CRETACEOUS CRUST IN SW BORNEO: PETROLOGICAL, GEOCHEMICAL AND GEOCHRONOLOGICAL CONSTRAINTS FROM THE SCHWANER MOUNTAINS

Lorin Davies*
Robert Hall*
Richard Armstrong**

ABSTRACT

New geochronological data from SW Borneo indicate that supposed basement rocks of the Pinoh Metamorphic Group are Cretaceous rather than Palaeozoic as accepted until now. They are intruded by Cretaceous granites in the Schwaner Mountains. The Southern Schwaner Zone (SSZ) intrusives are granites and alkali-granites. Petrological data and major and trace element compositions indicate that they are within-plate granitoids (WPG) with a mix of S- and I-type characteristics. U-Pb ages of zircons from SSZ granitoids record magmatism at c. 185 Ma and c. 75 Ma. Granitoid rocks from the Northern Schwaner Zone (NSZ) are I-type tonalites and diorites. Trace element compositions indicate an arc magmatic character. U-Pb ages of zircons from Schwaner granitoids demonstrate that NSZ magmatism took place from c. 120 Ma to c. 80 Ma. Unmetamorphosed and metamorphosed volcanic rocks from the NSZ are tuffs, ignimbrites, and lavas of intermediate to acid composition. Trace element compositions indicate a volcanic arc character and they chemically resemble the NSZ granitoids. U-Pb ages of zircons record volcanism from c. 130 Ma. Metamorphic rocks (the Pinoh Metamorphic Group) are pelitic schists and hornfelses, with occasional quartzites and metabasites. Major element geochemistry points to an igneous protolith. Trace element plots suggest volcanicogenic sediments which chemically resemble the NSZ granitoids. All metamorphic rocks contain Cretaceous zircons. Their ages overlap with zircons from volcanic and plutonic rocks, suggesting that rocks of the Pinoh Metamorphic Group were derived from a volcanicogenic protolith which was subjected to thermal metamorphism related to granitoid intrusion.

WPG magmatism at c. 185 Ma is considered to mark extensional rifting of a SW Borneo block from the northern margin of Australia. This block moved northwards during the Cretaceous forming an intraplate arc above a subduction zone in the early Cretaceous which provided the source of the NSZ arc granitoids. The block docked with Sundaland at about 90 Ma.

INTRODUCTION

SW Borneo lies at the heart of SE Asia, an area which has been the site of collisions of various tectonostratigraphic blocks since the Late Triassic (e.g. Metcalfe, 2011). The basement rocks of SW Borneo are igneous and metamorphic rocks which crop out in the Schwaner Mountains (e.g. Pieters and Supriatna, 1990). Many authors have suggested that SW Borneo represents an ancient continental fragment surrounded by younger rocks (e.g. van Bemmelen, 1949; Haile, 1974; Metcalfe, 1994), which was part of Sundaland (the continental core of SE Asia) by the mid-Cretaceous (Hamilton, 1979; Hall, 2012).

To the north of SW Borneo lies the Kuching Zone (Haile, 1974; Hutchison, 1989; Hutchison, 2005) which includes Carboniferous limestones, Triassic marine shales, and Cretaceous melanges. This is the NW Kalimantan domain of Williams et al. (1988, 1989) which is bounded to the south by the Boyan suture zone (Tate, 2001; Metcalfe, 2006). East of the SW Borneo block are the Meratus Mountains, which mark a Cretaceous suture between SW Borneo and the East Java–West Sulawesi block which is thought to be a Gondwana fragment (Smyth et al., 2007). To the west of the Schwaner Mountains, the nature of the boundary between Sundaland and SW Borneo is unknown.

Geology

Igneous and metamorphic rocks from the Schwaner Mountains were first described by Zeijlmans van
Emmichoven (1939), and have subsequently been studied by various authors working with the Geological Research and Development Centre (GRDC, Bandung) since the 1980s.

In the southern Schwaner Mountains, intrusive rocks have been described as granites (de Keyser and Rustandi, 1993; Tate, 2001) but little petrological or geochemical work has been carried out. De Keyser and Rustandi (1993) reported K-Ar ages from 65 to 103 Ma, whilst Haile et al. (1977) reported K-Ar ages between 87-78 Ma, with the notable exceptions of one Jurassic age (153.5 ±3.5 Ma) and one Early Cretaceous age (127.1 ±2.8 Ma). Amiruddin and Trail (1993) suggested that southern Schwaner Mountain granites were emplaced after subduction had ceased, and at shallow emplacement depths.

In the northern Schwaner Mountains, intrusive rocks are described as I-type calc-alkaline massive crystalline rocks (Pieters and Sanyoto, 1993). Haile et al. (1977) dated granitoid rocks from the northern Schwaner Mountains. K-Ar ages from 115-75 Ma were reported from tonalites, granodiorites, and one gabbro sample.

Volcanic rocks from within the Schwaner Mountains are associated with the plutonic rocks but are largely undated. They are generally considered to be Cretaceous to Early Cenozoic in age. There are intermediate and acid rocks including andesites, dacites, and rhyolites which are associated with quartz diorite and granodiorite post-subduction dykes, stocks, and sills (Amiruddin and Trail, 1993). K-Ar ages reported for some of these rocks range from late Cretaceous to 21 Ma. Volcanic rocks from north of the Schwaner Mountains near Sintang and Putussibau have been dated using the K-Ar method and yielded ages of 49 Ma (Pieters et al., 1993).

Metamorphic rocks from the Schwaner Mountains belong to the Pinoh Metamorphic Group (PMG). Prior to this study no radiometric dating has been reported for rocks from the PMG. Most authors have considered them to be Paleozoic (e.g. Haile, 1974; van Bemmelen, 1949; Williams and Simamora, 1988). Van Bemmelen (1949) first suggested that PMG rocks were Paleozoic on the basis of apparent similarities with known rocks of that age. Subsequently, the PMG have been correlated with rocks found far to the north in Sarawak, which are in turn considered to be pre-Carboniferous on the basis of a ‘dubious fossil tentaculid’ (Tate, 1991; Tate and Hon, 1991) and the fact that unmetamorphosed Carboniferous limestones are known from Sarawak and the metamorphic rocks are assumed to be older. Since the Boyan suture separates the Kuching Zone from SW Borneo (Tate, 2001; Metcalfe, 2006), this correlation is uncertain.

Pre-Cretaceous tectonic history

Two conflicting models have been proposed to explain the tectonic history of SW Borneo prior to docking with Sundaland during the Cretaceous.

Several authors have proposed a Cathaysian origin (e.g. Ben-Avraham and Uyeda, 1973) suggesting that SW Borneo was derived from East Asia during the Mesozoic. Rifting followed by southward migration of SW Borneo caused it to reach its current position during the Cretaceous. This model was first suggested by Ben-Avraham (1973), and has been supported by the presence of a flora with Cathaysian affinity in Sarawak (Tate, 1991; Tate and Hon, 1991; Metcalfe, 1994, 1995). This model relies upon correlation across what is widely recognised as a suture between separate blocks (Tate, 1991; Metcalfe, 1994, 1996, 2006). However, the model was proposed when it was believed that the South China Sea was Cretaceous and the southward motion of SW Borneo was considered to be related to South China Sea opening. It is now known that the South China Sea opened in the Oligocene to Early Miocene (Holloway, 1982; Taylor and Hayes, 1983; Briais et al., 1993).

An alternative is that SW Borneo has an Australian origin (e.g. Hall et al., 2009; Hall, 2012). This model suggested that the SW Borneo block rifted from NW Australia during the Middle to Late Jurassic. Subsequent movement from a high-latitude position during the Mesozoic was followed by docking with Sundaland by the Mid-Cretaceous. This model is incorporated in reconstructions (Hall et al., 2009; Hall, 2012) which postulate rifting of a fragment and formation of the Banda embayment at around 160 Ma. Diamonds found in Borneo in alluvial settings (e.g. Bergman et al., 1987; Spencer and Kane, 1988; Graham et al., 2006; Smith et al., 2009) have remained an unexplained phenomena; their presence is a possible indication of a Gondwana origin for SW Borneo.

The absence of data on the age and character of basement rocks have until now made testing either model problematic. This study sheds some light on the origin of SW Borneo based on detailed petrographic, geochemical and geochronological
data for rocks collected from the Schwaner Mountains.

METHODS

Rocks were collected over two field seasons in 2009 and 2010. Sample locations are shown on Figure 1. Thin sections were prepared at Royal Holloway, University of London. Modes were calculated from point count data for classification of intrusive igneous rocks. Metamorphic mineral assemblages were noted, paying particular attention to overprinting relationships. Tectonic sequence diagrams were produced following the methodology of Forster and Lister (2008).

Whole rock geochemical analyses were obtained for 16 igneous and 17 metamorphic samples. Major element analyses were acquired by inductively coupled plasma atomic emission spectroscopy (ICP-AES) at Royal Holloway, University of London. Sample powders were prepared using standard procedures. Data were averaged from 5 analyses and calibrated using reference materials. Trace element compositions were determined by X-ray fluorescence spectrometry (XRF) at Royal Holloway, University of London. Sample powders were set in PVP-MC binding resin and made into pellets. Analyses were run four times on a PANalytical Axios machine using a rhodium X-ray tube.

Zircon grains were separated from crushed rock samples using heavy liquids (sodium polytungstate solution, diiodomethane) and magnetic (Frantz) separation techniques. Zircons were also separated from river sediment samples. Zircon grains from igneous and metamorphic samples were dated using sensitive high resolution ion microprobe (SHRIMP) at the Research School of Earth Sciences, Australian National University. Detailed explanation of U-Pb geochronology by SHRIMP is given in Williams (1998). Data were reduced using Isoplot software (Ludwig, 2003). Zircons from river sediments were dated by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). Real time data were reduced using GLITTER™ software. Repeated analyses of the external zircon standard Plesovice, and NIST 612 silicate glass were used to correct for instrument bias and depth-dependant inter-element fractionation of Pb, Th, and U. SHRIMP and LA-ICP-MS data were filtered using standard 10% discordance test. The $^{206}\text{Pb}/^{238}\text{Pb}$ ratio was used to determine all ages (as all were <1000Ma). Data were processed using Isoplot (Ludwig, 2003). Weighted mean ages were calculated for igneous rocks in order to estimate an emplacement age. All ages were plotted on relative probability plots using Density Plotter (Vermeesch, 2012).

RESULTS

Intrusive rocks

Granitoids from the southern part of the Schwaner Mountains (SSZ) are granites and alkali-granites (Figures 2). SSZ granitoids show I-type characteristics (Chappell and White, 2004). However, enrichment of Rb, Fl, and Cl trace elements is indicative of an S-type character, making classification somewhat ambiguous. SSZ rocks all contain microperthite, indicating subsolidus unmixing. Geochemical trace element discrimination diagrams (after Pearce et al., 1984) indicate a within-plate granitoid (WPG) character (Figure 2). Zircons from SSZ granitoid samples record two quite different ages (Figure 2). One granitoid body has a mean age of 72.05 ±0.56 Ma, and the other 186.7 ±2.3 Ma.

Granitoids from the northern part of the Schwaner Mountains (NSZ) are tonalites, granodiorites and granites; one norite and one quartz-diorite were also observed (Figure 2). NSZ granitoids are I-type according to the classification of Chappell and White (2004). Plagioclase grains are clear and show little or no internal structure. Some samples exhibit myrmekitic textures, indicative of late stage metasomatism. Most samples are phaneritic, but a few sections show evidence of granoblastic textures, indicating that later recrystallisation has taken place. Some samples show evidence of shearing, with quartz recrystallisation along shear planes. NSZ granitoids show sloping incompatible element patterns with enrichment of large ion lithophile elements and relative depletions in Nb and Ti. This pattern is typical of granitoids produced by island arc magmatism. Trace element discrimination diagrams (after Pearce et al., 1984) suggest that NSZ granitoids have a volcanic arc character. Zircons from NSZ granitoids are Cretaceous. Cathodoluminescence imagery of zircon grains from NSZ granitoids reveals relatively simple growth structures. Xenocrystic cores, often taken to indicate recycling of old crust, were not observed in any grains, indicating that grains were either newly created during emplacement, or that inherited grains reached sufficiently high temperatures for complete resetting of the isotopic system. Figure 2 shows a relative probability plot for all samples in this group. Four pulses of
magmatism are recorded at c. 110, 100, 95, and 80 Ma.

**Volcanic rocks**

Volcanic rocks from the NSZ are tuffs, ignimbrites, and lavas of intermediate to acid composition. In some cases they appear to have been overprinted by thermal metamorphism, observable in thin section as mineral recrystallisation and alteration. Some samples have been overprinted by a shear fabric similar to that observed in intrusive and metamorphic samples. Geochemical analyses (Figure 3) indicate that the volcanic rocks are dacites and rhyolites (De La Roche et al., 1980). Trace element compositions (Pearce, 2008) indicate that they have a subduction-related volcanic arc character. All zircons from volcanic rocks yielded Cretaceous ages from c. 130 to 85 Ma. The most significant population recorded is at c. 130 Ma. This age population is recorded in both cores and rims of grains. Conversely, younger ages (ranging from 120-85 Ma) were all recorded from grain rims, or from grains which appear to have been recrystallized, and from samples which show signs of metamorphism.

**Metamorphic rocks**

The PMG rocks crop out exclusively along the northern margin of the Schwaner Mountains, in the NSZ. The metamorphic rocks are predominantly composed of meta-pelites, though meta-basites and quartzites are also found. Petrographic observations were recorded and summarised on Tectonic Sequence Diagrams (Forster and Lister, 2008; Figure 4.). At least three major periods of deformation are recorded: 1. Low grade metamorphism (F₀) interpreted as due to burial of sedimentary protoliths; 2. Low pressure-high temperature metamorphism (ΔC), characterised by andalusite- and cordierite-bearing mineral assemblages; 3. Shearing (Sz), often in association with fibrolitic sillimanite growth.

Geochemical analyses indicate that PMG rocks show compositional trends that resemble igneous rocks. Trace element compositions closely resemble those observed in intrusive and volcanic samples (Figure 5). Trace element discrimination diagrams (Winchester and Floyd, 1977) indicate that the pelites are similar in composition to rhyolites and dacites (Figure 5). What is particularly striking (Figure 5) is the similarity of the metamorphic rocks to both the volcanic rocks and the plutonic rocks of the Schwaner Mountains.

All PMG rocks contain Cretaceous zircons. Pelitic rocks record ages from c. 130 Ma to 85 Ma (Figure 6C). As with grains from volcanic samples, 130 Ma ages are typically recorded from the cores of zircon grains from meta-pelites. Younger ages were recorded from grain rims, or from grains which appear to have been recrystallized. With the exception of a quartzite samples (SW14) discussed further below zircons grains older than Cretaceous are either absent or very rare in the samples analysed. One Triassic age (213 Ma), one Permian age (289 Ma), two Carboniferous ages (326 and 333 Ma) and a single Proterozoic age (970 Ma) were recorded. These indicate reworking of older detrital material into the protoliths of the metamorphic rocks. The absence of older grains is not a sampling problem; a large number of samples were processed in the hope of finding older grains, and considerable effort was spent seeking older cores to grains. They were not found. One quartzite sample (SW14) yielded pre-Cretaceous ages in addition to Cretaceous ages similar to those found in the meta-pelites (Figure 6D). 63 concordant ages were obtained from this sample of which 11 were Cretaceous. The remaining ages were 7 Jurassic, 13 Triassic, 7 Permian, 2 Carboniferous, 2 Devonian, 4 Silurian, 1 Cambrian and 15 Proterozoic. This spread of ages indicates the quartzite had a detrital sandstone protolith.

**River sands**

The metamorphic rocks of the Schwaner Mountains in particular, and to some extent the plutonic and volcanic rocks, are difficult to access. Sampling requires long journeys up rivers and some other problems were encountered; as a result of logging and mining activity in some areas access was restricted or impossible. In order to check that zircon age populations from the igneous and metamorphic rocks were as complete as possible a number of river sands were sampled, and zircons separated and dated from them. Although the precise source of zircons in river sands cannot be known it can be expected that had there been age populations missed in the igneous and metamorphic rocks these zircons would be represented in the river sands. 729 grains were analysed from 6 sand samples collected from rivers that drain the Schwaner Mountains; 309 of the grains yielded concordant ages and dated from them. The relatively large number of discordant ages probably reflects common lead contamination during transport. Of the 309 concordant ages only 5 were older than Cretaceous: 2 Jurassic, 1 Permian, 1 Carboniferous and 1 Silurian. These results give confidence that no
significant age populations have been missed in the igneous and metamorphic rocks.

DISCUSSION

The zircon ages from the igneous rocks broadly support previous dating of the Schwaner region, almost all of which was by the K-Ar method. More precise ages were obtained for all rocks and ages can be interpreted as close to crystallisation ages, rather than ages of cooling or later metamorphism and/or alteration. All areas have abundant Cretaceous granites. The SSZ granites include at least one significantly older body, of Early Jurassic age, confirming the presence of Jurassic granites reported by Haile et al. (1977) based on K-Ar dating and indicated by van Hattum et al. (2013) based on zircon core ages obtained by SHRIMP dating. These granites have a within-plate character and some S-type characteristics. In contrast, the NSZ granites have a volcanic arc character and I-type characteristics.

The ages from the metamorphic rocks were a considerable surprise. When this project began there was no reason to doubt the Palaeozoic age previously assumed for the metamorphic rocks. They were known to be intruded by Cretaceous granites, although there were no other age constraints. It was expected that they would prove to be Palaeozoic or even older, and that they would yield ancient zircons. However, all metamorphic rocks yielded Cretaceous zircons and very few rocks have older zircons. The spread of Cretaceous ages indicate these are detrital populations, and the few older ages support this assessment. Geochemistry indicates that the predominant detrital component in the pelites is volcanic material of similar composition to the Cretaceous volcanic and plutonic rocks from the Schwaner Mountains. The metamorphic rocks record zircon ages slightly older than the oldest plutonic rocks but similar to the oldest zircon from volcanic rocks (Figure 6). The distribution of ages from all rocks suggests several pulses of magmatism during the Cretaceous in the North Schwaner Mountains (c. 130, 110, 100 and 95 Ma) which we interpret to be subduction-related. We suggest the WPG character and older granites of the South Schwaner Mountains (180-190 Ma) are likely to be rift-related. The youngest granites of the North Schwaner Mountains (c. 80 Ma) and the Cretaceous WPG granites of the South Schwaner Mountains (c. 75 Ma) may be post-collisional.

We propose that the simplest model to explain the new geochemical and zircon age data, and satisfy other observations (such as the detrital diamonds, and distribution of granites in Sundaland) is summarised in Figure 7. Rifting of the Australian margin appears to have been underway from the Triassic (Longley et al., 2002) and the older SSZ granites are suggested to be associated with extension and rifting of NW Australia, which led to separation of the Banda (SW Borneo) block and the Argo (East Java-West Sulawesi) block at the end of the Jurassic. Igneous activity from about 160 to 130 Ma is not recorded in the Schwaner Mountains but we suggest an oceanic arc developed on the northward-moving SW Borneo in this interval, since melting of such an arc would provide the I-type granites that were produced later. Alternatively, this could have been an interval of little magmatism during the early stages of separation of these blocks from Australia. From 130 Ma the SW Borneo block moved rapidly northwards and there was abundant acid arc magmatism above the south-dipping subduction zone which produced large volumes of volcanic ash. The volcanic ash was reworked with other lithologies from the SW Borneo block, deeply buried and then intruded by granite melts, intruded in several pulses. This episode ceased after collision of SW Borneo and the Sunda margin at about 90 Ma. Magmatism continued after collision, but was much less abundant and had a WPG character in the South Schwaner Mountains. Cretaceous granites known from the Malay Peninsula typically have ages corresponding to this phase of magmatism, but not the older Cretaceous phase.

CONCLUSIONS

Cretaceous zircon ages from all rocks, metamorphic and igneous, indicate that much of the crust observed today at the surface in the SW Borneo block, previously interpreted to be dominated by ancient continental material, is much younger than anticipated. However, detrital zircons recording ages into the Precambrian, indicate reworking of some older material, and with the presence of diamonds, are interpreted to indicate an older basement derived from Australia.

The Pinoh Metamorphic Group, which has previously been accepted to be part of an ancient Paleozoic core to SW Borneo, is predominantly composed of Cretaceous meta-pelites. We suggest that the meta-pelites were derived from volcaniclastic sediments erupted at c. 130 Ma, and subsequently metamorphosed during granitoid emplacement from 120-80 Ma, causing zircon rim growth and recrystallization.
Jurassic granites in the South Schwaner Mountains are interpreted to be the product of rifting of blocks from NW Australia. Cretaceous igneous rocks in the North Schwaner Mountains are interpreted to record magmatism in a volcanic arc due to subduction from c. 130 to 95 Ma. Volcanics from the NSZ are often metamorphosed, causing rim growth and recrystallization of zircon grains. Dating of zircon rims indicate that this metamorphism in contemporaneous with granite emplacement, and is interpreted to have taken place whilst subduction was still active. Post-collisional magmatism continued until at least 75 Ma in Borneo and Sundaland.

ACKNOWLEDGEMENTS

We thank the following people for their assistance and contribution to this study: Prof Matthew Thirlwall and Dr Dave Alderton at Royal Holloway University of London for assistance and discussion on igneous petrology and geochemistry; Prof Gordon Lister and Dr Marnie Forster at the Australian National University for assistance with U-Pb geochronology; Prof Andrew Carter at University College London for assistance and discussion on igneous petrology and geochemistry; Prof Gordon Lister and Dr Marnie Forster at the Australian National University for invaluable input on metamorphic petrology; Prof Andrew Carter at University College London for assistance with U-Pb geochronology by LA-ICP-MS; A M Surya Nugraha, Alfend Rudyawan, and Duncan Witts for assistance in the field; and fellow members of the SE Asia Research Group for discussions on SE Asian geology. This research was funded by the SE Asia Research Group at Royal Holloway University of London.

REFERENCES


De Keyser, F. and Rustandi, E., 1993, Geology of the Ketapang Sheet area, Kalimantan, 1:250,000: Geological Research and Development Centre, Bandung.


Haile, N.S., McElhinny, M.W. and McDougall, I., 1977, Palaeomagnetic data and radiometric ages from the Cretaceous of West Kalimantan (Borneo) and their significance in interpreting regional structure: Journal of the Geological Society of London, 133, 133-144.


Pieters, P.E. and Supriatna, S., 1990, Geological Map of West, Central and East Kalimantan Area, 1:1,000,000: Geological Research and Development Centre, Bandung.


Tate, R.B., 2001, The geology of Borneo Island, Geological Society of Malaysia.


van Hattum, M. W. A., Hall, R., Pickard, A. L. and Nichols, G. J. 2013. Provenance and geochronology


Zeijlmans van Emmichoven, C. P.A., 1939, De geologie van het centrale en oostelijke deel van de Westerafdeeling van Borneo: Jaarboek Mijnwezen Nederlandsch Oost Indië, Verhandelingen 1939, 68, 7-186.
**Figure 1** - Locations of the samples used in this study. A) All samples. B) Samples from along the Pinoh River, shown in small box on map A.
Figure 2 – Summary of key petrological and chemical features of plutonic rocks from the Schwaner Mountains with summaries of zircon ages. A. South Schwaner (SSZ) granites have Within-plate (WPG) character whereas North Schwaner (NSZ) plot in the Volcanic Arc field. B. NSZ rocks are typically hornblende tonalites, granodiorites and granites whereas SSZ rocks are alkali granites. C. NSZ granitoids were emplaced between 120 and 80 Ma, SSZ granitoids were emplaced at c. 185 Ma and c. 75 Ma. D. Representative photomicrographs of NSZ and SSZ granitoids.
Figure 3 – Summary of key petrological and chemical features of volcanic rocks from the Schwaner Mountains. A) Total alkalis vs SiO$_2$ diagram for NSZ and SSZ volcanics. B) Th/Yb vs Nb/Yb tectonic discrimination diagram for NSZ rocks. C) Relative probability plot for volcanic zircons (0-200 Ma). D) Relative probability plot for volcanic zircons (0-500 Ma).
Figure 4 – A) Tectonic Sequence Diagram for the Pinoh Metamorphic Group (PMG), illustrated by sketches of thin sections. $F_0$ is earliest sedimentary fabric, $\Delta Bt$ is biotite growth, $\Delta C$ is low pressure-high temperature metamorphism characterised by andalusite- and cordierite-bearing mineral assemblages, $Sz$ is shearing. B) Pressure and temperatures for metamorphism inferred from metamorphic assemblages.
Figure 5 – A) Total alkalis vs SiO$_2$ diagram showing compositions of meta-pelites and other rock types. B) Trace element protolith discriminator for Pinoh Metamorphic Group (PMG) meta-pelites. C) Incompatible trace element spider diagram showing compositions of PMG rocks compared with igneous rocks from the NSZ.
Figure 6 – Summary of Cretaceous zircon populations from: A) Unmetamorphosed and metamorphosed volcanic rocks from the NSZ, B) Granitoids from the NSZ and SSZ, C) Pinoh Metamorphic Group rocks from the NSZ, D) Quartzite sample SW14 from the PMG.
Figure 7 – Paleogeographic reconstructions from Hall (2012) showing the relative position of SW Borneo between the Late Jurassic and Late Cretaceous. A) 160 Ma, rifting underway at NW Australia margin. B) 145 Ma, initial subduction margin phase. C) 130 Ma, change in spreading direction and movement of SWB in Ceno-Tethys with main phase of magmatism in NSZ. D) 90 Ma, SW Borneo docks with Sundaland, subduction magmatism ceases.