Provenance Study and Tectonic Implications on Rock Sequences in The Lengguru Fold Belt of Western Papua: Constraints from Zircon Fission Track Thermochronology

Edy Sutriyono

Jurusan Teknik Pertambangan, Universitas Sriwijaya, Palembang

Abstract

The present zircon fission track thermochronology study reveals Triassic to Pliocene source terrains supplying clastic materials into the present successions in western Papua. The provenance of sedimentary rocks in the region appears to have associated with igneous activities, suggesting an episode of tectonic events in Mesozoic and Cenozoic. Importantly, the Pliocene Buru Formation in the Lengguru Fold Belt contains abundant Paleogene volcanic zircons, which might have been derived from erosion of the Weyland Terrane in the latest Miocene-Pliocene. This suggests the Weyland Terrane was part of the Paleogene 'Caroline Arc' that was eroded after Late Miocene collision with the western Papua microcontinent. The main compressional pulse in the studied area occurred from ~12-4 Ma. The deformation in the mountainous belt in western Papua from 4-0 Ma has been dominated by transpression. This transpressional regime continued in the fold belt, but with less convergence. Meanwhile, compression continued in the frontal part of the Lengguru Fold Belt, creating Pleistocene folding features such as the Buru Anticline, the Umar Anticline, and the Poronggo Anticline in the eastern Lengguru Fold Belt section. At the present day, transpression is occurring along the Tarera-Aiduna Fault with ongoing uplift of the western Papua Fold Belt. However, extension and subsidence are occurring in the Lengguru Fold Belt southeast of Cendrawasih Bay.

Keywords: *sedimentary rocks, zircon fission, transpression*

Introduction

Fission tracks are microscopic radioactively-disrupted zones resulting from the natural fission decay of Uranium isotopes within a mineral such as zircon. Fission track thermochronology is based on the idea that the number of spontaneous tracks preserved within a mineral grain depends on the thermal history of the host mineral since the time at which each track formed (Green et al., 1989). The radioactively-damaged zone within zircon starts to be repaired, or annealed, when exposed to elevated paleotemperatures between ~175°-250°C (Hurford, 1986). This temperature range is referred 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 10^7 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.

This study presents the results and interpretations of fission track analyses, using zircon grains separated from rock samples collected from outcrops in the Lengguru Fold Belt (LFB) of western Papua (Figure 1). A total of 12 samples have been analyzed by employing the external detector method (EDM) as suggested by Gleadow (1981).

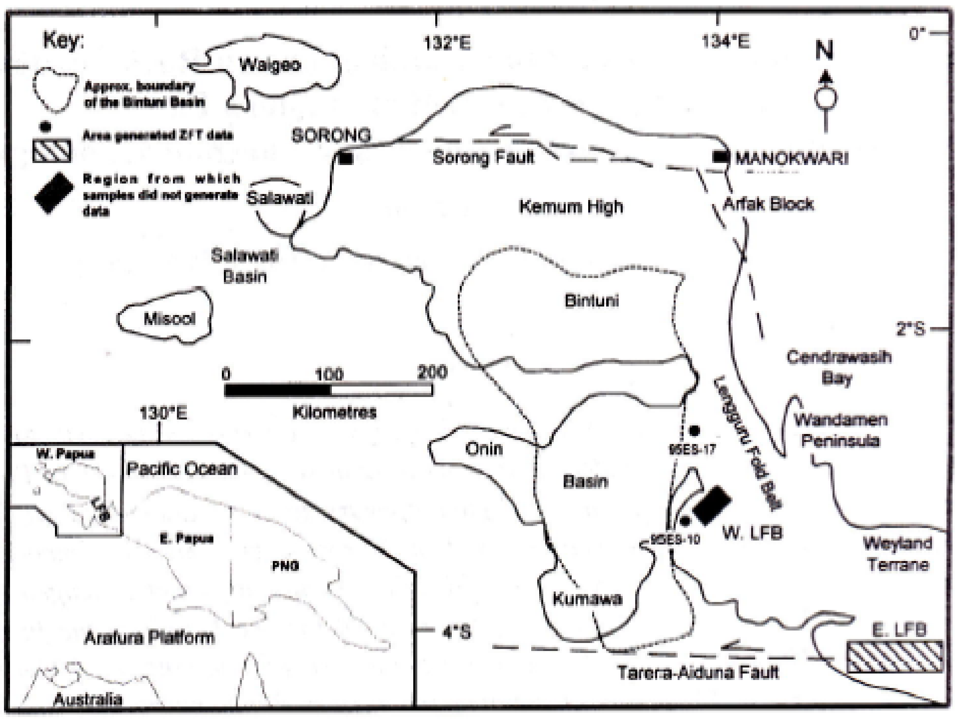

Figure 1. Map showing areas from which sedimentary rock samples were collected from outcrops for zircon fission track analysis.

External Detector Method

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. After irradiation, the mineral mount and the external mica detector are etched separately at different time intervals, ~20 seconds at room temperature of about 20°C using 5M HNO_3 for the mineral aliquot and ~20 minutes at room temperature using 48% HF for the mica. The external mica detector registers induced fission tracks only from one side of the internal polished minerals, known as a 2π geometry with a geometry factor of 0.5.

Experimental Results

Details for each sample, including elevations, formation names, stratigraphic ages, and zircons yields are presented in Table 1. Whereas, analytical results of ZFT analysis are presented in Table 2. A closure temperature of ~240°C is used in interpreting the ZFT data generated in this study.

To interpret the provenance of zircons which passed the χ^2 test at a 95% confidence level, the apparent ZFT ages of rock samples were tied into the geology of the region. In assessing the likely source terrains from the samples which had multi-component ages, i.e. the χ^2 test <5%, analyses of individual zircon crystals were undertaken using Galbraith's (1990) radial plot technique and/or a Sambridge and Compston's (1994) mixture ('Mix') model. Then, each of the ZFT populations was compared to the regional geology.

ZFT results and interpretations

Eleven ZFT ages from outcrops in the LFB region range from 12±5 Ma to 125±8 Ma (Table 2). All but one zircon age failed the χ^2 test at the 95% confidence level, suggesting that most samples contain mixed-populations of zircon grains. The Upper Miocene-Pleistocene Buru Formation samples, 95ES-01 to 95ES-16, yielded apparent ZFT ages which are all significantly older than the depositional ages for each sample. Thus, the ZFT data from these outcrops provide information about provenance terrains sourcing the present Buru sequence. The Upper Cretaceous-Paleocene Ekmai Sandstone sample 95ES-17 produced an apparent ZFT age which is consistent with the stratigraphic age of the section, but also failed the χ^2 test so probably contains some grains from a different source.

The western lengguru fold belt region

Two surface samples 95ES-10 and 95ES-17 in the western LFB area revealed ZFT ages of 66.4±4.8 Ma and 84.0±10.2 Ma respectively within 2 sigma errors of each other (Table 2). Both samples failed the χ^2 test at <5%, suggesting multiple single-grain age populations. The 'Mix' analysis of single-grain ages of zircons from these samples resulted in three discrete distributions (Figure 2). These populations are: (1) Triassic zircons of ~211 Ma; (2) Upper Cretaceous zircons of ~88 Ma; and (3) Paleogene zircons of ~54 Ma.

Table 1. Sample details and zircon yields of sedimentary rocks collected from the Lengguru Fold Belt region.

Sample Number	Longitude (°E)	Latitude (°S)	Elevation (m)	Formation	Stratigraphic Age	Zircon Yield
95ES-01	135°21'30"	4°17'15"	76	Post Buru	Plio-Pleistocene	Very Good
95ES-02	135°01'27"	4°12'00"	61	Buru	U.Miocene-Pleistocene	Very Good
95ES-03	135°01'28"	4°11'30"	76	Buru	U.Miocene-Pleistocene	Very Good
95ES-04	135°01'26"	4°11'00"	61	Buru	U.Miocene-Pleistocene	Very Good
95ES-10	133°41'00"	3°19'30"	76	Buru	U.Miocene-Pleistocene	Good
95ES-11	135°36'00"	4°22'31"	122	Buru	U.Miocene-Pleistocene	Fair
95ES-12	135°33'26"	4°19'00"	152	Buru	U.Miocene-Pleistocene	Fair
95ES-13	135°35'30"	4°17'30"	91	Buru	U.Miocene-Pleistocene	Poor
95ES-14	135°35'31"	4°17'02"	229	Buru	U.Miocene-Pleistocene	-
95ES-15	135°39'10"	4°19'30"	69	Buru	U.Miocene-Pleistocene	Excellent
95ES-16	135°39'10"	4°18'31"	69	Buru	U.Miocene-Pleistocene	Very Good
95ES-17	133°56'06"	2°39'10"	229	Ekmai	U.Cretaceous-Paleocene	Very Good

Zircon 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. Original samples weighed approximately 0.5-1 kg.

Table 2. Zircon fission track analytical results from sedimentary rocks of the Lengguru Fold Belt region.

Sample Number	Number of Crystals	Spontaneous Tracks		Induced Tracks		$P(\chi^2)$ (%)	ZFT Age (Ma) (±1σ)	Uranium (ppm)
		ρs	Ns	ρi	Ni			
95ES-01	20	8.099	2174	1.796	482	58.8	124.8 ± 7.9 ^	146.7
95ES-02	20	8.154	2545	2.457	767	0.0	64.8 ± 17.5 *	200.8
95ES-03	20	3.261	2023	3.002	1862	0.0	32.6 ± 9.1 *	245.3
95ES-04	20	8.365	2932	2.520	883	0.0	90.9 ± 13.3 *	205.9
95ES-10	16	5.567	2033	2.267	828	0.0	66.4 ± 4.8 *	185.3
95ES-11	14	1.865	422	3.283	743	0.0	14.0 ± 3.8 *	268.3
95ES-12	13	3.709	960	4.660	960	0.0	14.9 ± 4.3 *	380.8
95ES-13	7	2.284	139	5.077	309	0.0	11.6 ± 4.7 *	414.8
95ES-15	22	3.256	1677	4.555	2346	0.0	22.8 ± 6.4 *	372.2
95ES-16	20	7.594	4083	2.223	1195	0.0	99.4 ± 9.6 *	181.6
95ES-17	20	5.439	3650	1.800	1208	0.0	84.0 ± 10.2 *	147.1

ρ = fission track density ($\times 10^6$ cm^{-2}), N = number of fission track counted, ^ = pooled age used where $P(\chi^2)$ test >5%, * = central age used where pooled data fail the χ^2 test at 5%. ZFT counting completed by Dr. Paul B. O'Sullivan, using a zeta of 87.8 ± 3.0 for U3 glass (52 ppm). External detector method (geometry = 0.5) employed for ZFT thermochronology (Gleadow, 1981).

(1) Triassic ZFT grain ages

The Triassic population of zircons is derived from sample 95ES-17, as there is no single-grain age older than 100 Ma in sample 95ES-10. The presence of these zircons within the Upper Cretaceous-Paleocene Ekmai Sandstone suggests there was igneous activity or post-metamorphic cooling during the Triassic, and the Triassic provenance area was denuded in the Upper Cretaceous.

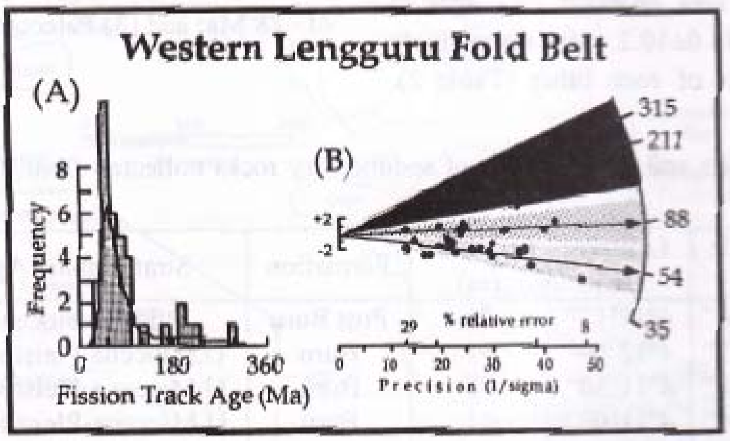

Figure 2. Single-grain analyses of samples 95ES-10 and 95ES-17 (combined) reveal three populations of zircons: (1) a Triassic age of ~211 Ma, (2) an Upper Cretaceous age of ~88 Ma, and (3) a Paleogene age of ~54 Ma. Modelling shows a histogram (A) and a radial plot (B).

Evidence for Triassic igneous activity in the western Papua region includes the Netoni Granite (K/Ar hornblende-biotite ~241-198 Ma) in the north, the Sorong Granite (K/Ar biotite ~224 Ma) in the west, and the Kwatisore Granite (K/Ar biotite ~197 Ma) in the southeast (Bladon, 1988). Therefore, it seems likely that the Triassic zircons were locally derived from plutons in western Papua that were exposed and eroded in the latest Cretaceous, indicating an Upper Cretaceous tectonic event. Alternatively, the Triassic zircons in the Upper Cretaceous section may have resulted from erosion of the volcanogenic Tipuma sequence (Lunt and Djaafar, 1991), which must have been emergent during the Cretaceous.

(2) Upper cretaceous ZFT grain ages

The ~88 Ma zircon population is older than the depositional age of the Upper Miocene-Pleistocene Buru Formation sample 95ES-10, but consistent with that of the Upper Cretaceous-Paleocene Ekmai Sandstone sample 95ES-17. The Upper Cretaceous volcaniclastics are common interbeds within the sedimentary successions in the western Papua area (Chevallier and Bordenave, 1986), particularly the Lower-Upper Cretaceous Jass Formation and the Upper Cretaceous-Paleocene Ekmai Sandstone (Pigram and Sukanta, 1989). In the island of Misool southwest of the western Papua mainland (Figure 1) there appears a 10 m thick basalt associated with the Upper Cretaceous sedimentary rocks (Visser and Hermes, 1962), suggesting contemporaneous volcanism during mid-Upper Cretaceous. Also, Lunt and Djaafar (1991) recorded the Campanian-Maastrichtian granites with K/Ar biotite and hornblende ages ranging from ~71 Ma to ~79 Ma in the K-IX well in the Salawati Basin.

Thus, the preservation of Upper Cretaceous zircons within the Ekmai Sandstone indicates that the Ekmai sedimentary basin was sourced from areas of Upper Mesozoic active volcanoes. However, the presence of Upper Cretaceous grains within the Buru Formation suggests Upper Miocene-Pliocene tectonic events, which involved regional uplift and erosion of either Upper Cretaceous plutons or the Jass and Ekmai successions.

(3) Paleogene ZFT grain ages

The presence of Paleogene (~54 Ma) zircons in the Buru column suggests they were sourced from an area that underwent Paleogene igneous activity or post-metamorphic cooling. The volcanism concords with the Upper Mesozoic-Middle Miocene Auwewa Volcanic Group, including the Paleogene Tobo Volcanics of the Weyland Overthrust in the Enarotali Sheet (Dow et al., 1990). The uplift of a volcanic block might have occurred during accretion of the Weyland Terrane although Dow et al. (1990) and Struckmeyer et al. (1993) suggest this occurred in the Oligocene. The data presented here suggest the Paleogene volcanic province underwent uplift and erosion in the Upper Miocene, supplying Buru sediments, consistent with Weyland Terrane accretion in the Upper Miocene. Therefore, it is interpreted that the Weyland Terrane was part of the Paleogene volcanic arc in the SW Pacific region.

The eastern lengguru fold belt region

Nine of ten eastern LFB outcrops were obtained from the Plio-Pleistocene Post-Buru Formation around the Umar Anticline (95ES-01), the Buru Anticline (95ES-02, -03, -04), and the Poronggo Anticline (95ES-11, -12, -13, -15, and -16). Of nine samples only one sample 95ES-01 passed the statistical χ^2 test at >5%. Therefore, most samples contain more than one component of zircon grains. The dated zircons generated apparent ZFT ages ranging from 11.6±4.7 Ma to 124.8±7.9 Ma, which are significantly older than the corresponding stratigraphic age of the section.

A. Southwestern umar anticline

Sample 95ES-01 collected from the southwestern Umar Anticline passed the χ^2 test, suggesting a single population of individual grain ages. The ZFT analysis of this sample resulted in an Early Cretaceous age of ~125±8 Ma, indicating Early Cretaceous igneous activity or post-metamorphic cooling in the source area. In either case, the source region would have been uplifted and eroded in the Upper Miocene with sediments redeposited into the present Buru section. As no Mesozoic orogeny is recorded in the region, post-metamorphic cooling and associated rapid denudation seems unlikely.

Alternatively, the ~125 Ma age is consistent with Aptian volcanism. To the northwest, contemporaneous volcanic arenites occur within the Early-Upper Cretaceous Jass Formation along the southern flank of the Kemum basement high in the central western Papua (Pigram and Sukanta, 1989). These volcanogenic arenaceous materials are thought to have been sourced by Cretaceous volcanism, which also supplied tuffs and a thick volcanic pile penetrated by a few offshore wells between the Salawati and Misool islands (Dow et al., 1988). Therefore, it seems likely that there might have existed post-Valanginian breakup-related magmatism during the northern margin of the Australian continent during the Aptian.

B. Northern buru anticline

Three samples, 95ES-02, -03, and -04, were collected from the Upper Miocene-Pleistocene Buru Formation exposed in the northern flank of the Buru Anticline in the southeastern LFB area. These samples failed the χ^2 test, implying a mixed population of zircons. Analyses of individual grain ages revealed at least three populations: (1) Upper Triassic/Early Jurassic zircons of ~189 Ma; (2) Paleogene zircons of ~56 Ma; and (3) Pliocene zircons of ~4 Ma (Figure 3). Importantly, each of these populations can be correlated to regional tectonics or volcanism.

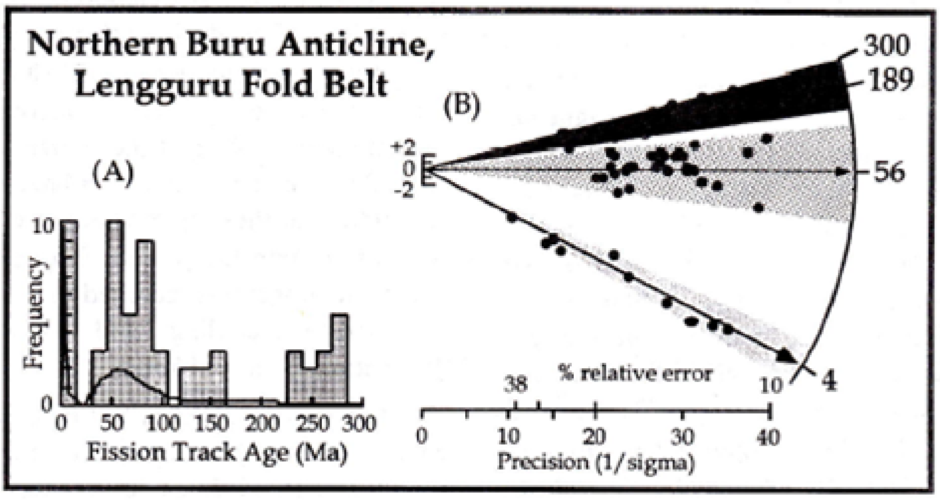

Figure 3. (A) a histogram and (B) a radial plot of single-grain ages of samples 95ES-02, -03, and -04 obtained from the northern flank of the Buru Anticline depicting three age distributions: (1) Upper Triassic/Early Jurassic, at ~189 Ma, (2) Paleogene, at ~56 Ma, and (3) Pliocene, at ~4 Ma.

(1) Upper triassic/early jurassic ZFT grain ages

The oldest age population of zircons separated from the northern Buru Anticline samples is ~189 Ma. The preferred interpretation is that there was significant Upper Triassic/Early Jurassic igneous activity in the source area, which was denuded in the Upper Miocene-Pliocene and redeposited into the present Buru section.

Along the NNW edge of the Weyland Overthrust, ~50 km north of the Buru Anticline, there is an extensive exposure of the Kwatisore Granite, regarded as Triassic on the basis of one K/Ar age of ~197 Ma from biotite (Bladon, 1988). This is well within error of the ~189 Ma zircons, so it seems likely that they were partially a result of denudation of the Kwatisore Granite inliers. As the Kwatisore intrusive body is almost entirely fault-bounded (Robinson et al., 1990), it seems likely that the unit is allochthonous and was transported westwards and eventually attached in the southeastern Wandamen Peninsula, prior to or during Upper Miocene uplift and denudation, depositing detritus in the Upper Miocene-Pleistocene Buru Formation.

Alternatively, the 189 Ma zircons within the section studied could have been supplied by a source terrain that received contemporaneous volcanic zircons. There is no evidence for the occurrence of contemporaneous volcaniclastics in a Jurassic sedimentary sequence throughout the Papua region. However, ~1000 km to the east, the Jurassic syn-rift Balimbu Greywacke in the northern Papuan Basin contains interbedded volcanic sandstones (Home et al., 1990). About 1000 km to the southwest, the Early-Upper Jurassic intrusive and volcanic rocks have been identified in the syn-rift succession of the Browse Basin, suggesting there was a nearby major volcanic province (Blevin et al., 1998). If the Upper Triassic/Early Jurassic zircons are volcanic in origin, either they travelled a long way to the western Papua region or the western Papua itself was nearer to one of those provenances in the Upper Triassic/Early Jurassic.

(2) Paleogene ZFT grain ages

The appearance of ~56 Ma zircon minerals in the Buru section of the northern Buru Anticline agrees well with the occurrence of ~54 Ma population in the western LFB section. Thus the LFB clearly received Early Eocene clastic sediments from a Paleogene volcanic province denuded in the Upper Miocene, probably the Weyland Overthrust region. This is consistent with the arrival of Early Eocene volcanic arc component at the Weyland Overthrust region in the Upper Miocene or earlier.

(3) Pliocene ZFT grain ages

The Pliocene ZFT age components are consistent with the depositional age of the sequence, suggesting a contemporaneous volcanic origin for the zircons. This interpretation agrees with significant volcanism following the main compressional pulse, which created the orogenic belt in New Guinea from ~12-4 Ma (Hamilton, 1979).

Locally, Upper Miocene-Pliocene volcanic rock assemblages occur within and/or south of the Weyland Overthrust region, including the Upper Miocene-Pliocene Nabire Volcanics (K/Ar ~6 Ma), and the Pliocene Timepa Monzonite (K/Ar ~2-5 Ma) (Bladon, 1988). This suggests that the Pliocene igneous activity south of the Weyland Overthrust supplied the contemporaneous zircons within the Buru section to the south.

Importantly, the ~4 Ma grains within the Buru samples demonstrate that deformation in the eastern LFB occurred in the Plio-Pleistocene, as the Buru Formation is deformed in the Buru Anticline. The recorded dips of beds range from 13°-45° in the Buru strata across the northern flank of the structure (Pigram and Panggabean, 1989). This interpretation is supported by the common occurrence of the ~4 Ma population of zircons within the Buru section around the Poronggo Anticline in the east.

C. Poronggo anticline

A total of six outcrops were collected from the eastern LFB around the Poronggo Anticline. Of these rocks, only five samples yielded datable zircons (Table 2). All of the analysed rocks failed the χ^2 test, indicating a mixed distribution of zircon grains within the samples. To assess the thermotectonic history of the provenance areas, samples 95ES-15 and 95ES-16 in the eastern portion of the anticline are analysed together (Figure 4), as they yielded apparent ZFT ages which are much older than those of samples 95ES-11, -12, and -13 in the western Poronggo Anticline (Figure 5). The latter three samples are equi-distant from the crest of this anticline and have young ages.

The 'Mix' analysis of single grain ZFT ages of the two eastern Poronggo Anticline results in two single-grain populations: (1) an Upper Cretaceous age of ~76 Ma, and (2) a Pliocene age of ~4 Ma (Figure 4). In contrast, the three western Poronggo Anticline samples revealed three discrete single-grain ages: (1) a Paleogene age of ~44 Ma, (2) an Early Miocene age of ~18 Ma, and (3) a Pliocene age of ~4 Ma (Figure 5).

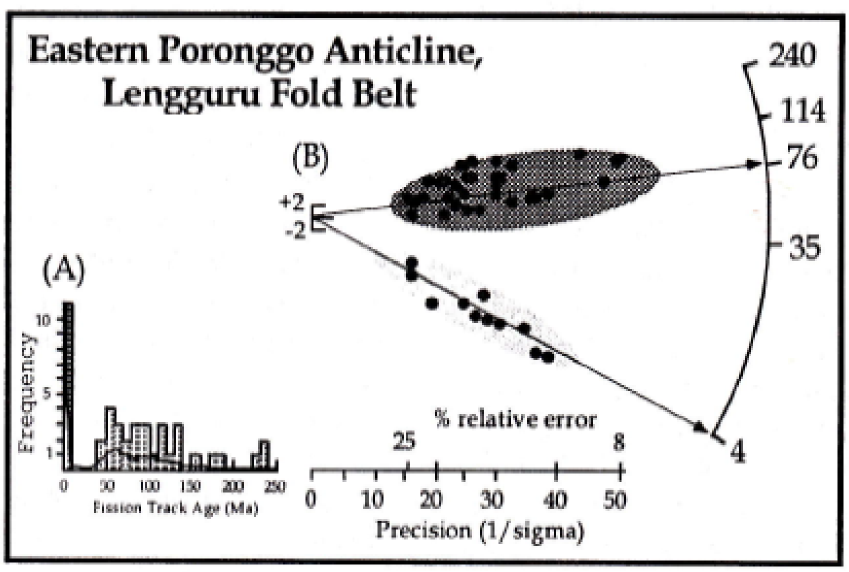

Figure 4. The diagram shows (A) a histogram and (B) a radial plot of individual zircon ages from samples 95ES-15 and 95ES-16 collected from the eastern sector of the Poronggo Anticline in the eastern LFB area. There are two populations revealed from these samples: (1) an Upper Cretaceous age of ~76 Ma, and (2) a Pliocene age of ~4 Ma.

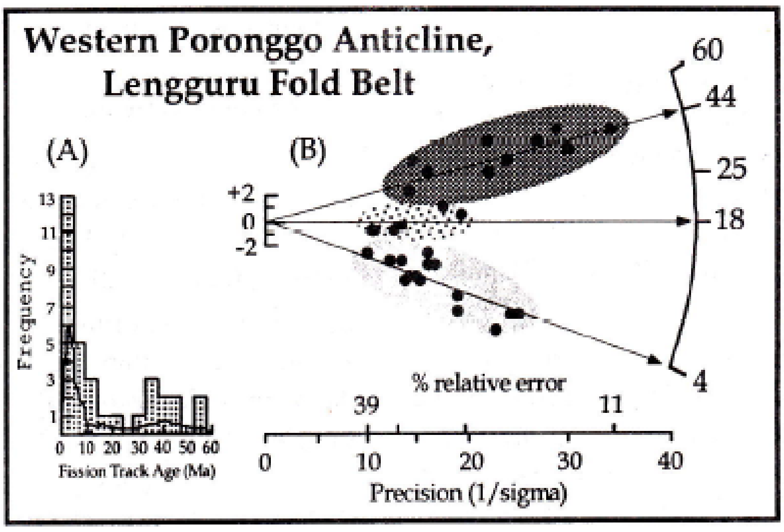

Figure 5. Single-grain age analyses of zircons from samples 95ES-11, -12, and -13 derived from the western Poronggo Anticline displays three populations: (1) a Paleogene age of ~44 Ma, (2) an Early Miocene age of ~18 Ma, and (3) a Pliocene age of ~4 Ma.

(1) Upper cretaceous ZFT grain ages

The population of ~76 Ma zircons in the Upper Miocene-Pleistocene Buru Formation in the eastern sector of the Poronggo Anticline (Figure 4) suggests an Upper Cretaceous provenance terrain. The ~76 Ma distribution shown in Figure 4 is well within error of the ~88 Ma age depicted in Figure 2. Thus the zircons are probably derived from local western Papua volcanism in the Upper Cretaceous, with the provenance terrain uplifted and eroded in the Upper Miocene-Pliocene.

(2) Paleogene ZFT grain ages

The population of ~44 Ma zircon grains within the samples indicates a Paleogene source (Figure 5). Therefore, it is interpreted that the ~44 Ma zircons within the Buru section were sourced partially from the Paleogene Tobo Volcanics in the Weyland hangingwall north of the sample areas and other Auwewa Volcanic rocks (Dow et al., 1990). This is consistent with the ZFT data from the Buru Anticline and the Poronggo Anticline samples (Figures 3 and 5) and confirms a Paleogene volcanic province, probably in the Weyland region, denuded in the Upper Miocene-Pliocene.

(3) Early miocene ZFT grain ages

A population of ~18 Ma zircons preserved in the Upper Miocene-Pleistocene Buru Formation suggests an Early Miocene provenance source (Figure 5). The Early Miocene source terrain is consistent with an E-W trending rock inlier of the Utawa Diorite (K/Ar ~11-18 Ma; Dow et al., 1990), exposed roughly over 95 km in length and up to 30 km in width and located ~50 km north of the sample areas. Therefore, it is possible that the 18 Ma zircon samples were supplied partially by Upper Miocene-Pliocene denudation of this Burdigalian-Serravalian igneous body.

Furthermore, the Utawa pluton is thought to have intruded the originally volcanic arc of the Paleogene Tobo Volcanics (Dow et al., 1988), consistent with the Paleogene zircons discussed above. Quarles van Ufford (1996) suggested that the Utawa Diorite was emplaced from southwest-dipping subduction associated with the arc-continent collision in the Early-Middle Miocene. This is consistent with the main phase of volcanism and metamorphism throughout the Mobile Belt in Papua New Guinea (PNG) in the Miocene (Page, 1976).

An alternative interpretation is that the ~18 Ma population of zircons may correspond to an episode of Early Miocene rapid cooling of the Oligocene Derewo Metamorphics. This metamorphic belt is exposed extensively along the southern margin of the Weyland Overthrust. The unit consists mainly of basic-intermediate volcanogenic rocks, conglomerate, and fine clastic rocks with interbeds of quartz-feldspar arenites, carbonates, and quartz sandstones (Dow et al., 1990). These rocks are regarded as continental-slope sediments that were metamorphosed to greenschist metamorphic rocks in the Oligocene (Dow et al., 1990). However, higher grade metamorphic facies outcrop near the Utawa Diorite, implying significant thermal effects from the intrusion prior to subsequent cooling events.

Therefore, the 18 Ma zircons preserved in the Upper Miocene-Pleistocene Buru successions could be derived from the Derewo Metamorphics that cooled rapidly through the ~240°C isotherm during the Early Miocene, and underwent regional denudation in the Upper Miocene-Pliocene. This is consistent with K/Ar thermochronology studies in PNG by Crowhurst et al. (1996). They suggested that the metamorphic rocks in the Mobile Belt and Bewani-Torricelli Mountains cooled from >500°C to ~150°C during the Early Miocene. Once again, this event was confirmed by widespread Miocene igneous activity and metamorphism across the Mobile Belt (Page, 1976).

(4) Pliocene ZFT grain ages

The occurrence of ~4 Ma zircons in the Buru section around the Poronggo Anticline (Figures 4 and 5) affirms the existence of nearby contemporaneous magmatic activity, as in the north Buru Anticline discussed above. The 1:250,000 geological map of the Waghete Sheet area shows the dips of beds in the Buru succession across the southern flank of the Poronggo Anticline vary from 10°-50°, whilst those in the northern limb are 20°-50° (Pigram and Panggabean, 1989). These surface data suggest that the Buru section has been involved in folding of the Poronggo Anticline.

The occurrence of ~4 Ma contemporaneous volcanic detritus within the Buru Formation indicates that the Poronggo Anticline formed in the Upper Pliocene-Pleistocene. This tectonic deformation was confirmed regionally by apatite fission track cooling ages of ~4 Ma in the western Papua Fold Belt (Sutriyono, 1999), 2-4 Ma in the vicinity of the Grasberg mine (Weiland and Cloos, 1996), and 4±0.5 Ma for the Kubor and Muller Anticlines in PNG (Hill and Gleadow, 1989).

Conclusions

Several concluding remarks of the present study, incorporated with the previously existing work, can be drawn as follows:

(1) The Pliocene-Pleistocene Post-Buru Formation in the LFB shows Lower Cretaceous provenance, suggesting Early Cretaceous Aptian igneous activity.

(2) The Upper Miocene-Pleistocene Buru sequence in the western section of LFB reveals provenance ages of Triassic, Upper Cretaceous, and Peleogene, whereas the Buru section in the eastern part of the region contains zircon detritals of Upper Triassic-Lower Jurassic, Paleogene, Lower Miocene, and Pliocene in age. This suggests that there appeared (a) magmatic intrusion and/or volcanism in the Triassic, (b) uplift and erosion of Upper Cretaceous igneous body during the Upper Miocene to Pliocene, (c) cooling of Paleogene pluton below 240°C prior to uplift and erosion in the Upper Miocene, and (d) contemporaneous volcanism in the Pliocene at 4 Ma.

(3) The Upper Cretaceous-Paleocene Ekmai succession in the eastern LFB area consists of Triassic zircons, suggesting Triassic igneous bodies underwent denudation in the Upper Cretaceous.

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