. Also, the conditions of metamorphism seem to have been of lower pressure and P/T gradient that those of the western complexes. There is no evidence for calcalkaline plutonism of late Paleozoic to Triassic age of regional extent in the Andes or in the extra-Andean Patagonian foreland at the corresponding latitudes, which would reveal the activity of subduction processes at this time. The flat-plate subduction model of Lock (1980) might be a good explanation for the lack of a magmatic arc close to the continental margin.

If the late Carboniferous to Early Permian Denaro Complex and the Tarlton limestone are really exotic to South America and far-travelled terranes, they were already docked to the continental margin in the late Early Permian when the Duque de York complex was deposited over them. The absence of a contemporaneous magmatic arc may be explained by the flat-plate subduction model, or, alternatively, by tectonic transport parallel to the continental margin without significant subduction. The southwards margin-parallel transport, which would have operated until at least the late Permian, might also explain the absence of the subduction complex and magmatic arc of late Paleozoic age. The latter would have been transported southward and may correspond to the rocks of that age found at present in the Antarctic Peninsula.

The large proportion of igneous detrital zircons of late Early Permian age in the Duque de York complex probably indicates the first flush of igneous detritus to the trench from an active nearby magmatic source. However, no abundant source rocks of this age crop out at present in the Andes or in the extra-Andean Patagonia, at the considered latitudes, as the outcrops of the coeval Choiyoi acid volcanic rocks and granitic bodies crop out only North of ca. 40^o S. Lat. Alternatively, the magmatic detritus could have originated in. a now displaced western source.

There is good evidence that eastward subduction was active in the Chonos Archipelago area after the late Triassic and during the early Jurassic, both from the presence of high P/T subduction complexes of that age, and from the presence of the Early to Middle Jurassic Sub-Cordilleran Batholith east of the present Andes. The initiation or renewal of subduction in the Diego de Almagro area must have immediately followed the continental-scale extensional and magmatic event which produced in the late Jurassic the Marifil - Chon Aike felsic LIP, as rocks equivalent in age are involved in the high P/T Diego de Almagro Metamorphic Complex. During this Jurassic and Cretaceous subduction events, the backstop of the subduction complexes was principally constituted by the Permian metasediments, metabasites and marbles of the western complexes, which were not deeply subducted but deformed together with their Jurassic cover. The Cretaceous - Cenozoic subduction record is revealed all over the considered segment by the presence of the Patagonian Batholith, and must have provided the tectonic scenario for the exhumation of the Mesozoic western metamorphic complexes, which have late Cenozoic apatite fission track ages. However, no accretionary complexes of Cenozoic depositional age are yet exposed in the continental margin above the present sea level.

ACKNOWLEDGEMENTS

Research in Aysén and Magallanes has been funded by Catedra Presidencial en Ciencias and Fondecyt project 1980741. SHRIMP dating at ANU was guided by Mark Fanning. R.J. Pankhurst provided stimulus and advice in all stages of this research.

REFERENCES

Forsythe, R.D., 1982. The late Paleozoic and Early Mesozoic evolution of southern South America: A plate tectonic interpretation. *Journal of the Geological Society of London*, v. 139, p. 671 - 682.

Forsythe, R.D. and C. Mpodozis, 1979. El Archipielago Madre de Dios, Patagonia Occidental,Magallanes: rasgos generales de la estratigrafia y estructura del basamento pre-Jurásico Superior. *Revista Geológica de Chile*, 7, p. 13 - 29. .

Hervé, F., 1993. Paleozoic Metamorphic complexes in the Andes of Aysen, Southern Chile (West of ?Occidentalia). Proceedings of the *First Circum Pacific and Circum Atlantic Terrane Conference*, p. 64-65, Guanajuato, México.

Hervé,F., C.M. Fanning, J. Bradshaw, M. Bradshaw and J.P. Lacassie, 1999a. Late Permian SHRIMP U-Pb detrital zircon ages constrain the age of accretion of oceanic basalts to the Gondwana margin at the Madre de Dios Archipelago, southern Chile. *IV International Symposium on Andean Geodynamics*, 327-328, Goettingen.

Herve, F., D. Prior, G. López, V.A. Ramos, A. Rapalini, S. Thomson, J.P. Lacassie and C.M. Fanning, 1999b. Mesozoic blueschists from Diego de Almagro, southern Chile. *II South American Symposium on Isotope Geology*, Actas, (Extended Abstract), p.318-321, Córdoba.

Ling, H.Y., R.D. Forsythe and C.R. Douglass, 1985. Late Paleozoic microfaunas from Southernmost Chile and their relation to Gondwanaland forearc development. *Geology*, vol. 13, p.357 - 360.

Lock, B.E., 1980, Flat-plate subduction and the Cape Fold Belt of South Africa. *Geology*, v.8, p.

Pankhurst, R,J. and C.W. Rapela, 1995. Production of Jurassic rhyolite by anatexis of the lower crust of Patagonia. *Earth and Planetary Science Letters*, v.134, p. 23 - 36.

Veevers, J.J., C.McA. Powell, J.W. Collinson and O.R. Lopez-Gamundi, 1994. in Veevers, J.J. and Powell, C.McA., eds., Permian-Triassic Pangean Basins and Foldbelts Along the Panthalassan Margin of Gondwanaland: Boulder, Colorado, *Geological Society of America Memoir* 184.

Willner, A.P., F. Hervé. and H.J. Massone, 2000. Mineral Chemistry and Pressure-Temperature Evolution of two contrasting High-pressure Low - temperature Belts in the Chonos Archipelago, Southern Chile. *Journal of Petrology*, Vol. 41, N.3, 000-000.