Thermal modeling of pluton emplacement, a case study: the Kranck Pluton, Fuegian Andes, Argentina

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Resumen: El plutón Kranck (PK) aflora en la margen norte del Lago Fagnano, Tierra del Fuego (Argentina), en la faja plegada y corrida del erógeno fueguino. Está emplazado en la secuencia sedimentaria (dominada por fangolitas) de la Formación Beauvoir (Cretácico inferior). Se trata de un intrusivo epizonal, con una amplia variedad composicional (desde facies ultrabásicas hasta sieníticas). El PK es un cuerpo de pequeñas dimensiones (~ 6 km^3) de forma tabular según surge del modelado magnético 3D. En esta contribución se presentan los resultados de un modelado térmico preliminar que intenta evaluar la evolución del sistema plutón/roca de caja desde el momento de la intrusión magmática hasta alcanzar el equilibrio térmico. En este modelo simple se considera que el emplazamiento es instantáneo y que la transferencia de calor se produce sólo por conducción; se analizan los resultados de este modelo en cuanto al impacto térmico y la posibilidad de generar cambios mineralógicos en la roca hospedante.

Palabras claves: plutón Kranck, modelización térmica, Tierra del Fuego, Argentina

1 Introduction

The Kranck pluton (KP) is a small (<10 km^2), subcircular, epizonal intrusive body exposed at the northern shore of Lago Fagnano, in Sierra de Beauvoir, Tierra del Fuego. The intrusive body is hosted in the pelite/mudstone sequence of the Lower Cretaceous Beauvoir Formation (Fig. 1B).

The KP is located within the Fuegian thin-skinned fold-thrust belt, the intrusive body is flanked by two major structures: a low angle NNE verging thrust (belonging to the main stack of Fuegian Cordillera thrust front at the boundary with the Magellan foreland) in the north, and the eastern tip of the M. Hope-Catamarca-fault segment belonging to the Magallanes-Fagnano Fault System, at the south (Fig. 1B; Menichetti et al., 2008).

Field and magnetic fabric data indicate concordant foliations within the pluton and its country rocks (Cerredo et al., 2010). The KP displays a large compositional span, from monzogabbro to syenite, of metaluminous, shoshonitic nature, as typical in other Fuegian plutons (Cerredo et al. 2005; Peroni et al. 2009). The KP encompasses minor cumular ultrabasic facies, gabbros, monzodiorite and monzonite facies and late stage syenite veins and dykes. Monzodiorite facies is generally heterogeneous, bearing mafic microgranular enclaves (MMEs) several cm to dm in size, either with typical crenated outlines or as diffuse ghosts parallel to magmatic banding. Some MMEs show clear textural features of undercooling suggesting a scenario of sudden mixing of magmatic liquids of contrasting temperatures which points to several injection episodes in the assembly of KP.

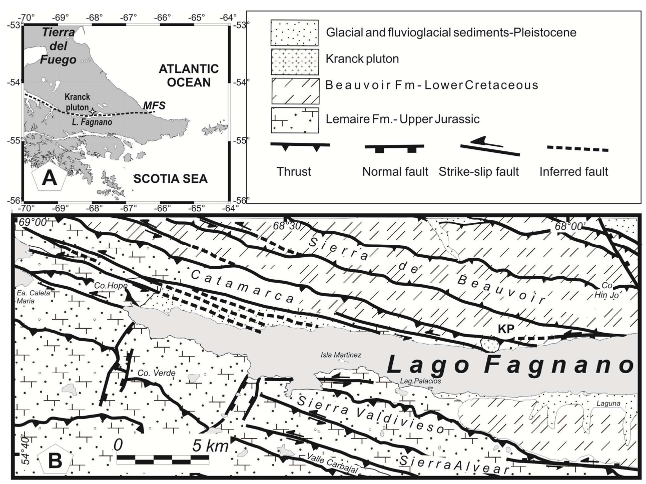

Figure 1. A) General map showing the tract of Magallanes-Fagnano Fault System (MFS) in central Tierra del Fuego; star indicates the Kranck pluton location. B) Geological sketch depicting the main structures and units in the area of Kranck Pluton (KP) within the fold-and-thrust Fuegian belt, overprinted by strike-slip structures.

Deformation/crystallization relationships indicate a dynamic scenario for the emplacement and cooling evolution; syn-magmatic foliations were recognized both at the meso- and microscales; not penetrative *subsolidus* medium- T microstructures parallel the submagmatic ones and both are variably overprinted by brittle deformation. A pilot AMS survey on KP suggests a probable layered nature for the central part of the intrusion (Cerredo et al., 2010).

Although the KP outcrops are restricted and largely covered by forest, we could decipher its 3D size and shape on magnetic modeling grounds. Within the frame of a project directed to geophysical modeling of plutons (e.g. Tassone et al., 2005) the KP was modeled. Aeromagnetic surveys have revealed an outstanding anomaly with a subcircular pattern and average diameter of around 6 km associated with KP oucrops (Peroni et al., 2007; Vilas et al., 2007). The modeling of the aeromagnetic anomaly yielded a thin sheet body (Peroni et al., 2008a and b).

2 Thermal modeling

Thermal modeling, following the observed geological features and with reasonable assumptions magma and country rock properties, helps to understand the geologic history of intrusive–country rock system and has to be used only as an approximation to the real behavior of the system. The conductive cooling model used here only applies to static, or motionless, magma bodies and do not consider heat transfer facilitated by fluid circulation. Nevertheless, it is useful as a preliminary scenario against which to evaluate thermal histories of more dynamic advective and convective systems where movement of liquids facilitates heat transfer. The cooling model attempts to estimate the highest temperature reached in the country rock at the emplacement depth.

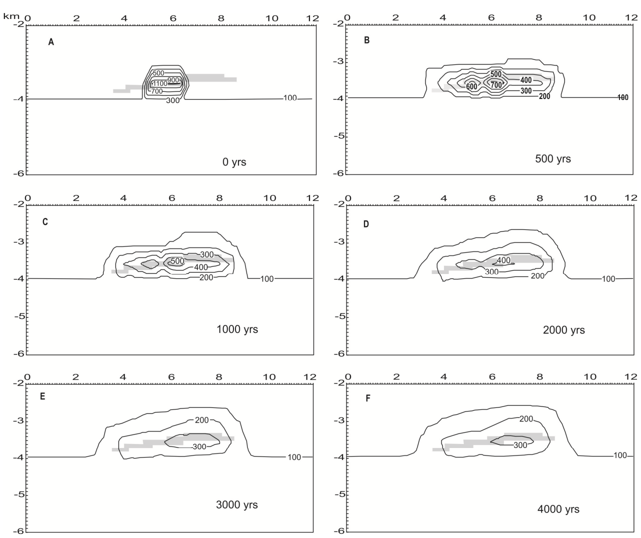

Figure 2. Thermal modeling results for different time stages displayed in S-N sections. The grey area in the figures represents the intrusive.

The initial conditions for the model are: magma temperature 1100 ºC (assuming the whole pluton emplaced instantaneously and had an intermediate composition), depth of magma emplacement 1 Kbar (based on published stratigraphic and tectonic data). The assumed pluton size and geometry are those provided by magnetic modeling (Peroni et al., 2007, 2008 a and b) which yielded a tabular, high aspect ratio 3D shape (~ 0.4 km thick, oval in plan view, ~ 2.5 km in E-W and ~ 5 km in N-S directions). It was assumed a surface temperature of 20ºC and a geothermal gradient of 20º C/km.

Figure 2 illustrates model states after the intrusion; in the initial stage, the magma is at an initial temperature of 1100ºC which just after the emplacement suddenly drops in contact with the host introducing an enormous thermal impact. The major part of the modeled pluton is below its *solidus* (Fig. 2A). At 0.5 x 10^3 years after intrusion (Fig. 2B), the temperature within the magma body had mostly decreased to less than 600 ºC and liquid crystallization had completed. By this time, thermal evolution in the country rock shows an anomalous high temperature geotherm. The temperature of the host increased up to *ca*. 400 ºC below the intrusive body along a belt ~ 150 m thick, whereas in the upper thermal aureole, host rocks mostly lie within 200-400 ºC. The thermal disturbance introduced by magma emplacement ceases by around 2000 years after the intrusion when the 400º C isotherm lies entirely within the cooling magma body (Fig. 2D). In the subsequent 3 x 10^3 and 4 x 10^3 years after the intrusion, the temperature profile in the country rock shows rapid relaxation of isotherms; at 4000 years maximum temperatures within the lower thermal aureole had dropped to 300º C in a narrow and localized belt of less than 150 m (Fig. 2F).

Model predicts that, at a depth of 3.5 km, temperatures above 400 ºC that could produce a metamorphic contact aureole in the country rock are only reached in a narrow zone of less than 200 m around the lower pluton/country rock contact and that the peak temperature is reached soon after the intrusion (at 0.5 x 10^4 years after the intrusion, see Fig. 2B). These peak T-conditions are maintained during less than 2000 years.

3 Discussion

The obtained results of the simple conductive model show that the thermal impact in the country rocks by the KP emplacement is extremely short-lived. The thermal model for the pluton-host rock system displays an asymmetric distribution of isotherms within the aureole and some diachronism in peak-T conditions (especially observable between the lower and upper aureoles, Fig. 2B, C, D).

Although the model considered an instantaneously emplaced magma body, we are aware that pluton construction likely occurred incrementally. Nevertheless, plutons with the volume of the KP (~ 6 km^3 as indicated by magnetic modeling) would assemble in a time-span ranging from 100 to 8000 years (de Saint Blanquat et al., 2011) which may be considered as instantaneous for geologic timescales.

This purely conductive model also ignores the possible occurrence of magma convection within the intrusion and of hydrothermal circulation within the country rock. If both processes were considered, cooling of the intrusion would be much faster. Therefore, we think that the heat conductive model here presented likely represents the scenario of maximum thermal perturbation produced by the KP in the host rocks. In this connection, the short-lived thermal anomalies > 400º C (< 2000 years) impede by kinetic factors the development of index mineral assemblages within the country rocks. The results of this preliminary model agree with the absence of petrographycally recognizable contact associations.

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References

Cerredo, M.E., Remesal, M.B., Tassone, A., Lippai, H. 2005. The shoshonitic suite of Hewhoepen pluton, Tierra del Fuego, Argentina. *In*: Congreso Geológico Argentino, Nº 16, Actas I: 539-544, La Plata

Cerredo, M.E., Remesal, M. B., Tassone, A. A., Peroni, J. I., Menichetti, M., Lippai, H. 2010. Magmatic activity and strike slip tectonics in the southernmost Andes: Kranck pluton, characterization and preliminary AMS survey. Bollettino di Geofisica Teorica ed Applicatta., Special Issue (Geosur), 51: 65-67

de Saint Blanquat, M., Horsman, E., Habert, G., Morgan, S., Vanderhaeghe, O., Law, R., Tikoff, B. 2011. Multiscale magmatic cyclicity, duration of pluton construction, and the paradoxical relationship between tectonism and plutonism in continental arcs. Tectonophysics 500: 20–33

Menichetti, M., Lodolo, E., Tassone, A. 2008. Structural geology of the Fuegian Andes and Magallanes fold and thrust belt: a reappraisal. GeoSur Special Issue. Geologica Acta. 6 (1): 19-42.

Peroni, J. I.; Tassone, A.; Lippai, H.; Menichetti, M.; Lodolo, E.; Vilas, J. F. 2007. Geophysical modeling of the Kranck pluton. Tierra del Fuego. Argentina. *In*: International Geological Congress on the Southern Hemisfere (Geosur 2). Libro de Resúmenes: 122, Santiago. Chile

Peroni, J. I.; Tassone, A.; Lippai, H.; Menichetti, M.; Lodolo, E.; Vilas, J. F. 2008. Estudio geofísico del pluton Kranck. Tierra del Fuego. *In*: Congreso Geológico Argentino, Nº 17, Actas; 1107. Jujuy, Argentina

Peroni, J.; Tassone, A.; Menichetti, M; Lippai, H.; Lodolo, E.; Vilas, J.F. 2008b. Geologia e geofisica del plutone Kranck. Rendiconti della Societá Geologica Italiana, Nuova Serie 1: 132-136

Peroni, J: I.; Tassone; A. A., Menichetti,M., Cerredo, M. E. 2009. Geophysical modeling and structure of Ushuaia Pluton, Fuegian Andes, Argentina. Tectonophysics, 476 (3-4), 25:436-449

Tassone, A. A, Lippai, H., Lodolo, E, Menichetti, M., Comba, A, Hormaechea, J.L., Vilas, J.F. 2005. A geological and geophysical crustal section across the Magallanes–Fagnano fault in Tierra del Fuego. Journal of South American Earth Sciences 19: 99–109

Vilas, J.F., Tassone, A.; Peroni, J. I.; Lippai, H.; Menichetti, M., Lodolo, E. 2007. Geophysical survey of the Fagnano pluton. Tierra del Fuego. Argentina. International Union of Geodesy and Geophysics (IUGG).. IAGA, ASI002: 2518. Perugia. Italia