From pluton intrusion to its exhumation: a case study from Barnard Point Batholith, Livingston Island, South Shetland Archipelago, Antarctica

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Abstract. Three samples from the main phase of the Barnard Point Batholith of granodiorite from the sea level up to 463 m of Mac Kay Peak – are analyzed. The U-Pb zircon geochronology reveals magmatic crystallization at 43.89±0.32 Ma. The Ca-amphibole thermobarometry shows a shallow crustal level emplacement (5–3.5 km and temperatures of 810–750 °C). Two main episodes that correspond to the uplift of the Tangra Mountain and exhumation of the batholith are distinguished using apatite fission-track analysis. The models reveal initial very rapid cooling to ~ 80–90 °C between 40 and 33 Ma and a second episode of uplift and moderate cooling to surface temperatures between 22 and 15 Ma. The obtained positive age-altitude correlation suggests moderate exhumation rate of 340 m/ Ma. The thermal modelling of the hypsometrically lowest sample reveals a later moderate cooling event to surface temperatures from 8 Ma to recent times, which corresponds to the Bransfield Rift initiation.

Keywords: Barnard Point Batholith, geochronology, fission-track dating, exhumation, Livingston, Antarctica.

Introduction and regional geological setting

The Lower Cretaceous to Miocene South Shetlands Islands volcanic arc is a result of the subduction of the Phoenix oceanic microplate (part of the Pacific plate) beneath the Antarctic Peninsula (e.g. Smellie et al., 1984; Kamenov, 2015; Bastías et al., 2023 and references therein). A general trend of rejuvenation of the magmatic activity on Livingston Island from the Early Cretaceous to present times is characteristic in the direction of the thrust plate from WNW to ESE. This could be explained as an effect of a flattening subduction that was active from the Early Cretaceous (135 Ma) to about 90–70 Ma. The
mixed ages of the dikes and the small intrusions in Hurd Peninsula are most probably a result of periods of rotation and probably beginning of a slab rollback. A regional Paleocene–Eocene (65–47 Ma) compressional episode that caused low temperature to high-pressure metamorphism (e.g. Trouw et al., 1998 and references therein) is registered for Smith and Elephant Islands. The regional metamorphism was followed by a vast extension between 50–30 Ma that culminated with the opening of the Drake Passage around 34–30 Ma (e.g. Livermore et al., 2005). The magmatic response of that regional scale extension was the intrusion of the Eocene Barnard Point Pluton (46–40 Ma) and dykes with youngest ages of ca. 30 Ma. The last magmatic event on the island is the intrusion of the contrastingly different in composition Quaternary alkaline mafic rocks (e.g. Kamenov, 2015 and references therein) related to the rifting along the Bransfield Strait.

Geology of the Barnard Point Pluton and aims of study

Barnard Point is situated at the south-eastern coast of the entrance of False Bay, where Eocene plutonic bodies are exposed and represented by the Barnard Point Batholith (Smellie et al., 1984; Willan, Kelly, 1999; Kamenov, 2015; Velev et al., 2022). The batholith comprises most of the Tangra Mountain ridge and consists of gabbro, pegmatoid gabbro, intruded by granodiorite with mafic mingling enclaves and dikes but is also cut by later mafic dikes (Willan, Kelly, 1999). The geochronological ages of the granodiorite obtained by Rb-Sr (Smellie et al., 1984) and K-Ar methods (Willan, Kelly, 1999) are in the interval 46–40 Ma. The pluton is cut by mafic to intermediate in composition dikes at 35–29 Ma (Willan, Kelly, 1999). The apatite fission-track (FT) low-temperature thermochronology of rocks from Livingston Island (Sell et al., 2004 and references therein) suggests that the metasediments from the Miers Bluff Formation (Hurd Peninsula) cooled during the Oligocene to Miocene (~30–17 Ma) and the Barnard Point Pluton – from the early to middle Miocene (22–16 Ma).

In order to reconstruct the geochronological history in terms of the pluton intrusion (using U-Pb zircon dating) to its later low temperature history (FT apatite analysis) related to the exhumation and uplift of Tangra Mountain, we have studied the petrology and geothermobarometry of the main phase (granodiorite) of the Barnard Point Batholith.

Sample strategy and analytical methods

Three samples of granodiorite were collected from the foot (Zagore Beach of False Bay) to 463 m of Mac Kay Peak (Fig. 1a). The section is lithologically homogeneous, not interrupted by faults. The chemical compositions of the minerals were analyzed at the Earth Institute of the Slovak Academy of Sciences, Banská Bystrica, Slovakia, using a JEOL JXA 8530F field-emission electron-microprobe in WDS. The U-Pb geochronology is obtained by LA-ICPMS at ETH Zurich. The LA-ICP-MS fission-track apatite analyses were carried out in the Low-Temperature Thermochronology Laboratory in Bulgaria.

Petrology and P-T conditions

The granodiorites (Fig. 1b) of the Barnard Point Batholith are medium to coarse-grained, with primary minerals of plagioclase (bytownite to oligoclase), K-feldspar, quartz and the mafics are biotite, amphibole – magnesiohornblende (Fig. 1c) and rarely clinopyroxene. Accessories areapatite and zircon. Both ilmenite and magnetite are observed as inclusions in the plagioclase and amphibole respectively, which is most probably due to changing oxidation conditions. Occasional reverse zoning after a sieve periphery is observed in the plagioclases (Fig. 1d), which corresponds to the mingling of mafic enclaves in the granodiorites. Analyzing the Ca-amphiboles gives an opportunity for modelling the thermo-barometric conditions of crystallization (Fig. 1e). The most reliable models are obtained using the equations of Ridolfi and Renzulli (2012; eq. 3: 130–500 Mpa), which shows good correlation. The P-T recalculations show shallow levels of crystallization (5–3.5 km) and temperatures of 810–750 °C.

U-Pb zircon geochronology and low-temperature thermochronology

Twenty-nine in-situ analyses of zircons are made. The crystals are medium to long prismatic with oscillatory and sector zoning (Fig. 1f), with Th/U ratio from 0.6 to 1.1. Most of the analyses are concordant and the magmatic crystallization age is calculated at 43.89±0.32 Ma (Fig. 1g).

The three samples yield the following apatite fission-track ages (Fig. 1h, i): 33.6±1.8 Ma (BP-FT-1, the hypsometrically highest sample), 33.2±1.9 Ma (BP-FT-2) and 32.3±2.2 (BP-FT-3 being the hypsometrically lowest sample). Between 15 and 24 single apatite grains were used for the age calculation. All samples pass the Chi-square (χ2) test. For each sample between 21 and 50 horizontal confined track lengths and corresponding C-axes angles were measured. The reported below confined mean track lengths represent un-projected onto c-axis values. The confined mean tracks lengths are between
Fig. 1. Petrology, geochronology and exhumation of the Barnard Point Batholith: a, samples along the section of the Mac Kay Peak; b, granodiorite with mafic mingling enclaves; c, microphotograph (cross-polarized light) of plagioclase (Pl), amphibole (Amph) and quartz (Qz); d, reversely zoned plagioclase with sieve periphery, indicating mixing; e, amphibole classification and thermobarometric conditions of crystallization; f, CL zircon images; g, Concordia diagram showing magmatic age of zircon crystallization; h, i, age-altitude diagram of the apatite FT ages (with 1σ errors). Thermal models of the samples BP-FT-1 and BP-FT-2 using HeFTy software with acceptable (green) and good (purple) time-temperature pathway envelopes. The black lines represent the best-fit paths. Time-temperature constraints are given with blue boxes. MTL: mean track length; GOF: goodness of fit value.
is supported by the apatite FT models obtained by Sell et al. (2004) which are made to the SE of the Charity Glacier. The obtained positive age-altitude correlation suggests a moderate exhumation rate of 340 m/Ma. The latest cooling event suggested by the thermal modelling from 8 Ma to the recent times is considered as poorly constrained out of the applicability temperature limit of the method. However, it perfectly coincides with the initiation of the Bransfield Rift.

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References