COOLING OF GRANITIC ROCKS IN THE PALU REGION, MIDDLE SULAWESI: ZIRCON AND APATITE FISSION TRACK CONSTRAINTS

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Abstract

Zircon and apatite fission track analysis has been employed to constrain a cooling episode of the Oligocene-Miocene granitic sequences in the Palu region, Middle Sulawesi. A fission track dating from five outcrops resulted in zircon ages ranging between 9.5 ± 0.5 Ma and 29.5 ± 2.1 Ma. These ages may represent the onset of crystallisation during magmatic emplacement. This interpretation is consistent with the corresponding K/Ar ages ranging between 8.6 Ma for biotite and 31 Ma for feldspar. All but one sample show apatite fission track ages younger than zircon ages. The apatite fission track ages range between 6.2 ± 1.3 Ma and 29.3 ± 2.5 Ma. Importantly, the oldest zircon and apatite crystals separated from the rock sample derived from pluton in the southern section suggest that the host sequence has not undergone a further cooling event since crystallisation in the Oligocene. However, the remaining apatite fission track ages from rock successions in the northern sector of the studied region reveal an episode of post-crystallisation rapid cooling of the Oligocene granitic pluton, possibly due to local-scale uplift in response to overthrust in the late Miocene.

Keywords: cooling, fission track, granitic pluton, Sulawesi

Abstrak

Analisis jejak belah pada zirkon dan apatit telah digunakan untuk mengungkapkan episode pendinginan sikuen granit berumur Oligosen-Miosen di daerah Palu, Sulawesi Tengah. Pentarikhan jejak belah dari percontoh singkapan batuan menghasilkan umur jejak belah zirkon antara 9.5 ± 0.5 juta tahun dan 29.5 ± 2.1 juta tahun. Umur tersebut menunjukkan fase kristalisasi selama penerobosan magma. Interpretasi ini selaras dengan umur K/Ar yang berkisar antara 8.6 juta tahun untuk biotit dan 31 juta tahun untuk feldspar. Keseluruhan, kecuali satu percontoh umur jejak belah apatit terlihat lebih muda dari umur zirkon. Umur jejak belah apatit berkisar antara 6.2 ± 1.3 juta tahun dan 29.3 ± 2.5 juta tahun. Umur tertua dari kristal zirkon dan apatit yang dipisahkan dari percontoh batuan pluton di bagian selatan mengindikasikan batuan induk belum mengalami pendinginan lebih lanjut semenjak kristalisasi pada Oligosen. Sebaliknya, umur jejak belah apatit dari percontoh yang berasal dari rumpunan batuan di sektor utara dari daerah studi memperlihatkan episode pendinginan cepat pasca kristalisasi batuan pluton granit Oligosen, kemungkinan disebabkan oleh pengangkatan lokal akibat overthrust pada Miosen Akhir.

Kata kunci: pendinginan, jejak belah, pluton granit, Sulawesi

Introduction

The present fission track study aims at constraining a cooling event of plutonic rocks in the Palu region. The application of fission track analysis is based on the idea that the number of spontaneous tracks preserved within a mineral grain relies on the thermal history of the host mineral since the time at which each track formed (Green *et al.,* 1989). At a given temperature level, fission tracks within a mineral grain are unstable, hence they start to be repaired or annealed.

The annealing temperature of zircon fission tracks is poorly constrained. Hurford (1986) suggested fission tracks within zircon may anneal when they are exposed to elevated paleotemperatures between ~175°-250°C. This temperature range is referred

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to as a closure temperature zone. However, the more recent studies reported higher closure temperatures of ~210°-320°C for geological heating times of the order of 107 years (Tagami *et al.,* 1998). Such a temperature range is significant to define an episode of cooling after magmatism or metamorphism, thus reveals a tectonic event at the time as suggested by the zircon fission track (ZFT) age.

In contrast to the zircon annealing temperature, the zone of apatite fission track (AFT) stability is better contrained, especially at temperatures below ~110°C (Gleadow *et al.*, 1986; Green et al., 1989). An upper zone of minimal annealing occurs at low temperatures (≤60°C) close to the surface. In this zone the apparent fission track ages essentially reflect the provenance ages of the detrital grains, which can sometimes closely approximate the depositional age of the samples. At higher temperatures between ~60° and ~110°C, the apparent fission track ages decrease and may become younger than the original depositional ages. This temperature range is referred to as the partial annealing zone (PAZ). At even higher temperatures (>110°C), the tracks in apatite will quickly be totally annealed, resulting in a zero age for the grains, and the system is being reset.

This study has analysed a total of five samples collected from the outcropping intrusive body (Fig. 1) by employing the external detector method (EDM) as suggested by Gleadow (1981). The quality of zircon and apatite yields varied between samples. In interpretaion of thermochronology of rock sequence, the fission track ages of the analysed samples have been utilised to determine the time of cooling event either during or post-emplacement of granitic magmas to the surface. Additionally, the available K/Ar ages from the studied sequence are also used to constrained the time of rock formation.

Method

Sample preparation and fission track counting were carried out in the fission track laboratory of Geology Agency in Bandung. Zircon and apatite crystals were separated from rock samples by using Frantz magnetic separator and heavy liquid bromoform (s.g. 2.88). Dating of fission tracks are undertaken using a high-powered microscope (mag.1250x). Fission track dating has employed an external detector method (EDM), following a standar procedure as suggested by Gleadow (1981). In the EDM the mineral aliquot containing spontaneous fission tracks is covered by a low uranium mica (Brazil Ruby), which records the induced fission tracks during irradiation. Spontaneous tracks are counted over the same area as induced tracks, hence mineral aliquot and external mica have to align in a mirror image.

A Brief Overview of Geology

The stratigraphy of the studied region has been presented by Sukamto (1973). The region consists of several units, from the oldest to youngest successions: metamorphic rock complex, Tinombo Formation, intrusive rocks, and mollase sequence. This section may not discuss in details the stratigraphy of the region. Instead, description of plutonic rocks from which the rock samples were collected is presented here.

The intrusive complexes consist mainly of granodiorite, diorite, andesite, and basalt. These rocks, especially small-sized plutons appear to have intruded Tinombo Formation and are underlain by mollase successions. Results of K/Ar dating using feldspar and biotite minerals reveal ages for granodiorite rocks of about 31 Ma and 8.6 Ma (Sukamto, 1973). However, the field observation and petrographic analysis show that the plutonic sequences comprise three different rock types, i.e. granodiorite, biotite granite, and granite phorphyry. Those are exposed principally in the Buluri, Uwentira, and Labean region (Fig. 2 – Geological map of the study area).

Fresh and massive outcrops of granodiorite are exposed at the slope of Gawalis hill around the Buluri village. The rock consists mainly of quartz, orthoclase, plagioclase, biotite, hornblende, and ore minerals. These crystals vary from 0.5-2.0 mm in size. It also composes other minor minerals such as apatite, zircon, and sphene, as well as some alteration minerals including chlorite, sericite, and epidote. Importantly, the rock sequence seems to have undergone tectonic disturbance as indicated by the bended edge of most crystals. In contrast, granite phorphyry found in the Labean region appeared to have been weathered significantly, and it was difficult to find fresh outcrops in the field. The thin section of granite phorphyry displays plagioclase phenocryst of 2.0-8.0 cm in size. This rock consists of quartz, plagioclase, orthoclase, biotite, hornblende, carbonaceous minerals, and

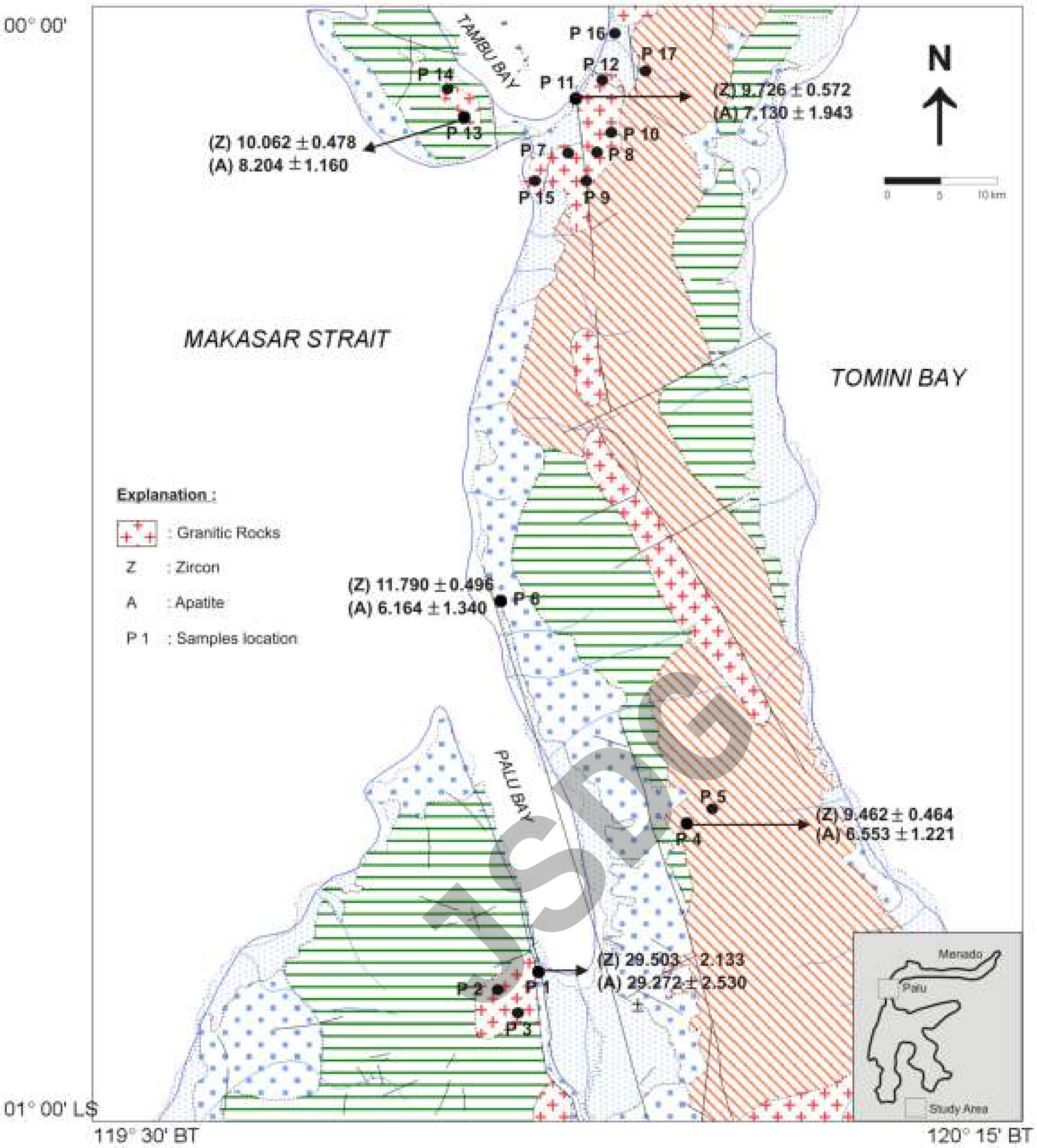

Figure 1. Location map of rock samples

minor apatite and zircon. Plagioclase phenocrysts are about 0.1-4.5 mm in size. Biotite granites in the Uwentira and Enu villages are weathered, and have irregular quartz veins.

Experimental Results

Details for each sample are presented in Table 1, whereas analytical results from the sampled succession are shown in Table 2. Five ZFT ages from the outcropping granitic pluton range between 9.5 ± 0.5 Ma and 29.5 ± 2.1 Ma. The oldest and youngest ZFT ages dated from samples P1 and P4 respectively appear to be identical with K/Ar feldspar and biotite ages reported by Sukamto (1973). Five AFT ages from the analysed samples range from 6.2 ± 1.3 Ma and 29.3 ± 2.5 Ma. All but one sample P1 have the AFT ages younger than the ZFT ages. The ZFT and AFT ages of sample P1 are identical, and again within error consistent with the corresponding K/Ar age.

Table 1. Sample details, zircon and apatite yields of rocks collected from the Palu region.

Sample Number	Longitude (°E)	Latitude (°S)	Elevation (m)	Rock Type	Stratigraphic Age	Zircon Yields	Apatite Yields
P1	119° 49’	0° 52’	200	Granodiorite	Miosen	Poor	Good
P4	119° 57’	0° 44’	500	Biotite granite	Miosen	Fair	Good
P6	119° 47’	0° 32’	50	Granite	Miosen	Good	Fair
P11	119° 51’	0° 05’	250	Granite porphyry	Miosen	Poor	Poor
P13	119° 45’	0° 06’	500	Granite porphyry	Miosen	Poor	Very Good

The yields based on quantity of crystals suitable for fission track age calculation. Excellent > 20 crystals, Very Good ~ 20 crystals, Good 15-19 crystals, Fair 10-14 crystals, Poor 5-9 crystals (Gleadow (1981). Original samples weighed approximately 0.5-1 kg.

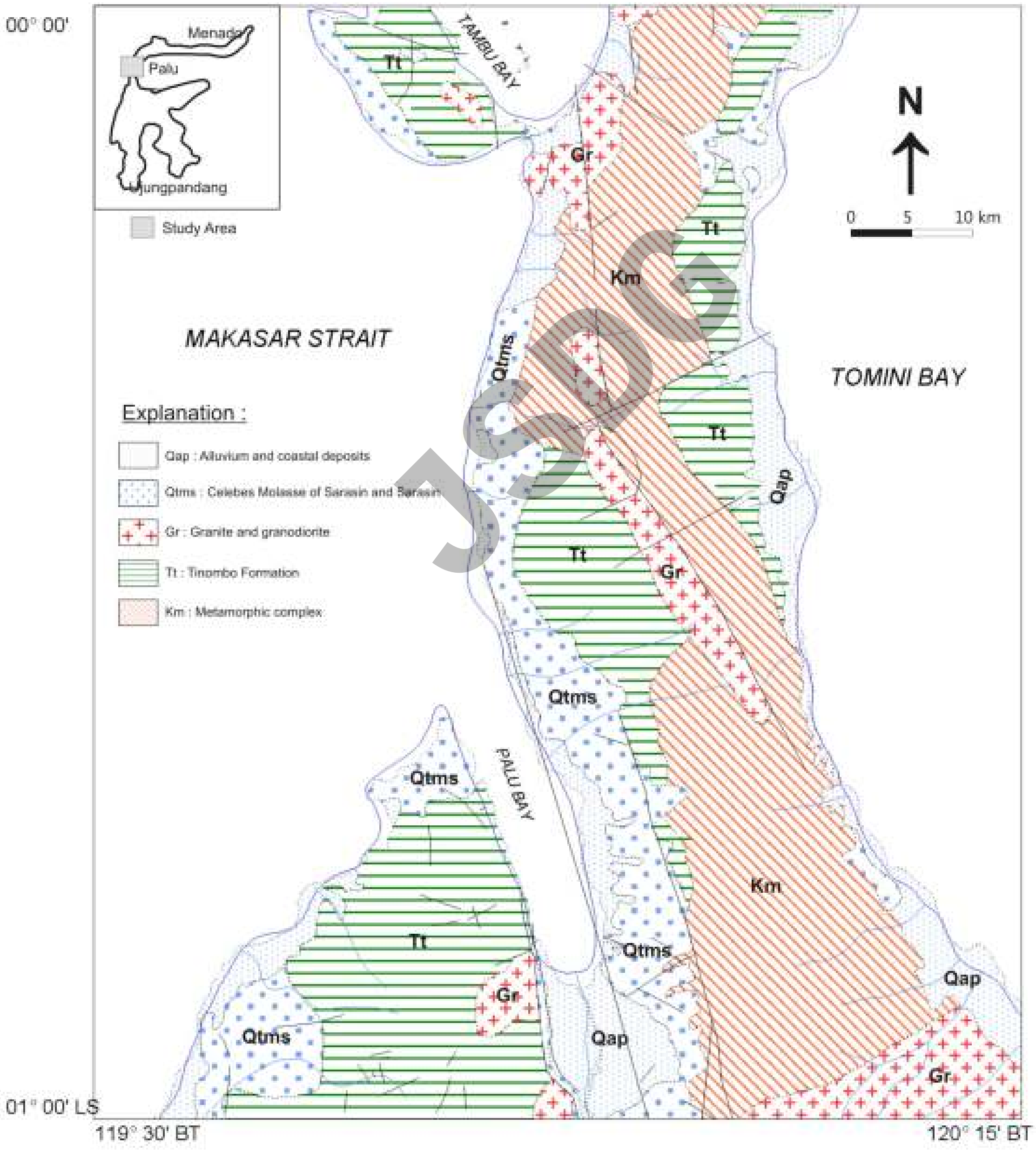

Figure 2. Geological map of the study area (Sukamto, 1973)

Table 2. Zircon and Apatite fission track analytical results from granitic plutons in the Palu region.

Sample Number	Number of Crystals	Ns	Ni	Ns/Ni	Fission Track Age (Ma)
Zircon					
P1	8	299	660	0.347	29.5±2.1
P4	13	561	3861	0.145	9.5±0.5
P6	16	839	4634	0.181	11.8±0.5
P11	9	371	2484	0.149	9.7±0.6
P13	9	612	3961	0.154	10.1±0.5
Apatite					
P1	18	49	109	0.449	29.3±2.5
P4	16	32	318	0.101	6.6±1.2
P6	7	23	243	0.094	6.2±1.3
P11	5	15	137	0.109	7.1±1.9
P13	20	149	1159	0.128	8.2±1.2

This study uses a zeta calibration (ζ) of ~134 Ma, and fission track density (ρd) of ~97.2 (Saefudin, 1994)

Discussion

Sampel P1 has ZFT age of 29.5±2.1 Ma, which is within error consistent with AFT age of 29.3±2.5 Ma and K/Ar dating of 31 Ma. If the K/Ar age represents the rock formation, therefore both ZFT and AFT ages may correspond to the time of fission track generation during crystallisation of granitic liquid in the late Oligocene. Importantly, preservation of fission tracks in apatite suggests that plutonic body has never been burried deeply at the level of total annealing (>110ºC) since emplacement. Alternatively, intrusion might have taken place at deeper level in the Eocene, and subsequently the intrusive rock underwent a cooling event due to erosional denudation of the overlying sequence at ~29 Ma or in the late Oligocene as suggested by ZFT and AFT ages.

Further to the north, sampel P4 shows ZFT age of 9.5±0.5 Ma and AFT age of 6.6±2.5 Ma. The ZFT age is within error consistent with K/Ar biotite age of 8.6 Ma, suggesting that the onset of latest crystallisation took place in the middle Miocene. If this interpretation is correct, hence the rock sequence might have cooled through the zone of partial annealing for apatite (60º-110ºC) in the late Miocene. Exposure of rock sequence in the annealing zone occurred due to uplift in response to erosional denudation at the time given by the AFT age. In addition, uplift of granitic rock in this particular region may occur locally, possibly due to post-crystallisation faulting by which the northern section of intrusive body (sample P4) moved upward and the rock succession cooled, whilst the southern block (sample P1) remained at the same level as it was. Furthermore, it is suggested that further work particularly focusing on structures is needed to test this theory.

Analytical results for zircon and apatite crystals separated from granitic intrusion (sample P6) show respectively ages of 11.8±0.5 Ma and 6.2±1.3 Ma. The ZFT age may correspond to the cooling event from higher paleotemperature through a zircon closure temperature. Thus, the zircon age represents the time of late crystallisation at relatively low temperature (<300ºC) in the middle Miocene. Subsequently, the rock section underwent a rapid cooling event below 110ºC in the late Miocene. The cooling pattern of sample P6 is very similar to that of sample P4. Regionally, the granitic rock succession of samples P4 and P6 seems to have involved in tectonic events responsible for local uplift in this area. Once again, further structural study is required to test the interpretation.

Samples P11 and P13 gained from the northernmost section of granitic sequence resulted in ZFT ages of 9.7±0.6 Ma and 10.1±0.5 Ma, and AFT ages of 7.1±1.9 Ma and 8.2±1.2 Ma. The ZFT ages of the two samples are identical, suggesting the age of granitic rock. Thus, the intrusion of granitic magma occurred in the late Miocene, subsequently cooled and crystalised at a relatively low temperature (<300ºC) at the time given by ZFT ages. In addition, the preservation of fission track in apatite crystals indicates that magma underwent rapid cooling to lower temperature (<110ºC) at 8 Ma or in the late Miocene. Significantly, the ZFT and AFT data suggest that the sequence has never been burried deeply at paleotemperatures of total annealing for both zircon and apatite since the onset of fission track generation. Therefore, the system has never been reset, and consequently the ZFT and AFT ages represent the time of emplacement from higher closure temperature for zircon to a zone of partial annealing for apatite.

Conclusions

Several concluding remarks can be presented on the basis of the above discussion as the following:

(1) The Oligocene granitic rocks in the studied region show two episodes of cooling in response either to crystallisation or to uplift followed by erosional denudation.

(2) The earlier cooling event took place during emplacement of granitic magma at ~30 Ma or in the Oligocene. A particular area of this event was in the southern region.

(3) The later and rapid cooling regime occurred after magmatic intrusion due to local-scale uplift, possibly in response to overthrust at ~6 Ma or in the late Miocene. This event took place in the northern sector of the region.

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