Magmatic arc tectonics in northern Chile: implications for coupling and decoupling between plates, the present crustal thickness, and changes in the level of intrusion

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INTRODUCTION

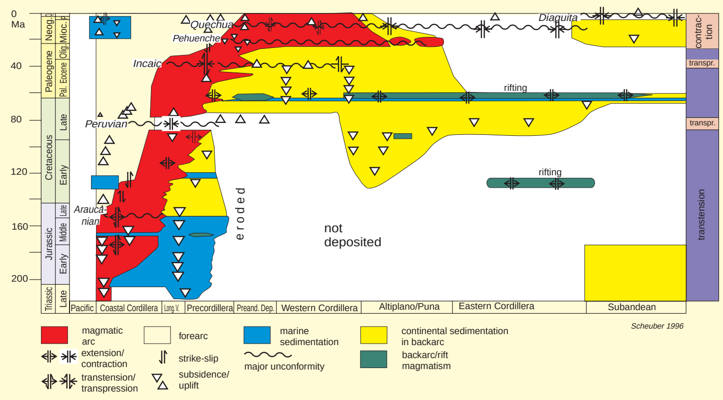
Tectonic studies carried out in the fossil (Jurassic to Paleogene) arcs of northern Chile have important implications for the understanding of the present crustal structures and the deformation processes operating in the crust. Here three major problems of Andean tectonics are addressed:

a) **Upper-plate tectonics and plate convergence**:
Is there a direct kinematic response of upper-plate kinematics on plate convergence?

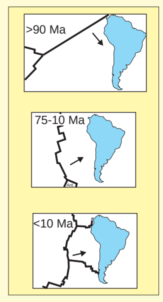
b) **Crustal thickness**:
Is the observed crustal thickness (40-65 km) in the present forearc, which cannot be explained by the Neogene-Quaternary shortening in the backarc, a result of cumulative shortening since the Mesozoic or is it due to other processes as e.g. hydration of the forearc mantle?

c) **Variations in the intrusion level**:
Geophysical data reveal the presence of melts in the present arc at a depth of some 20 km making it a weak zone which is very important for the rheology of the upper plate. Is this melting level constant through time or is it subject to changes which would result in changes in lithospheric strength?

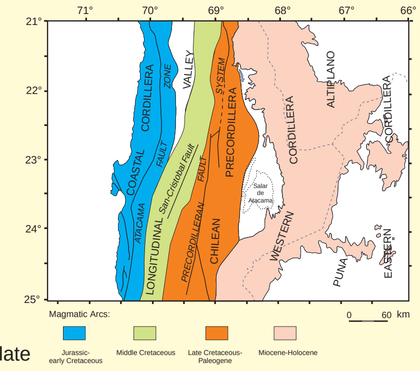
EVOLUTION OF THE CENTRAL ANDES 21-25 °S



Evolution of the Central Andes since 200 Ma in a time/longitude diagram. The magmatic arc migrated ~200 km eastwards since ~140 Ma. In the kinematic regime two major periods can be distinguished: general transtension (200-90 Ma) and alternating transpression and transtension since 90 Ma. The change corresponds to a major plate reorganisation around 90 Ma.



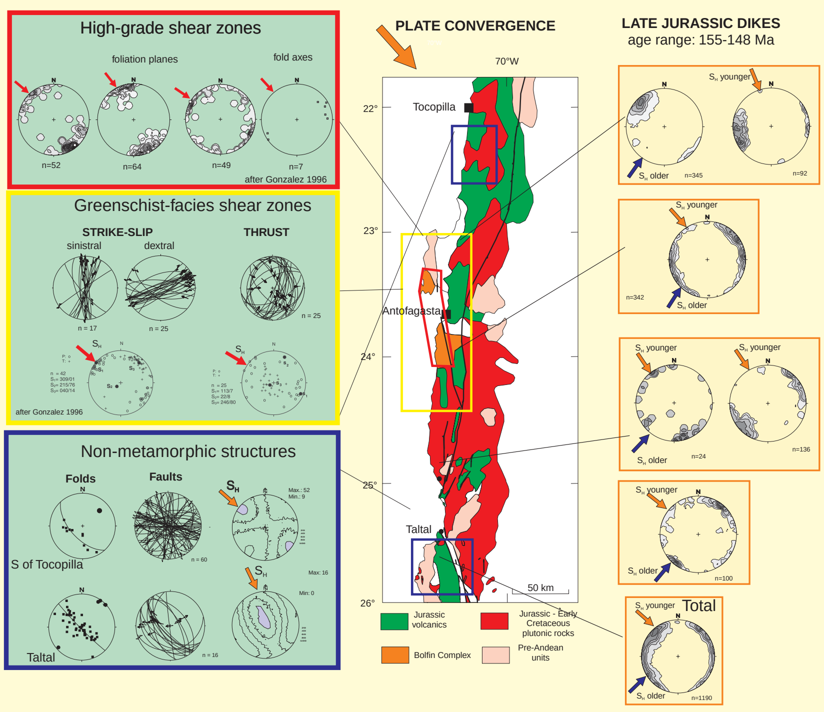
The SE-Pacific plate configurations since the late Jurassic.



The magmatic arcs of the Central Andes since the Jurassic.

Upper-plate tectonics and plate convergence

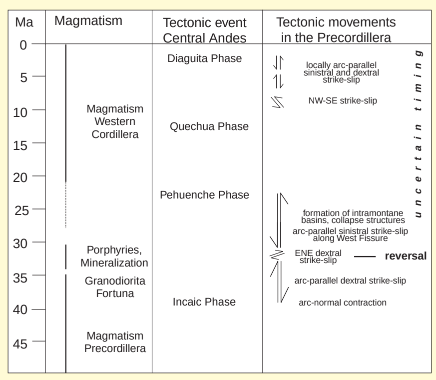
Late Jurassic structures in the Coastal Cordillera



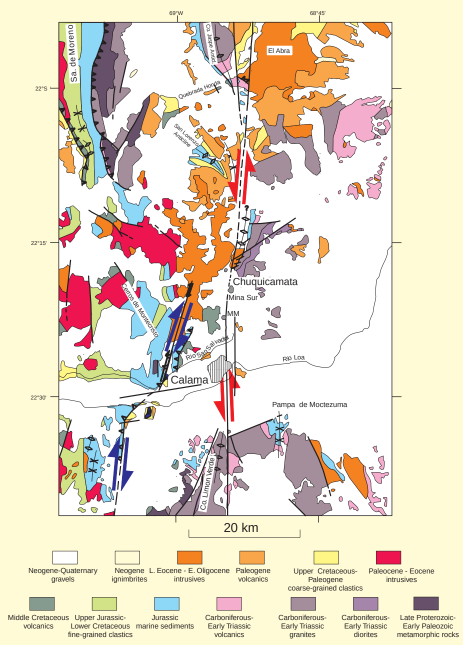
Structures from all exposed crustal levels of the Jurassic arc indicate a NW-SE-direction of shortening and/or S_{Hmax}. Thus, these directions are parallel to the vector of plate convergence. However, late Jurassic mafic dikes show two different directions of S_{Hmax}. An older generation of dikes strikes NE-SW indicating a NE-SW direction of S_{Hmax}. Younger dikes (also late Jurassic) strike NW-SE which agrees with the verctor of plate convergence.

Late Paleogene structures in the Precordillera

During the late Eocene/early Oligocene also reversals occurred along the Precordilleran Fault System. Movements started around 38 Ma with dextral displacements which are synthetical to the convergence obliquity. At ~34 Ma a reversal to sinistral movements took place which were antithetical to plate convergence.

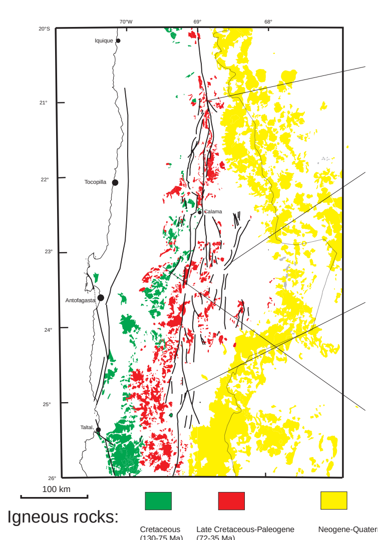


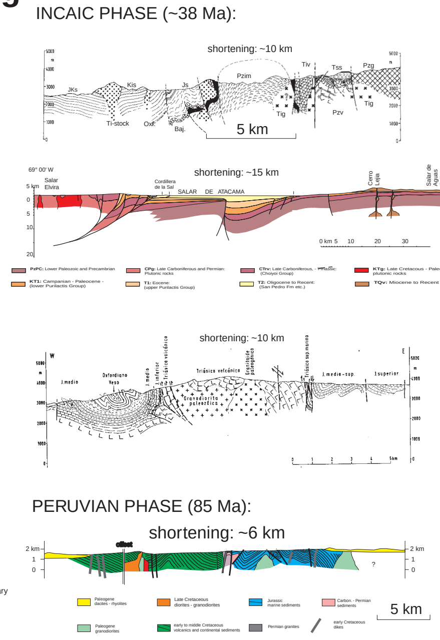
Tectonic scheme of the Precordillera near Chuquicamata.



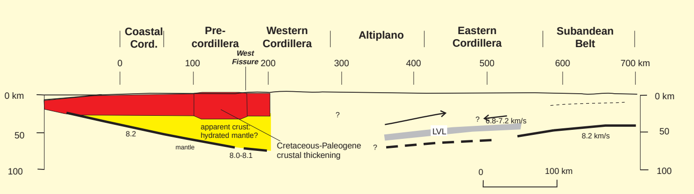
Geological sketch map of the Precordillera around Calama showing the Precordilleran Fault System. Segments showing mainly older dextral displacements are indicated by blue arrows, segments showing younger, sinistral shearing are indicated by red arrows.

Pre-Neogene shortening



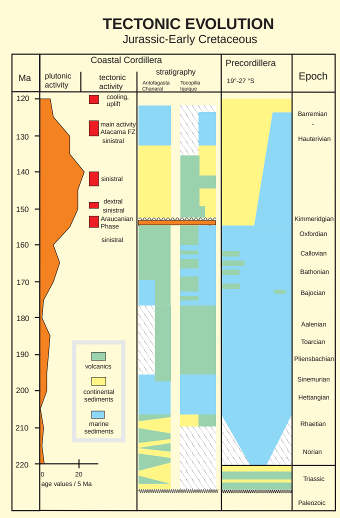


Pre-Neogene shortening events are restricted to the Cretaceous (Peruvian Phase, ~85 Ma) and the Paleogene (Incaic Phase, ~38 Ma). The total shortening amounts to ~ 15-20 km. Thus, there is only limited pre-Neogene crustal thickening.

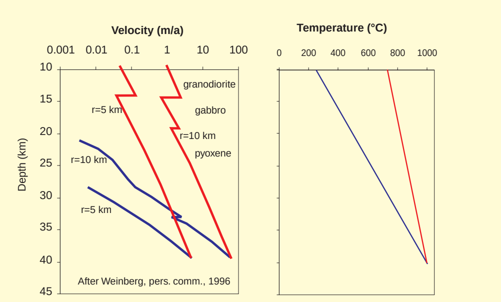


The Pre-Neogene shortening produced a crust that is only slightly thickened. In this figure the pre-Neogene crust (red) is pojected into the refraction seismic profile which shows mantle velocities at a depth of 40-65 km beneath the present forearc (Coastal Cordillera to Precordillera). Low-velocity, apparent crustal material which cannot be explained by pre-Neogene thickening is indicated in yellow. As late Cenozoic shortening in the backarc cannot account for the thick crust in the forearc it is suggested that the material between mantle velocities and the true crust is hydrated mantle material.

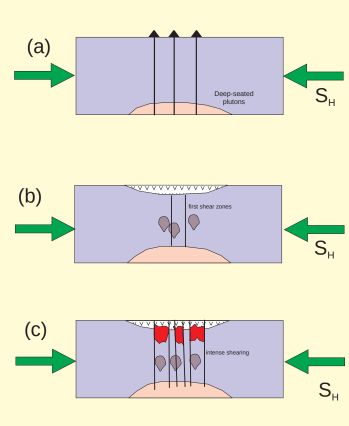
Variations in the intrusion level



The Jurassic-early Cretaceous evolution shows that volcanism clearly dominate over plutonism over most of the lifetime of the magmatic arc (220-160 Ma). Maximum intrusive activity occurred after volcanism had ceased. Most of these plutons were emplaced at shallow crustal levels. The peak in plutonism is accompanied by strong deformations (e.g. Atacama Fault Zone). It is important to note that deformations concentrated on the weak magmatic arc whereas the backarc remained undeformed. (Stratigraphy after v. Hillebrandt et al.)



Rising velocities of magma diapirs (viscous, strain-rate-softening) for two different thermal states of the crust ("hot" crust: red, "cold" crust: blue, temperatures are shown on the right side; velocities are calculated for diapirs with a diameters of 5 and 10 km; the compostion of the crust is indicated by granodiorite, gabbro and pyroxene). In a cold crust (=early stage of the arc) diapirs can rise only to a depth of 30-20 km. By contrast, in the hot crust diapirs can rise to levels <<10 km (Calculations by Roberto Weinberg, pers. comm.1996).



Model of shallowing of the intrusion level

In this model it is suggested that the arc's crust is progresively heated and weakened by a rising of the intrusion level. Heating and weakening leads to deformations in the final stage of an arc - even if the stress level remains constant over the lifetime of the arc (lateral stress indicated by S_H).

Early stage (a): Volcanism dominates over plutonism; volcanoes are fed from magma reservoirs at the base of the crust. The crust is relatively cold and there is little deformation.

Middle stage (b): Volcanism has stopped. Due to heating of the crust the intrusion level has risen to mid-crustal levels. The crust becomes weakened and first shear zones develop.

Late stage (c): The shallowing of the intrusion level leads to further heating of the crust. Magmas rise along fractures to form huge shallow-seated plutons which in turn further weaken the crust; this weakening leads to a catastrophic failure and the observed strong deformations of the magmatic arc.

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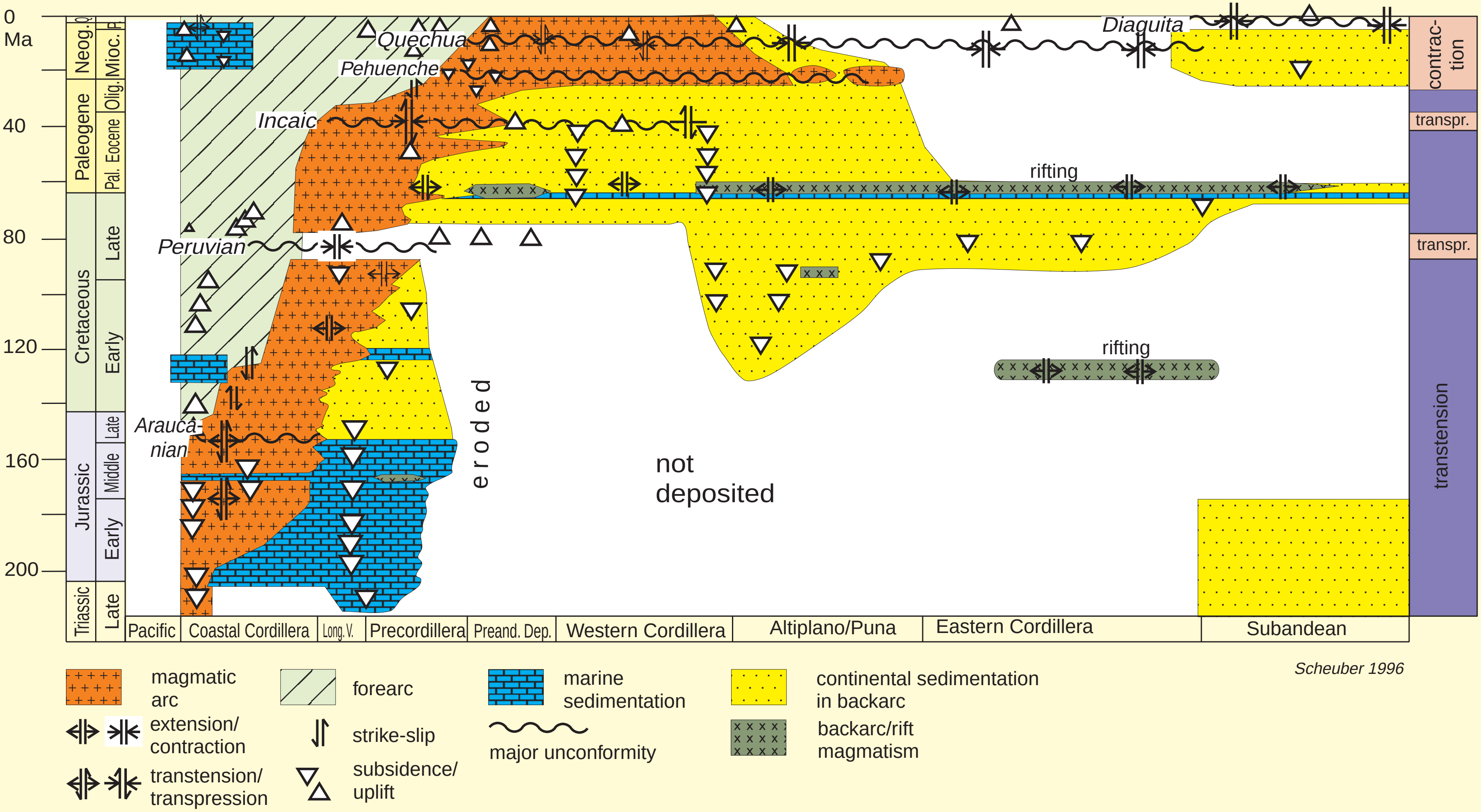

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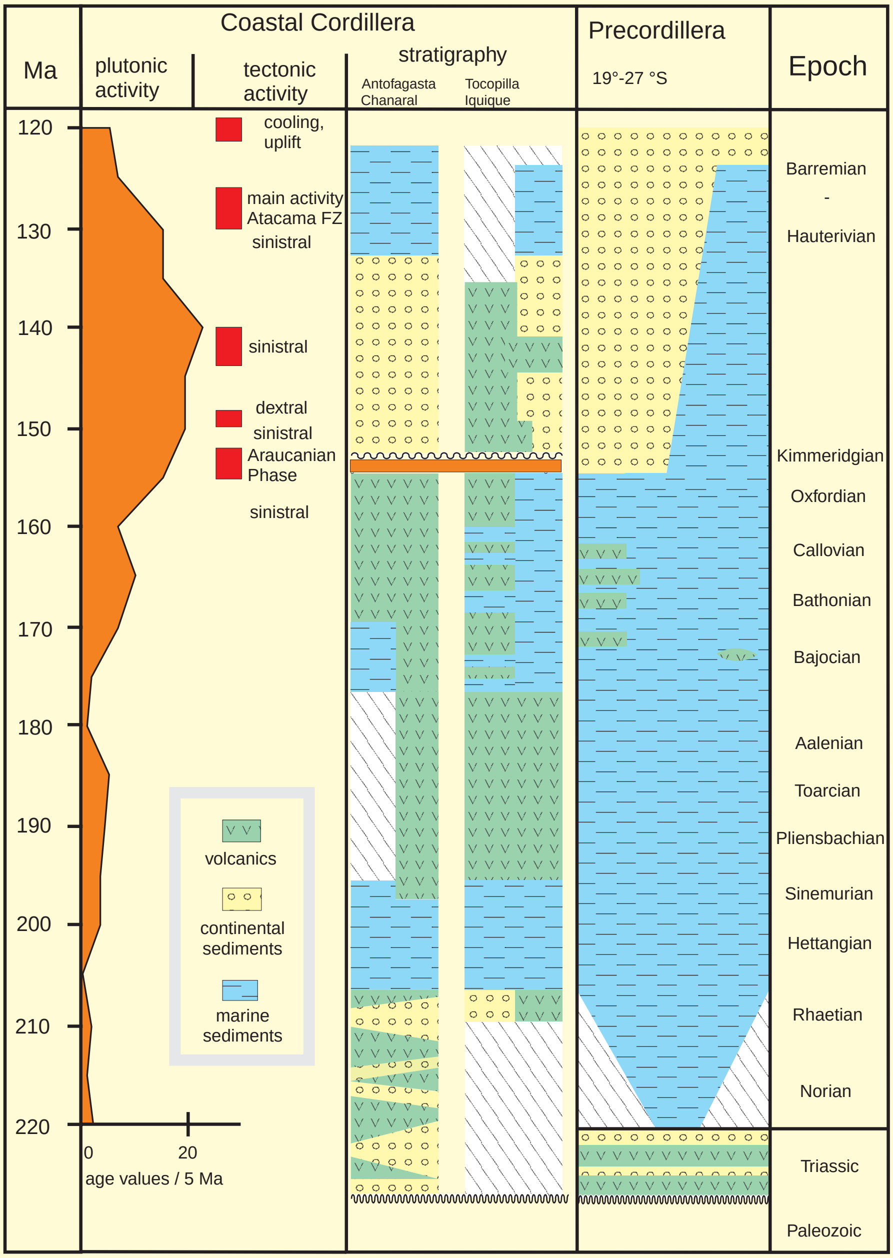
TECTONIC EVOLUTION

Jurassic-Early Cretaceous



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