ALONG-STRIKE SEGMENTATION OF THE ANDEAN FORELAND

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INTRODUCTION

Along most of its 8000 km length, the eastern flank of the Andean orogen is underlain by thrust belts of Tertiary (mostly Neogene) age. Structural styles, however, vary greatly along strike. It has been shown that the segmentation of Andean foreland deformation coincides both with the segmented geometry of the downgoing slab and with stratigraphic and structural inhomogeneities of the upper plate (northern Argentina; Allmendinger et al., 1983; Jordan et al., 1983). Here, we describe the varying styles of foreland deformation along the entire orogen and discuss the relative importance of the different controlling factors proposed.

TYPES OF FORELAND DEFORMATION

Three principal types of foreland deformation can be distinguished: (1) Thin-skinned fold-and-thrust belts with a basal décollement within the sedimentary cover (Fig. 1a). Shortening of the cover in the foreland belt is balanced by extensive overthrusts of basement sheets in the internal zones of the thrust belt. (2) Thick-skinned thrust belts with a décollement at mid-crustal depths. Some of these belts occur at the orogenic front in a position similar to thin-skinned belts (Fig. 1b), but others lie at a large distance from the orogen. (3) Laramide or Pampeanas-type basement thrusts which possibly affect the entire crust (Fig. 1c). The widely spaced thrusts usually occur in irregular, anastomosing patterns.

None of these structural styles are mutually exclusive, and the transitions between them are sometimes gradual (Fig. 2). Areas of thin-skinned thrusting may later become affected by thick-skinned thrusting as a result of the piggy-back propagation of basement-cover thrusts (e.g. Cordillera Oriental of Colombia; Interandean Zone of southern Bolivia; Fig. 1a). The structural style can also switch from thin-skinned to thick-skinned and vice versa in both space and time as deformation propagates cratonward. Deep-seated basement thrusts are the exclusive style of deformation in eastern Colombia and western Venezuela (Sierra Nevada de Santa Marta, Sierra de Perijá, Mérida Andes). In northwestern Argentina, however, the basement thrusts of the Sierras Pampeanas are coeval with thin-skinned thrusting in the Precordillera. Foreland basement thrusts may also pass laterally into basement nappes of the internal belt (Shira uplift and Cordillera Oriental in southern Peru).

FACTORS CONTROLLING STYLE VARIATIONS

Many regional studies suggest that stratigraphy and the pre-Neogene tectonic history of individual areas exert an important control on the development of distinct structural styles. Thin-skinned Fold-and-thrust belts depend on the existence of a more or less undisturbed sedimentary cover at least some 2-3 km thick, and in some cases on a particularly weak basal layer. Many, if not all, basement-involved thrust belts result from the inversion of Mesozoic rift basins (e.g.Colletta et al., 1990; Grier et al., 1991; Salfity et al., 1993; Uliana et al., 1995). The conditions for the development of Pampeanas-type

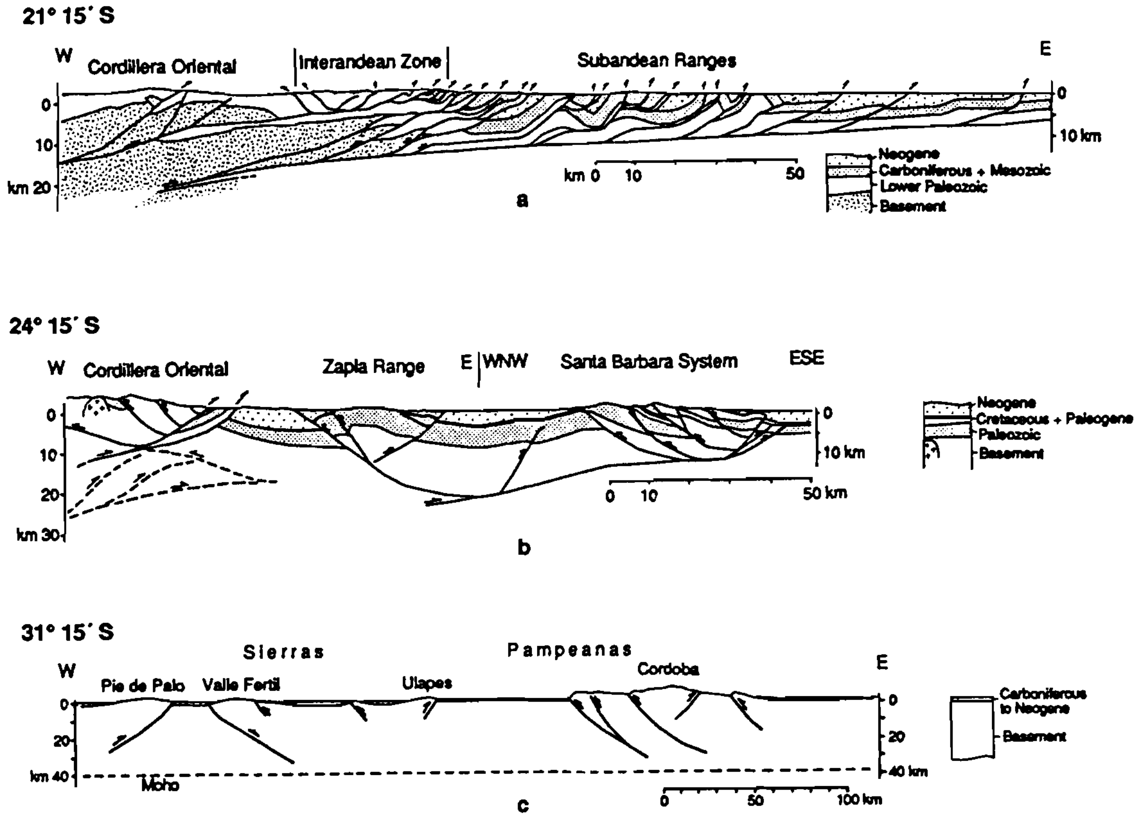

Fig. 1: Examples for the different styles of foreland deformation. Cross-sections are located in Fig. 2.
a) The Subandean Ranges in southern Bolivia, a well-developed thin-skinned thrust belt (structure from Baby et al., 1992, and Dunn et al., 1995, slightly modified). The Interandean Zone is a thin-skinned belt carried piggy-back on younger basement thrusts.
b) Zapla Range and Santa Barbara System of northern Argentina, a thick-skinned thrust belt developed from a Cretaceous rift. Depth to detachment is estimated from cross-section balancing. Deep structure of Cordillera Oriental is hypothetical.
c) The Sierras Pampeanas, Argentina. Names refer to individual ranges. Depth of faulting under Sierra Pie de Palo and Sierra del Valle Fértil from earthquake hypocenters (Jordan & Allmendinger, 1986).

basement thrusts are probably least understood. The boundary of the Sierras Pampeanas with the thick-skinned thrust belt of the Santa Barbara system is transitional. Reactivation of earlier normal faults does play a role in the development of some of the Sierras Pampeanas (Schmidt et al., 1995), but apparently not in all of them.

The correlation of subducted slab geometry and structural style is strongest in the foreland from 20° to 33° S (southern Bolivia and northern Argentina). It is less evident on an orogen-wide scale, where a well-developed thin-skinned belt occurs over a flat slab (Santiago and Huallaga belts of northern and central Peru) and deep-seated basement thrusts occur over a slab which dips at 25-30° at present (eastern Colombia and western Venezuela; Laubscher, 1987; Malavé and Suárez, 1995). If the coincidence of segmentation in the lower plate with an older segmentation of the upper plate in northern Argentina is not merely by chance, then we are forced to conclude that in some way the properties of the upper plate have influenced the development of the flat slab segment between 27° and 33° S. Isacks (1988) pointed out that a stiff upper plate will tend to flatten the slab dip if plate convergence is rapid. North of 22° S, thick Silurian shales unaffected by Cretaceous extension permitted the development of a wide thin-skinned fold-and-thrust belt, with internal basement thrust sheets advancing far over the craton. Farther south,

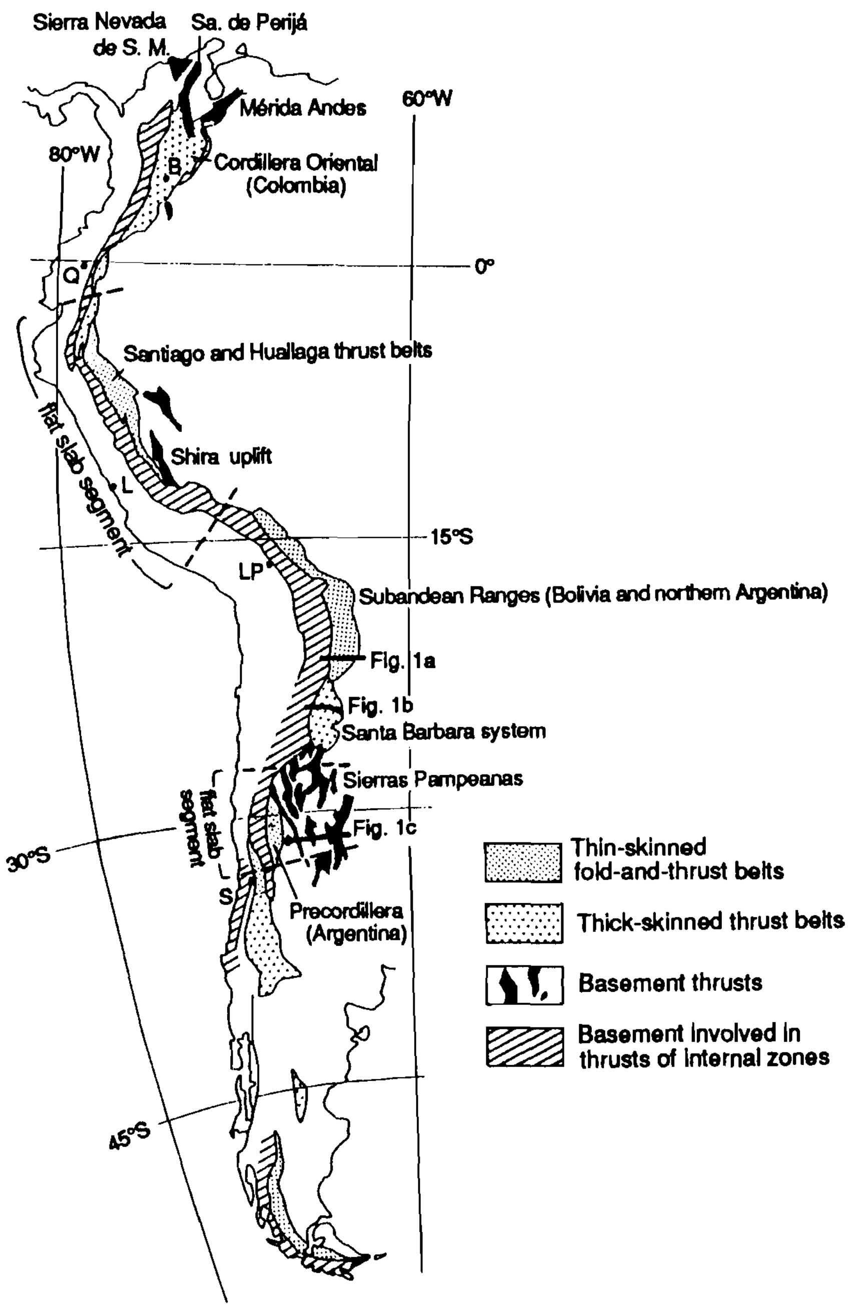

Fig. 2: The distribution of different styles of foreland deformation along the Andes. The extent of flat subducting segments of the Nazca plate is also shown. Only the structural units mentioned in the text are labeled.

where the Andean front impinges on the Cretaceous rift, a thick-skinned foreland belt developed, which eventually grades into the basement thrusts of the Sierras Pampeanas. These changes in structural style reflect an increasingly rigid upper plate, with shortening decreasing southward. The difference in shortening is not sufficient to explain the full downdip extent of the flat slab, but it might represent the trigger for its development.

CONCLUSIONS

Different styles of Andean foreland deformation are characterised by the way basement is involved in thrusting: Basement thrusts with large displacements are typical for the internal zones bordering thin-skinned belts. In thick-skinned thrust belts and provinces of Pampeanas-type basement thrusts, the displacement on individual thrusts usually does not exceed a few kilometers. Apparently, it is the development of a basal décollement in the overlying sedimentary cover that allows large slip to accumulate on a single basement thrust. The frequent link of thick-skinned belts with former rift areas might thus be explained by two factors: First, potential décollement levels can be offset by normal faults, and second, reactivation of earlier normal faults may be easier than the evolution of a new décollement. Outside the rift areas, the lack of a thick sedimentary cover may prompt basement-involved thrusting which possibly affects the entire crust.

REFERENCES

Allmendinger, R.W., Ramos, V.A., Jordan, T.E., Palma, M., and Isacks, B.L., 1983, Paleogeography and Andean Structural Geometry, Northwest Argentina: Tectonics, 2, 1-16.

Baby, P., Herail, G., Salinas, R., and Sempere, T., 1992, Geometry and kinematic evolution of passive roof duplexes deduced from cross section balancing: example from the foreland thrust system of the southern Bolivian Subandean zone: Tectonics, 11, 523-536.

Colletta, B., Hebrard, F., Letouzey, J., Werner, P., and Rudkiewicz, J.L., 1990, Tectonic style and crustal structure of the Eastern Cordillera (Colombia) from a balanced cross-section, in: Letouzey, J., ed., Petroleum and Tectonics in mobile belts: Editions Technip, 81-100, Paris.

Dunn, J.F., Hartshorn, K.G., and Hartshorn, P.W., 1995, Structural Styles and Hydrocarbon Potential of the Subandean Belt of Southern Bolivia, in: Tankard, A.J., Suárez Soruco, R. and Welsink, H.J., eds., Petroleum Basins of South America, AAPG Memoir 62, 523-544.

Grier, M.E., Salfity, J.A., and Allmendinger, R.W., 1991, Andean reactivation of the Cretaceous Salta rift, northwestern Argentina.: Journal of South American Earth Sciences, 4, 351-372.

Isacks, B.L., 1988, Uplift of the Central Andean Plateau and Bending of the Bolivian Orocline: Journal of Geophysical Research, 93, 3211-3231.

Jordan, T., Isacks, B., Allmendinger, R.W., Brewer, J.A., Ramos, V.A., and Ando, C.J., 1983, Andean tectonics related to geometry of subducted Nazca plate: Geological Society of America Bulletin, 94, 341-361.

Jordan, T.E., and Allmendinger, R.W., 1986, The Sierras Pampeanas of Argentina: A modern analogue of Rocky Mountain foreland deformation: American Journal of Science, 286, 737-764.

Laubscher, H.P., 1987, The kinematic puzzle of the Neogene Northern Andes, in: Schaer, J.-P., and Rodgers, J., eds., The Anatomy of Mountain Ranges, Princeton, New Jersey, Princeton University Press, 211-227.

Malavé, G., and Suárez, G., 1995, Intermediate-depth seismicity in northern Colombia and western Venezuela and its relationship to Carribean plate subduction: Tectonics, 14, 617-628.

Salfity, J.A., Monaldi, C.R., Marquillas, R.A., and Gonzáles, R.E., 1993, La inversión tectónica del Umbral de los Gallos en la cuenca del grupo Salta durante la Fase Incáica, XII. Congreso Geologico Argentino y II. Congreso de Exploración de Hidrocarburos, Tomo III: Mendoza, Argentina, 200-210.

Schmidt, C.J., Astini, R.A., Costa, C.H., Gardini, C.E., and Kraemer, P.E., 1995, Cretaceous Rifting, Alluvial Fan Sedimentation, and Neogene Inversion, Southern Sierras Pampeanas, Argentina. in: Tankard, A.J., Suárez Soruco, R. and Welsink, H.J., eds., Petroleum Basins of South America, AAPG Memoir, 62, 341-358.

Uliana, M.A., Arteaga, M.E., Legarreta, L., Cerdán, J.J., and Peroni, G.O., 1995, Inversion structures and hydrocarbon occurrence in Argentina, in: Buchanan, J.G., and Buchanan, P.G., eds., Basin Inversion, Geological Society Special Publication, 88, 211-233.